IAEA Nuclear Energy Series

No. NP-T-3.28

Basic Principles

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Technical Support to Nuclear Power Plants and Programmes

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IAEA NUCLEAR ENERGY SERIES PUBLICATIONS

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TECHNICAL SUPPORT TO NUCLEAR POWER PLANTS AND PROGRAMMES

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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

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

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

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

The provision of effective scientific and technical support is essential for sound decisions on developing and optimizing the safe and efficient operation of nuclear power plants. It is also essential to maximizing their quality, reliability, availability and productivity during their lifetime. Establishing and maintaining the safe electricity generation expected of a nuclear power plant requires decisions on its design, construction, configuration and operation to be made in a safe and informed manner. These decisions are supported by correct and adequate information — including technical and scientific information — that is prepared, verified, validated and approved by competent staff in a correct and timely way. Pre-operational, operational and post-operational decisions, as well as implementation, control and inspection of activities associated with these decisions, rely on safe, sound and effective technical support and advice provided by a competent and attentive technical support organization.

Additionally, in the case of newcomer countries, competent technical support can greatly assist the nuclear programme leaders, the appointed government organizations and other stakeholders with the key decisions in the development of their first nuclear power project.

The importance of scientific and technical support was emphasized by the investigations of the accidents at the Three Mile Island, Chernobyl and Fukushima Daiichi nuclear power plants, illustrating the needs and challenges associated with technical and scientific assistance throughout the lifetime of a plant, including in emergency situations. During these events, decision making and actions required timely and correct advice from technically knowledgeable and experienced persons, and the importance of adequate technical support was demonstrated. Beyond the decision making by the operating and regulating authorities, scientific and technical support was also shown to be critical for credible and effective communication about the events to the public.

This publication provides guidance for establishing and maintaining effective technical support in Member States. It addresses aspects relevant to all stakeholders in the various stages in the lifetime of a nuclear power plant, and shares information on challenges, solutions and good practices based on the current knowledge and operating experience.

The IAEA expresses its appreciation for the generous contributions of many Member States. The IAEA is grateful to all contributors listed at the end of the publication. The IAEA officers responsible for this publication were A.N. Kilic and R. Shouler of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The idea for IAEA guidance on technical support arose in the 1990s from a recognition that effective technical support is essential if a nuclear power plant is to operate safely and maximize its power producing potential. It was established in the IAEA safety standards [1, 2] that, as the bearer of full responsibility for safe design, construction, maintenance and operation of its plant(s), and the upholder of its reliable and efficient performance, the owner/operating organization has a need to establish, maintain and improve technical knowledge of its facility by a dedicated group of competent staff (as a 'technical conscience' and authority). It was realized then that the technical support function at some plants was sometimes not clearly understood or adequately addressed [3]. As a consequence, technical and scientific bases were not applied in a manner which would produce the most benefits to the plant with respect to maximizing availability and efficiency while optimizing safety, reliability and quality. As discussed in Ref. [3], the ineffectiveness (or deficiencies) that could be attributed to acquisition, provision or utilization of technical and scientific information affecting the soundness of decisions resulted, in some nuclear power plants, in acute or latent performance problems.

More importantly, lessons learned from the accidents at that time emphasized the critical role of technical and scientific guidance and support in understanding and mitigating accidents by technically assessing the plant response and operator actions. The assessment of the Three Mile Island accident [4, 5] identified the essentiality of maintaining a strong on-site technical capability and the necessity that qualified engineering and technical management staff with extensive knowledge of the plant design and configuration be a part of the operations and reactor operating shift crews [4]. Specifically, Ref. [5] noted: "Nuclear power requires … an extensive support system of scientists and engineers." It also asserted that substantial attention must be given to the writing, reviewing and overseeing of plant procedures such that they are based on "both engineering thinking and operating practicalities." Furthermore, following the Chernobyl accident, the investigations reported in Ref. [6] similarly determined that operating procedures were not founded satisfactorily upon the technical analyses and that the exchange of important safety information between the operators and technical support organization (TSO) were inadequate and ineffective.

In response, IAEA-TECDOC-1078 [3] was prepared. Published in 1999, the publication emphasized the importance of having competent and well focused technical support during the operation phase. It also provided key guidance to the plant management in establishing and maintaining an effective TSO.

1.1.1. Operating experience after the issuance of IAEA-TECDOC-1078 in 1999

During the two decades following the issuance of IAEA-TECDOC-1078, additional operating experience has been collected and more observations have been made regarding good practices (as well as continuing issues) with respect to obtaining, providing, understanding, valuing and utilizing technical support for (and in) making safe, informed and sound decisions. Since the publication of IAEA-TECDOC-1078, the nuclear industry has also been through various important phases, including:

— A 'nuclear renaissance' that comprised planning, design and construction of numerous new (or first) nuclear power plants;
— A performance enhancement phase that comprised power uprates and longer term operations which were coupled with associated major design and facility modification activities, such as heavy equipment replacements;
— Retrofitting of ageing nuclear power plants to continue or improve performance;
— Electricity market deregulation, which resulted in changes in business models and the need to re-evaluate sustainability of operations, in some cases resulting in plant closures, necessitating optimization of operation and maintenance costs through improved design and operation;
— The Fukushima Daiichi accident, which resulted in changes in licensing, design and operation criteria and requirements, as well as extensive required or voluntary facility modifications;

— The start of decommissioning of some nuclear power plants that had completed their licensed and/or design life.

As the roles and responsibilities of entities providing technical support have adapted to these phases, new challenges have appeared, while new solutions, methods and opportunities have also become available. Also, following the publication of IAEA-TECDOC-1078, the nuclear industry's awareness of (and attention to) technical support issues continued to increase, prompting issuance (or revisions) of a series of industry initiated standards, guidance and expectations in the 2000s aimed towards achieving best practices and excellence (see Refs [7–11]).

Importantly, deficient and inadequate application of technical and scientific bases has nevertheless continued, causing events impacting safety, reliability and quality, and leading to lack of availability and efficiency in nuclear energy generation, as reflected in the International Reporting System for Operating Experience, an international system jointly operated by the IAEA and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development [12]. In some cases, this has even resulted in premature cessation of operations [13]. This situation necessitated supplementing and/or revising the information discussed in IAEA-TECDOC-1078.

1.1.2. Effective technical support before and after the nuclear power plant operation phase

To address the issue at hand at the time (i.e. performance problems originating from unclear roles and responsibilities of TSOs and inadequate and unsatisfactory acquisition, provision and use of technical support at operating nuclear power plants), IAEA-TECDOC-1078 mainly targeted operating nuclear power plant management and aimed for the establishment and maintenance of a competent and effective internal TSO. Therefore, it particularly focused on the owner/operating organization's TSO and its scope was limited to the discussion of roles, responsibilities, functions and management of TSOs during the operation phase. However, Member States which are initiating and implementing new nuclear power plants requested that the IAEA provide more good practices and practical examples applicable to the phases before (and after) the operation phase. Also, it was observed that neither internal nor external technical support is clearly understood or adequately addressed when making decisions on nuclear in the energy mix and during design and implementation stages for new plants, resulting in ineffective decision making by the owners, as well as causing latent safety, reliability and performance issues during the operation phase.

It is also recognized that during the pre-operation phases and the transition to decommissioning and decommissioning itself, there are many technical support functions performed by various entities, including owner/operating organizations, architect–engineers, plant vendors, consultants, subject matter experts, and research and development entities, that interact and interface. Therefore, the challenges exist not only in the conduct of technical support activities but also, and more particularly, in managing interfaces during the pre-operation and post-operation phases.

The importance of technical support throughout the lifetime of a nuclear power plant was also emphasized by the accident at the Fukushima Daiichi nuclear power plant. Prior to the accident, as far back as the design and construction stages, decisions (for example on siting, design, licensing and inspections) reflected a lack of robustness or timeliness in technical input and arguments, and this played a major role in the cause, outcome and consequences of the accident [14]. The accident also highlighted the essentiality of technical support during emergency situations. The emergency decision making and actions required timely and correct advice from technically knowledgeable and experienced persons; and the importance of technical support was demonstrated thereafter during stabilization and recovery at an accident site facing dynamic conditions. In addition, scientific and technical information was shown to be critical for credible and effective communication to the public.

Furthermore, in the aftermath of the accident, the majority, if not all, of the nuclear power plant owner/operators and regulatory bodies embarked on systematic safety reviews to understand and identify deficiencies and strengths in light of lessons learned. Thorough and effective technical support has again been proven to be a fundamental part of deciding on, implementing and managing the associated actions taken by the industry stakeholders, including the determination of their appropriateness, effectiveness, priority and impact/value.

1.1.3. A comprehensive report on technical support need and provision

Therefore, it was decided to update the information in IAEA-TECDOC-1078 to represent additional years of nuclear power plant and project experience with technical support. The main reasons for this update are to develop an IAEA publication: (1) to re-emphasize the understanding of the technical support functions and essential elements and characteristics; (2) to summarize needs, challenges and opportunities for decision makers (e.g. owner/operating organizations, governments, nuclear power project developers) in obtaining and utilizing technical support; and (3) to provide lessons learned in order to strengthen the acquisition and use of technical support for decision making regarding the design, licensing, operation and effective performance for nuclear power programmes, projects and plants.

1.2. OBJECTIVE

This publication aims to address aspects relevant to obtaining effective technical support and appropriately utilizing it in decision making on nuclear power plant programme, project and plant safety and performance by providing a common understanding of the technical support functions and their implementation throughout the plant's life cycle. It also serves as a roadmap for capacity building in countries embarking on nuclear power programmes by describing technical support activities and associated skills.

The publication intends to disseminate the observations made, the lessons learned and the conclusions drawn regarding good practices for defining and maintaining roles, responsibilities and interfacing requirements for TSOs assisting owner/operating organizations and nuclear power project entities. Therefore, it provides a set of descriptive and widely practiced processes that integrate safety, performance and economic aspects for making safe, sound decisions — supported by accurate, appropriate and timely technical and scientific input — on safe, reliable and efficient operation of nuclear power plants.

Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

1.3. SCOPE

This publication describes the specific technical support functions throughout the nuclear power plant life cycle and the elements necessary for technical input and perspective to be obtained and used by the decision makers at a nuclear power plant or for a nuclear power plant project.

It further provides (or collects from other IAEA guidance) suggestions on what selection criteria to consider and what steps to take for the decision process, and information about what technical support related operating experience has been gained in the planning, design, licensing, operation and decommissioning phases. The scope primarily consists of:

— Clarifying the importance of technical support in nuclear power plant programmes, including in design, licensing and operation activities;
— Providing a comprehensive list of core technical support functions;
— Emphasizing the key roles, characteristics and responsibilities of TSOs;
— Presenting good practices in obtaining and utilizing technical support in decision making;
— Clarifying the drivers of technical support quality, effectiveness and timeliness;
— Offering suggestions with respect to the management role in dealing with and utilizing TSOs.

This publication is not intended to endorse or to invalidate a particular approach for obtaining and using technical support and managing TSOs; rather it is intended to provide Member States with understanding of the technical support needs for safe and efficient operation of nuclear power plants, and of the related challenges and their solutions. As the need for and method of obtaining technical support vary from one organization to another, this publication provides fundamentals and common elements of effective technical support acquisition and utilization and presents different options that have typically been practiced by owner/operating organizations and nuclear project entities, instead of giving prescriptive instructions on specific aspects.

Although similar fundamentals apply to technical support to regulatory bodies, technical support to and TSOs for these bodies are not within the scope of this publication. However, some IAEA publications address such aspects implicitly or explicitly. For example, Refs [15] and [16] discuss the use of external experts by the regulatory body, and TSOs and the services they provide in support of regulatory functions, respectively. It should be noted that Ref. [16] discusses the technical support from the point of view of the TSO (i.e. technical support provider), while this publication discusses it from the point of view of the technical support customer, and therefore, they may be complementary to each other in terms of selecting and establishing a TSO.

1.4. STRUCTURE OF THIS PUBLICATION

The main body of this publication is divided into eight sections including the introduction in Section 1 and the conclusions in Section 8.

Section 2 describes the terminology and the subjects discussed in the publication, providing an overall view of what technical support is and when and how it is obtained, provided and used.

Section 3 provides key elements of effective technical support and discusses the basic elements to build a strong technical support programme and process.

Sections 4 through 7 discuss the decisions to be made regarding needs for input on technical matters, identifying the scope of technical support throughout the nuclear power plant lifetime. It also expands on this scope by providing typical technical support activities, as well as organizational structures and staffing schemes used, for various phases in the life cycle of a plant.

Three annexes to the publication supplement the guidance by providing some examples from the experience of Member States concerning technical support acquisition and provision to illustrate some practices and specific discussions about technical and scientific support practices in the Member States.

A glossary of specific terms used and a list of abbreviations are also provided for the reader's aid at the end of the publication.

1.5. USERS

The targeted users of this publication are Member State organizations that need, acquire and use technical support for decision making with input from TSOs during consideration, commitment, design, construction, commissioning, licensing, operation, maintenance, modification and decommissioning of nuclear power plants.

Thus, the primary users of this publication include the decision making organizations in countries with experience with nuclear programmes and those embarking on new nuclear power programmes. Both may benefit from the operating experience and current knowledge in establishing, executing, assessing and continually improving a structured technical support acquisition and utilization process. Therefore, owner/operating organizations (i.e. utilities), nuclear energy project implementing entities (e.g. nuclear energy programme implementing organizations (NEPIOs[1])) and relevant government agencies are foreseen as the main users.

Although this publication is primarily written as a guide for such entities that need and receive technical support for their decision making, it may also help the organizations that provide technical support (i.e. TSOs) in understanding the 'customer' needs and the nature of decision making based on the technical support they provide. These organizations include architect–engineers, technology owners, responsible designers, independent technical experts and groups, academia and research and development staff, as well as the regulatory bodies whose oversight ensures that the licensees obtain adequate technical input and use it for making safe, sound and reliable decisions. Thus, the users of this publication may include entities providing technology and/or technical and scientific services for the design, construction, installation, commissioning, maintenance, modification, operation

[1] A NEPIO may or may not be a single entity. In some cases, it is a conglomeration of several entities working together towards the implementation of a nuclear power programme.

and decommissioning of the nuclear power plants within and outside the owner/operating organization through interfaces during the entire life cycle of a plant.

1.6. HOW TO USE THIS PUBLICATION

This publication can be used as a source of general guidance for understanding the characteristics of effective technical support acquisition and provision for making safe, sound and timely decisions on a nuclear power programme, project or plant. Therefore, it considers both new nuclear power plant projects and expansion of existing nuclear generation and provides key aspects of technical support for the consideration, commitment, design, licensing, configuration, operations and decommissioning of a nuclear power plant.

Users who are in the process of making a decision on whether new (or additional) nuclear energy 'makes sense', and if it does, whether it is feasible and viable for their country (or utility, as defined in the glossary), or on the manner of implementation, could refer to Section 4 in combination with Section 3 for information on what kind of technical support they would need and how to get and use it. They need to also be aware and informed about the discussions in Section 5 and Section 6 since what is done in preparatory phases will be the foundation of the stages after the decision is made on proceeding with the implementation of a nuclear power plant project and the operation of a nuclear power plant.

Users who are approaching the implementation of their nuclear power plant project and getting close to making decisions on design, construction and commissioning of their new (or additional) nuclear power plant could refer to Sections 5 and Section 6 in combination with Section 3 to establish and maintain technical support for their decision making.

In combination with Section 3, users who are already operating nuclear power plants and have established technical support processes could review Section 6 to assess some of the practices in managing the process of obtaining, providing and using technical support and in the composition, structure and interfaces of organizations that provide it. This review could provide ideas to improve the effectiveness of their programmes, processes and practices in these areas. Furthermore, these users can refer to Section 7 to learn more regarding their preparedness for the transition to the decommissioning phase during operations.

This publication does not provide comprehensive lists of all needs, challenges and solutions, but rather it provides key concepts that need to be taken into account in the technical support programmes and processes, based on operating experience and technical and administrative fundamentals.

As previously mentioned, this publication is not intended to endorse or to invalidate a particular approach; it is intended to lead to informed decisions — through a good understanding of how and why nuclear power programmes, projects and plants need technical support — and to guide Member States in acquiring and using technical support in decision making for their nuclear power plants and/or projects.

Nor is this publication a detailed and prescriptive implementation procedure for achieving ideal technical support or a 'one size fits all' method for obtaining and maintaining technical support and managing TSOs, but instead it contains descriptive guidance providing major technical and managerial elements, important milestones and roles and responsibilities of parties involved in the request, provision and utilization of the technical information for a decision. It can be used as a checklist for considerations relating to technical support during a nuclear power plant project life cycle, as it could be adapted to a particular corporate tradition and style. It is also useful as a roadmap since it directs readers to the other sources where specific topical and detailed guidance and discussions can be found.

The guidance is supplemented by specific examples of obtaining and maintaining effective technical support and managing organizations providing it, including operating experience as well as good practices and lessons learned; however, the IAEA does not take responsibility for the completeness and applicability of those examples in specific situations. Indeed, users need to validate and verify the application of guidance and practices for specific cases, and to assess them for adaptability to their own organization and situation.

2. DESCRIPTION OF TECHNICAL SUPPORT

Valid and complete scientific and technical information, perspective and advice are essential for developing, maintaining and optimizing safe and efficient operation of nuclear power plants since they provide the decision makers with accurate and objective technical input to reach safe, sound decisions on safety and performance, with complete understanding of all aspects.

The decision making entity (e.g. a government, a NEPIO, a nuclear power plant project company, a nuclear power plant owner/operating organization) is the requestor and user of the technical information for decision making on plant safety and performance objectives: safety, reliability, availability, operability and efficiency with quality and longevity. Therefore, the decision maker is the 'customer' of the technical information provider.

There is continuous exchange of technical information between the customer and the supporting provider(s) from the initiation of the project until the final phase of decommissioning, that is to say:

— In the preparatory phase of the project;
— During design and licensing;
— While construction and commissioning activities are performed;
— Throughout the period of nuclear power plant operation;
— In the preparation for and during the decommissioning.

During these stages, the exchange of technical information will vary in terms of extent, content, associated parties, roles and responsibilities, interfaces/directions, and so on, depending on the customer's decisions and on the specific needs for a particular decision at the applicable stage. Given the wide range of information exchanged and parties involved, it is helpful to begin this publication by identifying some of the common terminology used and the concepts discussed in it.

2.1. TECHNICAL SUPPORT

Technical support is an activity (or part of an activity) to assist decision makers by providing technical and scientific input in decisions related to the achievement of design and performance objectives.

Technical support is obtained and provided in various manners by different entities throughout a nuclear power plant's life; however, it has the following common characteristics:

— The technical support function is of a supportive and advisory nature to assist the decision makers in consideration of technical and scientific facts, principles, options, opinions and perspectives.
— Technical support activity consists primarily[2] of direct involvement in technical matters (e.g. preparation, review or oversight of technical matters and technical products) by experts and advisers representing technical conscience.
— Members of the technical support staff have direct roles and responsibilities with respect to performance and associated knowledge and expertise (as well as awareness of economic and schedule status) for nuclear activities being planned or implemented; however, they are not responsible for actual decision making.

2.2. TECHNICAL SUPPORT ORGANIZATION (TSO)

A TSO is any organization (or individual or group) that provides technical support to decision makers for decisions on preparation for a nuclear power plant project (e.g. establishing the case for the project, the solicitation and selection of technology and design, site survey and selection), and afterwards, on the design, licensing, construction, commissioning, operation, maintenance and decommissioning of a nuclear power plant.

[2] It might include, in some cases, indirect participation in non-technical matters (e.g. legal, financial, commercial, scheduling, planning or communication with public and other interested parties) through the provision of evidence based on special technical knowledge and expertise, for example as a subject matter expert or expert witness.

A TSO for a nuclear power plant (or a nuclear power plant programme or project) is an individual or an organization established (and/or contracted) to provide technical support in various areas, such as engineering and scientific services, development of technical improvements or exploration of specific research and technology, whenever needed for decision making for a nuclear power plant.

This organization could be placed within or outside the decision making entity that needs technical support (i.e. it can be an internal or external TSO), as shown in Fig. 1.

2.2.1. Internal technical support organization

An *internal TSO* is a dedicated technical group, or *in-house expert(s)*[3], within (employed by) the decision making organization, which has adequate knowledge to support technical matters and has competency to involve special technical expertise to assist — by providing technical input, opinion, advice or feedback to the decision makers — as needed and requested. Figure 1 illustrates an internal TSO and its customers and contacts, as an example, at the operation phase.

2.2.2. External technical support organization

An *external TSO* is a group or an individual, outside (organizationally independent from) the decision making organization, that has special expertise on a certain scientific and technical area (or areas) and provides it to the decision making organization through contractual agreements and partnership, as needed and requested. Figure 1 depicts a set of external TSOs that are typically used at the operation phase, as an example.

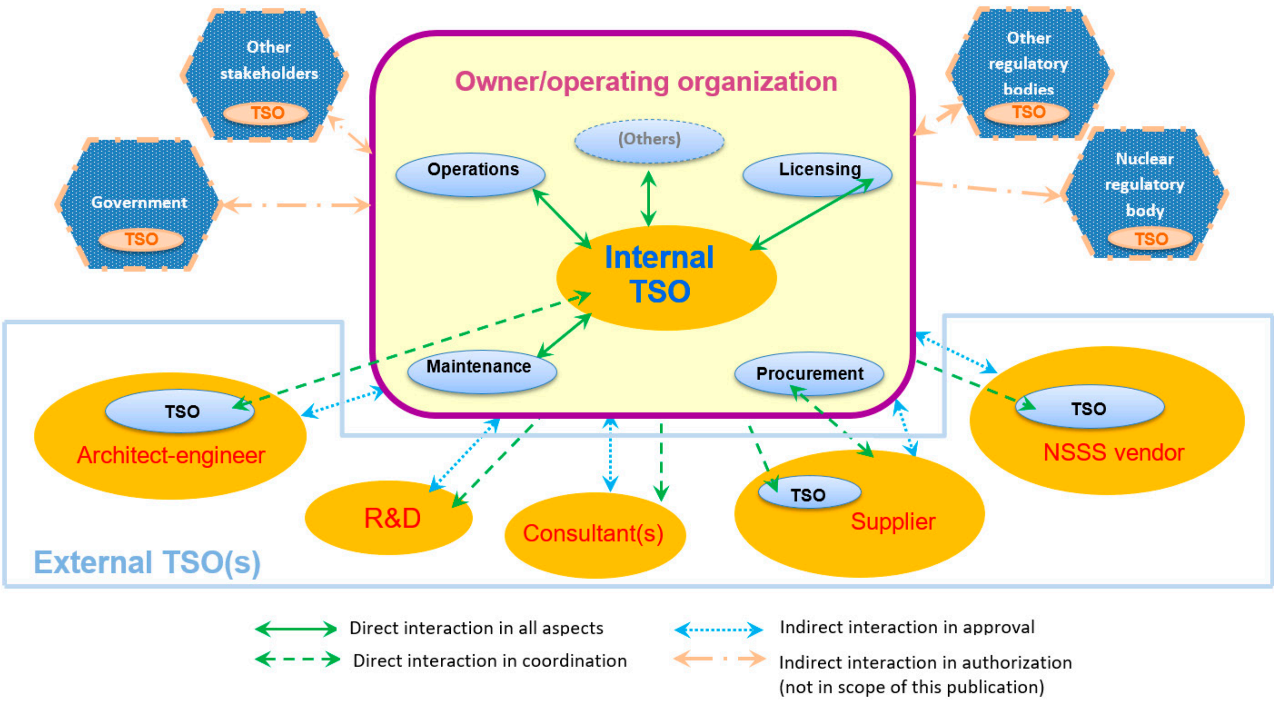

FIG. 1. Example of technical support sources and interactions for an owner/operating organization. NSSS — nuclear steam supply system, TSO — technical support organization.

[3] An *In-house expert* is an individual or group of individuals, within (employed by) the decision making organization, who have special expertise in certain scientific and technical areas and provide technical input, advice, perspective and feedback for the day to day decision making.

2.3. MAJOR ROLES IN TECHNICAL SUPPORT AND ITS USE

Technical support is needed to make decision in various phases of nuclear power development and utilization, starting with consideration of and commitment to nuclear energy in the energy mix and continuing until the plant is safely and efficiently decommissioned. There may be distinct and necessary roles and responsibilities (and interactions) at different levels, namely at the authorization, coordination and execution levels shown in Fig. 2.

When decision making on the tasks, priorities and plans occurs, there is a collegial relationship among all departments and all parties to ensure that the decision has collectively agreed priority and adequacy for safety and quality, with all concerns appropriately and completely addressed, including the technical and scientific aspects. Therefore, roles in these levels are particularly distinctive.

2.3.1. Decision authority

A decision authority is a person who is authorized to make a decision on behalf of the ultimate decision making body (government, parliament, plant or project owner, board of governors, executive board/committee, etc.). This person, who is responsible and accountable for the decision, will consider all the factors, including technical opinions and feedback, and will make an executive decision at the *authorization level* (typically in consultation with associated in-house or outside persons or groups, such as boards, commissions, committees, panels) in an integrated and binding manner. The responsibility and accountability to make that governing and binding decision need to be assigned to one person at the highest level in the decision making entity (e.g. ministry, cabinet, NEPIO, nuclear power plant project company, nuclear power plant operating organization) with the most authority and cannot be delegated.

2.3.2. Technical authority

A technical authority is a person with the responsibility and accountability for making decisions on technical activities. He or she determines, controls, manages and assesses the request for and the acquisition, provision,

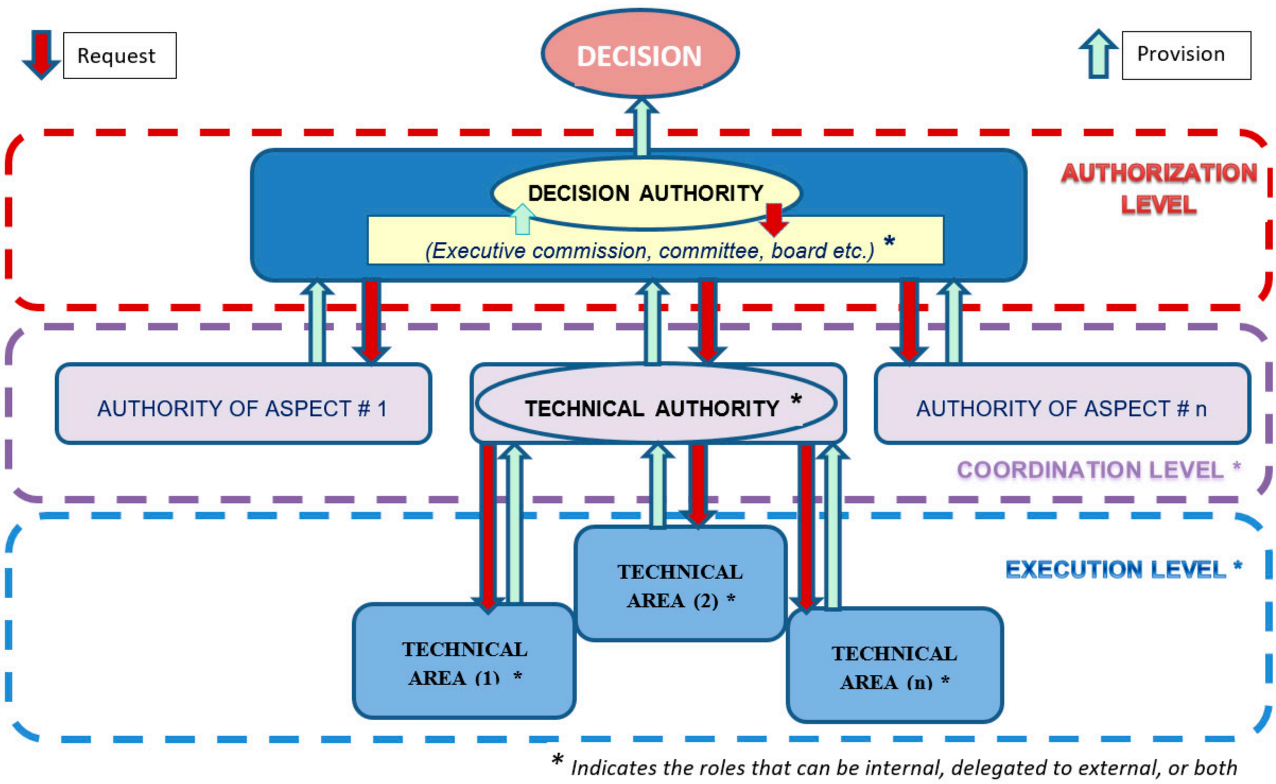

FIG. 2. Different levels of technical support provision and use.

description and expression of technical information and products, including their recording and preservation. As the head of the technical organization that determines, acquires, provides and assesses technical information for an input to the decision to be made by the decision authority, the technical authority is the decision maker at the *coordination level* and is typically the highest level technical manager. For example, he or she may be the vice-president of engineering of a nuclear power plant organization as it may be structured for a particular operation phase. Unlike the decision authority, the technical authority could be delegated to a responsible and accountable individual (e.g. the highest level technical manager in responsible design or external technical support entities) or group (e.g. design committee, technical review board, technical expert commission or plant review panel).

2.3.3. Technical conscience

The technical and scientific conscience of an organization is an individual or a group of technical experts with ownership of technical information and knowledge to understand and assess the technical aspects in decision making (for example, on design, configuration, operation and maintenance), and the ability to convey and explain the technical basis, criteria, status, requirements and characteristics, as well as owner's technical expectations. They are the decision makers at the *execution level*. The technical conscience roles and responsibilities can be delegated to various organizations, such as to responsible designers, external TSOs, subject matter experts and consultants.

2.4. TECHNICAL SUPPORT ACTIVITY TYPE

Technical support is often mistakenly perceived to be limited to the provision of engineering analyses and design documents, and TSO activities are often similarly misperceived to be limited to the conduct and verification of these. Although technical support relies on engineering principles and fundamentals, it may consist of activities and tasks extending to engineering and other applied and natural sciences (e.g. mathematics, statistics, environmental science, economics). In this publication, technical support activity means technical and scientific support activities including engineering activities.

Therefore, the technical support activities discussed in this publication consist of a variety of functions and areas, including engineering, design, fabrication, procurement, operations, quality assurance, maintenance, material and parts control, specialized oversight and inspections, planning and scheduling, information technology, training or any other technical support needed to develop and implement safe, successful, efficient and continuous operation of a nuclear power plant. Hence, the TSO activities include tasks beyond the conduct or review of engineering analyses, and the technical support can be provided in a variety of forms, which could be classified into seven groups:

— *Preparatory activities:* These are the activities that establish planning or preparation for the conduct of the technical support, such as the determination of tasks, scopes, schedules, competencies for technical support needed (or to be provided), and technical input needed (or to be provided) — for example, what data to collect/monitor and how to collect/monitor them, or the reason, basis or justification for needed technical support (such as identification of the issue(s)).
— *Demonstratory activities:* These are the activities that are performed to investigate, evaluate, analyse and demonstrate, as well as to draw conclusions, based on technical and scientific methods, such as conduct of engineering calculations, studies, evaluations and analyses, or collection, monitoring, regression and interpretation of data.
— *Confirmatory activities:* These are the activities that review, qualify, verify or validate technical products, such as analyses, results of investigations or conclusion of evaluations.
— *Advisory activities:* These are the activities that provide decision makers with recommendations, suggestions or views regarding technically viable options for courses of action, planning, costs or resources, and so on, based on technical and scientific information, knowledge, experience and expertise. These activities could include provision of technical opinions and judgement on, for example, definition, description and assertion of the significance of issues at hand, urgency of resolutions or advantages and disadvantages of potential solutions.

— *Anticipatory activities:* These are the activities that foresee and direct the awareness and attention of decision makers to potential and predicted technical and scientific issues/needs or anticipated courses of actions and conceptual resolutions based on technical and scientific information, knowledge, experience and expertise. Typically, these are based on observations, extrapolation of current and past trends, and predictions/estimations by analyses, including those derived from past operating experience and incidents in the nuclear and other industries.
— *Exploratory activities:* These are the activities that support the decision makers in predicting and envisioning the long term future or end state of plant design and configuration, identifying gaps and establishing strategies. These activities may involve improvement or optimization of the design and physical layout of the plant, advancement of corporate technical and scientific information and knowledge, investigations of more effective and accurate methods, and optimizing human–machine interfaces for improved operation of the plant.
— *Innovatory activities*: These are the activities towards invention or advancement of technical and scientific information and knowledge, creation of more effective and accurate methods, and development of advanced or special techniques or 'state-of-the-art' products and processes. These activities generally involve conducting research and development, and therefore they may require advanced expertise and special facilities.

The different types of support will require different levels of proficiency, competency, skills, experience or effort, as well as different approaches. The applicability of each type, and the scope and efforts related to performance in different organizations and different stages of the nuclear power plant life cycle, may be driven by the regulations, their frequency, periodicity and value/impact, as well as the corporate strategy, style and tradition. Figure 3 illustrates a basic tier set of typical activities in a plant lifetime and associated expertise, experience and knowledge of technical staff conducting such activities.

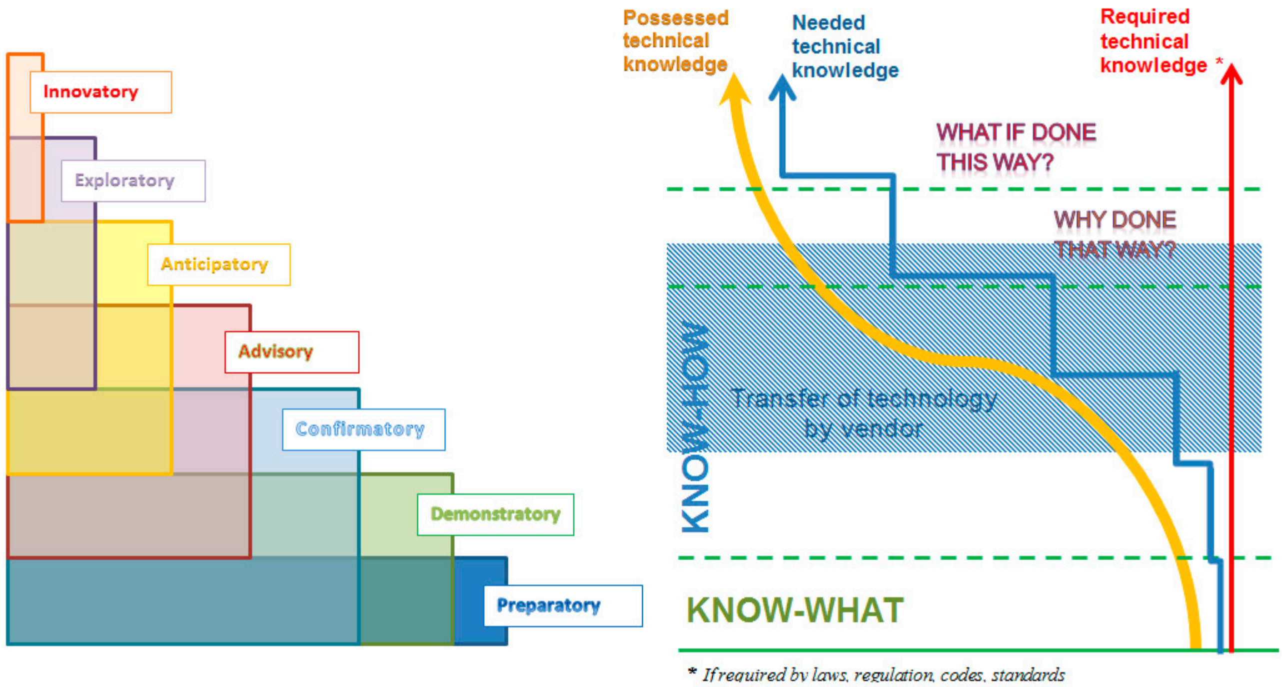

FIG. 3. Levels of the activities and the corresponding tiers of technical expertise, experience and knowledge.

2.5. TECHNICAL SUPPORT THROUGHOUT THE NUCLEAR POWER PLANT LIFE CYCLE

Both internal and external TSOs are utilized throughout the lifetime of a nuclear power plant, though the extent of their use depends on the decision making organization's structure and corporate strategy. Figure 4 provides a conceptual illustration of the utilization of, and variation in, sources of technical support during the lifetime of a nuclear power plant. There are a few distinct points in Fig. 4.

Point 1 in Fig. 4 indicates some periodic operational activities at the nuclear power plant for which support from external TSOs may be needed or preferred, such as periodic safety review, special test or inspection, or maintenance outage, while Point 2 could indicate a major plant modification or a very special, or significant, issue involving a decision.

Also noted by the horizontal dashed lines in Fig. 4, in some regulatory regimes, the owner/operating organization has to demonstrate to the regulatory body that it has the capability and capacity for technical support within the organization, as it may be an operating licence condition.

The organization that needs to obtain technical support for decision making (e.g. government, NEPIO, nuclear power plant project owner, owner/operating organization) has the prerogative to define the sources of its technical support (i.e. its TSOs) based on the technical activities needed at a particular stage of the plant lifetime and the resources available. There may be many factors in the selection of technical support providers by the customer, including one or more of the following:

- — Availability of expertise and resources in the particular field in the company, region or country;
- — Level of technical competency, proficiency and capability needed;
- — Existing industrial infrastructure and its projected future development;
- — National and international laws and regulations in areas such as foreign trade, ownership;
- — Economic and market drivers, such as localization;
- — Contractual and commercial agreements;
- — Technology transfer or partnership models or strategies.

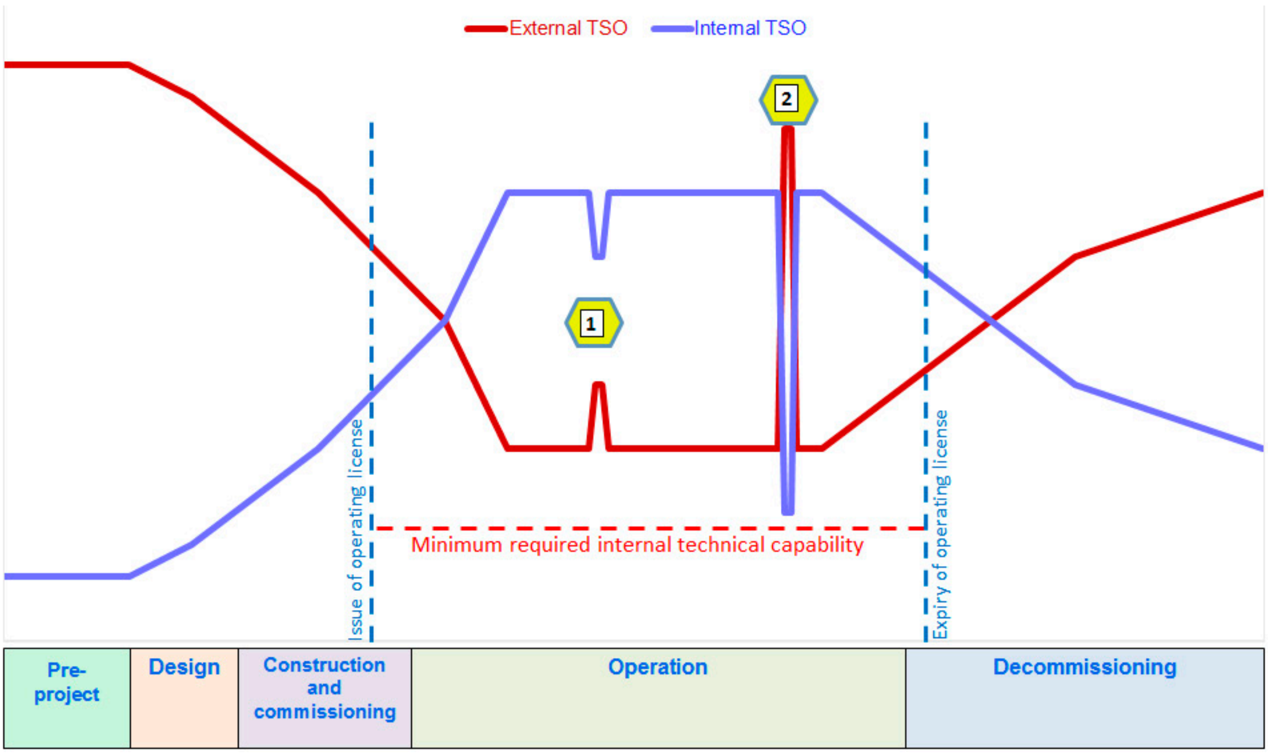

FIG. 4. Typical share of technical support throughout the nuclear power plant life cycle. TSO — technical support organization.

2.5.1. Pre-project technical support

From the consideration, affirmation and planning of new (or additional) nuclear power generation until the preparation to invite bids for implementation of a nuclear power plant project, preparatory activities of a technical nature are carried out in relation to the decisions on a nuclear power project. These typically consist of conduct (preparation and/or review) of preliminary technical studies associated with energy planning, siting, power and grid systems, and technology assessment. They involve determination and collection of the project technical input, such as site and power/grid characteristics, regulatory requirements, codes, standards, technical specifications and quality requirements. Typically, technical support for project decision making is obtained from external TSOs and sometimes from in-house experts within the project company/entity or governmental agencies. This is especially applicable to Member States embarking on nuclear programmes and owners/operators with limited technical support capabilities.

2.5.2. Design, construction and commissioning technical support

Once the technology is selected and the nuclear power plant is being designed and built, technical support is shared among the vendors, which vary from the reactor supplier and the architect–engineer to the suppliers and designers of components, and include many others involved in design, construction and commissioning.

Early in this phase, the owner/operating organization (i.e. utility) is formed and assumes a key (and gradually expanding) role in the development and implementation of the nuclear power plant project — as an organization independent from the political and regulatory establishments [17]. The owner/operating organization's need for technical support in order to make project decisions gradually increases, as the design is developed (design stage), implemented (construction stage) and verified (commissioning stage).

During this period, a core TSO is established within the owner/operating organization (as an internal organization/group of owner technical experts and in-house experts) in order to assess the adequacy of plant design, construction and commissioning and verify that it meets or exceeds the owner's requirements and needs. This internal TSO informs/advises the decision makers in the owner/operating organization on the technical issues in order to enable the project to progress with safety and technical adequacy, as well as within schedule and budget. The owner/operating organization also solicits technical support from independent external TSOs in highly specialized, trivial matters or in situations in which opinions differ between the stakeholders (e.g. reactor supplier, architect–engineer, supplier and/or designer of components).

Senior technical experts of the owner/operating organization maintain close contact with the responsible designers and vendors to ensure that the specific opinions and requirements of the owner/operating organization are clearly communicated in order to be given due consideration by the designers and vendors.

It needs to be emphasized that during this stage, members of the owner's staff also need to be closely involved in the activities performed by the external TSO(s) in order to gain in-house technical knowledge and capabilities, for example by having their technical staff shadow the members of external TSOs as they perform activities. This is essential (and in most cases required by laws and regulations), since the owner organization will become the operating organization upon the issuance of the operating licence and will assume all responsibility for safe and reliable operation of the plant.

More importantly, this is the time to record technical information and knowledge, for example design philosophy, basis, approach and methods, for later technical support needs and activities. This is a critical element, as it will be the foundation for providing, maintaining and improving technical support through a competent internal TSO or for exchanging accurate and pertinent technical information with external TSO(s) later, during the operation and decommissioning stages.

2.5.3. Operational technical support

During the period of safe and efficient operation of the nuclear power plant to achieve its purpose of reliable, economical and regular production of electricity, technical support is essential to operate the plant safely and efficiently, since it provides adequate, correct and timely input, information and advice regarding the operational decisions. The TSOs support safe and efficient operation by providing technical oversight and control of operational activities in order to:

— Ensure that the plant design and operation meets or exceeds the requirements and needs for safety and reliability;
— Optimize and improve plant operation and performance for effective and efficient electricity generation;
— Protect and enhance assets and their long term availability and operability.

Once the regulatory body grants authorization (i.e. the operating licence), the operating organization is fully responsible for the safety and reliability of the nuclear power plant [18] and for making safe, sound operational decisions. Therefore, for operation and asset management, it will have an established, capable and competent internal TSO in order to handle technical support acquisition and provision within the organization, as well as a set of arranged partnerships with qualified and competent external TSOs. It will also have established mature and structured programmes and processes for provision and procurement of technical support, including the management of interfaces.

There may be variations in the way internal and/or external TSOs are used during the operation phase depending on the plant activity for which the decision making relies on technical support, as well as the corporate strategy, style and tradition of the operating organization. For example, for the technical support needs for daily or frequent operational decision making, the operating organization may rely completely on an internal TSO, while for one time, first of a kind or special cases, such as cases involving major facility modifications (e.g. major equipment replacement, plant refurbishment), it may choose to utilize external TSOs to perform/review technical activities with direction, consultation and oversight by the internal TSO. Regardless of the share of technical support provided by external TSOs, the operating organization's internal TSO needs to be competent and involved in order to ensure that the technical support provided meets or exceeds the decision makers' needs in adequacy and timeliness (including schedule and budget), as the operating organization's responsibility for the safety and reliability of the nuclear power plant and the decisions associated with those cannot be delegated.

2.5.4. Decommissioning technical support

The technical support for decommissioning is typically twofold: (1) support for decisions on establishing and following national decommissioning policies and strategies at the beginning of the nuclear power plant project and during the entire life cycle (until the start of decommissioning activities); and (2) support for decisions on various aspects of decommissioning implementation, such as decommissioning plans and paths for management of large volumes of waste generated by the decommissioning, during the period of transition from the operations to the decommissioning phase.

A national policy and associated technical strategy (or best option strategies) for decommissioning, that are established at the earliest possible time, set a framework for nuclear power generation in the energy mix with the 'end in mind'. The formulation and optimization of the decommissioning strategy particularly reflect technical needs, priorities, constraints and infrastructure specific to the facility, owner/operator or country, and have to be considered together with the non-technical factors [19, 20]. The technical support, therefore, plays an important role in establishing and maintaining a policy and in the associated decisions taken in accordance with a decommissioning strategy in place throughout the life cycle, particularly due to technical factors that are anticipated and observed as the nuclear power plant project goes through all phases until the beginning of decommissioning, such as how the facility is designed, sited and operated. Reference [20] strongly recommends, based on the lessons learned, that the nuclear power project planners and nuclear power plant owner/operators consider decommissioning at the earliest possible stage of the plant life cycle and that the project owner organization maintain a decommissioning plan, which includes the management of radioactive waste, throughout the plant lifetime.

