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PROJECT MANAGEMENT IN NUCLEAR POWER PLANT CONSTRUCTION: GUIDELINES AND EXPERIENCE

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

IAEA NUCLEAR ENERGY SERIES No. NP-T-2.7

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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.

As of December 2010, there were 441 nuclear power reactors in operation, with a total capacity of about 370 GW(e). After a slowdown in the construction of new nuclear power plants, there has been a marked increase in recent years in the number of Member States with operating nuclear power plants that are interested in building new plants. Currently, 65 units are under construction in 15 'expanding' countries, the largest number since 1992.

In 2010, construction started on 15 new nuclear power reactors, the largest number since 1987, and projections of future nuclear power growth were once again revised upwards. Nuclear power plants are capital intensive, employ high technology, and feature 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 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 as a result of the steep cost escalation that results from unforeseen changes or delays.

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 special area, concerned primarily with the definition, coordination and control of large undertakings from the point of view of technical quality, schedule and costs.

Improved direction, 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.

This report, based on past proven practices in many Member States, provides advice and guidance on project management from the preparatory phase to plant turnover to commissioning for the construction of nuclear power plants. With this guidance, it is hoped that project managers and their staff will be able to better manage nuclear power projects and help maintain nuclear power as a viable energy option.

This report builds on and updates Technical Reports Series No. 279, Nuclear Project Management: A Guidebook. As such, this report supersedes the earlier publication. The IAEA received generous support from several Member States in providing experts and submitting written material for this report. Appreciation is expressed for their valuable contributions. The IAEA is particularly grateful to the members of the working group who provided the main text, recommendations and comments relating to the purpose, content and form of the book.

The IAEA officer responsible for this publication was K.S. Kang of the Division of Nuclear Power.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

In the context of growing energy demands to fuel economic growth and development, climate change concerns and price volatility of fossil fuels, and in consideration of substantially improved safety and performance records of nuclear power plants, some 60 countries have expressed interest in considering, actively planning or expanding nuclear power.

As of December 2010, there were 441 nuclear power reactors in operation, with a total capacity of about 370 GW(e). Sixty five reactors were under construction, the largest number since 1992. In 2010, construction started on 15 new nuclear power reactors, the largest number since 1987, and projections of future nuclear power growth were once again revised upwards. Current expansion, as well as near term and long term growth prospects, remain centered in Asia. Of the 15 construction starts in 2010, 11 were in Asia. Thirty-seven of the 65 reactors under construction are in Asia, as were 30 of the last 41 new reactors to have been connected to the grid.

Construction schedules of nuclear power plants, 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 recent experience in construction shows, there are other challenges, such as: 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.

Current proposed schedules from the evaluated vendors average 52 months. Because there is a big difference between the previous and the proposed schedules, 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. [1].

Although additional licensing requirements, public intervention, suppliers and funding problems have been attributed to most of the delays and cost increases, it is recognized that the lack of proper project management skills is also one of the major factors for delay.

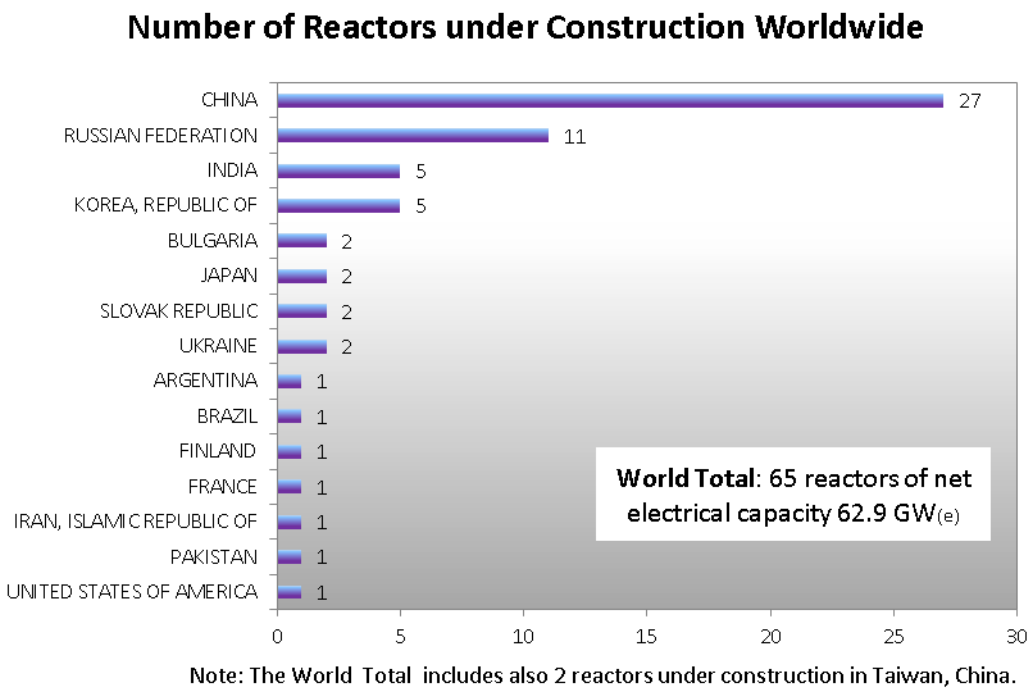

FIG. 1. Number of reactors under construction worldwide.

1.2. IMPLICATIONS OF THE FUKUSHIMA ACCIDENT

On March 11 2011, a nuclear accident took place at the Fukushima Daiichi nuclear power plant (NPP) in Japan, caused by a devastating magnitude 9 earthquake followed by a tsunami of unprecedented severity.

The earthquake and tsunami waves caused widespread devastation across large parts of Japan, causing the loss of 15 391 lives,8171 missing and many more people displaced from their homes; as towns and villages were either destroyed or swept away. Many aspects of Japan's infrastructure in the region have also been impaired by this devastation.

Several nuclear power facilities were affected by the severe ground motions and the large tsunami waves, namely Tokai Daini, Higashi Dori, Onagawa, and TEPCO's Fukushima Daiichi and Daini. The nuclear reactors at these facilities were successfully shut down as the earthquake hit and was detected by the automatic shutdown systems installed. Following the shutdown, also all available emergency diesel generator power systems went into operation, as per design.

However the large tsunami waves affected each nuclear facility in varying degrees, with the most serious consequences occurring at the Fukushima Daiichi plant. The waves reached the site about 46 minutes after the earthquake hit. The larger of these was estimated to be over 14 m high. It overwhelmed the facility defences, designed to withstand a maximum flood level of only 5.7 m. It reached areas deep within the units, causing the loss of all except one emergency diesel generator (6B), leaving the facility in a total blackout condition, with no other significant power source available either on site or off site, and little hope of prompt outside assistance.

The station blackout also meant the loss of all power to the emergency core cooling systems designed to remove decay heat from the reactor core after shutdown. The large magnitude 9 earthquake had also severely damaged the emergency cooling piping, taking the system de facto out of commission. In addition, even the post-accident monitoring instrumentation and control systems at reactors 1–4 were touched by the earthquake, which affected their reliability. Under these conditions, the reactors overheated and eventually underwent partial core meltdown which damaged their reactor vessel, from which radioactive material and contaminated water leaks were released into the environment. In addition, large quantities of hydrogen produced by the meltdown induced explosions that damaged the outer shell of two of the reactor buildings, exposing their containment structures.

At the same time, the fuel in the spent fuel pools also lacked cooling and power, resulting in overheating of the fuel bundles and consequent evaporation of the fuel submerging liquid, eventually exposing the bundles, which sustained severe fuel failures contributing to the radioactive releases into the environment. The only surviving emergency diesel 6B in unit 6 provided shared emergency power to the spent fuel pools of units 5 and 6. The reactors in those units were defueled at the time of the accident and hence they required no emergency cooling.

Nuclear accidents are perceived and considered as global issues, since they may have worldwide implications on agriculture, land use, fishery, tourism, transport and trade. The timely release of accident information to the public is of crucial importance, both to the nation where the accident occurred and to the international community and nuclear power organizations that can provide coordination and support in mitigating the accident consequences.

This publication was written pre-Fukushima and does not include lessons learned from that accident. It is therefore recommended that users of this report consider this fact and the additional requirements that may follow from the Fukushima experience. The sections most affected are those related to the pre-construction phase, when the final safety analysis report and the plant technical specification are finalized, the licensing parameters are fixed, including the maximum design flood levels, the site specific detail engineering is completed, the evacuation routes are traced, the designs of the emergency generators, of the administrative and engineering support buildings and other facilities are finalized, the excavation plans are completed, the intake and discharge canals are laid out, the design of the emergency cooling pumping station and its structures and components is finalized.

Details of the Fukushima accident are not completely known at this time. They will become clearer over time and lessons learned will be taken into consideration by NPP design and research organizations and by the project managers in all phases of a new nuclear power development programme; from the regulatory requirements, to the site selection phase, to the pre-construction and licensing phase and to all successive project implementation phases including construction, commissioning and operations.

1.3. OBJECTIVE

Project management is, by definition, an interfacing and an integrating activity and its description requires first an understanding of the associated functions such as engineering, quality assurance, procurement and accounting. This guide intends to address all relevant issues related to construction management of nuclear power plants and to introduce good management practices drawn from international experience which will allow commissioning to proceed promptly, safely and to high quality standards. Based on data available and information related to project management in construction of nuclear power plants, TRS No. 279 is no longer valid. This report builds on and updates TRS No. 279, Nuclear Project Management–A guidebook and TRS No. 279 is superseded and replaced with this report. Its main focal points are:

— Provide an effective guideline about construction management approaches to prospective owner organizations of countries that are embarking on their first nuclear power project under either a turnkey contractual approach or a split package approach;
— Define and explain the owners' duties in the preparation and execution phase of a nuclear programme with particular emphasis on construction management;
— Present advanced construction and scheduling methods and approaches that have been developed and successfully adopted in the past 25 years; including the growing use of computerized tools.

1.4. SCOPE

Project management comprises leadership functions such as primarily concern with the organization, coordination and control of large human, equipment and material undertakings, with the aim of achieving technical excellence, by working to quality standards, optimizing the schedule, the supply chain and minimizing costs. Competent project management can reduce costs through more efficient work sequences, higher productivity shorter activity durations and the parallel reduction of accumulated interest during construction.

This report covers all project management activities in nuclear power plant construction right from the preparatory phase to plant turn over to commissioning. The lessons learned during nuclear power plant construction were identified and included in the report to avoid costly surprises.

In addition, specific country reports describing the individual experiences of the various Member States can be found in Section 5 and Annex I.

1.5. USERS

The following organizations are foreseen as users of this guide:

— Owner/operator organizations;
— Regulatory authorities, and regulatory staff;
— NPP licensing specialists;
— Main Construction contractors;
— Architect-engineering organizations;
— Commissioning staff;
— Engineering consultants and construction consultants;
— Project managers;
— Planners and schedulers;
— Equipment Vendor organizations;
— Technical service support and training organizations.

1.6. STRUCTURE

This report consists of six (6) major areas explaining the main issues during nuclear power plant construction. Section 1 introduces the history and background of project management during nuclear power plant construction and Section 2 provides information related to the preparatory phases of construction such as planning, organization, engineering and licensing, risk and construction infrastructure. In Section 3, after concrete pouring, all major tasks such as manufacturing and erection, site management, construction work packages, quality management, project schedule control were described. In Section 4, commissioning phase activities were described with construction turn over approaches from construction team to commissioning team. The detailed commissioning and start-up activities are excluded in this report as the IAEA nuclear energy series on commissioning nuclear power plant focused on the technical and managerial issues on commissioning. In Section 5, experiences and lessons learned are introduced to provide a review of significant challenges and events related to construction from which specific guidance and recommendations may be made. Conclusions and recommendations are introduced in Section 6. The annexes contain country reports on construction from Brazil, Bulgaria, Canada, China, India, Japan, Republic of Korea, Romania, Russian Federation, and Slovakia.

2. CONSTRUCTION MANAGEMENT — PREPARATORY PHASE

2.1. PLANNING

2.1.1. Long term reactor deployment strategy

All countries today need to develop an energy plan that considers demand and supply, the necessary infrastructures, the overall goals of a national sustainable development policy. Once the decision that nuclear energy will be part of the country's energy mix, the country will need to select the most suitable reactor technology, the degree of infrastructure development required for the first plants. Nuclear power programmes are usually characterized by complex infrastructures and long life; easily extending over several generations. Developing or expanding nuclear energy requires extensive lead times and resources. Often the development of nuclear technology requires a parallel social and economic development, a culture of safety and protection of the environmental and effective government institutions.

Among the several criteria for selecting the size and type of reactor deployment, the existing grid size and the grid expansion plan will provide vital inputs. The long term fuel supply policy and the reliability of technological support for the long term will also govern the selection of the reactor technology.

Another decision in a comprehensive nuclear development plan is whether to adopt single or mixed technologies. Personnel training and spare part management becomes easier when a single technology is deployed. The deployment of multiple technologies on the other hand may reduce the risk of hidden technology weaknesses and of obsolescence that could exist when a single technology is selected. Multiple technologies may also provide greater bargaining power with technology vendors.

Ownership of nuclear power plants

Individual countries should establish a clear policy regarding the ownership of nuclear power plants. Often the ownership model assigns formal ownership to the utility with external government support. In this case, the utility must accept the entire responsibility for the material assets, the quality of the design, construction, operation and maintenance of the plant even if one or more of these activities have been offloaded to third parties. The utility is usually also the applicant for the construction license and becomes the licensee of the nuclear power plant. It is therefore in its own interest to establish an efficient mechanism for verifying the quality of the plant design and construction even for turnkey contracts.

2.1.2. Feasibility study

The feasibility study for a nuclear power plant project is the first step to determine whether the technology deployment is advantageous to the country and the most suitable characteristics and conditions for a possible plant. Consumer organizations and local residents should be invited to take part in the feasibility study of a nuclear power project. The study should include but not be limited to the following items:

- The current and the future capacity of the power transmission grid to help decide on the capacity of a possible nuclear power plant to connect to the grid;
- The availability of the necessary infrastructure in the country to support a nuclear power plant project, in terms of design capability, equipment fabrication, construction, operation and maintenance. This study should also help facilitate a decision regarding the technology to adopt and the size of the proposed nuclear power plant as well as the extent of the localization;
- The civil infrastructure like roads, bridges, power supply for construction and commissioning, land and water etc. (see 2.1.4: infrastructure development plan) the training capability available in the country for the creation of technical skills;
- The necessary laws and government policies to support nuclear projects and the necessary regulatory frame work to be developed.

Spent fuel management

Spent fuel management is an important subject to be tackled while launching a project. This topic also could form part of the feasibility study.

Nuclear liability

Nuclear liability is another important issue to be included in the feasibility study. A framework for damage compensation should be adopted. A good start could be the IAEA protocol to amend the 1963 Vienna Convention on Civil Liability for Nuclear Damage that sets the possible limit of the Operator's liability. In addition to Owner's liability, the Convention also defines on the subject of supplementary compensation the additional amounts to be provided through contributions by States Parties on the basis of installed nuclear capacity and UN rate of assessment. One simple solution could be that the operator levy part of the tariff of electricity generated by its nuclear plants to contribute to the nuclear liability fund.

2.1.3. Site selection and acquisition

The site selection criteria are normally defined by the regulators. IAEA publications, Site Evaluation for Nuclear Installations, Safety Requirement, IAEA-NS-R-3 [1] cover these aspects in much detail. There could however be several local factors beyond the regulatory guidelines which may impact the selection of a site for a nuclear power plant, such as:

- Proximity to large industrial consumers of electricity;
- Availability of skilled and semi-skilled manpower in the vicinity of the proposed plant;
- Adequacy of the approach roads or waterways for the transportation of over dimensioned equipment typical of nuclear power plants;
- Adequate water and power supply;
- Favourable perception regarding nuclear plants amidst the local population.

The lessons learnt from the recent experiences on the Fukushima Daiichi nuclear power plant should be considered during the decision making process in site section and acquisition.

2.1.4. Infrastructure development plan

The existing civil infrastructure at the proposed project site needs to be evaluated for adequacy and strengthened, if necessary, in a timely manner to allow an immediate start as soon as the project is launched. This includes housing facilities for the employees and their families, for the contractors' assets and personnel accommodation, storage yards, material transportation means, construction support, utilities such as water, gas and power.

The owner should work out a detailed time schedule for the creation of such an infrastructure. A first part may have to be executed as pre project activity and the remaining during the initial phase of the project.

2.1.5. Preparation of a detailed project report

The preparation of a Detailed Project Report (DPR) is an important step in the Pre-Project planning effort. The DPR should be a comprehensive report covering at least the following information:

- The technology selected for the proposed nuclear power plant and its relevance in the current scenario;
- If the technology has already been introduced in the country in previous projects, the DPR should examine the performance parameters which have been validated for these other plants and justify their continued relevance;
- The capacity of the plant and the reasons that dictated the capacity selection;
- Sourcing of the plant equipment and of the fuel;
- Ownership of the fuel including the spent fuel;
- Nuclear liability;
- Plant cost and the yearly budget;
- The sources of fund, the break-even point, the unit energy cost, and the return on investment period;
- The mode of execution of the project. It could be
  - Turnkey;
  - Engineering procurement and construction (EPC);
  - Procurement and construction (PC);
  - Construction (C) contracts.

Other contract types are also possible (see Section 2.4.2). Certain activities such as procurement of critical equipment may be done by the utility directly by awarding separate manufacturing contracts:

- Roles and responsibilities of the utilities and of the contractors may be discussed and laid out in the DPR;
- The life of the plant and the possibility of life extension at the end of the planned life may also be discussed. The possibility of technology obsolescence and the planning of countermeasures in such case may also be included;
- The human resource policy and the strength of the construction, commissioning and operation teams should be discussed in the DPR.

2.1.6. Environmental impact assessment

As a final step of the feasibility study, a scrutinized environmental assessment is performed. Typically, this assessment is categorized into three parts: a natural environmental impact assessment, a biological impact assessment and a socio-economic impact assessment. The environment impact of the nuclear power plant construction and operation should be assessed in totality including forest clearance, gas and chemical fluid release, vehicular traffic, and water use. The effect on the hot water release from the outfall structures on the marine flora and fauna should also be assessed in details. Clearance from appropriate authorities should be obtained before starting any site activity.

In addition to water and soil samples, milk and vegetable samples should be collected at regular intervals according to country regulations prior to launch of a nuclear power plant construction project to create base line data that will become a reference to compare environmental data changes after the plant is put into operation. If the local authorities request it, a health survey including sample collection on the population residing within a certain radius from the plant would be conducted and constitute a base line health survey for future reference.

An environmental impact statement and the clearance to proceed should be obtained from the appropriate authorities before starting any site activity.

2.2. ESTABLISHMENT OF THE PROJECT MANAGEMENT ORGANIZATION

Roles and responsibilities of project management in the realization of the nuclear power project are described in this section. A written instruction from the organization's top management announcing the appointment of the project manager should immediately follow the contract effective date (see Section 2.2.1). Since large amounts of materials and equipment must be ordered, manufactured and installed during this phase and the human resource profile reaches its peak, this is also when the largest part of the overall cost occurs and the highest degree of coordination is most necessary. It is during this phase that project management has to show its strength and use all the tools at its disposal. The phase begins with the contract effective date and ends with the handover of the completed and tested plant to the operating unit.

2.2.1. Definition and start of the project

Although project management activities are on-going from the pre-project phase to the execution phase, the contract effective date represents a major milestone in project work. The project ceases to be merely a planning exercise and becomes an actual implementation of construction and installation work in the field. Clear and well defined commitments should exist between the project partners and signed at the highest management level, expenditures begin to incur in orders of magnitude higher than before. Each day lost on a critical activity may now affect the schedule and cost. If a project management organization has not already been established by the contract effective date, the very first task should be that of appointing a project manager in each of the partner organizations, namely the Owner/Operator and the main contractor in a turnkey type contract and the Owner/Operator, the Architect/Engineer and the various contractors in a split package approach. It is, however, definitely preferable to appoint the project management team during the pre-contract phase and involve it in all pre-contract activities.

When the project manager is appointed, he or she should be officially introduced by a widely distributed project communication via the local area network (LAN) medium to the members of their own organization and to all project partners. Details of the overall project organization should be established and distributed to clearly indicate the key people in the organization and any relevant information to all project partners. Principle contact points and all senior staff members who have project responsibility (e.g. the licensing or QA manager) must also be made known. Organizational charts showing the project hierarchy inside and in partner organizations should be added as soon as they are made available. Project objectives, major project procedures, project code numbers for filing and documentation marking purposes reflecting the major budget areas, should also be made known as early as possible. It may be necessary to initially issue only the high level organizational structure and procedures and issue further details later in stages.

For the Owner/Operator, be it a public or private company, the contract means a substantial pledge of a major investment and a firm commitment to the partners. As the top executive level in the project, the Owner/Operator has the ultimate responsibility to ensure that the work is started and performed in accordance with project objectives and requirements. At the same time, since it holds the financial resources, the Owner/Operator has the means and power to control the work, to supervise the execution of the corresponding contracts and to delegate subsidiary tasks. The utility has also the responsibility to ensure that the requirements established by public authorities and/or by the regulatory body are met.

As ultimately responsible for the safe and reliable operation of the plant, the project manager for the Owner/Operator is responsible for the overall work coordination at the site and should oversee all aspects of the project, including:

— Establishment of all requirements;
— Target setting;
— Decision making;

— Communication processes;
— Monitoring and surveillance.

The Owner/Operator should provide channels of communications for all relations with governmental organizations that might be required in connection with the project, and the project manager should act as the communication link.

Regardless of the type of contract and of the partners, the utility project manager should first verify that his counterparts in other partner organizations are also in place. Every partner should be made fully aware of his or her role and responsibilities and the goods and services he or she is expected to provide. Even when a clear technical specification has been prepared there are often many details that need to be worked out before actual work can start.

The type of contract has little effect on the overall personnel requirements of a nuclear power plant project, but it does have a substantial influence on the distribution of personnel amongst the partners involved according to their particular functions and scope of work. It also affects the division of responsibilities and the distribution of the type and level of the staff in the various project management functions amongst the project partners.

For turnkey contracts where most of the execution work is delegated to main contractors, a typical Owner/Operator would require 50 to 100 engineering professionals involved in construction and installation support until operations takes over the plant. These numbers may vary with contract scope.

One of the first duties of the project manager for the main contractor is to make certain that realistic preliminary plans and schedules have been developed. A conflict may arise between the need to start work immediately and planning it first in more detail. The project manager should set priorities and resolve all conflicts in accordance with project goals, objectives and commitments. A summary of the contract information, in particular, the contractual level 2 schedule and/or the first draft level 3 plan based on it, should be distributed to every department involved as soon as the order is received.

Input from the line managers should be sought in the preparation of the level 3 schedules in order to minimize conflict. Involving the relevant departments in schedule and budget verification and in working out all relevant details is an important way of obtaining commitments and increasing motivation. Either the schedule diagrams or the tabular presentations of activities showing resources and scheduled dates should be issued to all line managers. This way, the affected sections and departments become aware of their interface commitments and are reminded of project milestones, obligations and objectives resulting from the contract. Apart from the schedule, budget aspects are also very important. A detailed project budget, based on the best available estimates, should be compiled and kept up to date during the duration of the project. It is one of the control parameters that the project manager needs to always keep in mind and report on.

Any estimate that appears incompatible with project objectives or unrealistic should be questioned immediately and difficulties resolved. From the schedules, the Work Breakdown Structure (WBS) should be worked out (see Section 3.4 for specific details on the WBS). Finally, the leading project tasks should be formally authorized.

In summary, the major aspects that require special attention at the start of a project are:

— Assignment of the project managers and establishment of the project organization charts;
— Issuance of project procedures, project numbering schemes and budget codes;
— Refinement of the project schedule and budget;
— Definition of the project requirements, in particular of the applicable codes and regulations;
— Authorization of the leading tasks;
— Setting up of the Work Breakdown Structure, authorization and assignment of work activities.

2.2.2. Organizational structure

The project management organization of the Owner/Operator is usually established at the start of the preparatory phase and the contractor’s organization is formally established after the authorization to proceed or the award of the contract. In the case of turnkey contracts with the main responsibility delegated to the main contractor, Fig. 2 shows a typical organizational structure for the project management team of the Owner/Operator, and Fig. 3 shows the corresponding structure for the project management team of the main contractor.

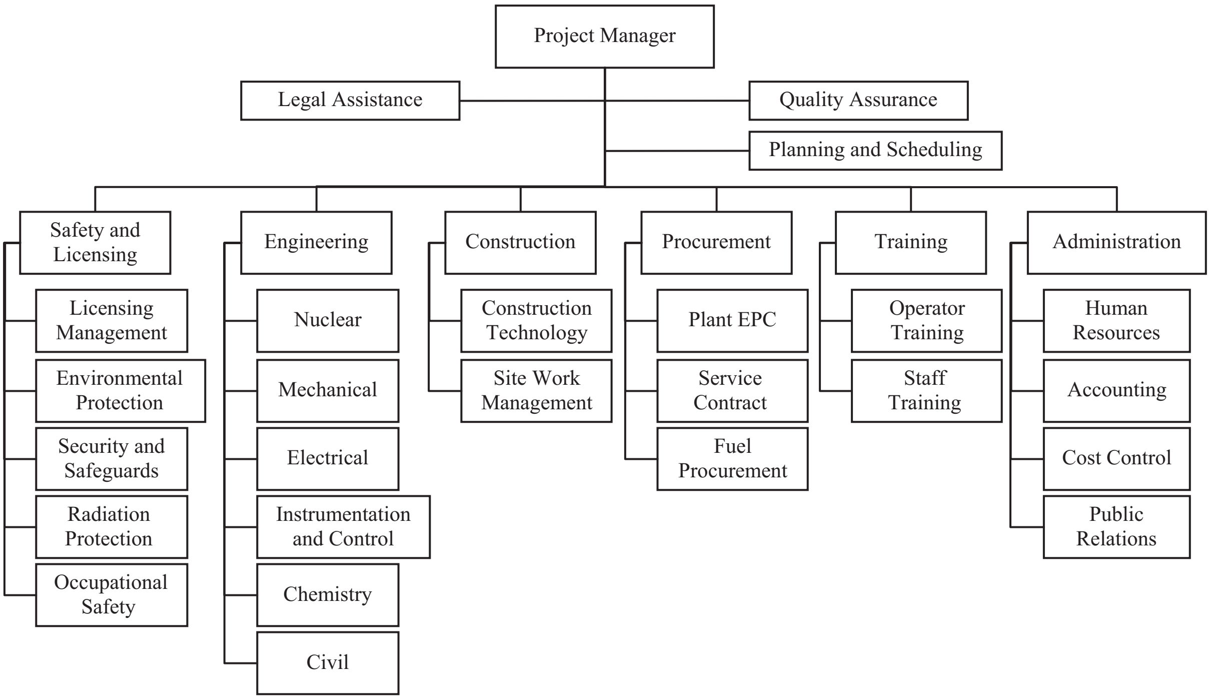

FIG. 2. Example of an organizational structure for project management team of the Owner/Operator.

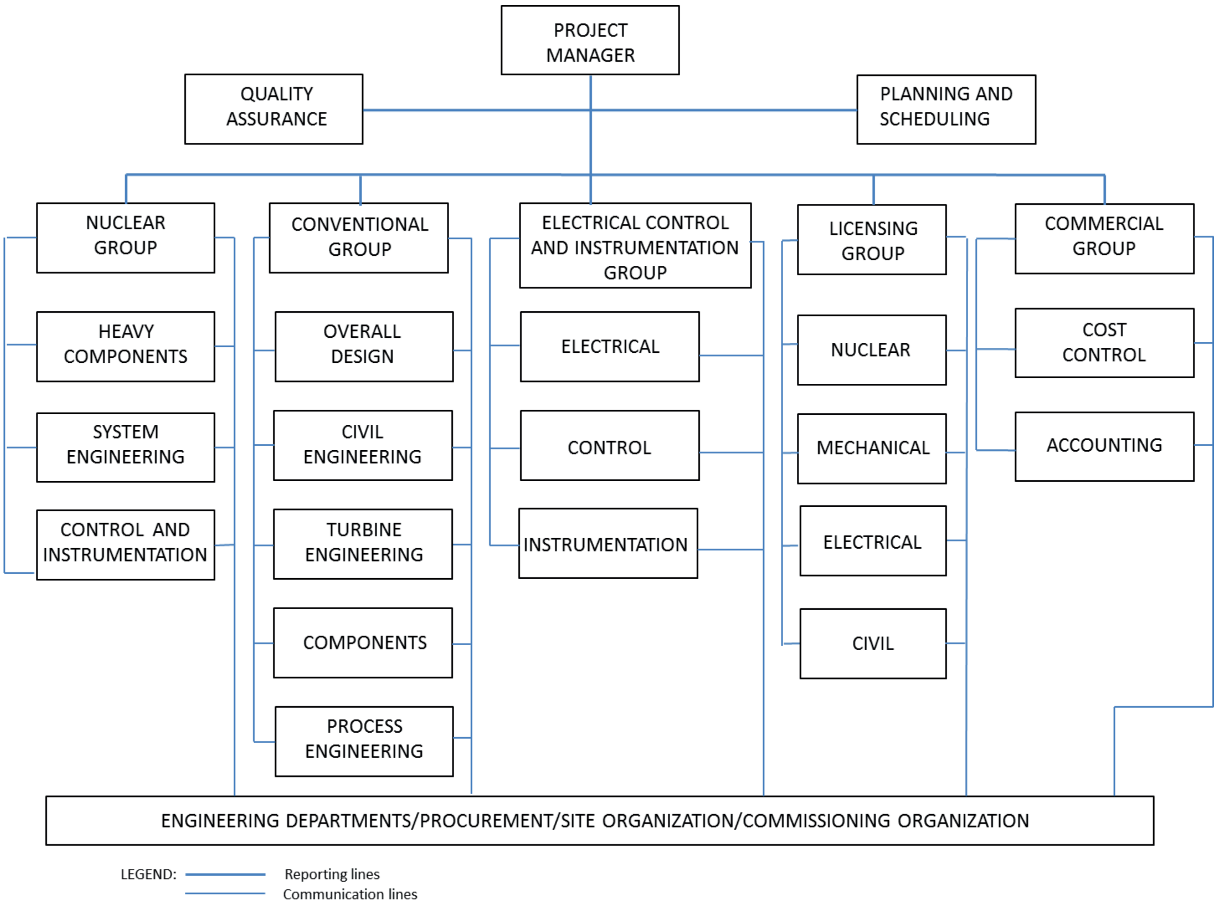

FIG. 3. Example of an organizational structure for the project management team of the main contractor.

In a split package approach, the Architect/Engineer under contract to the Owner/Operator should also set up and/or expand his project management organization when starting contract work. Depending on the type of contract, the architect/engineer may perform certain construction tasks in cooperation with the Owner/Operator or autonomously on its behalf.

The leading role in project management should be in the hands of the Owner/Operator which has overall responsibility for the project in all phases and usually assumes ownership and operation of the plant. The degree of involvement and therefore the human resource requirements depends upon the division of responsibilities established in the contracts. It usually is in harmony with the national development plans. The Owner/Operator accepts supervision from the public authority and the regulatory body in drawing up its contracts with the architect/engineers, the contractors and subcontractors representing the different industrial sectors, with foreign consultants and equipment manufacturers as needed. The utility and its project manager will then monitor and control the partners' compliance with the contracts, report to the regulatory authority, the local authority and generally takes the lead in conflict resolution, should disagreements arise.

The responsibility of project management in a large partner organization differs from that of the project management of the Owner/Operator because of the different levels of responsibility, the much larger volume of work and the higher degree of on the job proficiency required. Unlike the utility, the contractor neither owns the plant nor has to operate it. The contractor must fulfil its contract obligations within the given constraint of schedule, costs, warranties, etc. and do this at a profit. At the same time the organization's reputation in regards to its product and performance is at stake. It requires the constant commitment of its project manager to ensure the required technical quality, the correct plans, procedures and specifications and the implementation of effective project controls.

In a turnkey contract, especially for the first nuclear power project, all engineering and construction activities are usually delegated and the Owner/Operator remains responsible for the following typical tasks:

- Preparing, reviewing and adapting the necessary project planning and implementation schedules;
- Preparing local infrastructure such as emergency preparedness plan, hospital, information centre, etc;
- Preparing a public education and awareness programme on operations, incidents, accidents, radiation exposure, etc;
- Preparing the environmental reference data set;
- Establishing the overall requirements, monitoring progress and approving the main engineering tasks;
- Assuring timely delivery of items within the utility's scope of supply;
- Ensuring the transportation of equipment and the availability of site services;
- Carrying out or expediting services;
- Maintaining effective project cost control;
- Disburse interim progress payments;
- Authorizing payment of invoices from suppliers;
- Preparing and issuing progress reports;
- Carrying out plant design reviews to ensure adherence to contractual conditions and regulatory requirements;
- Introducing and coordinating quality assurance programmes (integrated management systems);
- Reviewing quality assurance programme of all contractor(s);
- Ensuring quality control and proper construction supervision at the plant site;
- Conducting surveillance of component manufacturing;
- Preparing for commissioning and operation;
- Applying for plant licences and revisions;
- Interface with local authorities;
- Reviewing and approving plant safety and engineering procedures, as well as plant operation and maintenance manuals;
- Training operations personnel;
- Implementing plant security plan;
- Preparing for commissioning and operation;
- Supervising plant commissioning and reviewing test results.

The monitoring of expenditures and the budget updates should be accompanied by technical supervision extending to approval of specifications, drawings and purchase orders, certification of work performed, inspections and quality control, provisional and final acceptance, study of discrepancies and corrective action, preparation of reports and most importantly, the management of the contracts themselves, their administration and enforcement.

The responsibilities undertaken by the project management of the Owner/Operator are:

- Supplying interfacing information and progress reports on work within the scope of the utility;
- Controlling the overall schedule and ensuring that only one valid schedule is being used by all project partners;
- Evaluating alternative options originating from the main contractor during the early development of the engineering work, or assessing necessary changes;
- Approving the list of qualified subcontractors put forward by the main contractor;
- Checking the bids received within the scope of the utility;
- Reviewing and approving project requirements, key analytical reports, drawings and technical specifications;
- Approving subcontracts or contract amendments, as needed;
- Supervising the administration and execution of contracts delegated to the main contractor and/or architect-engineer;
- Verifying compliance of design and manufacture within the established project requirements;
- Fulfilling all licensing requirements.

Independently of the contract, the details of cost control, disbursements, interest payments and other financial transactions are the responsibility of the Owner/Operator and must be clearly defined. Finally, the utility project management must be aware during planning and execution of the project of future responsibility for the operation of the plant. This involves the proper preparation for operation and maintenance, the securing of appropriate documentation and the drawing up of plans for the supply of spare parts.

In a turnkey contract, the responsibility for the design, engineering, construction and operability of the plant would normally lie with one main contractor or with a consortium of partners. Within the main contractor organization, its project management is in charge of the project technical and commercial success, and in this function it acts as an arm of the executive management. With respect to the other project partners, the project manager of the Owner/Operator is the main spokesman, the information link with its own executive on project matters and sometimes on company matters. A cooperative and business like relationship between project managers of the utility and those of the main contractor is essential. In general, the project management of the main contractor must pursue the main objective of producing a high quality, reliable product within the constraints of schedule, budget and project requirements. This includes:

- Defining the project requirements resulting from contractual terms with the project partners;
- Establishing a project work breakdown and allocate the project budget through individual project task orders;
- Defining the sequence of activities and initiate the activities in agreement with the sections and departments involved and ensure the availability of funds and personnel power;
- Dealing with problems that may hinder progress or threaten quality, providing problem solving assistance and leadership where needed;
- Establishing a project risk analysis team and risk reduction programme;
- Conducting separate regular meetings with project staff, line organizations and project partners in order to monitor progress, take any necessary corrective action and communicate essential project information;
- Monitoring expenses and project performance against budget and schedule, and obtaining proper authorization for major changes;
- Monitoring adherence to specifications and drawings by ensuring compliance with project requirements;
- Coordinating project activities and managing project interfaces inside and outside the organization;
- Authorizing specifications for manufacturing and installation of equipment;
- Setting up purchasing procedures and controls;
- Expediting engineering and subcontractor deliveries, ensuring that import procedures and custom formalities are followed;

— Ensuring timely and proper preparation of licensing documentation and applications as well as compliance to procedures;
— Monitoring and controlling costs;
— Ensuring progress payments are disbursed on time, preparing claims for justified price changes;
— Establishing a quality assurance programme (management system) and a quality control system and helping perform quality control tasks;
— Providing proper interfacing and transfer of information and assistance to site management and to the Owner/Operator;
— Reporting progress at regular intervals;
— The contracting, subcontracts;
— Experience;
— Industrial safety.

In addition to the project management organizations established within the utility and the contractor organizations, the establishment of task teams made up of staff from the utility and from the contractors organizations are worth considering for critical tasks in which close cooperation is essential. One example is an integrated schedule adherence team to control interfaces between the utility and the contractors and to tackle emerging schedule issues. A team leader would lead such a team consisting of members from the schedule control teams of each organization.

2.2.3. Implementation of management rules and procedures

A project the size of a nuclear power plant is made up of a number of large organizations. The project manager in each partner organization should be carefully selected before the pre-contract and contract phases. The hierarchical level below the project manager should include section and department heads in charge of typical technical specialities in a nuclear power plant.

The implementation of top management directives, the control of the project and the communication of decisions are on-going tasks during the project execution phase, but they are particularly important at the beginning. As far as possible, front-end task definitions should be decided and communicated early, even if corrections have to be made later. The translation of contractual terms into actual project requirements usually involves a special effort on the part of the project management team. Whatever is decided and detailed in a permanently valid form regarding the project organization charts, roles and responsibilities and the rules governing the hierarchical and lateral relationships should be established in writing and collected in an appropriate document; i.e. in a project manual. Wherever possible, organizational charts should also be made available and kept up to date online. The objective of a project manual is to make readily available the rules governing the relations and task distributions between the various participating departments and other project partners. The characteristics of such a project manual can be outlined as follows:

— The rules described in the manual should be compulsory for all organizational entities over which management holds authority;
— The project manual of each of the partners should observe the hierarchy of project contracts and partners; i.e. establish who is holding what type of funding and approval authority in which type of contract. The manual of the Owner/Operator may serve as a general guide for the architect/engineer, the main contractor and the various consultants, as needed;
— The manual should include a procedure for its own modification and updating;
— The manual should refer to the rules of engagement with other project partners, in particular the communication rules and the approval channels, without necessarily referring in detail to their internal partner organization;
— The Owner/Operator should discuss the contents of the manual with the main project partners, or at least with the main contractor or with the architect/engineer and the contractors.

Just as there is an organizational hierarchy for the project management among the project partners, there is also a hierarchy in the project documents (procedures and manuals). While the utility would have the lead in compiling the general portions of the project manual, other partners should add details and refer to their own internal processes. If one of the project partners is a consortium, there would most likely be a further hierarchy of project management and documentation flowing from the consortium level to that of individual organizations.

There is also a need for a manual that references the internal procedures of each of the project partner organizations. It is recommended that project specifics be outlined and proper reference made to other more general (higher level) procedures of the organization. If in some particular case or for some specific purpose the standard procedures are not sufficient, specific project instructions should be prepared. These should be written following the directions of the project manager. They may be collected in a project manual.

The project manual may also be in the form of a set of manuals, for example:

— Project reference information;
— Project procedures;
— Internal procedures and guides;
— Codes, standards and regulatory requirements.

The sections of the manual applicable to quality assurance (QA) should have the approval of the appropriate QA units within the partner organization. Sometimes the project manual (or portions thereof) may be part of the project QA programme. In such cases, a controlled distribution and a change control procedure that complies with regulatory requirements should be established and enforcement of the manual should comply with regulatory requirements.

2.2.4. Project integration management

Integration is a term widely used in engineering and management and depending on the context it can mean different things. Difficulties in the execution of nuclear projects have often been associated with a lack of project integration. Project integration in management entails making choices about resource allocation, negotiating trade-offs, selecting methodologies and alternatives, and managing the interdependencies among the processes involved.

