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IMPORTANCE OF ADVANCED PLANNING OF MANUFACTURING FOR NUCLEAR INDUSTRY

Nick Shykinov, Robert Rulko, Dariusz Mroz

Canadian Nuclear Safety Commission, Directorate of Assessment and Analysis, Canada

Corresponding author:
Nick Shykinov
Canadian Nuclear Safety Commission
P.O. Box 1046, Station B
Ottawa, Ontario, Canada K1P 5S9
phone: +1-613-996-8740
e-mail: Nick.Shykinov@canada.ca

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Abstract
In the context of energy demands by growing economies, climate changes, fossil fuel pricing volatility, and improved safety and performance of nuclear power plants, many countries express interest in expanding or acquiring nuclear power capacity. In the light of the increased interest in expanding nuclear power the supply chain for nuclear power projects has received more attention in recent years. The importance of the advanced planning of procurement and manufacturing of components of nuclear facilities is critical for these projects. Many of these components are often referred to as long-lead items. They may be equipment, products and systems that are identified to have a delivery time long enough to affect directly the overall timing of a project. In order to avoid negatively affecting the project schedule, these items may need to be sourced out or manufactured years before the beginning of the project. For nuclear facilities, long-lead items include physical components such as large pressure vessels, instrumentation and controls. They may also mean programs and management systems important to the safety of the facility. Authorized nuclear operator training, site evaluation programs, and procurement are some of the examples. The nuclear power industry must often meet very demanding construction and commissioning timelines, and proper advanced planning of the long-lead items helps manage risks to project completion time. For nuclear components there are regulatory and licensing considerations that need to be considered. A national nuclear regulator must be involved early to ensure the components will meet the national legal regulatory requirements. This paper will discuss timing considerations to address the regulatory compliance of nuclear long-lead items.

Keywords
component, construction, licensing, long-lead, nuclear, compliance, safety, regulation, procurement, design, standards.

Introduction

Over 430 nuclear reactors in the world generate electrical energy [1]. An increase in global nuclear power capacity up to 88 percent is projected for 2030. Interest in nuclear power remains strong in countries with fast growing energy needs [2]. The current world nuclear reactor fleet has a total nominal electric net capacity of over 330 gigawatts [3].

The global context of the growing economies, increase of energy demand, climate change, and fluctuating prices of fossil fuel raise interest in acquiring nuclear power capacity. Improved safety and performance of nuclear power plants are additional factors behind the advance of nuclear technologies. Technology development and innovation that will potentially result in deployment of advanced reactors continues.

In addition to the construction plans of new power reactors, some power companies and governments make the decision to extend the operating life of nuclear reactors by refurbishing them to meet electricity needs.

As of 2014, over 60 reactors were considered being under construction world-wide [4] (see Fig. 1 for distribution).

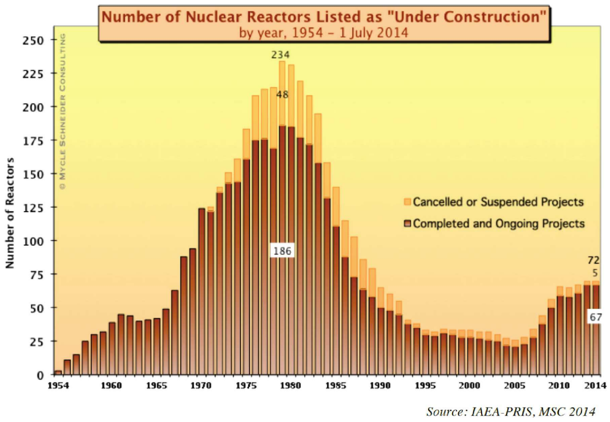

Fig. 1. Nuclear reactors under construction (Source: *World Nuclear Industry Status Report* 2014 [3]).

In the light of the increased interest in expanding nuclear power the manufacturing and supply chain for nuclear power projects has received more attention in recent years. As a result of some nuclear renaissance across the world, many manufacturers are entering this industry seeing significant opportunities in this growing market [4].