Before the start of decommissioning activities, there is a period of transition from operations to decommissioning that will require decisions mainly made by the owner/operating organization. The first and main decision on ceasing operation and on permanently shutting down the nuclear power plant marks the start of this transition period. Between the decision to shut down and the actual end of operations, the owner/operating organization will make more decisions on several aspects of decommissioning, such as the decommissioning plans and paths for management of the large volumes of waste generated by the decommissioning. The facility design and configuration information — and any compiled changes to it — has significant importance to decommissioning goals, plans and activities, including characterization of the waste. The internal TSO plays a central role in preparation for decommissioning strategies, programmes and plans, as it possesses an accumulated and detailed design and operation history of the plant and has the most authentic knowledge of these data.

2.6. TECHNICAL SUPPORT INTERFACES

It is also recognized that there are many technical support functions and activities performed by (and for) various entities, including government agencies, NEPIOs, project owner and plant owner/operating organizations, architect–engineers, responsible designers, technology vendors, independent consultants and subject matter experts, and academic and research and development institutions. These entities interact continuously, periodically or intermittently throughout the plant lifetime (Fig. 5).

The crowdedness of Fig. 5 attests to the complexity, variety and aggregation of these interfaces, which have to be managed carefully and effectively in order to achieve informed and objective decision making based on adequate, balanced, independent and unbiased technical input and knowledge without conflict of interest.

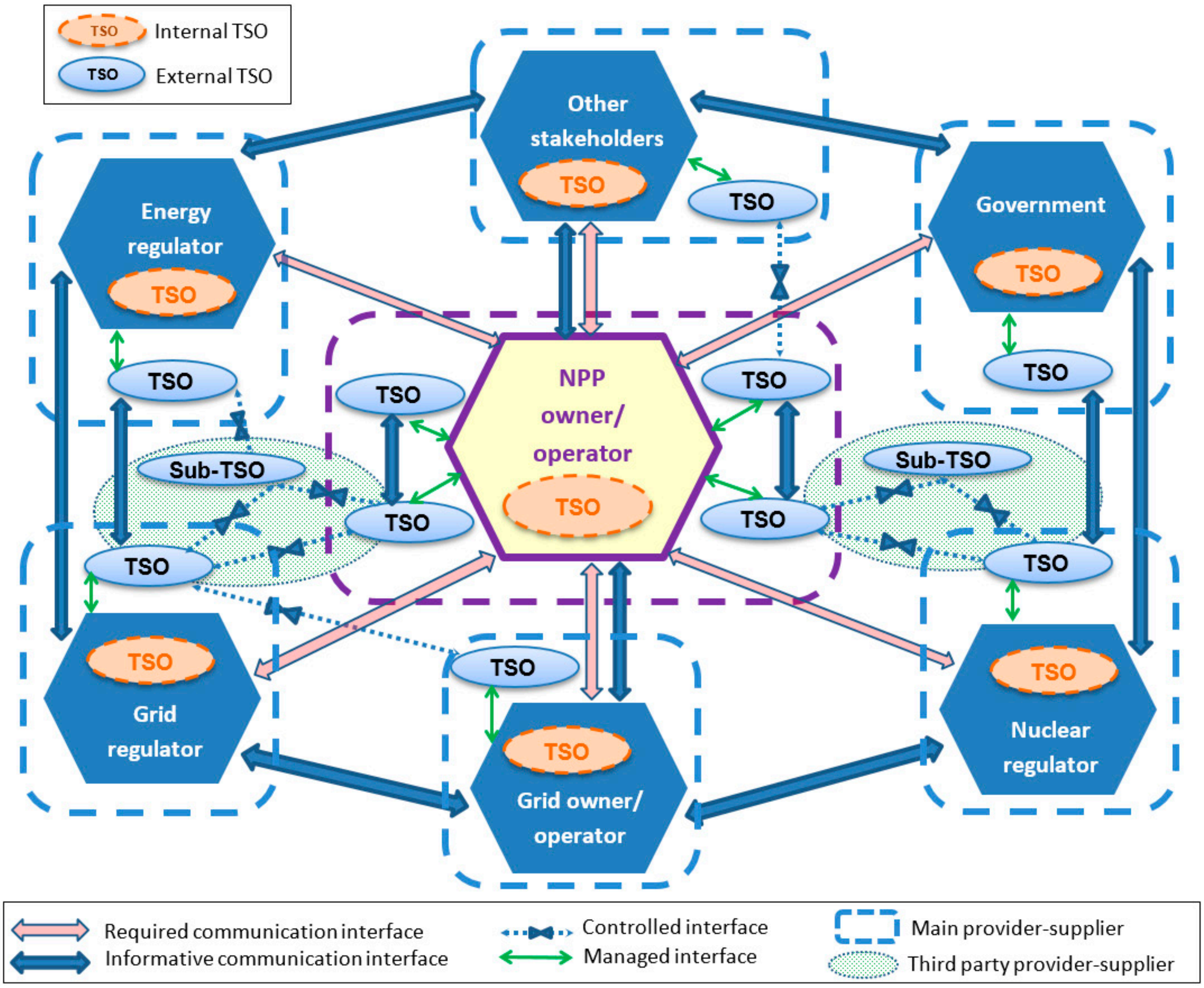

FIG. 5. Technical support organizations involvement in licensing and operation of nuclear power plants. TSO — technical support organization.

2.6.1. Types of interface for technical information exchange

The technical support interfaces, as well as their establishment, handling and maintenance, take certain forms in accordance with the associated and applicable laws, regulations, commercial and financial transparency requirements, contractual/commercial contracts or corporate level expectation agreements, as follows:

— *Managed interfaces:* These interfaces are the direct interaction paths between the organization that is requesting and receiving technical support and the TSO that is providing it. These interfaces are typically customer–provider interfaces and are managed by internal procedures and programmes of each organization and the contractual agreements between the organizations.
— *Controlled interfaces:* As a TSO may have several customers, particularly in a country where the expertise is not abundant, the exchange of technical information and knowledge in support of one decision from two different perspectives or roles (e.g. operational and regulatory) may cause lack of independence of technical support. Therefore, these interfaces need to be controlled by imposed programmes and procedures — typically within the TSO that is providing technical support to two (or more) different customers — to ensure independence and to prevent the contamination of information.
— *Third party interfaces:* These interfaces are indirect interfaces between the organization requesting and receiving technical support and organizations supplying technical support services (human resources, analytical tools, data etc.) to the main TSO that is providing technical support to the main customer. These interfaces are typically not obvious to, or controlled by, the decision making organization. Therefore, they require transparency and oversight of the main TSO in order to maintain a service supply chain without a conflict of interest.

2.6.2. Types of interface for communicating technical information and decisions

Since the technical matters associated with plant design, construction or operation involve decisions by many stakeholders, such as owner/operators, various regulatory bodies, government agencies, responsible designers and vendors, each stakeholder needs, requests and obtains similar technical support from its own TSOs for the corresponding decision making. Although each stakeholder's decision is made from a different perspective or for a different purpose, the interfaces exist at the execution level, for example, production of technical analyses and reports, and selection of inputs, assumptions and pertinent output. Figure 6 provides an example of such stakeholder involvement where each stakeholder gets technical support for its own decision making on the same topic (non-baseload operation of a nuclear power plant, in this example), based on its responsibility and authorization for the decision. When deciding whether a nuclear power plant is to be operated flexibly, technical capabilities and constraints together with economic and legal constraints or incentives within a national energy policy have to be taken into account systematically and in an integrated manner by each decision maker. As illustrated in Fig. 6, analysis and research and development play a central role in the decision for many activities involving and needing such technical support, particularly by nuclear power plant owner/operating organizations and grid system owner/operating organizations, as well as by all of the involved regulatory bodies.

Considering these combined/corresponding (but independent) efforts of technical support request and provision, it is also beneficial to establish interfaces at the execution level to ensure all involved parties are informed on the technical background, information and knowledge on the matter that requires a decision. These typically serve two purposes: either the information exchange is needed for the decision by either party, or it is informative to align each other's technical input in the decisions. Therefore, the interfaces may be of two types:

— *Required communication interfaces:* These are the interfaces that are used to convey the technical information required (e.g. by laws, regulations, owner requirements), such as the interface between the owner/operating organization and regulatory authorities (nuclear, grid, environmental, financial, etc.) on compliance, assessment, approval and oversight. These interfaces are not necessarily the interfaces between a regulator and an operator, as they may also exist, for example, between two non-regulatory entities due to a technical information exchange requirement (for example, communication between a nuclear power plant operator and a grid system operator as required by the grid code).

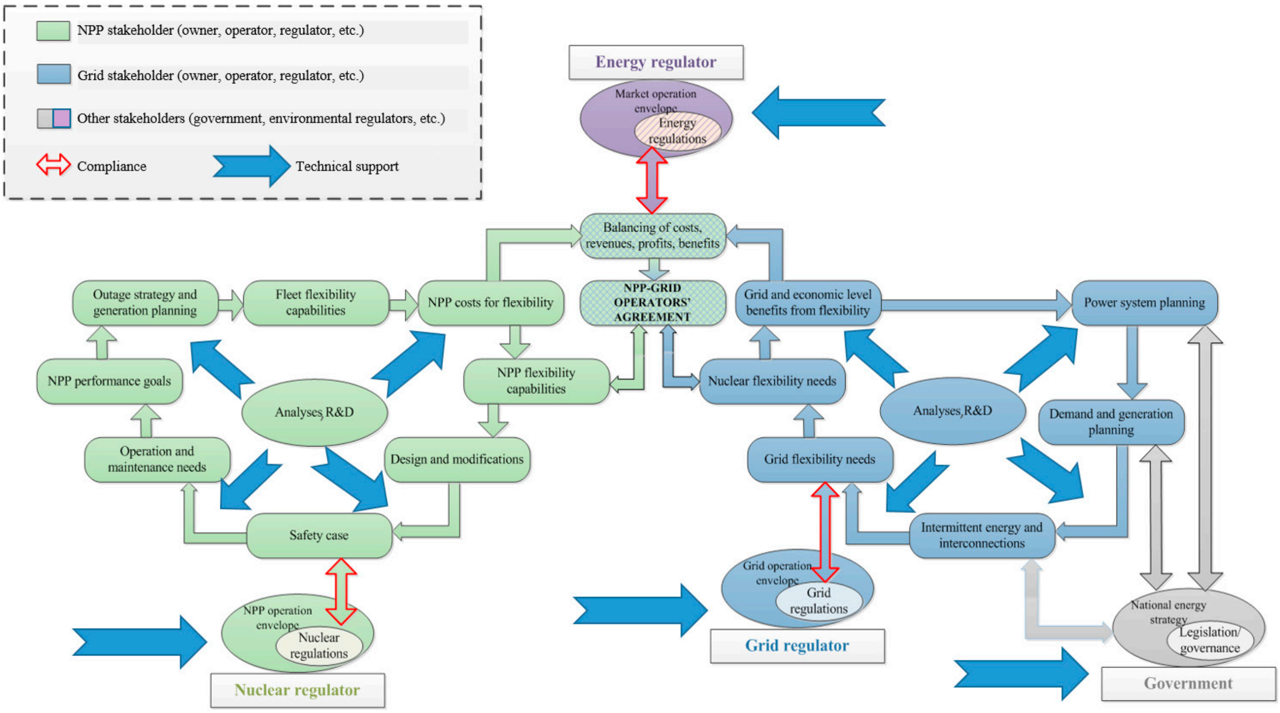

FIG. 6. Stakeholder interfaces to obtain and apply adequate technical support for the decision made by various stakeholders on the flexible operation of a nuclear power plant [21]. NPP — nuclear power plant, R&D — research and development.

— *Informative communication interfaces:* These are the interfaces that are open to exchange of technical information between the organizations, associated with decisions which have impact on all involved parties. For example, decisions on compliance with a particular nuclear safety requirement could be closely associated with, or could have an impact on, another regulatory requirement. Carrying on the example provided for illustrating required communication interfaces above, a regulatory requirement regarding limits in the variation of nuclear power plant electrical output which is developed by the nuclear regulator may contradict a regulatory requirement for the same characteristic by the grid system regulator. Here, there needs to be an interface between the two regulators for informative communication.
Informative communication interfaces are established and used to convey and exchange technical information and knowledge so that all parties can make balanced and informed decisions. However, these interfaces need to be carefully controlled by administrative procedures and professional ethics to prevent contamination of required and restricted communication.

Figure 7 provides another example (on a more specific and narrower scale) of such activities by matching corresponding areas/functions that may need similar technical tasks (in this example, by an owner/operating organization and a nuclear regulatory body) based on the role of the stakeholder and its responsibility for decision making. Since the assurance of safety in the plant design, construction and operation is part of the review, approval and oversight functions of nuclear regulatory bodies, they need technical support from their internal and external TSOs [16] to make safe, sound decisions in conducting these functions (e.g. authorization and issuance of licence for the subject nuclear power plant). Furthermore, the capabilities for the conduct of technical tasks and the adequacy of the programmes for the acquisition and utilization of technical support by (and for) the licensee, or licence applicant, may also be examined[4] by regulatory bodies. This role and responsibility may include the inspection of the technical support processes and products of licensee's TSOs, as well as the licensee's programmes

[4] For example, in some regulatory systems, good capacity and capability for technical support provision and acquisition may be a requirement for issuance of an operating licence. In some other regulatory systems, the regulatory body has oversight of the TSOs providing technical support to licensees, which includes qualification, certification and inspection of such TSOs.

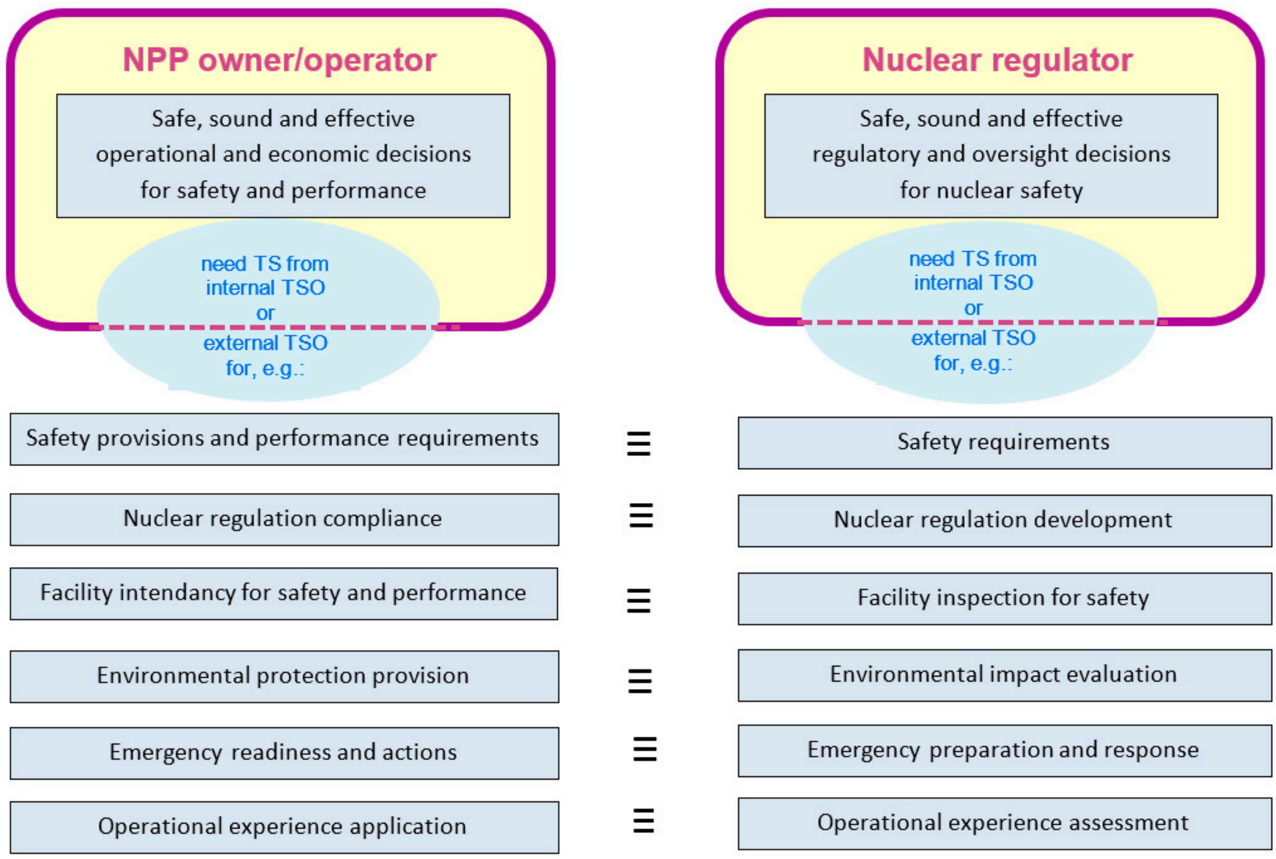

FIG. 7. A sample set of corresponding activities needing technical support for the decisions by different stakeholders: operational decision activities vs. nuclear regulatory decision activities (the latter are condensed from a discussion in Ref. [16]). NPP — nuclear power plant, TSO — technical support organization.

and procedures for ensuring adequate and correct technical support for safe and informed decisions by the licensee during design, construction, operation and decommissioning.

It should be noted that Fig. 7 is a very simplified presentation for illustration purpose only. As such, it lists a subset of many areas where an owner/operator would make decisions with their corresponding nuclear regulatory decision making areas. Similarly, the nuclear regulatory decision making areas listed in the figure are a sample set which is condensed from a comprehensive list discussed in Ref. [16].

3. KEY ELEMENTS OF ACQUIRING AND USING TECHNICAL SUPPORT

Regardless of the stage of a nuclear power plant’s lifetime, there are fundamental elements that are important to acquiring and utilizing adequate and timely technical support for making sound and informed decisions based on all relevant technical and scientific information available. The decision making entity (e.g. government, NEPIO, nuclear power plant project company, owner/operator) is the requestor and user of technical information, and as such, it is the customer of the TSO[5] providing it. Therefore, in requesting and obtaining needed technical support,

[5] Although an internal TSO is part of the decision making entity, for all practical purposes the internal TSO can be considered the supplier of technical information to the customer, internally. This is regardless of whether it actually performs the preparation, review or presentation of technical information or it only requests, receives, validates and accepts work by an external TSO in order to present the technical information to the decision makers of its organization.

and understanding and using it in decision making, the decision making organization has a collection of processes and subprocesses with key elements, including:

- A corporate level commitment and a resolute policy defining philosophy, strategy, value and allocation of resources for adequate and accurate technical input and support for making safe, sound decisions on safety and reliability;
- A culture of understanding, promoting and demonstrating the value of technical conscience and the associated values, practices and behaviours in provision and use of technical and scientific input and perspective in decision making;
- Establishing technical authority and technical conscience roles and responsibilities;
- Implementing processes for requesting, obtaining and utilizing correct and timely technical support systematically by an established governing programme and associated procedures that are written, controlled and followed;
- Support for training to build the awareness, knowledge, skills and attitudes which anchor competency and ensure prevention of undesirable effects in decision making due to miscommunicated, misunderstood, omitted, untimely or incorrect technical and scientific information;
- Effective work practices towards identifying technical issues and requesting or providing technical support to resolve these correctly, effectively and in a timely manner;
- Providing adequate time and resources for 'critical thinking' with regard to core activities, with additional allowance for such for critical thinking for discretionary and urgent activities;
- Implementing a systematic approach for continuous improvement with effective and prompt corrective action and trending programmes to document and track technical support related events, near misses, potential hazards, potential weaknesses and observed gaps;
- Ensuring oversight, both continuous and periodic, of the technical support and associated programmes and procedures through focused observations and feedback on engineering practices, procedures and programmes of technical support providers and technical information handlers;
- Developing conclusive and conducive metrics to assess the overall health of the process of obtaining and applying technical support in order to discover areas of improvement;
- Conducting periodic internal and external assessments including benchmarking to identify areas for improvement and implementing industry practices to develop and implement plans for technical support process optimization;
- Using operating experience in an effective and timely manner, including complete review and extraction of applicable lessons learned with timely incorporation in the technical support process to prevent or minimize similar deficiencies in the future.

This section expands upon these elements, which experience shows lead to effective establishment and implementation of — and continuous improvement in — the process of requesting, obtaining and applying technical support in decision making.

3.1. COMMITMENT

In order to effectively acquire and use technical support for informed decisions, the values, roles, priorities and responsibilities in the process of requesting, receiving and assessing technical information for a decision — towards safe, reliable and efficient generation of electricity with quality and longevity — need to be understood and agreed throughout the organization.

This understanding starts with a corporate commitment, since the corporate strategy, style and tradition will drive the technical task performance, resources, plans and schedules, as well as the determination of source, type, scope and quality of technical support needed for making safe, sound decisions. The organization's management commits to obtaining and using correct and sufficient technical and scientific information for/in decision making with the following key principles:

- Nuclear, radiological and environmental safety;

— Maintainability and operability as they relate to industrial and radiological protection of staff;
— Efficiency and effectiveness of electricity generation;
— Timeliness in consideration of plans and schedules; and
— Longevity of assets during the entire plant life cycle.

Therefore, a commitment for effectively acquiring (or producing, see footnote 5) technical support has to be initiated at the corporate level with the purpose of achieving safe, reliable and efficient electricity generation. To ensure this is accomplished, clearly defined expectations for all levels, including the nuclear power plant project (and later, owner/operating) organization's board of directors and chief officers, are established, documented and communicated. The commitment emphasizes the importance of technical information when needed for a safe, sound decision and of potential impacts from ineffective technical support resulting in improper decisions on safety, reliability and plant performance.

Managers at the most senior level demonstrate their commitment by their sincere and direct interest in, and the value they place on, technical input in decision making, and their understanding of its necessity for safe, reliable and efficient design and operation. Since the senior management plays a vital role in demonstrating this commitment and in disseminating the corporate strategy and vision, they assume ownership for and show active support of the process of acquiring, understanding and using technical information correctly and in a timely manner.

3.2. POLICY

For technical support and its use in decision making to be effective, it is necessary to declare and promote the commitment through a corporate level policy that sets expectations regarding behaviours and values. The policy statement declares management's sincere commitment to:

— Making informed and timely decisions by using all necessary technical information;
— Identifying, requesting and understanding the correct and relevant technical information needed for decisions.

The policy needs to make it clear that key attributes of the commitment have to be considered in every task which necessitates correct and timely technical support and that those attributes are valued and applied consistently throughout the organization. The policy promotes and values the use of technical and scientific factors in decision making, as this is important for the safety and performance of the nuclear power plant. Therefore, it has to be clear and concise, with credible and realistic implementation. It includes, for example:

— Promotion and expression of corporate and senior management commitment;
— Statement of objectives for acquiring and utilizing technical information;
— Core values for requesting, receiving and providing technical support;
— Framework for the management system for internal and external TSO support;
— Management structure with assignments and responsibilities within the organization for request, receipt, provision, assessment, explanation and use of technical information and advice;
— Clear definition and criteria for application of priority and graded approach to identifying, acquiring and using technical support;
— Assurance of allocation of resources based on priority and graded approach accompanied by the associated thresholds and criteria;
— Specific requirements and guidance for implementation of technical support acquisition and application internally and externally.

With this policy as the foundation, a governing programme and associated procedures will be built for requesting, obtaining and providing correct and timely technical support and utilizing it appropriately and without delay in decisions on safety and performance. The established governing programme and associated procedures are written, controlled and implemented in accordance with the requirements, expectations and framework defined by the policy such that the technical support requirements, risks and control measures are defined at the time assistance is sought and they are made part of the process until the final decision making.

3.3. CULTURE

While establishment of and adherence to the policy, programmes and procedures are necessary and essential for successful acquisition, provision and use of technical support and for the associated decision making, they are insufficient if implemented and applied impersonally. Effective inclusion of technical information in decision making needs to have two common characteristics:

(1) Everyone in the relevant organization acts to assist and contribute to a safe, sound decision with consideration of key attributes and with safety and reliability being the top priorities.
(2) Everyone in the organization is involved in the implementation of the technical support process and its improvement, not because they are told to be but because they want to be.

This is the behaviour and attitude of the organization (i.e. its culture). The following main elements of culture need to exist and be fostered in the organization for it to develop and maintain an effective technical support acquisition and utilization process for sound and timely decision making:

— Awareness of the importance of objectivity, impartiality, accuracy and factuality in technical information and its value and unbiased use in decision making;
— Ownership and accountability in identifying the need for technical support and the request, acquisition and use of correct and timely technical information;
— Valuing a questioning attitude and critical thinking at all levels;
— Respect for professional opinion at all levels;
— Respect for and professional resolution of differing technical opinions;
— An open and collaborative environment in which technical information and knowledge are shared for complete, comprehensive, transparent and integrated decision making;
— Learning and informing to understand and improve, including learning from mistakes with a ‘no-blame’ attitude.

3.4. PLANNING

Another essential element of sound and timely technical support determination and acquisition, and its use in decision making, is effective planning and preparation. Planning involves the identification and prioritization of activities and identification of critical paths regarding what support is needed (task review) and when it is needed (schedule) related to informed and timely project and operational decision making.

Task review and scheduling encompass: determination and understanding of need; purpose and timing of technical support during the project implementation; prerequisites and challenges of conducting the associated tasks, including necessary competencies, skills and tools; information exchange; hold, review and check points, and so on. It also identifies any support and interface required to ensure that technical support activities are carried out effectively and in a timely manner and defines their coordination with all the interested parties (government, NEPIOs, design organizations, manufacturers and suppliers of the equipment, regulatory body, etc.). All these have to be considered, understood and planned for prior to the performance of the task.

In particular, the task planning process needs to ensure that the significance of any known or anticipated change or abnormal situation is communicated and assessed in advance. The nature of the assessment and extent of communication will depend on the risks involved. This impact assessment will also help with planning and establishing interfaces, communication methods and timing among the relevant individuals and groups before and during the activity. Naturally, it cannot itemize acute needs that arise when the project is in a certain phase (e.g. off-design conditions during design phase, field changes during construction, equipment failures during operation) or for any unplanned or unexpected project status changes; however, it may anticipate and provide contingency and allowance for recovery of schedule and coordination of resources as a part of the main plan or may be a supplement to it as ‘contingency planning’.

Therefore, the planning will consider all the information and knowledge about the human, environmental, material and financial resources associated with the task, the risk and impact and operating experience to result in safe and efficient task performance through:

- Effective activity steps;
- Appropriate selection, training and qualification of the performers;
- Optimal time for allocation of tools and facilities;
- Adequate self and second party verification scope and intervals;
- Applicable rules, requirements and expectations governing the activity and its control and management [22], and so on.

3.5. ORGANIZATION

3.5.1. Clear roles and responsibilities

Regardless of the TSO, which may vary from one case to another, determination of the need for technical support, description of its objective and use of its output is the responsibility of the customer. In the customer organization, therefore, all team members, whether they are part of one or many internal and external organizations supporting the activity and assisting decision making, need to know and understand their role and the manner in which their task will be used in the decision. This requires definition of clear roles and responsibilities for identifying, requesting, providing, receiving and understanding the correct and relevant technical information.

All members of the staff of all organizations participating in the activities and tasks relating to acquisition/provision and utilization of technical support need to know what their role in the process is and how their skills and knowledge in specific areas are to be used in achieving sound decision making (this includes the identification of those who are responsible for decision making). Therefore, from the highest ranking officer down to the people conducting the activities, in every part of the structure, the staff members clearly understand their roles and responsibilities in identifying, requesting, acquiring, evaluating, and interpreting technical information and, more importantly, their roles and responsibilities in supporting informed decision making.

When the technical support tasks, priorities and plans are coordinated and executed, there is a collegial relationship among all involved departments and all concerned parties to ensure that the activities are conducted based on collectively agreed priorities and with adequate safety and quality, such that all concerns involving the technical and scientific aspects are appropriately, mutually and completely addressed. For that purpose, cross-organizational channels need to be defined and put in place to communicate input from (and output to) those who are working together in different organizations. This is particularly important in periods of rapid organizational change and for non-routine tasks.

As previously mentioned, there may be distinct and necessary decision making roles and responsibilities at different levels (i.e. authorization, coordination and execution levels). This makes it necessary to prevent overlap or contradiction of responsibilities with assigned authority and responsibility. Therefore, the roles of decision authority, technical authority and technical conscience, which were introduced in Section 2.3, need to be clearly defined, agreed, followed and respected throughout the organization. The following sections provide more information on each of these roles and its associated responsibilities.

3.5.1.1. Decision authority

Technical support is needed to make decisions in various phases of nuclear power development and utilization, starting with consideration of and commitment to nuclear energy in the energy mix and continuing until the nuclear power plant is safely and efficiently decommissioned. The responsibility and accountability for making that governing decision need to be assigned to one person at the highest level in the decision making entity (e.g. government, NEPIO, nuclear power plant project company, nuclear power plant owner/operating organization) and with the most authority. This person is the ultimate decision maker at the authorization level, who considers all the factors, including the opinions and decisions from the technical perspective, and makes an executive decision, in an integrated and binding manner.

Although it is a common practice to have decision making body (i.e. a group of people such as an executive committee or commission), the decision authority can accept or reject the view of such a committee or commission, as he or she is the person carrying the accountability and authority.

The decision authority cannot be delegated, as it is typically defined by laws and regulations. It should be noted that, in very special cases, there may be more than one decision making authority within the same organization depending on the laws and regulations. For example, during the operation phase, the person assigned and designated by laws and regulations as responsible and accountable for safe operation of a nuclear power plant unit (i.e. control room shift crew leader), has the authority to make decisions for the safe operation of the plant as prescribed by the 'operator licence' requirements. At the same time, the person at the highest level in the organization of the same nuclear power plant (e.g. chief nuclear officer) is the decision authority for decisions concerning requirements of the 'operation licence', as well as the needs of the facility and the site. In such cases, the clear line separating the authority needs to be defined and respected in accordance with the authority, responsibility and accountability that are prescribed by the laws and regulations.

This definition and assignment of decision authority may become particularly important during nuclear emergencies and accidents, as illustrated by the following statement from section 2.6.4.3 of the report by the IAEA Director General on the Fukushima Daiichi accident [14]:

> "During the accident, the site superintendent, with support from the shift supervisors and general managers of the operations department, was responsible for managing the response to the events at all units. Decisions related to core cooling and venting containment were the responsibility of the site superintendent. However, in some instances, instructions were provided directly by the NSC [Nuclear Safety Commission] or members of the Prime Minister's Office [see Ref. [23]].
>
> "The roles and responsibilities of the headquarters of the Prime Minister, national and local governments and nuclear plant operators were not clearly defined in the Nuclear Emergency Preparedness Act [see Ref. [24]], nor were the defined roles and responsibilities always followed [see Ref. [23]]."
>
> The report provides several examples, and concludes by stating:
>
> "Such situations were cited as leading to confusion with respect to the decision making authority and the review and the decision itself, especially since it appeared to some workers that 'external opinions were given priority over judgment of the director of the ERC at the power station (Site Superintendent)' [see Ref. [25]]. In general, the lack of clarity about roles and responsibilities increased stress and confusion for all parties, worsening the situation from a human and organizational point of view" [14].

3.5.1.2. Technical authority

An organization needs to establish and assign a technical authority role, responsibility and accountability to a person in the organization who will make decisions on the technical activities and will determine, control, manage and assess the requisition, acquisition, provision, description and expression of technical information, as well as its recording and preservation. The technical authority is the decision maker at the coordination level and carries the responsibility, accountability and authority to:

— Control and manage the determination, request, acquisition and provision of technical information;
— Present the technical results, conclusions, opinion, feedback and advice to the decision authority;
— Develop plans, programmes and procedures for technical support identification, request, acquisition and provision in accordance with the corporate strategy and project schedule(s);
— Determine needs for and establish a sustainable group of knowledgeable and well trained technical staff who can perpetually maintain the integrity of the facility and ensure the transfer of technical knowledge to the next generation of staff for the lifetime of the facility;
— Develop long term plans for technical resource and knowledge management.

Typically, the highest level technical manager (for example, the vice-president of engineering of a nuclear power plant organization as it may be structured for a particular operation phase), as the head of the organization that determines, acquires, provides and assesses technical information for an input to the decision by the decision authority, assume the technical authority role. However, unlike the decision authority, the technical authority can be delegated to a responsible and accountable individual (e.g. the highest level technical manager in responsible designer or external technical support entities) or responsible and accountable group (e.g. a committee, board, commission or panel).

Decision making boundaries for technical authority, particularly with respect to authority being applicable and limited at coordination level (i.e. applicable and limited to the technical activities and technical advice and perspective) need to be communicated to and understood by the entire organization. It may also be possible that ultimate decisions are made primarily on the technical and scientific facts, and in those special cases, the technical authority can have a major role in the final decision making (i.e. veto or request change to the decision solely due to technical conscience). Prerequisites, criteria and steps for such special cases need to be defined in the programmes and procedures of the organization.

3.5.1.3. Technical conscience

The technical support is requested, obtained, verified, understood, interpreted and expressed with a high degree of technical precision, accuracy, completeness and timeliness and with the application of professional and ethical practices in order to achieve a safe, sound decision. This is accomplished by technical staff, who have competency, proficiency, expertise, knowledge and technical and soft skills, assuming the roles and responsibilities as the technical and scientific 'body' of the nuclear power plant (project and/or plant). Technical experts as individuals and groups (with ownership of technical information and knowledge to understand and assess the plant design, configuration, operation and maintenance with respect to their basis, criteria, requirements, design and operational margins, past and current status and characteristics, as well as owner's technical expectations) are the technical and scientific conscience of the organization.

While performing the technical activities and tasks (i.e. while producing and consuming technical information), the technical conscience of the organization will make decisions on the task and its conduct, for example, on input, assumptions, methods, cases to explore. These decisions are made at the execution level and some of these may require concurrence by the technical authority. Thus, the criteria and the thresholds for higher concurrence or approval of such execution level decisions need to be clearly described in the plant's technical programmes and procedures.

The technical conscience will morph during the phases of a plant life cycle due to the nature of the technical information needed and the technical activity conducted for a particular phase. Accordingly, the execution level decisions involved will differ and the technical conscience may consist of internal or external technical staff and experts, or a combination of the two. Regardless of the organizational structure or staffing, roles and responsibilities are assigned to the technical conscience of the organization — with appropriate competencies and proficiencies and, more importantly, with ownership — such that the technical staff ensures:

- Technical and scientific fundamentals, processes and requirements are determined and followed, and any deviations from these are justified and communicated.
- Technical errors, deficiencies and failures are promptly corrected, and they, together with their impact on the decision, are communicated in a timely way. It is a good practice to rigorously determine the causes not only of errors but also of near misses, and to put corrective actions in place to eliminate future ones.
- Decision makers are supported by timely and complete technical input for an optimized and informed decision.
- A questioning attitude and critical thinking are reasonably used to consider and explore 'what if' scenarios, to elaborate potential fall back options and to inform the decision and technical authorities of predicted consequences based on sound technical evaluations and judgements.
- The need for decision making on issues related to safety, quality, reliability, availability and efficiency is understood, anticipated and proactively solicited when needed based on technical and scientific knowledge. This may include, but is not limited to:
  - Potentially existing and foreseen non-conformances;

- Legacy technical issues;
- Degradation of assets.

The owner of the project or the plant endorses the roles, responsibilities and accountabilities of the people who make up the organization’s technical conscience and guarantees critical support by providing sufficient staffing and financial resources to:

— Determine, coordinate or assess technical support request and acquisition, including the selection of TSOs;
— Ensure the technical input is assessed and presented to decision makers in a timely, clear and concise manner;
— Participate in technical consultations during the decision making process, as needed by the decision and technical authorities;
— Collect, record and preserve the technical information and products of technical activities for future technical support needs;
— Make technical information available to all interested parties in the organization in a clear and timely manner.

3.5.2. Structure and staffing according to the needs and tasks

The specific organizational structure for technical support acquisition and provision is not a primary factor provided the core technical support activities and tasks are correctly identified and performed in a timely manner and satisfactory technical support is provided for a safe, sound decision to be made. To effectively request and obtain technical support, it is particularly important to focus on the core activities, rather than a predetermined rigid organizational structure. As the need for technical support and its acquisition and use differ in each phase of nuclear power plant project and nuclear power plant lifetime (as well as within each phase), owing to the nature of the decisions to be made, the entity first has to determine what technical support activities will be needed and the preferred ways to perform or obtain these. The needs for technical input that arise during the nuclear power plant project and drive the type of technical support, and consequently the associated organization, can be viewed as falling into two types, based on the strategy and plans for the decision making:

— *Planned needs*: These are connected with the scheduled tasks related to the project (and later the installation and operation), and they are envisaged in the future and coordinated with all the participants of the nuclear power plant life cycle (design organizations, manufacturers and suppliers of the equipment, regulatory body, etc.);
— *Acute or non-routine needs*: These are the needs that arise as the project requirements change in a certain life cycle phase (off-design problems included) or due to an unplanned or unexpected situation.

An organization that is set up for technical support request and acquisition — including the selection of TSO, and its evaluation and use, needs to address these needs in an effective manner for timely provision of correct and adequate input to safe, sound decisions.

The ‘customer’ requesting, obtaining and using technical support has the choice to define and structure an organization in the way that best suits its needs as well as its goals and objectives. There is no ‘one size fits all’ organizational structure for acquisition and utilization of technical support for decision making. The decision authority in need of technical support for decision making has the prerogative to define the structure (as well as its technical support provider, i.e. the TSO) based on the technical tasks needed at a particular decision or phase and stage of the nuclear power plant programme or project.

Although the structure can be set up in many different manners at different stages of a plant life cycle, there are common features that can be observed in effective organizations:

— Understanding and knowing the activities and tasks needed for decisions and the time when they are needed.
— Identifying the level of skills and tools needed.
— Evaluating available (or potential) means and resources against needed tasks and competencies.
— Planning, deciding and organizing based on the ‘needs’ and the ‘means’ (i.e. human and financial assets) that are at hand and accessible.

— Arranging and sizing the organization such that people and responsibilities are assigned according to the tasks, rather than arranging tasks according to the size or form of the organization or the personnel at hand.
— Setting up clear functions and scopes for each organization such that there is:
  - No overlap of scope;
  - No shared responsibility;
  - No competing authority;
— Defining formal and structured interfaces, for example, with:
  - A single point of contact for internal and external interfaces;
  - 'Technical advocates' — responsible individuals in other key organizations who contribute to better and quicker understanding of interorganizational needs and capabilities (who also act as eyes and ears for the technical authority in the field);
  - Interface documents, such as baseline information documents and checklists;
  - Communication protocols, including scheduled or unscheduled bilateral and multilateral meetings.

3.6. KEY ATTRIBUTES OF EFFECTIVE TECHNICAL SUPPORT

3.6.1. Flexibility and adaptability

Because the needs for technical support vary from phase to phase (and even within a phase) throughout the nuclear power plant life cycle, technical support acquisition and use are not locked into a particular organizational form. The organization and its structure need to be flexible and adaptable and respond to changing conditions and phases during a plant life cycle while functioning in a planned manner with awareness of the schedule and long term plans, as well as the corporate strategy.

This also includes flexibility and adaptability in selection of the technical support provider in accordance with the goals and strategy. The flexibility is necessary to meet the technical support needs of the decision authority and comply at all times with the applicable laws and regulations. It is a good practice to describe the associated corporate strategy within the policy and to plan the middle term and long term resource allocations of the organization with anticipation and awareness of the morphing of TSOs.

3.6.2. Independence

In order to ensure a sound and correct decision, the technical information provided to the decision makers needs to be impartial and independent of the outcome of the decision. Conversely, the decision maker should not interfere with the technical support activity. Therefore, conflict of interest and influence in requesting, obtaining/providing and assessing technical information are avoided and neither technical support nor decision making is corrupted. This independence[6] typically avoids three situations:

— Decision authorities directing the outcome of technical support;
— TSO directing the outcome of decision making;
— Person(s) or organization(s) involved having an interest in the outcome of the technical support and/or decision, other than their obligations relating to the key attributes of effective technical support described in this section.

Lack of independence and impartiality would result in either an uninformed, insufficient or incorrect decision or incomplete or incorrect technical and scientific input to a decision. More importantly, it would lead to the creation of an environment that devalues or discredits technical conscience in safe and efficient decision making at a nuclear power plant.

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[6] Not to be confused with the 'independent verification', which is a specific quality assurance requirement that ensures that the person(s) verifying and validating a design activity did not participate in any way in the performance of the activity (i.e. he or she is an 'independent' reviewer).

3.6.2.1. Independence of decision making from technical support

This independence and impartiality means that the decision authority does not influence the conduct and results of technical support towards a particular outcome (i.e. favouring or hindering a predetermined decision). Therefore, the provider of technical support is not bound by directives from the decision making organization regarding the conduct and results of its technical work or any expected outcome.

Maintaining this independence requires an understanding by the customer and the supplier of technical support that, typically, there is a reason to request technical support and there is an objective in performing the technical work needed for decision making. Both the nature of the request and the objective of the technical support requested may be associated with possible and probable decisions; however, it is clearly understood that foreseen or expected decisions have no input into the technical work performed (or to its conclusions) in support of the decision making process.

In other words: the decision authority does not make a decision before having all the supporting evidence, including objective technical input, and the outcome of the decision making process is not a factor in the outcome of the technical support process.

3.6.2.2. Independence of technical support from decision making

Similarly, the TSO provides technical information to the decision makers objectively, based on scientific and technical facts and methods without being biased towards a particular decision. Independence of technical support activity from decision outcome ensures provision of objective and impartial technical input to the decision on the basis that technical output is not the decision but assistance to the decision making.

Maintaining this independence requires an understanding by the customer and the TSO that, due the advisory nature of technical support, the technical information provided by the TSO may typically point to a decision, may suggest several potential decisions or may recommend one decision over another solely based on technical and scientific judgement; however, the technical support is part of a set of other factors that will play a role in the final decision. The final decision is not made until all the factors (some of which may also be other technical factors provided to the decision maker by other TSOs or a third party on the same technical matter) are evaluated by the decision makers in an integrated and comprehensive manner.

Another case that highlights the independence of technical support from decision making occurs when technical activities of a TSO overlap with more than one customer related to the same technical issue from the perspective of different functional decisions. For example, as is mentioned in Section 2.6, different interested parties may seek technical support for their respective decision making and may have to use same technical resources due to limitations on availability of expertise and resources with the needed level of technical competency, proficiency and capability in the particular field in the region or country. In such cases, one TSO may have to provide technical support for, for example, the regulatory body and the owner/operator on the same issue. In order to ensure independence of technical support from decision making in both cases, one effective method is for the TSO to establish and institute an information separation policy and associated broad programmatic and procedural requirements implementing such separation (i.e. a ‘firewall’, in business, management, personnel and activity/task aspects and levels). Furthermore, the TSO has transparency with respect to its relationship with the customers.

3.6.2.3. Independence from personal or organizational interest

Whether it is in the preparation and presentation of technical information by the TSO to the decision maker or in the decision making by the customer, organizations’ activities can be hindered or corrupted (or may be perceived as corrupted) by organizational and/or personal interests and benefits. Although moral and ethical obligations establish impartial and unbiased technical support and decision, risk of such conflict of interest[7] needs to be minimized or eliminated in order to avoid improper decisions or distorted technical support.

[7] Reference [26] describes conflict of interest as follows: “A person has a conflict of interest when the person is in a position of trust which requires him/her to exercise judgment on behalf of others (people, institutions, etc.) and also has interests or obligations of the sort that might interfere with the exercise of his/her judgment, and which the person is morally required to either avoid or openly acknowledge.” Conflict of interest can also apply to organizations.

If other relationships, activities or interests are preventing an organization from providing impartial and objective products and services or the organization has (or may gain) an unfair advantage against competitors, an ‘organizational conflict of interest’ exists. If there is an organizational conflict of interest in a TSO, this would prevent this TSO from delivering fair assistance or advice to its customer, owing to potential loss or impairment of objectivity and impartiality in the technical support provided [27].

Such cases can be avoided or minimized by instituting ethics, conflict of interest, transparency and disclosure policies that would require disclosure of any current, past or future relationships and interests with other suppliers, customers, competitors, government agencies, and so on, and enforcing them through contractual conditions and requirements.

Although an organizational conflict of interest is more often associated with a TSO, it may also occur within the customer’s organization. When the objectives of one leader, section/department or individual are not aligned or collide with those of another — in spite of the corporate commitment and policy that define the common goals, values and priorities (see Sections 3.1–3.3) — the person or group may promote its own interests. This may affect the acquisition and use of technical information, as it may influence the determination of the need or objective interpretation and incorporation of information in decisions based on the objectives of the person or group rather than those of the entire organization. It is essential that organizations take steps to prevent such conflicts from arising among employees; these include establishing, communicating and anchoring the corporate commitment, policy and values, as well as establishing procedures for handling such conflicts when they occur, such as different professional opinion and conflict resolution procedures. Open vertical and horizontal communication and transparency among all levels of the organization, as well as a no-blame environment, can prevent potential or existing issues associated with conflicts of interest.

In addition to organizational conflict of interest, if a person does not (or cannot) perform his or her responsibilities and duties impartially and objectively owing to his or her private interests (e.g. outside professional relationships or personal financial assets), a ‘personal conflict of interest’ exists with the same results.

Conflict of interest cases may sometimes be unavoidable and do not always imply wrongdoing. However, if they are not identified and managed appropriately, they can compromise the safety and reliability of a nuclear power plant and the organization’s integrity, unity and credibility.

3.6.3. Competency, proficiency and training

To obtain the correct technical input for an informed and sound decision, the capabilities and capacities of technical support requester, provider, receiver and reviewer have to be adequate and sufficient for the activities and tasks involved in the technical support. A certain level of competency and proficiency is needed for various types of activities described in Section 2.4. For example, the preparatory and demonstratory activities may not require competency at as high a level as the exploratory or innovatory activities which necessitate high level expertise or special knowledge and experience.

Competency is an essential part of effective acquisition and efficient use of technical support in decision making for safety, reliability, availability and efficiency. A structured and systematic approach for selection and qualification of technical staff and the technical authority is essential in hiring, training and retraining of competent personnel in accordance with the needs and strategy for obtaining and applying technical information in decision making. Such an approach ensures a team of competent personnel who can define, acquire and understand the technical information and support informed and sound decision making. Competency is needed not only for performing technical support activities but also for planning and preparing for technical support needs and for implementing technical support output.

Proficiency is broadly developed for technical and scientific fundamentals and technical specifications to design, build, operate and maintain a nuclear power plant safely and efficiently. Proficient technical experts demonstrate ownership for the design, construction, operation and maintenance of a nuclear power plant and its systems and components to meet or exceed requirements and the owner’s expectations. While very specific knowledge and skills are crucial, experts also have a broader perspective of integrated plant design and operations and understand the context of how systems, structures and components (SSCs) support safe and efficient generation of electricity.