At the very basic hardware level, system integration is primarily an engineering task, accompanied by supporting measures from project management. Product, system or engineering integration is not to be underestimated in the roster of a project manager. The plant must come together as per the design intent and function reliably and safely despite the fact that many different organizations may be involved in its construction and in the manufacturing of its components.

Integration for the project manager also poses a challenge at the human resources level. When the project manager exerts a conciliatory function, such as resolving a miscommunication issue, weighing in on a situation requiring conflict resolution skills, that manager has exercised an integrating function. Management, in general, should always thrive to harmonize actions of the various groups and keep the project moving, no matter how difficult or divisive a problem may become. Frequent communication within the group and between the group members and the project manager are the best assurance of sound project integration at this level.

At the project management level in each partner organization, integration means that the project manager should provide enough leadership to ensure that the group acts with one mind and speaks with one voice, when it comes to project objectives, strategy, procedures, communications, etc.

The ultimate and most complex aspect of project integration is coordination among the project partners. Project failures have often occurred as a result of uncooperative attitudes, differing objectives, differences in understanding the contractual roles of the partners and in the reporting relationships with senior management. It is necessary, that the project management of the Owner/Operator takes steps to find common ground or even compromises between partners in the resolution of potentially damaging conflicts of interest and to always harmonize decisions and actions to be taken.

In order to achieve overall project integration, it is essential that all partners recognize the project management hierarchy. Such a hierarchy may be obvious in a consortium, where the General Project Manager may have the final say on certain objectives, procedures or decisions which affect the entire consortium. This is usually recognized even though the project managers of the various partner organizations do not directly report to the General Project Manager but to the senior management of their respective organizations. A more complex relationship may be the one between the project management of the Owner/Operator and its contractors. Even if not formalized, a hierarchy should be de facto recognized at common project meetings. In such meetings, the project manager of the Owner/Operator should take the lead and should have the final say, particularly when utility directives must be enforced or approvals are needed.

The recognition of a hierarchy, the holding of regular meetings with the partners, the establishment of effective communications and problem solving mechanisms provide effective project management integration between the Owner/Operator and the partners and among the partners themselves.

Questions of seniority, salary level or reporting relationships with a partner organization should play a secondary role in project integration, since the project managers of the partner companies generally have a matrix type organization which requires the project manager to cooperate with the line and seek the consent of the engineering and manufacturing organizations at many different levels, sometimes higher, sometimes lower than that of the project manager.

In summary, integration throughout the project is best ensured by:

— Clearly stated project requirements;
— Harmonized project management objectives;
— Recognized hierarchy for decision making;
— Clear communication paths;
— Common, up to date, well structured and compatible project schedules;
— Cooperative, business like working relationships.

Project management integration must also be reflected throughout the project. Maintaining a logical and complete integration in planning, budget distribution, execution, monitoring and controlling activities for regular and newly introduced tasks or changes is a constant challenge to project management. Priorities have to be frequently reviewed to maintain good performance in terms of schedule and costs. Continuity in project management personnel can help significantly in maintaining strong integration throughout the construction period.

Figure 4 shows the relationship among the main integration tasks. This concept applies to the Owner/Operator, the main contractors and any other partner organization.

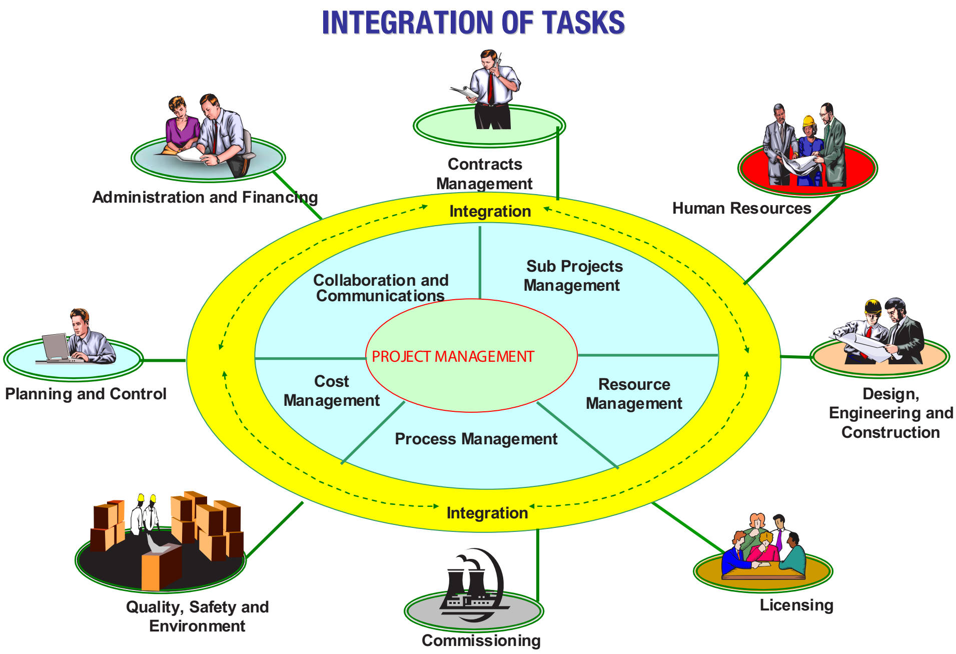

FIG. 4. Relations among main integration tasks.

2.2.5. Project communications management

One of the first steps that a project manager should take is to set up an efficient communication system. This should certainly be even more pressing when project partner organizations are separated from one another or when offices, even within one organization, are scattered throughout the territory. The project manager of the Owner/Operator should naturally be the person to initiate this work.

The project managers may have to set up first rudimentary communication procedures, to be expanded and detailed later as the volume of project communications increases. A lack of well-established communication procedures can cause substantial logistical problems and delays. It would be wise for all project managers to harmonize the main project communication tools among themselves, such as project designations, correspondence procedures and documentation standards. The establishment of regular progress meetings within each partner organization and among project partners should also be set up as soon as possible.

The project communications tools should include the processes required to ensure timely and appropriate generation, collection, distribution, storage, retrieval, and ultimate disposition of project information. [4, 5]

The basic processes to be developed are:

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

2.2.6. Project information management using information technologies

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, BOM etc.), enterprise or user related information (schedules, working processes, personnel power, materials, resources, quality records, working materials) or it can be information contained in contracts (project budget, timelines, supply deadlines).

Information may relate to various stages of an NPP construction project and at each stage there is information that must be transferred to the following stage in order to consolidate it within the body of mandatory documentation collected during the whole NPP lifecycle. It is therefore important to ensure that the information passing through various stages of an NPP construction project is compatible, correct, complete and up to date. Given the considerable length of an NPP lifecycle (60–80 years) such information must be maintainable, reproducible, and compatible with technology changes in terms of its form, contents, storage and integration.

Therefore, modern methods of information management in the development and construction of an NPP are based on the following principles:

— All information required during the NPP lifecycle must be clear and devoid of ambiguity;
— The form in which the information is presented must be unified and standardized;
— Any configuration management system must ensure that the existing version is constantly kept up to date, approved and relevant;
— Information is accessible only to authorized parties.

Nowadays information and communication are managed by means of computerized and electronic data management systems normally referred to as information technology (IT), which covers virtually all aspects of project management including requirements management, project schedule, working process, engineering data and documentation, design changes, resource, finance, asset and operational management. A modern NPP construction

FIG. 5. Information environment of the NPP project.

Note: MRO: Maintenance, repair and overhaul systems
PLM: Plant life management
AEC: Automatic engineering computer aided SW

project should be carried out in an electronic information environment which ensures effective interaction of all project participants (Fig. 5).

The current computer aided modelling techniques of physical, technological and logistical processes helped increase significantly the efficiency of the NPP construction processes, and the quality of the project as a whole. They helped reduce its cost as a result of fewer errors, corrections and rework during construction. Current trends in this area allow the use of electronically structured documents during installation which provide the latest up to date versions of the project data, interactive manuals for equipment assembly and operations. Accordingly, the installation of SSCs can be organized with the extensive use of mathematical models during the physical installation of equipment and components and so minimize hard and soft interference issues, simplify absolute and relative measurements, and help with the visualization of spatial relationships the verification of end results.

Modern information management technologies require special attention in the development of human resources. Careful staff selection, its organization and training, the distribution of project information to the staff is all very important and should be handled making use of modelling techniques. All personnel who use information management systems must be provided with the required instruments, the machinery, the software and the manuals to ensure correct and effective completion of their tasks (Fig. 6).

2.3. ENGINEERING MANAGEMENT

Engineering of a nuclear power plant starts from the conceptual planning of the plant and continues with detail engineering and engineering support during plant construction. This section mainly focuses on the management of essential engineering activities. Detail design solutions are developed from the standard product,

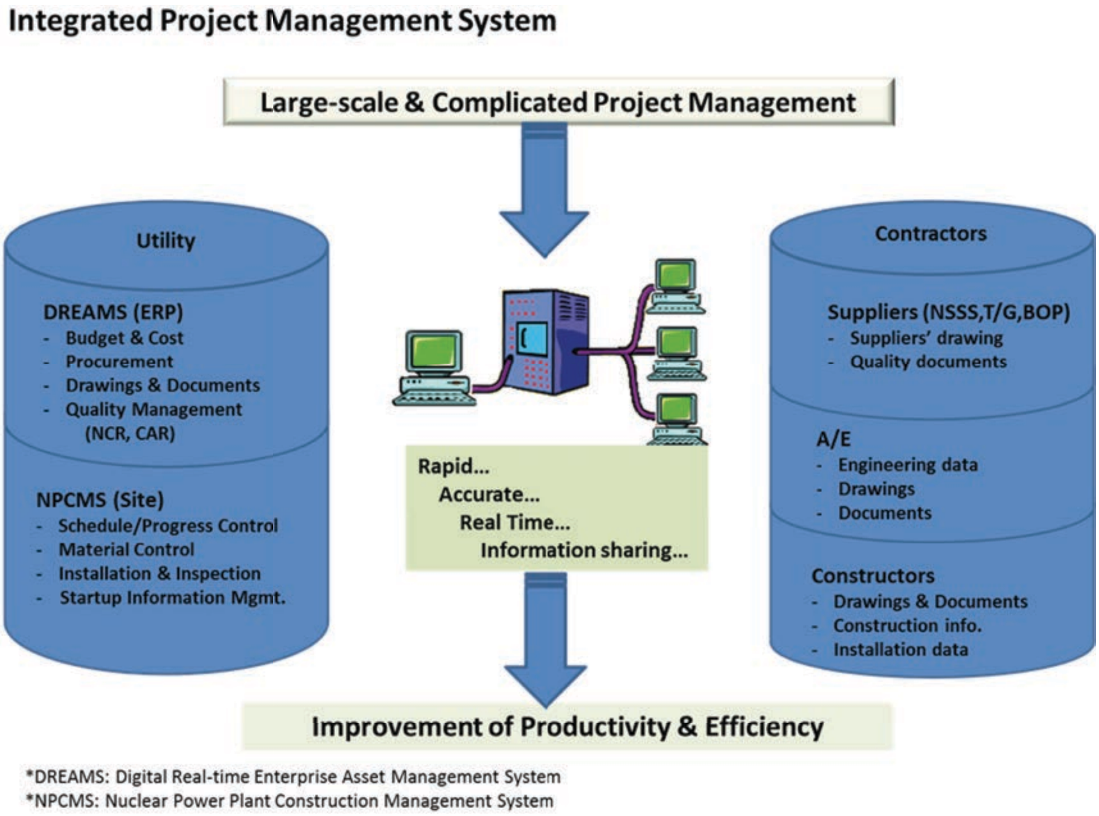

FIG. 6. Example of computerized information control system.

which is usually a standardized reactor design proposed by a vendor, to which project specific conditions are added. The specific detail design should be completed before the start of construction so that every major construction work package contains enough details to allow execution and possible conflicts or interface mismatches between work packages are minimized. An early design freeze is especially important if modern construction techniques such as open top construction or large scale modularization are applied because more complex interface controls are required between the civil design and the system and component designs.

The project manager of the Owner/Operator should make sure the following engineering activities are properly scheduled and executed by either the utility or by contractors in the preparation phase of the construction project. Figure 7 shows an example of high level engineering processes before the start of construction and its interface with construction planning.

The four phases of pre-construction planning are:

(1) Determination of project specific construction conditions

At first the utility needs to determine the project specific conditions. Typically the following factors need to be considered:

— Geographical layout of the site;
— Ground conditions;
— Meteorological and hydrographical conditions;
— External hazards such as earthquake, tsunami, tornado, airplane crash, etc.;
— Requirements from the power grid;
— Access routes to heavy component to the site.

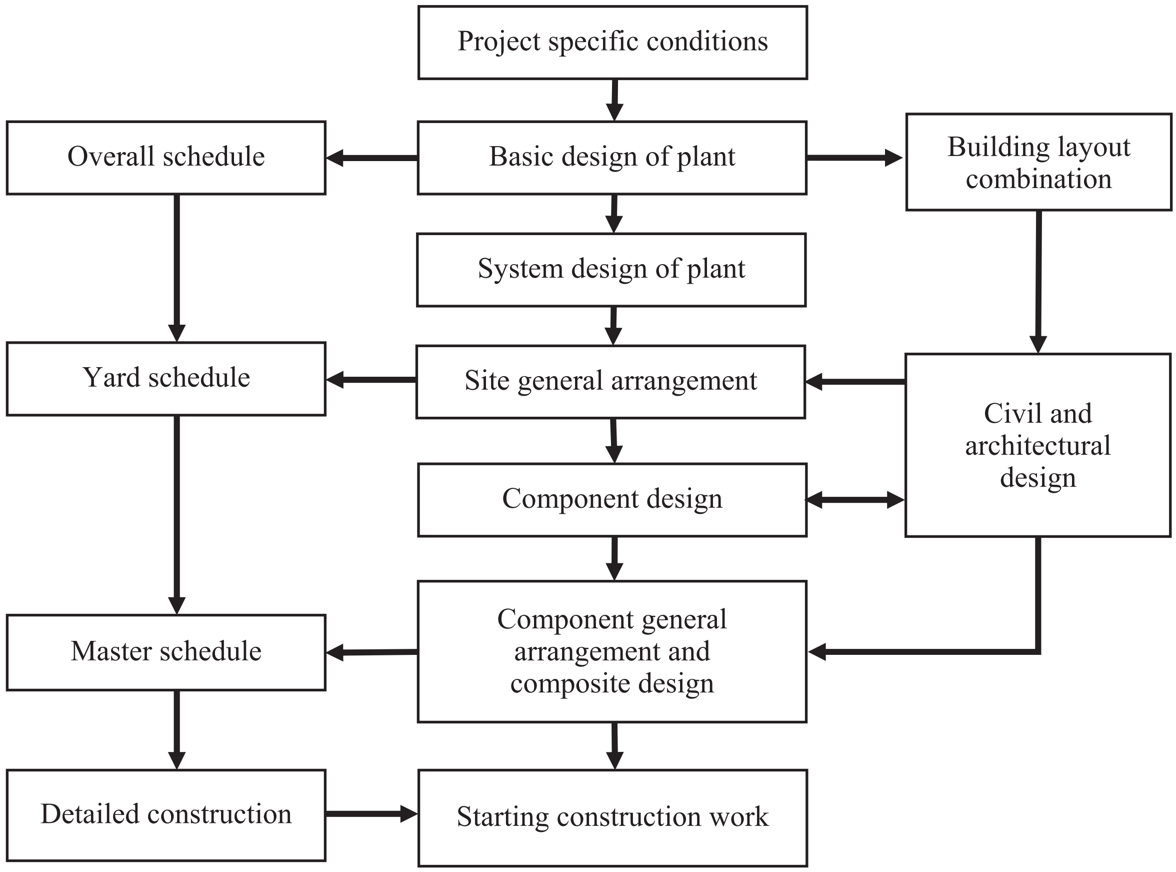

FIG. 7. Example of high level engineering process before the start of construction.

(2) Design of the systems, building layout combination and site general arrangement that need to reflect project specific conditions.

Although a standardized reactor design is adopted in most construction projects, the rest of the plant design needs to be adapted at the project specific conditions such as:

— Basic design of turbine-generators and balance of plant;
— Integration of the building layouts to house the above facilities;
— Site general arrangement including major buildings, tanks, intake and discharge structures of cooling water, switch-gear yard, access road, etc.

These engineering outputs are input to civil construction, to composite designs, to the overall construction schedule, which determines the critical path and the major milestones, to the yard construction schedule, which coordinates the construction of outdoor facilities, to the layout of temporary construction facilities, access routes, excavation and backfill.

(3) Civil and architectural design

After determining the building layout combination, the design of each building is developed reflecting the project specific conditions. By the time the structural design of the buildings starts, a set of assumptions about major components, piping sizes and loads need to be available. For a component of which the supplier is not yet determined, bounding conditions need to be provided to the building designers.

Designs of other major civil structures such as trenches, cooling water intakes and discharge structures are developed based on the project specific design conditions and the site general arrangement.

Construction is the most expensive period of an NPP project and reducing its schedule is the goal of every NPP vendor. A constructability study of the major structures may be needed to ensure that major construction milestones can be met. The use of large scale modules built offshore or the modification of the site layout to make room for temporary assembly facilities to build large scale modules in situ as well as the use of heavy-lift cranes and platforms must be considered if advanced construction techniques are used to improve the overall construction schedule.

(4) Component general arrangement and composite design

The general arrangement in each of the buildings is developed based on the specific component sizes or on the bounding conditions of those components whose dimensions have not yet been fixed.

Composite designs are typically developed in phases:

— In the first phase major building structures are laid out, the arrangement of major components and the configuration of major piping are added. Then the structural design of the buildings is checked;
— In the second phase details are developed. Using the bounding sizes of the potential components, the composite designs are further improved;
— When the suppliers are selected and the component weights and dimensions finalized, they are reflected in the layouts and small piping are added. Space allocation is completed including maintenance envelopes and component access routes. The final configuration should include all components, piping, cable trays, cable conduits, HVAC ducts and all structures;
— Identify civil and mechanical linkages;
— Constructability, maintainability and decommissioning aspects.

Before turnover to construction, the owner/utility should review the overall maintainability and accessibility of the arrangements.

Design change management process

The project manager of the Owner/Operator should set up an effective design change process to verify the safety, functionality and reliability of items different from the reference design. How much intrusively the utility should intervene in this process may depend on the contract type. In a turnkey contract the main contractor has the responsibility to manage design changes and the utility exercises the oversight function. In addition the utility carefully reviews the design changes and ensures that they have no negative impacts on the licensing basis, on the interfaces, on the supply scope, on the operability and maintainability of the system. In a split package contract the utility should also review potential impacts caused by design changes at the interfaces between contractors in addition to the reviews described above.

Design changes may be made at the system level such as changes in performance, function, operating modes, control methods, or at the component level such as changes to service conditions, structures, materials, manufacturing methods and so on. Even minor changes to service conditions may cause large cascading effects, though the components themselves may not have been physically changed. Therefore, design change control submissions for approval should include not only the design items themselves, but also changes to operating, environmental, interface conditions, and so on.

Secondly, design changes need to be graded and reviewed based on their potential significance to safety, reliability and economic impact. Verification and validation plans should be established. Such plans may include design examination, mock-up tests, trial production and additional performance tests at factories or at the site. Verification and validation plans should be reflected in the manufacturing or erection/construction schedule. The design change review and the verification and validation results should be documented.

Design changes during construction especially in its later phase should be minimized because they usually cause schedule delays and cost increases. Therefore, the original design should be carefully reviewed in the preparatory phase and design verification and validation activities should preferably be scheduled as early as practical.

2.4. MAIN CONTRACT MANAGEMENT

2.4.1. Contract implementation

Once all contracts for the project are signed and go into effect, the project moves to its execution stage. As the contract execution begins, all work in principle, including the work performed by the management team of the Owner/Operator, should be controlled by the articles of the contract. A number of critical meetings usually define in the contract are held. The utility often uses feedback from the various meetings as a management tool to monitor the status of the project with respect to the terms of the contract and achieve other critical control functions.

The first meeting usually held as soon as the contract becomes effective is the overall kick-off meeting the objective of which is to confirm and remind all intervening parties of the project schedules, of all the project major objectives, as well as to introduce the various project managers of the main contractor and of the subcontractor organizations.

Project progress is checked on a regularly basis. This is usually achieved through the project review meeting, usually held biannually in which the project status is reviewed and re-evaluated. Another important meeting is the project managers' meeting, held on a monthly basis. The main objective of this meeting is to coordinate the progress of the project among project managers.

2.4.2. Development of the procurement plan

Three types of contractual approach have been used for NPP stations, namely:

— The turnkey approach, where a single contractor or a consortium of contractors takes the overall technical responsibility for the construction work;
— The split package approach, where the technical responsibility is divided between a relatively small number of contractors, each building a large section of the plant;
— The multi-contract approach, where the owner or his architect/engineer (A/E) assumes the overall responsibility for detail engineering and constructing the plant. The A/E typically issues a large number of contracts.

Typical lead responsibilities for the different contractual approaches are presented in Table 1.

The selection of the type of contract is one of the fundamental decisions concerning the construction of nuclear power plants. It should, therefore, receive great attention and be based on a careful analysis of all aspects. These aspects include:

— Potential vendors and their particular experiences and attributes;
— Standardization and proven quality;
— Government and industrial relationships;
— Competitive and economic considerations;
— Foreign financing possibilities;
— Guarantee and liability considerations;
— Planning and implementation of the project and subsequent projects;
— Availability of qualified project management, coordinating and engineering human resources;
— Development of national engineering and industrial capability;
— Owner's experience in handling large projects.

Independently of the type of contract selected, provisions should be contractually arranged regarding the transfer of design information and as-built information in order to facilitate the procurement of replacement components and maintenance services[6].

In order to build a technically sound and economically competitive nuclear power plant, the utility should seek multi-discipline assistance in writing the main contracts and pay special attention to the development of the procurement plan.

TABLE 1. TYPICAL LEAD RESPONSIBILITIES FOR DIFFERENT CONTRACT TYPES

Activity	Contract types		
	Turnkey	Split package	Multiple package
Pre-project activities	U	U	U
Project management	MC	AE or U	U + AE
Project engineering	MC	AE or U + SS	U or AE
Quality assurance/quality control	MC + U	AE + SS + U	U + AE
Procurement	MC	AE or U + SS	U or AE
Application for license	U	U	U
Licensing	RA	RA	RA
Safeguard, physical protection	U	U	U
Manufacturing	MC	SS + EM	EM
Site preparation	U or MC	U or AE	U or AE
Erection	MC	AE + SS	U or AE
Equipment installation	MC	AE + SS	U or AE
Commissioning	MC	AE + U	U or AE
Plant operation and maintenance	U	U	U
Fuel procurement	U	U	U
Fuel fabrication	FS	FS	FS
Waste management	U	U	U

Symbols: AE: Architect engineer
EM: Equipment manufacture
FS: Fuel supplier
MC: Main contractor
RA: Regulatory authority
SS: System supplier
U: Utility

As part of developing the procurement plan, the utility in general organizes and operates a task team consisting of experienced professionals from various disciplines, such as system analysis, radiation protection, reactor systems, electrical systems, commercial area and so on.

The task team usually operates under the direction of the project manager until the closing of the main contracts. Its major activities at this stage include, but are not limited to the following:

— Preparation of the tender specifications and evaluation criteria;
— Preparation of the time schedule;
— Assignment of responsibilities;
— Verification of conformity to tender specification;
— Preparation of questionnaires;
— Formulation of deviations between tender specifications and proposals;
— Verification of the vendor performance during construction;
— Preparation of the evaluation report;
— Selection of preferred vendors if open tendering is adopted.

Preparation of the tender specification should be in the priority list during contract negotiations. Usually, the tender specification contains critical factors to both the utility and the contractors throughout the contract negotiations. It usually includes technical information describing relevant plant features and data as well as economic, legal and contractual requirements of the utility and of government authorities.

The tender specification also defines the scope of supply and the division of responsibilities. In addition, it becomes the basic reference for the contractors to prepare their proposals and for the utility to evaluate the proposals.

The project manager of the Owner/Operator must ensure that all technical specifications are complete, clear and accurate. Any subsequent requests for changes may weaken the utility's position during contract negotiations. Major items to be specified in this phase are:

— The selected site and the site parameters;
— The plant size;
— The reactor type; the choice of reactor type is often made after the tender evaluations (although sometimes it may be made before);
— Applicable codes and standards (including local codes and standards);
— Localization engineering and industrial participation;
— Required transfer of technology for plant systems and fuel cycle;
— Main characteristics and responsibilities within the project organization and overall project management;
— Required type of contract (turnkey or split package);
— Design data;
— Quality assurance programme requirements during component manufacture and plant construction;
— Supply schedule;
— Schedule and responsibility for developing the preliminary and final safety analysis reports;
— Responsibility for plant startup and commissioning (especially important for non-turnkey projects);
— Preservation of equipment;
— Supply of fuel and fuel cycle services;
— Supply of heavy water (if applicable);
— Training of personnel;
— Financing;
— Construction schedule;
— Role of the plant in the electric grid (base load or load following requirements);
— Special requirements for plant structures, systems and components and for their redundancy (if not covered in the general design criteria);
— Requirements on warranties;
— Scope of supply and services for all contract partners (domestic and foreign).

The plant technical specifications should be developed from these main parameters as a comprehensive document. It should include all information necessary to develop a proposal. The tender specification should be written in clear and well organized articles and the sections numbered so as to facilitate subsequent references and the evaluation of competing-tenders.

Preparation of the tender specification is best handled by the project manager of the Owner/Operator, who should primarily ensure:

— The correct usage of in-house and outside expertise;
— Completeness and clarity of all tenders;
— Clarity of Cost and schedule information;
— Clarity of interfacing and coordination considerations;
— Political constraints, which may result from supply issues and bilateral or multilateral government agreements.

Because of its complexity and of the many dependencies, the preparation of the tender specifications should be done with prudence and accuracy; therefore, six months or more should be allowed for it in the schedule, depending on the number and scope of the design changes to the reference plant.

Tender evaluation involves the consideration of contractual, organizational, technical, economic and political factors. The two areas which demand the greatest efforts from the project management viewpoint are the technical and economic ones. Main activities in the technical evaluation should be at least:

— Checking the conformity to technical requirements;
— Checking the scope of supply and services and their limitations and interfaces;
— Safety and performance features.

The economic evaluation involves the verification of the appropriateness of the costs and related items. The basic procedure is to evaluate the current worth of all items involved in plant construction and operation.

Evaluations are often based on those previously done for an existing reference plant. Several months of analysis and meetings with the vendors are usually required to clarify important points which might not have been properly defined, as well as any deviations and/or exceptions.

During the clarification and negotiation phases, options for the deviations requested by the vendor should be evaluated for their appropriateness and separate contractual additions or appendices to the contract are written to cover deviations as mutually agreed. When preparing for the contract closing date, the utility should ensure that the vendors completely cover all aspects of the deliveries as per contract and respect all interfacing requirements with other partners of the Owner/Operator.

The evaluation of the supplier’s organizational aspects could be considered separately or included within the scope of the technical evaluation. Its main purpose is to establish a measure of confidence, based on technical judgement, that the project can be implemented within the schedule and cost commitments. Within the organizational structure proposed for managing sub-contracts and interfacing issues, the methods set-up to coordinate and control the suppliers is possibly the most relevant aspect to the success of the enterprise and should be analyzed in detail.

Political considerations are an important parameter for the project manager as they point out advantages, disadvantages and may influence decisions, such as implications of international commitments, agreements, export licensing and the reliability and assurance of supply.

When preparing for the contract closing date, the management of the Owner/Operator should ensure that the main contractor can accept a lead responsibility for the entire plant (unless the utility can take on this responsibility itself). It is important to check at this time that supplies of the major equipment and of the nuclear fuel and their financing as well as have the backing of bilateral or multilateral company to company and government to government agreements.

A typical nuclear power plant contract contains, as a minimum, sections providing:

— A complete technical description of the plant;
— The regulatory requirements and status and/or a preliminary safety analysis report;
— Quality assurance programme;
— The scope of supply and division of responsibilities;
— A set of conceptual drawings;
— The schedule;
— An organizational chart.

In summary, the contractual activities of the Owner/Operator consist of the following:

— Selection of the contract type;
— Definition of the contract scope;
— The utility's scope of supply;
— Arrangements regarding the transfer of technology;
— Price negotiations, payment conditions and warranties;
— Commercial and financing arrangements, together with their legal implications;
— Procurement of lead materials, components and services;
— Procurement of fuel cycle materials and services; assurance of the supply of fuel (heavy water) and essential reactor materials and components;
— Site preparation;
— Selection and definition of the codes and standards for the plant design and construction;
— Support of regulatory-licensing and public information activities;
— Signing of the contract(s).

Contractor to subcontractor agreements can be very similar in principle and usually occur during the execution phase. Particular attention should be paid to local subcontracting. [7]

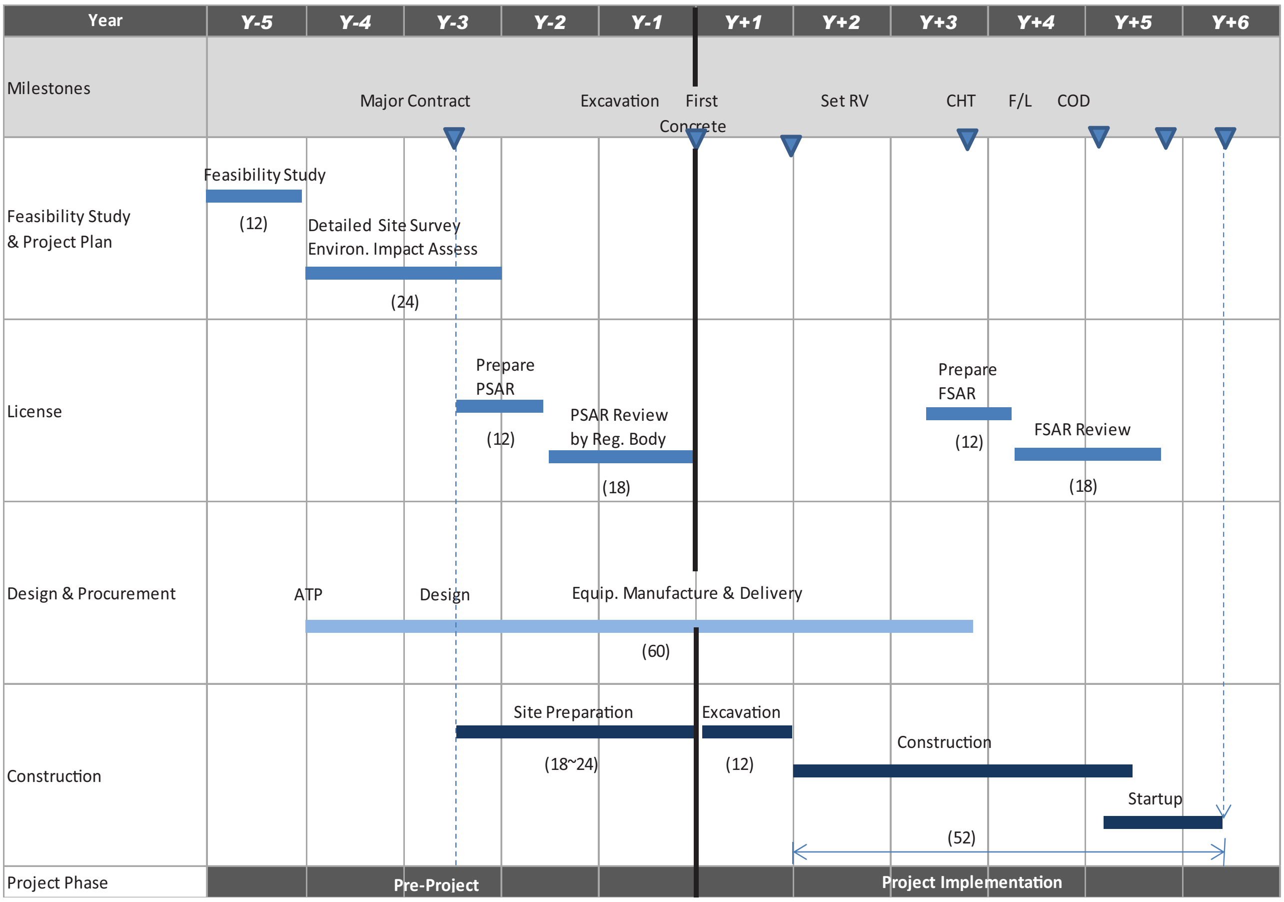

FIG. 8. Typical durations for the main contracts.

2.4.3. Authorization to proceed

Major equipment such as reactor vessels, steam generators, reactor coolant pumps and turbine generators are long lead items. Their delivery typically requires 60 months as shown in Fig. 8. Usually, the lengthy contracting process precedes the design and manufacturing and matches the lead time of the major equipment delivery. Therefore, if the conditions are favourable, an Authorization to Proceed (ATP) can be issued to the selected main contractors even before the contract is awarded so as not to jeopardize the overall construction schedule.

The Architect/Engineer also needs a lead time of at least 30 months to prepare the Preliminary Safety Analysis Report (PSAR) and to have it reviewed by the licensing authority. Likewise the ATP to the A/E is also issued ahead of the formal contract award.

All conditions covering the ATP process are governed by prior mutual agreements or by the contract documents if they have already been prepared and agreed upon by the mutual parties. All work under the ATP including design and manufacturing should be closely controlled by the pre-established QA procedures.

2.5. LICENSING MANAGEMENT

2.5.1. Preparing and submitting licensing documents

A project management approach should apply also to the licensing process. Typically, there are three interfacing partners in the licensing process: the vendor, the Owner/Operator and the regulatory body. The licensing project management should plan for a thorough and well coordinated licensing review to ensure that the established regulatory criteria are met. This task should be scheduled with due regard to the resources available in each partner organization.

The regulatory body should clearly define and communicate the relevant requirements to the project management of the Owner/Operator, indicate the type of documentation required, ensure timely availability of expert resources for review and inspection within his organization and expedite the timely completion of all reviews. It is recommended that the licensing authority and the licensee agree to create a common licensing plan detailed to the final document list so that there may be no surprises during the licensing process.

The Owner/Operator is responsible for applying and obtaining the construction and operating licenses for the plant. The project management of the Owner/Operator should have the responsibility of cocoordinating the preparation of the licensing documents (i.e. the Preliminary Safety Analysis Report etc.), of starting the licensing process, and of ensuring the compilation of the final licensing documents (i.e. Final Safety Analysis Report etc.). During project implementation the project management of the Owner/Operator must meet the requirements of the licensing authority and provide any necessary information or clarification. If the engineering for the plant is subcontracted, such information is usually produced by the main contractor or the Architect/Engineer. The utility is then only responsible for the submission of such information and, in some cases, for the content of the licensing material as well as its scope.

In executing its portion of the overall project, each partner has important responsibilities in the licensing area which require internal organizational support. This internal licensing function usually includes the following tasks:

- Developing company strategies in response to regulatory requirements and provide sufficient personnel and budget to execute the strategy;
- Understanding the licensing requirements, keeping a status list of all requirements and of all responses;
- Archiving licensing documents;
- Scheduling, updating and expediting licensing matters as they relate to construction and manufacturing activities;
- Allocate sufficient schedule time to account for possible updating of licensing documents following the regulatory review process.

In the partner organizations, management of the licensing function may be assigned to a separate section or to a group of the project management organization. However, it should be remembered that the overall responsibility for coordination of the licensing of the entire project remains in the hands of the project management of the Owner/Operator.

Appropriate construction license documentation is crucial for successful project implementation. The type, the number and detail of the documents required by the regulatory body varies depending on the nuclear regulatory requirements in the country and in the phasing adopted. Typical licensing documents are:

- Preliminary Safety Analysis report (PSAR);
- Design phase Probabilistic Safety Assessment;
- External Hazards PSA (Level 2 PSA) earthquake, flooding/tsunami, ambient temperature excursions, tornadoes, typhoons, hurricanes;
- Preliminary safety classification;
- Preliminary Technical Specification;
- Descriptions of the plant systems;
- Description of the project QA system and of the project organization;
- Preliminary emergency response arrangement plan;
- Preliminary physical protection plan;
- Preliminary safeguards plan;
- Licensing plan.

The information can be included in master documents such as the PSAR or be independently submitted depending on the requirements. Before the operating license process is started, the construction license documents are updated to reflect the final design and configuration of the plant.

Before starting detail design activities, it is important to verify with the regulatory body the acceptability of all external hazards. They include earthquake, flooding (variation of see/river water level), ambient temperature variation, wind conditions including typhoon/hurricanes, etc. Due to the increased global warming bias today these requirements might have to be reconsidered by the regulatory body and agreements may have to be reached well in advance of the start of the licensing process in order to enable the design phase to proceed smoothly.

It is also important to reach agreements on internal hazards such as fire, internal flood, etc. to ensure that they too are known early enough, so that the design and licensing can proceed without changes during the project implementation phase.

When the Owner/Operator is granted the construction license it becomes the license holder or licensee. At that time, the licensee must ensure that all international regulations regarding the handling and transportation of components or material listed as safeguard materials (subject to nuclear weapon proliferation controls) are applied and adequate licenses obtained from the proper national and international authorities.

2.6. PROJECT RISK MANAGEMENT

Risk management should be seen as a tool for improving project management and limiting the financial and schedule exposure of the project partners.

In principle, risk means financial and schedule exposure, in direct costs or through unavailability of the plant. Each project partner has to minimize these risks in his area of responsibility. Project management has the responsibility to manage risk, and coordinate with other project partners. However, since 'risk' is something only perceived or anticipated, it is hard for a risk management item to compete with pressing day to day issues, many of which may in turn be ironically former risk items, which were not dealt with in due time. The effectiveness of risk management is very much a question of timing. Risks should be reduced or eliminated at an early stage, but their management must be performed during the complete life cycle of the project.

The assignment of one person with enough authority within the project team to be exclusively concerned with risks can provide the necessary attention to proper risk management. Such a risk manager would not carry out the risk assessment himself, but would perform project management type coordination and performance evaluation. This would typically include the following steps:

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

Each active risk item should be matched to an action plan, with resource allocation and monitoring. The objective of the action plan is to reduce, contain and eventually eliminate the risk and to gradually incorporate any changes into the regular technical description, budget and schedule of the project.

Standard procedures, processes and widely recognized good practices are readily available [8, 9].

2.7. CONSTRUCTION INFRASTRUCTURE DEVELOPMENT

Wherever the infrastructure for nuclear power plant construction is inadequate, the management should focus its attention on creating the conditions to facilitate the establishment of adequate infrastructure without which no construction support is possible. Necessary preparation activities such as levelling, and grading of the land, the laying down of roads, of storm sewers, the provision of adequate water and power supplies, of labour housing, of concrete testing laboratories, of warehouses, of a security fence, of medical facilities, of schools, of recreational and sports facilities for employees and their families, of office space and transportation, of new approach roads, of widening and strengthening of existing roads and culverts. All this should be made possible and prepared in advance of the launch of the construction phase in order to avoid delays in the early stages of the project.

In the event that enough fresh water is not available in the vicinity of the project site, the utility may have to lay down fresh water pipelines from natural sources of water. Similarly, the utility may have to lay down new transmission lines to provide the necessary uninterrupted power supply to support construction and commissioning. Depending on site specific issues, backup power may have to be arranged by providing diesel generators or alternatively a connection to an existing transmission line to provide backup power from a different source.

If trained personnel is not available, the utility should create training centres in and around the plant to be able to meet the human resource skill requirements for the project. Depending on the scenario prevalent in the region, the utility may have to negotiate a compensation matrix for the workforce in advance of the launch of the project to avoid possible accumulation of resentment, mistrust and hindrances later during construction.

2.8. SECURITY

Safety and security of nuclear plants and equipment is a vital element of project management. This includes:

- Physical protection system;
- Access control;
- Imaging and monitoring;
- Central alarm station;
- Strategic material accounting.

Nuclear plants generally have three layers of a physical protection fence. Double fencing, with a single entry gate, surrounds the operating island. Access to the operating island requires authorization. The entry gate provides access control and identification of entrants. The operating island fenced area is surrounded by plant fence which includes offices, stores and many other facilities. Outer most physical protection measure is the property fence or compound wall. The entire space within the property fence is declared restricted area. Normally all the three physically separated areas have single entry gates which are monitored.