The objective of this paper is to provide information that may be helpful to project management and manufacturing in integrating successfully regulatory and safety aspects into the nuclear supply chain. The paper focus includes pre-licensing engagement, which should be considered to address regulatory compliance of the long-lead items for nuclear equipment design, manufacturing and delivery.

As it was comprehensively explained in a previous publication on this subject [5] any organization intending to build and operate a nuclear reactor facility requires a licence from its national nuclear regulatory body (nuclear regulator) mandated by national laws to regulate nuclear activities.

The International Atomic Energy Agency (IAEA) develops standards, fosters the exchange of scientific and technical information, and coordinates activities helping to ensure that the rigorous regulatory regime for safety is consistently applied to all the nuclear installations across the world [2, 6–10]. National regulators in the world are expected to regulate within robust regulatory frameworks consistent with international standards such as those promoted by the IAEA.

A regulatory framework continually evolves with the state of knowledge in the regulated industries. Specific to nuclear reactor based facilities, a balanced, efficient and transparent licensing process is used. National nuclear regulations typically provide requirements pertinent to ensuring safety, security and environmental protection. They may set timelines for regulatory reviews. Licensing requirements vary from country to country but generally address the same fundamental safety principles.

One of the key considerations for an organization seeking to construct and operate a nuclear facility is timely procurement of items which are critical for all nuclear systems. Well-planned activities towards construction and commissioning of a nuclear power plant (NPP) take typically up to 11-12 years. The average construction time of a unit is 7 years. The actual duration of a construction will depend on the complexity of the design and experience with a given technology. A typical timeline is shown in Fig. 2 (PSAR and FSAR stand for Preliminary and Final Safety Analysis Report respectively, usually required by a Regulatory Body).

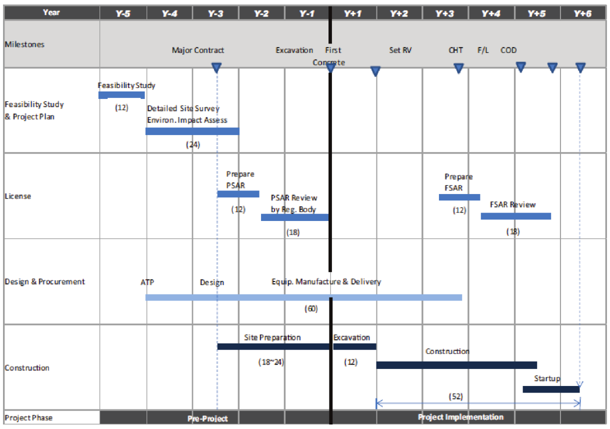

Fig. 2. Typical timeline of a nuclear plant construction and start-up project (Source: *IAEA, Project Management in Nuclear Power Plant Construction: Guidelines and Experience* [8]).

However, around 75 percent of nuclear reactors under construction worldwide are facing delays [3]. Eight reactors have been under construction for more than 20 years. The construction time of the last 37 reactors started up in 9 countries since 2004 ranged from 3.8 to 36.3 years [3].

The term long-lead items (LLI) refers to physical components equipment, products, and systems, as well as safety-important programs that are identified to have a long delivery time and can affect the overall time of a project. Their time to design, assemble, implement and verify may be longer than the construction time of the overall facility. These components may need to be designed, sourced and manufactured years before a project begins. Long-lead items include large reactor pressure vessels, steam generators, various types of heat exchangers, tanks, or instrumentation and control platforms. LLI can also include complex training programs, recruitment of qualified staff, and management systems.

Proper LLI planning is very important for maintaining plant safety, managing organizational asset, and making sound business decisions. Investment in a new NPP is significant.

Construction costs are a key determinant of the final nuclear electricity generating costs. Inaccurate business decision may lead to huge financial losses. Unanticipated changes in LLI design or fabrication may lead to additional delay and expenses. Therefore reactor vendors and LLI manufactures are intrinsically interested in getting early regulatory approvals for their product.

