Transactions, **SMiRT-22**
San Francisco, California, USA - August 18-23, 2013
Division VI

PROJECT MANAGEMENT IN NUCLEAR POWER PLANT CONSTRUCTION

Ki Sig Kang

Nuclear Power Division
Division of Nuclear Power
International Atomic Energy Agency

ABSTRACT As of December 2012, there were 437 nuclear power reactors in operation, with a total capacity of about 372 GW(e). The impact of the accident at the Fukushima Daiichi nuclear power plant was still felt in 2012 in the relatively low overall number of construction starts on new reactors. There were only four construction starts in 2012: Tianwan-3 in China, Shin-Ulchin-1 in the Republic of Korea, Baltiisk-1 in the Russian Federation, and Barakah-1 in the United Arab Emirates. Although similar to the 2011 figure, this is significantly fewer than in 2010, when the steady increase since 2003 reached its peak with 16 construction starts. Currently, 66 units from 15 countries are under construction in 'expanding' countries; the largest number since 1992.

Nuclear power plants are capital intense, high technology, complex systems and interfaces, not least because of the continuously evolving and increasing safety and quality requirements. Investment costs and their amortization make up the predominant part of the future power generation costs and effectively determine the competitiveness of the nuclear power option with power from fossil fuels or hydroelectric stations. High interest rates have made nuclear power plants particularly vulnerable through the steep cost escalation that results from unforeseen changes or delays.

Construction schedules of nuclear power plant, from the first placement of structural concrete to grid connections have ranged from less than five years to more than twelve years. Achieving short and accurately predicted construction durations is critical to the financial success of any new power plant project. This is one of the challenges facing the nuclear industry. As the recent experience in construction shows there is another challenge and this is the complexity of the vendor-customer relationship, length of the supply chain and the globalization of the nuclear industry. Thirty years ago nuclear power projects in the world took an average of 73 months from ground breaking to fuel load.

Although additional licensing requirements, public intervention and funding problems have been blamed for most of the delays and cost increases; lack of proper project management has been a major factor. Project management is a speciality primarily concerned with the definition, coordination and control of large undertakings, from the points of view of technical quality, schedule and costs.

Current proposed schedules from the evaluated vendors average 52 months. Because the difference between the previous and the proposed schedules is large, it is important to determine to what extent the proposed schedules may be relied upon, and to what extent there are risks that may be mitigated by further government and industry effort.

Improved steering, control and expediting of nuclear power plant projects by competent project management would reduce costs not only through more efficient work sequences and higher productivity but also through the reduction of accumulated financial obligations during construction.

Based on past proven practices in many Member States, this paper provides advice and guidance to project management from preparatory phase to plant turn over to commissioning for the construction of nuclear power plants.

1. BACKGROUND

There are excellent new nuclear plant constructions based on the experience of existing reactors around the world, and that could be deployed in the new nuclear power plant constructions. Readiness for deployment of new NPPs construction varies from design to design, based primarily on degree of design completion and status of regulatory approval and project management skill and competence. The current experience and lessons learned on management issues and country specific issues are introduced to avoid construction delays and improve quality.

2. CONSTRUCTION MANAGEMENT ISSUES

2.1 Selection of Local Suppliers

An Owner/Operator that is planning to enter the nuclear power arena will need to follow a number of gradual educational and training steps. A good starting point would be to learn about the safety, quality and qualification requirements for themselves and for any prospective supplier as well as specific regulatory requirements imposed on both Operators and Vendors.

Local suppliers may be either invited to expand their capabilities to include nuclear or to build it up from scratch. Opposition and reluctance to undergo the rigorous upgrades and training, the expansion and the economic burden that nuclear entails is to be expected, especially if the nuclear development program in the country is limited to one or two plants. Local suppliers may not be able to obtain a return on their investments if the scope of supply is limited and the intervals between orders are unsustainable. The Owner/Operator must keep in mind that the conventional industry has an outreach that is far greater than the nuclear industry and incentives may not be there.