Training enables individuals and organizations to understand and perform the required tasks with thorough knowledge of technical and scientific fundamentals, their use and consequences and their impact on one’s own and other organizations. The training programmes for performing technical support activities may use a wide variety of methods (e.g. formal professional education, specific classroom lectures, independent reading, shadowing other experts, sharing resources with external TSOs, tacit knowledge transfer). Techniques such as training needs analysis are valuable in defining the requirements for technical and personal skills (e.g. communication and team working) and oversight abilities, as well as — and particularly — their tie to the corporate goal and strategy in technical support acquisition, provision and utilization.

Regardless of the type and extent of technical support activities, training needs to provide knowledge and understanding of: why particular technical information is required or expected; how the trainees' functions and roles in determining, obtaining and using technical information are tied to the overall decision making; and how their work practices and attitudes in conduct of technical support activities ultimately support safety and efficiency in nuclear power plants. These essential needs are addressed by broader training, sufficient to ensure that individuals at every level and organization understand the significance of their duties and the consequences of mistakes arising from misconceptions or lack of diligence and knowledge.

Training also ensures that management skills are acquired and maintained to supervise activities with a collective goal of effectively identifying and obtaining technical input and presenting it as an input to decision making. As leaders recruit and develop technically competent staff based on this collective goal, they need to thoroughly understand, demonstrate and communicate corporate policies, expectations and goals. Leaders recognize and promote continuing training to expand knowledge and skills in accordance with the corporate goals and strategies for technical support request, acquisition and use in decision making.

An assessment of technical knowledge and skills has to be undertaken as part of the training programme. For particular tasks and personnel, this may require undergoing formal qualification (and certification) and authorization for task performance and responsibilities [28]. Qualification and certification is a management action (or in some regulatory regimes, a requirement for specific technical support activities) that grants permission to individuals to perform certain roles or tasks. The qualification/certification programme that is associated with requesting, obtaining and providing technical information establishes that the staff (and the contractors) preparing, performing and monitoring the tasks and maintaining the programme administratively are authorized to perform these tasks as required. The qualification/certification documents that the staff has the competencies and skills to acquire or provide necessary and reliable technical support in decision making.

In cases in which external technical support is used, mechanisms and procedures need to be established for the verification and qualification of vendors' and TSOs' competencies and proficiency[8], as well as the preparation of contracts, agreements and grants to acquire needed expertise. It is recommended that the contracted technical support staff be provided training by the 'customer' organization to support understanding, demonstrating and communicating corporate policies, programmes and requirements, as well as goals, values and expectations. It would be a good practice to integrate the external TSOs into the nuclear power plant's safety management system and safety culture. This may include involving external TSOs staff in safety meetings, planning, preparing work procedures and instructions, incident analyses, training programmes, updating plant records and providing information concerning lessons learned and standards.

3.6.4. Corporate technical knowledge

It is essential for the owner/operating organization to gain and preserve technical and scientific knowledge and information on a nuclear power plant by, since lack of awareness and cognizance of the plant technical basis and technical and scientific fundamentals will result in uninformed decisions and may cause (or accumulate or contribute to the causation of) significant safety and performance issues. When technical support is provided without a full and correct understanding of the technical basis, the decisions relying on that technical input could adversely affect the safety and performance of the plant. In this regard, establishment of a knowledge management programme has to be considered by the corporate management, with a key focus on knowledge transfer from other technical stakeholders (e.g. responsible designers, vendors, contractors, in-house and external TSOs) and retention of technical and scientific knowledge.

[8] In some regulatory regimes or in certain tasks, the qualification of vendors and personnel may be controlled and authorized by the regulatory body or other authorized professional organizations.

Technical information or knowledge provided, observed, collected and gained are recorded and maintained for technical support needs that could occur later in the nuclear power plant life. It is encouraged to rigorously collect and retain:

- Technical information beyond the regulatory requirements that prescribe design and record control for quality assurance purpose (see Section 3.7 for record keeping under management system requirements). There are many technical bases, expectations and requirements for design and performance of SSCs that could be outside the quality assurance requirements that impact a plant's efficiency and performance.
- Explicit technical knowledge and tacit technical knowledge, since the technical personnel will change during the phases of a nuclear programme, which is often referred to as a 'century long undertaking'.

This is accomplished through a systematic record keeping process that is timely, as clear and comprehensive as possible and in accordance with the corporate strategy for technical support. This is particularly important when corporate strategy mainly relies on internal TSO for technical support, and critical technical information needs to be exchanged with external TSOs while making high risk decisions relying on technical support during the operation as well as the decommissioning stage.

Prior to the operation phase, the owner of a nuclear power plant project, and later the owner/operating organization of the nuclear power plant facility, needs to have its organization gain and preserve knowledge and information of systems and components as well as programmes and procedures. In order to do so, it provides its technical staff, particularly those who will be part of the internal TSO later during the operation phase, with culture and opportunities to:

- Closely follow the progress of design such that the technical staff is aware of and attentive to design objectives and fundamentals of the plant, for example design philosophy, basis, approach and methods;
- Closely shadow and observe the technical support activities performed by the external TSOs during construction and commissioning, in order gain in-house technical information and knowledge on facility configuration;
- Think critically and explore technical aspects from the point of view of internal TSO in order to achieve the most efficient and practicable technical solutions, with advocacy for the interest and benefit of their own organization, to be considered in decision making;
- Stay current with the developments in the nuclear industry and use operating experience to improve performance by being aware of best practices and/or pitfalls, as well as the advancement of state of the art knowledge.

Acquisition and recording of technical information and knowledge during design, construction, commissioning and nuclear power plant 'hand over' stages are essential (and highly recommended), as this will be the foundation for providing, maintaining and improving technical support during the operation stage by a competent internal TSO or for exchanging accurate and correct technical information with an external TSO. The technical information and knowledge gained on the plant technical basis (e.g. design philosophy, basis, approach and methods, equipment and system as-built conditions, test results and performance trends, critical operating and design margins, important technical and analytical observations) are recorded and maintained to the maximum extent possible.

3.6.5. Continuous improvement

The execution of the technical support process — from the determination of the need for technical support to the expression of results and outcome of the support to the decision authority — is routinely monitored, and any areas for improvement as well as issues relating to declining performance or effectiveness are identified and corrected. Lack of an effective and structured programme to identify and correct (and record) issues, deficiencies and weaknesses in technical support request, provision and acquisition, and in expression of technical views to the decision authority would result in accumulation of errors and deficiencies in technical support conduct and processes. This, in return, could jeopardize safe and reliable operation of the nuclear power plant by eventually leading to a plant state where the decision makers would lose control and true knowledge of the plant. This would become a critical issue relating to operating the nuclear power plant with safe, sound decisions at authorization, coordination and execution levels.

3.6.5.1. Measuring effectiveness

To maintain an effective technical support process, the organization will develop measures to identify whether the activities relating to request, provision, acquisition, assessment and expression of technical support to the decision makers are deteriorating or are being maintained or improved. The measures (e.g. indicators) are tailored to allow identification and determination of the underlying cause of any deficiency in programme, process and procedures, which in turn will lead to identification and implementation of corrective actions. They also ensure that decision and technical authorities remain aware of actual practices and values. The key performance indicators can be used by the organization to monitor its performance by observing and assessing the recent and current performance of technical support tasks, the current awareness of past performance, the effectiveness of determination and implementation of preventive and corrective actions and the attitudes and behaviour of staff, managers and authorities. The development of metrics for technical support activities and processes could be undertaken in a manner similar to that described in Ref. [22].

Both reactive and proactive measures of effectiveness exist to indicate not only an internal TSO's performance but also the performance of external TSOs and that of other internal organizations (aside from the internal TSO). Forward looking measurements (sometimes referred to as 'proactive' or 'leading' indicators) enable recognition and awareness of efforts to improve the conduct of activity and the associated processes. They are particularly valuable for providing opportunities to anticipate and pay attention to, for example, developing or accumulating issues, and early signs of declining performance and processes. However, they may be difficult to develop and quantify. Measurements of personnel behaviour and attitudes, for example, are typically qualitative in nature.

Quantitative indicators (metrics)[9] provide a useful further input to the assessment of performance of activities and health of the programmes, processes and procedures. These could involve monitoring, for example:

— Number of errors in communication of technical support requests and information, or analytical errors (both in final analysis and at the confirmation). These could be measured by both number and consequence. They may provide indication of lack of competencies, insufficient or deficient procedures or inadequate training, as well as indications of the value of technical support to staff and management.
— Repeated errors and deficiencies in technical products, when these errors and deficiencies can be quantified. These provide a measure of the failures or defects in determination and implementation of correct, adequate or effective corrective actions, or they may lead to organizational factors such as not being a learning organization. Additionally, if the errors and deficiencies are the same as the ones that occurred in the past (internally or externally), this may indicate issues with previous assessments or with communication of operating experience, or with existing processes for both of these.

It is generally agreed that both consequential and non-consequential events have similar causes. Therefore, being aware and correcting the causes of non-consequential events (for example, a near miss or an unintentionally avoided consequential event) would also contribute to the improvement of the programmes and processes and help to prevent potential future events. Therefore, the monitoring and trending of such occurrences could be included in the metrics.

For measuring the effectiveness of technical support and TSOs, other detailed indicators could be useful for correcting or improving performance. These may include, for example:

— Number of backlogged activities or tasks;
— Measure of non-procedural practices (i.e. 'workarounds') employed;
— Amount of technical activity or task rework, such as revisions to fix errors and deficiencies;
— Average life of routine technical support tasks;
— Measure of common (often human) errors;

[9] Numerical measures must always be subject to careful interpretation and be used as part of an overall judgement about performance. They should not be regarded as an end in themselves [22].

— Completion of training to the agreed time scales;
— Numbers of minor defects and near misses reported (an increasing trend in the reporting of these may be viewed as positive, since they frequently represent awareness regarding the precursors of errors and deficiencies).

In principle, this approach allows deteriorating performance and process in technical support to be identified at an early stage.

3.6.5.2. Recognition of declining technical support effectiveness and conduct

Although it is useful to monitor and act upon some of the measures on a consistent basis, and they can provide an important input to the overall picture, close observation of attitudes and behaviours of the technical staff and management provides supplementary information in the identification of declining performance.

Typically, the first signs of declining technical support performance and effectiveness are increasing cases of:

— Fast actions (i.e. 'jumping the gun' or 'knee-jerk reaction') in providing technical input to decision making without careful and critical thinking. This also includes making fast decisions without including and considering all aspects, particularly all necessary technical aspects, and may illustrate a declining commitment to and value on technical support within the organization.
— Conversely, slow actions, also referred as 'paralysis by analysis' — providing technical input to decision making in an untimely and delayed manner. This may be caused by lack of proficiency, competency or confidence of technical staff (or technical authority) with respect to seeing the big picture, cumbersome or unclear procedures and directions or miscommunication or lack of clarity of scope and schedule.
— Actions without goals and clear objectives or with unrealistic and artificial deadlines, overworking the TSO and wasting resources on non-priority, unnecessary or excessively detailed or unfocused activities and tasks. This may be a sign of weaknesses in determining the scope of, prioritizing and planning technical support activities at the coordination or execution levels (typically show up as 'bring me another rock' or 'I need it by yesterday' syndrome).
— Lack of knowledge (typically including insufficient knowledge of scope, topic, methods, or purpose), which may point to lack of proficiency and competency, faulty design and configuration control and communication, or insufficient preservation of corporate knowledge or training.
— Lack of questioning attitude at all levels (typically observed as 'tunnel vision' and 'group think') as well as dismissal of challenging opinions, particularly on a personal basis (for example, dismissing questions and opinions of young staff based on the belief that they 'do not know enough', 'they do not understand' or 'they are too low in the hierarchy'), which point to poor corporate culture and weak core values.
— Lack of critical thinking, which indicates that either the organization is not planning allowance for critical thinking in technical support activities (which would point to weaknesses), or is not valuing it.

The attitude of the organization, management and staff can also be an indication of causes of declining performance. Examples include:

— Complacency ('we know everything', 'it is as good as it can get');
— Hubris ('we are the best experts and technical staff', 'we do not need anybody else to tell us what to do');
— Loss of knowledge ('we think this was the original thought', 'what has been changed since then?');
— Not learning from experience ('we had that issue before', 'we heard about a similar issue from another plant a while ago');
— Lack of exploration or innovation ('if it works don't fix it', 'we have always done it this way').

Section 4.1.2 of Ref. [3] provides further lists of symptoms which signal the existence of shortcomings in TSOs, as well as attributes of well managed TSOs. These lists, surprisingly, are still applicable after decades of dissemination of good and bad examples of technical support processes at operating nuclear power plants.

3.7. MANAGEMENT SYSTEM

A structured approach for determining the need for technical support and acquisition and utilization of technical information is necessary and needs to address processes involving identification, request, review, verification and validation, and use of technical information. These technical support related activities follow a formalized management system with policies, programmes, procedures and/or instructions that is developed, reviewed, implemented and continuously improved.

The organizations receiving technical support define and take into account any management system requirements based on the quality standards and practices — as well as the business needs and expectations — in their organization. They also establish the elements of a system to ensure that the quality requirements are consistently defined and expectations are understood and applied on the supplier side (i.e. by the TSO) to meet or exceed these requirements and customer expectations.

It is also recommended that the management system that is required and established for technical support for safety and quality related decisions also be utilized for technical support for non-quality/non-safety related decisions. The latter include decisions on non-quality related technical and economic features, such as those for efficient plant performance, although a graded approach could be used for these, based on a value/impact analysis.

The system includes the communication of principles, organizational culture and structure. Additionally, it describes processes to control non-conformances in technical support provision/acquisition and its utilization, including prompt incorporation of lessons learned and timely implementation of corrective actions, as well as the control of corrective actions thereafter. Accordingly, it ensures the establishment of processes and procedures to communicate changes to all parties involved so that they can incorporate them in their technical support activities.

An effective technical support acquisition, provision and utilization process also consists of barriers, guides and controls, such as written guidance in the form of procedures, requests and instructions, and interface requirements. Administrative barriers and controls rely solely on individuals or organizations adhering to administrative guidance to control the adequacy and correctness of technical support and prevent deficiencies in the technical information provided, as well as appropriateness and thoroughness in its use in decision making.

3.7.1. Design control and configuration management

The design control process ensures that all applicable design and licensing requirements, bases, and conditions, and associated design information and products, are correctly established and translated into plant technical specifications, drawings, procedures and instructions. It also ensures that the changes to these are conducted in a controlled manner. The configuration management programme is to ensure that accurate and up to date information expressed in plant documentation is consistent with the plant physical and operational characteristics and in accordance with the design requirements and descriptions. It also ensures that this information is maintained, in a timely manner, and is available for making safe, sound, informed and cost effective operational decisions with confidence [29, 30].

The owner of the design documents — typically the technical staff within the owner/operating organization — has roles and responsibilities for the control of the design and configuration of the plant, including collection, retention and maintenance of information to reflect the current design and configuration in an accessible form/medium and making it available to relevant organizations and interested parties in an applicable form and format.

In doing so, the owner/operating organization defines the requirements of plant configuration management and ensures the establishment of business processes, procedures and information systems to ensure consistency among the design requirements (what needs to be there), the physical and operational configuration (what is there) and design and configuration information (what the document says is there).

Effective configuration management is particularly important in detailed design, construction and commissioning stages, since it will: (1) primarily set the foundation for ownership and responsibilities in design and configuration of the plant that will be owned and managed by the owner/operating organization during the operation of nuclear power plant, and (2) help strengthen the owner/operating organization's corporate knowledge and understanding of design and configuration in the activities during these pre-operation stages, such as:

- Design and physical plant changes;
- Licence application and amendments;

— Procurement and storage for the selection and review for suitability and availability of materials, parts and equipment;
— Procedure development.

3.7.2. Control of activities

All activities need to be reviewed for the potential threat from improper technical input resulting in unsafe and unsound decision making. Further planning is undertaken (see Section 3.4) and guidance is established to control the performance of technical support activities and the communication of technical information and information on the progress of activity in order to eliminate or minimize the risk of deficiencies. The extent of control depends on the significance of the decision associated with the technical support task, which could be determined by the complexity and/or rarity of the activity, as well as the consequences of the decision at hand.

Therefore, the technical support activity process and procedures include and follow a standard method of determining the significance of the task with clear definition and boundaries of frequency, complexity and consequences. Furthermore, they need to provide adequate guidance and prescription of methods, such as supplementary and increased controls, to minimize or eliminate the risk. This may be done by flow charts, checklists or a grading system that targets the decision and the project stage, such that the associated capabilities and resources are visualized in order to carry out the activity in a controlled and attentive manner while keeping the risk of deficiencies that could adversely affect the decision making as low as is reasonably achievable.

Ultimately, control levels will be determined by use of a graded approach, and the appropriate levels of controls and guidance will be reflected in the selection and provision of, for example:

— Competencies, qualification and authorization;
— Tools and methods;
— Review steps or number of hold, check and review points;
— Protections against foreseen events that would adversely affect risk and identification of steps to be taken to minimize consequences in the event of error;
— Scheduling or prioritization of other activities.

3.7.3. Assessments and audits

Management of organizations requesting and using technical support needs to be aware of the strengths and weaknesses within their organization and external organizations, and in their interfaces with each other. Therefore, the management adopts a proactive stance towards checking, identifying and correcting weaknesses that could impact correctness and timeliness of technical support. To this end, the management of internal and external technical staff and organizations actively supports assessments (self-assessment, peer assessment) or independent audits at all levels of the organization, assesses the findings and implements corrective actions. Assessment and audits focus on the programme, process and procedures and deficiencies in the system, rather than examining the individual performance. They achieve improvement through:

— Building common commitment to corrective action and key attributes among the customer and supplier of technical support;
— Getting management and staff of all parties involved in identifying problems in their own and other organizations;
— Providing experience and assistance in analysing problems;
— Focusing on performance problems and deficiencies at all levels;
— Providing training in auditing and observation skills.

The peer evaluation, audit and assessment processes could identify and document problem areas very effectively. However, only the TSO line management and the line management of the department involved in the determination, request and acquisition of technical support activities can resolve these issues. Similarly, only high level management is capable of making the changes to improve decision making processes. Therefore, for this process to ultimately result in improved technical support performance, there needs to be a strong management commitment for timely implementation of appropriate corrective actions within the organization and ensuring that they are also implemented in the supplier's (i.e. TSO's) organization.

3.7.4. Management of interfaces and communication of technical information

Success of effective technical support relies on the successful communication and exchange of needs, the schedule for those needs and all associated technical (and relevant non-technical) information that is to be shared. Many significant events can be attributed to 'lack of communication' and can be traced back to: inadequate written and verbal communication; failure or non-existence of formal interfaces; omitted, contradictory or misleading information, directions and instructions; and insufficient coordination between individuals and groups at every level of the organization and between internal and external organizations.

Both vertical and horizontal communication is key to effective process implementation. Generally, vertical communication is necessary for the commitment, policy and programme expectations to permeate the organization and for it be aligned on the programme principles. Here, timely and effective communication by the senior management is essential if the commitment, policy and expectations are to be understood and consistently and collectively adhered to by everybody. Horizontal communication further reinforces individual or team responsibilities, situational awareness and organizational and individual interfaces prior to, or during, the conduct the activities. It particularly ensures that all involved parties exchange correct and relevant information in a timely and orderly manner such that miscommunication, misunderstanding, omission, and untimeliness or errors in technical and scientific information are avoided or minimized.

Communication methods for technical support elements can be formal or informal, depending on the significance of the information provided. As communication takes place in all directions, programmatic and organizational arrangements and methods are to be in place to promote feedback from individuals on operating experience and programmatic concerns, challenges and successes. It is important that the organization be open and responsive to feedback received from individuals to avoid inhibiting effective communication.

Effective organizations include both formal and informal communication and information exchange mechanisms in technical support activities:

— Formal mechanisms could include interface documents, procedural review and check requirements, scheduled and required meetings, periodic task review sessions, impact or concerned party checklists, as well as ad hoc training provisions.
— Informal mechanisms may vary widely, and can include prompt verbal feedback to line colleagues and leaders, discussions between internal and external points of contact, occasional discussions within groups and senior management, and activity knowledge or observation notes.

4. TECHNICAL SUPPORT FOR THE PREPARATORY PHASE

From the time when the inclusion of new (or additional) nuclear power generation in the energy mix is considered until the nuclear power project starts to be implemented (start of detailed design and construction), numerous technical and scientific activities are carried out in support of various decisions. These decisions on consideration, approval, planning, bidding, awarding, initiation and implementation of a nuclear power plant project are taken by different entities, the number of which varies depending on the type and identity of the nuclear power plant programme and project sponsor, owner, manager, implementer and user.

In an embarking country, for example, where a government would benefit from inclusion of nuclear energy in the energy mix, a NEPIO implementing the nuclear power programme, a project company managing the nuclear power project and owners possessing the assets and/or revenues would make some key decisions — alone, together or in consultation with each other, depending on the stage and its applicable decision authority. During the pre-Phase 1 stage, and during Phases 1 and 2 (as defined in Ref. [17] for embarking countries), significant decisions will be made on, for example:

— Long term energy needs and supply options;
— Consideration of nuclear energy generation in order to supply future energy needs;
— Inclusion of nuclear energy in future energy supply;
— Size, technology and location of the nuclear power plant(s) for nuclear energy generation;
— Bidding, financing and contracting of the nuclear power plant(s) for design and construction.

These decisions that are to be made in the preparatory phase are based on the overall social and economic development goals and will be supported by quantitative and qualitative assessments including national energy policy development, energy analysis and planning studies, prefeasibility and feasibility studies, as well as preparation of bid invitation specifications and technical bid evaluation. Scopes of these studies and activities typically include use of scientific and technical basis and fundamentals. Therefore, technical support is needed, requiring competency and proficiency in, for example, evaluation and assessment of:

— Generation and consumption sources and technologies;
— Siting;
— Power and grid system infrastructure;
— Environmental impacts;
— Reactor design and operation.

Technical and scientific activities (e.g. request, preparation, review, acceptance or assessment) associated with these studies include:

— Determination of potential and credible scenarios to analyse;
— Qualitative and quantitative analyses;
— Data collection and analysis of trends and characteristics;
— Identification, collection and determination of project technical input, such as site and power/grid system characteristics, and technical specifications for technology;
— Identification and determination of legal and regulatory technical boundaries, such as regulatory technical requirements, licensing conditions for technical aspects, and applicable and required technical codes and standards.

Typically, the decision maker in an embarking country (e.g. government, governmental agencies, NEPIO, project company/entity/owner) requests and obtains technical support from external TSOs, such as national or international consultants, academia, or experts from other local or foreign industries (nuclear and/or applicable industries), and from some in-house experts (when the head of the government is the decision authority, for example, this could include sharing of in-house experts of other government agencies, which could still be considered resources of the decision making organization). This is especially true and generally applicable for Member States embarking on nuclear programmes and owners/operators with limited technical support capabilities.

Similarly, in an expanding country (or in a fleet of generation units), decisions on the need, size, technology and location of nuclear power plant(s) are made. These decisions, as well decisions on bidding, financing and contracting options, are made with inclusion and consideration of technical and scientific information and input in areas such as siting, power and grid system reliability and connections, environmental impact, reactor technology, as well as generation and consumption sources and methods.

A major difference between an embarking country and an expanding country, in requesting and obtaining technical support for those decisions, is that the decision makers in expanding countries are likely to already have existing and mature internal and external TSOs to provide technical support in some, if not all, of these areas. For example, private owners or utilities who are considering an additional nuclear power plant near their site or a new nuclear power plant in their existing generation fleet may request that an engineering company that is already a partner perform seismic evaluations for siting. On the other hand, they may utilize their own internal engineering organization to provide technical support for cooling water management in support of technology selection since they may already have established and maintained these in-house skills, competencies and proficiencies in accordance with the company goals and strategies.

The following sections provide some examples of decisions made and associated technical and scientific support during the preparatory stage.

4.1. TECHNICAL SUPPORT FOR THE DECISION ON INCLUSION OF NUCLEAR POWER OPTION FOR ENERGY NEEDS

Reference [31] states that the development of a position for a new (the first or additional) nuclear power plant, which would be in close association with the government's energy policy based on the national strategic energy needs, begins with the evaluation of: "a State's long term energy needs and supply options, consistent with its social and economic development goals." As the government sets the national policy and associated regulations, input on the considerations for a new nuclear power plant will be at the different level. At the national and regional levels, taxes, incentives, emission limits, energy markets, transmission, energy exchange rates, environmental limits, and so on will be considered as input to the decision. Additionally, at the local level, factors such as codes, permits, usage rights or zoning requirements will be input into the decision making on a new nuclear power plant (Fig. 8). Therefore, the technical analyses, evaluations, assessments and associated planning include and are complemented by further social, economic, financial and technical evaluations for integrated decision making.

Government policy can provide very direct and significant input, particularly in embarking countries, in decision making for a new nuclear power plant, since the government typically formulates national policy and initiates the discussion regarding the introduction of a nuclear power programme [31]. This includes the authority to include (or exclude) nuclear power as a potential source of energy, in relation to the country's social and economic development goals (including goals for energy and electricity intense industries), international and bilateral commitments, and financial and physical resources.

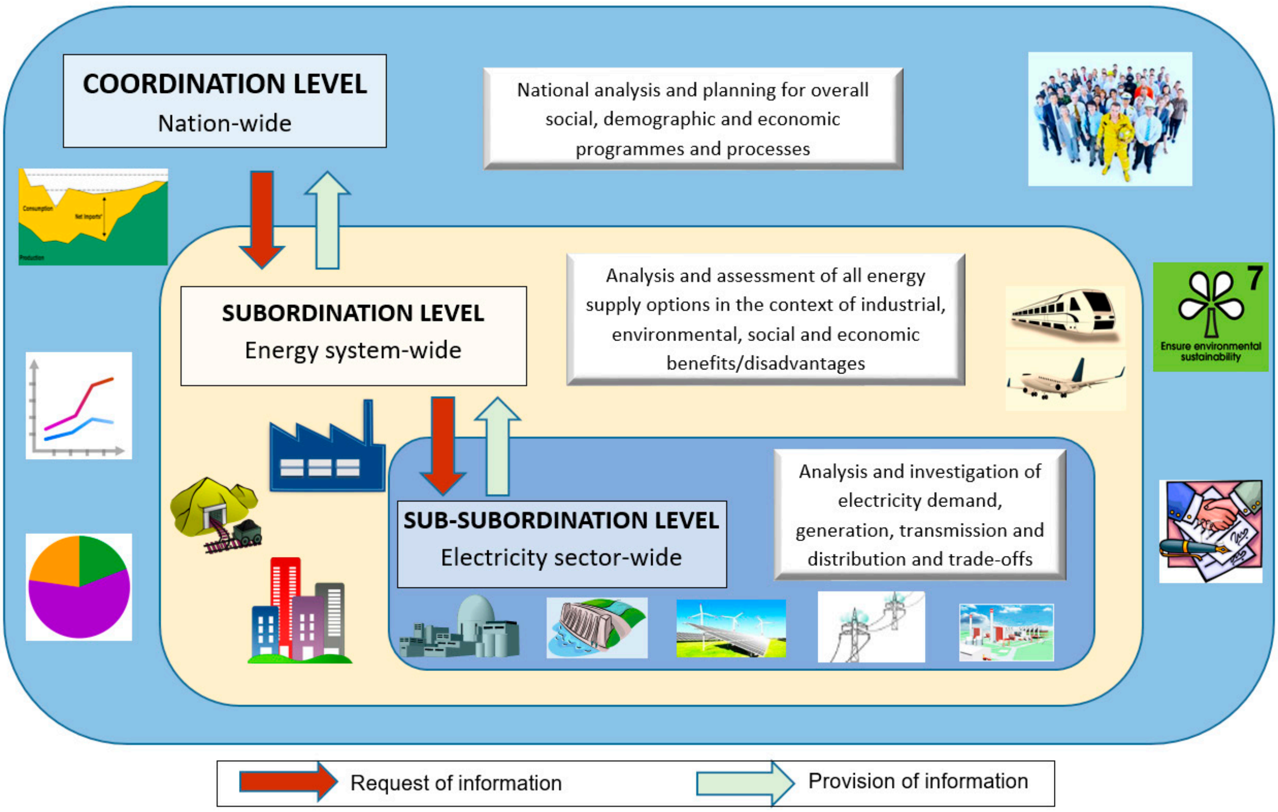

FIG. 8. Hierarchy of coordination and feedback in energy planning.

Also at the utility (or fleet) level, a policy is developed for generation options with input from the interested parties (e.g. national and local governments, consumers, shareholders, public). This policy also defines the corporate mission and strategy. The utility will decide on a new nuclear power plant in terms of investment and operation based on this policy and other information, including technical and scientific support.

The studies include a range of evaluations of scenarios for various planning time horizons (e.g. in 5, 10, 20 and 30 years). They particularly consider trade-offs between energy sources with respect to their benefits and disadvantages for the future needs in a manner that is consistent with the potential energy services and supply options.

The studies in support of decisions on energy policy and position on nuclear power may help determine whether the inclusion of nuclear power in the energy mix 'makes sense' with respect to the energy resource allocation, existing energy infrastructure, estimated energy demand and envisaged supply alternatives [31]. For an embarking country, this decision on energy policy and position, as to whether nuclear power could be an option in energy mix, marks the beginning of Phase 1 [17].

It is also beneficial for later assessment of the environmental impacts (see Sections 4.2.2. and 4.3.3) to ensure high level considerations to preview the likely issues in environmental feasibility. This high level cognizance is typically briefly documented in the strategic environmental assessment as discussed in Ref. [32].

During the entire decision making process, the alternative paths in energy and electricity demand and supply need to be updated and reviewed, giving the decision maker information on benefits and disadvantages. All of these studies need technical and scientific support to various extents, including preparing technical text for the report of analyses ('comprehensive report') [31].

4.1.1. Energy analysis and planning

4.1.1.1. Purpose

Energy analysis involves evaluation/assessment of the energy system with the intent of providing decision makers information that will enable them to make informed decisions on strategies needed to meet energy objectives [33, 34].

Energy planning investigates and evaluates future energy supply options within the overall economic system, considering positive aspects, such as social and industrial benefits, as well as negative ones, such as impact on the environment. As a part of the investigation, the potential role of various energy supplies in the country's or region's future energy mix is objectively evaluated.

The energy system analysis normally considers electricity system planning, which is typically a key element in energy planning (though it should be noted that electricity system analysis may not be a major part of energy planning, particularly in developing countries). However, electricity system analysis is much more detailed, and therefore, it is discussed comprehensively in Section 4.1.2.

4.1.1.2. Scope

Energy analysis is the study of all the factors that influence the evolution of national and regional energy systems, and it explores and assesses the types, quantities and qualities of future energy service needs. It particularly considers trade-offs between energy security, least cost energy supply, welfare (i.e. access to, and affordability of, energy services), public health and environmental protection. It investigates the factors for various time horizons (e.g. in 5, 10, 20 and 30 years).

Studies supporting the energy analysis typically include investigation and evaluation of the following aspects (refer to Ref. [35] for a comprehensive and detailed list of studies):

— Indigenous energy resources;
— Links to external energy markets;
— The vintage and performance of the existing energy infrastructure;
— Energy and electricity demand analysis;
— Electricity generation and fuel production;

— Electricity transmission and distribution systems and service technologies exploring system linkages and interdependencies, and comparison of the risks and benefits of alternative energy supply options;
— Relevant codes, regulations, standards and historical operating experience.

All of these studies would need technical and scientific support to various extents, including the preparation of technical text to report analyses (the ‘energy master plan’).

4.1.1.3. Technical support activities

The studies for energy analysis involve comprehensive qualitative and quantitative assessments of energy services and supply options undertaken by energy planners (engineers, scientists, economists, etc.) in a manner that is consistent with the country’s and region’s long term socioeconomic development objectives. Typical forms of technical support include collecting and monitoring technical and industrial parameters, properties and processes and analysing the collected/monitored data to determine energy generation characteristics, such as load factors, costs and reliability. The studies support decision making by providing analysis and information related to technical aspects of energy generation and use, as well as their management, optimization and sustainability from a technical perspective, particularly in:

— Fuel supply, including nuclear fuel[10];
— Performance of energy generation technologies, including nuclear energy generation;
— Technologies and services for electricity generation, transmission and distribution systems, including exploration of system linkages, management and optimization.

The technical support includes fundamental activities relating to preparation, review and assessment of analyses, including:

— Identifying, collecting (or requesting collection[11] of), verifying and validating data, trends and characteristics for input into the analyses, including identification of the ones that need to be updated later. Detailed technical information is needed in order to conduct analyses and evaluate the technical and economic viability of alternatives. Such information includes, for example, thermodynamic efficiency of energy systems, capital and operating costs of energy technologies, reliability and performance characteristics of systems, geological parameters of resource areas and macroeconomic parameters of the national economy. This information is essential for any analysis of the energy system.
— Defining and justifying assumptions for analyses and identifying the ones that require later confirmation and validation.
— Selecting applicable tools and methods for analyses.
— Selecting scenarios to evaluate, including sensitivity studies.
— Assessing the validity and reasonableness of results, and identifying key input and assumptions that have significant impact on the results.
— Identifying and describing contingencies, limitations and conditions of applicability, including potential or recommended future verification and validation of significant and highly variable input and assumptions.
— Drawing conclusions that include description, comparison and ranking of options, and making overall recommendations.
— Documenting the work performed.
— Providing assistance with preparation of the final report and its presentation to the decision makers, if requested.

[10] Technical perspectives and information on nuclear fuel supply and technology part supplies are needed by the decision makers, particularly for those considering nuclear energy.

[11] The majority of data, particularly historical data, to be used for studies are readily available. It is the expert’s responsibility to identify data that are needed but unavailable, and to request their collection, including specifying how, where and how long the data collection is to take place.

Technical support activities for review[12] of the energy planning analyses typically consist of:

- Verifying completeness and correctness of the input;
- Verifying completeness and reasonableness of the assumptions and appropriateness of their justifications and contingencies;
- Verifying appropriateness and applicability of the tools and methods used and correctness of their use;
- Verifying completeness of the scenarios evaluated and identification of the key input and assumptions;
- Validating the results and verifying completeness and correctness of the associated contingencies and limitations;
- Confirming the conclusions drawn and ensuring correctness and completeness of the description, comparison and ranking of options and overall recommendations;
- Documenting the review results;
- Providing assistance with preparation of the final report and its presentation to the decision makers, if requested.

4.1.1.4. Organization and skills

Energy system analysis and master planning are generally implemented by governments at the national level. Additionally, energy planning is conducted at the utility level, which takes the impacts from the national master plan into account together with the utility's own supply/demand assessments and the corporate business plans and energy portfolio goals and objectives.

At the national level, depending on the government's long term strategy for the preparation, review and confirmation of analyses and presentations to the decision authority, some of the tasks are performed by dedicated government agencies that are assigned specific roles and responsibilities in areas of energy planning. These agencies generally have in-house technical support staff (either within the planning organization or in other agencies of the government). The other special tasks, as well as third party independent reviews, assessments and consultations, are conducted and provided by external support entities, such as private or public energy institutes, academic and non-academic consultancy groups or individuals.

At the utility (or fleet) level, an internal energy planning organization is typically part of the decision making entity. This organization has knowledge about input, tools and methods, as well as the corporate goals and vision for future energy plans for optimization of generation supply and assets. The decision making entity either has in-house technical support (either within the planning organization or in other organizations of the company), including the in-house consultants, or it has established relationships or partnerships with external TSOs and technical experts and consultants.

The skills associated with the execution of technical tasks, which mainly concern analytical skills, include engineering (e.g. industrial, mechanical, electrical, environmental) skills, with experience and technical knowledge in the operation and performance of various generation sources with respect to production, energy use, environmental health and safety issues and engineering economics. Therefore, technical staff need to be well informed about and familiar with the energy and electricity system conditions and situation in the country or region.

In the case of newcomer countries, energy planning is an ongoing process with or without the inclusion of nuclear energy. The organizational structure and technical skills and expertise generally exist in every country (or utility) to a certain extent, and therefore, even for a country which is considering inclusion of nuclear power in the energy mix for the first time, there is existing infrastructure, experience and established support organizations to conduct technical activities in energy planning. For a newcomer country, the only area of speciality needed in traditional energy planning is the ability to include technical characteristics and performance data for nuclear technology in addition to, for example, fossil fuel technologies and renewable resource technologies. In such cases, the only distinction relates to inclusion of nuclear engineering expertise and knowledge of nuclear power plant performance related to energy input and output, thermodynamic efficiency, performance and capacity limits, operational constraints and status of technology availability and experience. These could be complemented by marginal outside support, in a newcomer country, as a minor part of the overall energy analysis.

[12] It is highly recommended that the review be performed by a person or group that was not involved in the preparation of the study.

4.1.2. Electricity system analysis and planning

4.1.2.1. Purpose

As a part of the entire energy system, the electricity system needs to be investigated and planned, as it is linked with the overall energy planning and economic system. The energy system analysis is a key element in overall energy planning providing a more detailed analysis of the current and future electricity system. Electricity system analyses encompass the broad collection and assessment of activities in specific time horizons and the investigation of electricity demand, generation, transmission and distribution, taking into consideration their reliability and availability in support of national, regional or utility development strategies.

Electricity system analyses also consider trade-offs between electricity sources and demand in terms of benefits and drawbacks relating to future needs in a manner that is consistent with the energy services and supply options. Particularly at the utility and fleet level, this provides support to the decision makers to plan and decide on assets for achieving the primary objective of adequately meeting the demand for electricity at the optimum cost (i.e. the minimum costs for the utility, the fleet, the economy or a combination of all three).

4.1.2.2. Scope

Electricity system analysis and planning refers to the conduct of qualitative and quantitative assessments of future demand and supply options for electricity. These analyses are typically exploratory, cursory and high level, and they investigate several options and scenarios, as well as trade-offs. The scenarios in the studies include past performance, current status and a range of alternative development paths for different time periods (year, week, day, etc.) in various time horizons (e.g. in 5, 10, 20 and 30 years). The results of the electricity system analyses are reported to the decision maker in the ‘electricity master plan’.

The scopes of the major studies included in electricity system analysis that would need technical and scientific support are [36]:

— *Analysing the evolution of the electricity demand:* Using the known past characteristics of electricity demand, combined with scenarios for economic and energy/electricity sector development, the future magnitude and shape of electricity demand can be estimated. It is necessary to consider several different energy scenarios, depending on the overall development policies of the Member State, to identify potential spectra of future energy use. The outcome of this analysis of electricity demand evolution, commonly known as the ‘energy demand analysis’, is often published as a part of the ‘power studies’ or ‘power master plans’.
— *Analysing the evolution of the electricity generation:* Starting from the installed capacity, electricity generation analysis outlines the future role of different generation technologies and the main factors influencing their future deployment (the cost of primary energy, environmental constraints, Member State governmental plans for development of renewable forms of energy, clean energy sources, etc.) in an integrated manner. It also considers associated economic and technical plans for the existing generating units, including their future life extensions, uprates or retirement/decommissioning. The outcome of the analysis of the evolution of the electricity generation is published in what is commonly known as the ‘generation master plan’.
— *Modelling power flows:* The analysis of power flow in regionally, nationally and internationally interconnected electricity networks is performed to model current and future evolution of those within an electricity system and, if applicable, the power transfer with other electricity systems, such as the electricity networks in neighbouring countries or regions.[13] The expected power flows in the electricity network(s) are modelled: to ensure the effectiveness of the transmission and distribution system, to assess the electrical losses and to determine any need for reinforcement of the systems and equipment (power lines, power stations, transformers, etc.) in the future electricity grid system plans. The results of the grid development studies and electrical power system simulations are published in what is commonly known as the ‘grid master plan’, and describe the structure of future stable and efficient electricity grid systems.

[13] In some cases, the power flow and exchanges may include regional electricity networks (e.g. North America, Scandinavia) or regional electricity systems within the same country, such as in China or the United States of America.

— *Assessing electricity generation–demand balance:* The balance between electricity generation and demand needs to be assessed to identify the risks to security of electricity supply. The risks of lack of energy or reserves are also identified through these probabilistic methods. Sensitivity studies on the critical factors in the scenarios, for example, intermittency associated with the development of renewable energy, may complete this step of assessment to provide a better understanding of the 'system adequacy', which is often the name of the study.

Reference [36] provides a more comprehensive and detailed list of studies that would be included in the scope of electricity system analysis and electricity planning. Some of those may require technical support at different activity levels.

4.1.2.3. Technical support activities

Similar to the energy analyses, the studies conducted for electricity analysis involve comprehensive qualitative and quantitative assessments. However, they are more detailed as to electricity demand, generation, transmission and distribution, including the consideration and assessment of availability, reliability and operation. Therefore, the activities include fundamentals of analysis preparation, review and assessment, particularly in technical and scientific areas of engineering (especially electrical engineering, but also including mechanical, civil, environmental, industrial engineering, etc.).

Technical support to the electricity system planner provides understanding (which will later be reflected to the decision authority) of:

— Interaction of electricity system planning with planning regarding the overall energy needs of a country (or other government organization or utility);
— Effect of the electricity system planning on overall energy use, reliability, availability and cost;
— Influence of overall national energy planning on the electricity system.

Technical activities assist the electricity planning as a part of overall energy planning in support of decision making. This support consists of providing technical input and understanding of: electricity grid system needs and sustainability issues; generation, demand, transmission and distribution fundamentals; generation and consumption management and optimization by deterministic, probabilistic and statistical analysis; identification and description of codes, regulations, and standards; and historical operating experience with reliability, stability and availability.

Overall, these studies involve data collection and assessment, and analysis preparation and review fundamentals that are listed in Section 4.1.1.3.

4.1.2.4. Organization and skills

The electricity master planning is at the national level with a contribution from the corporate level (i.e. generation and transmission companies or organizations) for the analysis and planning. These coordinated activities could include planning of new generation units, grid system improvements and demand management, as well as consideration and inclusion of goals and strategies of generation and transmission owner/operators, particularly in deregulated and unbundled systems.

At the national level, depending on the government's strategy and available expertise, some of the tasks, including the conduct, review and confirmation of analyses and their presentation to the decision authority, are typically performed by dedicated government organizations/agencies that are assigned roles and responsibilities in specific areas of routine planning. These agencies generally have in-house technical support (either within the planning organization or in other agencies of the government). The other special tasks, as well as third party independent reviews, assessments and consultations, are conducted and provided by external support entities, such as private or public energy institutes, and academic and non-academic consultancy groups or individuals.

At the corporate level (i.e. generation and transmission companies or organizations), internal technical support staff for planning relating to generation and grid (transmission and distribution) systems are typically present as a part of the decision making authority's organization. This organization has the knowledge of technical input, tools and methods, as well as the corporate goals and vision for future plans for the improvement of the generation and electrical grid infrastructure for safe, reliable and balanced generation and grid system design, implementation and operation, which need to be coupled with national electricity plans and infrastructure development. The organization either maintains an in-house technical staff (within the planning department or in other departments), including in-house consultants and experts, or has established relationships or partnerships with external TSOs and technical experts and consultants.

The skills associated with the conduct of technical tasks, which are mainly analytical skills, include engineering (particularly electrical engineering), with experience and technical knowledge in the operation and performance of various generation sources with respect to electricity generation, consumption, transmission and distribution.

Technical staff members are typically well acquainted with technical and operational parameters, processes and analyses to identify electricity demand, transmission and distribution. They are also knowledgeable about generation characteristics of different generation units, including such technical aspects as generation unit electrical output and its variation, design, operation and maintenance requirements; generator voltage and frequency capability and stability; grid–generation unit interaction and associated generation unit and grid co-performance (particularly for relatively large or new power plants). They are also aware of and capable of considering economic, financial and strategic aspects, which requires skills associated with engineering economics and financial analysis.

In the case of newcomer countries, electricity planning, as a part of energy planning, is an ongoing process with or without the inclusion of nuclear energy. The organizational structure and technical skills and expertise generally exist in every government and utility, and therefore, even for a country which is considering inclusion of nuclear power in the energy mix for the first time, there is existing infrastructure, experience and established support organizations to conduct technical activities in electrical power and grid system planning. For a newcomer country, the only area of speciality needed in traditional energy planning is the ability to include technical characteristics and performance data for nuclear power plant interfaces, particularly relating to their large size, special safety requirements and technical limits concerning grid system interface and special operational and maintenance conditions. Again, the distinctive skills are primarily expertise in nuclear power plant technology and knowledge with respect to nuclear power plant design, operation and performance, engineering economics and financial analysis.

4.2. TECHNICAL SUPPORT FOR THE DECISION ON A NUCLEAR POWER PROGRAMME

The decision on commitment to a new, or additional, nuclear generation unit is driven by the resulting national, regional and corporate (i.e. generation unit or fleet, transmission system owners and operators) policies in accordance with the results of energy and electricity planning, which together establish a case for inclusion/addition of nuclear generation in the energy sources. The energy and electricity analyses and planning are always complemented by further social, economic, financial and technical evaluations regarding the introduction of a new nuclear power programme, or additional nuclear power plant, in order to establish a business case (i.e. a justification based on expected financial, and/or socioeconomic benefit).

The studies in support of this decision on proceeding with a new nuclear generation source determine and communicate whether the introduction of nuclear power in the energy mix is ‘needed and viable’, considering the associated work, benefits, risks and barriers of a nuclear power programme.

During the entire decision making process, the business case, as well as the alternatives, need to be updated and reviewed, giving the decision authority the complete picture of costs and benefits associated with a nuclear power programme.

For an embarking country, this decision on proceeding, as to whether nuclear power could be an option in the energy mix, marks the end of Phase 1 [17].

4.2.1. Prefeasibility study

4.2.1.1. Purpose

Generally, the prefeasibility (or ‘preliminary feasibility’) study preassesses the need for and the viability of the introduction of a nuclear power programme, determines a potential schedule for the introduction of such a programme, identifies infrastructure (including safety and security infrastructure) gaps and 'showstoppers', and provides recommendations to address those gaps and showstoppers, should the decision maker decide to proceed with development of a nuclear power project.

The prefeasibility study does not evaluate and justify a specific nuclear power plant *project* (this is the role of the feasibility study), but it rather analyses the role of nuclear power in a country's or company's overall energy system and economy and determines if a nuclear power plant *programme* is, in principle, feasible and warrants further consideration and action. Therefore, the prefeasibility evaluation is mainly focused on the identification of technical, financial, operational or schedule impacts and potential actions to manage them, rather than detailed evaluations of these. It is advisable that a prefeasibility study be conducted to prepare government/company officials to make a knowledgeable decision regarding nuclear power, which is different from reaffirming a predetermined conclusion to proceed with the programme, which is supported by a feasibility study (see Section 4.3.1). In cases where countries have made a political decision to embark on a nuclear power programme, it is still advisable to perform a prefeasibility study to identify gaps and determine the infrastructure and capacity that is necessary to introduce nuclear power [31].