Globally, the nuclear industry is increasingly using modular design. This means that the supply chain for nuclear facilities is relying more and more on modules, complete systems, and large components that must be pre-ordered to meet a site construction schedule. The gradual introduction of modular reactor technology can turn the many components of the nuclear steam supply systems into long-lead items.

Timing of regulatory approvals of the NPP components must be properly incorporated into the manufacturing and construction planning to mitigate regulatory risks. Long-lead items can represent a substantive regulatory and economic risk to a project. For example, in Canada power plant components are usually not officially part of the licensing process until a formal application for a *Licence to construct* a reactor facility has been submitted to the nuclear regulator for detailed technical assessment.

When applying for a *Licence to construct* the applicant must demonstrate to the regulatory body that the proposed design of the facility meets applicable regulatory requirements. Safe operation of the facility on the designated site, over the full lifecycle of the facility, must be demonstrated before the NPP is authorised for construction (Fig. 3 depicts the major steps leading to an operational NPP).

The licence application is expected to contain the complete safety analysis and supporting technical data, as well as the management system for all activities associated with the facility. It is only during this detailed formal review that the full extent of safety implications of long-lead items can be considered in the integrated safety assessment of the facility.

Applicants should have plans in place to resolve any issues that could present potential barriers to licensing. Engagement with the regulator prior to the onset of the licensing process is important to understand and resolve such potential issues before becoming part of the licencing critical path. This paper uses interchangeably terms: "licensee", "proponent" and "applicant". "Proponent" or "applicant" may not be a "licensee". They may be "potential licensees" (but not necessarily) depending on a specific situation.

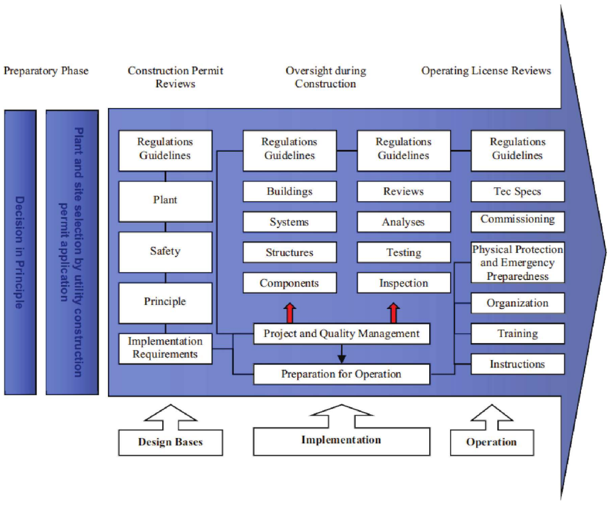

Fig. 3. Typical major steps leading to an NPP operation (Source: *IAEA, Project Management in Nuclear Power Plant Construction: Guidelines and Experience* [8]).

Many experienced national regulators have established pre-licensing processes to review key aspects related to the safety of a specific design. This is to ensure proponents understand which technical requirements should be applied for the proposed design including long-lead equipment. For example, in Canada, specific to nuclear reactor technologies, the Canadian Nuclear Safety Commission (CNSC) has a specific vendor-oriented pre-licensing design review process which can provide regulatory safety-related feedback to the vendor [5]. Term "vendor" refers to an organisation offering a reactor design. It may or may not be a "manufacturer" of the reactor. Usually it is not an "operator" or "licensee" of the reactor facility.

The focus of this paper is rather on the physical components as opposed to programs, processes, and management systems.

Facility structures, systems and components

Regulatory compliance of facility structures, systems and components

Nuclear plants contain hundreds of structures, systems and components (SSC) whose construction requires a reliable and diverse supplier base. Experience in the nuclear sector demonstrates that quality issues usually arise in long-lead items for novel plant designs. These issues may be safety-significant. Issues may also arise when a vendor with limited experience is engaged or innovative manufacturing technologies are introduced. It can take years to design and fabricate heavy forgings such as a reactor pressure vessel, coolant pumps, steam turbines or generators. Figure 4 below shows an example of a long-lead component – calandria of a CANDU reactor (calandria is a horizontal cylindrical vessel which has tubes inside for the nuclear fuel and circulating cooling water).