The access control for nuclear plants is an elaborate mechanism. The access gates for the operating island normally have turnstile gates and often more than one identification system. These could be smart card and biometric system of identity. The access gates control the access of vehicles, man and machines.

The entire double fence (2.5 m tall) has visual/laser monitoring for intruders. Sensor alarms are installed at identified locations. Entry to critical areas within the operating island is further restricted and controlled by various engineered features; e.g. biometrics. Surveillance cameras monitor for intruders; all this information is checked and monitored by the central alarm station which is always manned and is backed up by rapid action forces if needed. A perimeter road is constructed along the perimeter of the plant for patrolling purposes. The entire plant area and the perimeter are adequately lighted and security personnel carry out frequent patrols.

A well established communication system, with backup features, is an essential element of a security system. This may include wireless sets besides telephones. The role and responsibility of security personnel includes quick reporting of fire and the spill of hazardous materials.

Limited security measures need to be instituted in the early stages of reactor equipment installation to prevent theft, security of stores and sabotage of critical reactor components. However, full fledged security measures, as described above, should be in place prior to nuclear materials move to site [10].

3. CONSTRUCTION MANAGEMENT — CONSTRUCTION PHASE (AFTER CONCRETE POURING)

3.1. OVERVIEW OF ORGANIZATIONS (SITE AND HQ) AND MAIN ACTIVITIES DURING CONSTRUCTION

Construction management starts very early; during the infrastructure preparation. However, there is no nuclear construction activity until the first concrete pouring. This is a milestone that defines a new stage for the manager of the Owner/Operator at the site. To properly manage it, a construction management organization should be setup. Following is an example.

3.2. MANUFACTURING AND CONSTRUCTION MANAGEMENT

Potential risks of manufacturing and construction delays should be identified and minimized as early as possible. Significant risks may exist if structures, systems and components are different from preceding nuclear power plants or new manufacturing or building methods are adopted. Even if the manufacturing method is almost similar to the previous method, minor changes in production parameters, material properties or work environment may cause problems. Such risks should be identified in the design change management process and the significance of the potential consequences should be evaluated.

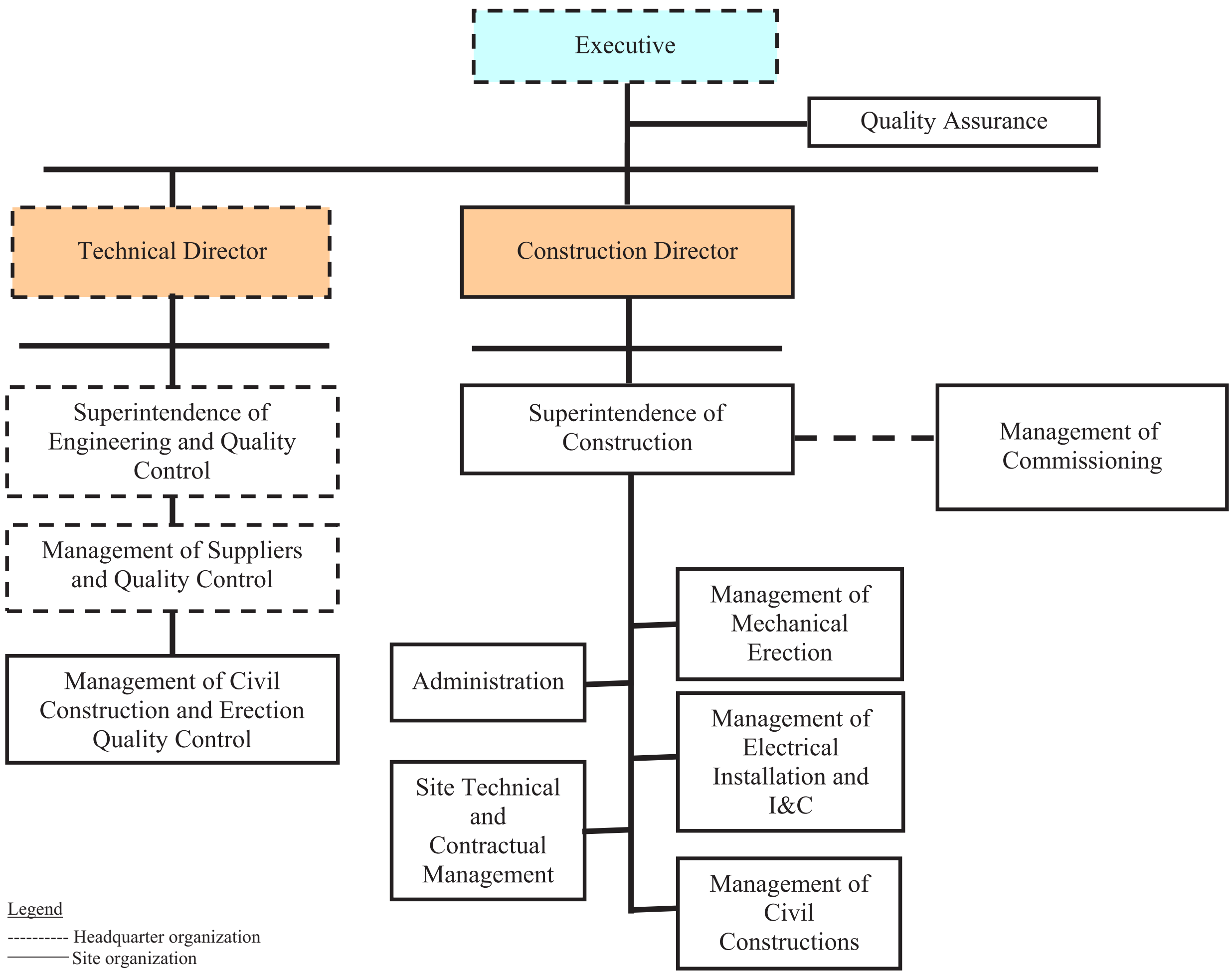

FIG. 9. Example of construction management organizational structure.

If identified risks are significant in terms of safety, reliability and economy, extensive verification may be necessary. Mock-ups and experiments may be used to confirm manufacturing methods, adjusting production control parameters, confirming the quality of the products, and to familiarize the workers with the new manufacturing or construction methods. These activities should be scheduled well ahead of the actual manufacturing or they should be allowed enough lead time in the building schedule.

3.2.1. Selection of sub-suppliers

The selection of sub-suppliers is important to minimize potential risks of manufacturing and construction delays. Significant risks may exist if sub-suppliers provide components or services that are outside of their experience and capabilities. The utility should approve the selection of sub-suppliers by the contractors. The following items are included in the evaluation of sub-suppliers although the depth of the evaluation varies depending on the significance of potential risks:

— Qualifications according to relevant regulations;
— Safety management system;
— Quality management system;
— Safety and quality records;
— Technical capability including required tools and infrastructures;
— Production or service-supply records;
— Availability of qualified human resources;
— Construction machinery and equipment.

3.2.2. Measuring progress

If a project is to be cost controlled with any degree of success, three factors assume major significance. The planned budgets versus the contracted budgets, the costs actually incurred, and the work achieved in relation to those costs. Knowledge of the budgets and costs by themselves will be of no use unless the corresponding progress in the field can be gauged. The three basic factors must therefore constantly be actively monitored during the life of the project [11].

Budgets should be easy to follow throughout the project. They are derived from the departmental estimates and may be amended from time to time to allow for authorized modifications. Cost recording for personnel hours, equipment and materials is an established routine in any well run organization so that records of project costs at any time can be obtained from the cost administration and accounting offices. One possible difficulty in cost analysis is the time delay which will inevitably occur between the actual expenditure, its local recording (entry) and the corresponding appearance in the books. With modern computerized methods a two week trailing is achievable and acceptable.

The project manager should have at his disposal the tools to analyse the progress of the project. The following areas are looked at for measurement of project performance:

— Engineering design progress;
— Procurement and manufacturing progress;
— Hardware installation and construction progress;
— Project management effectiveness.

It is necessary to constantly evaluate progress to be aware of potential deviations in cost, in order to take early remedial action, and to approve contractual progress payments. Specific rules for remuneration of the main contractor and subcontractors are normally part of the contract — except for cost-plus contracts, where performance is essentially based on trust — and they are usually tied to predefined progress milestones in the project schedule (which forces an evaluation). Delivery of equipment such as heavy components, completion and acceptance of major pieces of work in the manufacturing shop, and of certain building elevations are often used as payment milestones.

Since payment milestones are usually associated with the delivery of large items, they provide project management with a fairly good overview of progress. However, major problems in project progress are often related to smaller items in large numbers such as piping, electrical and ventilation work. Such problems normally originate during the engineering phase, and are usually caused by anomalies such as a late starts, undefined requirements, insufficient resources, bad coordination, inadequate methodologies or plain inexperience. In the initial construction phase, resources are often inadequate; the conventional parts of the plant may be awarded to less qualified organizations, not fully aware of the quality standards associated with nuclear work and with the complexity of the plant. An early measurement of progress and work quality in these areas is vital to allow early remedial action before serious construction delays occur. Management information systems can provide data on the usage of material and equipment and thus provide the project manager with weekly information on length of piping installed, concrete poured, etc.

Objective measuring of progress can provide an invaluable diagnostic tool on performance and uncover schedule issues and cost overruns which are elements of the utmost importance to the entire project. The project manager should therefore make every effort to establish performance measurement systems throughout the various departments from the very beginning. It is important that all department managers and their dependents understand that detecting problems and reporting them as soon as possible allows management to take remedial action on time, such as adjusting human resources, renegotiating contracts, where necessary, and keeping the project on track.

The surveillance of manufacturing progress should also be set up to identify potential risks with components and material deliveries. Delays in the delivery schedule may cause significant problems, especially if the components and materials are to be lowered in place with the open top construction method or if they are part of an on-site fabricated large module.

The main contractors should report manufacturing progress of major components and materials to the utility on a regular basis. Any problems that may cause significant delays should be reported immediately. Otherwise typical reporting frequency is once per month. The utility should witness key manufacturing stages at the suppliers' factories to assess the quality and progress of manufacturing. The scope and frequency of the inspection are determined by the functional significance of the product. In addition, the utility should conduct surveillance of the manufacturing of important components and materials to assess quality and delivery risks. Such activities are very effective especially at an early stage of the manufacturing process to confirm that the production is stabilized in terms of quality and output.

During construction, measuring progress in detail is important in organizations with execution responsibilities, typically the main contractor or the architect/engineer and his contractors. Many thousands of different activities may have to be examined, some of them not started, others in progress and a few already completed. Measurement should not be directed at the work of one person, or even one department, but at meaningful groups of project activities.

It is essential that the project manager of each partner obtains at least statistically significant statements of project progress for his contractual scope, in a detailed breakdown according to the appropriate measuring criteria. The cost centres used to establish the original project estimates and task orders provide the most logical framework of reference and is probably also broken down into meaningful types of cost centres such as labour, engineering, computers, bulk material and equipment.

3.2.3. Project meeting to monitor and control progress

Project report meetings and project status reports are among the main tools at the disposal of project managers in all partner organizations for monitoring and controlling progress. They enable project managers to undertake corrective actions in a timely manner.

Certain inappropriate discussions may occur during progress report meetings that may render them ineffective if they do not provide the answers that the project manager needs, for example, lengthy discussions concerning technical design issues that may distract from the meeting goals and lead to loss of concentration and interest. Although it may not be possible to remove design issues entirely from project meetings, discussion should be controlled and limited to the impact on project parameters. Technical exchanges and attempts to resolve design issues should be deferred to special technical meetings or to a specialized design or peer review. The project meeting should concentrate on updating management on current project activities and on answering questions related to project activities.

The selection of topics for a project meeting should generally be driven by schedule adherence, critical path issues, budget control, value based progress, interface issues and troubleshooting. The agenda should be distributed to the participants before the meeting with sufficient time for preparation. Problematic items, especially on the critical path that require particular attention and on which an interchange of opinions and ideas is important, do belong in the meeting. These discussions should always lead to action items. Participants should focus their attention on producing them. Before adjourning the meeting, all should agree on the list of action items with due dates and the assignment of responsibilities.

3.3. COORDINATION OF CONSTRUCTION ACTIVITIES

In a turnkey contract, the overall site management is the responsibility of the main contractor, while in a split package approach it remains in the hands of the Owner/Operator, who could in turn delegate it to the architect/engineer. Site management's main responsibility is the direction and coordination of the civil works of electromechanical system installation.

If the utility has the leading executive responsibility of the overall contractual and technical aspects of the civil works, it should perform this task through its site management team. If it does not have this experience and capability, the task should be subcontracted to a highly qualified construction company, closely controlled by the utility, and sometimes to an architect/engineer running a construction department or a subsidiary construction branch. A separate construction company may also receive a contract on the civil works, with similar contractual and management responsibilities.

Either the Owner/Operator or the main contractor or both may require a project management team located at its headquarters, in parallel with its site management organization. Usually Headquarters define and issue specifications and drawings and the site organization oversees construction in accordance with these drawings and specifications, a simple non-matrix, line organization with a strong chain of command is most effective. The site manager should have proven authority and management capability, preferably acquired at the site of another nuclear power plant or at another large construction project.

Varying degrees of headquarter support for site management are needed throughout the construction phase. Sometimes a small site engineering or field engineering group reporting to the engineering department at headquarters may prove very effective. Its responsibility would be to suggest/approve/reject on-site modifications as required, to ensure that the design requirements are upheld and that quality is always maintained during construction. A rigorous change control process and an effective documentation system are of the utmost importance to control the plant configuration under such circumstances. The site manager should be responsible for the proper execution of authorized changes, but the project manager stays in charge of all major project authorization and control.

As far as civil work is concerned, the civil construction manager at the site is responsible not only for the execution but also for all civil planning and coordination tasks. The leading coordination function at the site is best merged with the leading executive responsibility in the person of the site manager, with close liaison with headquarters. In case an external civil contractor is in charge of executing civil works, the Owner/Operator may appoint a separate site manager to oversee and co-ordinate the work. The main tool in co-ordinating construction and system installation work at the site, with headquarters and with sub suppliers, is the master schedule.

Site management may have its own planning and scheduling unit. It is necessary in such cases to ensure very close coordination with headquarters to maintain a uniformly valid overall project schedule. The site scheduling unit may also be supported by the headquarters organization in terms of computer services, if these are not available on site. Effective, formal and informal communication and coordination with engineering at the headquarters must be established.

In summary, the site manager or field engineering manager should be responsible for the following:

- Execute the construction contracts according to requirements, technical specifications and applicable quality standards;
- Lead and manage the site engineering and installation teams;
- Steer all activities at the site according to project schedule and taking into account safety, cost and quality requirements;

— Administer and control subcontracts for the site;
— Keep day to day contact with site managers, project management representatives and/or resident engineers of the other contractors at the site in order to maintain consistent communications and a common information database.
— Explain and document the status of the site activities, initiate corrective actions, optimise authorized configuration changes in schedule, cost, etc., and contribute to regular project meetings at the site and at headquarters.
— Obtain all necessary control on cost and schedule, in order to be able to report internally to the management and externally to other project partners.

In addition, the site manager of a partner organization has a number of generic coordination tasks as a delegate of the overall project manager in his organization's headquarters and of the utility, unless the utility handles coordination tasks through a separate site management team or within its own project management team. These include:

— Local contacts: The leading site manager and his organization are usually the first to arrive at the site. They will therefore have the responsibility of making the first contacts with local and central government officials, local labour officials, local contractors (to whom the site manager may eventually subcontract part of his work), and local suppliers of equipment and material.
— Indirect controls: Site clearing and the establishment of an infrastructure are usually subcontracted locally. During the important initial phase of this work, the site manager may have to deal with other project partners and outside organizations, over which he has no direct (contractual) control. The site manager and the project manager of his organization must therefore exercise particular care in incorporating effective controls and clear interface agreements with local subcontracts.
— Choice of material suppliers: The civil contractor's work involves enormous quantities of material (such as sand, earth, aggregate, cement, steel, etc.) and supply is often limited to one local source. The site manager, with support from headquarters and from the utility should negotiate the best terms possible from an inexperienced supplier who knows that he has a virtual monopoly.
— Concrete quality: An important point for site logistics and possibly even for the building design is the availability of high quality and high strength concrete; this implies high quality cement, rebars, machinery and test equipment, sometimes not available locally. This aspect must be examined early, preferably before the civil works contracts are signed.
— Use of local labour: A high percentage of indigenous labour is usually included in the civil contractor's work force. The site manager should therefore study and incorporate into the schedule the details of the traditional, locally accepted methods associated with the civil work.
— Starting on the critical path: When the civil contractor begins work, it usually the first activity on the critical path of the master project schedule with little or no contingency. Site and civil work should therefore start earlier than the contract effective date, notwithstanding the financial risks involved. The civil contractor may be obliged to also assume similar risks in order to gain a head start on the schedule, until his activities are no longer on the critical path.
— Subcontractor engagement: For some subcontractors nuclear power plant construction work is a one of a kind project with generally less standardization or prefabrication than other types of work and with stricter quality controls. They may have to plan for extra management and engineering support staff at the site of up to 8-10% of their workforce. The proportion is on the higher side at the beginning and becomes lower during workforce peaks.
— Utility supervision: If the utility retains the overall site management responsibility, its site staff will be somewhat larger than that of the main civil contractor, possibly involving two different departments, because it must carry out the responsibilities of both the supervising owner and the leading constructor.

Apart from pouring concrete, site work includes a multitude of other activities some in parallel others in sequence, such as; installing equipment, welding, material handling, shipping, storing, cleaning, inspecting, testing, modifying, repairing and maintaining. They should be under the control of the key representative (or the resident manager) of each project partner on site. Many mechanical and electrical erection activities are handled as subcontracts and executed at the contractor’s shop. They may be supervised by the engineering, purchasing and project management departments of the Owner/Operator from its headquarters.

During the equipment and system installation activities each contractor should submit regular progress reports to the utility and/or to the main contractor, related to the programme schedule. These reports must describe the work progress as it relates to the master construction schedule, which in turn is aligned with the master schedule of the entire plant. When construction management requires it, the contractor may have to prepare special or more detailed schedules dealing with specific coordination problems.

3.4. CATEGORIZATION OF CONSTRUCTION WORK PACKAGES

3.4.1. Work breakdown structure

An important step in project definition is the work breakdown structure. Considering the size of a nuclear power plant project and the number of people working on it, some type of division of the work into manageable segments and work units is a necessary step. A work unit may be conceived as one that can be understood and controlled by one person, or an activity related to a component that may be produced, tested, packed and shipped to the site as one entity. Subdivisions can be varied but they should be logically structured, documented, made known and incorporated into the schedule. The resulting arrangement defines the hierarchy of deliverables and is called the work breakdown structure (WBS). The work breakdown structure provides a necessary step in project definition, and is normally considered an important project management tool. Establishing and maintaining a breakdown structure is the responsibility of the main contractor in a turnkey contract.

A WBS essentially inter-relates hardware, software and personnel so that they can be budgeted, scheduled and controlled. A WBS may in some cases exist from previous projects and may have been referenced in the contract or elaborated during the pre-contract phase. Normally, the WBS has to be established and confirmed as a cooperative effort between project management; engineering and the production departments at the beginning. The faster and the more complete the project has been structured and its tasks defined, the easier it will be to assign, control and coordinate the work. Standard procedures, processes and practices widely recognized are available and can be used. [12].

Project management should be aware of the potential fragmentation aspects of a WBS and should apply integrating measures as compensation. Before establishing a WBS for the entire nuclear power project or major portions thereof, it is important to understand traditional ways of structuring hardware, engineering and personnel. A project is traditionally split along the lines of major plant divisions, namely the nuclear steam supply system (NSSS), the turbo generator (TG), and the balance of plant (BOP). Between these there are interfaces that should be kept simple and clearly defined.

Within one major plant division, for example the NSSS, systems are differentiated according to their function or type of hardware. Interfaces between systems would typically be identified in drawings and descriptions. Ultimately, the systems are made up of components, categorized differently according to their design, manufacture, licensing, installation, and commissioning phases. Large orders of similar or identical components are quite often divided into categories with specific system requirements, delivery requirements or unique erection conditions.

Since most of the project manager's coordination tasks deal with engineering, engineering specialities provide a basis for structuring the project which often overrides that of other categories. The work breakdown may be based on the following approaches:

(a) By hardware:
- — Fuel;
- — Primary system and components;
- — Auxiliary systems;
- — Buildings;
- — Etc.

The corresponding functions represented by organizational units could include development, design, analysis, licensing and procurement.

(b) By discipline:
- — Core analysis, physics, thermo hydraulics (structural, safety);
- — Safety analysis, accidents;
- — Systems analysis, steady state performance, operating transients, design support;
- — Structural analysis, steady state loads, dynamic loads, stress/strain;
- — Etc.

A combination of the above points of view is normally used. However, a good work breakdown structure is one that minimizes interface problems.

3.4.2. Work packages as a project management tool

Once the organization is established and its lead engineers and managers known, the project manager can define and assign the work within the scope of his organization. These items are identified in the WBS and can be assigned to the competent organizational units in manageable portions called work packages.

The work package is a type of subcontract between project management and the line organization. In a document known as work package description or task or work order, it typically contains the following information:

- — Task identification;
- — Start/end dates;
- — Ownership (lead engineer);
- — Budget data;
- — Task description;
- — Changes;
- — Outputs (project documents, data);
- — Associated hardware items.

The work order includes a brief task description and the budgetary figures for engineering and hardware. This information should be jointly agreed upon in writing. It is necessary to establish a complete reference budget for the work order as a baseline for future changes and/or claims. The standardized work orders reference number and identification should also be used for manual or computerized accounting, invoicing, recording of expenses and progress reports. Concurrently, human resources aspects should be considered in support of the engineering budget estimates, manpower demand, availability and schedules.

The work order provides a number of inputs to downstream activities:

- — Definition of work and work outputs (such as task connections and other schedule information);
- — Mechanism for applying changes;
- — Recording of changes and supporting of contractual claims;
- — Computerized reporting system including personnel-hour records and shift information.

Finally, the task order often imparts a form of positive motivation, both for the project management group and for the organization units. The latter should preferably assign a specific engineer (task engineer) to be in charge of the work order, and back this assignment at the section or department head level. Characteristics of a good work order system are:

- — The task engineer knows: what to do, how the task relates to the overall contract and how he is committed;
- — The line manager knows how he is committed;
- — Record keeping is simplified (automated);
- — Tasks are comprehensive, but not too detailed to become prescriptive;
- — Reporting and control frequencies are such that no ‘watching over the shoulder’ is felt;
- — Status and progress reports have a format that is well structured and referable.

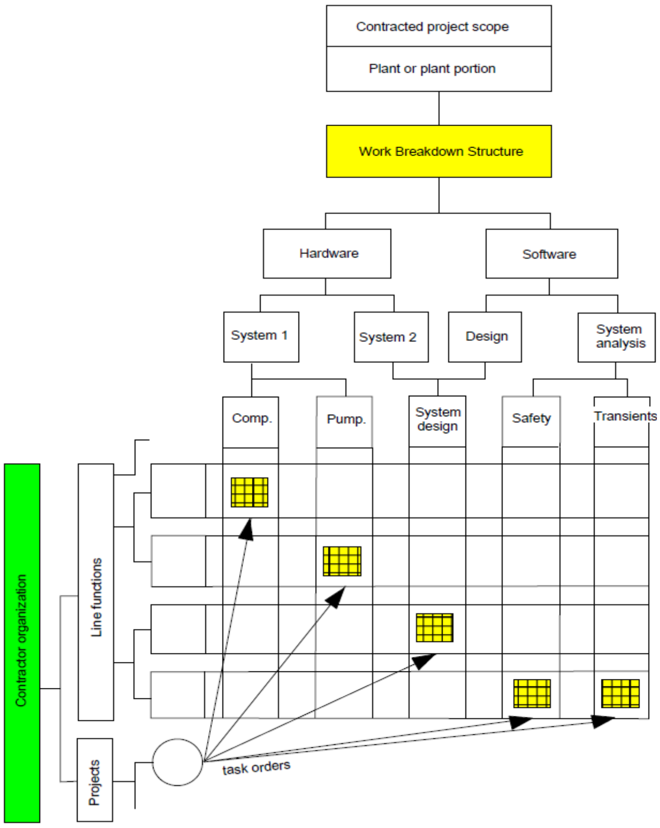

FIG. 10. Responsibility assignment matrix ('line functions' to be changed into 'functions').

The work package document should not be loaded with redundant information or should never repeat information found in other formal project documents. If needed, cross-referencing should be used instead. The referenced documents should include:

— Input requirements;
— Output specifications, drawings and analysis reports;
— Change orders;
— Purchase orders.

Even informal project documents can be referenced in the task order; these may include internal/external memoranda and schedules relating interface information and details of the task description. The quality assurance and/or licensing status is usually not directly reflected in the work order but rather through the review and approval status of referenced specifications, drawings and analysis reports.

In summary, the WBS, and the work orders resulting from it, should become a project management tool. As shown in Fig. 10, the responsibility assignment matrix (RAM) clarifies the association between work items for the plant (WBS) and the people working on them in each project partner organization with its specialized engineering, manufacturing and construction departments. The project management organization assigns specific work items to the appropriate discipline, to be completed in a certain time frame. These may be understood as specific work orders.

The WBS related to construction activities usually follows the divisions of the main disciplines, with adjustments taking into account expertise and skills.

Following is a general description of a work breakdown structure by discipline.

3.4.3. Civil/architecture

These work packages are usually classified into three main groups:

— Civil (all activities from excavation to the setting of the concrete, sometimes called 'humid works', and metallic structures);
— Architectural (all activities not included in the previous group sometimes called 'dry works' such as painting, ceilings, doors, windows, floors, etc.);
— Yard construction (all activities performed in open areas outside the buildings. This category includes buried pipes and cables).

Civil and architectural disciplines can be grouped by building (Ex.: Nuclear Steam Supply System and Balance of Nuclear Island).

3.4.4. Mechanical

Components

These work packages can be classified as:

— Special components (Ex.: Turbo Generator, Reactor, Steam Generators, Main Pumps and Motors). Sometimes primary pipes and associated equipment are classified as components and are included in this group;
— Process components (Ex.: Tanks, heat exchangers, medium and small size pumps and motors, etc.).

Related activities at lower levels of the WBS are the painting of mechanical components, prefabrication and installation of thermal insulation. Process components can also be grouped by building (Ex.: Nuclear Steam Supply System and Balance of Nuclear Island).

HVAC

These work packages include prefabrication and installation of ducts and of in-line components such as dampers, filters, ventilators including motors, etc. HVAC components can also be grouped by building: (Ex. Nuclear Steam Supply System and Balance of Nuclear Island).

3.4.4.1. Piping

This is normally considered the most complex and critical category. The work packages include site prefabrication (as defined by the construction technologies used), installation including supports, fittings and in-line components (Ex.: valves, instrumentation parts, filters, small process components not included in the first group).

Related activities at lower levels of the WBS are painting of mechanical components, prefabrication and installation of thermal insulation. Piping installation can be grouped by building (Ex.: Nuclear Steam Supply System and Balance of Nuclear Island).

3.4.5. Electrical and I&C

These work packages are usually grouped by sub-discipline:

— Electrical (Installation of cabinets and electrical components; cable trays, conduits; junction boxes; auxiliary systems such as lighting, fire alarms, loudspeakers, laying and connecting of cables, etc.);
  — Instrumentation and control (Installation of panels and cabinets, junction boxes, field racks, local instruments and transducers, etc.).

Physical separation in these disciplines should be carefully analyzed taking into account that most components are concentrated in the switchgear building; the laying down of cables cannot be grouped by buildings (except perhaps the reactor building). Similarly, most auxiliary systems are difficult to separate.

Switchyard

If the high voltage switchyard is included in the project scope, it is recommended to consider it as a sub project regardless of the disciplines involved because of the special expertise normally required to execute this work package

The described work breakdown structure reported in Sections 3.4.3 to 3.4.5 is given as a general reference. It can be used as a guideline for the establishment of the strategy regarding the breakdown structure, the grouping and separation and the work package assignments to contractors and subcontractors. Depending of the particular situation, the Owner/Operator should consider the following issues:

— Degree of local participation desired;
— Planning of development of local contractors and subcontractors according to disciplines and technical levels;
— Possible participation of the Owner/Operator in the execution of special packages (Ex.: reactor, I&C);
— Number of contractors and sub-contractors pre-qualified in each discipline;
— Special construction technologies to be used (Ex.: open top, modularization);
— Minimization of interfaces in working areas.

3.5. PROJECT SCHEDULING AND CONTROL DURING THE CONSTRUCTION PHASE

3.5.1. Schedule development and control

Controlling the project is one of the key tasks in project management. While planning and organizing have an initial peak and executive activities vary considerably over the duration of a project, control measures must always be present and applied to both near term and long term tasks. Control therefore affects all partners and all phases of a project; however, it naturally peaks during project execution.

Among the specific tools used for project control, namely the contract, project procedures, the budget, the schedule, project instructions, etc., the schedule stands out as the one that penetrates all phases and aspects of the project. The schedule has therefore correctly been closely associated with project management, although the idea that project management is just scheduling is incorrect. If schedules are to be established and maintained as an effective tool throughout the project, they must be realistic and stay reasonably up to date.

Types of schedules

The preparation of a logical schedule, with a foreseeable time frame, a meaningful degree of detail, and justification of the underlying assumptions, is an important task for project management.

The schedule appearance — e.g. a bar chart (which presents specific activities as a line or bar in time), or a highly interconnected network — depends on the size and nature of the tasks to be performed and sometimes on the capability of the persons involved. For nuclear projects computerization is necessary in view of the many interconnections and the large amounts of data. It can offer more systematic and quicker ways of examining and evaluating alternative approaches. With the speed of computers and the availability of specialized software tools, it is possible to realistically examine the permutations and combinations and provide project management with information on which to base its decisions and strategies.

A nuclear power plant schedule is typically developed in four distinct phases and corresponding levels of detail although their names and functions are by no means standardized.

The first level, Level I Schedule or Overall Schedule, represents the overview or summary for the whole project, usually in the form of a bar chart or a milestone schedule, which may emphasize specific aspects such as contractual obligations, partner interfaces and major systems. This level of schedule is usually developed at an early stage of the project preparatory phase based on the basic plant design information such as reactor type, configuration of major and auxiliary systems, layout of major buildings, site specific construction conditions such as available construction yard, transportation of heavy components, interface with existing facilities, and industry experiences of nuclear power plant constructions. If specific information on the previous projects of the same reactor type is available, it is very important to make sure that lessons learned from these projects are reflected into the schedule.

The next level of detail, Level II Schedule or Master Schedule, is still a summary level, but it is more complete. The master schedule expands the Level I schedule information to present comprehensive work packages and the interfaces among major activities are identified and written as logic-ties. The critical path and major sub-critical paths are identified. Schedule consistencies among the activities of engineering, procurement, erection and testing should be carefully checked. When modularization or open-top construction is used, the sequencing of building constructions of component and piping erections is more important than when conventional construction methods are used and should be reviewed very carefully.

In developing the master schedule, it is important to take into account the construction methods and coordinate the locations of temporary construction facilities with areas for other outdoor construction activities. Using the site general arrangement drawings construction yard layouts are optimised taking into account the location of cranes, construction platforms, on-site module fabrication bases, access routes, temporary facilities, and diagrams showing excavation and major construction procedural steps are developed. The cost of excavation and of temporary facilities should be evaluated and justified. Then the yard construction schedule is developed incorporating the civil structures and all major outdoor activities.

Typically in a project to which modularization and open-top construction are used, the yard construction schedule, the excavation diagrams and major construction procedural steps are developed about 2 years prior to excavation. Using this information, the general arrangement and composite design information as input from engineering, the master schedule is developed before the start of excavation.

At Level III, all required task elements are specified in detail to produce a complete *integrated project schedule*. The Level III Schedule includes the following characteristics:

- System-wise consistency among the activities of engineering, procurement, erection and testing;
- Correct sequencing of the schedules for area transfers from a building constructor to a party in charge of component erection;
- Area-specific work coordination;
- Consistency between outdoor activities, construction and erection, and necessary revision of the yard construction schedule and of the construction procedural diagrams;
- Component carry-in plans including temporary gateways;
- Deck plate plans for open-top construction;
- Application of other special construction techniques.

It is recommendable that the Level III schedule be developed prior to the first concrete.

Level IV, the most detailed level of information in the schedule hierarchy, includes amplifications of particular tasks: For example, the Level III schedule may show a single activity called reactor vessel procurement, which would correspond to a particular purchasing activity and subcontract. The detailed task network in the manufacturing shop for this major component may, however, fill an office wall and would normally be used by the subcontract manager, the engineers and foremen in their day to day coordination and monitoring activities. Such *detailed schedules* may also serve as progress information or as coordination tool to the utility to analyse the status of a critical component or to the regulatory authority and its inspectorate to plan fabrication surveillance for example.

Level IV schedules could also include details such as drawing lists with due dates, component specification issue schedules with target dates for first draft and preliminary reviews. Before turnover to commissioning, special ‘conversion schedule’ may be prepared. Because construction builds the plant by area and commissioning commissions the plant by systems, commissioning usually adds to the schedule those activities that convert the construction schedule into a system schedule according to the interfaces and turnover packages defined in the commissioning schedule.

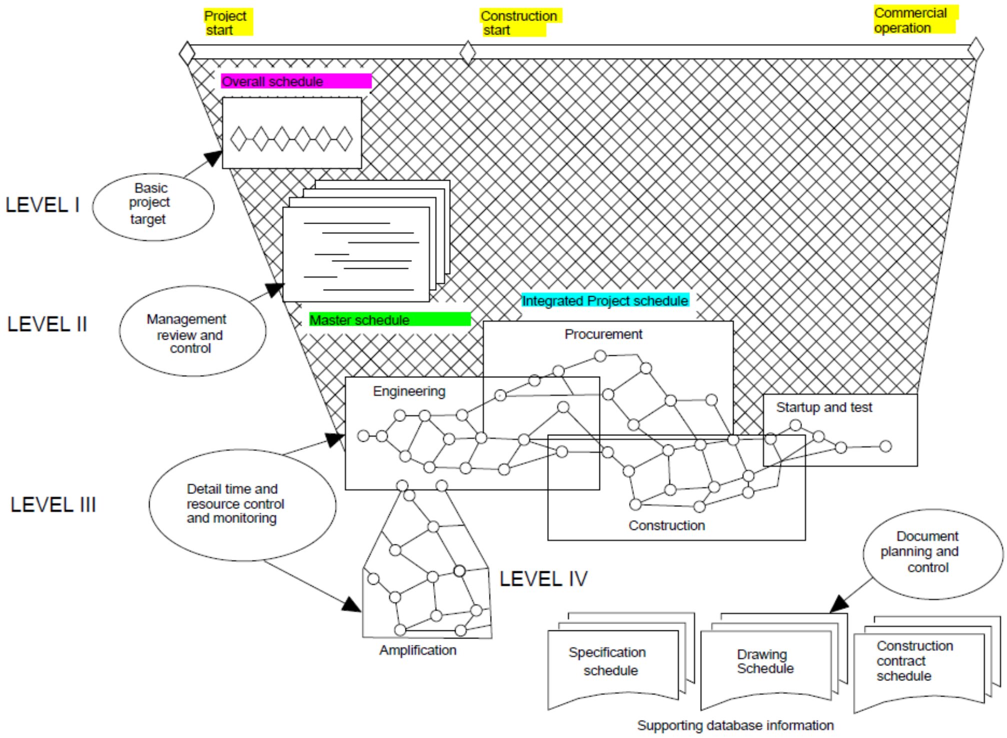

FIG. 11. Concept of scheduling levels.

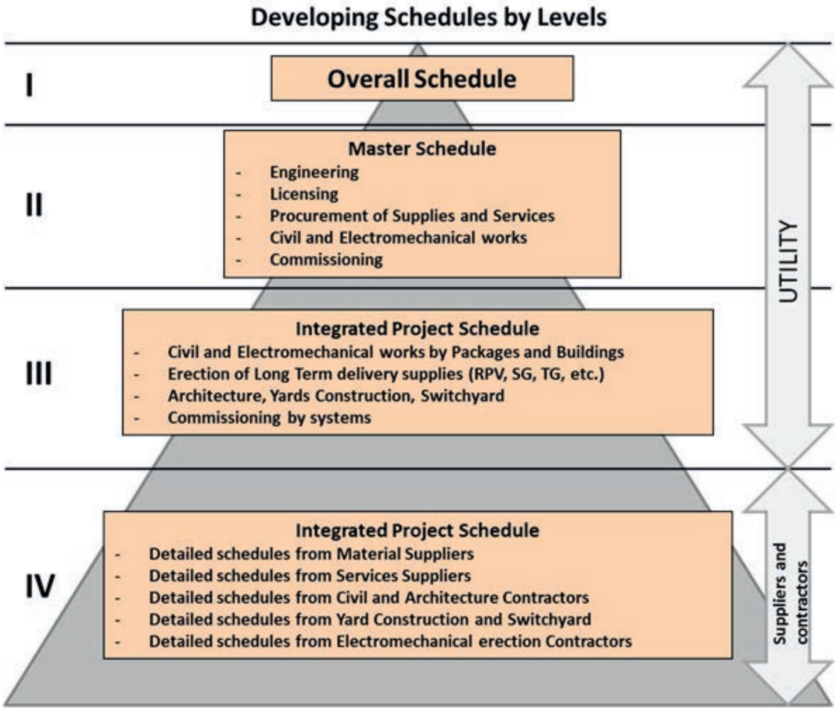

FIG. 12. Scheduling levels.

The project schedule as a tool

In a nuclear project, scheduling acts as the catalyst for project coordination and control because it:

— Helps detail the project scope of work;
— Identifies areas of responsibility for the work;
— Establishes goals and targets;
— Identifies potential problem areas;
— Identifies when decisions need to be made;
— Becomes the focus for project communications.

The schedule is really a model of the project. It employs various graphic or mathematical techniques to depict how the job is to be done. To be useful for planning and control, the schedule should provide the following information:

— What has to be done (the task);
— How the task relates to other tasks (the sequence);
— When it must be done (target or milestone dates);
— How long it will take (the duration);
— Who will do it (the function, discipline, organization);
— The resources needed (manpower, skills, equipment);
— A unique designation (numbering) for computer handling and sorting.

Many techniques and systems are available for establishing a schedule, some of them simple, others very sophisticated. Whatever technique is chosen, it must realistically depict the project work. It should be remembered that the schedule model and its results are as good as the inputs and that people working on the project have to be involved at regular intervals to keep the schedule correct and alive. If the schedule cannot be understood by the users, either they must be given schedule training or the schedule inputs or its outputs must be changed. Otherwise the schedule becomes an intellectual exercise for the scheduling specialist and not a useful monitoring and control tool for the project.

In summary, controlling the project through the project schedule means for the project manager receiving up to date, accurate, relevant and foresighted reports on the project performance against the project targets. By means of this reporting system, deviations from the target schedule should be automatically reviewed and highlighted (magnitude of the deviation, consequences, etc.) in order to allow the project manager to set priorities. This analysis of the project state via the schedule however, is not the end of the control process. The project manager must also initiate actions with the appropriate departments of his organization and/or other project partners to start resolving, i.e. removing or reducing deviations from the schedule.

Rescheduling may involve shifting of resources, compression of work plans, parallel work, changes to logical connections in the schedule, acceleration of preceding or following tasks (to regain lost time), and — only as a last resort — extension of target dates. To implement such actions realistically and firmly, substantial work and time should be first devoted to analyse and resolve issues instead of making an illusory and premature update. In the end, the corrected schedule should show no deviation and bring the particular task out of the management-by-exception area into the normal schedule range.

Use of the schedule

The real value of planning and scheduling work is the presentation of the right kind of schedule information to the appropriate level of technical and management personnel. While a project manager may want a single status report on project tasks (i.e. sorting by task number) as a complete overview, line management may prefer a sorting by technical disciplines or by task engineers to obtain an overview of a specific section or department.