A manufacturer or contractor willing to go through the nuclear qualification process will be looking for support. On the positive side, we should point out that with proven nuclear experience, suppliers will remain ahead of the competition in the nuclear field and having increased the quality and reliability of their products and services become more competitive in the conventional business as well.

A qualification program for local suppliers will entail the development of proper management system documentation, facility modifications or upgrades to comply with ISO 9001 and the establishment of a nuclear culture mindful of nuclear specific quality management requirements (IAEA-GS-R-3, CSA, ASME, RCC-M, KTA, etc.). Among these ASME Section III is the code most commonly used for the design, verification, fabrication, testing of a nuclear safety system. The staff involved in design and manufacture would have to be formally trained in applicable codes and standards, such as ASME, CSA, RCC-M, KTA, KEPIC.

In the project preparation phase, local suppliers very often get involved in providing elements or even large portions of the infrastructure needed to support a nuclear project. As nuclear reactor's life time cost is concentrated upfront as capital cost, and losses due to even one day of lost production is staggering, delays in construction become intolerable in terms of both lost revenues and interest on the capital. Consequently, Owner/Operator usually need a capable and qualified infrastructure to efficiently support construction, commissioning and start up activities.

The stakeholders involved in the regulatory approvals system are the owners or their designates, the regulatory authority, the investors, the operators, the installers / fabricators, the insurers, the designers/engineers/architects, various specialists and the jurisdictional authorities.

Most of the nuclear safety permits are obtained by the owners. They formulate their requirements to manufacturers and installers based on the requirements contained in the permits released by regulatory authority and jurisdictional authorities.

Interested suppliers, manufacturers or construction companies usually are required to prequalify for the services and materials they provide and depending on the contract type, the owner's representative i.e. the Architect/Engineer usually verify the suppliers ability to conform to nuclear procurement and installation requirements, prior to include them in their official tender lists.

It is therefore in the interest of a company new to nuclear to initiate its pre-qualification long before it submits its candidacy for nuclear related work. Usually the candidate supplier hires a nuclear consultant to guide its staff, represent the company with the owner, the quality representatives and the regulators and consequently accelerate the whole pre-qualification process.

Not all areas of a nuclear power station require the same qualification level. As an example, Owners/Operators may divide the plant into a number of sectors (or zones) as follows. Ref. [1]:

Sector 1 may be reserved to class 1 components:

For example the reactor core, its control systems, the reactor coolant system (RCS) and their supports systems. Codes and standards define the requirements for the materials, design, fabrication, examination, testing, inspection, installation, certification, stamping and overpressure protection of nuclear power plant components and their supports. The pumps, valves, metal vessels, systems, piping and core support structures are intended to function within the overall safety requirements of the nuclear power system.

Codes include design consideration such as mechanical and thermal stresses due to cyclic operation. They also provide the requirements for reactor vessels and concrete containments. In addition, they provide requirements for the transportation and containment of high level radioactive wastes.

Sector 2 may include safety related system such as the Containment System and the balance of systems and components inside containment.

This sector may contain all systems, including Electrical and I&C inside containment and inside the containment of the spent fuel storage. Excluded are the reactor core, its controls as well as the reactor coolant system. Depending on the system, the following may be required [16]:

- Material traceability
- Quality assurance programs such as ISO 9001 and other standards if applicable
- Submission of manufacturing procedures
- Submission of testing procedures
- Development of testing rigs
- Witnessed testing of components and systems as per specifications
- Complete documentation and update
- A registration number for all pressure boundary systems that may compromise the containment system even if they operate at low pressure.

Sector 3 may include for example the turbine generator and the steam system, and other systems.

The components in the turbine building, such as the feed-water heaters, re-heaters, condensers, pumps, storage tanks and cooling systems for the condensers and generator are included, but the Emergency Core Cooling System (ECCS) pumps and piping (if located in this building) is excluded because the ECCS is classified as a safety system. Codes and standards applicable to high pressure systems in class 3 require individual registration numbers and a quality assurance certificate as required.