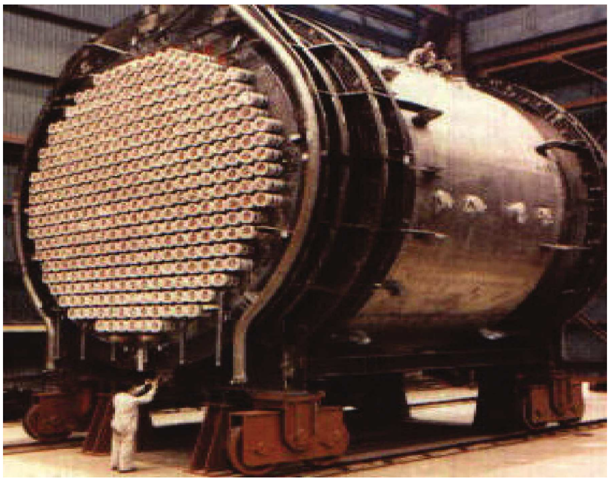

Fig. 4. CANDU reactor calandria
(Source: http://www.nuclearfaq.ca).

Instrumentation and control (I&C) architecture may be a potential problem area in licensing. It may lead to significant project delays due to regulatory issues and system rework. In part, issues result from the failure of reactor vendors to consult with the regulatory authority in advance. Often the proposed new I&C architectural concepts are likely to require significant evidence and convincing demonstration of safety. Early engagement with the regulator can improve an understanding of how safety principles associated with design can be addressed in an acceptable manner and timeframe.

One of the most significant issues arises when a technical code effective date for long-lead items comes under question due to major construction delays. As a result, the code effective dates for the completed plant, typically corresponding with the issuance of the Licence to construct, may differ by years from the versions initially applied to some long-lead items.

There is also a strong need for the future plant operator (generally the licensee) to exhibit strong "intelligent customer" ("smart buyer") capabilities in their supply chain activities. A "smart buyer" means in this context an organization that has a clear understanding and knowledge of the product or service supplied. The organization knows what is required, fully understands the need for services, specifies requirements, supervises the work and technically reviews the output.

Because the primary responsibility for the safety of a nuclear installation always rests with the licensee, it is the licensee who must retain the core capability to verify that long-lead items have been designed and fabricated to meet current safety and performance requirements.

The proponent's design and procurement organisations need to have the technical capabilities to engage with vendors to verify that their requirements are being met. This can include activities ranging from inspection of a vendor's management systems to field inspections of the vendor's work. In fact, it is a common practice for licensees to formally accredit suppliers through a comprehensive selection process. Supplier selection processes are typically encompassed within the licensing basis.

Pre-licensing engagement with nuclear regulators

The successful construction of new nuclear power plants depends on a robust supply chain and manufacturing. Nuclear manufacturers supply many components necessary to support current and future nuclear power projects including the long-lead items.

Integral to demonstration of safety of a specific SSC are the technical codes and standards applied to the design, manufacture and verification. Codes and standards contain generally accepted technical requirements and methodologies. When they are followed reasonable confidence that the SSC will perform its function reliably is assumed.

The regulator's role in the long-lead items procurement varies from country to country. Regulator's involvement can range from reviewing licensee's supply chain process including inspection practices, without visiting vendor's facilities, up to complete independent inspections at the vendor's site. In some cases regulators may require certification (accreditation) of vendor's facilities.

The management of the planning process for nuclear industries must include properly timed interactions with the nuclear regulator. Such planning must include consideration of the manufacturing aspects of long-lead items.

Regulatory risks can be reduced if a regulator can confirm early that licensee's procurement process, as well as the specifications supplied to the vendor will meet regulatory requirements resulting in compliant products.

Cooperative international regulatory efforts and experience sharing, such as Multinational Design Evaluation Programme (MDEP: https://www.oecd-nea.org/mdep) help understand better the rationale behind different national codes and standards; regulators' levels of involvement in inspections; and varying use of inspection findings for licensing reviews.

