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Construction and commissioning experience of evolutionary water cooled nuclear power plants

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CONSTRUCTION AND COMMISSIONING EXPERIENCE OF
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FOREWORD

Over the last four decades, the worldwide growth of nuclear power generation has been significant. While in 1965 there were only 45 nuclear power plants (NPPs) in operation with a total electrical capacity of 4833 MW(e) in the world, in 2002 there were 441 NPPs with a total capacity of 358 661 MW(e). However, the rate of increase in new capacity appears to have slowed down considerably since the late 1980s.

The urgent need for sustained human development will clearly necessitate increases in the supply of energy in the coming decades. Actually nuclear power remains the only energy source that can provide electricity on a large scale with comparatively minimal impact on the environment. The long term prospects for nuclear power, however, will depend on the industry's success in addressing concerns associated with waste disposal, proliferation, safety and security, while also improving the economic competitiveness of future reactors.

In order that nuclear power remains a viable option for electricity generation, its production costs should be competitive with alternative sources. In total electricity generation costs, the capital cost of a nuclear plant is significantly higher than coal and gas fired plants and most of it is due to construction and commissioning costs.

The length of the construction and commissioning phases of a NPP has historically been much longer than for conventional plants, having often a record of delays and additional costs. Completing construction in shorter periods, through improved technology and construction methods significantly reduces the net costs incurred prior to any production of electricity.

Following the recommendations made by the IAEA Department of Nuclear Energy's Technical Working Groups on Light Water & Heavy Water Reactors, the IAEA embarked in collecting, analysing and making available to Member States, in a consistent form, recent experience and achievements in the construction and commissioning of evolutionary water cooled reactors.

This study was performed in 2002–2003 in the framework of the IAEA's Nuclear Power Programme, with the support of two consultants meetings and based on project reports provided by participants. It can serve as a useful reference for the management and execution staff within utilities, nuclear power plant operators, regulators, vendors and other organizations involved in the design, construction and commissioning of NPPs.

The IAEA wishes to express its gratitude to all experts who participated in the drafting and reviewing of the publication and to all those contributing with information on recent NPP construction and commissioning experience and achievements. The IAEA officer responsible for this publication was M. Condu of the Division of Nuclear Power.

EDITORIAL NOTE

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CONTENTS

CHAPTER 1. INTRODUCTION

1.1. Background

Electricity market liberalization is an established fact in several countries and there is a trend to adopt it in other countries. The essential aim of market liberalization is to improve the overall economic efficiency. In order that nuclear power remains a viable option for electricity generation, its costs should be competitive with alternative sources while, at the same time, it should have a safe and reliable operation record.

The capital cost of nuclear power plants (NPPs) generally accounts for 43–70% of the total nuclear electricity generation costs, compared to 26–48% for coal plants and 13–32% for gas plants [1]. Most of these expenditures are incurred during the construction phase of a NPP.

The achievement of shorter construction periods using improved technology and construction methods has a significant benefit on the costs incurred prior to any production of electricity.

1.2. Definitions

Nuclear project implementation extends at both ends to cover all relevant activities from signature of the contract, start of site preparation, erection of the plant till the end of turnover of the completed and commissioned NPP to the operating organization. In order to facilitate the discussion on the construction and commissioning of evolutionary water cooled reactors, it is convenient to separate the construction and commissioning aspects. These two are clearly linked and even somewhat overlapping. For clarity, the following working definitions are used in the document:

- Construction: The IAEA Nuclear Safety Standards (NUSS) programme defines construction as "the process of manufacturing and assembling the components of a nuclear power plant, the erection of civil works and structures, the installation of components and equipment, and the performance of associated tests".
- Construction period: Usually the construction period is considered to be the interval between the first major pour of concrete for the plant main building and the commercial operation date.
- Commissioning: The process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent.
- Commissioning period: This period is included in the construction period as defined above.
- Evolutionary design: An advanced design that achieves improvements over an existing design through small to moderate modifications, with a strong emphasis on maintaining design provability to minimize technological risks [2].

1.3. Objectives and scope

1.3.1. Objective

This document is intended to make the recent worldwide experience on construction and commissioning of evolutionary water cooled NPPs available to Member States and especially to those with nuclear power plants under construction/planning, and to those seriously considering nuclear power projects in the future. The final aim is to assist utilities and other organizations in Member States to improve the construction of nuclear power plants and achieve shortened schedules and reduced costs without compromising quality and safety.

1.3.2. Scope

While construction, in general, includes also manufacturing of components, this document considers mainly activities at site and only a general consideration is given to construction activities at the manufacturers. Experience on detailed manufacturing activities is not reviewed, the main focus being on site construction. Throughout the document the terms "construction" and "site construction" are used alternately, but with the same meaning.