Sector 4 may include all non-nuclear systems.

They do not affect directly the operation of the plant: any failures can be repaired while the plant is in operation. The requirements of a class 4 system are similar to “Best Engineering Practices” and with codes and standards used in the conventional industry (building codes, fire codes, electrical codes etc.). A Quality Assurance Standard, ISO or other applicable standards, will be required. Small and low pressure vessels, piping and systems do not normally require a Registration Certificate from the boiler and pressure vessel safety authority.

Local suppliers are usually part of a general agreement between the local government, the Owner/Operator and the NPP vendor. Their participation tends to be expressed in percentage of the total cost and includes scope for which local suppliers can qualify. Normally the Owner/Operator awards them contracts and subcontracts in proportion to their capabilities, whether their facilities are upgradeable to meet nuclear standards or whether their staff is trainable and to what extent. The selection is in general terms based on the following:

- The local supply of material and services can be brought up to required specification.
- As a minimum the selection includes only quality conscious suppliers.
- Their involvement is essential and the Owner/Operator should support them financially and technically if nothing else as a demonstration of their corporate social responsibility.

2.2 Bulk Material Management

Shortage of bulk material availability can become critical during the course of the project. Standardization of bulk material can reduce the issues related to the unavailability of material.

During the construction phase of the plant, the construction organizations will have to use a lot of bulk materials, including metal sections, welding electrodes, bolts, screws, nuts, washers, standard pipe, fittings and supports, conduits, lubricants, sealants, paints, non-destructive examination materials, chemicals (used for leak detection, cleaning, markings) consumables, concrete anchors, pull boxes, junction boxes, terminals, etc. As there is a very large range of products that can be purchased for the same purpose, the Architect Engineer or responsible contractors should establish a procurement policy to avoid the use of products not meeting the specified requirements.

Whenever specific qualifications are necessary, or stringent quality requirements are applicable, the responsible contractors should purchase the bulk material and free issue it to the construction organizations, to be used under strict control and according to clear instructions. An alternate option is to positively identify products that are pre-qualified (with specific catalogue data) and allow the contractors to buy them.

Special care should be taken when using chemicals that are coming in contact with high alloy steels, as they are sensitive to halogens or sulphur content.

Another issue related to some of these materials comes from the fact that they are used throughout the construction period, therefore preservation is necessary, otherwise the delivery schedule should meet the site needs (use the min-max approach), especially if their guaranteed shelf life is short. The following precautions should be adopted:

- Free issue of material that have stringent quality specification.
- Preservation of the materials received.
- Identification/ cataloguing and numbering.

2.3 Worker Turnover

Workers turnover is an issue to be considered in a construction site. Most of the construction jobs are non-permanent in nature. Skilled manpower is required in different numbers at various times. Skilled staff recruited by contractors and sub-contractors, tend to be even more volatile.

With large number of contractors and sub-contractors operating on site, turnover may reach numbers as high as 25 percent, which would mean that one-quarter of the workforce present at the site at the beginning of the year has left by the end of the year. Causes for high turnovers could be various. Minimizing the turnover will improve quality and help meet the safety requirements.

2.4 Construction Equipment

Contractors without previous nuclear experience may enter the field through the competitive bidding process. They may not be aware of the criticality of nuclear requirements, high quality level and precise documentation. In moving heavy loads overhead material handling equipment should meet strict nuclear regulations for heavy load handling equipment (above one ton). Dropping a heavy nuclear load such as a fuel cask could rupture the load structure, damage safe shutdown equipment, or even cause fatalities during construction. It is important that nuclear plant construction managers be vigilant in the use that contractors make of their equipment in order to prevent or at least reduce the likelihood of severely damaging accidents. Vigilance should be applied both in the design of their equipment, but also in the way they use it in the site. It is imperative that contractors respect the site rules in order to avoid future safety incidents during operation, interference, delays and encroachments. The design of equipment and material handling machines should be certified in accordance with codes specific to nuclear facilities, which should include requirements set by the regulatory authority to establish quality assurance and safety criteria for the design, construction, and operation of nuclear material handling equipment and systems. Large crawler cranes may facilitate installation. Requirements for construction of overhead and gantry cranes should meet safety standards addressing the issues important for nuclear facility cranes such as quality assurance, dynamic analysis, crane features, and other design criteria specific to the prevention of overloading and load dropping.