In general, nuclear regulators do not regulate manufacturing of the industrial components. However the nuclear industry usually takes measures to ensure the highest safety and quality standards of the procured parts. The industry follows international and national quality or management system standards to gauge and often accredit and certify their suppliers. National regulators may assist these certification/accreditation processes. There are international services, often peer-review based that help assure consistency and adherence to the best practice across the world. Manufacturers or vendors may request regulatory review of the proposed design solutions of their nuclear reactors and get timely feedback helping to improve safety of the design.

Compliance with industrial technical codes and standards will be an important part of safety demonstration. It is vital that an early agreement is reached with the national regulator on the acceptability of these codes and standards, especially for the safety-related long-lead items. This pre-licensing agreement would be based on a detailed technical review of technical information submitted by the applicant. The application would include the design basis, technical requirements, and the safety functions required. Subsequently, a regulatory confirmation of an absence of any barriers to proceed could be issued allowing the manufacturing to proceed. Some regulatory risk is still to be assumed by the applicant as the safety case for the complete plant is unlikely to be comprehensive at the time of the pre-licensing review. The applicable code and standard versions are likely to have changed by the beginning of plant construction. Technical standards usually undergo periodical systematic reviews by the issuing/maintaining organizations to ensure they stay current, technically valid, and harmonized globally.

Any differences between the new standard/code versions approved under the licence and the version to which the long-lead item might have been manufactured must be reconciled to the satisfaction of the regulatory body before the plant can be used. The objective of reconciliation is to demonstrate that the identified differences will not result in degraded safety. In addition, the applicant must confirm that the conditions, under which the long-lead item is required to function, remain valid. If the safety case has identified additional conditions, they must also be addressed and reconciled. Additional requirements may be specified to provide added assurance that safety performance requirements will be met.

If considering the application of a foreign safety code or standard the application for a long-lead item will need to address any gaps that exist between the chosen code and applicable country's codes and standards. The rationale behind codes and standards is typically founded on the country-of-origins' national legal framework (laws and regulations); industry operational experience; and research, development, science and technology programs.

Approach to inspections of vendors

Taking Canada as an example, an approach used for long-lead item vendor inspections is to request the licensee to lead technical inspections or quality audits of a vendor's facility, including acceptance of the processes and components delivered by the vendor. The licensee may choose to procure external inspection and audit services. Regulator's staff review and inspect the licensee's management system controls contained in their supply chain processes. This review would include sampling the licensee's procurement and design processes and capabilities which establish acceptance criteria for long-lead items.

Where the licensee uses an external inspection and audit organisation, it is important to understand that the licensee retains the accountability of the decision to accept the inspection results. Licensees' "intelligent customer" attributes are still necessary to understand the results produced by the external organisation. The licensee's procurement organisation is expected to have appropriate controls in place.

For familiarization with new and alternative technologies, the regulatory technical specialists confer with other national nuclear regulators who have performed inspections of specific vendors or have already acquired relevant experience. The exchange of lessons learned allows technical specialists and inspectors to focus on the most likely problem areas. This approach confirms the licensee is aware and addresses suitably the known weaknesses. In addition, regulatory staff can also investigate whether these trends or issues exist in other areas not yet reviewed by other regulators. The results of these inspections have been shared internationally to improve overall operational experience. The role of international collaboration in the experience exchange, and adopting the best global practice, cannot be underestimated.

For key long-lead items arriving at construction sites the Canadian regulator, CNSC plans sample-based field inspections to verify the licensees' vendor qualification process and the corresponding implementation of acceptance checks of the products delivered for installation.

Programs and processes with long-lead attributes

Scope of long-lead programs and processes

Whether a program or process is long-lead depends not only on when it is needed to fulfil the timeliness of the construction and commissioning schedule but also on its ultimate impact on the facility. The changing nature of how nuclear facilities are designed, built and operated world-wide is leading to many programs assuming the same traits as physical long-lead items. The programs themselves are mission-critical to licensing and to the overall project success.