4.2.1.2. Scope

The preparation of a prefeasibility study provides valuable insights into the benefits, risks and barriers of a nuclear power programme as well as some of the information needed in support of the decision making process.

Surveys and scoping studies performed for the prefeasibility study need technical support in addressing and assessing some of the following issues, among others [31]:

— Siting;
— Legal and regulatory requirements;
— Electricity grid system;
— General environmental considerations;
— Available and viable nuclear power technologies;
— Nuclear fuel supply, spent fuel, special material and radioactive waste management;
— Any other additional information on a specific issue that is needed or requested by the decision making entity.

Technical staff could also assist in other non-technical issues, as needed, such as:

— National industrial involvement;
— Public acceptance;
— Financial risk analysis;
— Human resource development.

During the realization of the prefeasibility study, or following its completion, it may be necessary for the designated entity to conduct more detailed studies on specific infrastructure issues prior to the completion of the comprehensive report, which is the presentation of the study's results.

Two main conclusions that are typically requested by the decision making entity are the results of the site characterization investigation and the environmental scoping study (discussed in Section 4.2.2). These conclusions are presented to the decision authority by a site characterization report that typically would include an environmental monitoring report.

In most cases, additional and more detailed information on specific issues will be needed and requested by the decision making entity. One part of such information is the project proposal and outline presenting a preliminary project schedule with milestones and relative time span (i.e. numbers of years starting from the time of the decision to proceed with nuclear power). The other piece of information expected to be requested by the decision authority is the projected cost of addressing the identified gaps and showstoppers in the development of the nuclear power programme. The project schedule and costs can be roughly established based on experience from other programmes and projects within or outside the country. The cost estimates are typically imprecise (but described in general range) and the schedule is inexact (but inclusive).

4.2.1.3. Technical support activities

Technical support activities will involve identifying, collecting (or requesting collection of), verifying and validating data, trends and characteristics for input into the analyses, including identification of the ones that need to be updated later.

Additionally, the technical (and techno-economic) staff will perform qualitative and quantitative assessments for evaluating the technical and economic viability of a nuclear power programme with respect to the identification of infrastructure gaps and the provision of recommendations to address those gaps. The technical staff will also provide input and technical assistance to the macroeconomic study on the impact of introducing a nuclear power programme.

These studies involving preparation and review of analysis in the conduct of a prefeasibility study may include:

— Review and incorporation of the relevant energy planning studies;
— A preliminary evaluation of the suitable sites capable of hosting a nuclear power plant;
— Initial analysis of the electricity grid system requirements;
— A review of available and suitable nuclear reactor technologies and their adaptability;
— Any additional technical and scientific information on a specific issue that is needed and requested by the decision authority.

Overall, these studies include data collection and assessment, and analysis preparation and review fundamental that are listed in Section 4.1.1.3.

4.2.1.4. Organization and staffing

The technical support activity requires a combination of technical, commercial and financial expertise and can benefit from engagement of an international consultant to coordinate the technical part of the specifications. The team of technical staff for the prefeasibility study will include engineers (electrical, mechanical, environmental, industrial, etc.) with knowledge of electrical and nuclear technologies, safety and quality assurance, and economists with knowledge in techno-economics and power economics.

4.2.2. Site survey and characterization and environmental scoping studies

4.2.2.1. Purpose

The site survey and characterization are a major part of the prefeasibility study and generally involve collection and assessment of information for potential nuclear power plant sites to support considerations by decision makers regarding options for the location of nuclear power plant.

4.2.2.2. Scope

Technical activities will involve identifying, collecting (or requesting collection of), verifying and validating data, trends and characteristics of potential nuclear power plant sites for input into the analyses, including identification of the ones that need to be updated later.

Additionally, the technical staff will explore and develop criteria and methods for site surveillance and selection, qualitatively and quantitatively assess viability of a nuclear power programme and identify gaps in meeting requirements for infrastructure and characteristics of potential sites, including the measures and actions that could be taken to address those gaps.

The scope of studies covers surveying, characterizing and probing various aspects of a site, which would typically include [32, 37]:

— Electricity grid systems at and around potential sites with respect to ease of integration into the grid system;

— Geological, seismological, meteorological, hydrological, geographical and atmospheric conditions and characteristics for potential sites;
— Environmental conditions surrounding potential sites and an overview of external hazards, including extreme weather conditions and characteristics;
— Overview of data collection and preliminary analysis for environmental impact and environmental monitoring;
— Land and water use conditions and limitations at or near potential sites;
— Demographic (e.g. population distribution and centres near potential sites) and infrastructure (e.g. accessibility, major transportation types and structures, heavy cargo transportation limitations) conditions near potential sites;
— Conditions related to security and safety of potential sites.

The site characterization studies are compiled as standalone reports (e.g. site characterization report, siting report, environmental monitoring report or environmental scoping report) or as a part of the feasibility study in the comprehensive report, and are integrated into the information presented in support of the decision.

4.2.2.3. Technical support activities

Technical support activities will involve identifying, collecting (or requesting collection of), verifying and validating data, trends, and characteristics of potential nuclear power plant sites for input to the analyses, including identification of the ones that need to be updated later. These data would include geological, seismological, meteorological, hydrological, geographical, biological, atmospheric and demographic parameters, as well as electricity grid system characteristics and electricity ingression and egression paths, and historical information and trends in natural (and human-made) hazards.

The technical staff will develop criteria and methods to obtain and assess site data and information and will also perform qualitative and quantitative analyses towards identification of potential sites and preliminary investigation of the viability of these sites, as well as foreseeing the gaps in meeting requirements for infrastructure and characteristics of potential sites, including the measures and actions that could be taken to address those gaps.

4.2.2.4. Organization and staffing

The technical support activity requires technical expertise in areas such as geology, hydrology, meteorology, ecology, biology, seismology, as well as in siting of nuclear power plants, nuclear technology, environmental effects and safety analysis. The organization can benefit from engagement of an external consultant to coordinate the activities. The team of technical staff for the prefeasibility study will include engineers (geological, civil, environmental, industrial, etc.) with basic knowledge of nuclear technologies, safety and quality assurance, and economists with knowledge in techno-economics and environmental economics.

4.2.3. Grid system studies

4.2.3.1. Purpose

As a part of the preliminary assessment of the viability of a nuclear programme, larger scale electricity grid system studies provide the decision makers with identified gaps in meeting requirements for infrastructure and characteristics of the electricity grid system at large in support of the nuclear programme, including the measures and actions that could be taken to address those gaps, based on the electricity system analysis and plans. This is not a complete grid system evaluation and justification for grid system improvements for a specific nuclear generating unit at a specific location (this is the role of the comprehensive and detailed grid study performed for the feasibility study), but rather it analyses the influence of nuclear generation in a country's or company's overall grid system. Therefore, it determines if it is feasible, in principle, for large scale nuclear generation to interface with the grid system for transmission and distribution to consumers, and if this warrants further consideration and action. Reference [38] provides additional discussion and guidance in this area for the electricity system analyses.

4.2.3.2. Scope

The preliminary grid system studies focus heavily on the collection and assessment of the grid system characteristics at the transmission level with respect to potential connection of the site to the electrical grid and its interface in terms of availability, stability and reliability, as well as conduct of qualitative and quantitative assessments for planning. However, these assessments are more specific to the inclusion of nuclear generation in the grid system at potential locations, compared with the electricity system analysis that had been performed for the electricity master plan, with respect to electricity demand, transmission and distribution aspects. The grid studies at the preliminary level include consideration and assessment of grid system availability, reliability and operation, such as balancing of supply and demand with large scale nuclear generation at particular locations. Therefore, the activities include fundamentals of analysis preparation, review and assessment, particularly in technical and scientific areas of electrical engineering, with support from nuclear engineering, to provide the decision making entity with an overall and strategic understanding of:

— Interaction of electricity system planning with nuclear power generation and transmission;
— Estimated effects of the grid system on potential nuclear power plant sites;
— Estimated effects of a nuclear power plant on overall grid use, reliability, availability and cost;
— Foreseen gaps in meeting requirements and needs for infrastructure and characteristics of the grid system at large in support of the nuclear programme — including the grid system regulations, codes and requirements — and the potential measures and actions to be taken to address those gaps.

4.2.3.3. Technical support activities

Technical support activities will involve identifying, collecting (or requesting collection of), verifying and validating data, trends and characteristics of the grid system with generation addition at potential nuclear power plant sites for input into the grid system analyses and connection and transmission schemes, including identification of the ones that need to be updated later. These data would include design and operation characteristics of the grid system, such as historical frequency and voltage variations, grid incidents (e.g. blackouts, black starts) and physical infrastructure.

The technical staff will develop criteria and methods to obtain and assess grid system data and information and will also perform qualitative and quantitative analyses towards investigation of the viability of a large generation unit with specific design and operation requirements and identify gaps in meeting requirements for infrastructure and characteristics of potential sites, including the measures and actions that could be taken to address those gaps.

This support at the execution level is with respect to technical input and understanding of: grid system needs and sustainability issues (generation, demand, transmission and distribution), nuclear generation at certain locations related to transmission and consumption management and optimization, statistical analysis, data regression, as well as identification and description of codes, regulations, standards and historical operating experience in the areas of reliability, stability and availability.

4.2.3.4. Organization and staffing

The technical support activity requires technical expertise in electrical grid system design and operation with knowledge on siting of nuclear power plants, nuclear technology and safety analysis. The organization can benefit from engagement of an external consultant to coordinate the activities. The team of technical staff for the prefeasibility study will include electrical engineers with basic knowledge of nuclear technologies, safety and quality assurance, and economists with knowledge in techno-economics and energy and electricity economics and with the status and performance of transmission and distribution systems.

4.3. TECHNICAL SUPPORT FOR DECISIONS ON NUCLEAR POWER PLANT PROJECT IMPLEMENTATION

Following the decision to proceed with a new nuclear generation supply programme, the country/company will carry out the work required to prepare for implementation of the project (i.e. prepare the detailed project needs, expectations and input for project implementation). The overall efforts are usually twofold: initially the support will provide the decision makers with comprehensive and complete information for decisions on the site, technology, schedule and cost of a nuclear power plant project, and following that it will prepare for later decisions on contracting, financing and construction of a new (the first or additional) nuclear power plant. At this stage, the decision on proceeding with plant design, construction and operation will be complemented, in an integrated manner, by several decisions on key technical, commercial and financial aspects, including:

— Changes to laws and regulations, as well as codes and standards, if applicable and necessary;
— Expansion of the electricity grid system;
— Nuclear power plant technologies and locations;
— Contractual approach and implementation schedule.

The activities and processes — including those for technical support — during the decision making on nuclear power plant project implementation are usually long and iterative, requiring many cycles of exchanges between the interested parties. For example, bid initiation, invitation and evaluation may necessitate discussions for clarification through interactions among the project (or plant) owner, potential responsible designers, vendors and governmental organizations and agencies, among others.

Particularly in a newcomer country, the necessary infrastructure needs to be developed to the point of complete readiness to invite bids/negotiate a commercial contract between the owner and the supplier at this stage. The owner/operator has a key role at this time to ensure that by the end of Phase 2 it has developed the competencies to manage a nuclear power project, meet regulatory requirements and be a knowledgeable customer in Phase 3. By the end of Phase 2, the owner/operator also needs to have clear plans to develop or acquire (during Phase 3) the capability to safely operate the plant, including technical support on [17]:

— Developing a financing strategy, a contracting strategy, a fuel supply strategy and a spent fuel and radioactive waste management strategy;
— Assessing alternative energy technologies in conjunction with nuclear electricity generation to determine which are most appropriate or preferred;
— Completing site selection, site assessment and environmental impact assessment studies;
— Establishing bid invitation specifications and evaluation criteria;
— Building project management capabilities and a competent procurement team;
— Determining radiation protection and emergency plans to be reflected in the plant's design requirements;
— Preparing plans for enhancing or expanding the grid system to be compatible with the new nuclear power plant, including international and regional interconnections to achieve acceptable grid reliability and redundant, reliable sources of off-site power for the plant;
— Identifying necessary improvements and developing implementation plans for local infrastructure at the preferred site(s), such as access, services and facilities.

Once the site is selected and the site parameters affecting the design of the plant are known, the technical specification for the plant is prepared and the request for bids for the project proposal is issued. This activity requires a combination of technical, commercial and financial expertise and can benefit from engagement of an international consultant to coordinate the technical part of the specifications.

The following sections discuss various studies that require technical support.

4.3.1. Feasibility study

4.3.1.1. Purpose

A feasibility study is primarily a justification for the acquisition of one or more nuclear power plants to be integrated into the overall mix of energy and electricity generating plants [39]. It is also a summary of the elements necessary to support the authorities and other stakeholders in their key commercial and financial decisions for launching implementation of a new nuclear power plant, including decisions on:

— Changes to laws and regulations, as well as codes and standards, if applicable and necessary;
— Expansion of the electricity grid system;
— Nuclear power plant technology;
— Contractual approach and implementation schedule.

4.3.1.2. Scope

The feasibility study provides the required information to various depths and degrees, depending on the specific requirements in support of the decision. Among others, these include (see Ref. [39] for comprehensive scope):

— Determination of which laws, codes, standards and guides are applicable;
— Comprehensive evaluation of the electrical system, including electricity demand and supply systems, grid system expansion focusing on the nuclear power plant project — such as unit and site generation capacity and grid system integration (i.e. connection and off-site power reliability options), market structure and organization;
— Evaluation of characteristics of the site and supporting facilities, including natural and external events, effects of the nuclear facility in the region (such as impacts on population distribution), uses of land and water in the region, and preliminary site layout and site preparation plans;
— Assessment of nuclear power plant technology with a focus on safety and performance and with consideration of economics and price for available technologies;
— Assessment of fuel cycles including fuel cycle evaluation and impact assessments, and radioactive and conventional waste management and storage;
— Evaluation of environmental impact, including cooling water demand and use, environmental protection and environmental monitoring needs;
— Determination of licensing process needs;
— Assessment of project implementation approach, such as ownership structure, contract and procurement approaches, local industry involvement, and implementation schedule and risks;
— Estimation of project costs for capital investment and recurring costs (fuel cycle, operation and maintenance costs, including sensitivity and risk analyses), and analysis of technical, financial and economic viability;
— Assessment of alternative energy technologies and their applications in conjunction with nuclear electricity generation, such as cogeneration, desalination and district heating;
— Investigation of the costs of, possible schedules and plans for, and environmental impacts of decommissioning.

4.3.1.3. Technical support activities

Technical support activities will involve tasks to support items in scope and rely on the fundamentals of analysis preparation, review and assessment, including:

— Identifying, collecting (or requesting collection of), verifying and validating data, trends and characteristics for input to the analyses, including identification of the ones that need to be updated later. Detailed technical information is needed in order to conduct analyses and evaluate the technical and economic assessments.
— Defining and justifying assumptions for analyses and identifying the ones that require later confirmation and validation.

— Selecting applicable tools and methods for analyses.
— Selecting scenarios to evaluate, including the sensitivity studies.
— Assessing the validity and reasonableness of results, and identifying key input and assumptions that have significant impact on the results.
— Identifying and describing contingencies, limitations, and conditions of applicability, including potential or recommended future verification and validation of significant and highly variable input and assumptions.
— Drawing conclusions, including description, comparison and ranking of options, and making overall recommendations.
— Documenting the work performed.
— Providing assistance with preparation of the final report and its presentation to the decision makers, if requested.

Technical support activities for review of feasibility studies[14] typically consist of:

— Verifying completeness and correctness of the input;
— Verifying completeness and reasonableness of the assumptions and appropriateness of their justifications and contingencies;
— Verifying appropriateness and applicability of the tools and methods used and correctness of their use;
— Verifying completeness of the scenarios evaluated and identification of the key input and assumptions;
— Validating the results and verifying completeness and correctness of the associated contingencies and limitations;
— Confirming the conclusions drawn and ensuring correctness and completeness of the description, comparison and ranking of options and overall recommendations;
— Documenting the review results;
— Providing assistance with preparation of the final report and its presentation to the decision makers, if requested.

4.3.1.4. Organization and staffing

This activity requires a combination of technical, commercial and financial expertise and can benefit from engagement of an international consultant to coordinate the technical part of the specifications.

4.3.2. Site ranking study

4.3.2.1. Purpose

The site ranking study is the study needed for a decision on a nuclear power plant site. The site ranking and selection study narrows the list of *candidate sites* to a shorter list of *preferred sites*. The assessment of each preferred site will also establish site related design bases, which will be reflected in the bid invitation specifications for the plant.

4.3.2.2. Scope

The site selection is justified against clearly defined siting criteria covering safety, engineering, security, environmental impacts, emergency response and socioeconomic aspects. The outcome is the site assessment, which justifies the acceptability of the preferred sites based on detailed investigations and site characterizations. The scope includes:

— Comprehensive evaluation of characteristics of the site and supporting facilities, including natural and external events; effects of the nuclear facility in the region, such as impacts on population distribution and uses of land and water in the region; and preliminary site layout and site preparation plans;

[14] It is highly recommended that the review not be performed by a person or group involved in the preparation of the study.

- Comprehensive evaluation of the electrical system, including electricity demand and supply systems, grid system expansion focusing on the nuclear power plant project, such as unit and site generation capacity and grid system integration (i.e. connection and off-site power reliability options), market structure and organization;
- Determination of which national, international, regional and local laws, regulations, codes, standards and guides are applicable;
- Determination of site and construction licensing process needs.

4.3.2.3. Technical support activities

Technical support activities will include analysis and assessment of data, trends, characteristics and impacts for geological, seismological, meteorological, hydrological, geographical, biological, atmospheric and demographic parameters of the preferred nuclear power plant site, as well as grid system characteristics and electricity ingression and egression paths, and historical information and trends on natural (and human-made) hazards at or near the preferred site.

The technical staff will develop and use criteria and methods to assess site data and information and will also perform qualitative and quantitative analyses to support selection of a preferred site (or ranking of preferred sites) and a preliminary investigation of the feasibility of the site(s), as well as determining the measures and actions that could be taken to address issues in requirements for infrastructure and characteristics of the preferred site(s). It is also beneficial if the analyses and evaluations use the best available models to investigate and assess future impacts to the key siting parameters. Prediction models utilizing available state of the art technologies and methods provide comprehensive and precise input for sound and informed decision making.

4.3.2.4. Organization and staffing

The technical support activity requires technical expertise in areas such as geology, hydrology, meteorology, ecology, biology and seismology relating to siting of nuclear power plants, as well as nuclear technology, environmental effects and general safety analysis. The team of technical staff for the feasibility study will include engineers (geological, civil, environmental, industrial, etc.) with basic knowledge of nuclear technologies and safety and quality assurance, and economists with knowledge in techno-economics and environmental economics.

It is critical to have technical staff be aware of and/or trained in available state of the art models, methods and techniques, as well as being informed about experience of others in conduct of such analyses, evaluations and assessments. Therefore, the decision authority can benefit from the engagement of international consultants and subject matter experts.

4.3.3. Environmental impact study

4.3.3.1. Purpose

This is a study of the prospective impacts on people and the environment needed to select the preferred site (or a list of preferred sites) and to ensure that the site(s) can comply with the country’s environmental laws and regulations [32].

4.3.3.2. Scope

The scope of this comprehensive evaluation of environmental impacts on people and the environment includes analysis and assessment of:

- Pathways for effluent transport and concentration in the surrounding environment;
- Predominant forms of plant and animal life and their particular sensitivities (i.e. flora and fauna);
- Local demographics and trends;
- Predominant land use;
- Water use and the possible need for cooling towers;

— Impacts of construction activities on the local environment.

4.3.3.3. Technical support activities

The technical support activities in the scope of the environmental impact study particularly involve determination and assessment of land use and environmental protection and environmental monitoring needs. Therefore, the technical support activities for an environmental impact assessment study include comprehensive quantitative and qualitative assessments of the environmental site conditions, factors, characteristics and data related to the items in the scope described in Section 4.3.3.2.

Based on such assessments, the environmental impact assessment report includes a comprehensive specification of the environmental site conditions, factors, characteristics and data for the sites in the bid invitation specifications.

4.3.3.4. Organization and staffing

The technical support activity requires technical expertise in areas such as hydrology, meteorology, ecology and biology relating to siting of nuclear power plants, as well as nuclear technology, environmental effects and safety analysis. The organization can benefit from the engagement of an external consultant to coordinate the activities. The team of technical staff for the environmental impact study will include environmental engineers and ecological and biological scientists with basic knowledge of nuclear technologies and safety and quality assurance, and economists with knowledge in techno-economics and environmental economics.

4.3.4. Bid invitation

4.3.4.1. Purpose

The primary purpose of the bid invitation is to provide potential bidders with complete and precise information, including technical and scientific information, related to the project's specifications and implementation in terms of requirements, conditions, expectations and needs of the nuclear power programme owner. This information, together with the weighted importance for the owner, will consequently be the basis for the decision selecting a nuclear power plant project implementation entity and signing a contract with the successful bidder that "enables the licensing, construction, commissioning, operation and decommissioning of a NPP in an acceptable way for the owner" [40]. The technical support is essential for identification, determination and description of technical specifications, requirements, conditions, needs and expectations in the technical bid invitation and also for providing technical justification for their rank and weight in accordance with the technical importance and priority. Some technical support is also needed for providing technical perspective in the other aspects of the invitation. The following sections specifically focus on the technical aspects of the bid invitation; however, the supporting role of TSOs in non-technical parts is also discussed, where applicable.

4.3.4.2. Scope

The main scope of the bid invitation is to identify, collect, verify and describe the requirements, conditions and expectations for the project, as well as the conditions and criteria to later evaluate and confirm their fulfilment.

Generally, the scope consists of consolidating and summarizing information — from, and based on, all the studies that have been performed — and expressing information to the decision makers on further areas of interest and expectations in the preparation of the bid invitation specification, which is to be made available to the potential bidders. Among the aspects of the bidding process and the expected structure and contents of the bids which are described in detail in Ref. [40], the direct scope of the technical and scientific activities will consist of:

— Description of the project, including information about general plant characteristics, such as reactor type, electrical output and operating mode;
— Description of project implementation, such as contractual approach, timing of the project, national participation and local involvement [41];

— Information about the nuclear power programme in the country and information about how the project fits into the programme;
— All relevant site information (e.g. geography, topography, geology, seismology, hydrology, meteorology, demography, transportation, land and water use, site access, natural hazards, particular environmental sensitivities);
— Information about the electricity grid system, particularly information that will be applicable and relevant to the technical characteristics and electrical grid connection schemes of the nuclear power plant(s);
— Information on safety related and non-safety related codes, standards, regulations and guides applicable to the safety and good performance of the nuclear power plant(s).

4.3.4.3. Technical support activities

Technical support for bid invitation involves identification, collection and expression of the technical and scientific characteristics, requirements, conditions and expectations, as well as the conditions to evaluate and confirm their fulfilment. In particular, it involves identification and description of:

— Technical and commercial requirements, conditions and expectations, particularly for design and performance characteristics of the main SSCs, operability and maintainability, waste management and decommissioning, emergency preparedness, security safeguards and physical protection. Of special note is the establishment of the technical owner's requirements for the project, which may be above those of the base offering of the bidder (e.g. nuclear power plant vendor).
— Licensing requirements and conditions, particularly nuclear, radiological, environmental and electrical grid safety and operation regulations and requirements.
— Conditions and circumstances under which the implementing entity will have to perform the tasks.
— Technical and scientific criteria on which the bids will be evaluated, particularly regarding technical characteristics of the proposed plant, and status and experience with its design, construction, operation and maintenance.
— Requirements for documentation and configuration management regarding technical documentation to be submitted during project implementation.
— Conditions for technology transfer.
— Description of division of responsibility between the owner and the bidder.
— Scope of supply and services for various activities of the entire supply and back end process, such as basic, detailed and final design, engineering products preparation and review, manufacture or supply, transport, erection, commissioning and turnover to operation organization, licensing, spent fuel and special material disposal.
— Construction and commissioning conditions and expectations.

This means that the needed/requested information on all aspects of the project which may affect the decision, such as the requirements, conditions and expectations, is correctly and completely determined and is expressed clearly and in an informed manner, such that the subsequent bids will provide sufficient and correct input and information as to the fulfilment of those requirements, conditions and expectations in support of the evaluation to be expressed and presented to the decision authority.

4.3.4.4. Organization and staffing

This activity requires a combination of technical, commercial and financial expertise. The technical team that prepares the bid invitation encompasses a mixture of engineers (particularly nuclear, mechanical, electrical, civil and industrial), engineering economists and experts with technical knowledge in nuclear and power generation technologies (i.e. nuclear steam supply system (NSSS), balance of plant (BOP), nuclear fuel cycles and waste management, safety and design analyses, procurement), familiarity with local industrial and commercial requirements, and experience in large scale industrial projects. This technical team will also support other teams that typically consist of economists; finance, risk assessment, human resource and training specialists;

and lawyers [40]. The size and composition of the team vary depending on the owner's strategy and resources. Reference [42] provides an example of basic resources and skills in preparation of the bid invitation (Fig. 9).

The organization can benefit greatly from engagement of external consultants to coordinate the activities. Such use of consultants or an expert consulting firm is particularly necessary when a country is undertaking its first nuclear power plant bidding process, when the decision making organization's experience and expertise may be limited and/or a complex and large scope of activities require experience for coordination and implementation, as shown in Fig. 9. For the organizations which already have in-house expertise and experience, an independent perspective from and/or oversight by external consultants is also beneficial. These consultants hired to provide technical support for bid specifications bring in significant experience on different nuclear power plant types and vendors, as well as good knowledge of the latest internationally applicable technical requirements and good practices, including on regulations, standards, codes and strategies applied by different countries. They can also provide information and experience regarding the project structuring, organization and management.

4.3.5. Bid evaluation

4.3.5.1. Purpose

The primary objective of the bid evaluation is to evaluate the bids with regard to scope and limits of supply and services as well as the technical, economic and other relevant features of the proposed nuclear power plants to support the decision on negotiating and awarding the contract for implementation of the nuclear power plant project (i.e. to be used in making the decision on the selection of a nuclear power plant project implementation entity). Technical support is essential in technical bid evaluation, which could take the form of a pass/fail screening before other evaluations, and supports commercial bid evaluation by providing perspective and information on technical limitations, conditions and importance or value. In order to support the decision on negotiating and awarding the contract for implementation of a nuclear power plant project, the bid evaluation aims (among other things) to:

— Determine acceptability/non-acceptability or need for further information;
— Identify open and unclear points for negotiations;
— Narrow down the proposals to the two or three most viable bids;
— Provide decision makers with information about and ranking of different aspects (e.g. technical, economic, commercial and financial) of the bids.

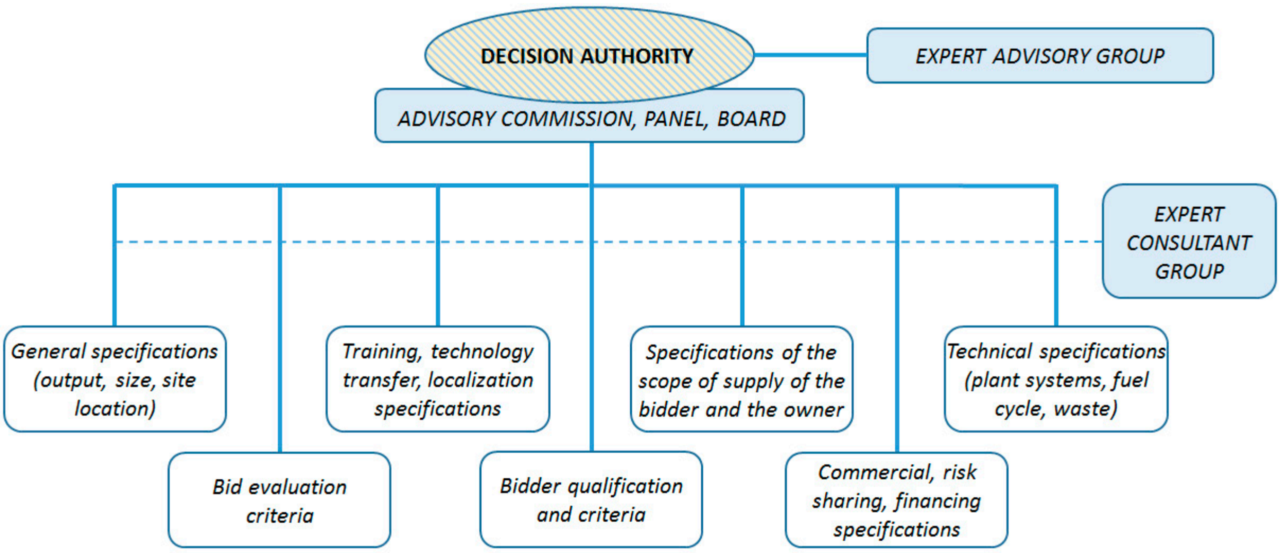

FIG. 9. An example of organizational arrangement and staffing for preparation of the bid invitation [42].

4.3.5.2. Scope

Elements and conduct of bid evaluation are described in detail in Refs [40] and [43]. Generally, the technical scope of bid evaluations includes:

— Review of the bids and verification that their information is complete as requested;
— Review and verification of the scope and limits of supply and services being proposed;
— Evaluation of the features, characteristics, specifications and properties for the items requested in the bid invitation, including the adequacy of the services;
— Determination of any need for further information and preparation of requests for information;
— Preparation of the evaluation report to present the results and conclusions obtained, including identification of open points for contract negotiations, identification of problem areas and special features, and suggested ranking of the different bids on the basis of the factors considered;
— Preparation of suitable technical clauses for the contract documents.

The evaluation can be either qualitative or quantitative. The aim of qualitative evaluation is mainly to determine the acceptability of a bid and to bring out the positive and negative features of a proposed nuclear power plant. Each aspect which is deemed to be important to evaluate is examined against the requirements of the specifications.

4.3.5.3. Technical support activities

The majority of technical support activities for bid evaluation are concerned directly with the technical bid evaluation, which typically includes the following tasks, as a minimum:

— Verification of the completeness and correctness of technical information provided, and of its compliance with the technical bid requirements;
— Assessment of the design parameters of the components, and an appraisal of the safety, reliability, function, operational performance, materials and maintenance requirements;
— Assessment of the technical design features of the equipment and structures, as well as the adequacy of the services;
— Validation of codes, standards, regulations, ordinances and utility requirements applied to the proposed scope and their compliance with the bid invitation;
— Identification of deviations from the bid invitation specification, as well as assessment of proposed technical alternatives;
— Confirmation and validation of technical references used for the proposed scope;
— Evaluation of technology transfer scope and deliverables proposed, if applicable;
— Assistance with clarification meetings with the bidders, if requested.

Typically, these activities for the technical bid evaluation are carried out on three levels: overall technical design evaluation of the bid, specific technical design evaluation for systems and main components, and general technical design evaluation of mechanical and electrical components [44].

The activities carried out for the economic bid evaluation also involve technical and scientific support — in accordance with the basic principles of engineering economic analysis — consisting of [45]:

— Provision of the right technical input and evaluation of contractual conditions and organizational matters, such as time schedules and domestic participation, from a technical perspective.
— Assessment of the technology transfer proposals in the various fields.
— Checking the plant performance guarantees (and warranties) for availability, load factor, power output, material properties and durability, including margins in the design for heat rate, steam conditions, load factor, load follow capability, discharge burnup and fuel failure rate, and release of radioactivity.
— Review of high level schedule and:

    - Assessment of delivery times for NSSS or components, as well as the major components of nuclear and conventional islands and BOP systems for turnkey plants' contract approaches (engineering documents, technology documents, software and hardware, etc.);
    - Assessment of the capability of sub-vendors to deliver major parts on time.
- Identification of uncertainties and risks (technical and commercial or financing).
- Checking the scope of wear and spare parts offered and evaluating the differences among bidders.
- Calculation of the total investment costs (vendor's portion and owner's costs, including costs for the site and site infrastructure, such as harbours, railways, roads, cranes, hoists, site village, workshops, firefighting installations and administration buildings).
- Assessment of various options at both the front end and back end of the nuclear fuel cycle, including options for disposal of spent fuel and special material.
- Calculation of the plant costs (e.g. capital, operation and maintenance, fuel) and estimation of decommissioning costs considering the load factors and plant output variations.
- Evaluation of any applicable warranties, alternatives and options.

4.3.5.4. Organization and staffing

The preliminary bid evaluation is carried out by the senior personnel of the evaluation team, typically six to eight senior professionals who cover all main aspects of the bid [42] (i.e. technical, commercial, financial, economic, legal), while the other members of the team use the time to get acquainted with the bid and give support as required. If specialized expertise is required for this preliminary 'screening', experts in the field are asked to give their opinion on specific aspects. This preliminary bid evaluation permits the senior personnel to also guide and supervise the subsequent detailed evaluation in a more effective manner.

Specialized technical experts, including engineers (particularly nuclear, mechanical, electrical, civil and industrial), engineering economists and experts with technical knowledge in nuclear and power generation technologies (i.e. NSSS, BOP, nuclear fuel cycles and waste management, safety and design analyses, procurement) may be needed for the subsequent detailed evaluation. This technical support team will also work with other support teams that typically consist of economists; financial, risk assessment, human resource and training specialists; and lawyers [42] who are familiar with financial, industrial, legal and commercial requirements for large scale industrial projects. Reference [42] provides an example of basic resources and skills in preparation of bid evaluation, as reproduced in Fig. 10.

For newcomer countries using competitive bidding, Phase 3 starts with the bidding and subsequent negotiation of the contract for the design, construction and commissioning of the nuclear power plant. For other newcomer countries, Phase 3 starts directly with the negotiation of the contract [17].

The utility implementing the nuclear project needs to acquire adequate knowledge of the bidding process and technology assessment as well as sufficient funds and human resources to carry out the task. For this purpose, the utility needs to develop in-house resources and engage expert consultants in all areas of customer/supplier interface. It is important that the consultants selected have experience in all technologies for which proposals are requested.

4.4. TECHNICAL SUPPORT FOR THE FINAL DECISION FOR INVESTMENT

Once the bid evaluation is completed, the decisions on the project commercial model and the partners in constructing, commissioning and operation of the nuclear power plant(s) will be made based on discussions and clarifications leading to the determination of the top-ranking bidder for the start of contract negotiations. After negotiations and agreement on the contract(s), as well as the final project cost, schedule and other financial arrangements, the final investment decision will be made. Whatever the detailed contract arrangements are, the final investment decision is a pivotal step for the implementation of a nuclear power plant project. The contract effective date (the first day of the project schedule) is the day that all technical, commercial, and financing contracts for the project are signed [42].

The activities and processes, including those for technical support, during the decision making on nuclear power plant project implementation are usually long and iterative, requiring many cycles of exchange between the

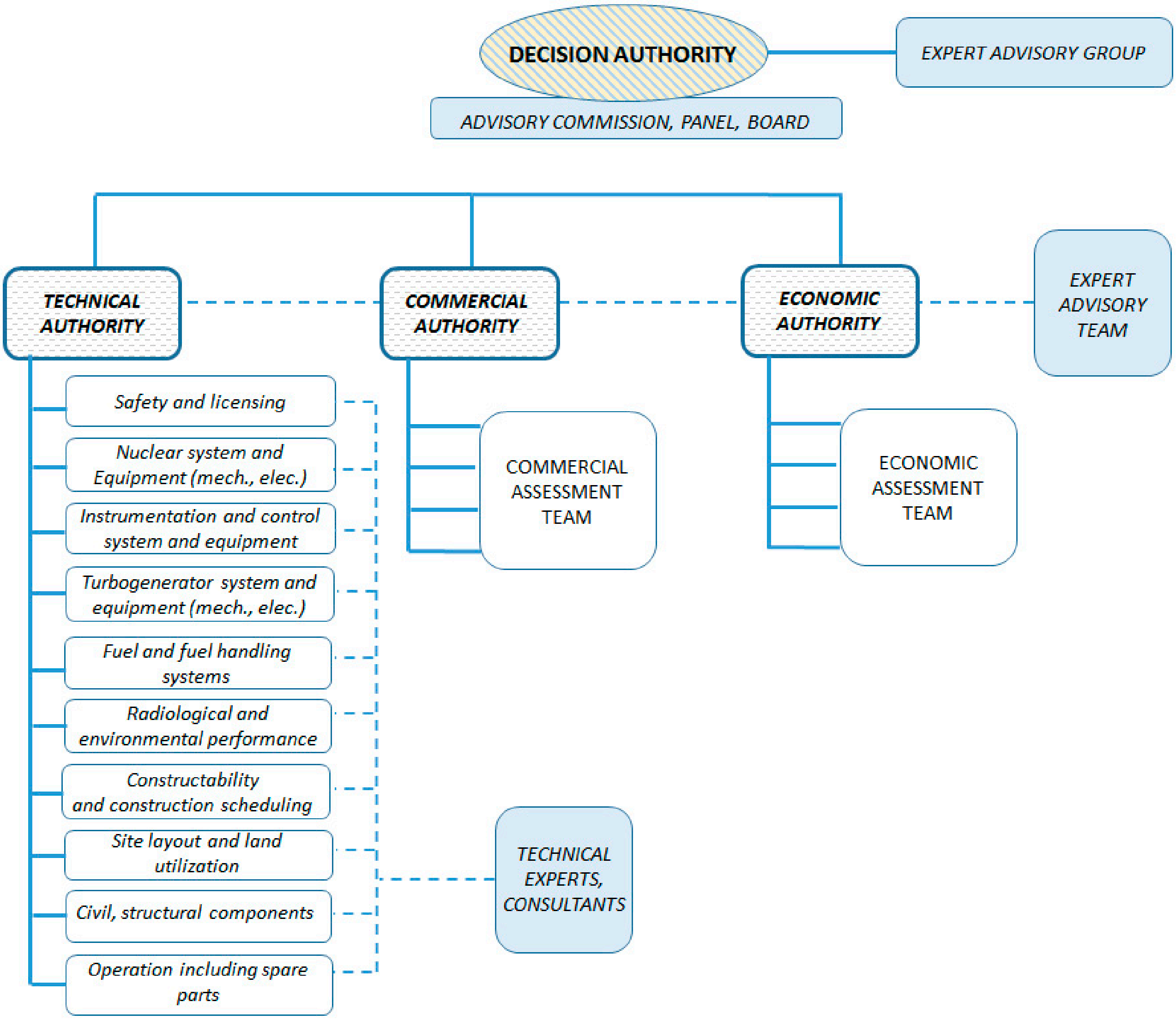

FIG. 10. An example of organizational arrangement and staffing for bid evaluation [42].

interested parties. For example, bid evaluation, acceptance and award may necessitate discussions for clarification among the project (or plant) owner, potential responsible designers, vendors and, of course, governmental organizations and agencies.

4.4.1.1. Scope

Contract negotiations cover technical, commercial and financing aspects of the project. In general, the technical and commercial contracts have to clearly identify the scope of the work of the supplier and the owner, schedule, price, performance parameters, warranties, rights and obligations of the utility and the supplier, and mechanisms of review, adjustment, approval and dispute resolution [42]. This requires technical support.

In order to finalize the project costs and schedule, there will also be work to develop the site specific design, produce the preliminary safety analysis report and collect all the technical information needed for licensing and planning approvals, which is controlled by the technical staff.

The basic technical contract documents comprise:

— Contract specification;
— Bid documents;
— Preliminary safety analysis report of a reference plant, if applicable;

— Safety evaluation report of generic/standard/basic plant design by regulatory body(ies), if applicable;
— Other documents agreed upon as technical contract documents.

4.4.1.2. Technical support activities

During the overall contract negotiation, agreement and finalization, technical support will be needed for technical negotiations on different detailed technical matters and for the final formulation of the technical contract with the selected bidder.

Technical negotiations with the preferred bidders are required to clarify any uncertainties in the bids in order to get a better understanding of the overall scope and of the technical designs offered. At the same time, special wishes of the utility with regard to any design modifications can be discussed and agreed upon. Further, the aim of the technical negotiations is to obtain a clear basis for the preparation of the technical contract. The basis for the technical negotiations is the bid specifications, bid documents, questionnaires, answers to the questionnaires and any evaluation reports available at the time of the negotiations.

A number of important technical points, such as licensability, changes, guarantees, rectification of defects and failures are not dealt with in the technical specifications, but in the terms and conditions of the technical contract. The negotiations required in coming to an agreement on those points are consequently not dealt with during the technical negotiations, but during the negotiations on these terms and conditions. Therefore, the members of the technical staff dealing with the technical specifications and negotiations need to know the content of these terms and conditions in order that no time is lost during the technical negotiations in dealing with matters which are already covered elsewhere.

The contract specification also gives the utility the necessary legal basis during the guarantee period for a claim for rectification of technical deficiencies if the performance of the plant does not comply with the requirements in the contract specification [42–44].

Representatives of the utility or its consultant will prepare protocols of these negotiations which are agreed upon with the corresponding bidder and which form the basis for preparing and issuing the technical contract document.

4.4.1.3. Organization and staffing

The responsibility for the entire bidding process lies with the plant owner and has to be performed in the owner's organization. If assistance in special fields is necessary, experienced consultants and architect–engineers may be integrated into the various working teams, which are structured as appropriate to support the overall project contract strategy. With respect to the BOP, the workload and the scope of responsibility of the owner is increasing as technology and regulation become more demanding.

The technical negotiations on different detailed technical matters are typically held by relatively small groups of people, with specialists of the utility or its consultant on one side and specialists of the bidder on the other side. It is important that these detailed technical negotiations be led by a member of the utility or a consultant who has good general project experience and who can understand the relative importance of the questions discussed and negotiated.

The structure of the negotiation teams is similar to that of the evaluation teams. Technical and commercial negotiations, when interrelated, can be conducted in parallel. Therefore, basic human resources will include technical support staff, such as:

— Lead technical negotiator for nuclear island and nuclear licensing;
— Lead technical negotiator for nuclear fuel cycle;
— Lead technical negotiator for turbine generator and BOP;
— Technical experts in support of the lead technical negotiators, as required.

5. TECHNICAL SUPPORT FOR THE DESIGN, CONSTRUCTION AND COMMISSIONING

Once the project commercial model and the partners in constructing, commissioning and operation of the nuclear power plant(s) are selected, the plant design is finalized and the plant is built and confirmed for operation. Subsequent work will include all procurement and construction activities, under appropriate management arrangements, and will also involve regulatory oversight and approvals throughout the phase.

During this phase, technical support is mainly shared among the selected vendors, which include the reactor supplier, the architect–engineer, the suppliers and designers of components and many others involved in design, construction and commissioning. The owner/operating organization is usually a customer of those entities but still bears the full responsibility for the design and consequent operation of the facility and is fully responsible for its verification, even if parts of activities, including TS activities, are entrusted to separate organizations within or outside the owner/operating organization. Although the responsible designers and constructors typically manage the technical activities, such as design activities, design outputs, field implementation design and necessary modifications to it in accordance with their quality and reliability requirements, the owner bears the responsibility for providing the approval to proceed.

Bearing the full responsibility for the safe and reliable design, erection and operation of the facility, the owner/operating organization (i.e. utility) assumes the key role of decision making in the development (detailed design stage), implementation (construction stage) and verification/validation (commissioning stage) of the nuclear power plant. It needs technical support for these decisions, and this need will gradually increase, as the design is developed, implemented and verified. Therefore, during this period, a TSO is established within the owner/operating organization (as an internal organization/group of technical experts) in order to assess the adequacy of plant design, construction and commissioning, with specific attention to verifying that it meets or exceeds the owner's requirements and needs. This TSO informs/advises the decision makers in the owner/operating organization on the technical issues in order to enable the project to advance with safety and technical adequacy as well as within schedule and budget.

The TSOs that provide this technical support carry the responsibility to review challenges and issues and recommend the best technical solutions — with an ownership attribute — to support ongoing regulatory reviews and the refinement of the design and physical configuration. Timeliness of this technical support for issue identification and resolution is also critical to meet the project schedule for the start of power operation. Therefore, it is essential that a mature internal TSO exist in the owner's organization, with expanding capacity, competency and proficiency to adequately support owner/operator decisions on the design, erection, procurement, installation and commissioning of the plant. During design, construction and commissioning, this competent internal TSO can strongly support the nuclear power plant owner in providing all necessary information to support its leader's decisions with ownership and responsibility:

- Initially, when the detailed design is documented, there will be a technical support need to perform a thorough review of the selected work by the implementing entities (e.g. design activities, design outputs) for the purpose of ensuring that the design and physical facility meet or exceed the legal, environmental, safety, contractual and other technical requirements and the owner's expectations.
- When the plant is being built according to the design, there will be a need for technical support to review and assess the work by the implementing entities for field implementation (e.g. design changes and physical modifications), to identify, describe and evaluate any necessary design changes and site specific adaptations with respect to whether they meet the requirements and expectations.
- When the regulatory body is conducting its review of the detailed design as described in the safety analysis report, some technical support will be needed to evaluate and respond to the considerations and issues relating to compliance with nuclear safety related requirements which are affected by plant design and layout, for example, physical separation and radiological shielding.
- When the non-nuclear and nuclear commissioning tests are conducted, technical support will be needed to perform a thorough review of the tests for the purpose of ensuring that the design and physical facility meet or exceed the technical requirements and the owner's performance expectations and to review and assess

pertinent issues and lessons from commissioning testing and incorporate them into design and configuration documents.
— Throughout the phase, the owner needs technical support to manage technical challenges impacting multiple organizations and communication of technical information and responsibilities between the owner, responsible designer, vendors, regulatory body and other involved parties.

The owner/operating organization may also solicit technical support from the independent external TSOs in highly specialized, trivial matters or in situations in which opinions differ between the stakeholders (e.g. reactor supplier, architect–engineer, suppliers and/or designers of components). At the end of this phase, the owner/operator needs to be fully capable of, and licensed for, operating the nuclear power plant. This capability also includes initiation, conduct and implementation of technical activities during the operation stage. Therefore, this is also a very critical stage in which the owner needs to be closely involved in order to ensure that its in-house technical staff gain technical knowledge by shadowing the external TSOs. Also, this is the time to record technical knowledge, for example design philosophy, basis, approach and methods, for later technical support needs. This is essential as it will be the foundation for providing, maintaining and improving technical support during the operation stage — as well as the decommissioning stage — by a competent internal TSO or for exchanging accurate and correct technical information with external TSOs.

5.1. TECHNICAL SUPPORT FOR DECISIONS ON DETAILED DESIGN ACCEPTANCE

At this stage, the decision on the nuclear power plant design approvals will be made by the owner: accepting and agreeing to the detailed design, its features and changes, while ensuring that the design and physical facility meet or exceed the legal, environmental, safety, contractual and other technical requirements, as well as economic and efficient plant performance needs and expectations.