For the project manager of a utility which has a supervising (non-executive) role, it would be most important to obtain biweekly or monthly reviews of the critical events in the overall project.

The project manager of the Owner/Operator should obtain the relevant information from the main contractor or architect-engineer, who should maintain a detailed schedule network for the project. A list of critical items is also needed for reports to upper management and should be communicated to project partners. The project management of the utility should have its own scheduling department and easy access to various levels of detail.

In a split package approach, the project manager of the Owner/Operator should:

— Insist on a uniform reporting system at the highest level of the schedule hierarchy, i.e. the overall plant. The system should be linked to the contractual schedule and its execution should also be spelled out in the contracts;
— Insist that the schedules be updated at intervals of less than two weeks;
— Encourage compatibility in computer software and reporting formats between the project partners;
— Have access, on request, to details of lower level schedules coming from the other project partners;
— Assign responsibilities among project partners and/or utility personnel for schedule items which need corrective action by special assignments, memoranda, task orders or meeting minutes;
— Allow only one set of coordinated schedules, authorized (signed) by the project managers in charge, for official purposes.

Schedule updating

To keep the schedule alive and up to date and to maintain its usefulness as a continuous planning and control tool, routine updating is necessary in all project partner organizations. Reports on actual status, milestones, terminated actions, etc., as well as expected new completion dates should be gathered on a biweekly or monthly cycle. Figure 13 illustrates a typical flow of information used to gathering data for schedule updating.

The project manager should prevent unrealistically optimistic forecasts. Large subcontracts will require scheduling and updating efforts similar to those for main contracts and will involve many of the same project management actions.

3.5.2. Cost control

Basic principles

The project budget is a powerful control tool. The project manager must have authority over the project budget to be able to manage the project effectively. The planned or target budget (basic cost plan) is usually set up for all project partners along with the project contracts and it is refined at the start of project execution. Once these planning and control elements have been defined and agreed upon, they become a fixed project reference.

At any time the committed budget should match the authorized resources; the overall economics of the project and its very feasibility can depend on keeping expenditures close to the budget.

Throughout the project any disagreements between original allocations and actual expenditures should be the object of a scope change requiring formal change control and reauthorisation for budget increases or decreases. The numbering scheme of the work breakdown structure should be used for unique budget identification and corresponding charge numbers should be followed and reported by the accounting unit in support of the project and of the line organizations. Suspension of payments can be used as an effective tool to control serious non-conformances in contracts and subcontracts. Much depends on the accuracy of the original allocations and work scope. Reliable budget estimates depend on the choice of reliable project partners, on the existence of a well-defined and proven contractual set-up, on accurate and detailed definition of the scopes of supply, and on a formal risk analysis of any remaining uncertainties.

Cost overruns

All cost report deviations or forecasts of increases should be immediately and carefully investigated. The project manager should explore in detail the reasons for major deviations and find out whether productivity has slipped, additional unauthorized work has been introduced, or new requirements have been added. Only when the nature of the problem has been clearly identified, can the project manager issue a ruling, or negotiate a solution with

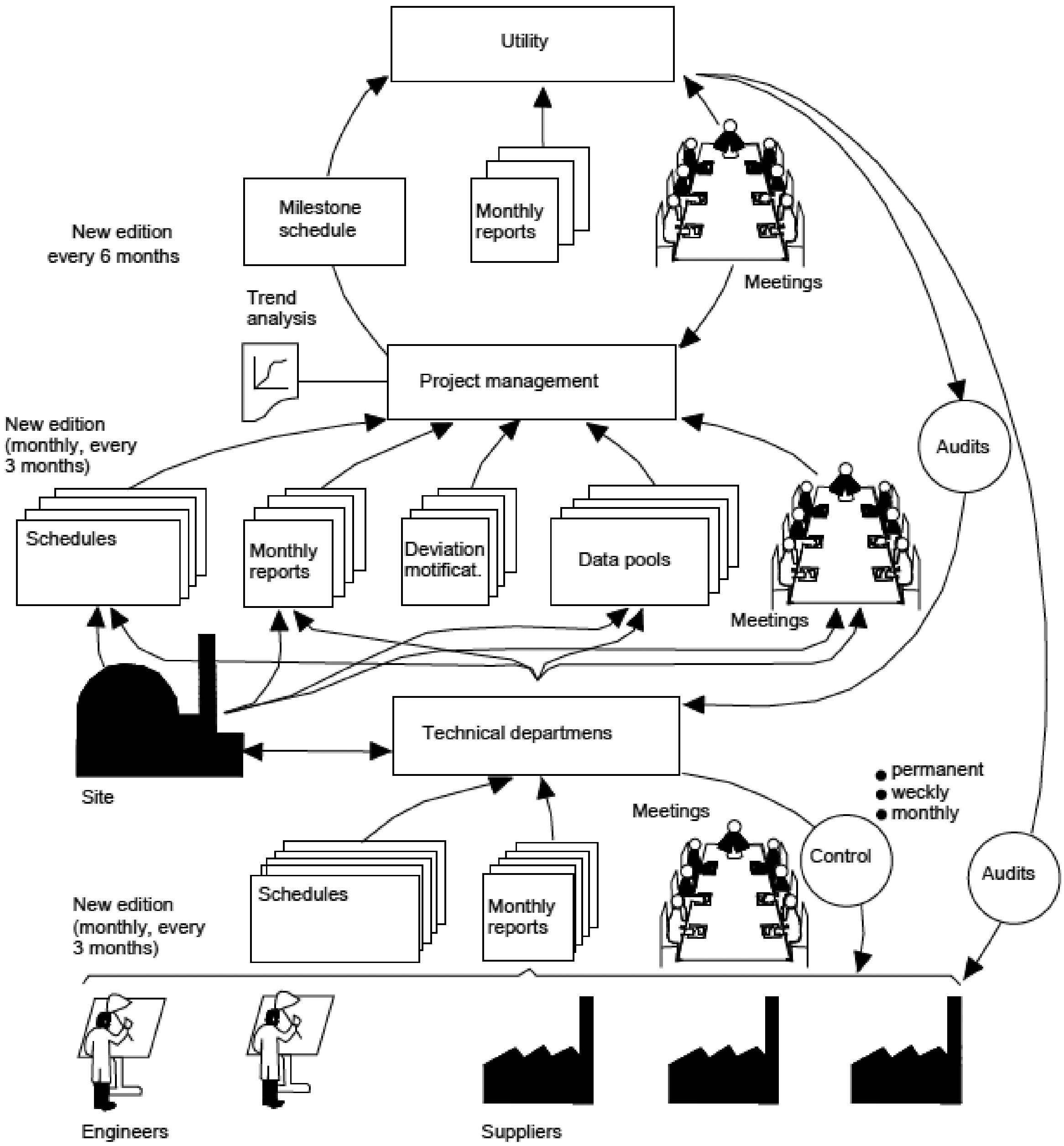

FIG. 13. Illustrates a typical flow of information in gathering data for schedule updating.

the departments and/or project partners affected, i.e. re-aligning the scope, reducing or shifting expenses or if all else fails requesting extra funding.

Cost escalation

Escalation is the provision in a cost estimate for increases in the cost of wages and salaries, raw materials and components, transport and other expenses due to inflation or other price changes over time. All cost increases imply a decrease in the real value of money (inflation). This decay in the value of the currency in time appears to be inevitable and therefore predictable and it must not be overlooked given the long duration of a nuclear power project. Methods and mathematical equations to anticipate such changes and apply corrections are quite common in budgeting and cost control. Establishing a baseline to allow budget and cost adjustments makes it easier to produce realistic forecasts and helps improve awareness of cost increases and of inflationary forces.

Contingencies

One common source of errors in overall project estimates can be the failure to appreciate that additional costs are bound to rise as a result of design errors, manufacturing mistakes, logistic errors, material or component failures, etc. Contingencies in the budget are used to account for these possibilities.

The degree to which contingencies must be added to estimated project costs will depend on many factors, including the soundness of the engineering concepts, the reliability and experience of project partners, contractual conditions, and so on. Performance in previous projects is a reliable precedent for deciding just how much to allow on each new project to cover such circumstances. For a proven product and contractual model, the total contingency allowance might be set at *5%* of the project scope of each partner. If the figure exceeds 15%, perhaps the utility should consider whether or not the partners or the contractual conditions are acceptable. It is probably better to set up a reserve fund to pay for statistical cost deviations rather than to re-examine the original estimates on an item by item basis. In the rarer cases where cost savings are achievable, these must be monitored and analysed equally carefully. Costs and possibly contingencies can also be divided into categories, such as changes, planning and logistic errors, scrap materials, rectification and so on. If a good accounting and cost control system exists with the production of biweekly or monthly sorted listings and trend curves, control can be concentrated in areas where unforeseen overruns are likely to be higher or more frequent and where corrective action would be most effective.

A systematic method of approaching contingencies associated with technical uncertainties is the use of the risk management method. Early discovery of trends and figures and corresponding remedial action can help project management stay within budgeted contingencies. As the ultimate holder and controller of the project funds, the project manager of the Owner/Operator has a particular responsibility in planning, using and managing budgetary contingencies. In a turnkey situation, for example, with a fixed cost, a predictable licensing situation and, above all, a sound and stable contractor, the utility may not need much contingency. Depending on the contracts, the main contractors and/or the architect-engineer may take on large portions of the project scope and budget and the planning of project contingencies. Correspondingly, a firm pricing and costing policy with reasonable (5–10%) contingency over the project life can be used for the partner organizations. An open ended, unpredictable, cost-plus situation on any portion of the project should be avoided.

3.6. QUALITY PLANNING AND MANAGEMENT

3.6.1. Establishing organization and basic programme for management system

A management system (MS) should start from the time the project is conceived. The entire range of activities including design, procurement, works, services, selection of human resources, of contractors, suppliers, etc. falls within the scope of management system. Quality assurance (QA) in nuclear facilities encompasses quality control efforts at every stage. The MS covers quality in design documentation, in manpower deployment, in the selection of manufacturers and contractors and in applying commissioning principles and procedures during commissioning and during the preparation of construction/commissioning records.

The responsibility for quality management is vested in the management of the facility and affects all staff in all functional areas and at all levels. During plant construction, one of the prime responsibilities of the Owner/Operator representative is to ensure that stipulated quality standards are adhered to. The management system group of the nuclear facility should be independent of the line, of the pressures of the schedule and of cost controls. Their prime responsibility should be to review the activities of the nuclear facility and ensure compliance to specifications and stipulated quality standards. Experts in various disciplines should be included in the management system team and the head of the team should report only to the senior most executive of the nuclear facility, i.e. the Chief Executive Officer of the utility.

3.6.2. Establishing the management system

The management system in a nuclear power plant should ensure that safety issues receive from the start an adequate importance and priority at the project management level. Safety is closely related to quality. There are interfaces between safety and quality that should be identified and planned simultaneously.

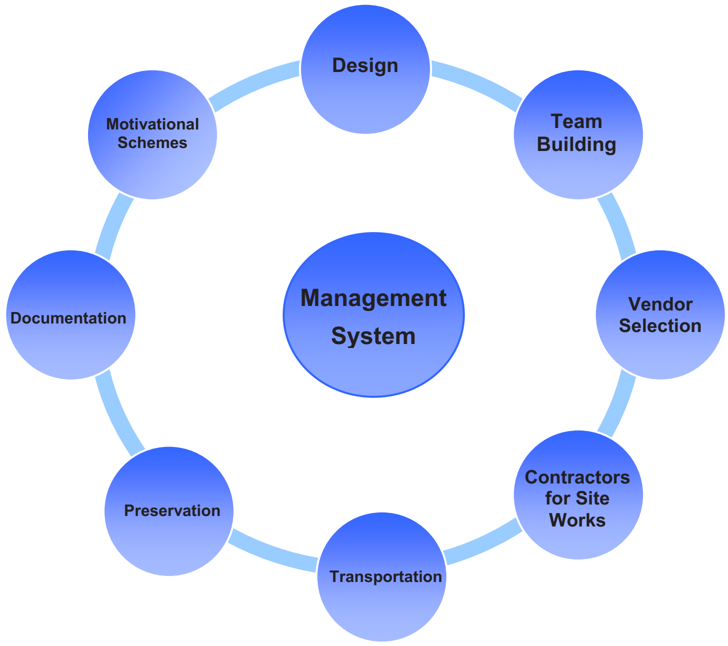

FIG. 14. Management system relationships.

Advanced experience on safety issues is particularly important when selecting the safety and licensing responsible persons. It is recommended that these individuals have about ten years of experience in nuclear safety and licensing. This should apply not only to nuclear safety, but to radiation protection and occupational safety positions as well. Figure 14 shows the relationship between management system and technical areas.

A quality assurance (QA) planning document should integrate all stages of a management system programme. QA programmes normally evolve in time. They are developed and documented based on the experience from reference projects. They should be reviewed periodically and updated to reflect evolving conditions and to incorporate the experience accumulated during their implementation.

Depending upon their scope and activities, utilities may adopt different organizational models for their MS group. Normally a QA group is formed by integrating the organizations of the various functional groups such as design, procurement, construction, erection and commissioning. The quality assurance in services such as transportation, equipment preservation, documentation, etc., is usually the responsibility of these functional groups.

The influence of MS groups and their effectiveness depends on the value the owner representative assigns to the QA functions. Unless the senior management commit themselves to quality at all levels and functions, quality will lag behind. A quality minded organization is normally formed by systematic quality training, a good set of procedures, penalties for non-conformances as well as periodic reminders of the consequences of poor quality in the history of nuclear facilities.

The director of MS should deal directly with the managers of various functional groups in the nuclear facility. The QA groups in the various functional areas should oversee quality performance in their respective functional groups. The QA personnel should be provided with complete autonomy in the practice of their functions. They should be empowered to take stringent measures, including work stop orders, if the required quality is not met.

A project has several functions, such as engineering, procurement, construction, manufacturing, installation, etc. The owner representative should ensure that each of the functions is covered by functional MS staff that is part of the overall QA group.

3.6.3. Ensuring quality control depending on safety significance

The term ‘quality’ has a broad connotation. It guarantees consistent characteristics when a product or service meet certain requirements and defines their relative superiority with respect to similar products or services without quality requirements.

Designers normally define quality as conformity to requirement usually expressed in the form of standards and technical specifications. Attainment of all product requirements within the tolerance band of a specification is sufficient for an engineered component to be a quality product. Efforts to manufacture products of superior quality (tighter than the tolerance band defined in the specification) involve higher cost and effort, without usable benefit for the plant. On the other hand, failure to attain the minimum specified requirements may result in failure of the component, with its associated hazards. Attainment of all requirements in a specification within the tolerance band is quality work.

Nuclear plants usually contain components at different quality levels. This is due to a graded quality approach for system structure and components (SSCs) in the various systems. The quality grade is dictated by the location and the safety significance of the SSCs in the plant. Depending on the reliability requirement of the SSCs, the nuclear power plant designer, specifies the grade also called class. Each quality class covers a range of reliability parameters.

The design criteria that determine the safety significance and the reliability needs of each system are normally reviewed by the regulators. Manufacturing can commence only after the regulators and the designers reach a consensus.

The manufacturing process verification and the extent of equipment and construction inspection depend on the quality grading specified. Safety significant systems such as the Nuclear Steam Supply System (NSSS), the Shutdown and Containment Systems, etc. are subjected to more rigorous design, manufacturing and erection process controls, and more detailed inspection, tests and documentation are required.

Nuclear power plant utilities should thoroughly review the management system (MS) plans of manufacturers and suppliers for custom built equipment. Depending on the safety significance of the equipment, they should define their inspection and hold points in their quality control plans. Quality controls for bulk materials or off the shelf items cannot be as rigorous. Utilities should select only reliable suppliers of bulk materials, recognised for their stringent quality controls, and select the products based on their reliability under similar past applications.

3.6.4. Quality assurance in design, manufacturing, transport, installation, etc.

Quality assurance is not a one-time effort. It is a constant endeavour in nuclear plants and requires reviews, vigilance and corrective measures. The IAEA and nuclear power plant regulators in several member states have their own codes and guides for quality assurance programme in nuclear facilities. Quality however is not assured merely by complying to theses codes and guides; it is attained by intelligent effort. Management should ensure that professionalism and a safety and quality culture govern every action. Verification is important in QA. Surveillance checks and audits by independent QA professionals, free of cost and time pressures should be conducted periodically and systematically.

Often procedures are too extensive to be effective in a large project. QA should review and stream line all procedures. Clarity in the requirements, in the organizational structure, in the decision making processes, in the method applied for vendor selection, in manufacturing, in equipment and system installation and in commissioning is crucial for the success of a quality plan. QA programmes should include flow charts and evaluation forms to help in decision making of all aspects of design, procurement, construction, erection, commissioning, inspection and testing.

An example of QA scopes for the functional QA groups is listed here below:

QA for engineering

— Ensure an appropriate organization for all design units;
— Ensure that only qualified designers are employed;
— Ensure that design documents undergo appropriate checks, review and approval;
— Ensure that design documents are controlled and changes are properly regulated;
— Conduct audits for a wider coverage of design activities;
— Ensure that the design validation and verification processes have been applied before the equipment is constructed.

QA for procurement

- — Vendor selection;
- — Ensure that machines and tools for production and instruments for inspection, testing and quality check are calibrated;
- — Ensure compliance with qualification/certification requirements are met at the vendors' shops;
- — Ensure that the approved QA plan is respected;
- — Ensure use of materials complying with the technical specifications;
- — Ensure traceability of the material through the entire production process, and the stamping of the materials during processing;
- — Ensure compliance with process controls (e.g. welding/ brazing process controls, maintenance of parameters during testing, etc.);
- — Ensure that non-conformances and changes are properly regulated and documented;
- — Verify that the issue of shipping releases is as per schedule;
- — Participate in inspections and testing as per approved QA plan;
- — Review the product selection process for bulk materials and off the shelf items;
- — Ensure proper packing for transportation to facilitate preservation and avoid handling damages;
- — Conduct periodic audits of vendors' activities and sub vendors' workshop practices to ensure that quality standards are maintained.

QA for site works

The site QA team should ensure compliance to quality requirements during construction, erection and commissioning. The QA team should also oversee that preservation of the equipment at the site stores and yards, as well as continuing post erection preservation, and compliance with statutory regulations on environment protection. Following is a typical list of activities at a construction site:

- — Inspect of materials received at site;
- — Select of contractors for site work;
- — Ensure that machines, tools and instruments for inspection, testing and quality check are calibrated;
- — Ensure compliance with qualification/certification requirements for construction, commissioning and inspectional personnel;
- — Ensure that the approved QA plan is respected;
- — Ensure that quality of construction materials and consumables comply with the specification and only materials cleared for use are taken to site;
- — Ensure that any special instructions, emerging from approved deviations during production are followed during erection;
- — Ensure that regulatory clearances wherever required are received prior to equipment erection. No work of irreversible nature should be allowed until regulators have cleared it;
- — Ensure material traceability, radiographs and various other production and inspection documents through the entire construction and commissioning stages. Participate in site inspection and testing to ensure compliance of approved QA plan;
- — Ensure compliance with process controls (e.g. welding/ brazing and with the expected parameters during inspection and testing etc.);
- — Ensure that non-conformances and changes are regulated and documented in accordance with procedures;
- — Ensure that equipment handling during erection follows installation manuals, manufacturer recommendations and procedures;
- — Ensure that the post erection preservation scheme is implemented;
- — Conduct periodic audits of contractors' and sub contractors' activities to ensure that quality standards are maintained;
- — Ascertain that the commissioning is undertaken as per approved processes and procedures;

— Ascertain that construction and commissioning records are generated and archived for future reference according to requirements, procedures and instructions. Ascertain compliance to statutory regulations on environment preservation and occupational health.

Quality audit of the QA groups

It is essential to ascertain that the QA group maintains high standards in its operation and therefore conducts periodic quality audits. Usually a third party (the authorized inspector) is engaged for such audits. The audit should include:

— Qualification and certification of all QA professionals;
— Compliance to procedures in QA activities and in the conduct of quality audits;
— Maintenance of records for activities of the QA group.

3.6.5. Surveillance of manufacturing processes

Quality in the manufacture of equipment has a great bearing on the safe and reliable operation of nuclear power plants. Several decisions may be made during the fabrication, machining, assembly and testing stages. Utilities often post their inspectors to the manufacturer premises to work in parallel with the manufacturer's own inspection teams. The main purpose is to ensure that QA self-audits are conducted according to the contract and the technical specifications. Their presence also helps ensure that the required priority is given to quality at the vendor's premises, and that machinery and expertise are properly allocated to fulfil contractual requirements and not diverted to other jobs in a multi-tasking fashion.

3.6.6. Conducting comprehensive inspection at critical milestones

The Owner/Operator might not inspect products and processes at every stage. Confidence that the selected manufacturers will produce quality components is essential. However, a balanced and graded approach and judgement should be applied. Quality conscious vendors should be sought during the selection process. Purchasers should identify major milestones in the QA programme document in order to gain confidence that all quality expectations are complied with. The Owner/Operator could conduct quality inspections itself or alternately employ third parties for the purpose.

The QA plan should specify witnessed checks or hold points at major milestones. These steps facilitate confidence and prevent detection of non-conformances only at the end of the manufacturing process.

3.6.7. Qualification of sub-suppliers

Sub-suppliers cannot usually be avoided in the supply chain management. They are present in large numbers and participate in the project through sub-contracts with the main contractors. While awarding manufacturing or

FIG. 15. Graded approach for inspection by the utility.

construction orders, the utility normally evaluates the capabilities, financial status, QA programmes, etc. of vendors and contractors. The main suppliers and contractors are awarded orders and contracts. They directly supply products and services; they carry out construction activities in the area of their core competence. They depend on sub-suppliers for the balance of supplies and services but remain responsible for the whole contract scope as it was awarded to them by the Owner/Operator.

Recognizing this fact, the tender document normally includes the requirement to identify the major sub-suppliers and the scope of their activities as bids are submitted. The bids should also require that sub-vendors and their QA programme be evaluated along with that of the main vendors as contracts are awarded. However given the sheer number of sub-contractors, the following facts cannot be ignored:

- The main contractors will identify only a few major sub-suppliers while submitting their bid. It would take them too long to seek quotations and select all their prospective sub-suppliers. Unless the contract is actually awarded to them, they cannot afford to deploy large resources to select and qualify all their sub-suppliers.
- Given their large numbers, it may be impractical to evaluate all sub-suppliers before awarding the purchase order to the main contractors.
- The main contractors may have to change their sub-suppliers occasionally and for various reasons, even those identified in the contract. The purchaser for the Owner/Operator may have to review and negotiate the change.
- Where evaluation of sub-suppliers requires visits to their premises, a combined team from the purchaser and the main contractor may have to be formed.
- It may not be possible to visit all the sub-suppliers and evaluate them before the main contractor awards the purchase order to them. It may be necessary to rely on the qualification of the sub-supplier and make it a major factor in their selection. This activity may extend throughout the span of the contract.

In order to avoid loss of time and effort for the evaluation of sub-suppliers, it may be advisable for the purchaser to include a list of pre-qualified sub-suppliers in the tender itself. However, the list should have options for widening the selection. See Fig. 16.

3.7. CONSTRUCTION INSPECTION

Construction inspection covers inspections and tests to ascertain that SSCs have been manufactured, modified or repaired and quality control implemented in accordance with an approved construction plan and procedures. In addition, an inspection should verify that the equipment or structures have not been treated in a way that would negatively affect their endurance and functionality during service life.

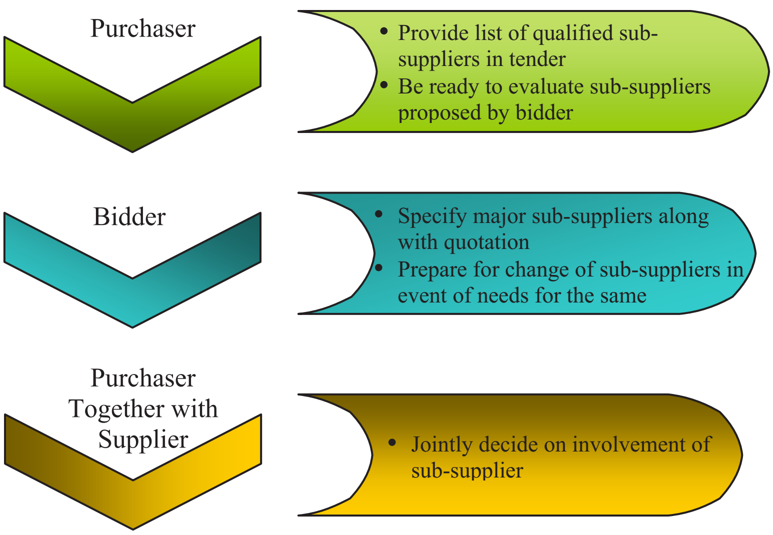

FIG. 16. Sub-supplier selection.

Based on their safety significance, SSCs may be divided into five construction inspection areas:

- — Equipment and structures inspected by regulatory authority;
- — Equipment and structures inspected by a regulatory authority approved inspection organization;
- — Equipment and structures inspected by the owner or utilities;
- — Equipment and structures whose construction inspection (conformity assessment) is conducted by a notified body or a user inspectorate;
- — Equipment and structures which are not subject to licensing.

3.7.1. Construction inspection areas

In view of quality control during construction, the following aspects should be considered:

- — The nuclear power plant construction extends over a large time span, often four to five years or even more. Work is carried out in two or three shifts. The quality control effort has to extend throughout the life span of the project;
- — Work is spread over vast areas of the plant; quality control and assurance are needed in every area;
- — Several types of activities are undertaken simultaneously in the construction project. Quality issues and control measures could be different for various activities;
- — The construction site conditions are normally more difficult to check compared to the conditions in a lab or manufacturing shop floor. Work and inspection are to be carried out simultaneously under often hazardous conditions in construction sites. The conditions at the site facilities (approach road congestion, inclement weather, housekeeping and cleanliness, etc.) change frequently;
- — Work is carried out by large numbers of people, most of which are not permanent staff of the utility and hence less concerned with quality which must be ensured even for migratory workers who stay at the site for a limited duration.

Quality management under such conditions require systematic action, good strategy formulation, periodic reviews of the results, and a constant updating of the strategy (see Figs 17, 18). It may be impractical for the nuclear power plant utility itself to carry out quality checks and inspection of the entire site. Following is a suggested strategy to obtain effective site inspections:

- — Ensure that candidate contractors have proven credentials, that they possess a quality assurance programme and can deploy an adequate and qualified quality assurance unit to carry out effective site inspections;
- — Work procedures are as planned and detailed in advance;
- — Records of compliance should be created, checked, verified and submitted to the utility for approval;
- — The Owner/Operator creates area coordinators where more than one contractor works simultaneously in the same area;
- — The utility conducts periodic audits of the contractors' QA programme, and conducts verifications to improve confidence;
- — For safety significant systems, the utility may either carry out inspections using their own employees or an inspection agency;
- — The adequacy of construction and the availability of records should be jointly verified by the construction and commissioning personnel during construction and recorded at the moment of turnover to commissioning in a construction completion certification document.

To define the construction inspection areas, the licensee should produce a document defining the general principles of inspection and the detailed inspection areas per the inspection plan. Construction inspection should include:

- — Review of the results of quality management activities in manufacturing;
- — Inspection of equipment or structures, their positioning and their dimensional verification. Pressure test, if necessary;

FIG. 17. Areas that may affect quality control in a construction site.

— Inspections after pressure test;
— Loading and leak tightness tests, if necessary;
— Functional tests, if necessary.

A construction inspection plan should be approved by the regulator and the manufacturer, the licensee and the supplier should verify that the SSCs are in compliance with the construction plan. Construction inspection is usually made on completed structures and components at the manufacturer's premises before delivery or installation. Inspection during construction is divided into two categories as shown in Table 2.

If inspection becomes more difficult as manufacturing proceeds, or after assembly, an adequate number of construction inspections should be carried out during the various manufacturing phases. The manufacturer is responsible for the timely performance of the inspections. The timing of construction inspections in relation to the manufacturing phases should be specified in the construction plan. See Figs 19, 20 for inspection principles during manufacturing and concrete structures.

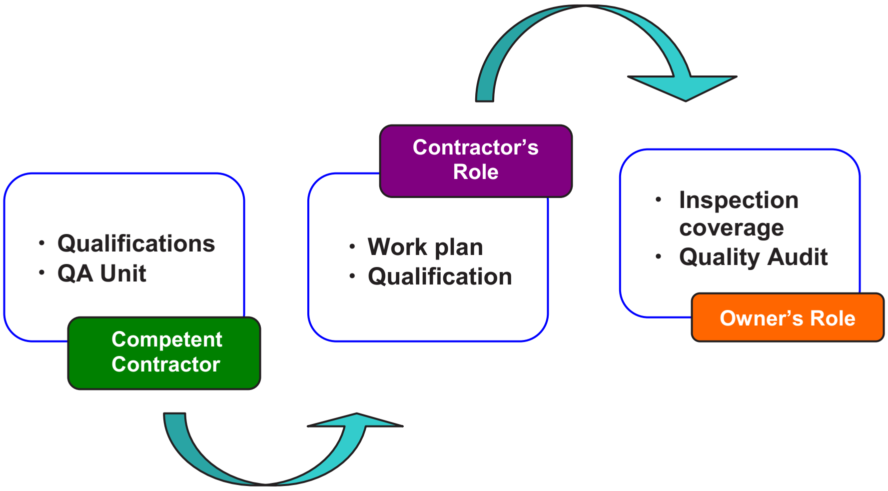

FIG. 18. Approach for quality management construction.

TABLE 2. INSPECTIONS DURING CONSTRUCTION CAN BE DIVIDED INTO TWO CATEGORIES

Inspections during construction on SSCs.	To verify QA and QC results and to confirm the acceptability of the activities of manufacturers, vendors and of the licensee; To meet inspection requirements defined in regulatory guides; To audit inspection organizations used in reviewing safety-related non-conformances.
Inspections on licensee's performance within the construction inspection programme	To verify the adequacy of project management, safety assessment, QA/QC programmes, etc. to check if performance expectations are being met.

3.7.2. Construction and erection tests

The construction and erection tests normally cover examination of mechanical components, electrical and I&C equipment and civil structures, according to the applicable codes and standards.

A. For mechanical systems, structures and components:
— Non-destructive testing;
— Hydro tests;
— Dimensional inspections, etc.

B. For electrical and I&C equipment:
— Insulation;
— Ground circuit;
— Continuity;
— Polarity wire;
— Phase sequence;
— Tests and calibration of instruments, etc.

C. For civil structures:
— Containment liner;
— Structural steel;
— Reinforcement steel: Tensile and bend testing;
— Aggregates;
— Cement;
— Concrete, etc.

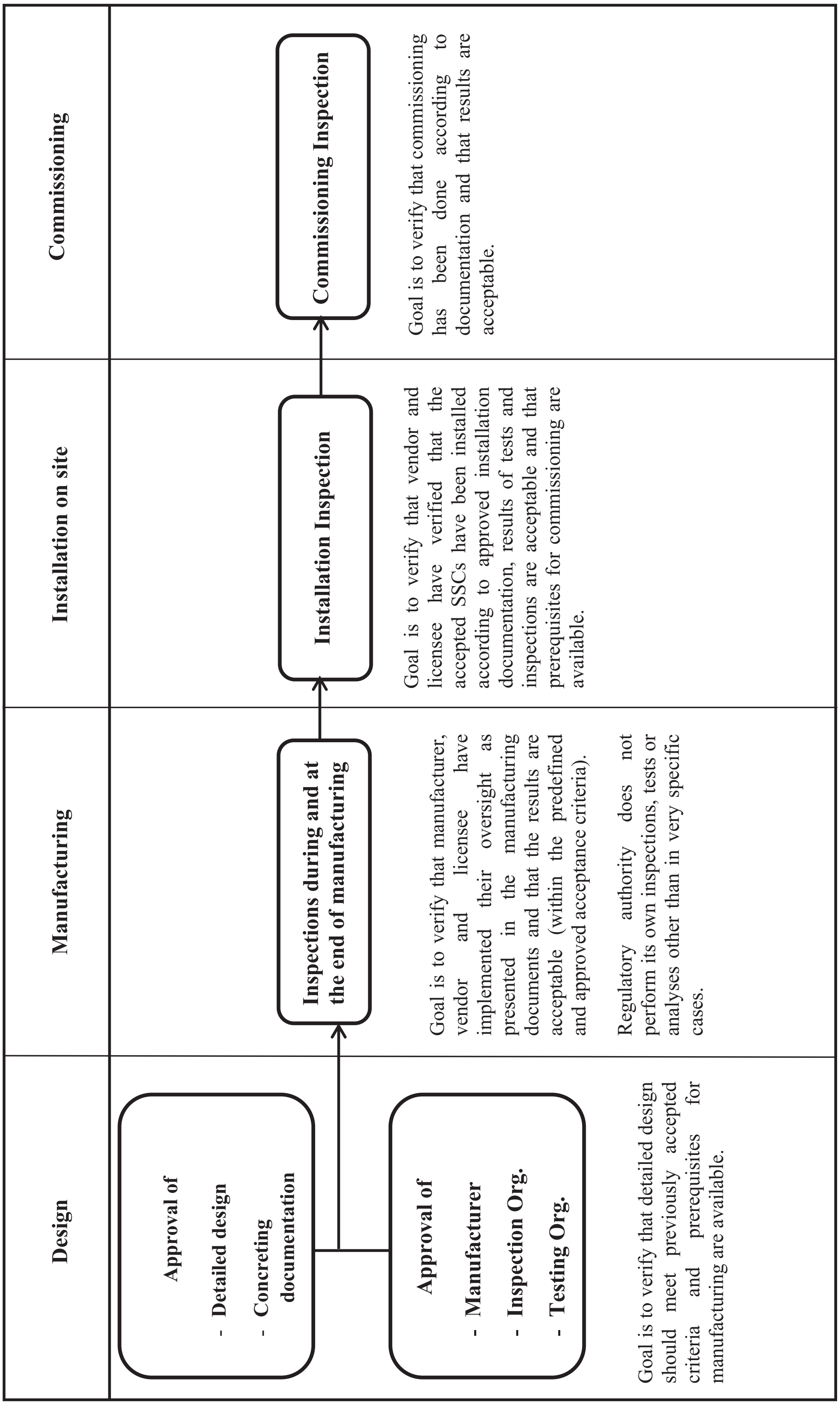

FIG. 19. Inspection principles during manufacturing and construction for pressure boundary equipment [13].

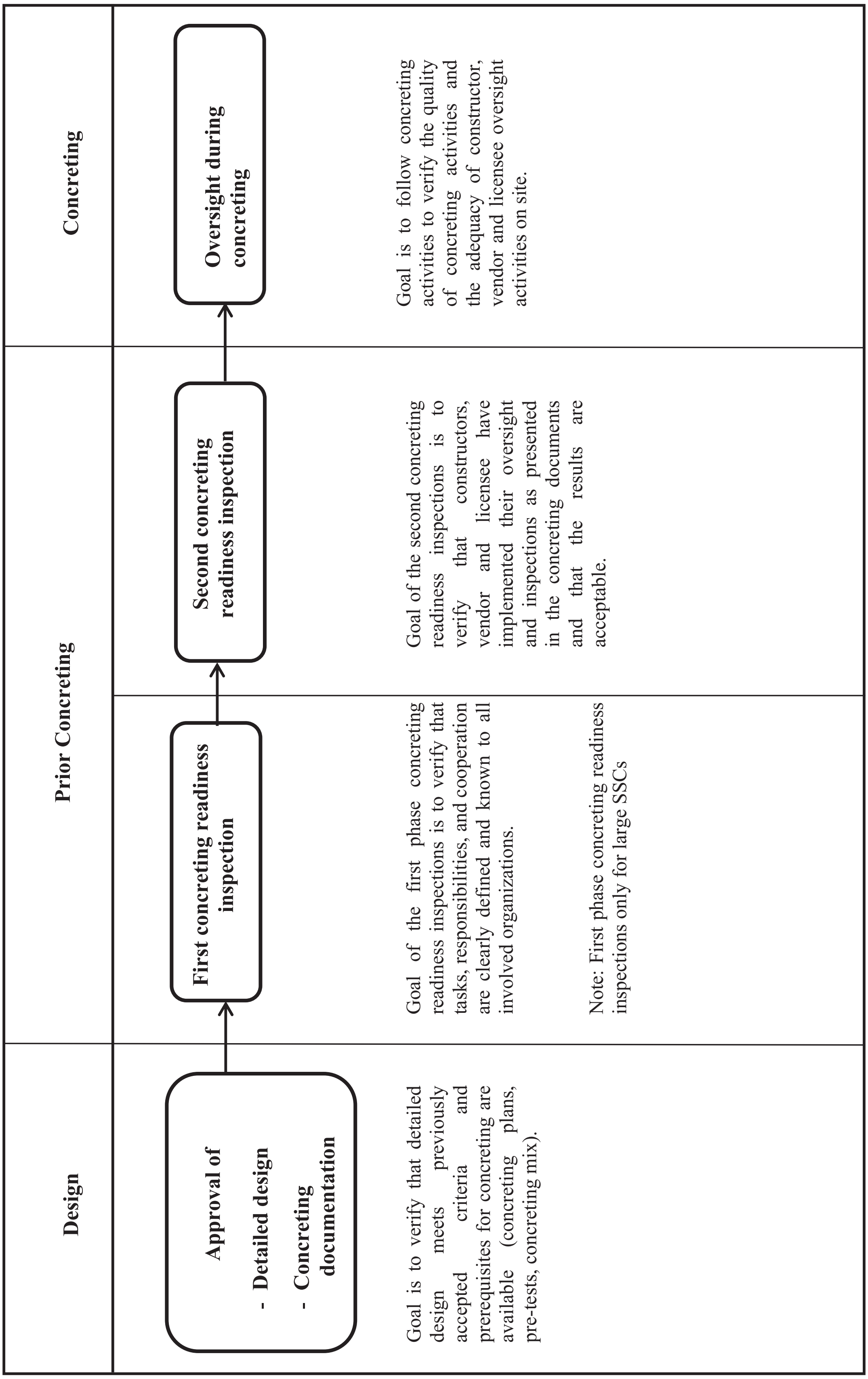

FIG. 20. Inspection principles during construction for concrete structures [13].

3.7.3. Recommendations

It is recommended to:

- Focus on the role and understanding of quality management;
- Clarify, consistency and effectiveness of the non-conformance report process;
- Organize the Owner/Operator's oversight and control of vendor activities (essential);.
- Ensure proactive actions by owner (plan future inspection activities and quality audits);
- Identify safety issues and use systematic ways to make decisions on safety issues;
- Connect with interfaces and external entities within the project organization especially from the safety viewpoints;
- Define clear criteria for competencies, tasks and responsibilities within project organization;
- Devote enough attention and resources to document control and management;.
- Audit the quality control unit performance.

3.8. SAFETY AND ENVIRONMENTAL MANAGEMENT SYSTEM

The project implementation phase should establish a good safety culture and maintain it throughout the operational phase. Good coordination of the various organizations participating in the project for the management of safety is essential in order to promote a strong safety culture and achieve good safety performance. Safety management should include nuclear safety, industrial safety, occupational safety, fire protection, radiation protection, etc.

The following specific aspects should be reflected in the safety management system for the project phase:

- Interfaces between vendor, Owner/Operator and regulatory authority should be well defined and all requirements clarified before project start and they should be enforced during the project implementation phase;
- Requirements should be understood by all partners prior to project implementation;
- Engineering interface and appropriate links should be organized to ensure that the project is implemented in accordance with the requirements of the Safety Analysis Report.

The safety management system should cover also the role of top management in the decision making of safety related issues and the importance and prioritisation of the safety issues (graded according to their safety significance) in the project decision process.

3.8.1. Safety culture

A safety and quality culture should be established from the start at all levels among the personnel involved in the project. The importance of the role of individuals in the various project phases in achieving quality and safety objectives should be highlighted in the training programmes [14].