Long-lead programs and processes are generally complex. They may require years to be established and properly staffed. They have to be in place well before certain site activities begin. Examples of such early items include:

- Processes to generate adequate and credible site evaluation data.
- Licensee's role as a design authority to set design requirements and to evaluate potential technologies.
- Licensee's procurement processes with early oversight of such activities as evaluation and technology selection.
- Operating training to set customer requirements for the facility before, during and after facility construction.
- Any future licensees' needs to plan for management program development and implementation.

Design authority is responsible for design control and ultimate technical adequacy of the design process. These responsibilities are applicable whether the process is conducted fully in-house, partially contracted to outside organizations, or fully contracted to outside organizations.

A plan developed by the customer organisation is needed to establish capacities for safety in key areas including:

- Licensee's safety analysis capabilities.
- Licensee's role in siting, construction, commissioning.
- Information management and technology infrastructure.
- Emergency planning and preparedness strategies.
- Waste management.
- Stakeholder relations.

Addressing long-lead programs and processes early

Lessons learned from new build projects around the world have shown that proactively planning and establishing well-supported long-lead programs and processes can improve readiness to enter into the licensing process and reduce project regulatory concerns during the execution phase. The Royal Academy of Engineering, Nuclear Lessons Learned highlights planning experiences for a number of new build NPP projects. The *Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) Working Group on the Regulation of New Reactors* (WGRNR: https://www.oecd-nea.org/nsd/cnra/wgrnr-pub.html) has also collected and discussed information on licensing experience from a number of projects around the world.

An authorized operator training program is an example of a long-lead item. Recognizing that licensing an authorized operator for a nuclear power plant can take years, the licensee should timely anticipate the training and related tools.

Operator training should interface with other programs where operators-in-training play a key role in the knowledge transfer from suppliers and contractors to the operating organisation. Establishing facilities, qualified instructors, training tools and materials must begin years before the operator training begins. Development of the operator training program needs to begin years before the construction licence is granted based on the assumed construction and commissioning dates.

Many nuclear regulators do not have the authority to compel a proponent to address such programs in a proactive manner prior to submitting an application for a licence. Licensee programs are normally assessed during the formal license application assessment process. The regulatory body will look for evidence that the programs meet requirements and will be in place on time to establish appropriate oversight of proposed activities. This also means that qualified persons will be deployed.

National regulators often use corresponding international standards, including those developed by the IAEA, as a basis to develop national regulatory documents and processes for their countries.

With some national variations, most developed countries use a nuclear facility licensing process similar to the one adopted in Canada (see Fig. 5).

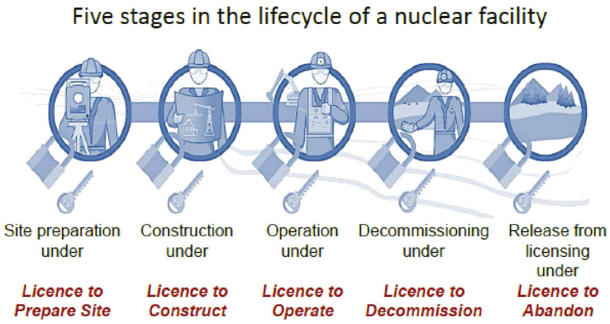

Fig. 5. Typical major stages of NPP licensing process (Source: www.nuclearsafety.ca).

A specific national regulatory infrastructure dictates particular details of licensing processes, including appropriate regulatory documents. For example the CNSC is publishing regulatory documents and additional guidance regarding the conduct of activities associated with construction, commissioning and operation of NPPs.

Pre-licensing engagement with the regulatory body

Regulatory risks can be reduced if a regulator has a chance to provide an early feedback on a proponent's proposed approach to long-lead items.