Responsible designers and constructors will manage the design activities and design outputs, per internal processes, requirements and competencies; however, the owner will bear the responsibility for giving approval to proceed. Therefore, it needs to be aware of the design issues and changes — especially changes to drawings and any major changes to the basic design — and understand them in order to make a decision on the acceptance with regard to:

— Plant safety;
— Power generation performance and efficiency;
— Maintainability and operability;
— Reliability, functionality, availability and longevity of equipment and controls;
— Constructability.

5.1.1.1. Scope

The scope of the technical support includes review and validation of the detailed design as to its consistency with the project design specifications, requirements for operating licence authorization and needs for plant performance. This is an in-depth and integrated (vertical and horizontal) technical review of the design — at SSC level — with respect to plant safety and power production. It will also include identification and resolution of any exceptions, deviations, substitutions to the project design input document and project milestones and major equipment scheduling. This will be performed with consideration given to concerns relating to key attributes:

— *Plant safety:* Compliance with nuclear safety related requirements which are affected by plant layout (e.g. physical separation, radiological shielding);
— *Power generation:* Reliability and dependability of turbine island SSCs;
— *Constructability:* Comparison of the on-paper plant and physical installation (e.g. plant layout versus reality of what will exist at the field and is constructible);

— *Maintainability and operability:* Later maintenance and operation of SSCs, such as access to places for performing maintenance or manual operations (e.g. pathways, confined spaces, keeping exposure as low as reasonably achievable, normal and emergency ingress/egress for personnel and equipment);
— *Equipment qualification and controls:* Qualification of SSCs (and their controls) for their mission meeting the requirements predicated by the safety analysis.

5.1.1.2. Technical support activities

The owner will mainly rely on technology providers' internal reviews; however, its technical staff in key areas will select and perform accuracy and completeness review of designers' analysis packages, component specifications, the final system description manual and design basis manuals.

The TSO will perform:

— Targeted quantitative reviews of design documents, such as the analysis packages (particularly the accident analyses, seismic analyses, equipment qualification parameters, and instrumentation and control (I&C) setpoints) and supporting reference technical documents, component specifications, final system description manuals, and design basis manuals;
— Detailed review of drawings, particularly structural and civil, isometric, electrical and piping routeing, piping and isometric, electrical single line and I&C logic diagrams;
— Detailed review of component drawings from vendors, manufacturers and technology providers other than responsible designers to ensure compliance with standards and specifications;
— Review of component operation and maintenance manuals, part lists and other relevant instruction documents to ensure sufficient information is provided for material compatibility, writing operation and maintenance procedures, and so on;
— Review of equipment performance data from tests for all safety related components, such as pump curves;
— Review of safety analysis report to ensure the content is valid and is in accordance with the design;
— Review of engineering documentation in conjunction with the construction;
— Assuming ownership of the design[15] as to design basis, philosophy, requirements, features, potential improvements, and so on;
— Determining, obtaining and recording all non-proprietary technical information for retention and later technical support use.

5.1.1.3. Organization and staffing

The owner's technical staff (on and off the site) and the in-house consultants make up the TSO. At this stage, the owner (via its own technical staff) is extensively involved in the design and performs the review for approval as the customer. It is beneficial for the owner to involve its own technical staff heavily in order to understand the design and to start assuming the ownership of the design.

This is a design stage, where the owner needs to be closely involved in order for its technical staff to gain in-house design knowledge by shadowing the responsible designers. This will be the foundation for maintaining and improving design during the operation stage. This is also the time to record design philosophy, design basis, design approach and design methods for later use. Operating experience shows that if this is not done properly, it is very difficult and costly to reconstitute the design basis later.

5.2. TECHNICAL SUPPORT FOR DECISIONS ON LICENSING

Generally, once the detailed design is 'frozen' (meaning that the physical plant is identical to the documentation prepared for detailed design as described in the final safety analysis report (FSAR)), it is incorporated into the FSAR and submitted to the regulatory body for review and approval. In the process of the regulatory body's review, there will be decisions to be made by the owner to resolve issues related to licensing review and approval, such as

[15] This refers to the internal TSO (i.e. design ownership by the owner/operating organization).

on the extent and type of response to clarify and resolve requests by the regulatory body, or on the proposed licence conditions.

5.2.1.1. Scope

At this stage of detailed design, all safety related and major SSCs are in place and the configuration of plant is frozen. Generally, the number of changes to the design and configuration is minimal during this time; however, significant effort and considerations take place in order to ensure that the accuracy and integrity of the FSAR being reviewed by the regulatory body are maintained. In particular, all changes to the plant require review and screening for their impact on the ongoing regulatory review. Plant changes, in addition to any impact on the FSAR or regulatory review, are communicated to the regulatory body in a clear, concise, timely and effective manner.

5.2.1.2. Technical support activities

Although minimal, there will be some changes to the design and configuration during the regulatory review. The technical support will involve review and screening of all changes to the plant impacting the FSAR and the associated regulatory review:

— Detailed review of changes to all design documents compared with the regulator submittal, and confirmation of compliance with all commitments and statements made to the regulatory body in order to obtain the operating licence and that the design and configuration continue to satisfy the requirements and conditions of the approved design and applicable codes and standards;
— Update/amendment of FSAR that has been (or is to be) submitted and determination and communication of relevant technical information to the internal organization that is responsible for communicating with the regulatory body;
— Provision of technical recommendations to appropriate internal organizations for any changes needed to regulatory submittal for power operation licence request.

Additionally, the TSO will continue to request, collect and retain approved design documents that are needed to operate the facility and take ownership of the plant. In addition, at this stage, it will collect and compile all relevant documents related to licensing, including the correspondence relating to technical information with the regulatory body.

5.2.1.3. Organization and staffing

The TSO consists of the owner's technical staff (on and off the site) and in-house consultants. At this stage, the owner (via its own technical staff) is extensively involved in the design and performs the review for verification and approval as the customer who is taking over the facility. It is beneficial for the owner to heavily involve members of its own technical staff in order to ensure that they understand the facility, as it is assuming the ownership of the design.

5.3. TECHNICAL SUPPORT FOR DECISIONS ON FINAL DESIGN ACCEPTANCE

The period of regulatory review is also typically used for conducting non-nuclear commissioning tests on systems. These tests will confirm the design of systems and will require the owner's decision on acceptance of the ownership of those systems based on their test performance. It is also possible that refinements to the detailed design will be generated as a result of these tests, and these refinement changes will require the owner to decide whether to accept and agree to them, ensuring that the design and physical facility meet or exceed the needs and expectations regarding economic and efficient plant performance.

As the operating licence is issued, the nuclear commissioning tests are performed in preparation for power operations, such as nuclear island system tests, fuel loading and pre-criticality tests of reactor systems, reactor criticality and tests at low power, and tests at various power levels. The results of the tests lead to a decision by the owner/operator on acceptance of the ‘final design’[16] to take full management and ownership of the complete design and facility.

5.3.1.1. Scope

The non-nuclear tests and subsequent nuclear commissioning tests and their results will provide data and information for the performance of all nuclear island systems, particularly for the fuel, reactor, reactor coolant system (RCS) and containment, and some performance significant systems, such as turbine and generator control, and steam bypass systems in the conventional island. These verification test are conducted to ensure systems meet or exceed the legal, environmental, safety, contractual and other technical requirements and expectations, in accordance with the project input and objective. The completed test results will require review and acceptance, in addition to potential incorporation into design and licensing documents.

It is also possible that refinements to detailed design will be generated as a result of these tests, and these refinement changes will require review and acceptance of the changes ensuring that:

— The design and physical facility meet or exceed the needs and expectations regarding economic and efficient plant performance;
— The accuracy, factuality and integrity of the FSAR that is being reviewed by the regulatory body are maintained;
— Any exceptions, deviations, substitutions to the project design input document are identified and justified.

It is beneficial and recommended for the owner to preserve the test data as ‘baseline’ information for SSCs related to safety and performance. For example, the commissioning test may be conducted for a moisture separator reheater to ensure turbine performance warranties; however, the data collected during this test may be useful for margin determination in accident analysis in the future. Even though some baseline data may not fall under the design document control requirements, it is suggested that it be preserved in an easily accessible form and place.

5.3.1.2. Technical support activities

The technical support is provided for the final design review for technical assurance that:

— The design is in compliance with all commitments and statements made to the regulatory body in order to obtain the operating licence;
— All systems and components, particularly fuel, core, RCS, containment and turbogenerator, perform as designed and are in accordance with all project design input, requirements and expectations;
— Functionality of SSCs is verified (by reviewing test results);
— Safety and operating margins are validated by the test data (and quantified if practical);
— The design continues to satisfy the requirements and conditions of the approved design and applicable codes and standards;
— All non-proprietary information is obtained by the owner for future reference.

The technical support activities in the review of commissioning test preparation include detailed reviews of test plans/procedures, particularly for containment integrity, fuel loading, reactor startup, and low power and power ascension test plans/procedures.

During the commissioning testing, the need for TSO participation and activities may include:

— Observation and assessment of test conduct for information on operation to be incorporated into plant documents, such as the operation instructions and procedures including access for manual operations;

[16] The state ‘final design’ varies based on the contractual agreement between the owner/operating organization and the design provider(s). For example, the state can be defined as “successful completion of continuous operation at full electrical output for a specific duration”, as agreed by the owner and the responsible designer. Then, once that specific duration is completed with successful continuous operation at full electrical output, the design can be declared as ‘final design’. It should be noted that nuclear power plant operation is typically considered to begin when the loading of nuclear fuel into the reactor is started.

— Observation and assessment of test conduct for information on as-built access to places for performing maintenance, such as ingress/egress paths for personnel and equipment, and confined spaces;
— Review and assessment of all changes made to the plant systems, particularly to protection, control and monitoring systems as a result of conduct and observations of commissioning tests.

Following the commissioning tests, the results are obtained and evaluated with technical support from the TSOs which may include:

— Detailed review of all commissioning (non-nuclear, nuclear and hot performance) test results and verification that the responsible designer is making required changes to all affected controlled documents;
— Detailed review of alterations to all design documents compared with the FSAR or operating licence;
— Detailed review of all nuclear and hot performance test results to ensure no impact on the licensing documents, particularly on the operational limits and conditions (OLCs), as well as licence conditions required by the regulatory body;
— Review of all changes made to the plant protection, control and monitoring systems as a result of commissioning tests;
— Detailed review and confirmation of test results regarding all system and equipment performance, particularly of fuel, core, RCS, containment and turbogenerator systems and components, including the system line ups, as well as the review and confirmation of updates of all affected control documents;
— Review of equipment performance data from tests for all safety related components (e.g. as-built reactor coolant pump curves);
— Detailed review and assessment of alterations to the design, including screening for their impact on the design and licensing documents, and particularly on the OLCs, as well as licence conditions required by the regulatory body (and communicating those to the appropriate owner organization, e.g. licensing department, for any changes needed to regulatory submittal for power operation);
— Review of all design items as revised or added (e.g. drawings, structure and system manuals, component operation and maintenance manuals, part lists);
— Review of all changes to component operation and maintenance manuals and part lists made by the provider as a result of tests;
— Review and incorporation (or ensuring incorporation) of all pertinent issues, lessons and corrective and preventive measures identified from testing into design manuals and system/component description documents, as well as procedures.

Also, when the commissioning is completed, the regulatory body may carry out an overall assessment of the test results and final design, particularly with respect to the OLCs, as well as licence conditions. Based on the assessment, the regulatory body may request additional information and conditions, in which case technical support may be required for resolution of these issues, such as on the preparation of technical responses, technical and scientific clarifications and resolution of requests by the regulatory body, in support of the internal organization which will communicate with the regulatory body. The technical staff may also assist in meetings and discussions with the regulatory body regarding the technical information, if requested.

5.3.1.3. Organization and staffing

At this stage, the owner (via its own technical staff) is extensively involved in the design and performs the review for verification and approval as the customer who is taking over the facility. It is beneficial for the owner to heavily involve members of its own technical staff in order to ensure that they understand the facility, as it is assuming the ownership of the design.

6. TECHNICAL SUPPORT FOR OPERATION

As the bearer of full responsibility for safe and reliable operation of its nuclear power plant and the upholder of its efficient and effective performance, the owner/operating organization will consider, evaluate, initiate, perform, implement and/or manage plant activities. During the safe and efficient operation of the plant to achieve its purpose of safe, regular and efficient production of electricity and energy, many safe, sound and timely decisions on these activities need to be made by the owner/operating organization, particularly to:

— Maintain and increase safety and operational margins;
— Maintain and increase performance (e.g. maintain and increase reliability and availability of SSCs, reduce unnecessary plant and equipment outages/unavailability);
— Maintain and increase return on investment (e.g. avoid premature replacement costs, extend operation life, protect equipment).

These decisions on ensuring, maintaining and improving safe and efficient design, operation, performance and configuration during operation will concern safety, reliability, quality, capacity, availability, operability and longevity of assets. Furthermore, these decisions need to be made in an informed manner, with consideration of all relevant information, which is provided to the decision makers with a high level of proficiency and competency by the supporting organizations, including the TSO(s), within and outside the owner/operating organization.

For example, as the design and configuration of the facility is controlled, plant modifications arising during the operation, no matter how minor, have to be made with a full understanding of all the design and technical information of, and for, the plant and the specifications for each system and component; of the engineering compromises and assumptions made by the designers about operation and lifetime; of why the plant has been designed and operated the way it has; and of the interactions with other systems and components. Failure to ensure adequate technical knowledge of plant design and configuration and utilization of technical expertise and scientific fundamentals will result in decisions being made on modifications, changes in operating procedures and new or revised specifications for replacement and spare parts without a full understanding of the effect that these decisions may have on the safety and performance of the nuclear power plant. As a consequence, technical and scientific bases will not be applied in a manner which would produce the most benefits to the plant with respect to maximizing availability and efficiency with optimized safety, reliability and quality, resulting in safety and performance problems.

Therefore, effective technical support is essential to optimize the safe operation of nuclear power plants and to maximize their availability and productivity. Maintaining and improving the safe and efficient operation required and expected of a nuclear power plant requires that the design, configuration and operation activities be prepared, verified and validated, implemented and controlled via a structured process by competent staff of the TSO. This includes keeping and improving the plant SSCs and programmes and procedures with adequate knowledge of technical basis.

Generally, the ownership of design and engineering may be assigned to one individual or department (i.e. the technical authority and technical conscience), which owns and controls the technical knowledge. However, depending on the stage of the plant lifetime, consistent with the organizational culture and corporate philosophy and commitment, the entire organization, from the highest ranking officer at the site down to the worker in the field, understands and shares equally in the goal of making sound and appropriate decisions supported by timely and accurate technical information, collectively.

The technical support will cover a spectrum of support to the various ‘customers’ within the owner/operating organization, for example, to the operations organizational unit (primarily) and other organizational units, including maintenance, procurement, licensing and work planning. The technical support by technical experts would include services for:

— Daily operation and routine activities that rely on technical information and perspective;
— Oversight of multiple technical areas and sources of technical know-how;
— Control of plant design and configuration information and judgement and authority in their use;
— Expert input, perspective or advice for special, non-routine or off-normal operational activities;

— Review and analysis of adverse events and trends experienced in the nuclear industry (or similar industries) and determination of corrective and preventive actions;
— Middle to long term focus, vision and strategy on technical aspects for plant operation and maintenance.

Sections 6.1–6.4 provide task and scope for core and common technical support activities during the operation phase. Again, technical support output provides support and advice for the decision making. While the technical experts are directly responsible for the technical basis and requirements for the plant operations, the direct responsibility for the nuclear power plant operation function rests with the operations staff.

6.1. CORE TECHNICAL SUPPORT FUNCTIONS DURING OPERATION

Being the technical conscience of the nuclear power plant operating organization, members of the technical support staff provide technical input, service, products, guidance, advice or feedback in support of the decisions — and, once the decision is made, in support of the implementation of the associated activities — to:

— Ensure that the plant design and operation meets the acceptance criteria for *safety*, *reliability* and *quality* in accordance with relevant codes and standards, laws and regulations;
— Maintain and improve safe and efficient operation and performance utilizing technical and scientific fundamentals, information and knowledge;
— Identify and resolve any design and performance issues in SSCs[17], as well as programmes and procedures that support safe, reliable and effective operation;
— Make effective facility changes with full knowledge of the technical basis and design and licence intent, philosophy and conditions;
— Liaise with the stakeholders in charge of overseeing the facility design and operation in a controlled and informed manner.

6.1.1. Scope

The objective and scope of the technical support is to ensure that the nuclear power plant is being operated in accordance with its design basis; the physical plant configuration and procedures adequately cover the technical basis, with technically sound instructions provided to the other personnel in the organization (e.g. operations, maintenance, procurement and radiation protection staff); and any deviations from the design basis in approved procedures/facility information or in physical configuration of the plant are promptly detected and corrected or responded to.

Being the technical conscience of the plant, the technical support personnel provide technical guidance and assistance not only in support of the identification of plant issues and resolution of problems which have an immediate effect on safe, reliable and efficient operations, but also in the determination and implementation of plant maintenance and improvements for the longer term.

Members of the technical support staff achieve these objectives through establishing and applying an effective configuration control and management programme for the facility. They also continuously monitor the plant systems and review daily operating plans and results, which requires constant awareness of the plant equipment status and frequent interaction with the operating staff providing them technical guidance and assistance in conduct of their roles and responsibilities.

Regardless of the scope, the operating organization maintains the capability of identifying, requesting/providing, understanding, assessing and confirming technical information that is needed for the decision to be made.

[17] Not only safety, quality and reliability related SSCs and SSCs supporting them, but also SSCs associated with effective, efficient and continuous energy generation.

6.1.2. Activities

The technical support activities during operation cover any activity for which the operating staff need technical and scientific information, assessment, evaluation, confirmation, opinion, advice or recommendations for safe and efficient operation of the nuclear power plant. These can be classified into different roles:

— *Preparatory activities:* These are the activities that establish the planning or preparation of the technical support, such as the determination of tasks, scopes, schedules, competencies for technical support needed (or to be provided) or determination of technical information needed (e.g. what data to collect/monitor and how to collect/monitor them). These activities also include issue identification.
— *Demonstratory activities:* These are the activities that are performed to investigate and demonstrate, as well as to draw conclusions based on technical and scientific methods, such as preparation of engineering calculations, studies, evaluations, analyses and data regressions.
— *Confirmatory activities:* These are the activities that qualify and review technical support products (e.g. qualification, verification and validation of data, analyses, investigation results, evaluation conclusions).
— *Advisory activities:* These are the activities that provide decision makers recommendations, suggestions or opinions regarding technically viable options on courses of action, planning, costs or resources based on technical and scientific information, knowledge, experience and expertise. These activities could include provision of technical opinions and judgements on, for example, importance of issues at hand, urgency of resolutions, and advantages and disadvantages of solutions.
— *Anticipatory activity:* These are the activities that provide awareness to the decision makers on foreseen technical and scientific issues and needs, anticipated courses of action and conceptual resolutions based on technical and scientific information, knowledge, experience and expertise. Typically, these are based on observations, monitoring of trends, predictions, past operating experience and so on.
— *Exploratory activities:* These are the activities that support the decision makers on predicting and envisioning the long term and end state of nuclear power plant design and configuration, identifying gaps and establishing strategies. These activities may involve improvement of the design and physical layout of the plant or advancement of corporate technical and scientific information and knowledge (such as creating more effective and accurate methods or optimizing human–machine interface for improved operation of the plant).

The corporate approach and strategy may also assign responsibilities and roles for the TSO (internal or external) for *innovatory activities*, which would include activities such as discovery of new technical and scientific information and knowledge or creation of more effective and accurate methods during the operation stage. Typically, for these activities, the TSO identifies and performs research on safety issues that meets the needs of the decision makers: implementation of a research and development programme allowing the development of new knowledge and techniques as well as new experts in support of TSOs' missions. The conditions and criteria for graded research and development activities and the acquisition of advanced or special technical information and knowledge and techniques for decision making may vary from one corporate strategy to another and could be developed on a case by case basis; however, the process needs to be clearly described in the corporate policy and programmes.

It should be noted that the different types of activity will require different levels of technical proficiency, knowledge and expertise, as well as different thinking abilities and approaches. For example, demonstrative activities can be performed by technical staff with basic knowledge and training on technical and scientific fundamentals and applicable methods, while advisory, anticipatory or exploratory activities require knowing and understanding not only the execution and confirmation of other activities but also interpreting and expressing results of demonstrative activities in an overall perspective and in an integrated manner, which requires broader knowledge as well as competency and experience in highly specialized matters.

During the operation phase, the majority of TSO activities are generally preparatory, demonstratory, confirmatory and advisory activities, particularly involving preparation and confirmation in the form of engineering analysis, studies, evaluation and monitoring and oversight. Specific tasks for preparatory and demonstratory activities typically include:

— Identification, collection (or requesting collection of), verification and validation of data, trends and characteristics for input into the analyses, including identification of the ones that need to be updated later;

- Definition and justification of assumptions for analyses and identification of the ones that require later confirmation and validation;
- Selection of applicable tools and methods for analyses;
- Selection of scenarios to evaluate including the sensitivity studies;
- Assessment of the validity and reasonableness of results, and identification of key input and assumptions that have significant impact on the results;
- Identification and description of contingencies, limitations and conditions of applicability, including potential or recommended future verification and validation of significant and highly variable input and assumptions;
- Drawing conclusions, including description, comparison and ranking of options, and making overall recommendations;
- Documentation of the work performed.

Specific tasks for preparatory and demonstratory activities typically include:

- Verification of the completeness and correctness of the input;
- Verification of the completeness and reasonableness of the assumptions and the appropriateness of their justifications and contingencies;
- Verification of the appropriateness and applicability of the tools and methods used and the correctness of their use;
- Verification of the completeness of the scenarios evaluated and identification of the key input and assumptions;
- Validation of the results and verification of the completeness and correctness of the associated contingencies and limitations;
- Confirmation of the conclusions drawn and of the correctness and completeness of the description, comparison and ranking of options and overall recommendations;
- Documentation of the review results.

6.1.2.1. Engineering analyses

Engineering analysis is the primary activity of technical support. Engineering analyses are demonstratory and confirmatory activities and tasks, and they deal with the analysis of the plant and its SSCs' characteristics, capabilities and behaviours to satisfy the safety, design and regulatory requirements and expectations of routine and non-routine operation. These analyses demonstrate, throughout the plant life cycle, the engineering and technical predictions, results and conclusion, as well as identifying contingencies and applicability of engineering and scientific bases.

The technical and scientific areas of these analyses cover fundamental engineering fields, such as nuclear, mechanical, electrical, electronic, civil, radiological and chemical engineering, as well as science fields (e.g. material, environmental, thermohydraulic, manufacturing, computer, risk and hazard assessment). Accordingly, the analyses developed in the design and operation of the nuclear power plant for specified SSCs or functions may be grouped in various ways, including:

- Nuclear fuel and core;
- RCS;
- Reactor protection systems;
- I&C systems;
- Electrical systems;
- Fluid, pneumatic, heating, ventilation and air-conditioning systems;
- Heat transfer and power conversion systems;
- Civil structures, including containment and support structures;
- Radiation monitoring and shielding;
- Personal and equipment radiation protection;
- Fuel handling and storage systems;
- Radiological waste control and management;
- Environmental impact and protection;

— Equipment qualification;
— Surveillance and testing;
— Risk assessment, including human factor related risks.

For these various fields of engineering and SSCs, overall engineering analysis activities encompass the following aspects:

— Development of design and operation limits, margins, prerequisites, conditions, requirements, standards and targets based on technical and scientific fundamentals and expertise for use in safe, reliable and efficient operation;
— Prediction, modelling and anticipation of response and behaviour of SSCs under normal, abnormal and accident conditions;
— Recording the facility analytical basis and supporting information for inclusion in plant design and configuration documents to be used as a reference in all operational activities;
— Application and development of computational tools, methods and technologies;
— Provision of recorded technical perspective and basis to organizations in areas other than operations, such as training, work planning, emergency response, industrial and radiological safety and environmental protection.

6.1.2.2. Engineering monitoring and oversight

The TSO, based on the staff competencies, knowledge and experience, is able to review and confirm that the SSCs are operating in the ranges and in the conditions intended by the design for performing their specified functions correctly and reliably. It is also able to observe and validate that the SSCs are operated and maintained as prescribed by the design. Technical support experts can also assess the past and current performance of SSCs in order to predict future courses of action for their operation and maintenance. Therefore, one of the technical support activities during operation is to monitor and observe trends in characteristics and behaviours of the plant, particularly those important to safety and performance, and to analyse and evaluate them against the design intent and requirements as well as performance expectations. Some examples of these areas included in the engineering monitoring and oversight activities are:

— Fuel and core performance (e.g. neutron and thermal power, core power distribution, RCS activity), for assessment of fuel and cladding integrity;
— Mechanical characteristics (e.g. vibration, humidity, temperature, pressure, flow, noise), for structural integrity of systems and components;
— Plant transients (e.g. variation of power, temperature, pressure, flow), for assessment of fatigue;
— Water chemistry of the primary and secondary systems (e.g. impurities and chemical preservatives), for assessment of erosion and corrosion;
— Radiation levels, for assessment of shielding integrity, and radiological and environmental protection;
— Heat balances in the steam power conversion (e.g. temperature, pressure, flow), for efficiency of power conversion;
— Electrical properties (e.g. voltage, current, temperature, battery capacity), for integrity, capacity and efficiency of electrical supply and distribution systems;
— Technical surveillance of fuel performance and fuel inventory control.

6.1.3. Organization and staffing

There may be variations in the use of internal and/or external TSOs during the operation phase depending on the plant activity for which the decision making relies on technical support, as well as the corporate strategy of the owner/operating organization. For example, for technical support needs for daily or frequent operational decision making, the owner/operating organization may fully rely on an internal TSO. On the other hand, for one time or special cases involving major facility modifications (e.g. major equipment replacement, plant refurbishment), the owner/operating organizations may choose to utilize external TSO(s) to perform/review technical activities with the direction, consultation and oversight by the internal TSO. Regardless of the share of technical support provided by external TSOs, the owner/operating organization's internal TSO needs to be competent and involved in order to ensure that the technical support provided meets or exceeds their decision makers' needs in adequacy and timeliness (including schedule and budget), as the owner/operating organization is fully responsible for the safety and reliability of the nuclear power plant operation and the decisions associated with this safety and reliability.

The key elements for structuring of TSO(s) were presented in Section 3.5, and the current practices in terms of TSO structures are further discussed in detail in Section 6.5.

6.2. TECHNICAL SUPPORT FOR OPERATIONAL DECISIONS

Support of the safe operation of a nuclear power plant is the primary role and responsibility of the TSO, and is of the utmost importance. Safe plant operation requires provision of adequate margins such that the plant does not operate outside the conditions required by the design and licence, as well as ensuring the SSCs are preserved in a condition in which they retain the capability at all times to perform their design functions. The TSO, in close coordination with the decision maker in the control room, will provide continuous support for operational decisions to be made for safe operation. Furthermore, the technical expertise will support the plant's decision maker in improving plant performance and efficiency without compromising safety.

The activities performed by the TSO in support of plant operation are mainly: preparatory (such as issue identification); demonstratory (i.e. investigation, demonstration and drawing conclusions regarding the condition of SSCs from technical information); confirmatory (such as review and assessment of plant data); or advisory (i.e. recommending a course of action to resolve issues, based on technical and scientific fundamentals and technical expertise and experience).

6.2.1. Determination of system and component status and condition

The operating personnel (e.g. shift crew) of the owner/operating organization are responsible for overall control of nuclear power plant operation. As part of that responsibility, they have to be aware of the operability and functionality of plant equipment and the status of degraded or nonconforming conditions that may affect nuclear power plant operation. Therefore, verification of status and condition of systems and components is a routine, typically daily, activity by the operations staff, particularly for the SSCs important to safe operation. This verification ensures (or calls into question) the availability, operability, functionality or efficiency of SSCs. When the operators' monitoring and inspection activities in the main control room and in the field, such as walkdowns of the system and components, indicate (or raise reasonable suspicion regarding) an unusual or a degraded condition, the ability of the system (or component) to perform its functions — as required[18] or expected for safe or efficient operation and performance of the nuclear power plant — is called into question and a decision needs to be made on the condition of such system or components. This decision will be supported by condition determination for that particular equipment, and the decision maker[19] will need input from the plant staff in other organizations with expertise in the subject matter and appropriate knowledge of affected SSCs' design and operation, including the TSO. The technical experts from the TSO provide technical information, opinions and/or advice in support of a timely decision on the status, and condition determinations, which typically include:

— Specified functions performed by the affected SSCs;
— Design requirements or performance expectations established for the affected SSCs;
— Effect or potential effect of the degraded condition on the affected SSCs' ability to perform specified functions, including margins to the applicable criteria for satisfactory performance of specified functions;
— Effect or potential effect of the degraded condition of the affected SSCs on other related or associated SSCs' status and conditions;

[18] In most regulations, an operability or functionality assessment is required when degraded or non-conforming conditions of SSCs performing specified safety functions are encountered.

[19] For the SSCs performing specified safety functions (which are typically described in the nuclear power plant's OLCs), a senior licensed operator on the operating shift crew with responsibility for plant operations — in most cases the crew leader — makes the declaration of operability (i.e. 'makes the call' on whether an SSC described in OLCs is operable or inoperable).

— Any compensatory measures (e.g. technical solutions, temporary physical or administrative changes in accordance with the design basis and based on the technical and scientific knowledge; see Section 6.2.4.1 for a detailed discussion of technical support in support of temporary modification decisions) that could be put in place to establish or restore satisfactory status and condition for the affected SSCs.

In some cases, the decision needs to be made immediately upon discovery of a degraded condition, depending on the importance of the system or component. Information and recommendations provided by the TSO for such determination may be limited but sufficient. Therefore, the TSO could continue the support to obtain/provide further information in a timely manner to confirm or alter the immediate decision to minimize any undesired effects on the plant operation.

It should also be noted that, although status and condition verification activities, for example walkdowns, are generally carried out by the operating staff, in some nuclear power plants, the system engineers or the specific component engineers who are part of the TSO may perform these activities on a system basis. Also, monitoring of system operation and maintenance involves periodic presence and observation by the responsible engineer for the activities in the control room and in the field. In such cases, field walkdowns become an essential part of technical support activity that needs to be performed at a frequency sufficient for the engineer to stay in touch with system condition and performance. This technical support activity for daily oversight by the TSO consists of a number of distinct roles:

— Provision of daily technical advice and guidance, in response to current problems;
— Frequent formal and informal contacts with operations personnel;
— Frequent and visible presence at the plant, particularly to observe work being done and assess the condition of plant equipment;
— Control of modifications to SSCs and their operation and controls, and to the operating procedures.

These activities ensure that technical information on the condition and characteristics of systems and components is accurate and current, and consequently, that any technical support requested or provided for decisions on those systems and equipment is performed with up to date knowledge regarding: the conditions of the plant, systems and equipment; the planned and ongoing work; and the problems that have been encountered. Therefore, they provide the ability to the TSO to promptly and correctly offer technical advice and support in problem identification and resolution.

6.2.1.1. System and equipment surveillance

The objective of system and equipment surveillance is to detect or prevent equipment and procedural degradation in order to ensure satisfactory and reliable operation of equipment and systems over the middle and long term. The surveillance programme is designed to confirm that:

— The plant is operated and maintained in accordance with its design and operating licence conditions;
— Systems are being operated and maintained in a manner which optimizes reliability while being cost effective in terms of human resource and material usage;
— System performance is routinely monitored and tested in a systematic manner such that trends towards degradation of performance and documentation are identified early;
— Management systems are in place to confirm effectiveness of surveillance.

All three major components of a surveillance programme (i.e. technical surveillance, operational surveillance and maintenance surveillance) involve TSO activities — particularly the technical surveillance, which is directly performed by the TSO — in order to ensure that:

— The current state of the plant is routinely assessed through evaluation of results of surveillance testing and also through observation of operations in the control room and the field;
— Operating parameters are reviewed with regard to trends;
— Current deficiencies, operating logs and maintenance activities are reviewed and assessed;

— Results of routine system tests are promptly reviewed, evaluated, trended and reported;
— Technical, operating and maintenance documentation is periodically reviewed.

The TSO typically has the overall responsibility for the basis of surveillance programmes, including the development of technical requirements by ensuring that the surveillance programme is specified, documented and cross-referenced to design and licensing requirements and bases. The TSO also ensures that the surveillance programme addresses possible failure and deficiencies in equipment, materials, software, configuration and human performance, and that surveillance tests adequately demonstrate and verify compliance with all technical, scientific and regulatory requirements, such as:

— Selection of adequate test instrumentation, including location, range, accuracy, calibration and frequency of recalibration of test instruments;
— Determination of test prerequisites, methods and steps;
— Ensuring all essential operating and annunciation components are tested;
— Validation of test sequence, including the appropriateness of special actions taken in advance to ensure a successful test;
— Consideration of human factors to minimize mistakes and errors during testing;
— Identification of hazards and risks of performing tests, as well as precautions and hold points;
— Identification and determination of acceptance criteria;
— Setting the frequency of testing in accordance with the condition and status to be confirmed.

6.2.1.2. Reactor monitoring and advice

The TSO, based on the staff competencies, knowledge and experience, is able to assess, predict and confirm that the nuclear fuel and core are operating in the ranges and under the conditions intended by the design. It is also able to assess, predict and confirm that the nuclear fuel, cladding and core integrity is sustained and reactivity is managed as prescribed and expressed by the core design. These activities may be performed during:

— Routine operational activities, such as normal 'at power operation' and reactor startup, power ascension, specified times of core life and reactor shutdown, specific life cycle stages of the fuel and core, as well as during the performance of periodic tests, including those for SSCs that are not related to fuel and core but that could affect the function and behaviour of the fuel and core;
— Non-routine operational activities, such as in case of deviation from routine operation which may occur in response to change in the facility conditions, such as an unexpected reduction of power due to loss of redundancy of equipment, or change that would impact the reactor core and fuel characteristics, as well as special tests, including those for SSCs that are not related to fuel and core but that could affect the function and behaviour of the fuel and core.

The TSO provides technical support both in the conduct of these activities and establishing underlying core physics analysis, operation and test procedures, and in the evaluation and assessment of the impact on safety and operational margins arising out of such operational activities, for example:

— Develop test procedures for monitoring fuel and core during initial fuel loading, startup (i.e. criticality, zero power, low power, power ascension) and power operation;
— Develop the requirements and expected behaviours of fuel and core, as well as standards and targets in areas such as reactor physics, reactivity control, chemistry of coolant and cover gas, fuel management, fuel performance and fuel inventory management during normal and low power operations, and shutdown configurations, and make them available for decision making by the control room shift crew leader via an easily accessible platform and in a clear and concise manner;
— Perform tests to determine characteristics and behaviours of the nuclear fuel and core during initial fuel loading, criticality, zero and low power, power ascension and full power;
— Assist with tests on the SSCs not related to nuclear fuel and core that could impact characteristics and behaviours of the fuel and core;

- Analyse and evaluate tests and monitoring results for fuel and core characteristics and behaviours against the design intent and requirements as well as performance expectations, recommend actions in case of abnormalities and deficiencies, as applicable;
- Provide technical input and information, as well as appropriate course of action, potential issues and contingency actions regarding the fuel and core during non-routine operational activities;
- Monitor and trend characteristics and behaviours of the nuclear fuel, core and RCS radioactivity during 'at power operation';
- Provide other advice on the fuel and core behaviour or characteristics as input for informed decisions by the operational decision maker (i.e. the shift team leader), if requested.

Some examples of these areas included in these 'reactor engineering' monitoring and oversight activities that deal with the analysis of reactor operation and the capability of reactor systems to satisfy the safety, design and regulatory requirements of routine operations are:

- Fuel and core performance (e.g. neutron and thermal power, core power distribution, reactivity management), for assessment of fuel and cladding function and integrity;
- Water chemistry of the primary systems (e.g. impurities and chemical preservatives), for assessment of erosion, corrosion;
- Plant transients (e.g. variation of core power, power distribution, reactivity coefficients, RCS activity);
- Heat balances in the steam power conversion (e.g. temperature, pressure, flow) for effect of power conversion on fuel and core;
- Technical surveillance of fuel performance and fuel inventory control.

6.2.1.3. Plant technical overview and advice

The TSO provides on-shift support on special technical information and knowledge to the operating staff (i.e. to the control room shift crew leader) during off-normal operations, particularly for event evaluation and accident assessment.

The primary scope of this technical support activity is to provide technical, scientific and engineering advice for informed decisions by the operational decision maker (i.e. the shift team leader). This advice provides a technical perspective through additional separate poised and composed observation, review and evaluation of off-normal operational events, incidents and accidents in assuring safe and reliable operations of the plant during such situations. The associated technical support activities include additional and independent reviews and evaluations of operating events and accident and incident assessments. The technical staff may also provide support for decisions on the safety significance and reporting needs and requirements.

6.2.2. Corrective (remedial) maintenance

Although a mature preventive maintenance programme intends to maintain and preserve the nuclear power plant and its SSCs in proper condition for performing their specified functions for safe and efficient operation, deficiencies, malfunctions and failures of SSCs may occur unexpectedly. The need for remedial maintenance may arise when deficiencies or failures are detected during plant operation [46].

When deficiencies or failures are detected, owing to unexpected safety or performance constraints placed on the plant operation (and design), decisions need to be made on changing the plant conditions (e.g. reducing power or shutdown, unplanned and urgent maintenance to correct plant equipment issues, and when and how to bring the plant back to the safe and efficient power operation mode). Also, a decision needs to be made on the type of maintenance (i.e. repair, overhaul or replace) to restore the deficient or failed SSC to the acceptable level of performance of its specified functions, in a safe and timely manner. This decision will need support from various organizations, including the TSO, that assist to determine the need and extent of maintenance, as well as determining the cause of the failure, describing the repair, replacement or overhaul and verifying the restoration of functionality.

The extent of technical support needed for a remedial maintenance decision may vary from minor assistance to significant efforts, depending on:

— The extent of the deficiency, failure or damage and the associated repair;
— The cause of the deficiency or failure;
— The availability of replacement parts and components;
— The importance of the defective or failed SSC (i.e. important to safety, important to efficient plant performance);
— The conditions in which the plant needs to be placed to perform maintenance activity;
— The urgency and duration of the repair and replacement of defective SSCs;

Typically, substantial technical support activities are performed when [47]:

— The SSC is important to safety or supports safety related SSCs, or the component is not important to safety but the portion or part being repaired/replaced affects safety or a safety function and will not be physically isolated;
— The function of the defective/failed component or part involves relates to environmental protection;
— The integrity of the component will be disturbed or upset, or disassembly of the component or part will be required;
— Parts and material substitution and procurement will be involved, which may even include the need to replace obsolescent components;
— Welding will be performed on a component or part of a component that is important to safety;
— There will be a need for system or equipment lockout/tagout;
— There will be industrial and radiological safety hazards during the work performance;
— A special or non-standard procedure, work planning, work order or work package needs to be developed for repair or replacement work;
— Detailed review, assessment and documentation of post-maintenance testing will be required;
— The repair or replacement work is complex, unique, non-routine, non-standard or has high risk or serious consequences;
— The work will need a long outage and unusual plant conditions.

Furthermore, if unexpected failures of the same kind (same equipment, same apparent causes, etc.) or similar failures (i.e. similar equipment, similar apparent causes) repeatedly occur, comprehensive root cause analyses may be required to prevent or minimize recurrence. Such analyses require technical support activities performed by technical staff with the necessary special expertise and detailed knowledge of the system, equipment and materials, or even access to external TSOs with subject matter experts and special facilities such as laboratories and hot cells.

6.2.3. Risk assessment

The risk assessment is used by the operating staff to plan and coordinate plant activities and make decisions on their timing, sequence, duration or deferral, in addition to the traditional deterministic assessment (see Section 6.1.2.1). Nuclear power plants may utilize risk assessment to ensure that core damage frequency and large early release frequency are minimized during plant configurations that arise from atypical operating conditions and to inform the plant organizations, particularly operations and maintenance, regarding risk. Such assessments are especially conducted for:

— Plant evolutions outside OLCs;
— Inoperability and availability of equipment identified in OLCs;
— Outage of non-OLC equipment;
— Routine operations that are not explicitly included in the plant OLCs;
— Non-routine corrective maintenance;
— Special inspections and tests.

The risk assessment may be used for daily activities, periodic maintenance and refuelling outage activities, as well as specific one time plant evolutions. In general, the risk assessment determines:

— The ‘safe operating envelope’ where risk is minimized or eliminated;
— Consequences of adverse events if the risk cannot be minimized or eliminated;
— Possible counter measures to reduce the risk generated by abnormal events and operating conditions and to provide the lowest possible risk increase.

In order to make decisions to manage plant activities with minimal risk during operations, the decision making is supported by plant specific probabilistic risk analysis applications and tools that quantify the risks, provided by the TSO. Also, technical experts may provide qualitative assessment, opinion and/or advice in support of timely decisions on the implementation of plant activities.

In case of deviation from the routine operating configuration, which may occur in response to changes in the facility conditions, such as an unexpected reduction of redundancy of equipment or changes in reactor core and fuel characteristics, the TSO also provides support to evaluate and assess the risk significance of reduced safety margins arising out of such plant configurations.

6.2.4. Design control and configuration management

The design control process and the configuration management programme ensure that accurate and up to date information consistent with design basis and the plant physical and operational characteristics is adequately and clearly described in plant documents. These ensure that the information needed for making safe, sound, informed and cost effective operational decisions with confidence is readily available [29, 30]. These decisions will include the decisions on operational activities during normal, abnormal and emergency operations, such as system line up, troubleshooting and functional verification, as well as maintenance activities, such as repair/replace and work order, based on the plant documents. In particular, the decisions will be made based on the information in the drawings (e.g. general plant, structural and component drawings; piping and isometric, flow, electrical single line and I&C logic diagrams), SSC description manuals (e.g. system description manuals, component operation and maintenance manuals) and/or operating and maintenance instructions, such as normal, abnormal and emergency operating procedures, and maintenance work performance procedures.

Generally, as the owner of the design documents, the TSO plays the major role in the control of the comprehensive configuration management programme of the plant. Through its configuration control in association with its knowledge and understanding of the design bases and margin management, the TSO ensures safe and efficient plant operation by:

— Knowing the design and configuration of plant SSCs, including the associated design philosophy, bases and requirements, functions, limits and margins for normal, abnormal and accident conditions;
— Having the expertise and proficiency to clearly define the underlying design principles, regulatory requirements and industry codes and standards and having experience in their plant specific operational application;
— Retaining and maintaining information to reflect current design and configuration in an accessible form and making it available to relevant organizations in an applicable form and format, including the expression of their applicability and limitations.

In doing so, the TSO defines the requirements of plant configuration management and ensures establishment of business processes, procedures and information systems to prevent divergence, over the plant’s life cycle, in order to maintain conformance among the design requirements (what needs to be there), the physical and operational configuration (what is there) and the design and configuration information (what the document says is there). Typically, the TSO, as the ‘owner’ of the design control and configuration management programme, is responsible for its continued implementation through oversight and control of activities that include:

— Physical (facility) and information (document) changes and design (requirement) modifications;

— Operation, maintenance, surveillance and testing instructions to prevent unauthorized or unrecorded modifications and to ensure continued compliance with design and licensing requirements throughout the life of the facility;
— Management of materials to ensure conformance of materials to design requirements;
— Management of documentation and database to ensure that relevant records and documents are updated and controlled;
— Management of temporary plant modifications.

Effective configuration management is also important because it will strengthen the TSO itself in supporting the correct and timely execution of activities (owing to having the applicable background and current information needed to evaluate and to change plant procedures readily available and accessible) such as:

— Design changes for safety and performance improvement and associated permanent and temporary physical modifications;
— Licence amendments for compliance with new or revised regulations and safety reviews (periodic or specific);
— Material control, equipment qualification, procurement and storage for the selection and review for suitability and availability of materials, parts and equipment;
— Equipment and component life assessments for plant life management;
— Procedure development and revisions for new or improved operation and maintenance instructions.

6.2.4.1. Temporary modifications

Temporary modifications are made to facilitate operations when the plant has to operate in an unusual and temporary configuration either due to conditions existing at the plant (equipment out of service) or due to conditions outside of the plant (e.g. an issue on the electricity grid). Such situations may require decisions to implement temporary modifications, such as a temporary operating procedure, equipment condition or physical configuration change, to ensure the plant is safe until a permanent solution is implemented. Although, to preserve safe and regular production of electricity, the design and configuration of the facility is controlled, and the majority of design activities are initiated, performed, and/or implemented by the TSO of the operating organization — including temporary modifications, these temporary modifications may require implementation by the operations organization (i.e. control room manager) as an exception owing to these modification being of very short duration and necessary to place the plant in a safe condition.

Maintaining the very high level of safety expected of a nuclear power plant requires that modifications arising during the operation, no matter how minor, be made with a full understanding of: all the design information for the plant and the specifications for each system and component; the engineering compromises and assumptions made by the designers about operation and lifetime; why the plant was designed the way it was; and the interactions with other systems and components. Failure to ensure adequate knowledge of plant design will result in decisions on modifications or changes in operating procedures being made without a full understanding of the effects that they may have on the safety and performance of the plant.

Therefore, the operations department needs to inform and cooperate with the TSO in support of evaluation of the temporary conditions and configuration and for obtaining clear instructions outlining operations under these unusual conditions. It is presumed that temporary modifications are minor in scope, short in duration and few in number. However, they are evaluated by the TSO and appropriately approved before installation and removal. Temporary equipment modifications may also require temporary procedure changes, drawing revisions or annotations and training.

The TSO ensures periodic review of all these temporary changes for continued applicability and conducts risk assessments to justify that with the temporary modifications in place there is no risk to safety. Based on the nature of the temporary modifications, technical support (e.g. an analysis) might be needed to assess the cumulative effects on plant safety and operability.

6.2.4.2. Technical oversight and control of special plant evolutions

TSOs play a major role in safe conduct of special plant evolutions, such as the special tests and surveillance that may be performed one time or infrequently to demonstrate and verify meeting the regulatory requirements and applicable codes and standards or licence conditions, for example:

— Containment, RCS and steam generator (for pressurized water reactor plants) pressure or long term post-accident leakage tests;
— Reactor natural circulation cooldown tests;
— Integrated test of emergency diesel generator start and sequencing and loading tests;
— Turbogenerator load rejection and rundown tests.

These tests could be performed for verification of compliance with codes and standards, or they could be related to power production and plant performance, such as secondary system moisture separator testing in pressurized water reactors, or cooling water heat transfer effectiveness tests. Infrequent and special inspections and surveillance, such as in-service inspections and groundwater surveillance for radiological, chemical and other hazardous contamination, may constitute special and infrequent plant activities.