Test and measuring equipment should be arranged by the Owner/Operator and their calibration should be planned. Any tool and equipment required by contractors for brief applications should be made available at the site and given as free issue.

2.5 Massive Movements of People and Material

Depending on the location of the construction site it may be necessary to import large numbers of labour. Shortages may be a reality that must be faced. The lack of capable management and labour is a very real problem that should be studied in the preparatory phase of a nuclear programme. The development programme should not be started without a clear staffing plan.

One way to staff nuclear construction sites is to outsource jobs from nations that currently develop nuclear energy. As in most cyclical labour availability issues, as the construction of new nuclear power plants expands, the labour force will lack the necessary skills to perform the essential functions at construction sites. Once the labour force begins to flow in, first time training is a large and complex task that should be budgeted and planned.

In addition to training of new workers, experienced workers from contracting segments of the economy such as manufacturing (e.g., the auto industry) may be retrained in nuclear supplier or manufacturer. Construction workers may also be able to transition from the commercial and industrial markets to nuclear power industry construction. Programs should be in place to begin early training and certify the needed skilled labour. In addition retiring industry workers must be able to continue working and mentoring until adequate replacements can be found.

From a human resource management perspective, the needs of large numbers of a migratory labour force will then have to be met such as housing facilities near the site and in the townships surrounding the site as well as transportation. Private automobile and bus parking spaces would have to be provided. Longer distance commuting may be inevitable. Adequate security entry points will have to be designed for quick processing to suit the quantity and movement of people, an adequate number of washrooms in strategic locations and cafeteria facilities should be provided and their volume handling capability designed to avoid unnecessarily long down time.

Material handling management should be well organized in order to avoid delivery issues at the working stations and movements interference with other activities. Location of warehouses and transport routes should be adequately planned. This is especially important in tight sites as well as in large multi-unit sites.

2.6 Public Perception

Public relations is a task that requires continuing time and effort. The public at large (such as locals, professional associations, national and regional governmental organizations, etc.) should be invited to visit the site to presentations and discussions. Critics of the industry often have no apparent vested interest to do so, while the industry's responses may be easily discounted, as marred by conflicts of interests. Public acceptance depends to a large extent on these factors. The key to successful public relations lies in fostering transparency at all times. Keeping in touch with the media, distribution of the printed flyers, local paper advertisements, with job offers and training opportunities is crucial to the establishment of good relations.

2.7 Construction Phase Closure Activities

The closure of the construction phase includes all activities necessary to formally finalize the scope of the assigned work. A considerable investment of effort and resources should be planned for these activities. During this process, the following should occur Ref. [2]:

- Conduct a closing review of the scope and develop punch lists of all outstanding items.
- Obtain provisional and definitive acceptance by the utility of all deliverables included in the scope.
- Collect documentation, records and reports of the implemented processes.
- Archive all relevant project documents.
- Close contracts for procurement of products and services, including material warranties and workmanship guarantees.
- Document lessons learned and historical information.

Closure activities should not be delayed until after project completion. During the closure process, the utility may begin occupying and running completed portions of the plant even before the entire construction scope is completed. Ref [3-4].

3. COUNTRY REPORT SUMMARY

Following are highlights from the individual country experiences.

3.1 Legislation, Regulation and Planning Consents

Clear understanding of the safety requirements is essential to avoid delays during construction. The Owner/Operator and the regulatory authority need to discuss early enough how the national safety requirements can be best presented in the call for bids.