This document aims to provide an overview of the most advanced technologies, methods and processes used in construction and commissioning of recent nuclear projects. To better achieve this objective the presentation is selectively focused more on the new developments rather than providing a full review of all issues related to construction and commissioning.

1.4. Target audience

The experience described in this TECDOC applies to managers, engineers, supervisors, technicians and workers in various organizations dealing with the site construction and commissioning of nuclear power plants, such as utilities, designers, vendors, suppliers, architect-engineers, construction contractors, plant operators and nuclear safety regulators.

1.5. Working method

The objectives of this study were briefly laid out by the IAEA's Department of Nuclear Energy's Technical Working Groups (TWGs) on LWRs and HWRs. These TWGs recommended to collect, analyse and make available to Member States the experience available on construction and commissioning of evolutionary water cooled reactors. IAEA invited experts from utilities and vendors involved in construction and commissioning of these types of plants to provide advice to the IAEA on the approach and details to implement the TWGs' recommendations. In a consultants meeting, held in October 2002 the objectives were detailed and there were prepared a list of relevant projects and a list of topics for which information would be requested from the main actors running those projects.

The information was provided during January–March 2003 on the following projects:

- Qinshan III Units 1 & 2 (Peoples' Republic of China) by Third Qinshan Nuclear Power Company (TQNPC) and Atomic Energy of Canada Limited (AECL).

- Kashiwazaki-Kariwa Units 6 & 7 (Japan) by Tokyo Electric Power Company (TEPCO) and Hitachi.

- Lingao Units 1& 2 (Peoples' Republic of China) by Lingao Nuclear Power Company (LANPC).
- Yonggwang Units 5 & 6 (Republic of Korea) by Korea Hydro & Nuclear Power Company (KHNP).
- Tarapur Units 3 & 4 (India) by Nuclear Power Corporation of India Limited (NPCIL).

NPP type, rated power and the main milestones for each of the above projects are shown in Tables 1 to 5.

Table 1.1. Qinshan III Units 1 & 2

	U1	U2
Reactor type	PHWR	
Power output-gross	728 MW(e)	
Contract Effective Date (CED)[1]	12 February 1997	
First concrete	8 June 1998	25 September 1998
Commercial Operation Date (COD)	5 January 2003	24 July 2003

Table 1.2. Kashiwazaki-Kariwa Units 6 & 7

	U6	U7
Reactor type	ABWR	
Power output-gross	1356 MW(e)	
CED	17 July 1991	
First concrete	3 November 1992	1 July 1993
COD	7 November 1996	2 July 1997

Table 1.3. Lingao Units 1& 2

	U1	U2
Reactor type	PWR	
Power output-gross	990 MW(e)	
CED	15 January 1996	
First concrete	15 May 1997	28 November 1997
COD	28 May 2002	8 January 2003

Table 1.4. Yonggwang Units 5 & 6

	U5	U6
Reactor type	PWR	
Power output-gross	1000 MW(e)	
CED	March 1995	
First concrete	29 June 1997	20 November 1997
COD	21 May 2002	24 December 2002

[1] CED is the date the contract enters into force, which might be different from the date the contract is signed.

Table 1.5. Tarapur Units 3 & 4

	U1	U2
Reactor type	PHWR	
Power output – gross	540 MW(e)	
CED	03 December 1997	
First concrete	08 March 2000	12 May 2000
COD	30 June 2005 (Planned)	31 December 2005 (Planned)

Note: Throughout the document the projects will be referred to as: Qinshan, Kashiwazaki-Kariwa, Lingao, Yonggwang and Tarapur.

Although the information provided was extensive on most topics, it varies in the degree of detail and coverage. It should be noted also that while all projects considered have water cooled reactors, neither the main technical features nor the specific circumstances of the projects are comparable. Therefore, the information presented in this report should be considered generic and under no circumstances should be used as a basis for comparison between vendors/utilities, countries and projects.

1.6. Structure of the report

The report is divided into eight chapters. The chapters are arranged, to the extent possible, in the chronological sequence of the activities during nuclear power plant construction.

To facilitate the readers' understanding, for each of the construction and commissioning activities reviewed, the document presents: background information, a brief description of the scope & generic good practices and specific examples selected from the collected data[2].

Because of the different context and environment for each of the discussed projects, creating a specific framework for construction and commissioning, the first two chapters describe project specific information and regulatory context to allow a better overview of the experience shared in this document.

The topics covered by the subsequent chapters are listed below:

Chapter 2 describes specific information for the reviewed projects, such as contract type, project organization and responsibilities, etc.

Chapter 3 highlights the licensing and regulatory issues and the way they were dealt with in the respective projects.

Chapter 4 addresses quality assurance as a management system, responsibility for quality and a performance based quality assurance approach with examples from the analysed projects.