The special plant evolutions may include those that are performed to enhance plant effectiveness, such as performing mid-loop operation for effective outage execution or multiple system or equipment maintenance with approved temporary provisions for safety and reliability.

Members of technical support staff support the conduct of these plant evolutions by:

— Assessing the adequacy of design capabilities, conditions and margins during the conduct of these evolutions;
— Considering potential SSC response and behaviour under the conditions that they will be subject to during the evolution, including the impact of time under those conditions;
— Advising operations personnel on changing key conditions and prevention and protection measures;
— Exploring potential reasons for, and consequences of, deviating from planned activity steps and observing and predicting the state and conditions under such cases;
— Determining and planning courses of action in carrying out mitigation measures for potential failures and malfunctions of equipment;
— Defining operational restrictions and communicating them to the operation organization by establishing procedures (see Section 6.2.4.3) and preparing a technical basis for the conduct of operator actions and steps;
— Keeping oversight of parallel conduct of multiple plant evolutions, such as simultaneous or subsequent tests and other activities performed while the plant is in a special configuration, with regard to their impact on plant response and operation.

Associated technical evaluations and assessments are most often conducted to determine (based on the design basis, functions, boundaries and experience and knowledge) that during these special plant evolutions the 'safe operating envelope' is not breached or that the possibility of unsafe conditions and potential consequences is minimized and mitigated.

6.2.4.3. Plant programme, process and procedure control and oversight

Programmes, processes and procedures are key ingredients for consistently safe and satisfactory plant operation and performance. The investigations following the Chernobyl accident, which were reported by the IAEA's International Nuclear Safety Advisory Group in Ref. [6], determined that operating procedures were not founded satisfactorily in the technical analyses and exchange of important safety information between operators and the TSO was inadequate and ineffective. Reference [6] also states that: "Well planned procedures are very important when tests are to take place at a nuclear plant. These procedures should be strictly followed." Noting that special test procedures were also changed in an ad hoc manner without thorough evaluation and confirmation by the TSO, it recommended: "Where in the process it is found that the initial procedures are defective or they will not work as planned, tests should cease while a carefully preplanned process is followed to evaluate any changes contemplated."

Technical support is, therefore, necessary in preparation, revision and review of operating and maintenance procedures, particularly of those involving operation during abnormal, emergency and accident conditions and during the aforementioned special tests, inspections and surveillance. The TSO has a role and function in ensuring that these key ingredients in the procedures and programmes are:

— Prepared consistent and in compliance with the design and licensing requirements;
— Revised in conformance with design and configuration;
— Verified and validated as being complete and correct concerning design and configuration of the plant.

Members of TSO staff ensure that operational prerequisites, restrictions, entrance and exit conditions, and so on are explicitly, unambiguously and clearly defined and described in the procedures and informs operations organization personnel and management of the basis for these and possible consequences of deviating from procedures.

Operating aids, such as process flow sheets, power supply lists, functional descriptions of equipment and technical bases of actions, or maintenance aids (e.g. system and part lists, system wiring diagrams, list of lubricants, filters), which may be a part of or supplement to the procedures, are ensured to be correct and meticulously kept up to date.

Similarly, severe accident management instructions and their basis (functional basis documents, severe accident management guidelines, etc.) are prepared, periodically reviewed and updated as changes are made to the facility and accident management strategies.

6.2.5. Radiation protection

Radiation protection deals with minimizing exposure to ionizing radiation in the safe operation of the nuclear power plant. The radiation protection measures are implemented by operations personnel in accordance with standards laid down by plant management. All levels of line management and all site personnel have individual responsibility for safe work practices and for keeping the exposures as low as reasonably achievable [2, 48]. Therefore, periodic and continuous decisions will be made on operational activities based on associated radiological conditions, risks and consequences, particularly on radiation monitoring and shielding.

The TSO has the primary responsibility for assuring effectiveness of radiological protection by identifying and assessing radiological requirements, conditions, monitoring methods, hazards, risks and consequences and providing technical support for assistance, advice and recommendations for engineered and administrative measures and controls within and around the nuclear power plant for the conduct of operational activities.

6.2.6. Environmental protection

Based on the conditions of the environmental licence, a comprehensive environmental site monitoring programme is established together with all appropriate procedures to implement the programme. All the results of this programme are the subject of continuous assessment and analyses of the current status versus acceptance criteria in the design basis. The TSO is responsible for preparation of all environmental impact studies and applications to the environmental regulatory bodies to maintain and comply with the environmental licence throughout the life cycle of the plant. As the owner of the environmental impact assessment, the TSO performs activities such as:

— Assessment of radiation measurements in air, food, water, soil and groundwater;
— Selection of adequate monitoring instrumentation, including location, range, accuracy, calibration and frequency of recalibration;
— Development of networks of monitoring data and facilities;
— Assessment of natural (e.g. seismic, flooding) and human-made hazards.

6.2.7. Fuel handling

Fuel handling activities deal with the management of fuel movement in and out of core while maintaining control of the reactivity and preventing damage to fresh or spent fuel assemblies during their transportation, storage or manipulation. Taking into account the significance of fuel movement, the refuelling activity is the most important element of fuel handling. The operating staff will make decisions on the timing and conduct of fuel movement, including suspension or resumption of fuel handling activities based on the plant conditions. In making these decisions, the operating crew will need technical information to confirm or alter the decisions. In most cases, the TSO establishes technical requirements, methods, standard plans and procedures for the use of operators in decision making on safe and efficient fuel movement. Examples of these boundaries of the ‘safe operation envelope’ include:

— Identification of the earliest time after shutdown to remove fuel from the core to the spent fuel storage;
— Determination of the configuration of the reloaded core and spent fuel storage (i.e. location of specific fuel assemblies);
— Determination of the sequence of off-load and reload and fuel shuffles in the core and the spent fuel storage;
— Determination of the sequence of ‘at power’ (or on-line) refuelling, for some particular designs.

These pre-set technical and administrative controls — during both core off-load/reload and storage — are specified, authorized and performed in accordance with the calculated core and spent fuel storage requirements and configurations, which are also performed by the TSO.

In case of deviation from routine fuel handling operations, which may occur in response to incidents such as fuel failures, unmoveable fuel assemblies, handling of damaged fuel, or changes in the facility conditions, the TSO also provides technical support to evaluate and assess the risk significance of reduced safety margins arising out of such fuel handling situations.

6.2.8. Emergency response and preparedness

As the accident at the Fukushima Daiichi nuclear power plant showed [14], one of the key tasks of the TSO is to provide timely, accurate, clear and concise technical information and advice to the decision makers during the response to emergency situations for:

— Assessing and establishing a prognosis for the state and conditions of the affected unit;
— Assessing and ensuring safety of unaffected units (in a multi-unit site);
— Assessing and predicting the conditions of the area around the affected unit and the entire site;
— Determining and planning courses of action in carrying out mitigation measures;
— Advising emergency response personnel on radiological conditions and radiation protection measures;
— Identifying single points of contact from local and national agencies as the conditions change and participating in information exchange.

In case of emergency management, the role of TSO becomes significant as the responsibility of decision making shifts from the main control room to the technical support centre. The technical support centre is a combination of experts from the TSO, plant operations and other supporting groups to assist the emergency crisis centre in decision making. Because of the transition of responsibility, the technical support centre personnel have to be trained and qualified on accident phenomena and the plant specific emergency procedures and severe accident management strategies, guidelines and computational aids. They have to be knowledgeable on plant specific design, plant response to changing conditions and all available tools and equipment which are foreseen to predict the progress and explore prevention and mitigation of the consequences. With the emergency response centre in this emergency mode, the need for technical support becomes essential for:

— Dispatching and staffing technical support centre with appropriate experts;
— Assessing, predicting and communicating the situation in the affected unit and at the site on the basis of available information;

— Preparing periodic or updated reports about the state of the unit and its main systems, the damage, and the radiation situation at the unit and in the nearby area;
— Developing technical recommendations for prevention and mitigation schemes based on the plant design and configuration;
— Supporting assessment of the results of the emergency monitoring;
— Supporting the implementation of the personnel protection plans;
— Assessing the emergency and the damage;
— Assessing, diagnosing and establishing a prognosis for the overall condition, particularly with respect to the fission barriers, sources of radioactive emission and releases and dispersion to the public and environment.

6.2.9. Computer security, safety and reliability

6.2.9.1. Plant hardware and software used in safety and performance

Software quality assurance and the high risk of using unverified or commercial software programs, particularly those for design, control, monitoring and operation of safety equipment, requires TSO involvement to ensure qualification, protection and maintenance of plant software. Furthermore, technical support for identifying cybersecurity threats, risks and consequences — and in what software areas these are applicable, based on technical information — is necessary for secure and safe application and use of software [49].

Also, assistance, protection and control for the use of software and databases for nuclear power plant operation, analysis, monitoring, protection and prevention is one of the most important aspects of technical support. The TSO also ensures that computer software meets technical, security and regulatory requirements with respect to function and control of software and documentation.

The TSO identifies and sets specifications for use, procurement/development, verification and validation, and it controls the software used at the nuclear power plant. This software can be placed in two groups:

(a) *Intermittent use software* — This includes the following kinds of design, engineering and analysis software:
  — Safety analysis software: Software which is used to carry out safety analysis and assessment of plant systems, structures and equipment. This software may be specifically identified in the licensing or design requirements, and is generally subject to quality assurance measures.
  — Performance evaluation software: This is the software which is used to carry out design or to evaluate performance of plant systems and equipment. It may or may not be subject to quality assurance measures; however, it requires similar controls in a graded approach.
  — Operation assistance software: This is typically software in a calculator or simple software that is designed to automate or aid operator calculations and verifications.
(b) *Continuous use software* — This is the specific software used in real time to control and monitor the functioning, status and characteristics of SSCs and equipment with:
  — Specified functions for maintaining plant safety;
  — Specified functions for supporting safety systems;
  — Specified auxiliary or indirect functions in the achievement or maintenance of nuclear power plant safety;
  — Specified direct or indirect functions in the achievement or maintenance of nuclear power plant performance.

6.2.9.2. Protection against cyberthreats

Technical support for identifying cybersecurity threats, risks and consequences — and in what software areas those are applicable, based on technical information — is necessary for secure and safe and secure application and use of software for operation [50].

Technical support promotes the application of cybersecurity engineering and the use of solutions to prevent cybersecurity events and protect against cybersecurity threats throughout the plant and in its operation. These technical support activities include:

— Identification of the interfaces between computer security and operational safety, reliability and performance;

— Determination and implementation of state of the art and appropriate cybersecurity measures;
— Identification and prevention of potential cybersecurity issues;
— Risk assessment in addressing vulnerabilities and their possible and potential exploitation;
— Assessment and application of advances within the wider computer security community.

6.2.10. Licensing

Licensing in all stages of the nuclear power plant life cycle is one of the most important tasks that may require technical support. Generally, as the owner of the design basis, and the technical conscience, the TSO's support is needed to decide whether the condition of the plant and its SSCs are in compliance with the licensing conditions and requirements. Additionally, proposed changes to the plant configuration and procedures need to be technically verified against the operating licence and plant design by the TSO, either to provide technical justification and/or concurrence that the safety and reliability of the plant is in compliance with the existing licence conditions and design requirements, or otherwise, to provide technical basis in support of a proposal to revise the licencing basis through licence amendments.

The TSO assists the unit of the owner/operating organization that interfaces with the regulatory body (for example, its licensing division) to present a technical basis that demonstrates compliance with design requirements and the conditions established by the regulatory body in the nuclear power plant's licensing basis. It also makes available to the licensing interface organization all the documentation and technical justification/opinion that may be presented to the regulatory body.

6.2.11. Training

Training by the technical staff enables individuals both in the internal TSO and the other organizations in the nuclear power plant to understand and perform the required tasks with thorough knowledge of technical and scientific fundamentals, their use, and the consequences and impact on their own and other organizations. The initial and continuing training programmes for the TSO staff (see Section 3.6.3) ensure a team of competent technical support personnel with proficiency in technical and scientific fundamentals and technical specifications to design, operate and maintain the nuclear power plant safely and efficiently.

Beyond the training of its own staff, the TSO is responsible for conveying technical information, knowledge and perspective to all relevant staff in the plant through training to ensure that the plant personnel have sufficient knowledge and understanding of plant design and technical bases to perform their activities. The TSO staff has a broader perspective of integrated plant design and operations and understands the context of how SSCs interface with each other to support safe and efficient generation of electricity. Therefore, the TSO has roles and functions in determination of necessary, applicable and targeted training areas, preparation and conduct of training, and assisting the preparation, revision and review of training materials to ensure that the conduct of plant activities is consistent with the technical and scientific fundamentals and in compliance the requirements of the nuclear power plant design and licence. Through training of plant staff, the TSO provides, for example:

— Fundamental understanding of technical and scientific topics relevant to the plant configuration and operation, for example, nuclear physics fundamentals for knowledge of the fuel and core behaviour or characteristics, or electrical engineering fundamentals for power supplies and single line diagrams;
— Adequate understanding of relevant technical information on the plant systems and equipment (i.e. design fundamentals, design requirements or performance expectations of the SSCs, e.g. their design basis, design functions, capabilities, limitations, margins);
— Technical overview of integrated plant operation and system interfaces, including redundant and diverse systems availability and utilization, dependency such as the effects of malfunctions and degraded performance by SSCs on interfacing plant systems and equipment;
— Knowledge of important technical properties of SSCs related to their operation, such as material characteristics, ageing mechanisms, impacts of operating conditions/environment, performance criteria and limits, and symptoms of poor performance;

- Technical basis of actions in the operating procedures regarding the system operation per design and technical limits and functional requirements, as well as causes and consequences of incorrect operation or malfunction, particularly of those involving abnormal, emergency and accident conditions, special tests and surveillance;
- Technical perspective and basis for emergency response, industrial, nuclear and radiological safety, waste management, radiological and environmental protection, and so on;
- Timely updates and impacts of revisions to the design and configuration.

6.3. TECHNICAL SUPPORT FOR DECISIONS ON PLANT PERFORMANCE

Optimization of plant performance (i.e. improving safety and performance in an effective and efficient manner) is one of the technical support functions which has the most potential for positively affecting the long term performance and viability of a nuclear power plant. As such, optimizing plant performance must be recognized as one of the key activities and outputs of a TSO and be included in annual work plans and reviews. As discussed in Section 6.1.2, these technical support activities are of the advisory, anticipatory and exploratory types (and are performed in cooperation with operations, maintenance and other departments), and have the following scope:

- Providing the decision makers with recommendations, suggestions or perception for technically viable ideas and options on plant safety and performance improvements for design, operation and maintenance, including the programmes, procedures and computational aids;
- Increasing awareness and drawing the attention of the decision makers to foreseen issues and needs, and anticipated courses of action, and considering their conceptual resolutions based on the observations, monitoring of trends, predictions, projections, past operating experience of the plant and other nuclear power plants in the world, and so on;
- Supporting the decision makers in predicting and envisioning the long term and end state of plant design and configuration, identifying gaps and establishing strategies.

These activities may involve improvement of the design and physical layout of the plant, advancement of corporate technical and scientific information and knowledge (such as creating more effective and accurate methods), and optimization of human–machine interfaces for improved operation of the nuclear power plant. As the owner of plant design and configuration management and control, the TSO leads and coordinates these activities.

6.3.1. Plant programmes, processes and procedures

Procedures are a key ingredient of consistent satisfactory performance for nearly all plant activities. Since the TSO is heavily involved in preparation, revision, review and approval of operating and maintenance programme and procedures, particularly those involving abnormal, emergency and accident procedures, it ensures that they are optimized to improve operations and maintenance, procurement, material control, radiological and environmental protection, and so on. More information is provided in Section 6.2.4.3.

6.3.1.1. Operation procedures and human–machine interface

Operating activities are carried out in accordance with procedures. Maximum stability and predictability of operations is essential for good operations to minimize human errors and optimize human–machine interfaces. The TSO supports — by procedure reviews and frequent interaction with the operating department, as well as monitoring component, I&C system responses and behaviours — improvement and optimization of normal and, particularly, abnormal and emergency operating procedures, as well as the equipment that operators interface with, by:

- Minimizing the possibility of introducing plant transients and off-normal conditions due to inadvertent operator actions or untimely equipment response.

— Providing and maintaining sufficient operating margins such that the OLCs are not exceeded and the design intent is preserved, while ensuring that these margins do not restrict or complicate easy and efficient plant operation.
— Tuning process control set points to provide better preservation and operating margins and to make operations easier, while improving plant performance.
— Exploring possibilities of rotating the duty cycles of equipment among redundant components (if this is a permitted as a normal operating practice), and when possible, determining the frequency and specifying plant, equipment and component conditions under which equipment service could be rotated.
— Improving methods and frequencies of routine testing, since the frequency and method of testing influences equipment wear and therefore needs to be balanced against benefits, such as assurance of availability. Furthermore, method of testing and the timing of tests might in fact temporarily diminish plant reliability by reduction of redundancy.
— Making manual controls simpler and less prone to human error.
— Making the alarms and annunciation schemes more user friendly to facilitate interpretation of information.

6.3.1.2. Maintenance

Maintenance activities are carried out in accordance with the maintenance programme developed and controlled by technical support staff. The TSO can therefore optimize maintenance by contributing to its improvement in a number of ways:

— Optimization of the maintenance programme (assessing the results of the maintenance efficiency monitoring programme, applying predictive, risk based, condition based, on-line maintenance possibilities):
  • Deciding which equipment should be the subject of condition based maintenance and which parameters should be monitored;
  • Supporting the establishment of an equipment database and providing the necessary technical information;
  • Deciding on the frequency and extent of preventive maintenance;
  • Specification of testing and acceptance criteria following maintenance;
  • Promotion of integrated maintenance planning techniques.
— Continuous improvement of maintenance procedures (for example by introducing integrated maintenance planning).
— Implementing effective work control methods to reduce ‘wrench time’ (mobile workflow).

The TSO has to have continuous contact with maintenance department for:

— Analysis of unexpected and repeated failures;
— Equipment layout and specialized tooling;
— Accessibility;
— Control of material.

Unexpected and repeated failures represent a shortcoming of maintenance and ought to be analysed to determine the root cause. This analysis is best performed by the TSO staff with the necessary expertise, detailed knowledge of the system and equipment and access to supporting services (laboratories) and experts outside the plant.

Being aware of difficulties and conditions of the work, the TSO can optimize working conditions and improve the quality of the work, through:

— Improving layout of equipment;
— Improving access to equipment; providing lifting facilities; easing removal, calibration and adjustment of equipment;
— Providing specialized tooling and testing equipment;
— Providing permanent or temporary radiation or thermal shielding.

TSO input also plays a major role in the control of spare parts and especially of material substitutions, including:

- Identification of parts that have to meet requirements of traceability and certification as nuclear parts;
- Specification or confirmation of storage conditions for parts (in many cases, parts, such as elastomers, have to be stored under specified conditions in order to maintain their shelf life);
- Evaluation and approval of the substitution of parts.

6.3.1.3. Equipment qualification

The objective of the equipment qualification programme is to provide assurance that the equipment will perform intended functions when demanded or required. It ensures that the equipment is always capable of executing its functions during its lifetime and under the conditions in which it is anticipated to operate. This assurance is particularly important and required for safety related equipment [51], and it is achieved through assessing, monitoring and maintaining the required capabilities of all safety related equipment over the operational life of the plant.

In achieving these objectives, there are two concerns which an equipment qualification programme is typically intended to address:

- The principal concern of equipment qualification is with ageing effects that occur during the equipment's long term exposure, since the capability of equipment to perform as designed under design basis assumptions becomes gradually impaired over time.
- A secondary concern of equipment qualification is the reduction of the capability of equipment to operate, sometimes for a long time, in a hostile environment.

The TSO is responsible for continued implementation of the equipment qualification programme, through the following activities:

- Identifying and defining normal, abnormal and accident condition requirements for qualification;
- Maintaining and updating the list of equipment and required qualification;
- Drawing up the plans for equipment qualification and oversight of its implementation at the plant, including requirements for:
  - Special documentation;
  - Maintenance, calibration and replacement of some qualified equipment or parts;
  - A 'condition surveillance programme', by which the condition of qualified equipment can be assessed;
  - Evaluation of equipment following failures, which considers the effect of failure on maintenance of the qualification of the equipment in question and similar equipment.

Oversight, evaluation and assessment of the results of these activities and specification of appropriate corrective measures also require technical support.

6.3.1.4. Fuel handling and spent fuel management

The TSO participates in establishment of the fuel handling and irradiated (spent) fuel management activities by providing technical and scientific information and perspective with consideration of applicable design and licensing requirements, including the applicable regulations, codes and standards [52–54]. Such technical support would include:

- Development of standards and procedures for transportation, receipt and storage of fresh fuel;
- Development of analyses, standards and procedures for handling and storage (wet and dry) of irradiated fuel;
- Development or review of design, operating and maintenance documentation regarding fuel handling equipment, spent fuel storage facilities and fuel reconstitution apparatus;

— Review and assessment of proposed modifications to fuel handling and storage programmes, procedures, equipment and facilities;
— Assistance for security and safeguard activities.

6.3.1.5. Radiation protection

Radiation protection deals with minimizing exposure to ionizing radiation in safe operation of the nuclear power plant.

The TSO has the primary responsibility for assuring effectiveness of radiation protection by identifying and assessing radiological requirements, conditions, monitoring methods, hazards, risks and consequences. It provides advice and recommendations for engineered and administrative measures and controls within and around the plant for dose reduction methods and improvement of shielding, equipment qualification and radiation monitoring.

The TSO also ensures that the plant configuration concerning the radiation protection features, such as shielding and equipment qualification under radiological conditions, including the applicable regulations, codes and standards [48], is preserved, while any changes for improvement are assessed and concurred. It also ensures that the radiation protection practices, relevant programmes and procedures are improved in accordance with the pertinent design and licensing basis by routinely evaluating radiation protection practices at the nuclear power plant for effectiveness of radiological protection.

6.3.1.6. Radioactive waste management

It is desirable to minimize the amount of radioactive waste generated in the power plant because radioactive waste represents a potential hazard to workers and ultimately to the public, and because handling and disposal of radioactive waste is costly. The TSO supports the decisions on generation, storage and disposal of radioactive waste, including interim and long term storage, providing assistance for proper conduct of activities based on technical and scientific information and the radioactive waste management objectives [19], for example, by ensuring that:

— Procedures are prepared detailing the activities necessary to implement waste management programme;
— Limits are set for radioactive waste, based on IAEA safety standards [48] and national guidelines;
— Challenging but achievable targets are set for the waste management programme, and progress with respect to these targets is tracked;
— Appropriate training materials are available and training is conducted;
— Improvements complying with industry practices, or by new technical developments, are assessed and incorporated as appropriate.

Technical support is needed for safe and effective radioactive waste management activities, which include, for example, choosing radioactive waste storage and processing methods, setting packaging standards, minimization of radioactive waste, storage provisions and monitoring compliance with the operating licence conditions. Members of TSO staff actively explore new technologies and application of good practices at their nuclear power plant [55, 56].

Members of the technical staff also provide expert perspective in the subject matter in liaison with the national radiological waste management authorities, as well as assuming responsibilities for record keeping, knowledge management and integration with the overall management system.

6.3.1.7. Chemistry control

Chemical impurities (e.g. aluminium, calcium, magnesium, silica) and corrosion products have an impact on components. These form corrosive environments, which accelerate typical degradation processes on the materials. Furthermore, corrosion particles may be activated in the reactor core and then transported into other parts of the plant, where they may increase the personal dose rate.

The TSO supports addressing and improving the water chemistry by, for example:

— Improving the water chemistry procedures or guidelines for stricter monitoring and control of impurities and erosion corrosion products;

— Advising on targeted continuous monitoring of the RCS and the steam power conversion side (conventional island) water chemistry and improved maintenance, for example on condensate polishing systems and resin replacements;
— Recommending improvement to the plant's chemistry programme for monitoring and control of water chemistry based on technical and scientific knowledge and information, for example, monitoring and the control band for lithium and pH levels (applicable to the primary side of pressurized water reactor plants), recommending changes in lithium levels as required in plant's fuel reliability procedures or guidelines based on input from the fuel vendor for protection of the fuel.

6.3.1.8. Emergency plan

During operations (non-emergency situations), technical support is provided by the TSO for improvement of execution during emergencies and accidents. This improvement support includes:

— Determining and planning courses of action in carrying out prevention and mitigation measures;
— Predicting emergency situations and making recommendations on how to prevent and mitigate accidents using technical fundamentals and plant design and configuration;
— Preparing and implementing emergency response operations;
— Emergency planning;
— Developing and improving methodologies for accident prevention, mitigation and management based on technical and scientific information and knowledge and the nuclear power plant's design and physical configuration;
— Developing tools, methods and procedure for organizing and conducting emergency exercises.

Technical support is provided in the review and establishment of emergency operating procedures and severe accident management instructions and their basis (preparing functional basis, severe accident management guidelines), as well as in their periodic updates, as changes are made to the facility and emergency/accident management strategies. The TSO could provide technical input to drafting regional and national emergency response programmes and procedures, if requested.

6.3.1.9. Procurement, storage and use of material

Procurement starts with the establishment of the need for equipment/service as dictated by the project schedule and the existence of equipment designs and specifications. It ends with the verification of the fulfilment of the supply contracts, which can last through the decommissioning stage of the plant.

In the front end of procurement, the technical support is needed for:

— Procurement planning;
— Procurement documents;
— Supplier qualification and selection;
— Bidding and bid evaluation;
— Contracting;
— Contract monitoring and enforcement;
— Expediting (i.e. securing the quality and timely delivery of materials, equipment and components);
— Handling of warranty claims.

The TSO activities associated with procurement include:

— Developing and/or reviewing the project procurement plan in view of technical and commercial concerns. The procurement planning results in the documented identification of procurement methods and organizational responsibilities.
— Developing the management system specification with a grading approach based on the characteristics of procured items and services as defined in Ref. [57].

- — Reviewing project procurement documents to verify adequate description of applicable design bases and other requirements necessary to ensure adequate quality as required.
- — Providing supplier evaluation and selection criteria to determine its capability to provide the items and services in accordance with procurement document.
- — Reviewing the bid invitation and bid evaluation process to verify that the process is adequate to determine the supplier's conformity with the technical and quality requirements.
- — Reviewing the plan of offering items and services for its acceptability, including the adequacy of measures for validation, such as a supplier certificate of conformance; source verification; or receipt and post-installation inspection.
- — Monitoring and auditing progress in design, manufacturing and shipping to ensure that the plant configuration is not impacted.

It is also important for the technical support to continuously monitor the appropriateness of storage conditions and their effects on the stored components. Adequately defined safety reserves need to be established in the warehouse, and timely procurement has to be initiated if the level drops.

6.3.2. Operating cycle management

The fuel and core engineers can support optimization of the thermal energy generated by the nuclear fuel and the core in order to optimize the use of fuel and the operating cycle for efficient performance while not compromising safety. These activities require understanding of burnup and associated fuel properties (e.g. enrichment, composition and material of cladding). They also require understanding of core behaviour, characteristics and parameters (e.g. critical boron concentration and rod position, reactor kinetics, reactivity coefficients, control rod and bank worth, power distribution) and reactor operation schemes. There are several ways that the operation and performance of the reactor could be optimized, which include:

- — Exploring and evaluating various fuel designs;
- — Investigating and assessing possible core loading configurations;
- — Utilizing available energy left in the used fuel inventory;
- — Determining optimum fuel cycle lengths and load following patterns;
- — Improving prediction methods for core physics parameters, reducing analytical uncertainties;
- — Improving the simulation of core depletion and better determining in-core fuel conditions.

Core reload depletions and core physics calculations provide input to downstream safety analysis, plant monitoring and protection systems and operator guidance. Therefore, optimization can contribute to:

- — Fine tuning instrumentation and protection and control system settings and operational margins without compromising safety limits and margins;
- — Improving the setting quality and calibration of instrumentation;
- — Optimizing the normal operating procedures to provide better usage of fuel.

6.3.3. Outage management

Detailed work plans need to be available for major outage tasks well in advance of their execution, and be updated during the outage as necessitated by field changes and conditions. Technical support can make a very significant contribution to optimization of refuelling and/or maintenance outages (i.e. for orderly, timely and effective execution of outages), by contributing to outage preparation and planning [58] in the following areas:

- — Reactor safety considerations, such as reactivity control and provision of heat sinks. These considerations include:
  - Activities to enhance and continually monitor safety margins;
  - Verification of status of safety systems and operating plans prior to return to power.

- Industrial safety as impacted by hazards which might arise from unusual configurations or operations. Both conventional and radiation hazards are to be dealt with.
- Unexpected work identified during an outage as a result of inspections or maintenance of equipment. This is evaluated through careful assessment of surveillance results and operational records of equipment to determine appropriate corrective actions and to minimize recurrence.
- Modifications to be installed during an outage, which ought to be ready to go well in advance, with design documentation, approvals, materials and installation plans all available.
- Any special and non-routine inspections, which have to be carefully planned and prepared, with their consequences reviewed with special emphasis on plant safety, personnel safety and licensing requirements.
- Review of the preventive maintenance programme to minimize shutdown work by:
  - Modifying work procedures and tooling;
  - Assessing equipment condition and deciding to defer the work.
- Planning and spacing of in-service inspections among several outages, so as to minimize the overall outage time.

6.3.4. Plant simulator

Plant simulators are a very important tool in nuclear power plant operation for visualizing, understanding or contemplating plant response to anticipated events and evolutions. They are also a powerful instrument used for training the control room staff and evaluating their capabilities, competencies and reactions when faced with anticipated or unexpected plant conditions and events. Any modifications or changes made to the plant and operating procedures need to be added, modelled and validated on the plant simulator. The TSO may also use plant simulator as a 'test facility' for predicting and understanding the SSCs' responses, identifying potential improvements and predicting the effects of plant changes.

Therefore, the TSO ensures that the plant simulator uses the up to date design and configuration of the nuclear power plant, and the plant SSCs are correctly modelled, with technical and scientific methods correctly and rigorously applied, including the controls for nuclear and conventional island components and consideration of the dynamic response of the components.

Additionally, the TSO may develop accident and severe accident scenarios as well as tools (incorporated into the plant simulator or desktop simulators) used for training operators in off-normal operational recovery and severe accident management [59].

6.3.5. Operating experience assessment and feedback

The TSO develops a structured and consistent approach to review and analysis of adverse events and trends within its nuclear power plant and those experienced in other nuclear power plants, or even in other industries utilizing the same or similar equipment, systems, programmes or processes. Such analyses contribute significantly to achieving improved plant and human performance through identification and understanding of past and present problems and correction or prevention of conditions which led to them.

The internal TSO has roles and responsibilities that include closely following all adverse events, including near miss events, at its nuclear power plant and other nuclear power plants for their impact (or potential impact) on safety and reliability, as well as efficiency and plant performance. It screens the events for relevance and applicability to its facility design and configuration from the technical perspective and based on technical and scientific information, as well as their transferability to the plant's programmatic elements relevant to technical areas and activities. Relevant and applicable events are examined and evaluated by the technical staff for causes, consequences (or potential consequences) and lessons to be learned that can be reflected in corrective and preventive actions.

Typically, the TSO administers (or interfaces closely with the organizational owners and coordinator(s) who administer) a structured operating experience programme at the nuclear power plant with the support of other organizations, and members of technical staff participate in event evaluations of other organizations, as applicable. In particularly, it may initiate and consistently participate in teams and committees investigating special or high level events (e.g. events with significant consequences), to provide and present technical aspects and the views of technical experts to determine the causes and corrective actions. As the technical conscience of the plant, it leads identification actions and correct, timely and effective implementation of corrective actions and preventive measure involving the design and configuration of the plant. It also supports dissemination of information on operating experience to organizations within the plant and other nuclear power plants, industry organizations and interested and relevant parties outside the plant.

Various international and interregional nuclear organizations and associations (IAEA, Nuclear Energy Agency of the Organisation for Economic Co-operation and Development, World Association of Nuclear Operators, Institute of Nuclear Power Operations, technology owner's groups, responsible designers) operate several databases to record and disseminate operating experience. Most of these organizations record and disseminate not only the adverse events but also the proven practices, knowledge and standards for good plant and human performance. Members of the technical staff are expected to closely follow such reports to assess and provide advice for technical issues or advances for improved programmes and processes towards optimization of plant operation and performance.

6.3.6. Awareness and transfer of newly available and applicable technical knowledge

Members of the technical support staff continuously follow information that is available throughout the nuclear industry and other industries and stay aware of the advancement of the state of the art through, for example, participation in conferences, seminars and publications in peer reviewed scientific journals. The TSO personnel investigate and evaluate such information and knowledge for suitability and applicability to their own nuclear power plant for improved plant performance and advise the decision makers on the value/impact of such improvements from the technical perspective.

Therefore, it is a good practice to align with international and interregional nuclear organizations and associations (e.g. IAEA, Institute of Nuclear Power Operations, Nuclear Energy Agency of the Organisation for Economic Co-operation and Development, World Association of Nuclear Operators, technology owner's groups or responsible designers), academia or other industries applying or exploring the same or similar facilities, programmes or processes.

This is accomplished by raising interest and encouraging technical staff to participate in nuclear industry activities, such as:

- Industrial and organizational standard and guidance development and application, for example, standard development committees;
- Topical and relevant general industry working conferences, seminars and workshops;
- Technical and scientific visits, peer review exchanges, benchmark missions;
- Technical paper and document publications and presentations.

Active involvement of technical staff in these activities provides the nuclear power plant with knowledge and awareness of technical and scientific developments, challenges and success strategies in the industry. This, in turn, serves the owner/operating organization through excellence in the advisory, anticipatory, exploratory and innovatory technical support activities (see Section 2.4 for definition of these technical support activity types).

6.4. TECHNICAL SUPPORT FOR DECISIONS ON PLANT ASSET MANAGEMENT

6.4.1. Management of systems, structures and components

6.4.1.1. Permanent modifications (change control)

Plant modifications can be initiated by operations or design organizations and will frequently be desirable in order to:

- Further improve the safety features of the plant;
- Satisfy new regulatory requirements;
- Take advantage of operating experience;

— Benefit from new technological developments;
— Manage obsolescence of components or parts.

Based on the requirements and guides, the owner/operating organization needs to establish the design change management system to provide confidence in the technical adequacy of the design changes and to ensure the effective resolution of identified problems and enhancement of plant safety and reliability.

The TSO, as the owner of the design and configuration, controls and approves all permanent modifications. It may also assume the role and responsibility of project manager on behalf of the plant and confirm, through periodical progress reviews, appropriate coordination and timely progress of work. Since many groups are involved in the modification process, it is necessary to clearly identify respective interfaces and responsibilities. As such, the TSO ensures that a coherent and rational modification policy and process is in effect and assists with the decisions on the prioritization of plant modifications by providing requirements and criteria which reflect the plant's safety and performance objectives. In accomplishing this, the TSO establishes and implements a management system to ensure that all safety requirements established for the design of the plant are considered and implemented in all phases of the design process and that they are met in the final design. The management system includes provisions for ensuring the safety, reliability and quality of the design of the nuclear power plant at all times. This includes the means for identifying and correcting design deficiencies, for checking the adequacy of the design and for controlling the design and configuration.

The modification process includes the following elements:

— Encouragement of ideas for improvements in plant design;
— Careful review, approval and establishment of priorities for modifications to ensure the best use of limited resources;
— Tracking and timely feedback on the status of modifications;
— Thorough and documented technical reviews, with participation from plant technical support, including review with respect to effects on safety design assumptions;
— Commissioning and testing to ensure design conformance and system compatibility;
— Updating of documents used in plant operations prior to returning affected systems to service (configuration control);
— Training of personnel to ensure their understanding of the modification.

Also, design changes have to be justified and be subject to design control measures commensurate with the original design. Design changes include field changes, modifications and non-conforming items designated for use 'as is' or for repair. Changes are subject to configuration control and design control measures and subject to approval by the original design organization or by an alternative, technically qualified body as stated in Ref. [60].

6.4.1.2. Major equipment replacements and design modifications

The TSO takes steps to ensure compatibility, consistency, verification and prompt updating when changes and modifications of plant technical and operational documentation are required owing to changes such as:

— Refurbishments;
— Extensive modification for longer term operation or power uprates;
— Replacement of a major component, such as a steam generator, turbine or reactor vessel head.

Tasks associated with these projects involve a wide range of technical support, including:

— Preparation of feasibility studies, analysis and review;
— Preparation of specifications, requirements, expectations and technical manuals;
— Control of original design documentation and documentation of subsequent modifications, in accordance with configuration control requirements.

6.4.2. Procurement, warehousing and supply chain

The overall objective of supply management is to ensure that correct components are consistently obtained and used throughout the plant life [43]. The TSO is responsible for the provision of technical advice in matters of:

- Availability of spare parts over the plant's life (consideration of the spare parts policy at the plant — the responsibility for procurement — includes a very significant technical support input);
- Evaluation and approval of new parts and substitutions;
- Storage requirements in cases where parts/materials need a special, controlled environment to meet their 'shelf life';
- Ensuring that correct materials are installed through provision of appropriate information and controls on issue of materials;
- Defining traceability requirements for nuclear class materials;
- Extent of inspection of components on receipt at the plant.

The technical issues that would involve technical support are:

- Identifying the technical inputs necessary to develop alternative suppliers;
- Addressing problems of rapid obsolescence of some specialized equipment (e.g. plant computers, instrumentation, electronic parts, radiation monitoring equipment) and associated dwindling or non-availability of replacement or spare parts;
- Identifying and dealing with anticipated upgrading of regulatory requirements for replacement of parts, particularly obsolescent items;
- Exploring possibilities, permissions and techniques for in-house manufacturing in accordance with the corporate policy.

6.4.3. Management of long term assets or non-routine activities

Successful long term asset management requires that long term focus and planning be maintained with dedicated, adequate and skilled resources. Considerable benefits can be gained by the plant when these programmes are successfully executed. Conversely, the consequences of poor execution can be severe, as the benefits that arise from improvements in, and assurance of, satisfactory plant condition and extended operational life are lost.

All long term technical programmes use the same basic, generic management techniques. These programmes, which aim at establishing the condition of plant components and extending their life, are discussed with emphasis on technical support activities and involvement.

The long term management of assets involves all types of technical support activities, from preparatory to exploratory, but mainly relies on advisory, anticipatory and exploratory activities. In particular, the TSO anticipates potential technical and scientific issues and needs (as the plant ages) and explores and provides advice. It proposes administrative and engineered controls and provides advice (including on courses of action, planning, costs or resources.) regarding technically viable options for maintaining long term assets based on technical and scientific information, knowledge, experience, expertise and exploration. Typically, as the performer and the designated follower of observations, current and past trends, evaluations and derivations from the operating experience and incidents in the nuclear industry and other industries, the TSO investigates and provides previsions and reflections based on the technical analyses, assessments and judgements.

6.4.3.1. Ageing management

An ageing management programme is typically executed by the internal TSO of the owner/operation organization on the basis of the assessment of nuclear power plant operation and plant data [61] against the design basis, requirements and specifications. The basic functions of technical support are the following:

- Assessment of the operating conditions of equipment and systems;
- Assembly and processing of statistical information about the failures of elements;

- Assessment of the existing time limited ageing analyses, identifying degradation mechanisms of the SSCs;
- Evaluation of the residual service life of equipment and the prognosis regarding the need for replacing the parts and materials;
- Development of operational and design policies and programmes to optimize SSC life.

6.4.3.2. Plant life management

The objective of a plant life management programme is to set in place mechanisms and controls which enable the management to:

- Assess the condition of the plant's components (age based degradation);
- Identify operational strategies to minimize deterioration so that extension of the originally licensed nuclear power plant life can be technically justified;
- Identify any design and performance strategies (or their optimization) to maintain or improve plant SSCs to accommodate longer operating licence periods.

The TSO is responsible for continued implementation of the ageing and plant life management programmes, through the definition of an action plan to preserve the option (i.e. by enabling the plant life management programme to be implemented) to extend the life of critical components. This includes:

- Establishing an appropriate database, listing details of critical components;
- Undertaking initial inspections, preferably at the time of construction, to establish 'baseline' conditions (see Section 5.1);
- Establishing a long term inspection plan;
- Developing continuous monitoring and engineering programmes for anticipated and known technical SSC issues from the operating experience, such as erosion/corrosion, fatigue, chemistry and foreign material.

6.4.4. Periodic safety reviews

As a rule, the activities for periodic safety reviews are executed by the internal TSO. External TSOs (scientific institutes, designers, engineering offices) are also used. As a result of the periodic safety review, a corrective action plan is developed, primarily by the internal TSO. Further details about the periodic safety review are provided in Ref. [62].

6.4.5. Information technology

Effective management of nuclear power plant hardware and software is of the utmost importance for safe and reliable operation with quality, as discussed in Section 6.2.9 with respect to protection, monitoring and analysis functions. The TSO ensures that computer software continues to meet technical, security, quality and regulatory requirements with respect to function, use and control of software and documentation. In doing so, it assesses, anticipates and explores advances as digital solutions are increasingly adopted in nuclear technology, including for hardware and software and their qualification and use in protection, control and monitoring of nuclear power plant operations.

Furthermore, in the information technology area, availability of design, operation, procurement and maintenance information, including the technical and licensing specifications and requirements, is an essential component of safe, reliable and efficient nuclear power plant operation and is typically controlled by technical staff. Therefore, the TSO has a key role in supporting the development and control of complete, comprehensive and up to date information, such as databases and shared platforms and tools. These include the selection and collection of data to be included in the database, particularly for purpose of predicting trends in SSC conditions, characteristics and health in order to provide timely advice to the decision makers.

The use of specialized information technology solutions can contribute to dramatic improvement in efficiency of work and reduction of errors. Technical support promotes the use of these information technology solutions throughout the plant as follows:

- Determination and implementation of appropriate quality assurance measures for software;
- Identification and prevention of potential cyber security issues;
- Installation of improved and integrated information technology systems, hardware and software to support core business processes for operation, maintenance and technical support for safety and performance of the nuclear power plant;
- Exploration of improvements to maintain the integrity of the software of the plant;
- Assessment of advances as digital solutions are increasingly adopted in nuclear technology, including for hardware and software.

Therefore, the TSO explores the use of specialized information technology solutions in hardware, software and database aspects that can contribute to improvement of efficiency in the conduct of tasks and coordination of activities in order to reduce potential for errors and deficiencies. The TSO promotes the use of these information technology solutions in plant improvements in the following ways:

- Installation of improved and integrated information technology systems to support core business processes for operation, maintenance and technical support activities;
- Assessment of advances as digital solutions are increasingly adopted in nuclear technology, including in hardware and software and their qualification;
- Exploring improvements to maintain the integrity and usability of all master databases of the nuclear power plant;
- Identification of the interfaces between computer security and operational safety, reliability and performance;
- Determination and implementation of appropriate measures for potential cybersecurity issues, state of the art and appropriate cybersecurity measures and advances within the wider computer security community;
- Identification and prevention of potential cyber security and information technology reliability issues;
- Risk assessment in addressing information technology vulnerabilities and their potential exploitation.

6.5. ORGANIZATION AND STAFFING OF TSO DURING OPERATION PHASE

There is no ‘one size fits all’ organizational structure for organizations that provide technical support to nuclear power plants for decision making on operations and asset management. The nuclear power plant decision authority in need of technical support for decision making (e.g. the highest level of the licensee organization or the main control room manager) has the prerogative to define the source of its technical support (i.e. the TSO), based on the technical tasks needed for a particular decision or situation and in accordance with company policy.

As mentioned in Section 2.5, there may be many factors affecting the way the nuclear power plant decision maker organizes and staffs the TSO, depending on the decision making needs. For an owner/operating organization (utility), the structure and staffing of the TSO are particularly driven by the corporate policy, strategy, goals, finances and character of the utility.

Regardless of these factors, the owner/operating organization needs to maintain a dedicated technical capability and competency, as a minimum: (1) to recognize and express the need and scope for technical support for an informed decision; (2) to identify the competencies and qualifications needed for technical support; (3) to identify potential sources for technical support; and (4) when the support is provided, to understand the relevant and accurate input to the decision [2, 63].

The maximum size and staffing is, of course, associated with the ‘one house approach’ (i.e. establishing and maintaining a fully capable and competent internal TSO). Even with this approach, it is highly likely that there will be complex or special issues or unique and urgent decisions which exceed the capabilities and capacities of the internal TSO and for which an external (or outsourced) TSO will be necessary. These may include, for example, major modifications such as heavy equipment replacement, plant refurbishment or extensive backfits.

The optimum size and staffing of the internal TSO — in organizing for gathering the most effective and efficient technical support for the nuclear power plant decision making — will be driven by three main considerations, which can be observed from the existing requirements and practices, as well as operating experience:

(1) The regulations for the operating organization (i.e. operating licence holder) for maintaining adequate and appropriate capability, qualification, competency and capacity (which could include those of a TSO), as well as a management system (which would include obtaining and using technical support);
(2) The frequency, periodicity, significance, urgency or uniqueness of the decision and of the technical support needed;
(3) Balance of financial costs associated with purchasing technical support from the external TSO(s) and maintaining in-house staff and competencies, including the value/impact of owning technical knowledge, such as knowing the design and licensing basis better than any external TSO[20].

Furthermore, the owner/operating organization needs to be aware that it is responsible for supervising the activities of all external (on-site or off-site) organizations, such as suppliers, manufacturers and constructors, employers and contractors, including those activities and services provided by the external TSOs.

Therefore, a comprehensive and common policy for effectively and efficiently requesting, providing, acquiring, understanding and using technical support needs to be established to determine the optimum size and staffing of the internal TSO. Additionally, the corporate commitment and strategy need to ensure that the level of collective technical competency, knowledge, experience and expertise at the plant do not decline below optimum level. This also includes the control and management of technical information exchange and deliverables within and outside the nuclear power plant organizations, from both the receiver (utility decision authority) and provider (TSO). This is accomplished by implementing an internal TSO under the owner/operating organization's policy, programmes and procedures and by additionally establishing a well designed and controlled management system for procurement of technical support from the external TSO(s).

6.5.1. Internal technical support

For an owner/operating organization, maintaining the expected safe and efficient operation of a plant requires that the design, configuration and operation activities be prepared, verified and validated, implemented and controlled via a structured process. Additionally, daily oversight of operations, including operational and facility documentation and recommendations, requires technical support that is, in some cases, readily available.