Understanding regulatory practices is essential for a successful project implementation. For ensuring smooth progress of the project, all parties (vendor, Owner/Operator and regulatory authority) should be familiar with the licensing, regulatory oversight, and inspection practices in both the customer country and as far as necessary in the vendor country.

3.2 Planning and Scheduling

In planning and scheduling new builds, it is necessary to recognize the different circumstances in each country.

- In Europe, Canada and the USA circumstances today are quite different from the 1970's when most of the currently operating plants were constructed: Vendors of the 1970´s had large

experienced organizations, with comprehensive in-house capability for design and manufacturing and less need for subcontractors and there was enough skilled manufacturing capacity in the market. Designs were often based on work done earlier in similar projects or reference plants and experienced project managers were available.
- The situation in India, Japan and Korea is different. Vendors and main contractors have been constructing NPPs without a break and have short supply chains in design, manufacturing, and construction.
- First of a kind and new generation reactor designs require additional effort regardless of the experience history in the country.

3.3 Design

If design work is conducted by different organisations and in different places (or even in different countries), good coordination and communication is vital for a successful outcome. Qualification of a new construction or manufacturing method may take time if it has not been tested or applied before the project starts, for instance:

- New advanced safety features are not easily implemented.
- New welding solutions were a challenge during the reactor pressure vessel manufacture, and additional evaluation and welding repairs became necessary.

Inadequate completion of design and engineering work prior to the start of construction is detrimental to the implementation of the project as per the target schedule. Lack of details in the design documentation leads to:

- Delays in the start of construction activities at full speed.
- Continuous pressures to all involved organizations.
- Attempts to reschedule the manufacturing and construction steps, thus further complicating project management.
- Reduced quality due to time pressure and often corrections and reassessment.

During the project development, information is created, accumulated, classified, stored, and transferred to the relevant parties, distributed and when necessary destroyed. It can be technical and project information (drawings, diagrams, tables, 3D models, descriptions, analysis reports, R&D reports, Bill of Materials, etc.), user related information (schedules, working processes, manpower, materials, resources, quality records, working materials). It is important that this information be accessible to all from designers through to all operational staff, and that the status of the model is controlled and clear to users at all times.

3.4 Construction and Manufacturing

Vendors and their sub-contractors have lost much knowledge and skill when experienced experts have retired. In addition, a new type of competence is needed for the new technologies. Thus, vendors need to establish new sub-contractor networks from companies with proven skills.

- A good name earned in the past by a company is no guarantee for success. In contrast, the experience and competence of the key persons assigned to the project becomes of the utmost importance.
- Awareness of nuclear quality and understanding of the nuclear safety culture must be taught to companies that have lost their nuclear experience or have no previous nuclear experience.

Preparedness of all parties must be ensured before starting the project implementation. In order to avoid delays and difficulties, it is necessary to allocate enough time and resources for the planning stage and to assess the preparedness of each party before starting construction. Each of the parties (vendor, Owner/Operator, regulatory authority) should assess whether:

- The Owner/Operator's capabilities and resources are adequate.
- The vendor capabilities and resources are adequate.
- The design has been done to a sufficient detailed level, as required for a controlled construction start and for smooth implementation.
- Qualified subcontractors are available as needed, and plans and contracts available for managing the subcontractor chains.

Both the Owner/Operator and the vendor must have:

- Project management and quality management skills.
- Experience from management of a large construction project.
- Knowledge and experience in all technical areas relevant for nuclear safety: civil, mechanical, electrical, and I&C engineering, and nuclear technologies (water chemistry, nuclear fuel, reactor physics, thermo-hydraulics, and safety analysis).
- Skills and arrangements to verify achievement of required quality.
- Arrangements to control and correct non-conformances.
- Experienced designers/engineers who have a realistic view on the actual challenges involved in construction and manufacturing.
- Access to manufacturers and constructors who have proven capability to meet the designer's intent and related specifications.