During the construction phase, it should in addition be emphasized that especially challenging is the situation where the staff has never worked on a nuclear power plant construction project. The challenges are compounded when the staff is hired from various countries where practices and habits of individuals might differ remarkably. Management would have to find ways to amalgamate a multicultural workforce. Another challenge may be represented by frequent staff turnovers during various project phases. This would cause issues with the continuous need to re-instate safety culture concepts and practices and may require the application of on the job training methods. The several layers of sub-contractors typical of a mega project of this size may constitute a challenge for the project organization in terms of imposing the safety culture down to the last worker of these companies who may be on site for a very limited time.

However, with a few simple but important steps and clear rules a basic understanding of safety concepts and of individual responsibilities can be reached. One fundamental starting point is that rules and procedures must be enforced at all times; no deviations should be allowed. A computerized system to record non-conformances and

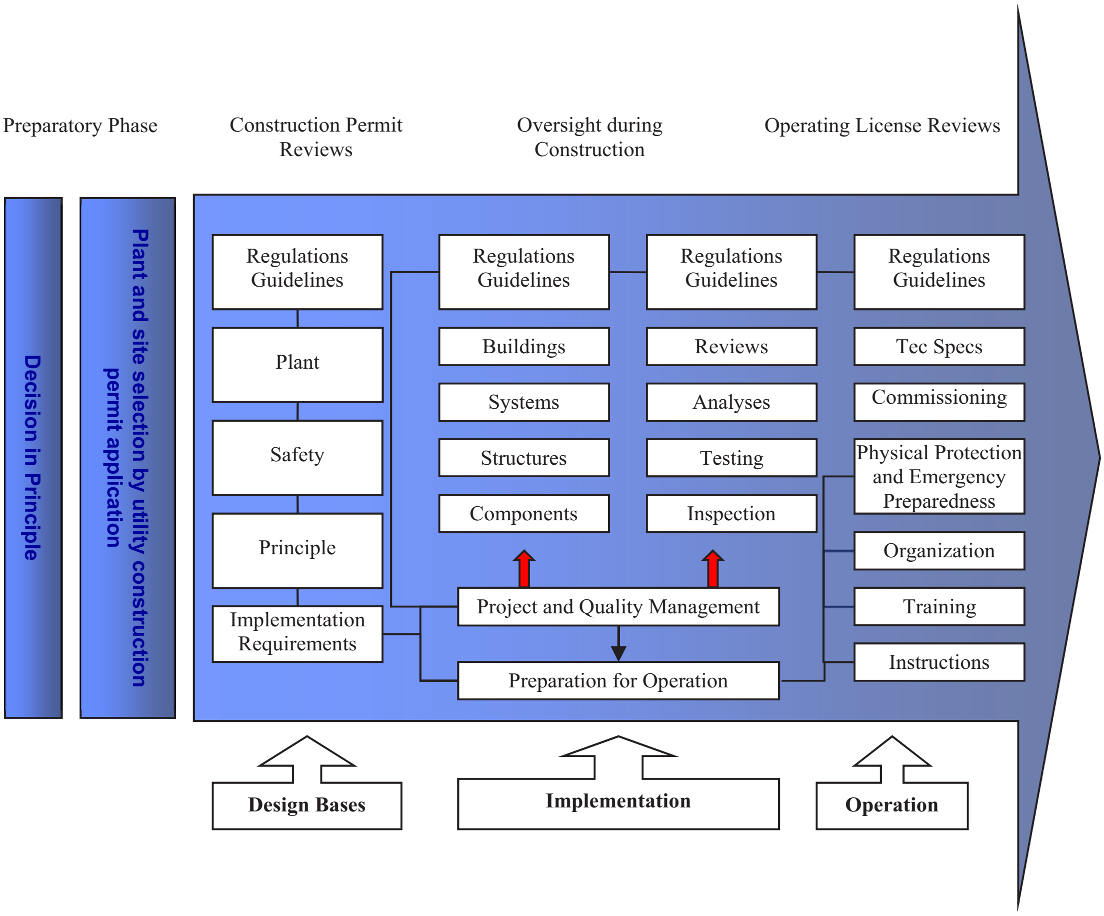

FIG. 21. Three steps of construction inspection programme [13].

safety significant events and to facilitate corrective action should be made universally available. Superiors must be notified of every non-conformance. Depending on the gravity, work may have to be stopped. Issues must be identified and handled at the proper level before continuing with the work. A second important point is to include in all kick-off meetings before starting work a brief safety session, where safety principles are reminded and the worst consequence of non-conformances highlighted.

3.8.2. Industrial and occupational safety

Industrial and occupational safety is vital in all places where physical work is performed. It is important that all employees return unhurt to their home after work every day. In a nuclear power plant it is evident that the safety culture would play a remarkable role.

From the project perspective, every accident causes delays, additional pressure to catch-up and additional costs. Thus, it is recommended that industrial and occupational safety issues be reported to top management on a regular basis and timely processed.

3.8.3. Safety evaluation prior to contract negotiations

It is extremely important that all partners (vendor, contractors, sub-contractors suppliers, Owner/Operator and regulatory authority) be well aware of safety requirements, of licensing requirements and of the applicable codes and standards.

The Owner/Operator should review the safety and licensing management system of its contractors and manufacturers in order to ensure their adequacy in fulfilling the licensing requirements and in resolving safety issues. Similarly, the contractor should perform a safety review of its own sub-contractors. As guidelines for the review, the contractor should use the outputs from previous audits, from assessments and seek compliance in the

FIG. 22. Creation of environmental survey laboratory to create background data.

implementation of safety and quality goals, check the status of corrective and preventive actions, check the implementation of follow-up measures and suggestions for improvement recommended in other safety management system reviews, and review attentively any procedural of managerial changes that could affect the company safety management system.

The regulatory authority should ensure that it has adequate resources available during project execution, so that guidance reviews and audits are carried out on time allowing the licensing process to proceed without impediments and decisions are rapid and well informed so as not to slow down and complicate the licensing process and project implementation.

3.8.4. Project environmental management

Project environmental management include all the activities of the project utility and the performer organization which determine environmental policies, objectives, and responsibilities in order to minimize the impact on the surrounding environment and natural resources and to operate within the limits stated in legal permits. [15].

Project environmental management shares many common characteristics with quality management and safety management, and it is for this reason, their requirements appear very similar. Project environmental management includes the developing of the following processes:

— Environmental planning;
— Perform environmental assurance;
— Perform environmental control.

3.8.5. Environmental standards

Each country has its own environmental regulations that must be meticulously followed during the construction of nuclear facilities. The environmental assessment is normally obtained even before the site is cleared for construction. Data on the use of the land and the water as well as data on the releases to the environment during construction and operation of the plant are usually required. The effects of the plant construction on vegetation and various life forms, including marine life, have to be evaluated and submitted to the national regulator in order to obtain site clearance.

The Owner/Operator is usually required to enforce compliance to the environmental regulations during construction and to ensure that all statutory regulations for environmental protection are compiled and properly archived. QA groups often assume this responsibility. In order to verify compliance with the environmental protection rules an environmental survey lab is normally established much in advance of the start of construction of a nuclear facility.

Occasionally the Owner/Operator may arrange a third party review of environment protection measures to test its effectiveness.

3.9. DEVELOPING A HUMAN RESOURCES PLAN

The construction team is comprised of staff with diverse roles and responsibilities. The type and number of team members may change according to the progress of the work. Early involvement during the project planning process of the team leaders helps build disposition to teamwork, strengthens awareness of interface requirements, of project goals and objectives, of critical safety and quality requirements and generally adds expertise and commitment to individuals and to the teams at work [16].

Managers of human resources should consider the following:

— Developing a human resource plan in which roles, responsibilities, required skills and reporting relationships are identified and documented;
— Recruiting the construction team: confirming resource availability and obtaining the team necessary to complete the assignments;
— Developing the construction team: improving competences, team interaction and team performance;
— Managing the construction team: tracking team member performance providing feedback, resolving issues, and managing changes to optimize performance.

3.9.1. Human resources

One of the distinguishing features of human resource management in a construction project is the fact that the project location is almost always unique to the project and is away from 'home'. The project team works in an unfamiliar environment. The methods for acquiring construction personnel can vary significantly in different parts of the world, and managers of construction projects need to be aware of local conditions and customs.

3.9.2. Assigning supervisors in accordance with work progress

Supervisors are very important players in the construction industry since they have a decisive influence on the quality and productivity of the work force. The most serious root causes for non-conformances are found in leadership deficiencies or at least in lack of initiative in the supervisor's role. The most common consequences of poor performance are classified and listed below:

— Poor planning and management of work, lack of attainable targets;
— Errors and rework;
— Underestimates;
— Lack of training;
— Morale problems, low motivation;
— Staff turnover;
— Material and equipment unavailability;
— Long and excessive overtime;
— Excessive changes;
— Work area crowding;
— Difficult site access;
— Natural calamities.

Assigning supervisors in accordance with work progress is an activity that must be carefully planned. It should closely follow the human resource requirements in the schedules. The first step is to define the estimated staff numbers for each trade and the respective dates when they need to be available and ready to start their activities. Depending on the project, supervisors should be appointed to their workplace two to three months before the actual work starts in order that they might:

— Be familiarized with the specifics of the project, the documentation, the procedures, the quality requirements, the safety and security requirement, etc.;
— Receive additional training to fill any gaps in their education and previous experience. For example special construction methods they may not be familiar with;
— Participate in the selection and hiring of foremen and workers;
— Participate in the procurement of equipment, tools and consumables;
— Participate in detailed planning and scheduling.

3.9.3. Defining the required skill level of supervisors and workers and carrying out education and training

Given the strict quality requirements and the high upfront costs of a nuclear power plant project, the intervention of the utility together with its main contractors and subcontractors in sponsoring, establishing and implementing training is of the utmost importance.

Planning and implementing effective education and training programs depends on several factors: country and location of the project, infrastructure and human resources available, specific requirements linked to construction methods and procedures, etc. In all cases, sufficient funding should be provided to allow on the job training and activities such as developing special skill requirements.

Skill level, education and training of supervisors

Usually, supervisors have several years of previous experience as trade workers and then as foremen. The basic skills needed can be either previously possessed or developed, such as:

- Planning, scheduling, organizing work;
- Directing and coordinating work;
- Leadership skills, human relations, problem solving methods;
- Understanding the elements of a safety culture;
- Quality principles, quality implementation and quality control skills;
- Motivation, effective communications.

The skills indicated above should be complemented by formal education and training where and when necessary or gradually improved through informal on the job coaching (apprenticeship with more experienced co-workers or supervisors).

Skill level, education and training of workers

On-going issues for employers have been present in the construction work force due to a lack of sufficiently detailed skill requirements and ineffective personnel training. Education and training efforts should be on-going to meet the needs due to the typically high attrition levels and worker turnover numbers on a construction site.

Training and certification as well as special skills for all relevant areas should be developed (such as welders, electricians for cable connections, etc.).

4. CONSTRUCTION MANAGEMENT — COMMISSIONING PHASE

4.1. CONSTRUCTION COMPLETION PROCESS

Project progress has to be controlled from bulk material installation basis to system turn over basis. Around six to eight months before supply of electric power, construction office sets up the construction completion group (CCG). The main functions of CCG are:

- Overall responsibilities of construction completion and system turn over;
- Preparation turnover package to commissioning group based on the turnover schedule.

At the early stage of construction, the commissioning group has to prepare procedures for the commissioning and operation including a training programme. After completion of each test, final turnover has to be done by the

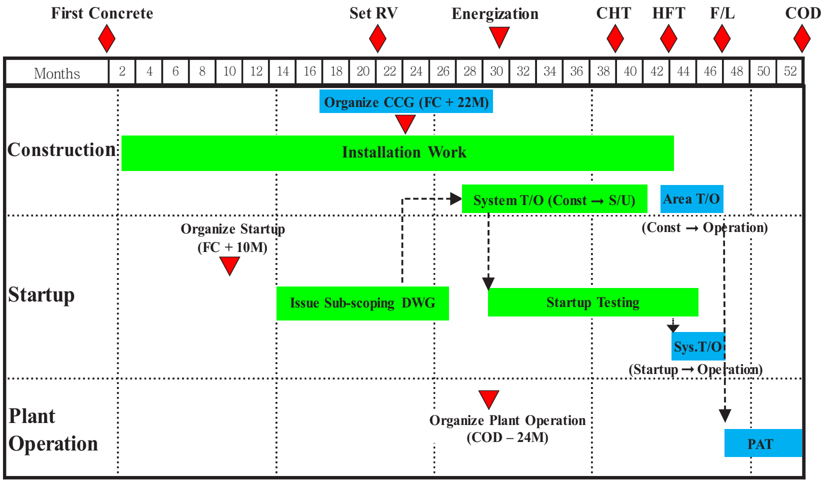

FIG. 23. Typical construction completion process.

CHT : Cold hydrostatic test
HFT : Hot Function Test
F/L : Fuel Loading
COD : Commercial Operation Date
PAT : Power Ascension Test

commissioning group. From the fuel loading (F/L), operation organization starts the power ascension test, plant performance test for commercial operation.

4.2. TURNOVER PROCESSES

Typically, there are three turnover processes from the end of erection to commercial operation.

— The first is the system turnover. It is a transfer of system and components jurisdiction from construction to commissioning after checking and testing the system and components being turned over for installation correctness, cleanliness and completeness;
— The second turnover is the one in which systems and components are transferred to the plant operations after the construction activities and start-up tests have been completed;
— Finally, the room turnover is done to transfer jurisdiction of the construction areas from construction to plant operations.

The construction group submits the turnover (T/O) package to the commissioning group in which are included; i.e. the following documents:

— Completion certificates;
— Marked up piping and instrumentation diagrams (P&ID) and electrical drawings;
— Copy of outstanding non-conformance reports (NCR), field change records (FCR);
— Equipment alignment data sheet;
— List of special tools and spare parts;
— Turnover exception list;
— Test results (hydro test and pneumatic test etc.), vendor testing and calibration records;
— Equipment specification;
— Maintenance records, vendor drawing, etc.

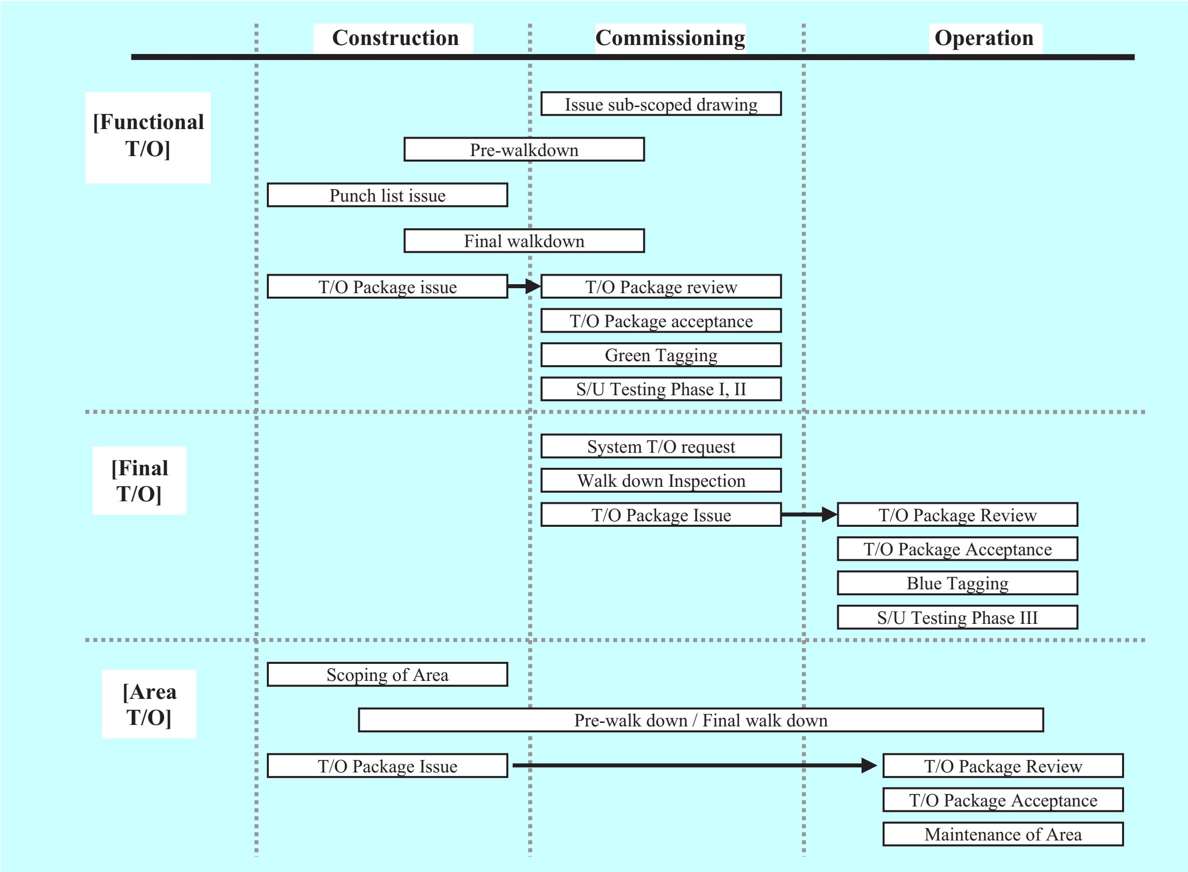

FIG. 24. General turnover process from construction to operation.

The commissioning group submits their T/O package to operations which contains the following documents:

— Turnover exception list;
— Markup P&ID and electrical drawings;
— Copy of the outstanding non-conformance report (NCR), and the field change record (FCR);
— Startup test results;
— Specific construction assurance testing like flushing, pre-operational summary sheets and event records;
— Preventive maintenance records, special maintenance records, etc.

The construction group submits the room T/O packages to operations organization comprising the following documents:

— Work completion certificate;
— Area/room check and exception list;
— Building layout drawing;
— Area/room key list.

4.3. PRESERVING REFERENCE DATA, MATERIAL CONDITIONS, KEEP TEST MATERIAL

Construction records in nuclear power plants are required by applicable codes, standards, specifications, regulations and by the Owner/Operator. These records are assembled and retained as history dockets for nuclear systems and as history files for non-nuclear systems by the construction contractors during the construction phase

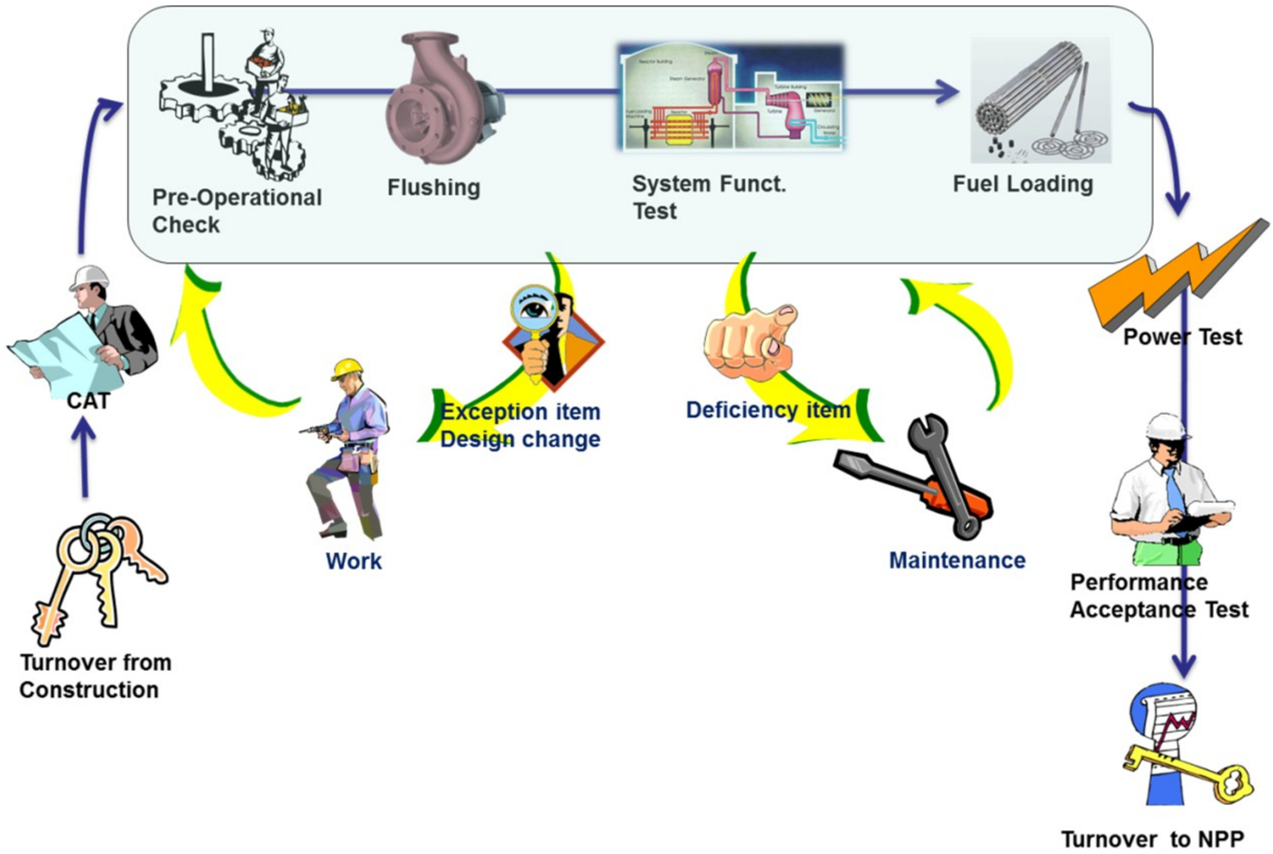

FIG. 25. Typical turnover process to commissioning and operation.

of the project, by the commissioning team during the commissioning phase of the project and by the site project management.

History dockets and history files are also prepared for equipment and materials in the nuclear steam plant by material suppliers. They are then reviewed and accepted by the general contractor/architect engineer and by the owner. Preservation of all history dockets/files, prepared by all parties involved is the ultimate responsibility of the Owner/Operator.

Construction contractors and sub-contractors prepare their history dockets and history files as per the site project management organization requirements. Project management should have a construction quality assurance program and procedures governing it. They should contain clear requirements and performance expectations regarding record keeping of all contractors in order to ensure that the contractors inspect the installation/fabrication in accordance with the inspection and test plan (ITP) and all applicable procedures, technical and quality requirements, that the drawings, specifications, codes, standards, regulations have been followed.

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

Requirements on manufacturing records and their contents should include:

- Certificates showing that the inspection status was maintained and items were properly identified;
- Qualification of the suppliers was demonstrated through audits and quality system verifications, that the correct revision of applicable specifications, drawings, standards and procedures was used;
- Qualified personnel executed the work, that environmental and seismic qualifications are complete and acceptable;
- Measuring and testing equipment was calibrated;
- Data and test results were accurately recorded and evaluated;

— Non-conformances were properly documented and controlled, that equipment and materials have met all specified requirements;
— Packaging and marking were correct and meet project requirements;
— Equipment and materials were all duly released.

Finally that the history dockets and record files themselves are correctly compiled and meet all requirements.

During the commissioning phase history dockets are the responsibility of the system engineer. Usually commissioning of a system is done under the supervision of a system engineer responsible for all aspect of commissioning a plant system or a group of systems. Each system engineer is therefore responsible for preparing commissioning documentation, interfacing with engineering and construction on design and/or turnover issues, providing technical support for field execution of commissioning procedures, assessing test results, and preparing commissioning reports, commissioning completion certificates and commissioning history dockets.

Experience dictates that the site management team/architect engineer should check the legibility of history dockets and history files and that clarity should be included as a requirement in the procedures and in the contracts with all interested parties. Legibility and clarity should be checked upon reception and rejected if it does not meet expectations [15].

5. CONSTRUCTION MANAGEMENT ISSUES AND LESSONS LEARNED

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. In this Section, the current experience and lessons learned on management issues and country specific issues are introduced to avoid construction delays and improve quality.

5.1. CONSTRUCTION MANAGEMENT ISSUES

5.1.1. 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, and 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, the Owner/Operator usually needs 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:

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 and components in the turbine building, such as the feedwater heaters, re-heaters, condensers, pumps, storage tanks and cooling systems for the condensers and generator. Excluded is the Emergency Core Cooling System (ECCS) pumps and piping (if located in this building) 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.

5.1.2. 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.

5.1.3. 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 per cent, 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.

5.1.4. 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.

5.1.5. 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. Programmes 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.

5.1.6. 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 flyers, local paper advertisements, with job offers and training opportunities is crucial to establishing good relations.

5.1.7. 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:

- 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 [19, 20].

5.2. COUNTRY SPECIFIC LESSONS LEARNED

- Lessons learned directed to cover country nuclear programs level (Example: India);
- Lessons learned directed to cover specific projects level like individual NPPs or grouped units in the same or different sites (Examples: Brazil, Bulgaria, Canada, China, Japan, Republic of Korea, Romania, Slovakia);
- Lessons learned directed to cover some main processes and activities focusing on delayed NPP (Example: Argentina).

Detailed lessons learned are included in the country reports in Annexes 1–5.

5.2.1. Argentina

Lesson learned and issues found in a delayed nuclear power plant are described in the Argentina country report of Annex 1.

5.2.2. China

At the time this guide is being prepared, two AP1000 nuclear power units are under construction at the Sanmen and Haiyang sites where extensive modularization and advanced construction methods are being applied. Many sub-modules, either structural or mechanical, are fabricated in the shop, shipped to site and assembled in-situ. Several of these modules are larger than 1000 metric tons. Very heavy lift (VHL) cranes capable of handling modules of up to or over 1000 metric tons travelling on crawlers with full load are being used. Lampson LTL-2600B VHL crane is utilized in Sanmen, and a Terex-Demag CC8800-1 Twin crane in Haiyang.

The ownership of the VHL cranes in Sanmen and Haiyang is different. The Sanmen owner purchased the Lampson LTL-2600B and the construction contractor has the right to use it, while the Haiyang owner only rents the Terex-Demag CC8800-1 Twin crane which was purchased by the construction contractor. The cost of operating the VHL cranes, including their maintenance, is borne by the construction vendors at both sites.

Utilization of the VHL cranes has produced the following suggestions:

- Maximize the utilization factor of the VHL cranes by using them to lift both the large components and the large size structural modules in order to better distribute their cost;

— During construction of the twin AP1000 units, the VHL crane could not leave the site for another site until structural module CB20 has been lifted. This module, which weighs over 157 metric tons, should be lifted within 40 months after the first construction date of the second unit (First Concrete Pouring Date : FCD+40 months). After FCD+40 months for the second reactor unit, the VHL can be disassembled, packed, and transported to another site. In a multiple unit site, the VHL can be used for every unit if a haul access road stretches to all units and scheduling is set accordingly;
— Every component of the Terex-Demag CC8800-1 Twin crane is designed to be less than 3.5 m in width and to weigh 60 metric tons, so as to conveniently allow several transportation modes either by waterway, or railway or even by road after disassembly. The largest component of the Lampson crane has a relatively larger size and weight which makes it harder to move from site to site;
— The maximum lifting capacity of the Demag CC8800-1 Twin crane is 3200 metric tons. At a lifting radius of 56 meters, the corresponding lifting capacity is 618 metric tons. By comparison, the Lampson LTL-2600B has a smaller maximum lifting capacity below 3200 metric tons whereas it has a larger lifting capacity of 1283 metric tons at the lifting radius of 55 meters. This means the Lampson LTL-2600B is better at lifting heavy modules and equipment for the AP1000 since the VHL foundation can be farther away from the excavation perimeter and so reduce interference issues.

Challenges from design changes

Design changes could cause design schedule delays, increasing the difficulties of schedule management. Frequent design changes will lead to increase of durations and costs of procurement and construction.

Design standards and material substitution management

The inconsistency between the metric system and British units, as well as between US standards and international/Chinese standards may further impact the selection of onshore procurement of bulk materials and equipment.

Characteristics and difficulties during the module fabrication process: Wide application of modules is one of the main features in the design and construction of AP 1000 projects. The main difficulty in the fabrication of the structural modules is distortion control of the welding between stainless steel and low carbon steel plates and hence the installation of such large components.

Challenges related to module procurement (fabrication)

As some equipment modules are pre-installed in the related structural module, equipment and materials need to be available in advance to satisfy the demands of module fabrication and site assembly.

The modularization system needs further improvements: The interface between module procurement and manufacturing is greatly increased. Design progress and design integrity (no errors) exert a much greater influence upon module procurement and fabrication than on conventional construction.

Challenges from modularization during construction: Modularization of the nuclear island radically changes the traditional construction process from past practices of performing civil works before installation to a new parallel or cross construction of both the civil works and equipment installation activities. This requires an adjustment of the logical construction sequence on site in order to optimize the construction schedule and minimize construction duration. Currently, major challenges in the switch to modularization are:

— Assembly technology of large-sized modules;
— Welding technology of modules;
— Lifting deformation control technology of large-sized structural modules;
— Transportation plan of large-sized modules;
— Installation, measurement and positioning technology for large modules.

The first of a kind activities for Sanmen 1 and AP1000 equipment design and manufacture have produced a number of lessons learned which have benefited the follow-on units, for example:

— The nuclear island base mat at Haiyang 1 and Sanmen 2 were laid down in less time than at Sanmen 1;
— The ultra large steam generator and reactor pressure vessel forging lead times were reduced for the 3rd and 4th units;
— The auxiliary building module fabrication for Haiyang 1 took far less time to build that for Sanmen 1;
— The containment vessel bottom head welding at Haiyang was performed in a fully-enclosed building;
— Safety documentation must be of high quality and a comprehensive understanding of the safety case and any outstanding issues must have been reached with the regulatory authority prior to start of construction;
— Partner organizations and main contractors must have shared goals and work collaboratively together;
— Schedules must be detailed and actively managed;
— Quality is paramount so subcontractors need to be experienced and Quality Assurance arrangements must be comprehensive and robust;
— The modular construction of mechanical/electrical systems is well established and the use of civil/mechanical/electrical modules has been demonstrated to save construction time and improve quality, by having module fabrication and testing carried out off-site in more carefully controlled conditions. This also allows work on many different parts of the plant to be carried out in parallel.
— In circumstances where the modular approach requires novel construction or manufacturing techniques to be used, there may be a requirement to do additional work with the regulatory authorities in order to demonstrate full compliance with accepted regulatory standards.

5.2.3. Finland

The process of nuclear new build in Finland is currently under way with the construction of a new nuclear power plant at Olkiluoto, the site of two existing reactors, and the investigative digging for a deep geological repository. In addition to this, two more decisions in principle for nuclear power plants were ratified in parliament in July 2010 [18, 19].

The lessons learned described here are from the viewpoint of the Finnish Radiation and Nuclear Safety Authority (STUK) and were presented by the STUK Director General at the 20th International Conference on Structural Mechanics in Reactor Technology [20]. The lessons learned were grouped into several areas as outlined below:

Changed nuclear power plant construction environment:

— Vendors have lost much knowledge and skills when experienced experts have retired and new types of competence are needed for new technologies. Thus, good reputations earned in the past are no guarantee for success and the experience and competence of persons assigned to the project is more important.
— Vendors need to establish a subcontractor network from companies with proven skills; awareness of nuclear quality and understanding of nuclear safety culture must be taught to companies that have no previous nuclear experience; management of work conducted by subcontractors is a challenge in its own right.

Preparation of project:

— Early contact between vendors, licensee and regulatory authority.
— Feasibility studies of several designs in the early stages of the project were found to be very useful and facilitated the subsequent licensing process. These involved:
  - Technical discussions between potential vendors, license applicant and regulatory authority;
  - Allocation of adequate regulatory resources to the safety assessment of each alternative design;
  - Identification of crucial safety issues before and during the Decision-in-Principle (DiP) process; these issues were addressed by the licensee and the potential vendors during bidding;
  - Each design proposed in bidding was improved from the original version that was reviewed tentatively during the DiP process.

Making safety requirements clearly understood:

— European Utility Requirements (EUR) were used to present most of the technical requirements to potential bidders, but these did not include all necessary national safety requirements. The licensee and the regulatory authority need to discuss how the national safety requirements are best presented in the call for bids in good time. Just making reference to national requirements and regulatory guides is not adequate to ensure that requirements are correctly understood by the vendors.
— Discussions in preparing for the Olkiluoto 3 project should have been more extensive to better clarify all national safety and quality requirements and the regulatory process to the bidders.

Understanding of regulatory practices

— To ensure the smooth progress of the project, the vendor needs to understand and take national regulatory practice correctly. In Finland, regulatory practice is different from what the reactor vendor had encountered elsewhere.

Preparedness of parties for project implementation

— In order to avoid delays and difficulties in the project implementation, it is necessary to allocate sufficient time for the planning stage and to assess the preparedness of each party before starting construction. Before starting, each of the parties (vendor, licensee, regulatory authority) should conclude that the:
  - Licensee's capabilities and resources are adequate;
  - Vendor's capabilities and resources are adequate;
  - The design stage is adequate for a controlled construction start and for smooth implementation;
  - Qualified subcontractors are available as needed, and plans and contracts exist for managing the subcontractor chains.

Importance of timely completion of design

Inadequate completion of design and engineering work prior to start of construction is detrimental to the implementation of the project as per the schedule:

— It delays the start of construction activities at full speed;
— It leads to attempts to reschedule manufacturing and construction steps, thus making project management complicated;
— It causes continuous time and cost pressures to all organizations involved.

In the Olkiluoto 3 project, it was concluded that the detailed design had been completed too late. Consequently, delivery of the Construction Plan (CP) to STUK's review has often been delayed relative to the planned schedule. The CP has also been split to many batches; this has made the inspection complicated and time consuming. Fixing the sometimes inadequate quality of design and engineering has caused major difficulties for the project management.

Management of subcontractors

To ensure good management of the subcontractor chains, it is important that in each call for tender for subcontracts the vendor clearly indicates and emphasizes the nuclear specific practices, such as:

— A requirement to provide design documentation well in advance of planned manufacturing;
— Multiple quality controls and regulatory inspections to be conducted during manufacturing;
— Expectations of safety culture.

Communication within the vendor consortium

If design work is conducted by different organizations and in different places (or even in different countries), good coordination and communication is vital for a successful outcome. The licensee and the regulatory authority should audit and carefully assess the communication approach and the adequacy of communication between those designers who are expected to interact during the design process.

Mastering the manufacturing technologies

New advanced safety features are not easily implemented. Qualification of a new construction or a manufacturing method may take time if it has not been done before the project start. For instance:

- New welding solutions were a challenge during RPV manufacturing, and additional evaluation and some repair welding were needed;
- Pre-assembly welding of main coolant line legs showed micro-cracking that had not been faced by the manufacturer before (it was demonstrated that the indications can be removed by grinding and re-welding);
- A number of components for Olkiluoto 3 had to be remanufactured to achieve acceptable quality and to ensure a 60 year lifetime such as some main coolant pipe sections and some main circulation pump casings.

Licensee responsibility

- The respective roles and responsibilities of licensee and vendor need to be specified accordingly, and also for the construction phase. The licensee should:
  - Conduct its own safety assessment to verify that the plant and its systems, structures and components (SSCs) are licensable;
  - Have its own requirement management system and an independent capability to verify and prove that all requirements are met, with support of third party where necessary;
  - Have a system for reporting and resolving all non-conformances identified in quality controls;
  - Have an opportunity to require use of proven, state-of-the-art technology in manufacturing and construction (not only to accept final products that meet minimum agreed quality requirements).

Safety culture during construction:

- Strong message and transparent actions and decisions are expected from the management of the vendor and the licensee to promote safety culture: “safety and quality have higher priority than costs and schedule”;
- A questioning attitude is needed at every level and in all organizations: licensee, vendor and subcontractors;
- Safety concerns and questions raised by workers need to be responded to properly. Each person attending the project needs to understand the safety significance of their own work, to promote personal responsibility.

Importance of regulatory oversight of construction:

- Throughout the project there have been multiple quality controls, carried out by manufacturers themselves, and independent third parties. Therefore, the product deviations have generally been detected with high sensitivity. Nevertheless, in some situations, the QC inspectors by the manufacturer, vendor, and licensee have faced too much economic pressure, and may not be in a position to enforce stopping of work to making necessary corrections. Even when the work is not progressing as expected in such situations an intervention by a regulatory inspector is needed.
- A stringent regulatory approach and inspections are thus needed to verify that new manufacturing techniques and new type of equipment meet the specifications set by the designer.

Construction schedule:

— The schedule for the Nuclear Island at Olkiluoto 3 is now about four years behind the original plan. The main reasons for the delay are:
  - The original schedule was too ambitious for a plant that is first of its kind and larger than any NPP previously built;
  - Inadequate completion of design and engineering work prior to start of construction;
  - A shortage of experienced designers;
  - A lack of experience of parties in managing a large construction project;
  - A worldwide shortage of qualified equipment manufacturers.

— The construction of Turbine Island has progressed much better. There is close cooperation between the Turbine Island vendor and an experienced construction company, resulting in good integration of design and construction work.

5.2.4. France

The board of directors of the utility Électricitê de France (EdF) decided to start the process of building a new reactor at the Flamanville site in 2004. The preparation of the site started in the summer of 2006 with the construction permit granted in April 2007 and the first concrete was poured in December 2007.

Site layout

Issues were raised by the regulatory authority (ASN) regarding the site layout and, in particular, the consequences of crane failure and the possibility of certain cranes being able to fall on the auxiliary building of the existing reactor Flamanville 2, which is adjacent to the construction site. This was remedied by EdF arranging for the construction of concrete stacks around the cranes in question [21].

Concrete operations

Several issues concerning the concreting operations for Flamanville 3 have been highlighted by the regulatory authority during the course of the construction programme, the first being the cracking of the concrete block making up the foundation of the nuclear island. The cracking phenomenon is frequently observed in large scale concreting operations and is often due to shrinkage as the concrete hardens. EdF proposed to remedy this problem by injecting pressurised resin into the cracks which was accepted by ASN.

As the concreting activities on the Flamanville 3 progressed three further issues were raised by ASN:

— The first was highlighted during an inspection in May 2009 examining the preparatory work for the concreting of the foundation raft for the internal structures of the reactor building;

— The second issue concerned the treatment of construction joints, i.e. the area of contact between two layers of concrete placed at different times;

— The third issue concerning concreting operations reported to date by the regulatory authority was the positioning anomalies of pre-stressing sheaths for the reactor building inner containment wall.

Steel containment liner

During inspections by ASN in June 2005 it was noted that there were deviations in the welding method for the liner from what was originally specified in the EdF technical specifications. Several inspections of liner welds were conducted during the last quarter of 2008.

Sea outfall tunnel

Given the proximity of the existing Flamanville 2 reactor, ASN asked EdF to check the analysis of safety risks for this reactor (for example the possible impact of mine blasting operations and vibrations induced by the excavation work).

Reactor components

During its review inspection of licensee nuclear pressure equipment manufacturing activities, ASN observed that key production quality assurance procedures were satisfactory, but noted that the various tasks of those responsible for quality needed to be made clearer. ASN asked licensee to improve their decision making procedures, supplier approval and monitoring, and to move forward in the area of regulatory documentation.

5.2.5. India

India initiated atomic energy R&D and industrial activities in the mid-20th century. Plans were systematically developed and strategies evolved to ensure the mastering of the entire fuel cycle. Over six decades India has developed uranium exploration, mining, fuel fabrication, reactor design, construction, operation, maintenance, fuel reprocessing and waste management.

The Department of Atomic Energy planned and managed the entire fuel cycle development right from uranium exploration and mining to fuel fabrication, reactor design, construction, operation, maintenance, reprocessing of the spent fuel and waste management. For this the department strategically planned and established several institutions, spread over the length and breadth of the country. These include:

- R&D capabilities in frontier areas of science and technology;
- Manufacturing capability for fuel;
- Manufacturing capability for heavy water;
- Radio Isotopes for industrial applications and social causes;
- Atomic Minerals Directorate for exploration and research, Hyderabad; Exploration capability;
- Uranium, thorium and rare earth exploration and processing;
- Electronic and Instrument design and manufacturing capabilities;
- Power reactor design, construction and operation capability under government control until the operation is stabilized and later transferred to the private sector to develop its commercial viability;
- Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI) for design, construction, operation and maintenance of fast reactors;
- R&D in fundamental and basic sciences, mathematics and cancer research under autonomous bodies.