6.5.1.1. Reasons for internal technical support

As the bearer of full responsibility for safe design, construction, maintenance and operation and the upholder of reliable and efficient performance of the plant, the owner/operating organization has a need to establish, maintain, and improve technical knowledge of the plant by a dedicated group of competent staff (as a technical conscience and authority). Regulations typically require a competent and knowledgeable technical support staff (and in some cases this is a condition of the operating licence), which is one of the principal reasons to have an internal TSO [1, 2]. This ensure that the necessary engineering expertise and scientific and technical knowledge are maintained within the operating organization; furthermore, the formal system for ensuring the continuing safety of the plant design includes a formally designated entity responsible for the safety of the plant design within the operating organization's management system. The formally designated entity ensures that the plant design meets the acceptance criteria for safety, reliability and quality in accordance with relevant codes and standards, laws and regulations. Design integrity, which includes maintaining a formally designated entity that has overall responsibility for the continuing integrity of the plant design throughout its lifetime, and managing the interfaces and lines of communication with the responsible designers and equipment suppliers, contributes to this continuing integrity.

[20] Operating experience shows that exchanging such information with an external TSO could increase the likelihood of omissions or misunderstanding of information, particularly when the technical support requires a large volume of information or a non-standard form and format of information.

In addition to requirements, other benefits to maintaining an internal TSO relate to effective service, financial feasibility and ownership in accordance with the company strategy, culture and traditions. Examples of those benefits may include:

— The TSO being the technical authority and the owner of the design and configuration control, and therefore, all aspects of design and configuration control and maintenance being addressed comprehensively and efficiently;
— The staff being familiar with systems, components or functions, having extensive historical knowledge of all of their aspects and being dedicated to the nuclear power plant's technical issues and better aware of the challenges and resources;
— Alignment of staff with corporate and organizational goals, strategies and behaviours;
— More control over staff decisions, schedules and priorities;
— Technical support costing less if work is long term, owing to avoiding overheads and administrative costs of managing a contract with an external service provider;
— Dedication to developing staff competencies and expertise;
— Reduced risk of, and protection against, the external TSO deciding to leave or not do business;
— Technical staff being closer to each other and familiar with area responsibilities and personal capabilities and competencies;
— A consistent standard being applied to all staff, with a corresponding consistent set of instructions, procedures, expectations and training for task performance;
— In-house knowledge ensuring that the organization is an 'informed customer'[21] (also known as 'intelligent customer', 'knowledgeable customer' or 'smart buyer') when technical support is requested and obtained from external providers.

6.5.1.2. Structure and location of internal technical support

The size and shape of this internal TSO, made up of the owner/operating organization's own technical staff, will vary depending on the need and the utilization. Also, the structure and location of the TSO will match the expectations of the organization relating to ownership and timeliness. Based on the survey of operating nuclear power plants, three basic organizational patterns have been generally practiced [3]: *centralized*, *permeated* and *matrixed*.

In a centralized pattern, the technical support is centralized in a single division, commonly referred as the 'engineering organization', with departments and sections designated to specific technical areas (e.g. mechanical, electrical, civil), systems (e.g. NSSS, BOP), components (e.g. turbine, valves) or functions (e.g. in-service inspection, fuel management). This pattern is 'provider based' and intends to provide long term services to the various areas ('customers') of the plant (i.e. chemistry control, mechanical maintenance, reactor safety) through a single organization providing engineering support and technical conscience. The head of the engineering organization is the 'technical authority' and has the responsibility for decisions on the execution and accomplishment of objectives for maintaining, requesting, acquiring and recording needed technical information, as well as for expressing and reporting to the decision making authority the relevant technical input and perspective (Fig. 11).

Advantages of a centralized technical support structure include the following:

— The TSO is the technical authority and the owner of the design and configuration control, and therefore, all aspects of design and configuration control and maintenance are addressed comprehensively and efficiently.
— The staff consists of experts in areas, systems, components or functions with extensive knowledge of all aspects of these.
— Members of the staff are focused on and dedicated to technical issues.
— Members of the technical staff are close to each other and familiar with area responsibilities and personal capabilities and competencies.

[21] Section 2.3 of Ref. [42] defines and describes the informed customer's roles and properties, in detail.

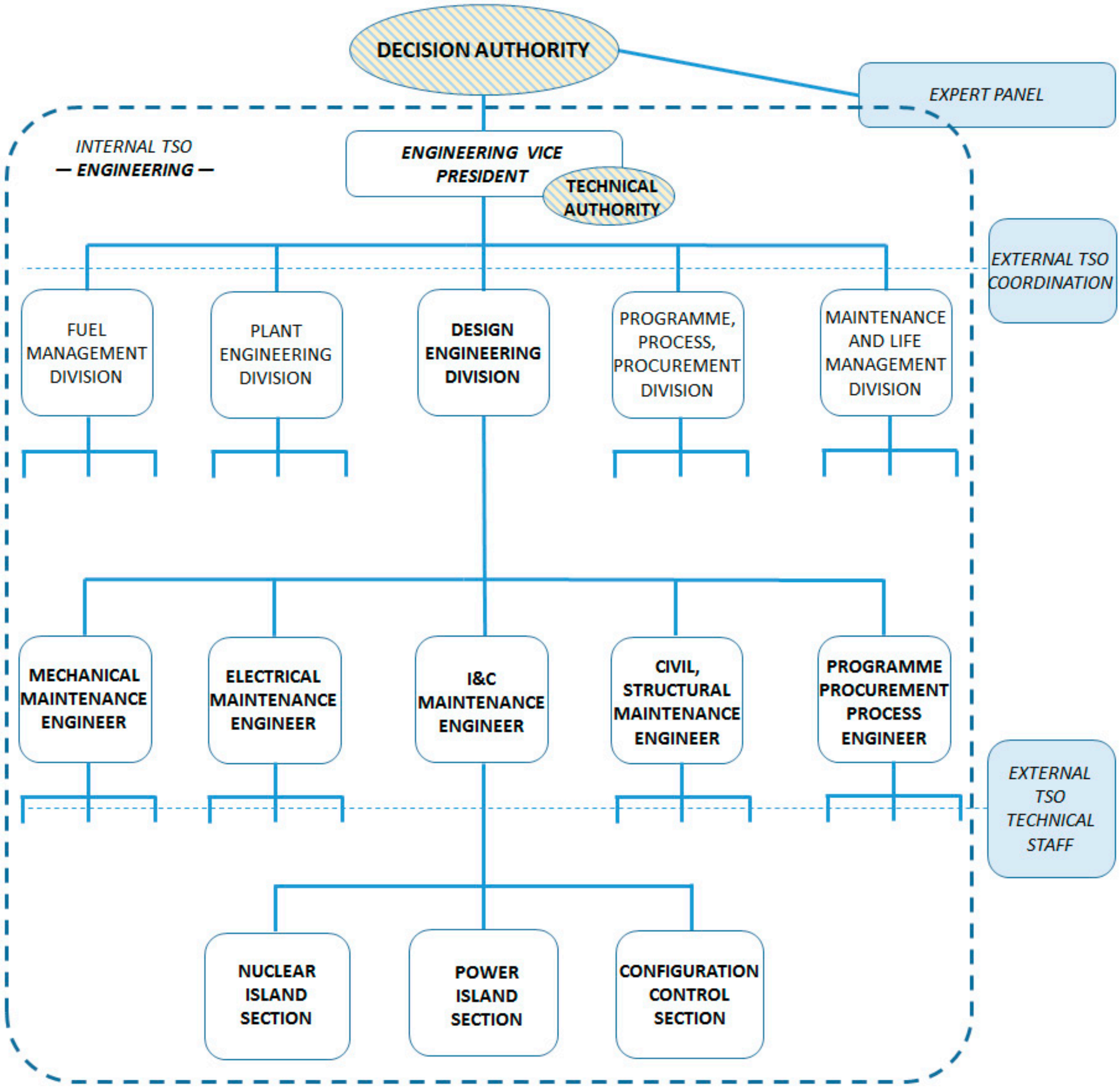

FIG. 11. An example of centralized technical support within an owner/operating organization. TSO — technical support organization.

— A consistent standard is applied to all staff, with a corresponding consistent set of instructions, procedures, expectations and training for the task performance.
— If needed, overall plant priorities can be addressed by concentrating personnel on the big problem(s) at hand.

Drawbacks of a centralized structure and potential actions to prevent or overcome them could include the following:

— Having one organization serving many customers can cause issues with prioritization of work. This requires the TSO, the customer and the decision making authority to reach an initial agreement on the priorities.
— The TSO is not close to the customer and therefore may not fully understand the customer's issue and environment and may not be able to determine the satisfactory solution or options for the customer. This can be prevented by keeping close contact with the customer as the scope is determined and the technical support work progresses (e.g. observing the issue by being present in the customer's environment, walk downs, interviews with members of staff who identified or described the issue).

— The staff may focus too much on their own and closely associated areas (or systems, components or functions), which may result in segregated views. This requires formal processes and procedures (e.g. impact review processes), controlled documents (e.g. system interface manuals and design interface documents) and training to ensure integrated plant system knowledge.
— The staff being in close proximity and familiar with area responsibilities and expectations may result in technical support activities being performed in silos. This can be prevented by joint activity review meetings and leader update meetings at the group, section and department level.

In a permeated structure, the technical staff (i.e. engineers) are assigned directly to the departments they are supporting, for example, maintenance, operations, procurement (Fig. 12). This pattern is 'customer based' and intends to include TSOs dedicated to their own areas as the technical conscience of the area activity. The head of each organization is responsible for the decisions on the execution and accomplishment of objectives of the tasks in their responsibility area, including conduct of associated technical support activities. Members of the technical staff are responsible for determining the need for technical information from other organizations and maintaining, requesting, acquiring and recording information received for comprehensive consideration of all aspects. The head of the organization has the responsibility for reporting all the relevant aspects, including the technical input and perspective, to the technical authority and the decision making authority.

Benefits of a permeated technical support structure include the following:

— Technical support staff are closer to the customer and the technical issues, therefore they can provide more focused execution and support for the task at hand.
— Unified ownership and commitment may provide stronger and faster resolution owing to internal prioritization and planning.

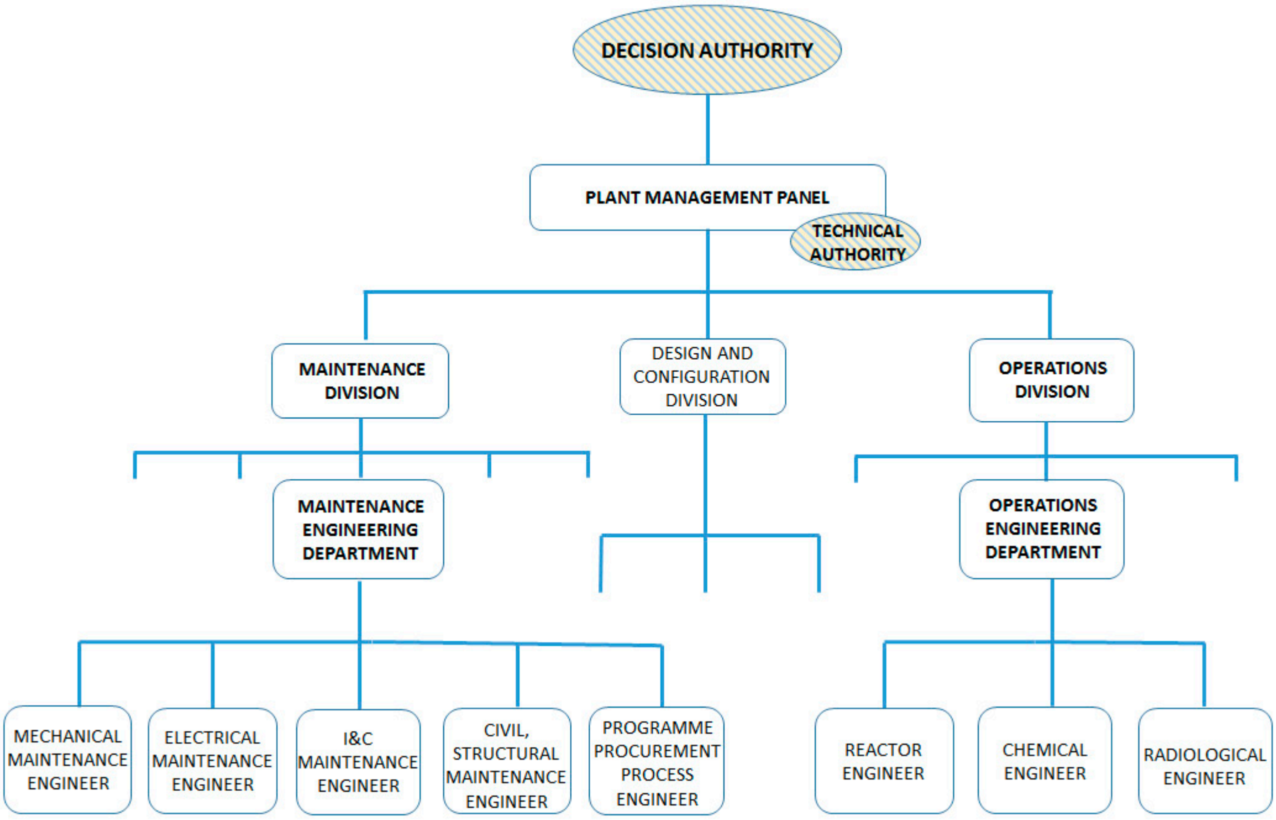

FIG. 12. Examples of permeated technical support in various functions of an operating organization. I&C — instrumentation and control.

— As the organization consists of all parties interested in the task, all aspects can be considered together with the technical aspect for an integrated resolution.
— Technical support is generally specific, and the TSO is likely to be familiar with the majority of the tasks owing to the routine, repetitive or similar nature of the tasks; therefore, the technical support may be more effective.

The disadvantages of a permeated structure arise from isolation from other departments and the technical authority and/or from overlapping responsibilities. These require preventive measures and administrative controls, with particular emphasis on adequacy and control of interfaces and communication, as well as on clear roles and responsibilities. Examples of these disadvantages and their remedies could include the following:

— The fact that none of the individual TSOs is the nuclear power plant's sole overall technical authority and none is the owner of the design and configuration control may result in aspects of design and configuration control and maintenance not being addressed comprehensively and efficiently. Combating this requires formal processes for notification and concurrence of the nuclear power plant's technical authority and exchange of information at the start and the end with adequate hold and check points during the work.
— The staff consists of 'subject matter experts' in the tasks relating to specific areas; however, they may not have thorough knowledge and expertise in all systems, components or functions involved, resulting in considerations being omitted or requirements or expectations not being met. This requires a strong training programme on the design and licensing basis of all plant SSCs to ensure TSOs have adequate and necessary knowledge of them. It also requires maintenance of comprehensive documentation describing the design basis, requirements, expectations and performance characteristics of all SSCs in detail and at a level that non-experts could understand and follow. Establishing a mature impact review process is also essential to prevent information from being omitted or misunderstood.
— There may be separate departmental standards and procedure applied to the departmental TSO staff, creating several sets of instructions, procedures, expectations and training for a similar technical support activity to maintain and keep consistent throughout the site. The remedy for such situations is to establish standard procedures and activity instructions that apply to all personnel performing technical support activities.
— There is more focus on departmental tasks, which requires strong interfaces and effective communication (both vertical and horizontal) processes and procedures for preventing defective implementation of technical recommendations.

The matrixed pattern is practiced owing to the uniqueness or timeliness of the technical support needs to support decision making on addressing a nuclear power plant's special projects or issues. This type of TSO is typically structured as a 'special project group' or a 'rapid response group', with the technical experts drawn from different vertically and horizontally oriented units according to the tasks involving a specific project or issue based on the areas, systems or functions involved (or to be involved), as illustrated in Fig. 13. Typically, the teams are dissolved once the project is completed (or the issue is solved[22]), or they are assigned to the next technical project or issue with some rotations of staff or addition or removal of positions in accordance with the aspects of the next project or issue.

Benefits of the matrixed structure include the following:

— Technical support staff are closer to the technical issues; therefore, they can provide more focused execution and support.
— There is a more concentrated group, typically together in a reserved facility, resulting in effective communication and therefore better implementation of technical recommendations.
— The technical support needs and scope are well defined and more specialized, and the decisions to be made are more specific; therefore, the technical support is more effective.

[22] Depending on the frequency and variety of plant issues that need to be promptly addressed, some owner/operating organizations may decide to have a permanent 'fix it now' department. The TSO within that department could have a structure similar to a 'centralized TSO' (though on much smaller and more focused scale). As part of the permanent response organization, a 'fix it now' TSO consists of technical experts to cover the areas, systems and functions with the competencies needed for providing technical input and perspective to resolve the nuclear power plant's issues.

On the other hand, in order to achieve goals in a timely manner, the matrix personnel and the plant management need to understand that their time is dedicated as a priority to the project or issue, and therefore they are isolated from their 'real jobs' (i.e. the activities of their home organizations).

6.5.2. External technical support

During the operation phase, there will be complex or special issues and projects, with unique or urgent decisions to be made, that need technical support which exceeds the capabilities and capacities of the internal TSO, and therefore, technical support from an external (or outsourced) TSO will be necessary. These issues or projects include, for example, major modifications, such as heavy equipment replacement, plant refurbishment or extensive backfits, or special issues that would require the use of special facilities or expertise or require specific certification or qualification.

Making the decision to procure external technical support and obtaining the support is no different than procuring services for other needs. References [40, 43] provide a structured procurement process, including the procurement of engineering, technical and consulting services, in a detailed manner and can be referred to for implementation of the discussions provided in the following sections.

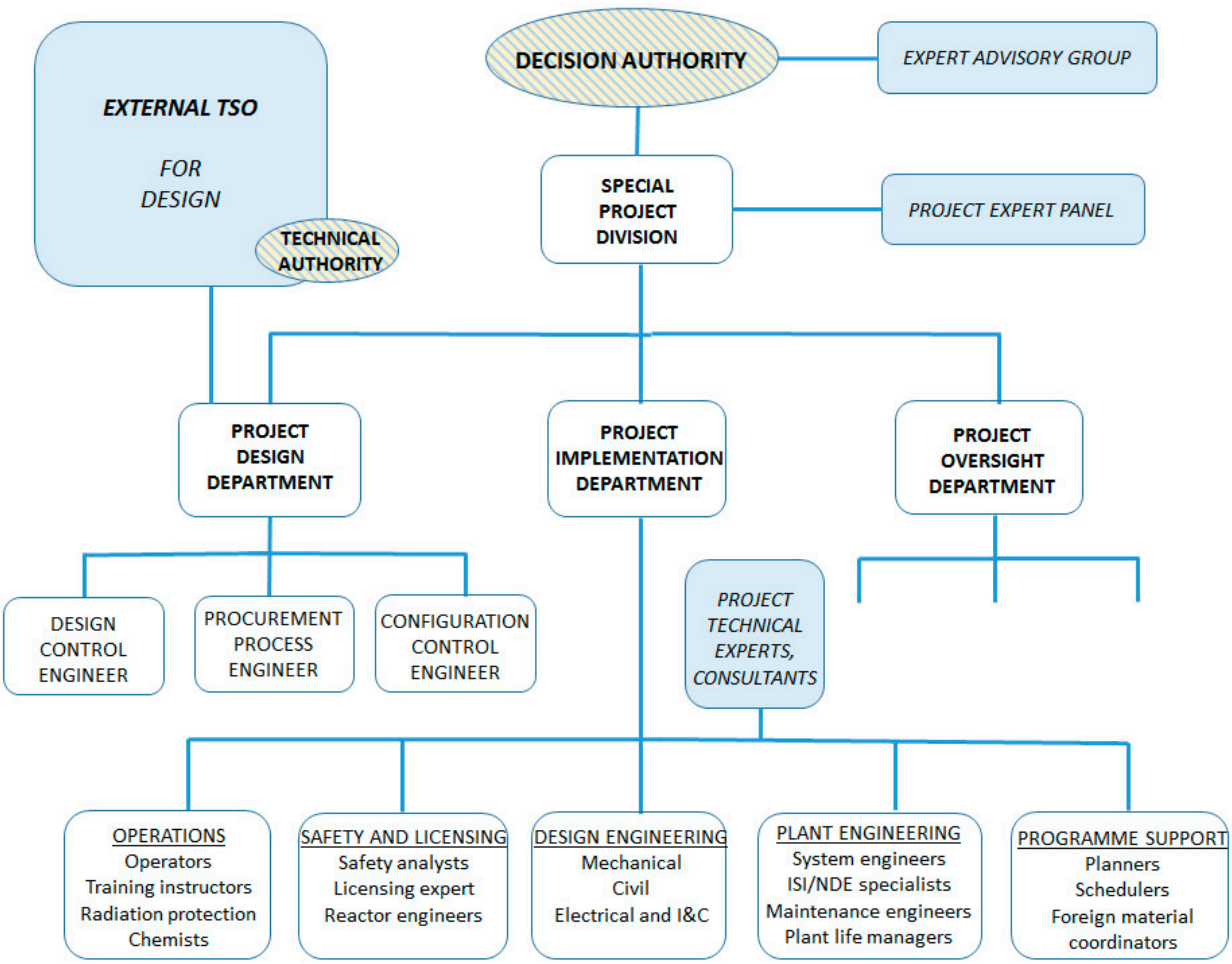

FIG. 13. An example of matrixed technical support for a specific project within an operating organization. ISI — in-service inspection, I&C — instrumentation and control, NDE — non-destructive examination, TSO — technical support organization.

6.5.2.1. *Reasons for external support*

Based on operating experience, there are several instances when utilization of external TSOs may be inevitable for the nuclear power plant, including the following:

- Expertise beyond the capability of internal TSOs;
- Core technology issues that may be best handled by the technology holder;
- Technology ownership, know-how, special skills, tools, methods;
- Research and development investment (e.g. financial, human, facility) needs that are not aligned with the corporate business strategy or for which the operating organization does not want to allocate money in the operation budget;
- Regulatory or legislative compliance;
- One-of-a-kind or first-of-a kind activity;
- Existing contractual obligations.

Even if outsourcing is not absolutely necessary, it may in some cases be preferable owing to one or more of the following benefits (in accordance with company strategy):

(1) Not reserving human resources for one time activities;
(2) Increased assurance for high risk, high consequences activities;
(3) Accessing or gaining expert and experienced knowledge;
(4) Accessing or acquiring valuable methods and techniques;
(5) Pursuing high quality products;
(6) A desire for cost effective and/or time efficient service;
(7) Establishing long term strategic partnerships either only for technical support or as part of a larger range of services and products.

Figure 14 illustrates two different approaches to technical support for a particular process: reactor refuelling design work for an owner/operating organization. In the first case (top part of Fig. 14), the owner/operating organization's corporate strategy is to establish a technology transfer and long term partnership contract for fuel design and delivery, but to conduct most of the technical activities internally. However, in the second case shown in the bottom part of Fig. 14, the owner/operating organization prefers to delegate technical support activities to the external TSO of the fuel and NSSS vendor, in accordance with the corporate strategy and resources.

6.5.2.2. *Obtaining external technical support*

The first step to be taken by the owner/operating organization is to decide whether or not external technical support will be procured by:

(1) Determining the activities and scope of activities associated with the technical support needed for decision making;
(2) Determining the competencies, proficiencies and qualifications needed for performing those activities;
(3) Deciding on the need (or preference) for external acquisition of technical for the needed activities;
(4) Specifying the role and responsibilities of the projected TSO.

Once a decision has been made to outsource the technical support, its acquisition follows common practices (discussed in Refs [43] and [64]) similar to those for any other contracted or procured service or product. These typically consist of: preparing the bid invitation, if applicable, and selecting (after bid invitation and evaluation, if applicable) external TSO(s) for contracting the activities. Therefore, similar methods can be used for qualification, bid specification and contracting conditions, technical and economic bid evaluation and contract negotiation and approval, as applicable and needed. Reference [65] is an on-line tool that applies these basic contracting methods and may be utilized for procurement of technical support services.

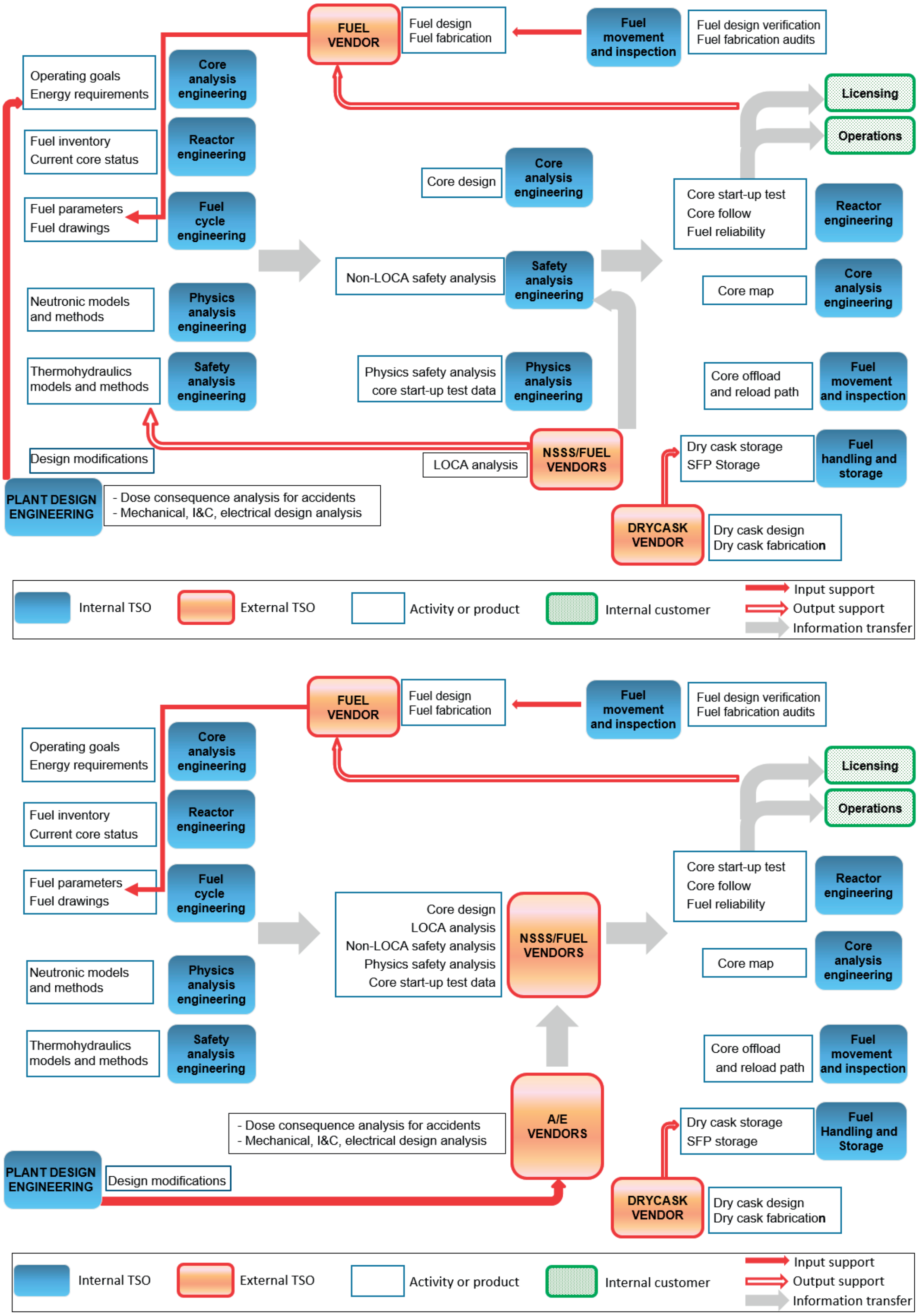

FIG. 14. Examples of shared core reload activities where: an internal technical support organization (top) or an external technical support organization (bottom) conducts major technical support activities. A/E — architect–engineer, I&C — instrumentation and control, LOCA — loss of coolant accident, NSSS — nuclear steam supply system, SFP — spent fuel pool, TSO — technical support organization.

If it is decided that the technical support will be obtained from an external TSO, that entity needs to be evaluated against certain elements and applicable requirements (and regulations where applicable) to ensure an effective technical basis for decision making. These generally are:

- The quality, competency, availability and reliability of the TSO as to:
  - Being able to demonstrate technical competency.
  - References (past performance on similar tasks — e.g. quality, accuracy, schedule adherence — is heavily weighted in the selection process).
  - Having an established and recognized quality control process which meets applicable regulatory requirements and industry best practice goals.
  - Not having actual conflicts of interest. In the case of a potential or perceived conflict of interest, the situation needs to be explicitly discussed with all involved parties and managed.
  - Trustworthiness, particularly in terms of handling any applicable confidential, security related or protected information. Conversely, there are no legal or copyright issues when dealing with the TSO's proprietary or commercially sensitive information. Otherwise, a legal agreement between the various organizations may be necessary.
  - The TSO's assurance, motivation and incentive for long term partnership.
- The TSO's ability to conduct its work within the specified and agreed time frame. The time allowed for the work to be performed by the TSO has to be commensurate with the scope of the work and consistent with the established time frame. The risk inherent in long term support is that an external TSO might decide to leave or not do business.
- The TSO's cost of services if work is long term owing to overheads and administrative costs of managing the contract.
- The terms of the TSO's oversight of work performed, as to:
  - Verification, validation and acceptance schedules, methods and times for technical services and technical products;
  - Details of quality checks in review and acceptance of the TSO services, including their sufficiency[23] and accuracy, as well as the consistency of the supporting documentation and deliverables with the scope of work.

6.5.3. External and internal TSO relationship

Once the technical support contract is awarded, the owner/operator needs to provide adequate management, supervision and oversight of the work of the external TSO. The owner/operating organization, through its internal TSO, evaluates the work performed by the external TSO as the work progresses in accordance with the defined objective and scope of work and the contractual agreements. The technical support by the internal TSO includes, as a minimum, ensuring:

- Clear understanding of the need, objective and provisions of performing the technical support activities and tasks, including all the requirements (technical, regulatory and owner's), by the external TSO;
- Provision of all relevant and correct plant information to the external TSO;
- Conveying specific technical and programmatic (regarding technical support) expectations and concerns of the nuclear power plant management and decision makers to the external TSO;
- Assessing the correct and appropriate use of technical information and compliance of methods and tools used for the technical support product with regulatory and quality requirements.

Therefore, the internal TSO staff members assigned to interface and oversee the external TSO's work need to:

- Have sufficient knowledge and proficiency to understand the work performed by the TSO;

[23] When the use of a TSO from a foreign country is considered, it is necessary that all parties involved communicate in a common language. All parties need to be aware that the use of translation services in a highly specialized technical area bears a risk of misunderstandings.

— Fully understand the need for the TSO's support and the context in which the work is being performed;
— Know what is required and needed and how the work will be used;
— Know the objective, scope and requirements so that the product received meets the intended needs;
— Be aware of the time frame for delivery of the work;
— Provide any information that could be useful to the TSO;
— Understand the outcome;
— Not inappropriately influence the outcome or advice from the TSO (or allow any other body to influence the TSO), to ensure that its advice or service is unbiased and clearly reflects its own technical opinion;
— Supervise the work in accordance with the owner/operator procedures and perform technical reviews on it whenever necessary;
— Ensure regular interaction with the TSO and facilitate the interaction of the TSO with the other parties (internal and external) related to the task, if necessary.

After the work is completed, the owner/operator needs to review and accept the product of the TSO. The owner/operator has to ensure that the work has been verified in accordance with the TSO's quality assurance procedures and satisfies any applicable regulatory requirements with respect to quality and documentation, as well as the other contractual requirements.

To achieve continuous improvement of the effectiveness of external technical support, one of the most relevant attributes is a collaborative relationship between the plant and external TSOs. Such a relationship, based on long term contracts and mutual benefits, supports the plant's vision, goals and objectives. Several plants with good experiences with external TSOs have found that building strong relationships with external TSO workers, treating them with respect and integrating them fully into their plant teams are indispensable to good execution. External TSOs (manufacturers, architect–engineers, major vendors, etc.) can also contribute to optimizing the conduct of technical support activities. Development of trust between the plant and the external TSOs allows the latter to readily identify problems, concerns and errors.

One area of importance is the right, correct and understandable exchange of technical information, This exchange between the internal and external TSO, including the exchange within the each organization and between the external TSO and its supporting vendors, becomes challenging since it involves both outgoing as-built plant information and incoming design information requiring effective management of seeking, acquiring, providing, validating and accepting technical support from both receiver's and provider's sides. There is an essential need in these cases to establish and maintain strong interfaces and a well defined formal communication format, and often and periodic review and confirmation meetings between the parties involved, preferably at the task level since preparer of the request and the performer of the task could validate the information by direct interface instead of via management. However, the results of these front-line meetings have to be communicated to the management of both organizations.

7. TECHNICAL SUPPORT FOR DECOMMISSIONING

The technical support for decommissioning covers the entire nuclear power plant life cycle, as described in Section 2.5.4. From the beginning of the nuclear power plant project until the start of decommissioning activities it takes the form of technical support for decisions on establishing and following national decommissioning policies and strategies. During the period of transition from the operations to the decommissioning phase, it takes the more active (from the owner/operator perspective) form of assisting the decisions on various aspects of decommissioning implementation.

A national policy and an associated technical strategy (or best option strategies) for decommissioning, that are established as early as possible, set a framework for nuclear power generation in the energy mix with the 'end in mind'. The formulation and optimization of the decommissioning strategy particularly reflect technical needs, priorities, constraints and infrastructure specific to the facility, owner or country, and have to be considered together with non-technical factors [19, 20]. Such establishment of a national policy is particularly important for newcomer countries[24] where a potential site needs to be identified for storage of radiological waste generated by operation and decommissioning. It is highly recommended that a site be identified to receive the radiological waste and spent fuel before any plan for decommissioning is established, and that it be ensured that this back end cost is covered and the facility is ready before a plant can be decommissioned.

Before the start of decommissioning activities, there is a transition period from operations to decommissioning that will require decisions that are mainly made by the owner/operating organization. Generally, the first (and main) decision on ceasing operation and on permanently shutting down the nuclear power plant marks the start of this transition period. Between the decision to shut down and the actual end of operations, the owner/operating organization will make more decisions on several aspects of decommissioning, such as the decommissioning plans and paths for management of the large volumes of waste generated by the decommissioning. Therefore, TSOs, particularly the owner/operating organization's internal TSO, play a central role in supporting the preparation for decommissioning strategies, programmes and plans, while interfacing directly or indirectly (Fig. 15).

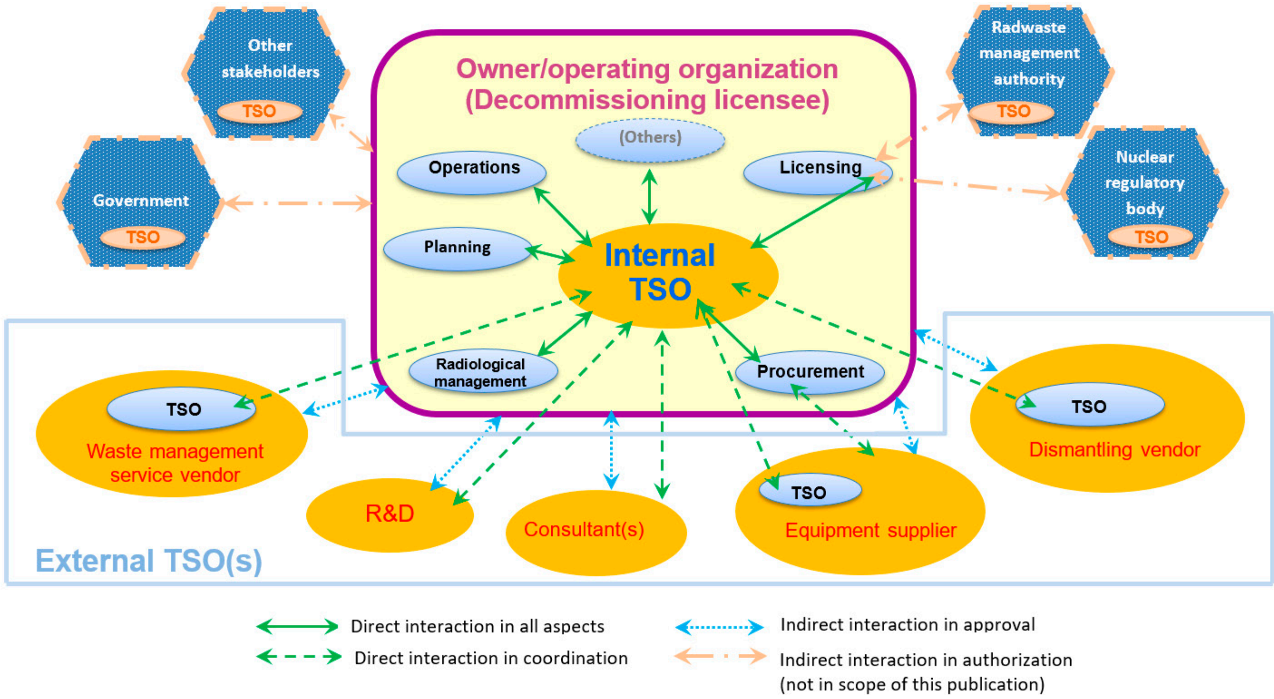

FIG. 15. Example of technical support sources and interactions in decommissioning. R&D — research and development, TSO — technical support organization.

7.1. SCOPE OF TECHNICAL SUPPORT

7.1.1. From pre-project phase to end of operation phase

Technical support plays an important role in establishing and maintaining a policy and in the associated decisions taken (or to be taken) in accordance with the decommissioning strategy throughout the life cycle, particularly due to technical factors that are anticipated and observed as the nuclear power plant project goes through all phases until the beginning of decommissioning, such as how the facility is designed, sited and operated. As is stated in Ref [20], the nuclear power project planners and nuclear power plant operators consider decommissioning at the earliest possible stage of the plant life cycle and the owner/operating organization

[24] This may also be applicable to expanding countries that do not have convenient sites, such as those countries that may find, at least temporarily, storage in government facilities, such as existing research laboratories.

maintains a decommissioning plan, which includes the management of radioactive waste, throughout the lifetime of the facility. In some regulatory frameworks, this may be a requirement.

The objective and scope of the technical support in the establishment and maintenance of decommissioning strategies, which also include radioactive waste management, is to ensure that the plant is designed and operated with the management of radioactive waste and the end phase of the facility in mind. Also, the intentions of the plant/site owner, or the government, with respect to the future of the site are a major input into decisions on the decommissioning strategy. As the technical factors (together with other non-technical factors at the legislative, regulatory, commercial and socioeconomic levels) contribute heavily to decisions on strategy and preliminary plans, they are part of the technical support scope in addressing many aspects and finding an optimal solution in a logical, structured and justifiable manner for safe, sound and effective decisions.

7.1.2. Scope at end of operation phase

In the transition from operations to decommissioning, the first (and main) decision typically made by the owner/operating organization is on ceasing operation and permanently shutting down the nuclear power plant, which marks the start of this transition period that lasts until the actual end of operations. Later in this transition, the owner/operating organization will make decisions on several aspects of decommissioning, such as the decommissioning plans and paths for management of the large volumes of waste generated by the decommissioning.

Responsibility for defining the decommissioning strategy, on which the planning for decommissioning will be based, typically belongs to the owner/operating organization [20]. The internal TSO of the owner/operating organization, as it possesses and knows the accumulated and detailed design and operation history of the plant and has the most authentic knowledge of the facility configuration information, plays a significant role in fulfilling this responsibility by:

- Performing technical assessments of post-operation state(s) and risk as well as developing programmes, processes and procedures;
- Supporting decommissioning goals, plans and activities, including characterization of the waste produced during decommissioning;
- Providing technical input and perspective for decisions on the preparation for decommissioning strategies, programmes and plans;
- Being closely involved in decommissioning planning and scheduling;
- Leading the technical efforts in support of obtaining the decommissioning licence from the regulatory authorities;
- Providing technical information related to the selection of final repositories or applied decommissioning technologies, if requested or needed;
- Making the accumulated knowledge and information available.

TSO staff can also provide technical information related to the selection of final repositories or applied decommissioning technologies, if requested or needed. The accumulated knowledge and information of the TSO is used, for example, to assess the approaches for particular cases and assists the decision makers during the transition phase and the implementation of early phases of decommissioning.

7.2. TECHNICAL SUPPORT ACTIVITIES

7.2.1. From pre-project phase to end of operation phase

Technical support activities throughout the life cycle of a nuclear power plant include [20]:

- Collecting and assessing available data and considering all key and potentially important technical factors;
- Formulating strategic options and selecting the optimum strategy, which relies on technical needs, priorities, constraints and technical information on the infrastructure specific to the facility (or future facility), owner or country;

— Preparing technical perspective on decommissioning method and schedule, such as immediate or deferred dismantling or converting the facility into a form of waste disposal (i.e. entombment);
— Identifying and preserving necessary technical information;
— Playing the technical intermediary role between the stakeholders (i.e. NEPIO, regulators, owners, future operators, public or elected representatives).

For example, general approaches to decommissioning known in the industry have benefits and disadvantages, and technical support is needed to assess which approach or combination of approaches could fit the particular case best and to assist the decision makers.

7.2.2. Transition from operation to decommissioning

The technical activities during the transition from operation to decommissioning in support of decision making by the owner/operating organization and the decommissioning entity consist of:

— Collection of information and analysis before shutdown (operating experience, accumulated radiological waste, incidents, inventory, configuration documents).
— Determination of installed equipment that is to be retained for use in decommissioning (cranes, ventilation, etc.).
— Preparation of design and engineering modifications in preparation for the decommissioning stage in accordance with the decommissioning plans and all associated documents. Such modifications may include, for example, dismantling SSCs, configuring shielding, or designing or installing facilities, structures and equipment for packing, storage or transport.
— Preparation and/or verification of design bases and safety analyses.
— Preparation or review of studies for current and historical site assessment and site characterization.
— Support for the liaison with national radioactive waste management authorities on the technical aspects and assistance in preparing the application to the regulatory bodies for the decommissioning licence.
— Preparation of waste management, segmentation and packaging plans.
— Review and verification of decommissioning scenarios and assistance in preparation of decommissioning cost estimates, schedules and plans as well as development, issuance and review of programme, processes and procedures.
— Identification and incorporation of necessary changes in operational procedures in transition from operations to decommissioning.

7.3. ORGANIZATION AND STAFFING

7.3.1. Staffing and organization during pre-project phase

Preparation of decommissioning policy and initial strategy (or strategies) is typically conducted by an interagency policy committee rather than a standalone organization, as the policy statement represents the consensus view of all of the organizations concerned. Therefore, an appropriately representative committee develops the decommissioning policy. This committee is staffed by the representatives of the parties that are involved and interested (e.g. government agencies, nuclear project company, owner/operator (or future owner/operator), regulatory bodies, radioactive waste management entities). References [20, 66, 67] discuss necessary competencies and typical organizational arrangements for decommissioning related activities during the pre-project phase.

7.3.2. Staffing and organization following the pre-project phase

As the responsible party, the nuclear power plant owner/operating organization is the key entity in updating, maintaining and executing the strategy. While the design of the facility is conducted by the responsible designers, the owner/operator’s in-house staff and technical staff contracted/consulted provide technical support for the decisions on design proposals related to the decommissioning strategy, particularly to those about the radiological waste management. This organizational structure of in-house experts on radiological waste and outside consultants on decommissioning strategy maintenance typically exists during the operation phase. During the transition from operations to decommissioning, the owner/operating organization relies heavily on internal TSOs for technical support, especially on the current and future facility status and changes in preparation for the decommissioning [68]. Once the actual dismantling begins, the TSO of the decommissioning entity (hired by the owner/operating organization) conducts the majority of the work with support and oversight from the owner/operating organization's internal TSO (Fig. 16).

It should be noted here that, as Ref. [20] emphasizes:

> "When there are significant delays between permanent shutdown and the completion of dismantling, problems can arise due to the loss of knowledge about the facility. This is due to the unavailability of key members of the operational workforce to assist in planning or to supervise the decommissioning work."

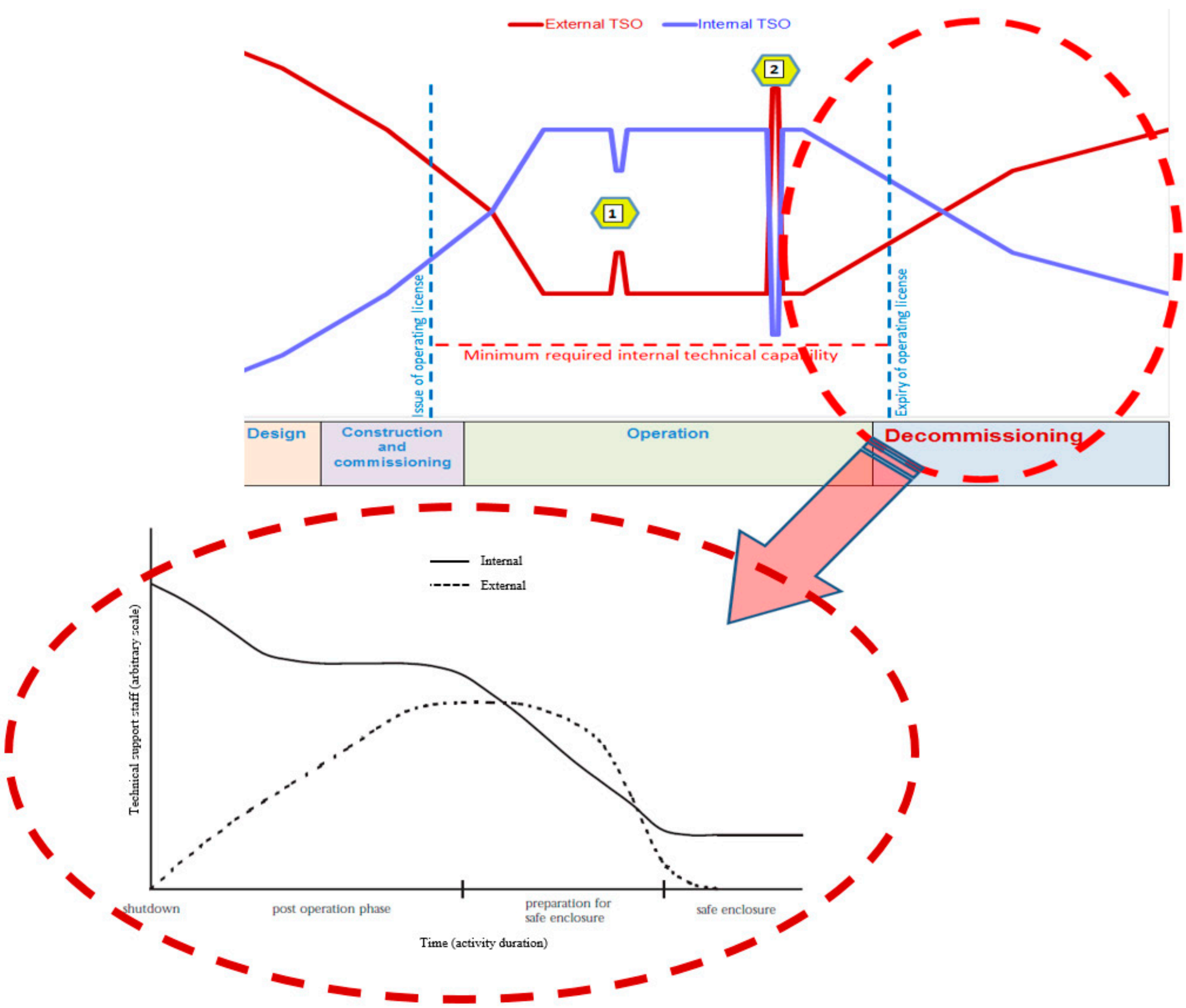

FIG. 16. Example of sharing of technical support activities during decommissioning (reproduced from Ref. [68]). TSO — technical support organization.