Experience and skills needed for a successful construction management team. In awarding contracts for construction, the following requirements underline the importance of proven experience from large projects. The selected contractor should know:

- How to schedule the work.
- How to manage the construction site.
- What resources are needed and when.
- How the vendor can find competent contractors and how it should manage them.
- How the Owner/Operator should conduct its oversight.

For ensuring good management of the subcontractor chains, it is important that in each call for tender for sub-contracts the vendor clearly indicates and emphasizes the nuclear specific practices, such as:

- Requirement to provide design documentation well in advance of the planned start date for manufacturing.
- Multiple quality controls and regulatory inspections to be conducted during manufacturing.
- Expectations about the safety culture and safety requirements.

If nuclear specific practices are not recognized and understood by the sub-contractors at the time of contract signature, difficulties are to be expected at a later stage. It has been noted that:

- The real competence of manufacturers and sub-contractors is not easy to judge through auditing only.
- Evaluation of the manufacturer's ability at the shop / factory is important.

- The vendor needs to ensure not only their sub-contractors uphold the nuclear quality standards but that its sub-contractors in turn require the same nuclear quality standard throughout the entire supply chain.

The Owner/Operator needs to have means to ascertain that the issues specific to nuclear safety and quality management, and the respective controls are properly agreed upon in each contract between the vendor and its sub-contractors, including the entire supply chain.

3.5 Commissioning and Operation

The transfer of responsibility and knowledge from the construction teams to the commissioning teams and on to operational staff can be facilitated by appointing commissioning and operations teams early and actively encouraging collaboration. Making equipment suppliers and installers responsible for the work and having commissioning staff as members of their team ensures that the right expertise is made available in a timely way, experience is gained and knowledge transferred. Ensuring that foreign material is prevented from entering the process systems and taking measures, prior to nuclear power generation, to reduce the corrosion products that could circulate through the core, will reduce radiation fields and operator dose that arise from subsequent operation of the plant. A lack of cleanliness during commissioning of either circuit can result in problems several decades into operation.

4. CONCLUSIONS AND RECOMMENDATIONS

Experience has shown that nuclear projects have faced challenges similar to other complex mega projects with additional specific issues. The major conclusions and recommendations are as follows:

- Assign high priority to safety and quality over cost and schedule;
- A regulatory framework should be established before launching the nuclear power project and the regulatory process is rigorous for nuclear power plants;
- First of a kind projects are more challenging, complex, and costly than follow on replica plant;
- Establish a high qualified project management team;
- The design must be mature, and licensing issues resolved prior to start of construction and sufficient project pre-planning done;
- Ensure that sub-contractors are of high quality and experienced in nuclear construction or are taught the necessary special skills and requirements for quality, traceability and documentation;
- Establish and maintain good communications with the public;
- The QA programme for the nuclear power industry is more stringent than for other industries. The QA programme interfaces the design, procurement, construction, manufacturing, installation and commissioning functions;
- The systematic generation, preservation, verification and administration of documentation is of a vital significance supporting the license configuration and traceability of the design and safety parameters for future modifications;
- Nuclear reactor’s life time cost is concentrated upfront as capital cost, and therefore delays in construction may become intolerable in terms of both lost revenues and interest on the capital;
- Security has a special significance at nuclear power plants and should be taken into consideration during the construction. Ref [5].

REFERECNES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Managing the First Nuclear Power Plant Project, IAEA-TECDOC-1555, IAEA, Vienna (2007).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Invitation and evaluation of bids for nuclear power plants, Nuclear Energy Series, No NG-T-3.9, IAEA, Vienna (2011).

[3] Fennovoima Press Release 06/05/2010, http://www.fennovoima.com/en/pressreleases/

[4] LAAKSONEN, J., Regulatory oversight of Olkiluoto 3 (EPR) construction lessons learned, 20th International Conference on Structural Mechanics in Reactor Technology, Espoo (2009).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Project Management in Nuclear Power Plant Construction: Guidelines and Experience, IAEA-NES NP-T-2.7, IAEA, Vienna (2012).