Every institution took up their task with professionalism. Elaborate planning and several strategies were formulated to achieve the mission; their accomplishments are testimony of the success of India's plans and strategies.

The commercial electricity production through nuclear reactors in India started with commissioning of two boiling water reactors (BWRs) at Tarapur from General Electric in the year 1969. These twin reactors of 200 MW(e) were built under a turnkey supply and erection contract.

India moved to a pressurised heavy water reactor for power production by entering into contract with Canada. Rajasthan Atomic Project Unit-1 of 220 MW(e) was commissioned under this contract. Major supply for this reactor came from abroad. Later, India completed and commissioned the Rajasthan Atomic Power Station Unit-2. Madras Atomic Power Station Units 1&2, Narora Atomic Power Station Units 1&2, each of 220 MW(e), built by indigenous effort. For these reactors the nuclear equipment erection and commissioning were undertaken by the utility. The construction and commissioning of the conventional systems were awarded to third parties.

From the Kakrapar Atomic Power Station onwards the share of work offloaded to contractors substantially increased. Though the design and engineering of nuclear systems for the pressurised heavy water reactors (PHWRs) for the 220 MW(e), 540 MW(e) and 700 MW(e) plants were developed by the utility, detail design of many systems were offloaded. The plant activities are divided under several Engineering- Procurement- Construction (EPC) contracts. The utility carried out extensive monitoring of the EPC contractors' works and met its stipulated quality through supervision, inspection, reviews and audits.

The Kudankulam Atomic Power Plant, twin WWER units being constructed with Russian aid has a different model, where responsibilities for equipment supply and erection are shared by the supplier and the utility. Various models are under review for future imported and indigenous plants. India has kept its options open for type of nuclear reactor and the contract models for nuclear power plant construction in future.

For the technology launch of the prototype fast breeder reactor (PFBR), a 500 MW(e) plant using mix plutonium-uranium oxide fuel, the model adopted for construction is altogether different. This being the recent venture is elaborated in detail here under. This case study may provide direction to many countries that plan to enter nuclear power plant construction for the first time and wish to gain self-reliance in due course in the future.

Before venturing into a commercial application, a sodium cooled fast breeder test reactor (FBTR) was constructed and is operating at the Indira Gandhi Centre for Atomic Research (IGCAR) since 1985. This reactor has operated exceedingly well and has established the competence of Indian engineering in handling a technology where large quantity of sodium is used for cooling the reactor. Encouraged with the performance and safety record of FBTR, India took a quantum leap from 13 MW(e) FBTR to the launch of a 500 MW(e) PFBR.

The fast reactor technology experts from IGCAR, the designer and construction professionals from the Nuclear Power Corporation of India Limited (NPCIL) work together in mission mode to accomplish the technological goals within stringent time and cost targets. PFBR is thus a role model in handling new technologies where experts have been drawn from different organizations with the backing of their organizations to work jointly in a task force mode and make the fast breeder power reactor a reality.

Modern construction concepts have been effectively used at PFBR. Large capacity tower cranes, automated batching plants, computerized data acquisition, spare capacities for concrete pumps and pipe line to maintain continuity of concrete pouring, large capacity of chilling and ice plants and transit mixers are only but a few of the measures taken to attain high quality in civil construction. A large capacity crawler crane has de-linked civil construction and equipment erection allowing parallel activities. PFBR has pioneered fabrication of large size nuclear equipment at the reactor site. Very critical equipment such as the safety vessel, the main vessel, the inner vessel and the thermal baffle were fabricated at the site. High standard of nuclear clean environment were maintained for the fabrication of nuclear equipment for PFBR which uses 1750 t of liquid metal sodium at a temperature of around 820 K. Large vessels made of specialized grades of stainless steel have been fabricated to very stringent dimensional tolerance and metallurgical controls during welding.

Strategic planning in the PFBR project is not only formulated and steered at the highest level encompassing the entire project, but also integrated planning and strategies were formulated at each functional unit management level and even at the individual level. Strategic planning, at different levels of PFBR have adopted a unidirectional approach; i.e. to fulfil the vision of the Department of Atomic Energy and to accomplish the mission, the intermediate goals and targets that were determined prior to the start of project activities. Thus the entire organization and every individual on the project is knitted to a common objective.

Working on a mega project, irrespective of the type of venture, requires careful finalization of strategies. It is essential to move on the strategies with caution, with an open mind and be ready to alter strategies, keeping however the focus on the target set in the initial plan. A mega project venture can succeed only when a plethora of strategic plans developed at various hierarchical levels are integrated with the mega project plan. The nuclear energy production plan in India, through its three stage programme which covers the entire fuel cycle has remained firm and was successful. Its accomplishment was the result of good strategic planning across organizational boundaries and across generational boundaries considering that it has run through several generations of scientists and engineers.

5.2.6. Japan

Kashiwazaki-Kariwa Unit 6 (K-6) started commercial operations in July 1997. Although it was a first of a kind ABWR plant, the construction was completed in 37 months from the first concrete to fuel loading on time and on budget. Several lessons learned were identified from this construction project. Among them the importance of a detailed construction plan supported by a detailed schedule prepared before construction and during construction by a stringent design change management system proved to be the most significant factors in the success of this endeavour.

TABLE 3. PROJECT DATA FOR KASHIWAZAKI-KARIWA UNIT 6

Power output-gross	1356 MW(e)
First concrete	3 November 1992
Fuel loading	30 November 1995
Commercial operation	7 November 1996
Licensee	Tokyo Electric Power Company (TEPCO)
Main contractor	Toshiba/Hitachi/GE joint venture
Contract type	Split package

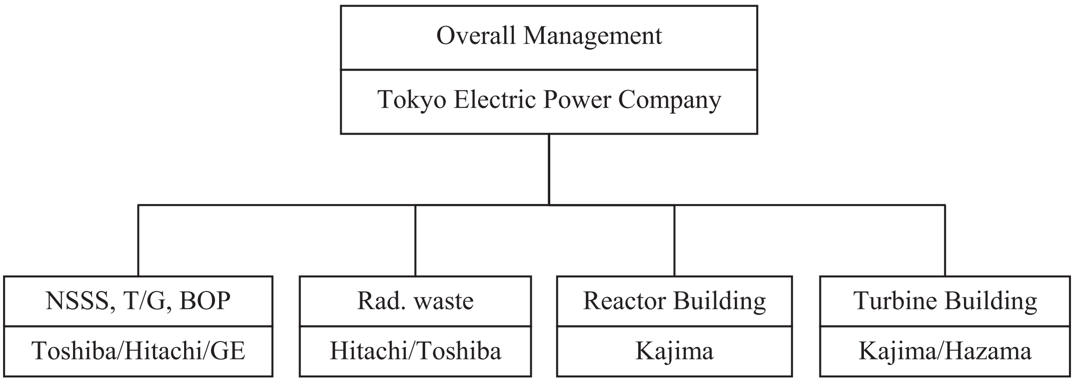

FIG. 26. Project organization and scope of supply.

Lessons learned

Design management

Kashiwazaki-Kariwa Unit 6 was the first of a kind ABWR plant and risks associated with new designs were well recognized and managed. The following activities effectively reduced the risks and the plant was constructed without delays or cost overruns.

Full size verification tests before construction: during the ABWR development, more than 20 new design changes were tested with full size mock-ups. Feedback from operating experience was fully incorporated. Through this method, potential problems were identified and fixed and performance and reliability were confirmed before actual construction started.

Joint design review by TEPCO and suppliers: joint design reviews by TEPCO and its suppliers were conducted on 28 new design changes. A total of 175 meetings were held over a period of two years in the preparatory phase. Reliability of the new design as well as its operability and maintainability were analyzed and thoroughly reviewed. All concerns raised in the review were listed indicating when further confirmation reviews should be conducted in the project schedule.

Design change control: all the system and component design changes were checked against the latest reference plants, and were classified as follows: Class 1, ‘Significant’, Class 2, ‘Major’, and Class 3, ‘Minor’ changes. TEPCO and its suppliers confirmed the adequacy of the Class 1 and 2 items, while Class 3 items were checked by the suppliers themselves.

Product verification: all products had to pass individual and/or combined tests before shipment.

Overall check-up at site: overall checkups were conducted at site during the commissioning tests. The commissioning tests were conducted at atmospheric conditions and 20%, 50%, 75% and 100% power levels. The plant was shut down for a short period after each stage. An overall check-up was conducted before reactor restart.

Developing the schedule

Modern techniques, such as open top construction and modularization were widely applied in this project. Detailed coordination between engineering, manufacturing, scheduling and between building construction and equipment installation was revealed more important in this project than ever before. It took only 37 months from the first concrete to fuel loading. The following schedule charts and work execution plans were developed in the preparatory phase:

- Detailed system work schedule including engineering, procurement, manufacturing, installation, testing and commissioning activities;
- Detailed building construction schedule including area transfer dates;
- Area specific detailed work schedule;
- Yard construction work schedule;
- Construction procedural diagrams including excavation diagrams and outdoor work schedule;
- Component carry-in plans including temporary gateways;
- Deck plate plans (open-top carry-in plants);
- Permanent formwork plans;
- Plan for temporary facilities such as cranes, platforms and on-site module fabrication bases.

5.2.7. Republic of Korea

Shin-Wolsung Unit 1,2 are the sixth 1,000 MW(e) class optimized power reactor (OPR) 1000 project. Since the first concrete pouring in November 2007, the project has been going well ahead of schedule. General data on the Shin-Wolsung Unit 1 reactor are shown in Table 4.

Lessons learned-Benefits from Standardization

Since Yonggwang (YGN) units 3&4, through which technology self-reliance was almost accomplished in Korea, KHNP has pursued a design standardization policy. Changes to the standard design of the OPR 1000 were only limited to experience feedback and lessons learned from previous projects. This allowed the standardization policy of the OPR 1000 to remain unchanged for the most part all the way through to the Shin-Wolsung 1&2 project. Standardization allowed, KHNP to shorten the construction period of the OPR 1000 by about 12 months on account of the accumulated experience. KHNP is now able to build a 1000 MW(e) class PWR in less than 52 months from the first concrete pouring to commercial operation, making it possible to significantly reduce construction costs.

5.3. COUNTRY REPORT SUMMARY

Following are highlights from the individual country experiences.

5.3.1. 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.

TABLE 4. PROJECT DATA FOR SHIN-WOLSUNG UNIT 1

Gross output	1055 MW(e)
First concrete	20 November 2007
Fuel loading(scheduled)	August 2011
Commercial operation(scheduled)	March 2012
Licensee	Korea Hydro & Nuclear Power Co.
Main contractors	Doosan/KOPEC/Daewoo
Contract type	Split package

5.3.2. 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 1970s when most of the currently operating plants were constructed: Vendors of the 1970s 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 the Republic of 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.

5.3.3. Design

If design work is conducted by different organizations 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, personnel, 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.

5.3.4. Construction and manufacturing

Vendors and their sub-contractors have lost much knowledge and skill when experienced experts 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.

5.3.5. 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.

6. 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.

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ABBREVIATIONS

ABWR	Advanced Boiling Water Reactor
CAR	Construction Assurance Report
AE	Architect Engineer
ATP	Authorization to Proceed
BBS	Budget Breakdown Structure
BOP	Balance of Plant
CAT	Construction Acceptance Test
CHT	Cold Hydro Test
COD	Commercial Operation Date
COTS	Commercial of the Shelf
EPC	Engineering Procurement Construction
EPR	European Pressurized Water Reactor
FSAR	Final Safety Analysis Report
HFT	Hot Functional Test
I&C	Instrumentation and Control
ILRT	Integrated Leak Rate Test
INIR	Integrated Nuclear Infrastructure Review
IRSS	Integrated Regulatory Review Service
MDEP	Mutual Design Evaluation Process
NCR	Non-Conformance report
NSSS	Nuclear Steam Supply System
OSART	Operational Safety Review Team
PAT	Power Ascension Test
PC	Procurement and Construction
PIP	Project Implementation Plan
PNSC	Plant Nuclear Safety Committee
PSAR	Preliminary Safety Analysis Report
QA	Quality Assurance
QC	Quality Control
RCS	Reactor Coolant System
SAT	Standby Auxiliary Transformers
SIT	Structure Integrity Test
SG	Steam Generator
STUK	Radiation and Nuclear Safety Authority from Finland
TG	Turbo Generator
TWG	Test Working Group
WBS	Work Breakdown Structure
CSA	Canadian Standards Association
ASME	America Society Mechanical Engineers
AEC	Architecture, Engineering, Construction
INCOSE	International Council Of Systems Engineering
P&ID	Process and Instrumentation Diagrams

GLOSSARY

BOM - Bill Of Materials - This software stores the bill of materials of a product type as well as that of a specific instance of a product type.

CAD - Computer-Aided Design - Interactive computer graphics applications that enable users to create geometry accurately both as to-scale 2D illustrations and 3D digital models.

PDM - Product Data Management is data management software specifically designed to store and manage product design and manufacturing information including product configuration information.

PLiM - Product Lifecycle Management is the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal.

Annex I

BRAZIL

I–1. BRIEF DESCRIPTION

I–1.1. History

In 1975, Brazil and Germany signed a Cooperation Agreement to develop in Brazil a complete nuclear fuel cycle. It included the development of a heavy equipment industry, a nuclear fuel factory and a protocol for purchasing eight NPPs of the PWR type.

The two first 1300 MW units were ordered in 1975. In 1976, at the beginning of the Project, a twelve month time gap between the completions of the two plants was planned. Later these time gaps were changed to 18 months and, then, to 24 months, until the investments were substantially reduced from 1984 to 1994.

Engineers, technical and administrative personnel were kept employed to continue the engineering, to set up a component preservation and inspection programme, and to proceed at a very slow speed construction of the site structures.

In 1976, during the construction of Angra 2 concrete analysis of the containment foundations carried out in cooperation with the Licensing Authority led to a recalculation of this structure. This caused a severe schedule delay and the foundations were completed only in 1982.

From 1984 onwards the slow economic conditions in Brazil had a serious effect on the implementation of the nuclear power program and the construction of Angra 2 and Angra 3.

This situation led the utility to proceed with the construction of Angra 2 and the rock excavation of Angra 3, according to the annual budget authorized by the Brazilian government, until 1986 when the whole project was stopped.

In March, 1996 the mechanical, electric and I&C erections were re-started and all the systems, whose erection was a pre-condition for core loading, were installed and ready for operation in March, 2000. Angra 2 was declared operational in December 2000.

Angra 3 received a Construction License from the Brazilian Authorities in June 2010 and the first concrete of the Reactor building was poured June 1st, 2010. According to the Time Schedule, Commercial Operation should start in December 2015.

I–1.2. Project data — Angra 2 & 3

REACTOR		CIVIL CONSTRUCTION	
Type	PWR	Reinforced Concrete	209 000 m³
Reactor System Supplier	SIEMENS/KWU	Steel Platform	2000 t
Number of Loops	4	Drilled Penetrations	2720 unit
Electric Power	1350 MW	Addition Anchor Plate	19 600 unit
		Painting	400 000 m²

ELECTROMECHANICAL		ELECTRIC AND I&C	
Components	17 000 ton	HV/LV Transformers	30 unit
Piping, Supports and Components Engineering preparation Work Folders	71 100 unit	HV/LV Switchgears	1300 cubicles
Pre-fabrication Piping and supports	4300 ton	Grounding and lightning	110 km
Erection Piping, supports and valves	6300 ton	Installation stands	54 ton
Ventilation, Galvanized and welded ducts	32 000 m2		
Components	4421 unit		
CABLING (POWER AND I&C)			
Power cabling pulling	800 km	Power cable and I&C connections	1 000 000 unit
I&C cable pulling	1700 km	Cable trays	1100 ton

I–1.3. Contract type (Company)

A multi-contract model was used. The Owner/Operator assumed the overall responsibility for engineering, awarding the main contracts and a number of multi-contracts.

The main contracts were:

- Architectural design (KWU/Siemens) which included services such as design, commissioning and erection supervisors and main equipment supply;
- Civil detailed design;
- Piping detailed design;
- Civil construction;
- Mechanical and electrical erection.

The multi contracts were:

- HVAC — Components supply and erection services;
- Painting services;
- Insulation — Supply and erection services;
- Supply and erection of steel containment, cranes, heat exchangers, pool liner;
- Secondary system condensers.

I–2. LESSONS LEARNED

I–2.1. Project management — Construction phase

The construction control software was EMS — a data base, which was connected to: FUP — Follow-up system; WHS — Warehouse handling system, TESP — Test and examinations sequence plans.

To qualify the welders, a good practice was to implement a welding training school. During the peak of construction there were 450 skilled welders. The components supplied were sent to site and stored in warehouses. Because of the length of time before the resumption of the Angra 2 project, a programme for equipment storage and preservation was implemented and proper inspections were planned. This programme aimed at protecting components against humidity and corrosive agents.

The programme comprised four stages:

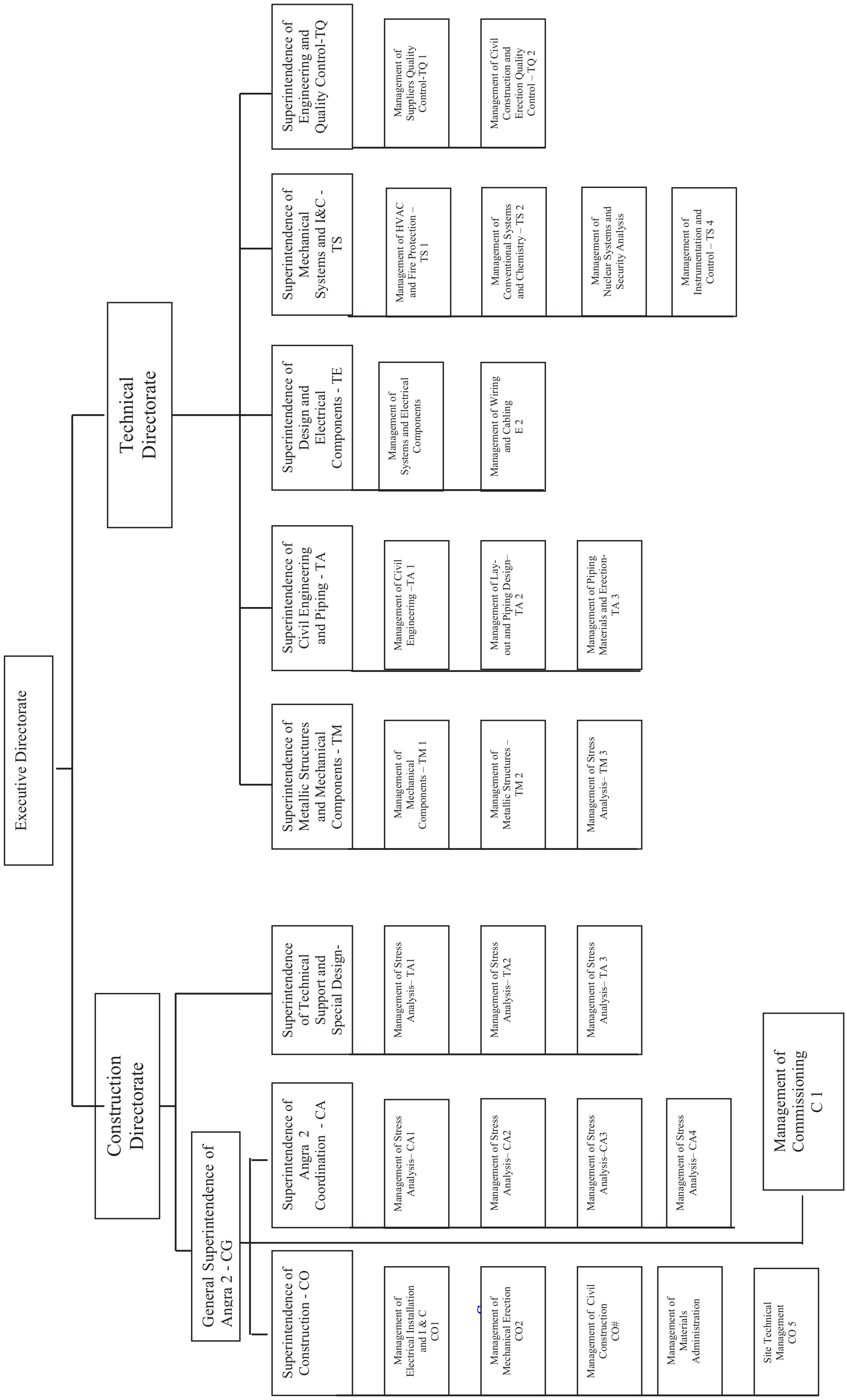

FIG I–1. Project organization.

- — The long term storing process was specified by the original supplier and implemented before the supplies left the factory;
- — Preservation programme of the storage conditions at site followed several written procedures;
- — A ‘24 months rotating inspection programme’, which established a rule where at least one sample of all suppliers was disassembled and inspected every 24 months;
- — A General inspection programme, which disassembled completely the component to substitute replaceable internal parts such as rubber and lubricate as necessary before erection/or commissioning. The purpose of the programme was to assure the functionality of the components and parts due to the long term storage and to verify possible damage that could interfere with operation.

The existence of three contracts to install the equipment was not advisable. However, it was supported by an Operational Agreement, whereby site activities were ordered only by one organization.

I–2.2. Project management — Commissioning Phase

It is advisable to prepare a commissioning schedule based on a reference project, and then improve on the milestones and shorten the commissioning period. Experience shows that in some project, the schedule could be reduced by 60% in comparison to the reference project.

The following was implemented:

- — Daily follow up meeting to interact with construction personnel;
- — Work was organized in two shifts.

I–2.3. Recommendations for new sites or to newcomer countries

I–2.3.1. Preparatory phase

Procedure for site evaluation or selection: Criteria for site exclusion could be, among others, vibratory soil movement (history of earthquakes), surface flaws (deformations of the soil), existing industrial facilities (refineries, pipelines, risk of nearby explosions, etc.), topography (maximum slope). A good guide for site selection according to EPRI is the Siting Selection and Evaluation Criteria for an Early Site Permit Application (Siting Guide-2002) and practices recommended in the IAEA Nuclear Energy Series No. NG-T-32.

I–2.3.2. Construction and erection phase:

Recommendations to improve construction schedule:

- — Highly efficient equipment and electronic devices, digitally controlled;
- — Optimised design of the main components to reduce fabrication time and ease transportation and erection;
- — Use of management support software to guide the events during Construction and Installation such as: Primavera, MS Project, Follow-up – system – FUP, Warehouse Handling System – WHS, and Test and Examination Sequence Plan – TESP;
- — Improved construction techniques/ open-top construction, pre-fabrication and modularization, encouraging the use of weather covers for outdoor activities.

I–2.3.3. Commissioning phase

- — Mandatory participation of the owner’s operation and engineering personnel on commissioning activities;
- — Daily meeting with the construction and commissioning personnel;
- — Keep well defined milestones for systems transfer from construction to commissioning and from commissioning to operations.

Annex II

BULGARIA

II–1. BRIEF DESCRIPTION OF BELENE NPP

II–1.1. Background

The Belene site on the Danube River was approved by the Bulgarian Government in 1981 for the construction of a second nuclear power plant in Bulgaria. The same year, preparation of the site preparation commenced with:

— Construction of anti-filtration walls;
— Erection of external communications, civil and installation facilities.

To avoid the risk of site flooding, the terrain was built up by eight meters and levelled at the same time. By 1989 the following erection works were completed:

— Circulation pipelines
— Units 1&2 ballast mats,
— Unit 1 reactor building up to elevation 13.20 m, and the foundation and support structure of the turbine hall;
— Diesel generators cubicles.

In 1990, the Bulgarian Government decided to suspend project execution due to financial difficulties. Since then, multiple measures have been undertaken to preserve the equipment supplied, the construction site itself and the buildings. Various investigations and assessments have been carried out with respect to the site suitability and the equipment status, all of which yielded positive conclusions. New investigations were conducted in relation to site safety and its compliance with international safety requirements. An extensive research on the seismic safety of the Belene site was carried out. A number of missions were dispatched by the IAEA and other authorities. All these came up with positive conclusions and confirmed that the Belene site was suitable for the construction of a new nuclear power plant.

At the end of 2002, the Bulgarian Government took a decision in principle to re-start construction at the Belene site.

An Environmental Impact Assessment was carried out in the period from October 2003 to November 2004, and the final report was submitted for public discussions in both Bulgaria and Romania. The procedure ended up successfully, resulting in Decision No.18-8 from the Ministry of Environment and Waters, dated November 22, 2004, to approve the investment proposal for the construction of a Nuclear Power Plant at the Belene site.

The Feasibility Study Report substantiating the construction of the Belene NPP included an analysis of eight types of nuclear technologies currently available on the market, on the basis of the technical and economic data provided by the potential vendors. The technical and economic results of the Feasibility Study showed that the optimal choice, based on the levelized electricity cost, would be the construction of two pressurised water reactor units at the Belene site.

The Feasibility Study Report was made public in November 2004, and a public hearing was held in January 2005 according to the requirements of the Act on the Safe Use of Nuclear Energy.

Fulfilment of all legislative requirements made it possible for the Bulgarian Government to enact Decision No.260 of the Council of Ministers dated April 8, 2005, thus approving the construction of a nuclear power plant at the Belene site with a rated electric capacity of 2000 MW(e).

Pursuant to the above mentioned decision, on May 10, 2005, the National Electric Company placed a Public Procurement Order for selection of a contractor for engineering, procurement and commissioning of two units at the Belene Nuclear Power site.

Two companies submitted their offers — JSC Atomstroyexport and AREVA NP as their subcontractor, and the Skoda Alliance with Westinghouse as a subcontractor. Nine months later, the Board of Directors of NEC officially announced that JSC Atomstroyexport was the selected vendor for the construction of two light water reactors units, based on the A-92 design at the Belene site.

The contract between the National Electric Company and JSC Atomstroyexport for the engineering, procurement, and commissioning of the Belene NPP was signed on the 29th of November 2006.

Project data

The WWER-1000/V-466 Evolutionary Design (A92 Design) main characteristic is the improved safety, better technical and economic features in comparison with the existing nuclear power plants of the previous generation, the VVER-1000/V 320 series design. These improvements were achieved by:

— Ensuring faster shutdown of the reactor core, thanks to the presence of two completely independent reactivity control systems;
— Redundancy of all safety functions provided by the use of both active and passive safety systems (including a Passive Residual Heat Removal System and a Passive Filtering System), which require neither operator's intervention, nor electric power supply;
— Use of a special protective enclosure structure to isolate the accident products. This structure consists of a primary containment of pre-stressed reinforced concrete with a leak-tight metal liner, a secondary reinforced concrete containment and a cast concrete external structure designed for a wide range of potential internal and external events.

A specific feature of the third generation reactor WWER-1000/V-466 Evolutionary Design (A92 Design) is the provision of an ex vessel corium retention area (core catcher) for severe accidents. This prevents the occurrence of containment integrity violations and releases of highly radioactive substances to the environment.

A comparison between the general data of WWER-1000/V-466 Evolutionary Design (A92 Design) and VVER-1000/V 320 serial design is presented in Table II–1.

TABLE II–1. MAIN GENERAL DATA OF THE WWER-1000/V-466 EVOLUTIONARY DESIGN (A92 DESIGN) VS. WWER-1000/V 320 SERIAL DESIGN.

Parameter	WWER-1000/V-466 Evolutionary Design	VVER-1000/V 320 Serial Design
Service life, years	60	40
Thermal power, MW(th)	3012	3000
Electric output, MW(e)	1049	980
Capacity factor, %	90	80
Safety systems capacity		
Reactor protection system	1×200%	1×100%
Fast boron injection system	4×25%	—
Safety systems including DG+UPS+I&C+HVAC+SW	4×100%	3×100%
Passive ECCS	4×50%+4×33%	4×50%
Passive heat removal system	4×33%	—
Melted core retention and cooling system	1×100%	—
Core damage frequency, reactor-year	1.5E-07	<1E-05
Early large release frequency, reactor-year	5.5E-10	<1E-06

II–1.2. Project organization

The National Electric Company in Bulgaria is a 100% state owned single owner joint stock company which generates electricity at HPP and PSHPP, provides power transmission services and trades in electricity on the national and international markets.

NEC is the owner of the power transmission network in the country; it owns and operates 29 hydro power plants with a total capacity of 2563 MW. Of these, the 14 largest plants cover the power demand of the electric power system. NEC investment strategy is intended to ensure security of supply and the development of the electric power system. The investment portfolio includes new builds and the modernisation of existing generation facilities as well as grid infrastructure improvement projects. NEC's largest investment project, awarded by the Government of the Republic of Bulgaria, is the construction and commissioning of the Belene Nuclear Power Plant, consisting of two 1000 MW reactor units.

The project organization is presented in Fig. II–1.

II–1.3. Contract type (company)

In 2008 the National Electric Company and JSC Atomstroyexport signed a Turn-key EPC Contract Agreement for the Belene NPP. The main foreign subcontractors of JSC Atomstroyexport are AREVA NP and Siemens.

Up to 30 % of the total scope of supply and services is contracted to domestic companies.

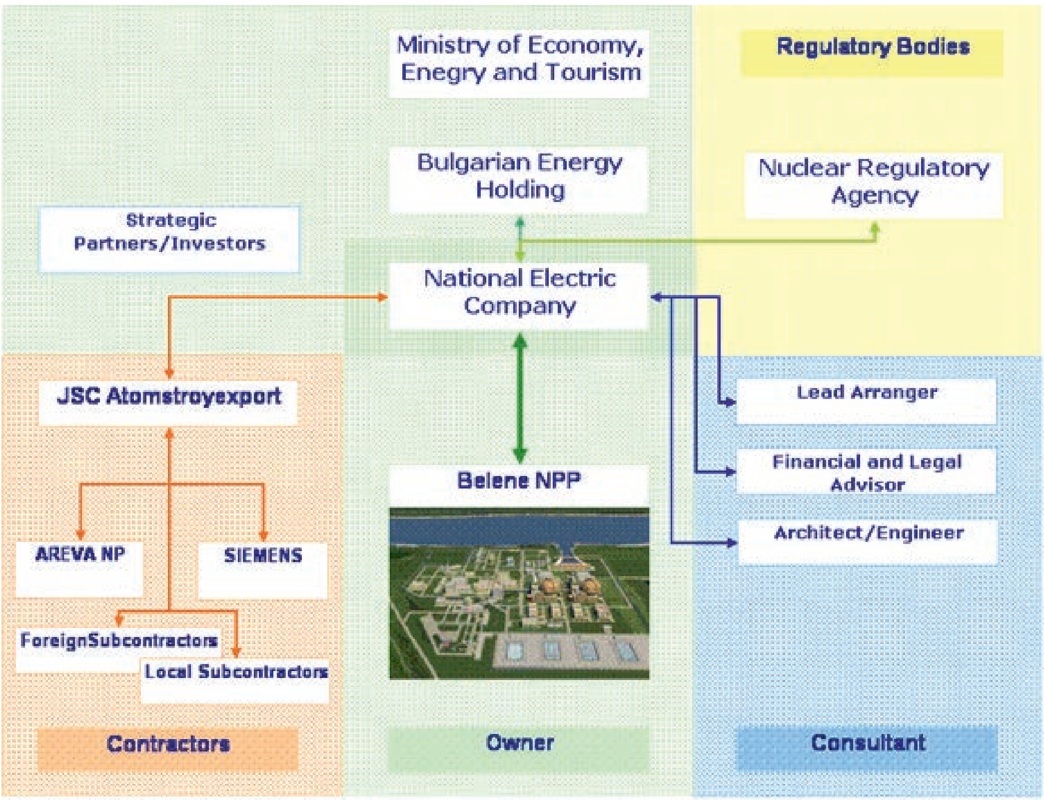

FIG. II–1. Project organization of Belene NPP.

II–2. LESSONS LEARNED

II–2.1. Project management — Preparatory phase

II–2.1.1. Site preparation

The preliminary activities at the Belene site focused on the removal of all the existing structures that could not be integrated into the new plant design.

In the course of a few months, 8780 tons of metal structures and 150 298 cubic meters of concrete and reinforced concrete structures were dismantled and removed. In addition, 150 923 cubic meters of soil were excavated. The areas being totally cleared of dismantled structures are the reactor building, the diesel generator stations, the sprinkler pools, the auxiliary building, the turbine hall, trestles and cable tunnels, the administration area buildings and the water treatment plant. In addition to the dismantling work, much excavation work and erection of temporary pathways and working sites have been completed.

The diamond wire sawing type tool was selected for the dismantling of reinforced concrete structures at the plant. This tool was chosen taking into account the existing civil structures configuration, its dimensions and the material properties. The main features of the wire sawing tool are the possibility to cut walls with nearly unlimited thickness, composed of different materials, its suitability for both horizontal and vertical cuts, its operability in limited space with extremely high functional modularity and flexibility in small areas, where high performance and ease of positioning of the tools are required with guaranteed safety, precision assembling and optimal water guidance. Wire sawing provides reduced levels of noise, dust and debris and above all, it allowed preservation of the structural integrity of the ballast mats under the foundation.

Prior to work commencement, much planning and preparation was carried out. All operators were made familiar with the work. Operators were trained for the possible hazards associated with wire sawing, with handling of heavy concrete blocks and were familiarized with industrial safety principles applied to the Belene NPP site. Engineering documents and as-built drawings related to the site (previously archived) were reviewed. Quality plans, installation, dismantling logs and other documents were compiled in compliance with the ISO 9001/2000 standards.

All the required equipment for project implementation was specified and delivered at the site, including heavy lifting equipment, such as 350 and 500 t cranes needed to remove the discarded concrete sections. Cabling and piping structures were connected to provide the temporary supply of water, air pressure and lighting. Other protective measures ensuring safety were taken as well; i.e. the erection of fencing, railings and of temporary pathways to keep workers not involved in the cutting process at a safe distance from the demolition areas.

A major part of the planning of this project included the rigging and removal of the cut concrete blocks. The weight of the blocks varied from 10 to 100 t. The cut blocks were transported to a storage area via platforms with a loading capacity up to 150 t. In the storage area, the blocks were crushed into smaller pieces in order to be processed into a by-product.

Another specific feature of the concrete cutting work that had to be addressed from the very beginning was the quantity of water used and the slurry produced during the cutting process. Cores were removed and placed in containers especially provided for this purpose and the slurry was cleaned up on a daily basis. The proper disposal of waste water was an important issue and an appropriate water drain system was assembled for each area. Waste water was filtered and treated, then disposed into the sewage system.

The know–how in diamond wire sawing of the Bulgarian cutting contractors proved a basic advantage as they completed the project in August 2009 — 4 months earlier than planned with a high degree of accuracy and an average daily capacity 43% higher than expected, at a budget –7% lower than estimated.

II–2.1.2. Design under new licensing requirements

The new regulatory requirements for the plant protection against external hazards were adequately addressed in the early design phase. Special attention was paid on the large commercial aircraft impact assessment and related design changes were made to ensure adequate protection with sufficient thickness, reinforcement of the outer building walls, separation from the inner structures and by taking other measures such as physical separation, appropriate design features and functional capabilities of the structures, systems and components.

II–2.1.3. Detail design

The contractor was authorized to proceed with the detail design phase of the structures, systems and components in steps based on the approved conceptual plant design in order not to jeopardize both the foundation preparation schedule and the plant construction schedule.

II–2.1.4. Long lead equipment manufacturing

In order to meet the plant construction schedule, the contractor was authorized to proceed with the long lead equipment manufacturing phase based on the agreed specifications of the main equipment of the Nuclear Island, including the RPV, RPH, RCLs, RCPs, SGs, RPV Internals, PRZ, ECCA Hydro-accumulators, the Polar Crane, the Turbine Island comprising the Turbine, the Generator, FWPs, LPHs and HPHs, MSRHs etc.

The contractor is responsible for reviewing and approving the QA programmes in accordance with the contractor's Quality Management System Procedure, as well as approving the Quality Plans of the subcontractors. The Employer obtains information related to the contractor's approval of the QA programmes, the Quality Plans and, if required, other QA documents of the subcontractors for the LLEM. The employer and the contractor carry out scheduled and unscheduled internal and external audits of the LLEM subcontractors.

The scheduled audits aim at:

- Assessing the quality system potential during the sub-contractor selection;
- Controlling the effectiveness of the QA program implementation during work execution or partial execution as per the agreements and/or contracts signed, as applicable;
- Systematically assess the effectiveness of the QA programme.
- Unscheduled audits may be conducted in case of:
- Considerable modifications to sections of the QA programme, reorganization of the programme structure, substantial modification to the quality management procedures;
- Evidence of unsatisfactory quality of products or services caused by an ineffective QA programme or its improper implementation;
- Required verification of the appropriate implementation of corrective actions following findings, observations or recommendations from previous audits.

The results of all audits are to be documented in audit reports in accordance with the contractor's and the employer's Quality Management Systems. The QA audit reports are to be sent to the audited organization for analysis and elimination of the detected non-conformance as well as for taking corrective and preventative actions resulting from the audits. The monitoring of corrective and preventative actions for the elimination of non-conformances, include:

- Analysis at different levels of the corrective action plans for the detected non-conformance and of the implementation of the corrective actions;
- Assessment of the information received for the resolution of non-conformances and the execution of the corrective action plans;
- QA follow-up audits, as decided by the above assessment.

The contractor's LLEM subcontractors should submit information on the corrective actions performed to the Owner/Operator based on the results of the audits conducted in cooperation or participation of the Owner's representatives.

Quality control is a systematic control activity executed by the employer, the contractor, and LLEM subcontractors by means of measurements, tests and inspections in order to ensure that activities and processes meet quality requirements.

The employer and the contractor conduct inspections in accordance with quality plans approved in advance, aiming at confirming that the work is performed in compliance with the approved documentation and that the subcontractors' quality records are reliable. The employer's inspections do not relieve the contractor from any responsibility to ensure quality and the contractor's inspections do not relieve the LLEM Subcontractor from the responsibility for the quality of its products and/or services.

The need for inspections and their scope are defined by the quality category. Inspections for quality categories QA1, QA2 and QA3 are performed according to the respective quality plans. The quality plan for each product categorized as QA1, QA2 and QA3 contains a list of technical and control operations important to quality. The subcontractor/contractor is responsible for the identification of control points, reference documents and the type of control for all technical operations addressed in the quality plan.

Control points of three types can be used:

- HP (hold point) — The activity is held up until inspection or tests (as applicable) are completed and clearance for further activity is given;
- WP (witness point) — The activity is not held up until inspections or tests are complete (as applicable). Based on their conclusions on all WP both parties can release their final approval of the quality plan;
- WP (R) (witness point on report) means witnessing on reporting documents without holding up work;
- Based on their conclusions on all control points defined in the quality plan both parties can release their final approval of the quality plan.

Invitation of the employer as witnessing party is mandatory for the manufacturing control points, such as the 'Factory Acceptance Tests (FAT)' for equipment of the QA1 and QA2 quality categories. An accepted product is one that has successfully passed all measurements, inspections and other tests envisaged in the technical documentation and in the quality plans.

Annex III

CANADA

Status of Canada's nuclear fleet (2010)

Canada generates about 15% of its electricity from nuclear, compared with 58% from hydro, 17% from coal and 6% from gas. The country plans to expand its nuclear capacity over the next 10 years by building up to nine new nuclear reactors. During the course of the current decade all efforts have been focused mainly on extensive modernization of the first series of the nation's nuclear reactor fleet, the so-called A-plants as opposed to the more recent B-plants.

Four are the Utilities that operate the 20 active Canadian Power Reactors: Ontario Power Generation (OPG) (10 units + 2 under lay-up); Bruce Power (8 units); Hydro Quebec (1 unit + 1 decommissioned); New Brunswick Power (1 unit). Canada has not built a new reactor on Canadian soil since the Darlington 4x 881 MW(e) CANDU units. The last Darlington unit was brought on line in 1993.

Ontario Power Generation (OPG)

At Pickering, OPG operates four 531 MW(e) units of the older A type of which Units A1 and A4 have both been refurbished in recent years, thus extending their operation to 2022, while units A2 and A3 were laid up indefinitely. At Darlington, OPG operates four 881 MW(e) CANDU units that are expected to continue operation to between 2020 and 2023.