8. CONCLUSIONS

From the beginning of consideration of nuclear power in the energy mix of a country to the end of decommissioning, there are many decisions to be made and technical and scientific information and advice are essential parts of input to those decisions. This technical input and advice carries much weight in the decisions on viability, safety, reliability, efficiency, availability and longevity of nuclear generation, because nuclear energy is:

— Expected to provide safe, clean and economical energy;
— Heavily based on technology and science;
— Associated with financial and technical risks;
— A major investment for owners;
— Expected to perform with quality and longevity.

Therefore, obtaining accurate, adequate and timely technical information is essential for the majority, if not all, of the decisions during a plant’s life cycle, to ensure they are as safe, sound and informed as possible.

To effectively obtain appropriate and adequate technical input to the decisions, a systematic approach with well thought out steps is essential. First, it must be determined what technical information is needed for confident and comfortable decision making. Then, the associated scope and activities, as well as the areas of competency and experience needed for these, are foreseen.

Once the needed technical support and the associated competencies are defined, the organization in need of technical support for decision making (e.g. government, NEPIOs, nuclear power plant project owner, owner/operating organization) has the prerogative to select its technical support provider — the TSO. Many factors may influence the selection of the TSO, including one or more of the following:

— Availability of expertise and resources in the particular field within the company, region or country;
— Existing industrial infrastructure and its projected future development;
— National and international laws and regulations;
— Economic and market drivers;
— Contractual and commercial agreements;
— Long term strategy of the decision maker.

The significance, complexity, level of risk and consequences of errors in technical information as well as the periodicity, frequency and urgency of associated activities also play a role in selection of the TSO based on the value and impact of the technical input. They also drive the planning and strategy for utilizing in-house sources or purchasing from external TSOs, both of which come with associated obligations and costs, during the entire nuclear power plant life cycle.

There is no ‘one size fits all’ structure and size for effectively determining need for, requesting and obtaining, receiving and evaluating and expressing the technical perspective to the decision maker. This is because of the fact that the need, scope, complexity, needed proficiency and frequency of the technical input vary from one organization to another and the corporate strategy, management style, tradition and values are different for each organization.

Regardless of the provider or the practice, the decision maker needs to have its own internal capabilities and capacities for technical support. This individual or group (i.e. the internal TSO) is part of the in-house technical staff and is dedicated to the decision making organization’s concerns and goals, with high level ownership and interest. The internal TSO is, as a minimum, able to:

— Recognize and express the need for and the significance and scope of technical support for an informed decision;
— Identify the competencies and qualifications needed for the scope of the technical support;
— Identify potential sources for technical support and select external TSOs as applicable and needed;
— Communicate the scope and any technical and relevant information to the external TSOs for complete and correct execution of the activities;

— When the outcome of the technical support is provided, understand and know the relevant and accurate input to the decision;
— Express relevant information to the decision authority with clarity and describe technical perspective by providing technical opinion, options, recommendations, advice or feedback;
— Gain, preserve and transfer the technical and scientific knowledge and information about the nuclear power plant for the continuity of its design and configuration integrity throughout the plant's lifetime.

Ideally, a fully capable and competent in-house technical competency and expertise (a 'one-house approach') would be established and maintained throughout the plant lifetime. However, the needs and means vary during the life cycle of nuclear power plant, and therefore this may not be feasible. Even with the hypothetical 'one house approach', it is highly likely that there will be complex or special issues, or unique and urgent decisions, that exceed the in-house capabilities or capacities of the internal TSO and necessitate an external (or outsourced) TSO.

Therefore, a systematic approach needs to be applied continuously throughout the nuclear power plant lifetime for each and every decision. This approach starts with planning and determining the technical information that is needed and associated competencies for providing it, and ensures correct and timely technical information is provided so a safe, sound decision can be made with confidence and comfort in accordance with the policy, programme, strategy and goals of the decision maker. This continuous process will provide flexibility, adaptability and effectiveness in technical support acquisition, provision and utilization to satisfy the decision maker's needs.

Lastly, good practices of effective technical support acquisition, provision and utilization observed in other organizations need to be thoroughly assessed for adaptation and implementation by the organization. This has to be accomplished with the premise and understanding that the safety and reliability of the nuclear power generation are ensured, and all laws, regulations and requirements are fully complied with throughout the plant lifetime.

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Annex I

THE STRUCTURE OF EXTERNAL TECHNICAL SUPPORT AT THE PAKS NUCLEAR POWER PLANT IN HUNGARY

During the construction period and the years after commissioning of the Paks nuclear power plant, the technical support was provided mainly by foreign entities, primarily the dedicated institutes of the former Soviet Union.

By the beginning of the 1990s, a significant drop in the availability of the Russian technical support organizations was observed, and sometimes a lag in development of expertise compared to the industry worldwide was also experienced. Meanwhile, the scientific and technical competencies and capabilities of the domestic institutions meaningfully increased.

Based on the last several years of cooperation, the following organizations are considered the most important external technical support providers for the Paks nuclear power plant:

— The *Hungarian Academy of Science, Centre for Energy Research* (in Budapest) performs research and development in the field of nuclear science and technology for facilitating the adoption and the safe use of nuclear technology in Hungary. It participates in international research efforts aiming at the establishment of a new generation of nuclear power plants and closed fuel cycles. The centre also studies the interaction of radiation (including neutrons, gamma rays and electrons) with matter, and does isotope and nuclear chemistry, chemical analysis by nuclear methods, radiography, radiation chemistry, radiation protection and nuclear security, surface chemistry and renewable energy research. A 10 MW(th) research reactor is operated in the campus of the centre.

— The *Nukleáris Biztonsági Kutatóintézet Kft. or Nuclear Safety Research Institute Ltd*, (in Budapest) is mainly concerned with the safety analysis and assessment of nuclear installations. One area of focus of the institute is the enhancement of the nuclear safety level of the Paks nuclear power plant. It also contributes to the determination and evaluation of the specific conditions for the safe and efficient long term operation of the nuclear power plant.

— *PÖYRY-ERŐTERV Co.* (in Budapest) covers the engineering and design of nuclear installations, providing high level engineering support in construction, commissioning and operation of nuclear power plants. The company is also competent in all aspects of radioactive waste management.

— The *Budapest University of Technology and Economics, Institute of Nuclear Technology*, operates a 100 kW(th) training reactor and performs scientific research in specific areas. It plays a significant role in graduate level education of engineers and physicists for development of competent technical staff.

— The *Hungarian Academy of Science, Institute of Nuclear Research* (in Debrecen) operates a 20 MeV cyclotron and two Van de Graaff accelerators (5 MV and 1 MV) which provide research opportunities in different areas of nuclear physics and nuclear technology.

— The *"Frédéric Joliot-Curie" National Research Institute for Radiobiology and Radiohygiene* has a wide spectrum of research areas encompassing areas such as the biological effects of radiation and radioisotopes, health physics (operations and environmental protection), disinfection and detoxication.

— *SOM System Ltd* (in Budapest) provides engineering services in licensing and regulatory issues particularly related to nuclear fuel. This office ensures expertise in a wide range of nuclear technical issues and plays a leading role in independent safety assessments and reviews of the nuclear power plant.

The Paks nuclear power plant also maintains relationships, partnerships or interfaces with foreign companies (or their successors) that have contributed to the design and construction of the nuclear power plant or to the manufacturing of its main equipment. This includes TVEL Fuel Co., ATEP Ltd, Skoda and Gidropress.

Besides the single contract technical support services, the Paks nuclear power plant has also established an institutionalized structure for technical support in general design and for principal consultancy services (Fig. I–1). Based on contracts currently in force, the general design services are provided by MVM ERBE ENERGETIKA Engineering Ltd, while the joint principal consultants are the Hungarian Academy of Sciences Institute for Energy Research and Nuclear Safety Research Institute.

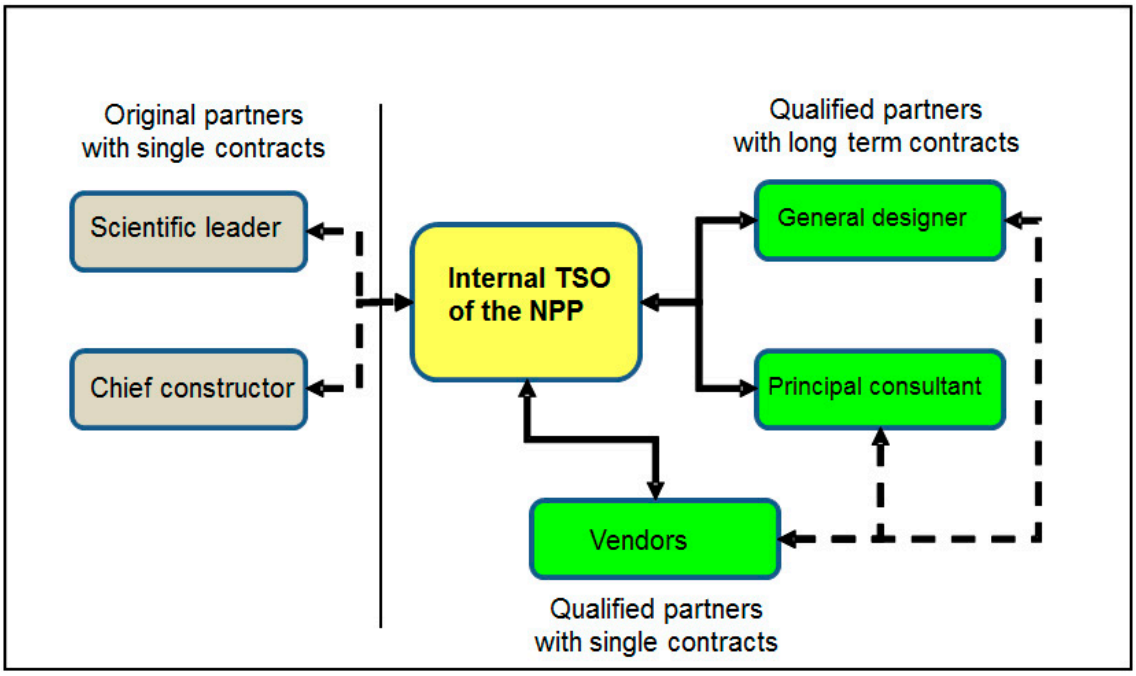

FIG. I–1. Structure of technical support at the Paks nuclear power plant (courtesy of G. Pekarik, MVM Paks nuclear power plant Ltd). NPP — nuclear power plant, TSO — technical support organization.

This comprehensive technical support structure has developed based on the local/domestic conditions and the operating history of the Paks nuclear power plant — as has been the case in many other utilities. This structure is based on the effective cooperation of the operator, consultant and general designer and covers all necessary areas of technical support, with the Paks nuclear power plant owner/operating organization in the leading role.

The general designer provides continuous design and engineering support for the plant under a long term contract, and the support is particularly focused on the projects for the plant's safety enhancement programme. The significant elements of the general designer's technical support are the following:

— Maintaining the design standards and recommendations up to date;
— Reviewing modification concepts for the systems, structure and components;
— Participating in information exchange with authorities for the clarification of design specifications and concepts;
— Contributing to the annual review of the final safety analysis report;
— Preparing feasibility studies;
— Preparing licensing documentation;
— Localizing foreign design documentation;
— Contributing to execution and commissioning of modifications.

The principal consultant provides technical support and advisory services in nuclear safety and nuclear engineering issues including:

— Preparing specific studies to promote decision making;
— Playing the role of the opponent when results are provided by third parties;
— Determining and preparing concepts, technical solutions;
— Following the developments in the international nuclear industry and developing advice for the nuclear power plant to enhance its safety, efficiency and reliability.

The principal consultant acts according to the predefined annual plan and schedule and prepares biannual progress review reports which provide the plant with a list of tasks and their status and describes the progress of safety analysis work. The results of the principal consultant's activities are summarized, reviewed and discussed in a meeting conducted annually and providing a formal report about the completion of tasks.

This structure for the external technical support organizations allocates clear roles, responsibilities and competencies and fully complies with the relevant procedures regulating selection, qualification and evaluation of the vendors.

Annex II

THE INTERNAL TSO AND INTERFACE WITH EXTERNAL TSOs AT THE CHASHMA NUCLEAR POWER GENERATING STATION, PAKISTAN

II–1. BACKGROUND

The two nuclear power plant units, C-1 and C-2, at the Chashma Nuclear Power Generating Station (CNPGS) started operation in September 2000 and May 2011, respectively. Before the commissioning of C-2, it was realized that a combined organization for the two units was necessary for optimum utilization of human and other resources. After thorough deliberations, an internal technical support organization (TSO) was established in September 2010 to provide common services (engineering, maintenance, procurement, etc.) to the individual plants, who would restrict their scope to plant operations, routine maintenance and day to day engineering work only. The role of the internal TSO will be even more significant when two more nuclear power plants, C-3 and C-4, start operation at the same site. The internal TSO is envisaged to be a self-sustaining, well resourced and well integrated organization capable of providing quality maintenance and engineering services to all the operating nuclear power plants of CNPGS during operation, shutdown and refuelling outages. The internal TSO was established with a view to:

— Developing a stronger base of expertise, tools and facilities to effectively handle routine and periodic short and long term support needs of current and future plants within CNPGS;
— Separating routine and developmental work, so as to deal with them in a better way and evolve capabilities for fast approaching challenges.

Currently, the internal TSO has the capabilities to provide technical support in the areas of:

— Reactor engineering and core management;
— Safety analysis;
— Design modifications;
— Refuelling operation;
— Maintenance work for mechanical, electrical and instrumentation and control (I&C) equipment;
— Radioactive waste management (low level and high level waste conditioning, reduction and storage);
— Ageing management for equipment, pipes, cables and structures;
— In-service inspection and calibration of measuring and test equipment.

The TSO also provides technical expert support for fuel handling and in-service inspection services to units of the Pakistan Atomic Energy Commission that are operating and undergoing commissioning.

II–2. ORGANIZATION OF THE TSO

The organizational structure of the CNPGS's TSO is shown in Fig. II–1. The organization is headed by a director who is assisted by two deputy directors who are responsible for technical support for engineering and maintenance including fuel transportation. The managers of the procurement, quality assurance, accounts and administration departments report directly to the director. The director of the technical support division reports to the director general of the nuclear power plant.

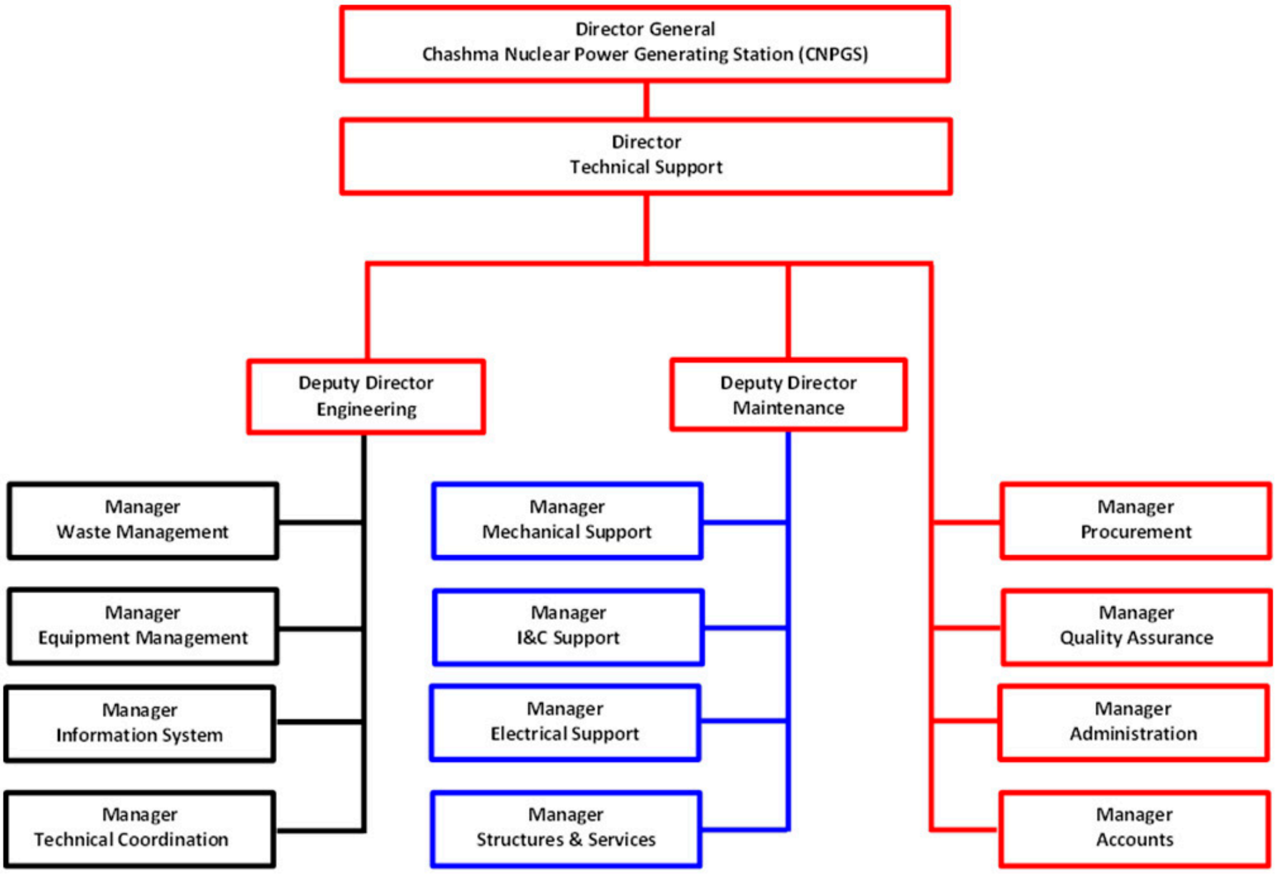

FIG. II–1. Technical support organization at CNPGS (courtesy of M. Saeed, CNPGS).

II–3. MAJOR RESPONSIBILITIES

The activities of the internal TSO particularly cover the areas with ownership and responsibility, which consist of:

— Reactor engineering;
— Analytical support;
— Pre-service/in-service inspection;
— Equipment reliability programme;
— Ageing management;
— Flow accelerated corrosion programme;
— External operating experience;
— Root cause analysis;
— Information management;
— Low level and high level radioactive waste management;
— Permanent plant modifications;
— Execution of refuelling outages at operating plants;
— Major and common equipment overhaul and maintenance (mechanical, I&C, electrical, etc.);
— Fuel handling and fuel transportation and on-line visual testing during unloading by using underwater cameras;
— Procurement;
— Structure maintenance and in-service inspection.

The internal TSO also has the responsibility for outsourcing tasks to the external TSOs as needed. Services are also available to CNPGS plants from external TSOs in the areas of radioactive waste management, fabrication and servicing of parts (mechanical, electrical, and in particular, I&C), in-service inspections, various design and manufacturing of equipment.

II–4. DIVISION OF RESPONSIBILITIES BETWEEN PLANT AND TSO

As soon as problems appear that are outside the framework of the regulatory operational documents, the appropriate services of the power unit operator make an inquiry to the internal engineering support service on providing the required conditions, limitations, margins, design information and engineering support. The means at the disposal of the nuclear power plant engineering support service make it possible to solve some of the problems, within the framework of the risk informed approach.

If the solution to the problem has been found and substantiated, it is accepted by the operation service for implementation. Then, a procedure for coordination of the given solution with the representatives for supervision of the design organization and a representative of the regulatory body is envisaged.

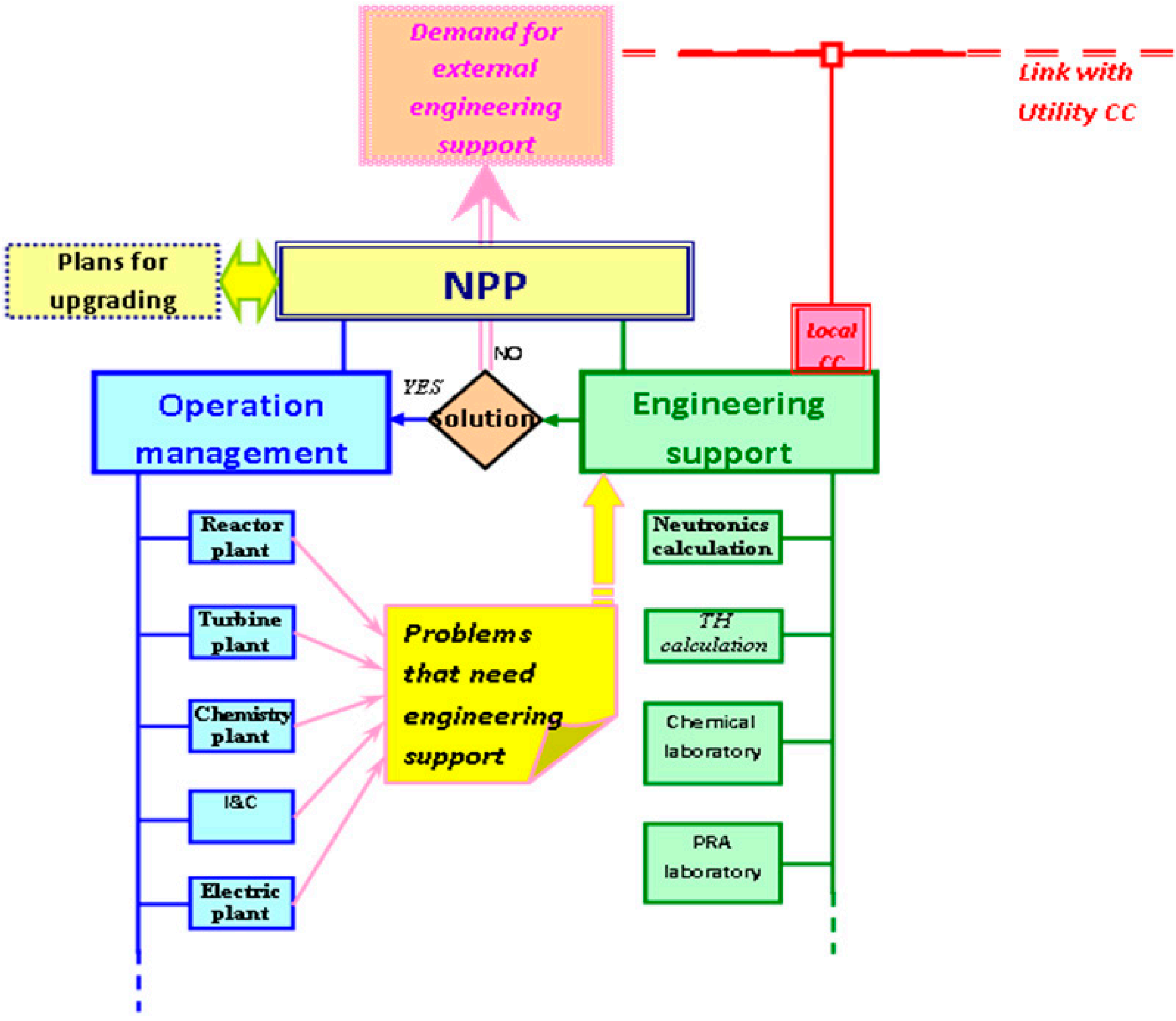

FIG. II–2. Interfaces and roles of TSOs with crisis centre approach (courtesy of M. Saeed, CNPGS). CC — crisis centre, I&C — instrumentation and control, NPP — nuclear power plant, PRA — probabilistic risk assessment, TH — thermohydraulic.

If the solution either cannot be found or needs deeper insight from the designer organizations or additional effort on the part of the experts, a request is formalized from the operating utility (nuclear power plant owner) for external engineering support.

For some urgent issues related to the nuclear power plant safety assurance, the system of the operating utility envisages engineered features for operative on-line solution of the problem with the participation of experts of any level (crisis centre system) (Fig. II–2).

In the case of non-emergencies, the crisis centre channels can be used to solve minor or organizational engineering support issues.

As the request for external engineering support is formed, the operating utility determines the level of the problem's complexity from the point of view of the hours needed and the experts to be involved in the activities and, depending on the type of nuclear power plant involved, a preliminary programme with measures to solve the problem is developed and addressed to a group of enterprises/organizations that participated in the creation of the plant.

For minor issues that do not require large scale response, the nuclear power plant internal engineering management service can operatively address the dedicated enterprises/organizations.

The programme of activities proven through such cooperation is accepted for implementation according to the established procedure, with correction (if necessary) of the earlier accepted plan of unit modernization. Such correction can also be made on the initiative of the plant management.

For urgent issues, as stated above, the crisis centre organizes via its communication system the involvement of experts to solve the problem, first and foremost from the organizations that participated in the creation of the unit.

Annex III

EXTERNAL TECHNICAL SUPPORT DURING VARIOUS STAGES OF THE NUCLEAR POWER PLANT LIFE CYCLE

III–1. INTRODUCTION

This annex provides examples of technical support provided by an external technical support organization (TSO) in China at the pre-operation and operation phases

The first example describes the technical support provided by the external TSO, which is the responsible designer, the Shanghai Nuclear Engineering Research and Design Institute (SNERDI), in support of the decisions to be made on a CAP1400 demonstration power plant during the pre-operation (i.e. preparatory, design, construction and commissioning) phase.

The second example discusses external TSO activities that support a nuclear power plant in the operation phase. Two specific areas that are supported by the external TSO are illustrated: periodic safety review and plant life extension.

III–2. TECHNICAL SUPPORT FOR PRE-OPERATION PHASES

III–2.1. Overview

During the preparatory, design and construction phases for nuclear power plants, technical support services in China usually refer to technical support for licence application and engineering. Except those provided by the owner itself, technical support services mainly come from design institutes or relevant suppliers, covering most of the design and construction phases. These services constitute the bulk of the design contract (usually a turnkey contract) and other specific support contract. The nuclear island design institute, conventional island design institute and other suppliers provide the relevant technical support according to the contract, and the owner supervises and assesses the support as specified in the contract and/or agreed by all parties. In China, there are only 3–4 nuclear design institutes, so these institutes always provide most of the technical support service.

The CAP1400 demonstration project has adopted the engineering, procurement and construction contract management model. The owner of the project is the State Nuclear Power Demonstration Plant (SNPDP), and the general contractor is the State Nuclear Power Technology Company Consortium. The State Nuclear United includes the State Nuclear Power Engineering Corporation (SNPEC) (project management and equipment purchases), the SNERDI (general design and nuclear island design), and the State Nuclear Electric Power Planning, Design and Research Institute (SNPDRI) (conventional island design institute), which are the main technical support suppliers for the CAP1400 demonstration project. At the same time, the owner (the SNPDP) set up its own technical support group, which includes departments of technology and design management, engineering management, equipment purchase and management, and production preparation. Technology and design management covers the overall management of technical support, which is the interface contact with all permit review departments, including the National Nuclear Safety Administration (NNSA) and the National Energy Administration

The CAP1400 demonstration project also needs a number of specific technical companies or institutes to provide support for the professional work, such as the prefeasibility study, feasibility study, project approval review, environmental impact assessment report, safety review and independent verification. This technical support mainly focuses on fields such as seismogeology, engineering hydrology, heated water and low level radioactive wastewater, fishery resources, ecology, local radiation and occupational safety and health. The owner signs separate technical support contracts with the specific companies or institutes undertaking the above work.

During the construction phase for nuclear power plants, the owner can also organize separate technical demonstrations, which are normally held as technical consultation meetings with industry experts invited. Examples include general layout expert consultation and first concrete date plan expert consultation. The overall technical support model is shown in Fig. III–1.

Several special reports about the site, in areas such as seismogeology, engineering hydrology, population and environment investigation, are requested during the preparation of the preliminary feasibility study report. These are provided by professional research institutes, for example, Institute of Geophysics, China Earthquake Administration, Institute of Oceanology, Chinese Academy of Sciences, China Institute for Radiation Protection and Zhengzhou Geotechnical Engineering Limited.

According to the requirements of the Ministry of Environmental Protection and the NNSA, an environmental impact assessment report (siting phase) and site safety analysis report should be provided. These two reports are organized and compiled by the SNERDI, and reviewed by the Nuclear and Radioactive Safety Center (NSC) of the Ministry of Environmental Protection, which is approved as a review body by the NNSA. Following review meetings and communications, the report is cleared by the NSC and officially approved by Ministry of Environmental Protection and the NNSA.

Overall, the SNERDI is in charge of the main technical support at this stage, while other special technical reports are provided by the specific companies or institutes. The owner, the SNPDP, is responsible for communication and coordination.

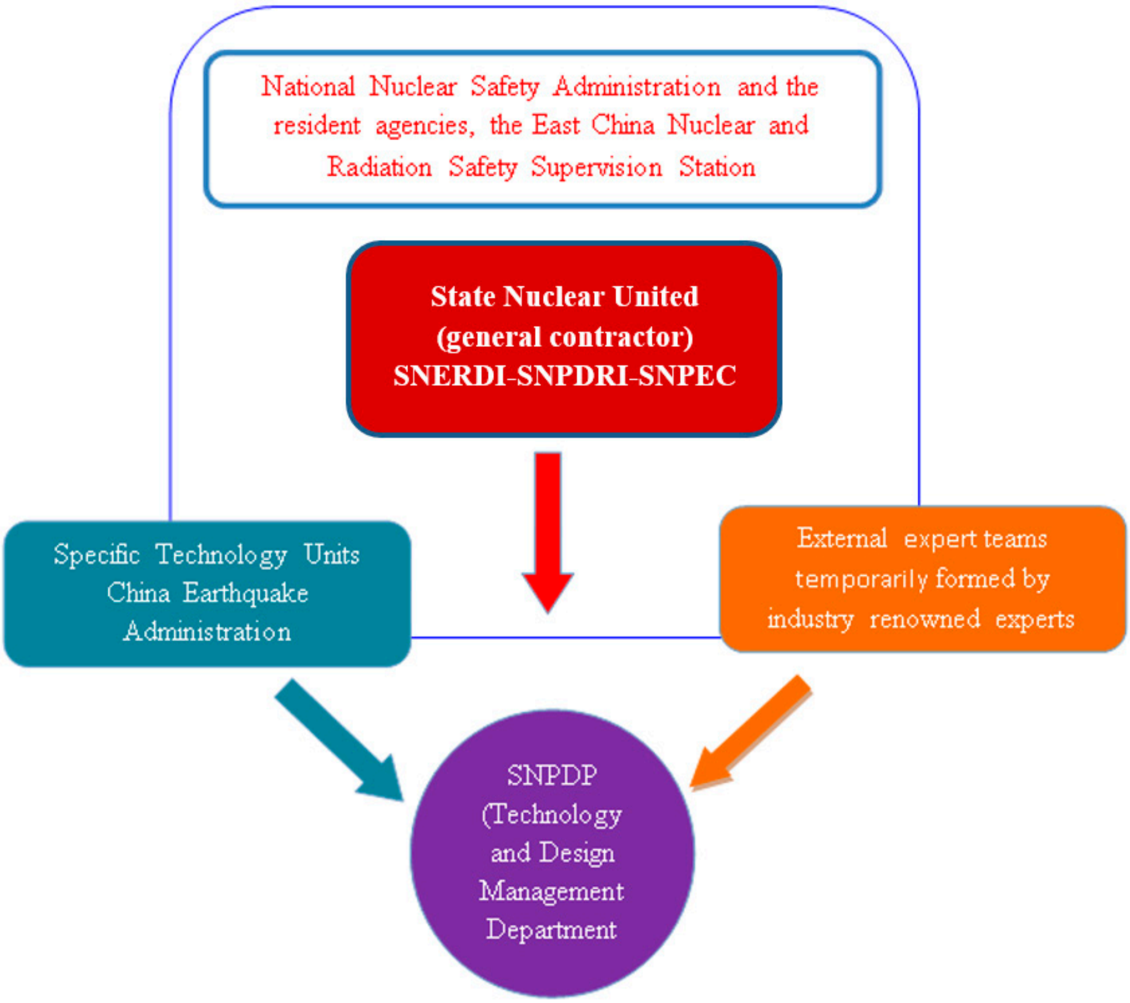

FIG. III–1. Technical support for a newly built nuclear power plant in China (courtesy of X. Wang, SNERDI). SNERDI — Shanghai Nuclear Engineering Research and Design Institute, SNPEC — State Nuclear Power Engineering Corporation, SNPDP — State Nuclear Power Demonstration Plant, SNPDRI — State Nuclear Electric Power Planning, Design and Research Institute.

III–2.2. Technical support for project approval

China's nuclear power plant implementation adopts a project approval system and nuclear safety licence system in parallel. The National Energy Administration is responsible for approving the project, while the NNSA is responsible for issuing the construction permit.

Project approval includes three major areas of preparation work: feasibility studies, preliminary design review and project approval report. All require supporting documentation.

The SNERDI is responsible for compiling the feasibility study report, preliminary design report and project approval report, and for providing technical support when these reports are being reviewed. Meanwhile, the Technology and Design Management Department of the SNPDP is responsible for compiling the content related to site condition in the above reports and providing technical support as well.

The feasibility study report is reviewed by the Electric Power Planning and Engineering Institute, which also provides review comments. The preliminary design report, as a requirement of the National Energy Administration, is reviewed by subject experts from seven different groups, organized by China International Engineering Consulting Corporation, who provide official review comments. Project approval report (review of which is also required by the National Energy Administration and organized by China International Engineering Consulting Corporation) is approved by the National Energy Administration and National Development and Reform Commission.

Construction permit application includes the review of the preliminary safety analysis report, environmental impact assessment report (design phase) and quality assurance programme. As the CAP1400 demonstration project belongs to a new kind of research and development plant model, it is required by the NNSA to carry out special reviews on four aspects: specific review, independent verification, calculation review and test verification. The independent verification is organized by the SNPDP; calculation review is implemented by the NSC; and test verification is undertaken by the relevant test units. All of the above review work should meet the NNSA review requirements.

Therefore, the SNERDI, as the general design institute, is the main provider of technical support at this stage, and the SNPDRI, as the conventional island design institute, provides coordination and assistance. In addition, some specific units also provide technical support when needed.

During the preparation of specific reports, the terms of reference and quality assurance programme should be compiled and approved by domain experts, as should the final reports. This work guarantees the technical quality and reliability of the specific reports.

III–2.3. Technical support for construction

After the first concrete is poured for the nuclear island, the project enters the site construction phase. Technical support during this phrase changes from design review to project construction. Site construction mainly includes land levelling, construction of engineering facilities, nuclear island excavation, civil construction, installation and module assembly.

The SNERDI and the SNPDRI, as design units for the State Nuclear United, which is responsible for the engineering, procurement and construction for CAP1400, should send engineers and designers to the site to provide technical support for project implementation. Meanwhile, as the general management unit, the SNPEC should arrange for more staff to work on-site, to effectively manage and supervise all the construction and installation work of the subcontracting companies, and also manage the design, design changes, clarifications and so on, together with the design institute.

Another important kind of technical support provided by the SNPEC is the on-site supervision of major equipment manufacturing, which is typically performed by resident experts at the manufacturing facility to monitor activities there. This technical support particularly focuses on ensuring conformity and controlling equipment design changes during the manufacturing process.

As the owner, the SNPDP supervises and manages the project, through its project management department, technical and design management department, security and quality assurance department and other departments, in conjunction with the third party company that focuses on the supervision and management of the general contractors at the site, and that, to a certain extent, provides technical support for the important construction interface at the site. For important technical issues, such as the large crane lifting plan and mass concrete pouring plan, the SNPDP separately organizes specific review by industry experts to ensure the quality and safety of the project.

As the resident agency of the NNSA, the East China Nuclear and Radiation Safety Supervision Station of the Ministry of Environmental Protection will send two or three supervisors to the site after the first concrete is poured. In accordance with the surveillance programme requirements, the supervisors will focus on nuclear safety during the entire construction and installation process. And relying on the technical strength of the NSC, the station arranges annual inspection and special inspections to ensure that the construction and installation of the items important for nuclear safety are quality controlled and that they meet the requirements of the nuclear safety regulations and standards.

Therefore, technical support during this phrase is mainly from nuclear technology departments of the SNPDP, members of the State Nuclear United, teams of external experts and national safety supervision institutions.

III–2.4. Technical support for commissioning

Fuel loading at a nuclear power plant in China implements the licence approval system. Several application documents need to be completed before fuel loading, such as the final safety analysis report (FSAR) and environmental impact assessment report, which are all prepared and provided by the nuclear island institute, the SNERDI, and are required to eventually be reviewed by the NNSA.

The commissioning work for the CAP1400 nuclear demonstration project is led by the SNPEC, which will set up on-site commissioning teams covering all professions and implement the commissioning work until the plant can be operated stably. Then the plant and its operation will be transferred to the owner.

During the commissioning phase, the technical department of the SNPDP will participate in the whole commissioning process and implement effective supervision, to ensure the quality and safety of the commissioning.

Meanwhile, as the future operation maintenance technical support unit of the nuclear power plant, the State Nuclear Power Plant Service Company will also participate in the preparation of the operational maintenance programme and provide technical support.

As the resident agency of the NNSA, the East China Nuclear and Radiation Safety Supervision Station will set specific areas and activities to oversee, in accordance with the requirements of the outline of supervision, which must be met during the commissioning of the plant.

In short, the main technical support during the commissioning phase still comes from the three parties of the State Nuclear United, especially the commissioning teams of the SNPEC. The owner fully participates in the commissioning work to ensure good operation of the plant in the future. As the professional technical support service provider of the subsequent operation, the State Nuclear Power Plant Service Company participates in the commissioning as much as possible, and is also responsible for the compilation of the subsequent operation outline and manual.

III–3. TECHNICAL SUPPORT DURING OPERATION PHASE

Generally, nuclear engineering designers can provide very important technical support services for nuclear power plants in some special areas involving safety assessment and systematic modifications during plant operation based on their special knowledge of the design basis and nuclear engineering and experience and/or skill on communication with the regulatory authority. These include periodic safety review and licence extension applications.

In the case of periodic safety review, designers may help and/or work together with the internal technical staff from the nuclear power plant to carry out activities such as the following:

- Establishing a list of original design standards and current safety standards for a nuclear power plant, and collecting the latest good practices and feedback in the field of nuclear safety;
- Clarifying safety standards and/or design specifications for historic modifications during operation;
- Making a corrective plan for the weaknesses found in the periodic safety review, providing design service for the modifications and/or follow-up communication with regulatory authorities;
- Updating the FSAR to reflect the latest status of the nuclear power plant after its periodic safety review activities.

Since the owner/operating organization makes the decision to submit an application for licence extension for a nuclear power plant, as one of the main technical supporters of the external TSOs, the designer could play an important role in the preparation stage and subsequent safety assessment processes. Typical technical support activities carried out by the designer could include the following:

— Establishing a set of safety standards for the licence extension application (i.e. licence basis), and demonstrating its effectiveness;
— Cooperating with internal technical support staff for scoping, screening and review for ageing management for the plant, and/or developing new follow-up programmes, if necessary;
— Retrieving the time limited ageing analyses and their bases from the original design and engineering records, and supporting activities for updating those;
— Preparing the application documents and the necessary support materials;
— Conciliation with regulatory authorities for the safety assessment results regarding the licence extension application;
— Updating the FSAR with the latest results from the safety assessment of the plant after submission and approval of the licence extension application;
— Carrying out research and development activities on new issues arising from the extended operation and the provision of continuous technical support for whole lifetime of the nuclear power plant.

GLOSSARY

conventional island. The part of a nuclear plant that incorporates and contains all systems, structures and components that are related to conversion of steam to electricity and do not form a part of the nuclear island. Typically, the conventional island consists of the equipment in the turbine building.

mid-loop operation. A refuelling outage procedure (in pressurized water reactor plants) in which, after shutdown and a cooling period, reactor coolant is lowered below the hot and cold legs, permitting work to be performed in a relatively dry environment.

normal operation. Operation of nuclear power plants within specified operational limits and conditions.

nuclear island. The part of a nuclear power plant that incorporates and contains all systems, structures and components that are related to nuclear steam supply. Typically, the nuclear island consists of the equipment in the reactor and auxiliary buildings.

nuclear power plant owner/operating organization. The company or organization that is the operator of a nuclear power plant. This organization has the primary responsibility for the safe operation of the plant and has to satisfy the requirements of the nuclear regulatory body in the country.

nuclear steam supply system. The reactor and the reactor coolant pumps (and steam generators for a pressurized water reactor) and associated piping in a nuclear power plant, used to generate the steam needed to drive the turbine generator unit.

nuclear unit/nuclear energy generating unit. Comprises a nuclear reactor and all the auxiliary equipment (generator, transformers, motors, pumps, electrical supplies, protection systems, etc.) that are required for operation. A nuclear power plant may have one or more nuclear units.

off-normal operation. Operation of nuclear power plants outside specified operational limits and conditions.

operational limits and conditions. A set of rules setting forth parameter limits, the functional capability and the performance levels of equipment and personnel approved by the regulatory body for safe operation of an authorized facility. Also referred to as limiting condition for operation.

safety case. A collection of arguments and evidence in support of the safety of a facility or activity. Normally includes the findings of a safety assessment and a statement of confidence in these findings.

technical support. An activity (or part of an activity) to assist decision makers by providing technical and scientific input in decisions on the achievement of design and performance objectives.

technical support organization. Any organization (or individual or group) that provides technical and scientific support to decision makers for decisions on preparation for a nuclear power plant project and afterwards, for the design, licensing, construction, commissioning, operation, maintenance and decommissioning of the plant.

utility/electric utility. An entity that owns assets and operates facilities for the generation, transmission or distribution of electricity/energy for commercial sale to individual and/or industrial consumers.

ABBREVIATIONS

BOP	balance of plant
CNPGS	Chashma Nuclear Power Generating Station
FSAR	final safety analysis report
I&C	instrumentation and control
NEPIO	nuclear energy programme implementing organization
NNSA	National Nuclear Safety Administration
NSSS	nuclear steam supply system
OLCs	operational limits and conditions
RCS	reactor coolant system
SNERDI	Shanghai Nuclear Engineering Research and Design Institute
SNPDP	State Nuclear Power Demonstration Plant
SNPDRI	State Nuclear Electric Power Planning, Design and Research Institute
SNPEC	State Nuclear Power Engineering Corporation
SSCs	systems, structures and components
TSO	technical support organization

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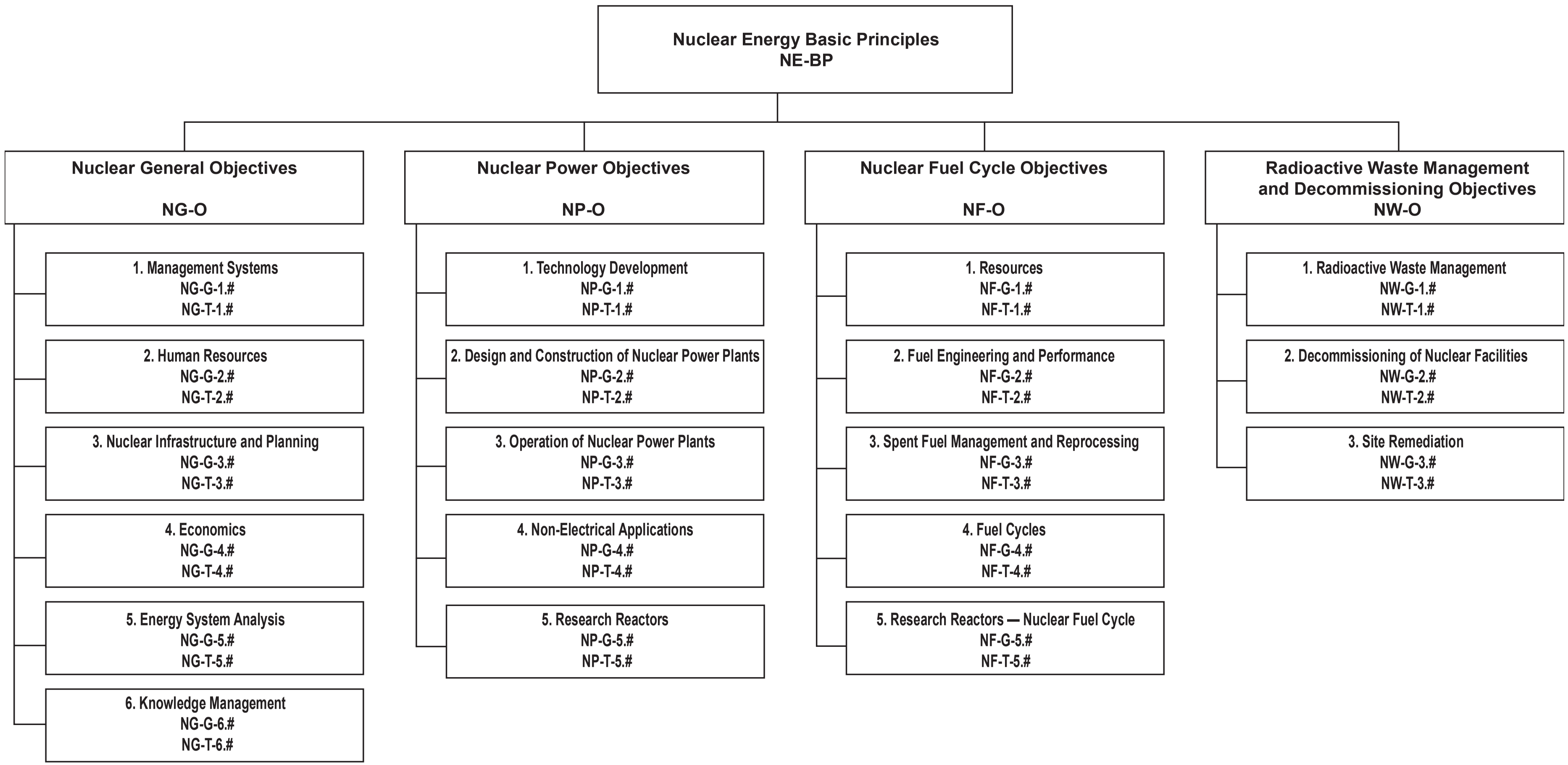

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