For example, the process discussed in the CNSC Regulatory Guide GD-385 [11] assures an early feedback against regulatory requirements on selected technical topics. During these reviews vendors receive regulatory feedback on the vendor's management programs and processes associated with design, safety analysis and associated research and development activities. If the vendor approaches the regulatory body in a timely manner an acceptable approach to manufacturing/procuring the long-lead items can also be clarified. This process is discussed at length in GD-385 [11].

A regulator's technical capacity to engage into high level specialized discussions with proponents seeking early feedback on specific proposals against regulatory requirements is required.

This feedback offers an early opinion on whether the proposed design and programs might present fundamental barriers to licensing. Additional work may be identified to meet the requirements.

This type of feedback allows the proponent to plan, develop and implement necessary corrective actions early to avoid more severe complications during the licensing process, or even worse difficulties during the licensed activities.

It is important, however, to recognize that the national regulatory body must always retain its regulatory independence [7] and cannot become part of the proponent's preparatory activities. Review outcomes from pre-licensing engagement do not result in formal acceptance of a proponent's approach and do not bind, or otherwise influence, decisions made by the decision-making regulatory entity responsible for licensing.

A cohesive management of the holistic logical integration planning of all the inputs to the project, regulatory consideration being critical for NPP construction, must be maintained. Figure 6 below illustrates dependencies among all the essential integration tasks.

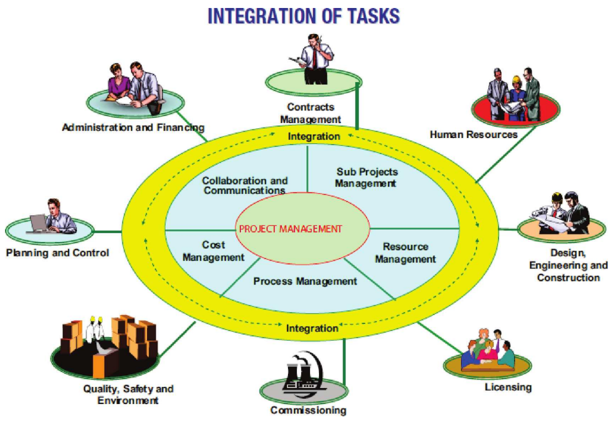

Fig. 6. Relation among essential integration tasks (Source: *IAEA, Project Management in Nuclear Power Plant Construction: Guidelines and Experience* [8]).

Conclusions

Considerable increase in global nuclear power capacity can be anticipated due to the growing energy supply demands of the emerging economies, climate change considerations and fossil fuel pricing.

Numerous nuclear projects have experienced delays or cancellations resulting in large cost overruns. Construction costs are a key determinant of the nuclear electricity costs.

Proper timing of the procurement of nuclear components in the regulatory context is key to the successful completion of a nuclear facility.

Due to the increasing pressure on the nuclear power industry to meet demanding construction and commissioning timelines more activities are being undertaken years in advance at the inception of the project to mitigate the risks to a project timeline.

Licensees, reactor vendors and LLI manufacturers could significantly decrease regulatory risk by addressing any potential fundamental barriers to licensing and ensuring meeting regulatory requirements for any NPP construction. Therefore, seeking an early feedback from corresponding national nuclear regulators is encouraged.

Manufacturers could facilitate early discussions between NPP proponents and regulatory authorities.

Each national nuclear regulatory body should consider having the following elements of their effective regulatory framework:

- Pre-licensing processes in place to review and approve design proposals, including long-lead items, against national safety requirements.
- Well-articulated formal requirements and guidance to reinforce the need for proponents to proactively establish key management systems and associated programs and processes before submitting an application for a licence to the regulator.

During the reviews and debates the national nuclear regulator must always retain its effective regulatory independence and cannot participate in the proponents' technical activities.

Reactor vendors or manufacturers are expected to be qualified to lead and oversee their proposed activities, and have robust management systems in place to enter the licensing process.

Review outcomes from such pre-licensing engagement are not a substitute for a formal licensing process and do not result in official acceptance of a proponent's approach. The conclusions must not bind, or otherwise influence, decisions made by the regulator's decision-making regulatory entity until the formal licensing process is set out.

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