In September 2006, OPG submitted an application to the Canadian Nuclear Safety Commission (CNSC) for a Site Preparation, Construction, Operations, Decommissioning and Abandonment license for 4 new nuclear units of up to 4800 MW(e) at their Darlington site. In December 2010, the Joint Review Panel (JRP) managing the license is expected to submit a report to the Federal Government and in April 2011 the Darlington site preparation license.

Bruce Power

The Bruce nuclear complex, located on Lake Huron near Tiverton Ontario, has a total output capacity of 6224 MW (net) and 6610 MW (gross). It houses 4 older 769 MW(e) CANDU (A-Units) and 4 newer 822 MW(e) CANDU (B-units). The facility was constructed in stages between 1970 and 1987

The older Units 1 and 2 at the Bruce A plant have been undergoing a major modernization effort including the replacement of their fuel channels, their steam generators and the upgrade of a number of ancillary systems to current standards, which should enable these units to operate for an additional 25 years. Once Units 1 and 2 are re-started, Units 3 and 4 will follow.

Bruce Power also submitted an application to the CNSC for new construction, but decided to withdraw it saying it would first focus on the refurbishment of the existing Bruce plants. Bruce Power also announced it was abandoning plans for another new nuclear complex at Nanticoke in Ontario.

New Brunswick Power

New Brunswick Power operates Atlantic Canada's only nuclear facility, the Point Lepreau Generating Station (PLNGS), a CANDU 6 unit, with net capacity of 635 MW. It was the first CANDU 6 design to be licensed for operation beginning commercial operation 02/01/1983.

Currently the Point Lepreau generating station is undergoing extensive modernization. The scope includes replacement of the pressure tubes, Calandria tubes, feeder pipes up to the feeder headers (excluded), partial replacement of the liquid injection shutdown system rod set, refurbishment of the reactor coolant pump motors, installation of passive H2 recombiners, the replacement of the moderator and auxiliary systems valves, the refurbishment of the shutdown cooling system and of the pump by-pass valves, the replacement of the main turbine controls, of the inverters and rectifiers in the uninterruptible power supply system (UPS), the refurbishment of the raw service water (RSW) and of the recirculating cooling water (RCW) system, the replacement of the dousing tank NORMAC liner and of the epoxy liner in the D2O storage tank, the expansion of the Solid Radioactive Waste Management Facility (SRWMF) and an update of the safety analysis and PSA.

Recently, New Brunswick Power has been studying the possibility of new construction at its Point Lepreau site on the Atlantic Ocean after the refurbishment of its CANDU 6 unit is completed.

Hydro Québec

Hydro Québec is primarily a hydroelectric producer. However it also owns a CANDU 6 type nuclear unit Gentilly II, that provides 3% of Québec's electricity production. Hydro Québec plans to start the refurbishment of its Gentilly II nuclear reactor in early 2011. The scope follows in the footsteps of the Point Lepreau refurbishment with some distinct differences.

Gentilly-2 NPP is an important element in the reliability of Québec’s electrical production. Since HQ is primarily a Hydroelectric producer, its production depends on the level of its water reservoirs, hence its only nuclear plant constitutes also its only reliable base load and a strong backup to the low capacity factor of the renewable sources. Gentilly-2 NPP occupies a strategic position in the network also because of its proximity to the large population centres, otherwise vulnerable to interruptions of the extremely long and difficult to service distribution lines from the hydroelectric production points.

Projects abroad

The latest CANDU plant project was built in Zhejiang Province, China (completion Aug 2003). The Owner was the Third Qinshan Nuclear Power Company (TQNPC). The main contractor was Atomic Energy of Canada Ltd. The reference plant was Wolsong 3, 4 built in the Republic of Korea. Improvements in design and construction methods allowed Unit 1 to be completed in 51.5 months from first concrete to criticality.

Construction schedule

The construction schedule was a critical part for the success of the project. The Qinshan Schedule was an 8500-activity Level 2 Project Coordination and Control (C&C) schedule. It was produced within 6 months of the Contract Effective Date (CED).

The Level 3 engineering and supply schedules were developed within the first 12 months of the project.

The Level 3 construction and commissioning schedules were developed in the first two years.

The individual subcontractors produced their own Level 2 and 3 schedules to comply with the overall Level 2 C&C schedule.

Quality assurance

AECL as the main vendor/contractor was responsible for:

— The overall quality assurance programme;
— Conducting information sessions and program reviews in support of the nuclear steam plant sub-contractors;
— Conducting audits and quality surveillance on NSP sub-contractors, analysing trends on a continuous basis and reporting results and corrective actions monthly to TQNPC.

TQNPC as owner and licence holder:

— Conducted quality surveillance on AECL QS;
— Audited with AECL the BOP construction management for the implementation of the BOP construction quality assurance programme;
— Reviewed and accepted AECL’s procedure for equipment procurement and quality surveillance;
— Conducted off-shore equipment surveillance and review of manufacturing records;
— Participated in 85% of the witness points selected.

TQNPC with AECL were coresponsible for the implementation of the commissioning QA programme.

Specific construction features at Qinshan phase III:

- — High intake water silt content: This required four 50 meter long undersea intake ducts designed for high silt and 4m/s velocities of tide inflow into Hangzhou Bay.
- — Surrounded by water on 3 sides, retaining walls around the site became necessary.
- — Open top and all-weather construction:
  - An all-weather temporary roof (150 t) was placed on top of each reactor building. It allowed insertion of large equipment and modules from the top and permitted working around the clock, both indoors and outdoors
  - Conventional construction of the lower dome in-situ would have required suspension of the reactivity deck installation for safety and protection. Instead the lower dome was assembled as a module on the ground and lifted into position using a VHL crane.
  - The dousing system steel frame with piping, tanks, valves, electrical and instrumentation was also assembled on the ground as module. The last two techniques resulted in a 3-month net saving over previous projects.
  - A VHL crane installed many pieces of equipment in record time: four steam generator (220 t each) and the pressurizer (103 t) were positioned in two days instead of two weeks. It also installed the reactivity mechanism deck (43 t), the feeder frames (40 t each), the fuelling machine bridges (16 t each), the condenser lower shells (270 t each), the turbine generator stator (280 t)
  - On completion of the equipment and module installation, the temporary roof was replaced by a permanent reactor concrete dome.

3D CADDS as basic design tool

- — A 3D-CADDS model and interfacing engineering tools (for sizing verification and analysis) were used to increase speed and quality of detail engineering;
- — A special QA programme and procedures for 2D extraction and production of Release For Construction (RFC) packages were developed;
- — The database in the 3D CADDS model contained stock code number (SCN) and material descriptions and was integrated with the CANDU Material Management System (CMMS) eliminating duplicate SCNs, procurement errors, rework etc;
- — IntEC was the tool that provided live wiring, cabling and connection design and as-pulled data;
- — Integration of the IntEC and 3D-CADDS databases allowed precise control and management of materials and documentation - They tracked equipment and material;
- — The Weld Information System (WIS) was used to record quality information for all pipe welds.

Information management

- — An information management tool called ‘TRAK’ was used. It managed drawings, documents, correspondence and other records in electronic format and made available on line;.
- — It facilitated scheduling, RFC packages issue, distribution and shipping of project deliverables;
- — It provided revision control and electronic approval of documentation;
- — It maintained the project document baseline;
- — It facilitated configuration management. TRAK improved quality and reduced costs.

Electronic tools for commissioning

Commissioning used the following tools:

- — The plant parameter LAN and project management LAN;
- — Work Permit Management System (WMS): to achieve control during commissioning and production; to manage work permits, work processes and tests;
- — Work Package Database Management System: to store basic information of various commissioning and maintenance work packages;
- — The In-core Physics Calculation and Optimisation of Fuel Management System (IFOS);
- — Nuclear Material Accounting System (NMAS).

Annex IV

CHINA

IV–1. BRIEF DESCRIPTION OF NPP

In March 2009, China began the construction of four AP1000 units in the context of its Nuclear Power Self-reliance programme of which two units at Sanmen in Zhejiang Province and two units at Haiyang in Shandong Province. The Chinese government and every other party involved in the construction of these 4 AP1000 units paid particular attention to the progress, the safety and the economy of this project.

IV–1.1. Project data

The AP1000 standard design was imported from the Westinghouse Electrical and Stone & Webster International Consortium (WEC) as a Generation III nuclear steam supply system (NSSS) capable of delivering 3415 MW(th) of thermal power. Given the different coastal environmental conditions, particularly the different water temperatures of Sanmen and Haiyang, and the turbine/generators designed and manufactured by Mitsubishi Heavy Industry, the plants will develop a gross electric power of 1251 MW(e) for Sanmen and of 1253 MW(e) for Haiyang respectively. The construction duration for a single unit is 56 months from the first construction date to commercial operation date (COD).

IV–1.2. Project organization

The two utilities, Sanmen and Haiyang together with the State Nuclear Power Technology Company of China (SNPTC) are the joint-Purchaser of the AP1000 Nuclear Islands (NI). SNPTC is responsible for providing the whole NI to both utilities. The Shanghai Nuclear Engineering Research and Design Institute (SNERDI), subsidiary of SNPTC provides support to both utilities as the overall design Institute. The two utilities are responsible for the procurement of the CI and of the Balance of Plant.

IV–1.3. Contract type (Company)

Sanmen and Haiyang with this project in the context of the self-reliance programme use a multiple package contract type. An outline of the Sanmen vendors is provided in following Table IV–1.

TABLE IV–1. OUTLINE OF THE SANMEN MAIN COMPONENT SUPPLIERS

Activity	NI	CI	BOP
Pre-project activities	Utility (U)		
Project management	SNPEC *	U	U
Project engineering	WEC consortium	MHI+ECEPDI ★	U+SNERDI
Quality assurance/quality control	SNPEC *	U	U
Procurement	WEC+SNPEC	U	U
Application for license	U		
Site preparation	U		
Erection	SNPEC	U	U
Equipment installation	SNPEC	U	U
Commissioning	U+SNPEC+WEC	U	U
Plant operation and maintenance	U		

* SNPEC : State Nuclear Power Engineering Company.
★ ECEPDI : East China Electric Power Design Institute (design supplier for the Sanmen Conventional Island)
* U : the utility

IV–2. LESSONS LEARNED

IV–2.1. Project management — Preparatory phase

The differences between the Chinese and the US regulatory requirements should be seriously dealt with during the project preparatory phase.

For instance, in China, the licensing process is more similar to the traditional two-step licensing process outlined in 10 CFR 50. A construction permit is issued before the issuance of a license. Upon completion of the construction phase, which is monitored by the regulatory authority, an operating license is granted through the amendment and the review process. On the other hand, in the USA, 10 CFR Part 52 outlines a Construction and Operating Licensing (COL) process for new nuclear power plants as a combined one-step construction and operating license and is issued upon completion of the NRC review of a standard design.

This difference was extensively discussed during the licensing phase of the Sanmen and Haiyang projects and finally the Sanmen and Haiyang utilities agreed to prove to the regulatory authority that the work done will be equivalent to all the steps required in 10 CFR Part 52. Other issues such as containment resistance to airplane collisions resulting from the 9-11 tragedy, occupational radiation exposure limits, and structural changes due to the extensive modularisation of the plant also drew intense attention during the construction licence process.

It is certain that inadequate completion of the design and engineering work prior to the start of construction is detrimental to the timely implementation of the project. WEC had still not completed the engineering work 18 months after the first concrete pour. This fact delayed construction activities causing continuous pressures on all organizations involved. It led to rescheduling of the manufacturing and construction steps, and to compromises on quality due to time constraints. Frequent engineering errors, corrections, rework and reassessments resulted in frustration and disappointment with regard to WEC's engineering, although, to be fair, new engineering approaches in third generation reactors, first of a kind advanced safety features, and unproven equipment are not easily implemented.

IV–3. PROJECT MANAGEMENT – CONSTRUCTION PHASE

Structural modularization causes new challenges to manufacturing and construction. A steel type containment vessel is difficult to erect. Canned reactor coolant pump are still under testing and face construction schedule pressures. All obstacles should be moved in order not to delay project milestones.

To reduce construction cost, bulk materials should be procured internally in China rather than on the international market. Large amount of materials are specified in accordance with US industry practice, while they are not available on the Chinese local market. Bulk material equivalency studies and substitutions with local materials should be carried out. How to speed up the approval process for material substitution is a hot topic for project management. A lesson drawn from this is that bulk material substitution issues should be resolved at the very beginning of the construction phase.

In China, the construction of most of the currently operating plants and the new plants under construction has been awarded to large experienced organizations with comprehensive capabilities in nuclear component manufacturing, erection, and installation, with a basic understanding of the nuclear safety culture. However there are not enough skilled human resources from specialized workers to experienced project managers to handle the new generation reactor types such as the AP1000 that require new construction organization modes due to extensive modularisation, advanced construction methods etc. China is confident that the whole supply chain for nuclear power plants, from the design institute, to the equipment manufacturers and construction companies will accumulate much more experience and achieve excellent efficiency through the self-reliance programme of the Sanmen and Haiyang AP1000 nuclear power plant projects.

Annex V

JAPAN

Construction and Start-up of Tomari NPP Unit 3

V–1. CONSTRUCTION APPROACH

The Hokkaido Electric Power Company (HEPCO) is the owner of the Tomari NPP comprising three operating PWR units. The latest unit to be connected to the grid, Tomari Unit 3, is a 3-loop PWR power plant with an electric output of 912 MW(e) supplied by Mitsubishi Heavy Industries (MHI). This is the newest unit in HEPCO and it is the newest PWR unit in Japan as well. The first concrete at Tomari Unit 3 was poured at the end of summer in 2004. The unit entered into commercial operation in December 2009. Figure V–I. is the construction schedule of Tomari Unit 3.

The Tomari site is located on a northern Japanese island. It is battered by strong winds and receives much snow in the winter. Therefore, civil works and building construction were temporarily suspended every year from the beginning of December until the end of March. This increased construction duration by one year compared to other sites. Consequently from first concrete to the start of commercial operation construction at Tomari lasted 64 months.

There are specific factors in the approach to construction of nuclear power plants in Japan.

(1) Japanese legislation defines that the sole licensee must be the electric power company. This implies that the electric power company is responsible for the safety of the plant and in that capacity it must submit for approval the Safety Analysis Report (SAR) but it is also responsible for the design and reliability of the plant; hence it must also submit for approval the Construction Plan (CP), containing all necessary detailed design information. Consequently, the electric power company becomes the sole counterpart to the regulatory body on all aspects of the project.

(2) All Japanese electric power companies are considerably large and have the tradition to do the engineering of their power plant themselves, and this not only for nuclear but also for conventional power plant. Therefore, the owner/utilities in Japan carry themselves the burden of major portions of the engineering, procurement and construction (EPC) of their NPPs. Although the conceptual design work may be outsourced, the utilities manage everything else from the infrastructure, the access roads, the supply of utilities to the site (electricity, water, etc.), the site preparation, the general arrangement of the work areas, the interface between contractors, the scheduling of construction activities, at the site, to overseeing the work of all contractors from the safety, quality, scheduling and contractual standpoints. In order to manage and oversee the suppliers' construction works at the site, a considerable number of qualified engineers and inspectors are required.

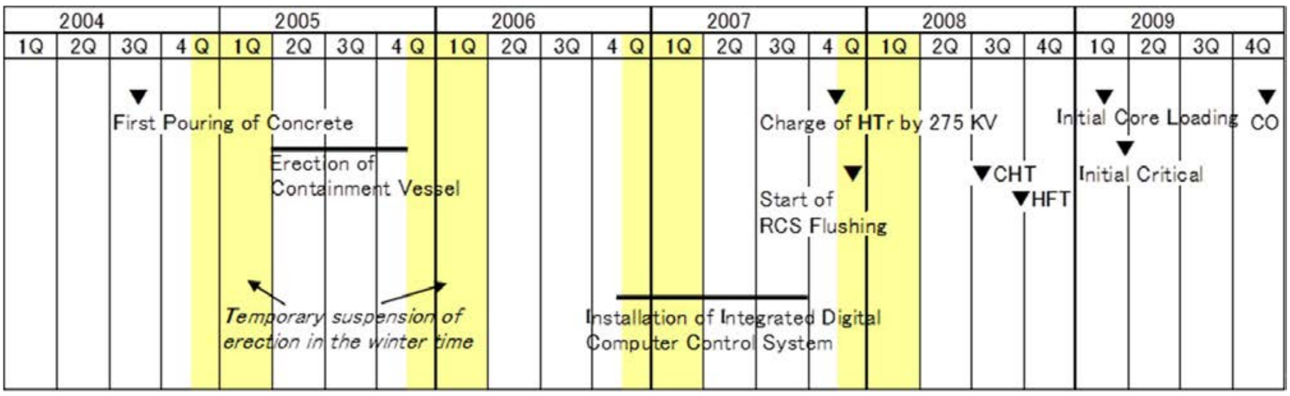

FIG. V–1. Construction schedule.

(3) Consequently to the previous two factors, the Japanese electric companies have built nuclear power plants by awarding split-package contracts (the so-called island approach) as well as smaller component contracts. E.g. HEPCO awarded some 150 contracts for the construction of Tomari NPP Unit 3.

(4) Given the large number of utilities in Japan, each company built relatively few new nuclear power plants and this has made it difficult to maintain on their own a highly qualified workforce. Fortunately all utilities in Japan have developed and maintained good relationships with one another and willingly share their human resources where the need arises. Salaries and expenditures however continue to be paid by the original employers. This way the host utility can use the borrowed staff for its construction and the lending utility can maintain its qualified engineers for its next construction project.

The traditions and practices mentioned above were developed by HEPCO and other utilities as a result of their very large and intense involvement in their nuclear power plant construction activities. Participation in depth in the construction process was key to the success and accomplishment of nuclear construction in Japan. In addition, the following factors strongly contributed to the efficiency and rationalization of the construction process of Tomari Unit 3:

— Standardization of designs of SSCs particularly in the nuclear island due to systematic feedback from preceding plant construction projects;
— Maximization of factory pre-fabrication of SSCs;
— Large scale module pre-fabrication and open top installation;
— Construction schedule integration of main contractors with HEPCO's schedule and confirmation of the activity sequence at the site;
— Cooperation between HEPCO's construction and operation divisions.

V–1.1. Establishment of the start-up organization

The management responsibility of each system was gradually transferred to the Operation Preparation Division after commissioning. It meant that the shifts to operations had to be established before the first system turnover. The first commissioning and turnover to operations was that of the emergency transformer, because it had to provide electric power from the external transmission lines to the installed components and systems in the plant to allow their commissioning. The operation organization was initially small but sufficient to take over the emergency transformer and the house load bus. Then it was gradually strengthened as the following commissioned systems were one by one transferred under its jurisdiction.

HEPCO' established that all commissioning and turnover should be done as early as possible taking into consideration the training time of the shift operators. That is to say, systems that could be tested before initial core loading should have been turned over. Consequently before initial core loading, the Operations organization was in full force and ready for stat-up since most systems had been transferred to Operations by that time.

V–2. COMMISSIONING SCHEME

V–2.1. Definition

The definition of 'commissioning' according to the IAEA glossary is; "The process by means of which systems and components of facilities and activities, having been constructed, are made operational and verified to be in accordance with the design and to have met the required performance criteria". According to this definition, commissioning includes not only the system functional tests or plant startup tests, but also the turnover of all SSCs and of the whole plant from the construction contractors to the Owner/Operator.

The Owner/Operator had the right to take over only those SSCs (and at the end of the process the whole plant for the matter) that proved to meet the contractual specifications. The turnover commitments to HEPCO were defined in documents such as the supply technical specifications attached to the supply contracts and the suppliers' design documents approved by HEPCO. However it was impossible for HEPCO alone to confirm all those items. Therefore, HEPCO employed a classification method and a component grading system to decide what items could be accepted in the construction/commissioning turnover to operations.

V–3. GRADING OF HEPCO’ INVOLVEMENT

HEPCO determined what components the company should accept by itself and what products HEPCO would entrust the suppliers to accept on its behalf. HEPCO developed detailed acceptance criteria for each component of each system as per the table below. The items confirmed in commissioning tests were also accepted in accordance with this strategy. See Table V–1.

The roles and responsibilities to carry out confirmations and to manage the recorded data necessary for commissioning were shared in HEPCO as follows:

- Tests which could be carried out within one of the construction divisions were planned, implemented and managed in that division;
- System tests shared by two or more divisions were controlled by the System Commissioning Test Control Group;
- Plant tests (startup tests) were controlled by the Startup Test Control Group;
- Tests inspected by the authority or its technical support organizations (TSO) were controlled by the Quality Assurance Division with cooperation by the corresponding construction divisions and the System Commissioning Test Control Group.

V–4. PROCESS OF TURNOVERS

There were two different kinds of turnovers at Tomari; one was from the suppliers/contractors to the construction divisions of HEPCO and the other from the suppliers/contractors to the Operations Preparation Division of HEPCO.

The former turnover was applied to structural products such as civil works and entire buildings in the plant. To give an example, the reactor building was built by a construction company called Taisei Corporation and the primary coolant system components were installed in the reactor building by MHI. A room turnover of the pump room was necessary before the pumps could be installed. The responsible engineer for the civil and architectural contractor confirmed acceptance of the rooms at the turnover. Then a responsible engineer of the Mechanical Division took over the room from Taisei Corporation in the presence of the responsible engineer of the civil and architectural contractor. Following that, the responsible engineer of the Mechanical Division turned over the room to MHI for equipment installation. If damage to the equipment occurred after the turnover to the mechanical division, the equipment had to be repaired under the responsibility of the mechanical division.

The latter was a system turnover or plant turnover applied to systems and plant. These were transferred from suppliers to the Operation Preparation Division in the presence of the responsible engineers of the corresponding construction-related divisions, namely the Mechanical and the Electrical and I&C Divisions after completion of the commissioning tests. The commissioning tests were controlled by the System Commissioning Test Control Group. At the technical level, they were organized by the responsible engineers of the corresponding construction-related divisions, acting within a commissioning test implementation team. The responsibility of the system was transferred to the Operation Preparation Division after commissioning was completed. In cases where portions of a large system needed to be operated before the whole system was turned over, then that portion could be commissioned and provisionally turned over. For example, a complex system such as the CCWS required this kind of treatment.

A noteworthy practice by HEPCO was the fact that the commissioning and turnover of systems were done back to back. The responsibility of the operation and management of a system moved from the contractors/suppliers to the Operation Preparation Division immediately after its commissioning test had ended well.

Theoretically speaking, a damaged component caused by a failure under the watch of an operation crew had to be restored under the responsibility of the Operation Preparation Division. On the other hand, the flushing of the primary and secondary systems before the commissioning tests was still the responsibility of the construction contractor.

TABLE V–1. SAFETY CLASSIFICATION OF TOMARI NUCLEAR POWER PLANT

<table>
<tr><td colspan="2" rowspan="2">Nuclear safety</td><td colspan="3">Safety Class-1</td><td colspan="2">Safety Class-2</td><td colspan="2">Safety Class-3</td><td rowspan="2">Others</td></tr>
<tr><td>PS-1</td><td colspan="2">MS-1</td><td>PS-2</td><td>MS-2</td><td>PS-3</td><td>MS-3</td></tr>
<tr><td colspan="2" rowspan="2">Reliable operation</td><td>Failure can lead to
(a) a significant core damage, or
(b) a bulk-failure of fuel rods</td><td colspan="2">Equipment in the mitigation systems for the reactor shutdown.</td><td>Failure can lead to
(a) an excess release of radioactivity,
(b) a loss of heat removal during the normal operation or operational transients.</td><td>Equipment having the mitigation function for the failures of PS-2 equipment.</td><td>Failure can lead to
(a) a trigger of abnormal conditions, or
(b) a loss of radioactivity concentration control.</td><td>Equipment in the mitigation systems except MS-1 or MS-2.</td><td></td></tr>
<tr><td>Components of reactor pressure boundary, reactor core internals, fuel assemblies, etc.</td><td>Reactor shutdown system, RHR system, ECCS, CV boundary</td><td>Auxiliary systems for ESF, etc.</td><td>Charging and let down of CVCS, SFP, etc.</td><td>Auxiliary systems for PS-2 equipment, CRE panel, etc.</td><td>Main steam, main feed water, CVCS, mail transformer, etc.</td><td>Auxiliary systems in the primary island, radiation monitoring system, etc.</td><td></td></tr>
<tr><td>R1</td><td>Failure can lead to a loss of power generation capability in 24 hours.</td><td colspan="2" rowspan="3">A1</td><td>A1</td><td colspan="5">B1</td></tr>
<tr><td>R2</td><td>Failure can affect the stable operation of power plant. The equipment is essential for the power generation and it has less than 24-hours grace time for the restoration.</td><td rowspan="2">A2</td><td colspan="5">B2</td></tr>
<tr><td>R3</td><td>Others</td><td colspan="2">B2</td><td colspan="2">C</td><td>D</td></tr>
</table>

V–5. COMMISSIONING FOR SYSTEMS AND PLANT TURNOVER

There were two kinds of commissioning tests; one was the pre-operational test and the other the startup test which included the initial core loading and post-core hot functional tests. The split between the two types of commissioning tests was the time of the initial core loading. The installation of equipment had been completed before then and the number of operating systems reached the peak at that time. Therefore, the structure of the operations organization was very similar to that of a commercially operational plant. The staff engaged in construction activities was gradually moved to the administration office of the operating units during the 8 month period of the startup tests.

(1) Pre-operational tests:

- Component tests: E.g. H-Q characteristics of the RCP, pressure test of a CV, flow rate tests of safety valves, inspection of seismic supports of pipes, etc;
- System or subsystem functional tests except reactor system: E.g. level control test of volume control tank of CVCS, etc.

(2) Startup tests:

- Fuel loading and sub critical tests of reactor system;
- Initial criticality and reactor physics tests of the reactor system (at 0 power);
- System functional tests except the reactor system at power conditions;
- E.g. level control test of steam generators, control test of turbine bypass valves, etc.;
- Power and reactor physics tests of reactor system (at several power levels).

V–6. SECTORS IN CHARGE OF COMMISSIONING TESTS FOR SYSTEMS & PLANT AND TRANSFER OF OWNERSHIP

Commissioning was a step necessary for the turnover of installed equipment, systems, facilities or the whole plant from the construction divisions to the operation division and had to be accomplished before their turnovers. Sectors in charge as per practice are shown below.

TABLE V–2. THE RESPONSIBILITY OF TEST SCOPE

Pre-operational tests		Startup tests;	
Planning of each test	Suppliers	Planning of each test	HEPCO and Suppliers
Preparation of tested equipments and system	Suppliers	Preparation of tested equipments and system	HEPCO and Suppliers
Operation of tested equipments and system	Suppliers	Operation of tested equipments and system	HEPCO
Operation of turned-over systems	HEPCO	Operation of turned-over systems	HEPCO
Recording of test results	Suppliers	Recording of test results	HEPCO and Suppliers
Evaluation of test results	HEPCO and suppliers	Evaluation of test results	HEPCO and Suppliers
Documentations of test results	Suppliers	Documentations of test results	HEPCO and Suppliers

At the moment of the turnover the ownership moved from the suppliers to HEPCO. The responsibility in maintaining the systems after their full turnovers or provisional turnovers was of HEPCO. Operations of turned-over systems were done by shift operators belonging to the Operation Preparation Division of HEPCO's construction office. Even before the initial core loading, shift operators were engaged in the operation of turned-over systems such as the electric power buses and the component cooling water system (CCWS) needed for the commissioning tests of other systems.

The plant turnover from MHI to HEPCO occurred before the scheduled commissioning of the entire plant, since continuous operation for the duration established by contract was achieved at 100 % of the rated reactor power, which yielded at the time even greater electric power than rated by design. This was caused by a lower than design sea water temperature. There was actually a general celebration, since the plant had been turned over to HEPCO even before the completion date of the plant commissioning as foreseen in the official schedule.

Annex VI

REPUBLIC OF KOREA

VI–1. STATUS OF NPP IN THE REPUBLIC OF KOREA

Since the issue of global warming, the time of 'nuclear renaissance' has become a reality as many nations in the world choose nuclear power as a significant option for reducing greenhouse gas emissions and meeting growing needs for electricity supply.

As the Republic of Korea lacks natural resources of energy, it has been increasing the capacity of commercial nuclear power to support the rapid expansion of the national economy by providing stable and economical electric power. Since the first commercial nuclear power generation in 1978 in the Republic of Korea, a total of 20 nuclear reactors are currently in operation. South Korea has become the nation with the 5th largest nuclear generating capacity in the world.

VI–1.1. Development of nuclear power

Technology self-reliance on nuclear power plants in the Republic of Korea has been accomplished through a long term localization programme, led by its government and owner, including NPP standardization.

OPR1000 (Optimized Power Reactor) has been developed as an integral part of the nuclear power plants standardization program which was launched in the middle of 1980s by incorporating the latest technology and lessons learned from the previous experience on design, construction and operation of nuclear power plants in the Republic of Korea.

Improved OPR1000s (Shin-Kori units 1&2 and Shin-Wolsung units1&2) are now under construction in which advanced technology features and lessons learned from the repeated construction and operation of OPR 1000s have been applied.

The new features of the improved OPR 1000 are:

- Adoption of advanced and proven technology;
- Achievement of advanced construction management utilizing the ERP system and the latest construction technology;
- Reduction of construction costs and schedule by optimising the system design and plant arrangement;
- Enhancement of safety, operability, maintainability and reliability.

The Republic of Korea has also developed the APR1400, a GEN III reactor, which features a significantly enhanced nuclear safety design and 4 units of the APR1400 are being built in the Republic of Korea. Various advanced construction methods such as modularization of the containment liner plates and of the reactor internals, parallel installation of reactor coolant piping and reactor vessel internals, and a computerized construction management system have been applied to improve its competitiveness in the global commercial nuclear market.

VI–1.2. Construction status

The current share of nuclear power generation, 36%, will increase to 59% by 2030 according to the National Energy Strategy Plan. To meet such a goal, eight nuclear units are under construction and 10 more will be constructed by 2030.

As a nuclear power plant construction is a comprehensive and long term project, systematic and specialized construction management skills are needed to meet both a high construction quality and schedule requirements with the limited availability of resources.

VI–1.3. Project organization

See Fig. VI–1, VI–2 for head office and site organization structure.

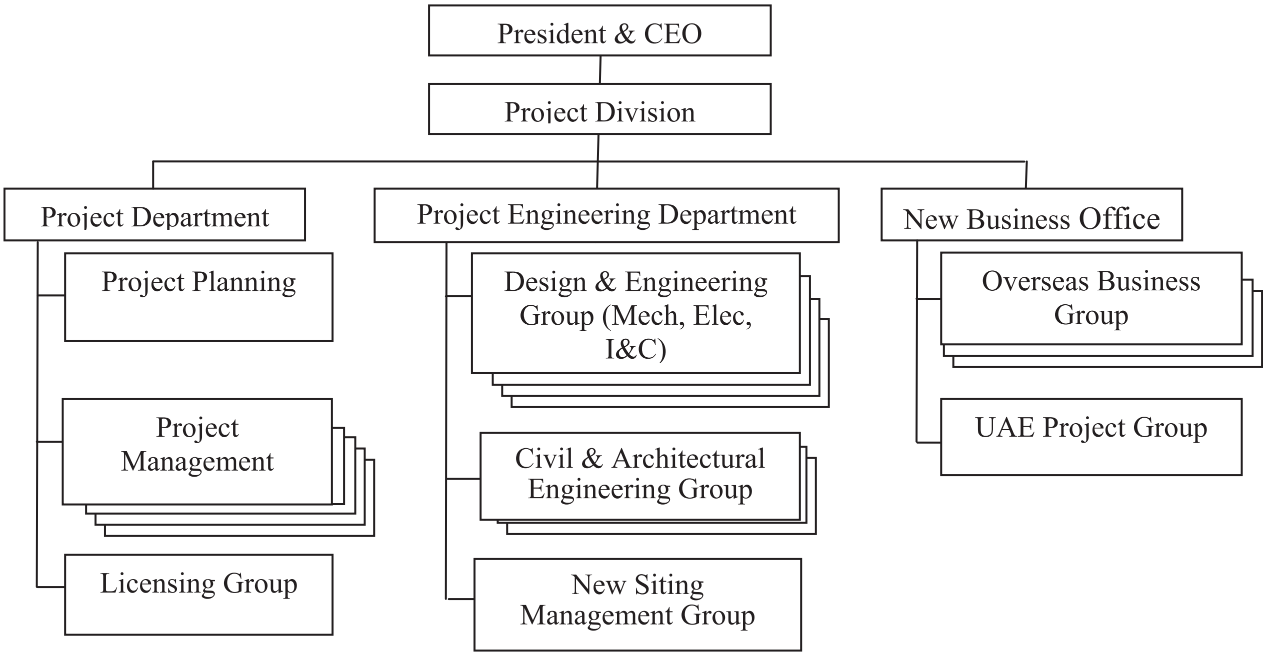

FIG. VI–1. Head office project organization.

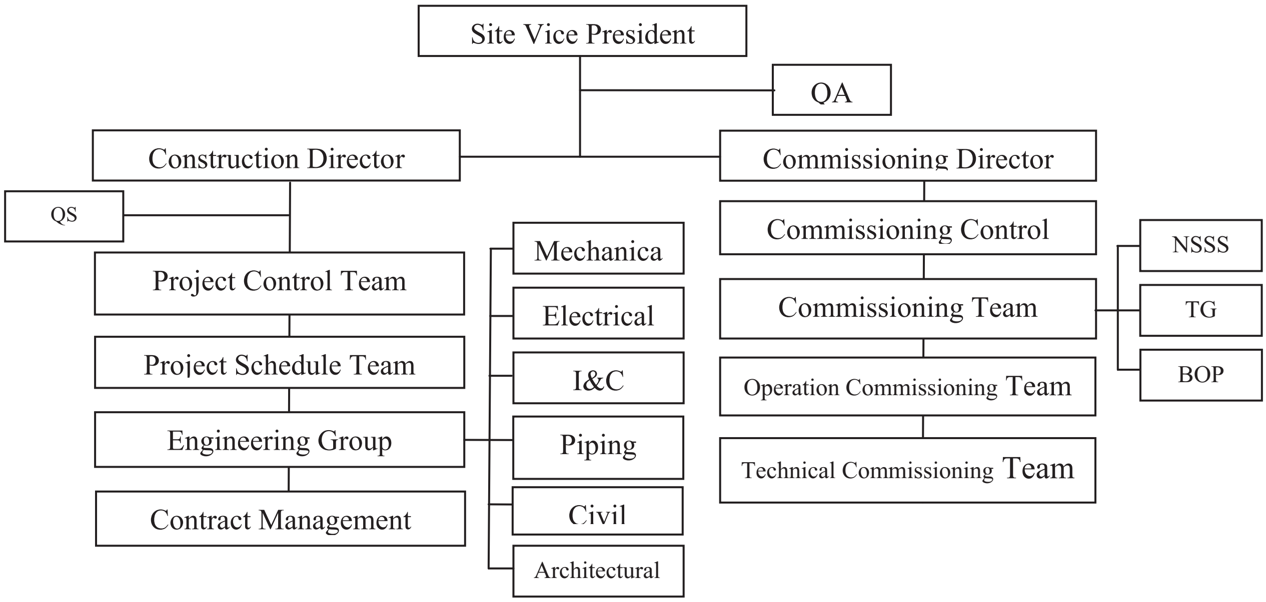

FIG. VI–2. Site project organization.

VI–2. CONSTRUCTION MANAGEMENT ISSUE

VI–2.1. Selection of local suppliers

Korea Hydro and Nuclear Power Company (KHNP) has a very competitive bidding process. KHNP applies its pre-qualification in areas such as construction experience, technical ability, financial condition and credit rating, etc. to select local suppliers for bidding. In some cases, in order to ensure the timely mobilization of labour, equipment and tooling, for maintaining a planned schedule, KHNP expedites the construction work by direct control of the required resources. See Fig VI–3.

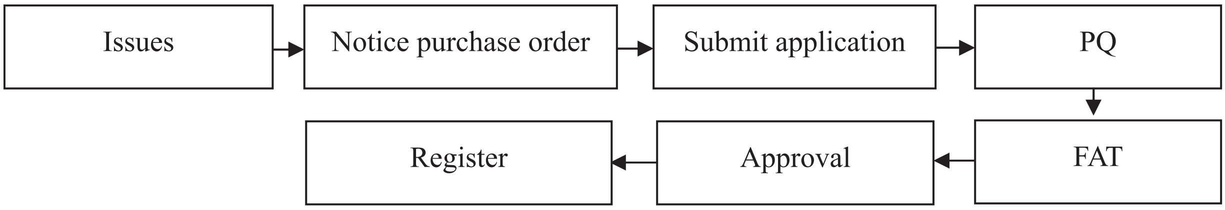

FIG. VI–3. General local supplier selection process.

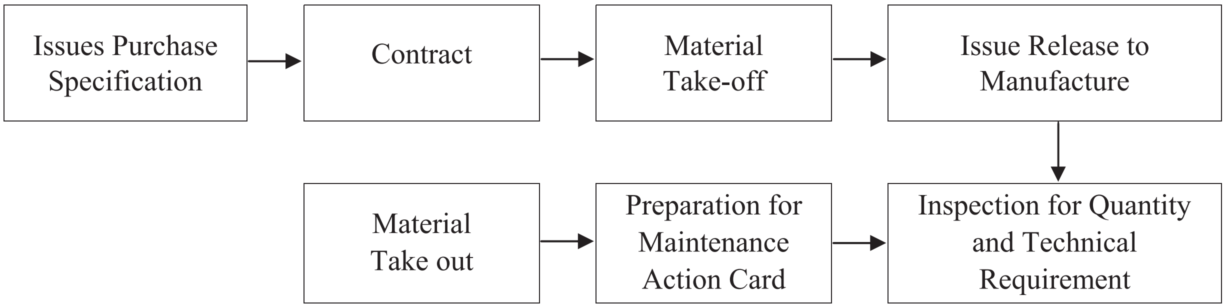

FIG. VI–4. General process for material control.

The application forms of the local suppliers are submitted to KHNP on a real time basis. The applications are verified and various reports are generated on the suppliers' ability to perform the required tasks. These reports include evaluations of areas such as technological ability, appropriate resources, quality programs, adherence to environmental requirements etc. If necessary, inspection teams survey the local suppliers in the field to gather more data. Based on the results, the successful local suppliers are registered in the KHNP supply chain vendor list, and become qualified bidders.

VI–2.2. Bulk material management

There are two classes of materials in construction: the TAG materials such as equipment, valves and instruments. These are uniquely tagged items and the BULK materials such as piping material, pipe support components, HVAC duct, cable trays, conduit, cement, etc. These are classes of equal components that can be used or installed interchangeably in several locations of the plant. See Fig. VI–4.

During the preparation stage of the construction project, the Material Assignment Schedule, including scope of supply (owner or constructor), source of shipment (local or foreign), and quality class (Q or non-Q), should be established.

Based on the Material Assignment Schedule, purchase specifications are written by KEPCO E&C and submitted to KHNP. KHNP's Project Engineering Department initiates a purchase request to the Material Department.

Bulk materials are contracted on a unit price basis according to estimated quantities. The actual quantities as per the design drawings are determined by the Architect Engineering Company. KHNP's construction site office orders the needed quantities and specifies the delivery schedule to the supplier considering the lead time (manufacturing, shipping, customs, etc.) through an RTM (Release to Manufacture) form. The materials supplied through purchase orders undergo quality inspection following delivery at the warehouse. From the warehouse they are then supplied to the construction company according to the installation schedule requirements.

As soon as the constructor receives the material from KHNP, a Maintenance Action Card for the materials is issued and checked to verify the specifications, such as power of motors, of space heaters, lubricant of rotating equipment, and protection cover for fragile items during the construction period.

For the BOP equipment, KHNP has about 400 qualified vendors. KHNP issues the procurement schedule, which contains the number of procurement packages, specification issue date, ITB issue date, the contract awarding date, and so on. The BOP equipment is grouped into 190 packages based on quality class, equipment type, etc.

KHNP has developed a computerized material management system, the Information Control System to control the materials from the contractual step to the installation step. Through the computerized information control system, KHNP manages all data including orders, receipts, inspection, supply to constructor, supply to maintenance, quality documentation and other aspects of material control. This process is especially efficient for construction materials, which are managed interactively through the material purchasing process on a just on time basis.

VI–2.3. Worker turnover/shift approach

KHNP has made every effort to maximize employment and retention of skilled engineers and workers. Projects requirements are forecast in advanced and human resources are recruited as needed. KHNP mobilizes the key construction personnel in accordance with the construction schedule. Most construction jobs aren't continuous in nature and require skilled manpower in different numbers at various times.

KHNP, as the owner of projects, runs shifts even on weekends in cooperation with the construction companies in order to expedite, supervise, and inspect the construction process during peak construction times. With regard to workers, KHNP operates shifts for construction work including night shifts or all-night shifts, if needed, in addition to the daytime shift.

KHNP is currently operating 20 nuclear units and eight units are under construction. Due to uninterrupted construction cycles, KHNP uses two major channels to optimize recruitment and continually improve efficiency. One channel conveys workers from the completed construction projects to the current construction projects. This allows the transfer of skilled construction workers to new projects with the right person in the right position at the right time. The second channel allows experience to be captured and recorded. Through technical exchange visits, and periodic meetings, with engineers from previous projects, KHNP tracks issues and problem areas and applies the solutions developed in previous projects as well as the lessons learned in previous projects to the new projects.

VI–2.4. Construction equipment

Standard construction equipment such as the crane and dump truck has not had a major impact on improving the construction process. However, special equipment such as polar cranes, construction trolleys and ringer cranes had the greatest impact on the construction process. KHNP prepared and made available to contractors all construction equipment at its sites, such as crawler cranes ahead of time so as to facilitate speedier erections.

The utility should arrange the procurement of test and measuring equipment ahead of time in order that equipment calibration can be planned in good time and contractors who require calibrated tool or equipment can be issued such items on time. Concrete test labs should also be set up in advance. Special equipment such as polar cranes, construction trolleys that are used in previous projects should also be transferred to the new project on time.

VI–2.5. Massive movement of people and material

Smooth supply of material and labour is essential to a successful completion of construction. KHNP has been able to build nuclear power plants consistently. KHNP's strong competitiveness is its human resources and high level of expertise were built over a period of 30 years of construction experience. This technical expertise includes construction labour, engineering, contractor coordination and commissioning. The high level of expertise and labour is transferred to the new construction project continually through a systematic long term construction planning. Engineers, materials and feedback of experienced human resources contribute to this high level of expertise.

New contractors who get involved through competitive bidding may not be aware of the criticality of nuclear construction requirements, such as quality, documentation, skilled labour and other specialized personnel needs. KHNP has rapidly reduced construction durations owing to the establishment of computerization in the area of piping systems, cable and cable tray runs, system turnovers and through the systematic organization of training facilitated by repetitive construction.

VI–2.6. Public perception

KHNP will achieve its corporate mission of ‘Enriching Lives with Eco-Friendly Energy’ through mid and long term management strategies and is committed to producing clean and safe electricity. Its corporate goal is to become the ‘World’s Best Power Company, Valuing People, the Environment and Technology’.

To improve public perception and achieve a win-win relationship with local communities, KHNP formed a framework of community involvement. KHNP actively engages in community services through institutional support systems, which includes voluntary medical services, promotions of culture and art, cultivation of talent including scholarship programs, of community training including engineering skill programs and revitalization of the local economy. Also deemed highly important are improvements to the local environment by initiating programmes customized to the needs of local communities.

KHNP invites local people to visit its plants frequently and remains in touch with newspaper and media with truthfulness and transparency. Through the community service groups, KHNP has been a responsible social partner by actively engaging in community service activities. There are also working subgroups funded by voluntary employee donations (the love fund) that are matched by company grants and engage monthly in community service activities. Furthermore, KHNP continuously reaches out to the socially marginalized and underprivileged in our society. See Table VI–1. Thus, public approval rating of nuclear power has been constantly improving:

TABLE VI–1. PUBLIC APPROVAL RATINGS CHANGE

Classification	NPP is necessary	NPP is safe	Support new NPP
2007 Year	82.8	51.4	43.6
2008 Year	92.5	63.4	67.5

VI–3. LESSONS LEARNED

Shin-Wolsong #1,2 are the sixth 1000 MW(e) class Optimized Power Reactor (OPR)1000 project. Since the first concrete pouring in November, 2007, the project has been going a couple of months ahead of time. Overall data on Shin-Wolsong #1 is shown in the Table VI–2:

TABLE VI–2. PROJECT DATA FOR SHIN-WOLSONG #1

Gross-output	1,055MW(e)
First Concrete	November 20, 2007
Fuel Loading(scheduled)	August, 2011
Commercial Operation(scheduled)	March, 2012
Licensee	Korea Hydro & Nuclear Power Co.
Main Contractors	Doosan/Kopec/Daewoo
Contract Type	Components Split Approach

Since Yonggwang (YGN) units 3&4, through which technology self-reliance was almost accomplished, KHNP has pursued a standardization policy. Limited changes have been incorporated into the standard design of the OPR1000 mainly those dictated by the experiences and lessons learned in previous projects. This has allowed the application of the standardization policy which has been successfully maintained through to the Shin-Wolsong 1&2 projects. Thus, KHNP succeeded in shortening the construction period by about 12 months as shown in Fig. VI–5. KHNP is now able to construct a 1000MW(e) class PWR in less than 52 months, making it possible to significantly reduce construction costs. See Fig. VI–5.

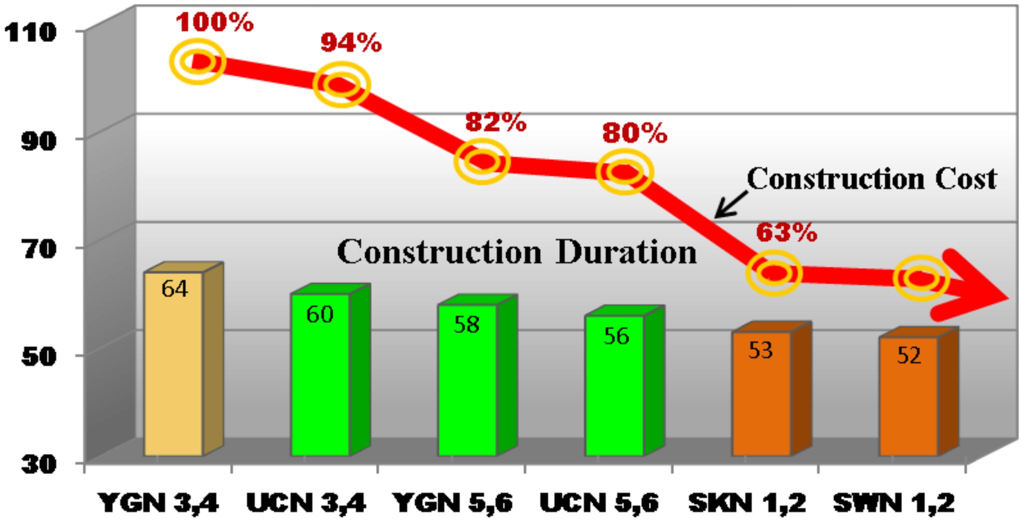

FIG VI–5. Construction cost reduction.

Annex VII

ROMANIA

Cernavoda Units 1 and 2

VII–1. BRIEF DESCRIPTION OF NPP

VII–1.1. Project history

The Cernavoda NPP Project was initiated in 1979, with the signature of an Engineering, Procurement and Technology Transfer contract with Atomic Energy of Canada Limited. Work at site started in 1981 (for Unit 1) and 1982 (for Unit 2). Two different approaches were followed for construction management, with different results in project progress. The initial ambitious programme to build the plant with the Owner assuming the overall responsibility was a political decision intended to increase local participation that proved unrealistic. Economic instability (financing and staffing problems) and lack of competent project management resulted in major project delays. As a result, new completion contracts were signed with AECL and ANSALDO in 1991 and in 2003. Unit 1 and Unit 2 were completed as delayed projects in 1996 and 2007, respectively.

VII–1.2. Project data

The site was initially designed for five 706 MW(e) CANDU 6 units (fuelled by natural uranium, and heavy water cooled and moderated).

VII–1.3. Project organization

The successful formula proved to be a joint Project Organization between the Owner and an AECL and ANSALDO Management Team. This organization included all the necessary groups to cover the responsibilities related to construction and commissioning of the units and on to the transfer to commercial operation. It included the Management Directorate, Quality Assurance, Engineering/Quality Surveillance, Construction, Planning, Scheduling and Budget Control, Finance and Accounting, Safety and Licensing, Procurement, Material Management, Training, Commissioning/Operation and Services/Logistics.

Participation of the owner personnel in the Management Team, together with the rule of appointing a local deputy for any managerial position occupied by an experienced expat from AECL or Ansaldo ensured a smooth transfer of responsibility for the operation of the plant to the owner.

VII–1.4. Contract type (company)

The approach followed in the Cernavoda Units 1 and 2 delayed project completion was basically the implementation of a Multiple Package type of contract. The responsibilities for different activities involved project management, engineering, procurement, quality assurance/quality survey, construction, installation, licensing, commissioning, etc. and was shared between the two main contractors and the Owner. Thousands of contracts were signed with manufacturers and suppliers for different types of equipment and materials (including some bulk materials) and tens of contracts, with site sub-constructors. A special case was represented by the Turbine-Generator and the Stand-by Diesel Generators (SDGs), where the installation was contracted to the equipment supplier.

VII–2. LESSONS LEARNED

VII–2.1. Project management – Preparatory phase

Experience showed that in the project preparatory phase, some key problems were not properly addressed (staff selection and training, lack of adequate social program, unrealistic attempt to increase the local supply, unsecured financing, etc.). This resulted in project delays, quality issues and extra costs.

The lessons learned on Unit 1 were applied to Unit 2. In addition to sufficient lead time for contract preparation, a lot of work related to placing the orders for the long term delivery items was completed in the preparatory phase. Also, agreements were reached with the regulator on the licensing requirements and the definition of the reference design, including the required design changes, and the applicable codes and standards.

VII–2.2. Project management – Construction phase

At the moment of the project restart, the actual condition of the available local subcontractors did not offer many possibilities for selection and imposed the need to sign many contracts with relatively small construction organizations, having limited resources and work capabilities (civil, mechanical or electrical and C&I). Therefore special actions were taken to ensure that their work would be performed on schedule, at the required quality level and within the approved budget.

The actions included a verification and acceptance of the subcontractors QA manuals, and quality plans, supervision of their work, providing technical support and performing thorough quality surveillance. When specific requirements or qualifications were met the bulk material was purchased and free-issued to the subcontractors for use according to clear instructions. Efforts were put to help with the preparation of ‘as built’ drawings, quality records and History Dockets.

The use of electronic tools for design documentation and material management helped maintain a permanent configuration control.

Design, procurement and construction work coordination was performed by regular coordination meetings, punch lists and team work.

Whenever considered necessary, contracts were signed with the equipment manufacturers (General Electric- for the turbine generator, Alstom for the Standby Diesel Generators, etc.), for technical support during installation and commissioning.

VII–2.3. Project management – Commissioning phase

The Romanian experience with the Cernavoda units shows that successful commissioning was to be based on a lot of preparatory actions performed in advance. These included the selection and training of all the commissioning and operational personnel and the preparation of the Commissioning Procedures. Implementing the ‘build clean’ concept during construction and increased pre commissioning verifications helped eliminate extensive flushing and reduce the duration of the commissioning tests. During commissioning, all the ‘nice to have’ design changes were eliminated. The full support provided by Engineering, including the timely preparation of the ‘as commissioned’ drawings, also contributed to meeting the turnover schedule.

VII–2.4. Recommendations to expanding or new comer countries

Based on the Cernavoda experience, the following recommendations are offered for new comer countries:

- Selection of the type of contract should realistically consider the actual experience and capabilities of the Owner and local participants;
- Preparation in advance for every project phase (including licensing aspects, procurement, personnel selection and training, social issues, planning, etc.) should be scheduled and completed ;
- Consider the use of advanced tools to help engineering, installation, material management, etc. from the beginning of the project.

Annex VIII

RUSSIAN FEDERATION

Reactor unit AES-2006

VIII–1. HISTORY OF THE DEVELOPMENT AND INTEGRATION OF DESIGN SOLUTIONS IN THE REPUBLIC OF RUSSIA

At the end of 2005 the management of the Federal Atomic Energy Agency (FAEA) set the objective to develop the design of a two-Unit NPP with a lead unit of enhanced safety — AES-2006, to be highly competitive in the foreign and domestic markets. The goal was to be met at the expense of achieving the world level of engineering and economic indices and safety criteria accepted by the international energy community.

With this goal in mind, the design requirements of the AES-2006 of 1100–1200 MW per unit were set to allow construction of 2–3 Units per year with commissioning of the lead Unit at the beginning of 2013 at the latest.

Following the evolutionary approach to design, the fundamental design features, the calculations and experimental verification of the V-320, V-392 reactors were used in the development of the basic design of the AES-2006 reactor unit. In addition, the whole operations feedback experience from the VVER-1000 Reactor units was also incorporated. As a result, the following technical requirements were set for the AES-2006 reactor unit:

TABLE VIII–1. TECHNICAL REQUIREMENT OF AES-2006 REACTOR.

Parameter	Value
1 Installed nominal power per Unit [MW]	1200
2 Reactor nominal thermal power [MW]	3200
3 Primary coolant pressure [Mpa]	16,2
4 Steam Generator pressure [Mpa]	7,0
5 Coolant temperature at the reactor inlet [°C]	298
6 Coolant temperature at the reactor outlet [°C]	329
7 Service life of the Reactor unit main equipment [years]	60
8 Load factor [%]	up to 90
9 Efficiency [%]	35.7
10 Fuel cycle length [year]	4–5
11 Interval of refueling [months]	12–18

The primary sites for implementation of the AES-2006 design were designated in Russia:

— Novovoronezh NPP (NVNPP-2), General Design Organization is “Atomenergoproekt” (AEP), Moscow;
— Leningrad NPP (LNPP-2), General designer is “St. Petersburg Atomenergoproekt” (SPb AEP), Saint Petersburg.

For the above sites the General Design Organization used to the maximum extent the practical experience in design solutions of “Kudankulam” NPP in India (AEP) and “Tianwan” NPP in China (SPb AEP) as those units were at a further degree of implementation.

To reach the stated goal and the maximum integration of RU equipment the list of the unified solutions on the AES-2006 Reactor unit was prepared under the guidance and the responsibility of the “Rosenergoatom” Engineering Unit in August–September 2006. The list of technical design improvements was selected and these solutions, being implemented, achieved the goal of an evolutionary development of the main components of a Reactor unit design and of its verification.

Development of the basic design of the Reactor unit for AES-2006 was started in 2006. The organizational structure of two AES-2006 designs was arranged in the following way:

Customer of NPP designs for NVNPP-2 and LNPP-2 is Operating Organization “Rosenergoatom” Concern:

- Subcontractor-1 of RU design for the NVNPP-2 site is the Organization of General designer, AEP;
- Subcontractor-2 of RU design for the LNPP-2 site is Organization of General designer, SPb AEP;
- and two organizations on the side of Subcontractors:
- Subcontractor-1 is Organization of Reactor unit General designer, OKB “GIDROPRESS”;
- Subcontractor-2 is Organization of research supervisor, RRC “Kurchatov Institute”.

The basic design of the Reactor unit was developed during 2006-2009. In the course of the development the following approach was implemented on the design documentation deriving from the principle of unification of the technical solutions for the conditions at NVNPP-2 and LNPP-2 sites:

(1) Documentation was divided into three types:
    - Generic design documents (applicable to the conditions of both the NVNPP-2, and LNPP-2 site);
    - Plant-specific documents for NVNPP-2 site;
    - Plant-specific documents for LNPP-2 site.
- RU design documentation for NVNPP-2, index V-392M, contains the whole scope of RU basic design documents, and, respectively, they can be both generic and plant-specific for the NVNPP-2 site.
- RU design documentation for LNPP-2, index V-491, contains only plant-specific documents for LNPP-2 site, the rest of documentation can be taken from V-392M as applicable.
- Identification of the site specific documents was made with the appropriate labeling and the specific letter-and-digit symbols in the code of each document:
    - 2006 – generic documents;
    - NW2O – plant-specific documents only for NVNPP-2 site;
    - LN2O – plant-specific documents only for LNPP-2 site.

In 2007 the equipment with a long-lead manufacturing cycle was already put into production according to the primary documentation. The Construction licenses for the Reactor unit and the NPP design were granted in 2008 for Units 1&2 on NVNPP-2 site and Units 1&2 on the LNPP-2 site. The basic design was completed in 2008–2009. The process of ordering and manufacturing the equipment outside the long-lead item list has been underway since 2009. At present construction activities for the AES-2006 design are being carried out at the NVNPP-2 and LNPP-2 sites. In 2009 construction started on the Baltic NPP site (similar to LNPP-2 design). At the same time work is underway on an extension to the LNPP-2 site (Units 3 & 4).

For each RU design (NVNPP-2, LNPP-2, Baltic NPP), with V-392-based common design solutions available, the Particular quality assurance programs were developed that meet the requirements of the Russian regulatory documents and of the plant specific general quality assurance programme. Quality assurance programmes take into account the specific requirements of different sites, but each program always includes the following main principles:

- A clear cut division of duties and responsibilities for the designers;
- Consistent supervision of compliance with the regulatory requirements and documentation of the findings;
- Responsibility for quality assurance on the contractor and not on the quality inspector;
- Involvement of all participants in the design process also in the management of quality and in quality assurance.

Annex IX

SLOVAKIA

IX–1. BRIEF DESCRIPTION

According to the original design, Mochovce NPP consists of 4 pressurized water VVER 440 reactors (Vodo Vodni Energeticeskij Reaktor) of the V213 Russian class. The Mochove 3, 4 units are integrated to the Mochovce 1 & 2 units and use the same auxiliary systems common to all 4 units.

MO 1and2 have been in commercial operation since 1999 and 2000 respectively.

Construction for MO3,4 started in 1986 with the civil works for the foundations of the main buildings (reactor building, longitudinal electrical building, basement of transformers, cooling towers, vent stack) and continued until 1992. In 1992 construction was suspended. From 1992 to 2000 maintenance and conservation of the suspended equipment and components and of the civil structures were carried out by the original main suppliers and constructors. From 2000 to the re-opening of the construction site, preservation and protection have been carried out by the Owner/Operator Slovenske Elektrarne (SE) on the basis of programs approved by the NRA and in compliance with the relevant IAEA guidelines.

In 2006 Enel of Italy acquired 66% of the share capital of SE by the Slovak Ministry of Economy and committed to the Government of Slovakia to complete a feasibility study concerning the completion of units 3 and 4 of the Mochovce nuclear power plant. In 2007 Enel-SE completed the Feasibility Study and prepared the Investment Memo, necessary for the project evaluation. In July 2007 Enel-SE provided Communication about the Mochovce Project to the European Union as per Article 41 of the EURATOM Treaty. Construction (Early works) at the site was re-started in November 2008. The main contracts were signed in June 2009. See Table V–1 and V–2.

IX–1.1. Project data

TABLE IX–1. MAIN PROJECT DATA

Investment costs	About 3 Billion Euro	
Construction period	Unit 3 → 50 months	Unit 4 → 58 months
First synchronization	Unit 3 → 30.12.2012	
Site construction	Site man-hours → more than 15 million	
Peak number of workers	More than 3500	

TABLE IX–2. ACTUAL STATUS OF WORKS (AUGUST 2010)

	Completed	In progress
Civil works	Seismic reinforcement of steel structures of the turbine hall and refurbishment of unit 3 turbines supports	Erection of simulator building
	Seismic reinforcement of internal steel structures of auxiliary nuclear buildings	Reinforcement of roads, corridors and slabs for the RPV transport
		Refurbishment works — steel structures and external walls of connection bridge — roof and external walls of auxiliary nuclear building — emergency generators building and cooling towers — lengthwise and cross-side electrical buildings — internal walls of vent stack — rooms in reactor building
Mechanical works	Refurbishment of the steam generators (unit 3)	Refurbishment works — bubble condensers (unit 3) — anchoring structures of steam generators (unit 3) — condensate tanks on the roof of Auxiliary Nuclear building — emergency generators
	Refurbishment of the auxiliary structures for transport of the RPV and of 250t crane in the reactor hall	

IX–1.2. Project organization

The combination of the experience of Slovenske Elektrarne in construction and operation of 6 WWER 440 units in the last 25 years with that of ENEL in the management of very large construction projects in an international context is the key to the success of the MO3,4 construction.

SE-Enel has set-up a large team with the purpose of managing the project. The team includes two parallel structures dealing with the nuclear and conventional island of the plant. The nuclear island is directly managed by SE-Enel, whereas the conventional island is managed by *Enel Ingegneria e Innovazione* through the EPCM contract. At the moment, the team counts 260 people for the nuclear island. The following figure shows the details of the organization of the nuclear island team. See Fig IX–1.

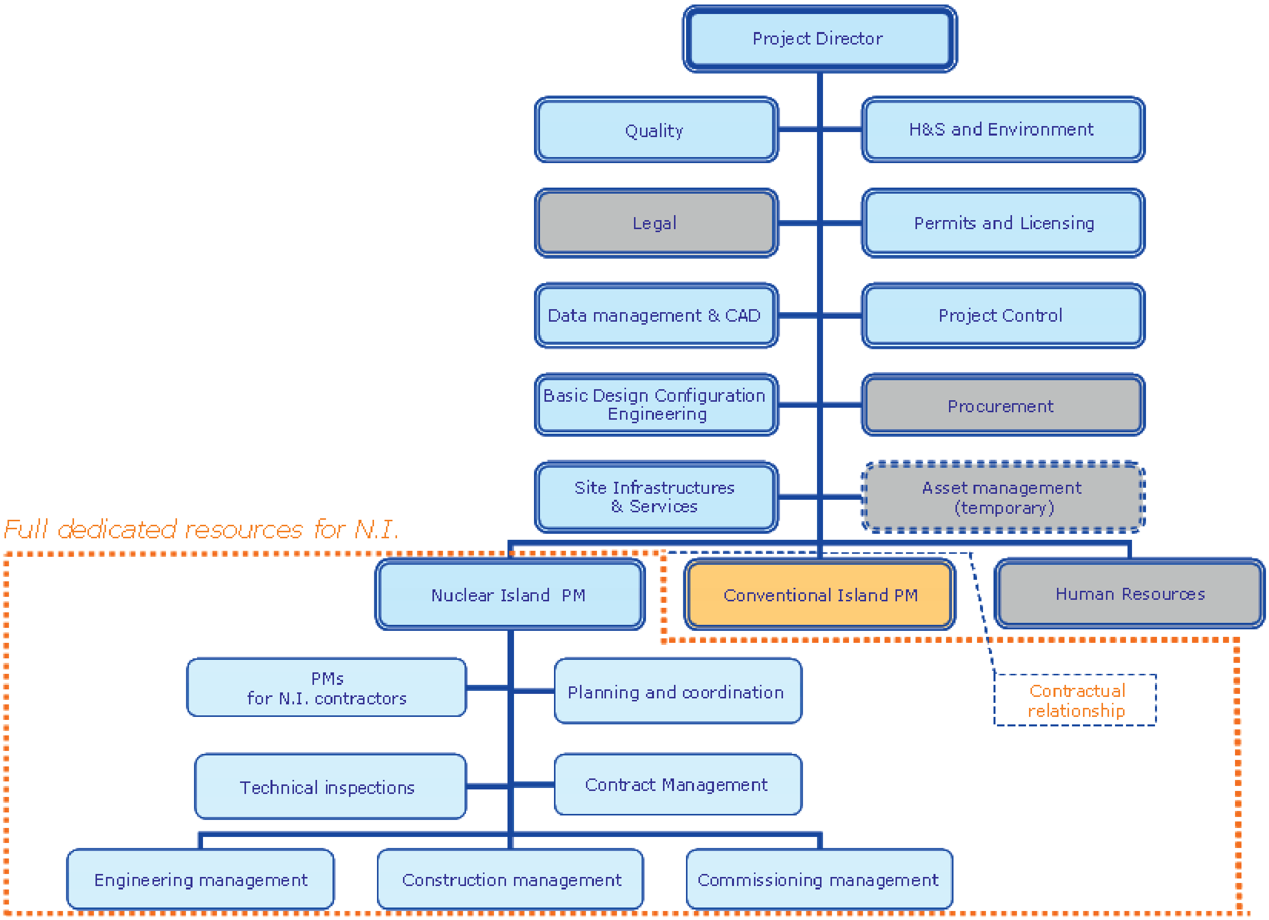

FIG. IX–1. Project organization.

IX–1.3. Contract type

The strategy chosen for the completion work of MO 3,4 was a multi-contract (more than 100 contracts), that the Owner, acting as general contractor, assigned to suppliers of engineering, procurement, construction and commissioning services.

Main advantages of this approach compared to the turnkey lump sum are:

- Better control over safety at site, over the quality of design, equipment, construction, of the schedule and of the budget;
- Optimization of the project in terms of full cycle cost analysis;
- Maximization of local content (i.e. fragmentation of the scope assured access to local companies);
- Maximization of the interaction with centralized engineering functions and operational experience (leverage on experience of a first class nuclear operator);
- Financial solidity (compared to that of any other EPC contractor available);
- Long term well established relationship with NRA and other authorities in Slovakia.

The main contractors were:

- For the Nuclear Island: Skoda JS, ASE, VUJE, Enseco, ISKE, PPA, Rolls Royce;
- For the Conventional Island: Enel (EPCM Contractor), Skoda Power, Brush, ZIPP;
- For Main Instrumentation and Control: Areva-Siemens.

See Fig IX–2 for contractor type.

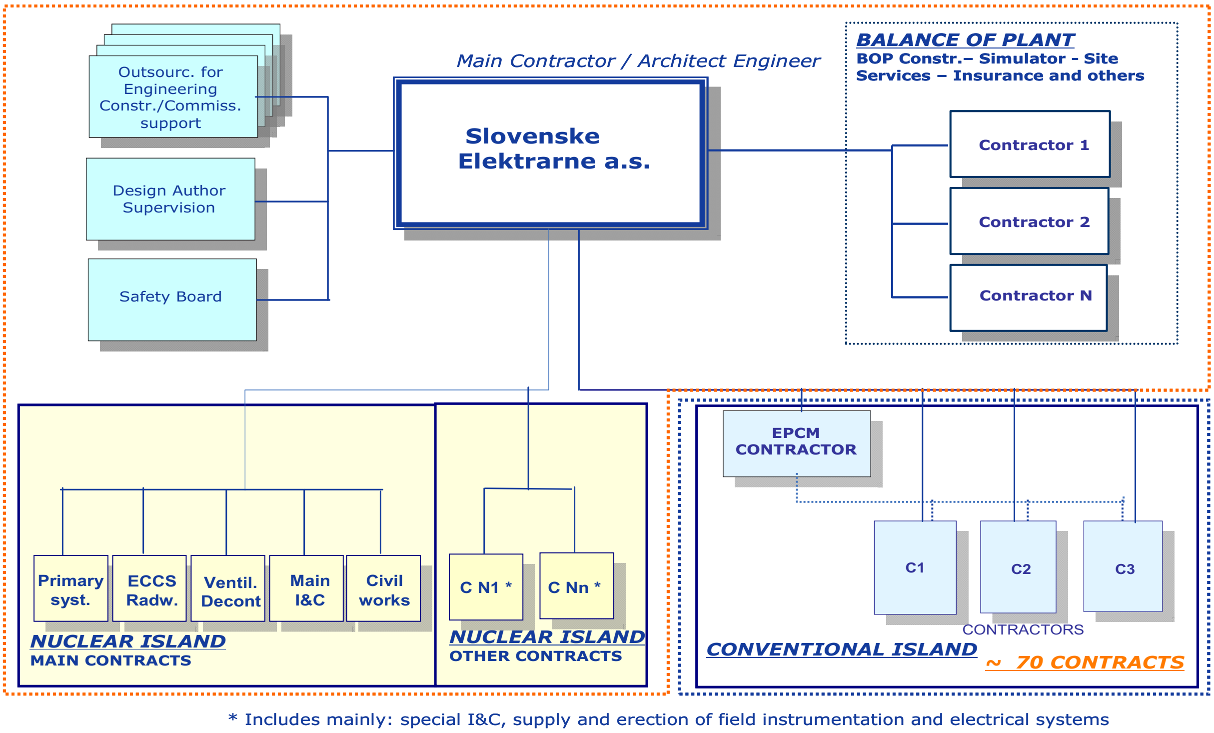

FIG. IX–2. Mochovce NPP contractor type.

IX–2. LESSONS LEARNED

IX–2.1. Project management — Preparatory phase

The feasibility study for MO 3, 4 began in January 2006 and set the basis for the re-starting activity. The purpose of the feasibility study was to define in detail all technical, financial, legal and authorization aspects of the completion of MO34 in order to provide the Utility management with all the necessary information for a final decision.

The feasibility study structure is composed of three main objects:

— Elaboration of a basic design
— Approval of design changes by NRA
— Preparatory works for tenders

In 2007 Enel-SE completed the Feasibility Study and prepared the Investment Memo, necessary for the project evaluation. In July 2007 Enel-SE provided communication about the Mochovce Project to the European Union as per Article 41 of the EURATOM Treaty. Enel-SE obtained approval of the European Commission in July 2008.

The interface with the state and regulatory bodies is managed through official channels between the MO 3, 4 project and the state and regulatory bodies — Permits and Licensing Managers (appointed by two members of the Board of Directors).

Internal directives are issued to regulate the interface with supervisory and state authorities. They contain the main principles to abide by:

— Good underlying knowledge of the legal framework of the MO34 project;
— Good underlying knowledge of the professional areas;
— Openness and willingness to communicate;
— Open mind and attitude understanding to avoid misunderstanding (troubles).

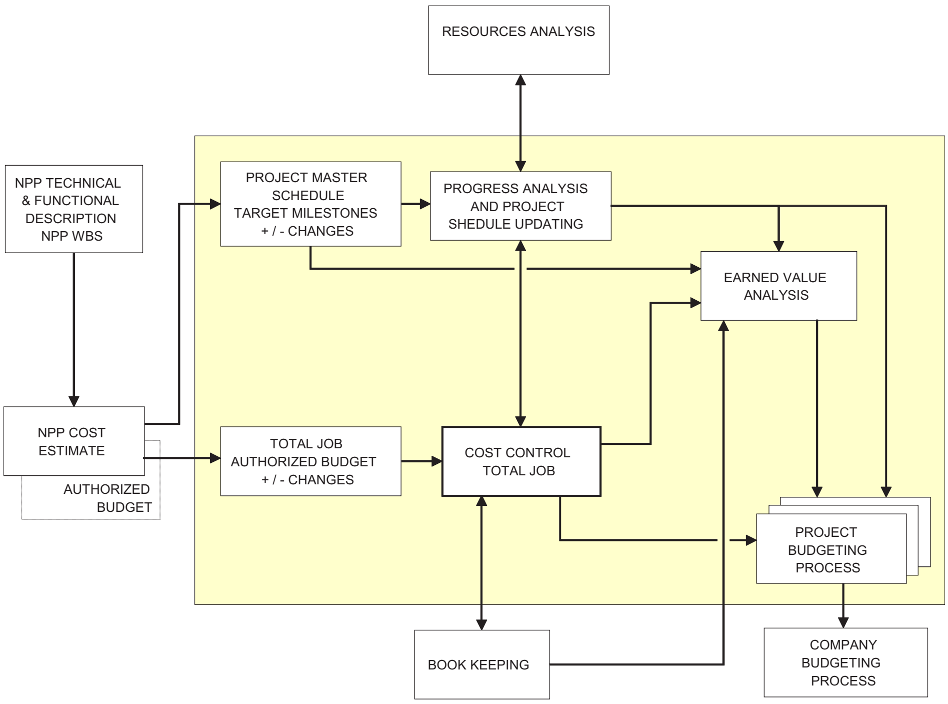

FIG. IX–3. The macro flowchart of the project planning and control.

Planning and scheduling, physical progress control, total job or period cost control, performance assessment through the "earned value analysis" method are correlated activities and are considered essential parts of the same activity '"project planning and control', although each one applies different methodologies.

The integrated project planning and control activity is not limited to verifying the degree of achievement of the project objectives, but it includes also the promotion and the implementation of suitable measures to pursue the respect of the objectives, and where possible, their improvement.

The macro flowchart of the project planning and control process is represented in the following picture. The process owner defines the distribution of responsibilities in the directives if the process involves units that are subordinated to the process owner. From the point of view of the process management, the procedure set forth in the Process Model application is binding and decisive for all employees involved in the particular processes.

The Work Breakdown Structure — WBS is the typical hierarchical tree representation of the overall Project scope and constitutes a basic reference point for the Project Planning and of the estimating phases, assuring consistency between the activities and physical items.

The WBS for each contractor scope of work originates from a unique element representing the Contractors Schedule and it is developed into lower levels, each providing a subsequent breakdown of Project scope and a more detailed description of its elements – WBE.

The project planning and control process includes:

— Project WBS definition;
— Project realization time scheduling;
— Planning and control of the project physical progress;
— Project total job costs control;
— Control and management of project changes;
— Project accounting period planning and control;
— Performance assessment through the 'earned value analysis';
— Reporting on project status.

IX–2.2. Project Management — Construction phase

Completion activities included in Mochovce NPP units 3&4 completion or related early works is performed and managed in line with the project management principles so that the implementation meets the project goals without exceeding the budget and in compliance with the construction license.

The Construction organization plan (COP) was revised in order to define the areas of the related site facilities; this revision incorporates comments from all contractors. To ensure the proper handover of the defined areas to the contractor in line with the COP revision, the handover is documented in a protocol.

Construction Management — main responsibilities

- Oversee observance of quality in accordance with the design documentation, relevant acts and regulations;
- Implement Technical Superintendent of the owner activity system;
- Handover the site/workplaces and all related areas to contractors, define requirements regarding the site management;
- offset up interfaces and coordinate completion activities;
- Manage the COP processes;
- Call completion kick-off meetings with individual contractors;
- Appoint the owner's technical superintendent for the site;
- Provide for preparation of equipment/construction and technical support for inspection and supervisory activities by the authorities;
- Provide for data collection regarding work processes, prepare monthly progress report and submit it to the project controlling manager;
- Oversee the identification process and management of non-conformities in line with valid internal procedures;
- Provide for evaluation of takeover protocols and final protocols (or MoM);
- Provide for implementation and maintenance of the monitoring system, analyzing and improvement of the completion management system (including coordination of contractors);
- Organize takeover of units 3&4 equipment to technical operation and maintenance, call and manage takeover commissions and provide for preparation of Work takeover protocols.

The main quality document which describes the quality system related to project MO34 is the quality assurance programme that complies with NRA requirements, IAEA recommendations and STN EN ISO 9001: 2009, STN EN ISO 14001: 2005 and OHSAS 18001:2008 standards. It contains:

- The description of the quality system of the license holder or the part related to a particular nuclear facility (facilities);
- Details of processes, which fall under the responsibility of the SE-MO34 Plant Director (non-centralized processes), or when details of the centralized process provided in the IMSM were not sufficient for the specific conditions of the plant;
- A complete description of the SE-MO34 management system;
- Quality assurance requirements for the completion/performance of Detailed Design of the 3rd and 4th units of Mochovce NPP;
- Quality requirements for all Safety related and to all activities influencing the quality of these items and thereby also NPP safety.

The Reference Quality Assurance (RQAP) programme states the basic requirements, principles and objectives to be applied so that the quality of the nuclear facility is upheld. Acceptance and application of these basic requirements are applied to all individuals and companies that perform actions influencing the nuclear safety during construction, commissioning, operation and decommissioning. The RQAP is valid for the responsible organization and its suppliers. The suppliers should transfer the requirements of this RQAP to their sub-suppliers.

The Sub-supplier quality assurance program (SQAP) relates to all items /equipment, systems/ important in terms of the NPP nuclear safety and to all activities influencing the quality of these items and thereby also NPP safety.

The SQAP is not directly provided to employees of contractors´ organizations. Its requirements, concerning directly the performance of safety related activities and the safety of the NPP, are transferred through the RQAP and constitute annexes to the contracts. Contractors are thereby contractually bound to respect and meet these requirements.

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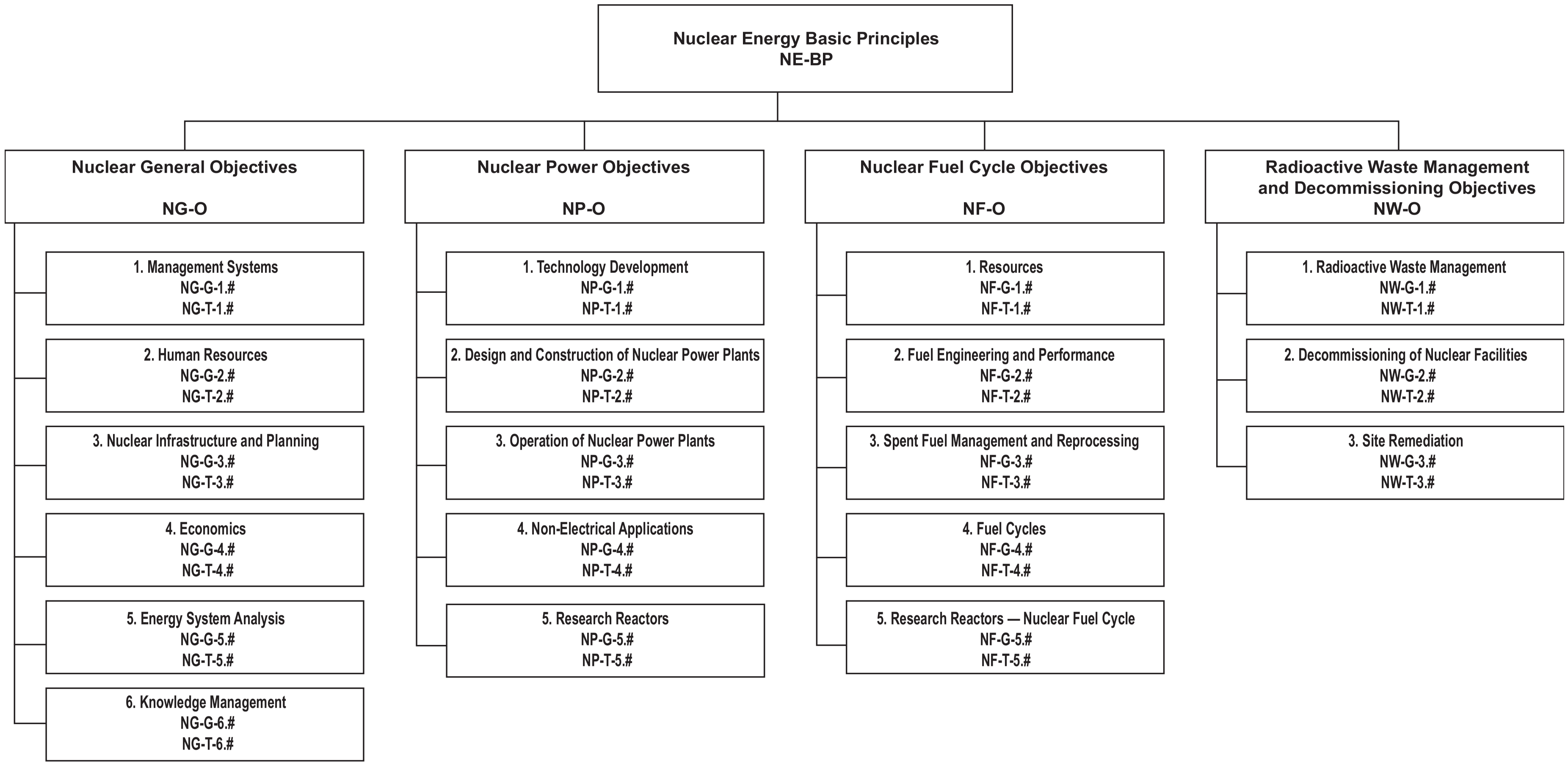

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