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[2] The generic good practices were developed, to a certain extent, drawing on the IAEA's working document "Good Practices for NPP Construction", drafted in the late 1990s.

Chapter 5 presents a review on the latest improvements of the technologies, methods and processes used in the construction of evolutionary water cooled reactors, resulting in cost and schedule reductions.

Chapter 6 describes the methods and approaches used to reduce the commissioning period used in the reviewed projects.

Chapter 7 highlights the feedback from the implementation of these projects to be considered for future projects to further reduce schedule.

Chapter 8 presents the conclusions of the review.

The Annex presents some of the resources involved in the analysed projects.

CHAPTER 2. PROJECT SPECIFIC INFORMATION

Project specific information and regulatory issues (Chapter 3) are reviewed and analysed essentially from the viewpoint of the framework they create for the management and implementation of a nuclear power project. In this connection, contract types, project organization, main actors, their scope of supply, interfaces and licensing and regulatory issues are detailed as necessary to describe the specific circumstances for each of the reviewed projects. These aspects give a broad overview on the projects and allow a better understanding of the methods and features to complete the work on (or even before) schedule and within the budget in the overall context of the project.

The type of contracts may influence all aspects of the project implementation, from siting, design, construction and commissioning to commercial operation. In practice, the following are the main contract types:

- Turnkey contract (plant approach)
- Split-package contract (island approach)
- Multi-package contract (component approach).

At one end of the strategy spectrum is the turnkey contract approach where a main contractor is responsible for design, construction and commissioning of the whole project and in charge of the project management. The bulk of the capital cost as well as the risk of the project is placed with the main contractor.

In the split-package contract approach, two major contract packages for nuclear and conventional islands are defined. There could also be separate contracts for the balance of plant (BOP), civil works and fuel supply. Usually, an architect engineer is contracted to manage the project and to perform services in engineering, procurement, construction and commissioning together with the plant owner. The portions shared by the architect engineer depend on the plant owner's experience and capabilities.

At the other end is the multi-package contract approach, potentially with several hundred contracts. In this case, the plant owner takes the major responsibility and risk associated with the project implementation. This approach may provide the best chance for the plant owner to optimise the scope of each contract, to balance costs against risks and to maximize the participation of the national industry in the project. However, the plant owner should clearly define the respective responsibility and level of authority of each contractor and carefully control all organizational interfaces.

Selecting an appropriate type of contract is one of the most important decisions made by the plant owner before project implementation. Major contractual arrangements should allow for a balanced distribution of risks between the owner and the contractors. Nevertheless, the responsibilities of the contractors are always limited — consistent with their obligations in the contractual clauses. The plant owner shall retain the ultimate legal responsibility for plant safety, reliability and technical performance and, therefore, shall take an active part in the project management. The owner’s organization should assume activities in accordance with its preparedness (staff qualification, experience, know-how, etc), and contract out the balance of activities to experienced vendors and architect/engineer companies.

Out of five projects reviewed, one was built under a turnkey contract (Qinshan), two under split-package approach (Kashiwazaki-Kariwa and Lingao) and two under a multi-package contract (Yonggwang and Tarapur). Specific information including scope of supply, overall project organization and main participants is presented below for each of the reviewed projects:

2.1. Qinshan

In the framework of a turnkey contract, the vendor (AECL) was the main contractor and overall project manager for the owner (TQNPC), working with international project participants. The overall structure of the project and the site organization are shown in Figures 2.1 and 2.2. Specific for this turnkey type contract was the important direct scope the owner had.

- *Owner*: Site preparation; provision of permanent site facilities (offices, warehouse, etc.) and of local staff to the Site Project Management Organization (SPMO); management of the BOP construction; execution of commissioning; management of licensing; provision of Quality Surveillance[3] (QS) of Nuclear Steam Plant (NSP) and BOP off-shore equipment during manufacturing; provision of additional site QS of NSP construction through an independent QS company; and provision of the first fuel load and initial heavy water fill.

- *Main contractor*: Design and supply of the NSP; management of NSP construction; and provision of guidance and direction to the owner for commissioning. As overall project manager, the main contractor subcontracted site project management & overall commissioning management, NSP equipment procurement and design of the Balance of Nuclear Steam Plant (BNSP). Also, the main contractor subcontracted the training of owner’s plant management, operations and maintenance staff.

- *Bechtel/Hitachi Consortium*: Design and supply of the BOP and provision of technical assistance to TQNPC for BOP construction management, as a subcontractor to AECL.

- *Chinese construction contractors*: performance of the construction work as subcontractors to AECL for NSP and as subcontractors to TQNPC for BOP.

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[3] Quality surveillance: the act of monitoring or observing to verify whether an item or activity conforms to specific requirements (IAEA-TRS-317, 1990)

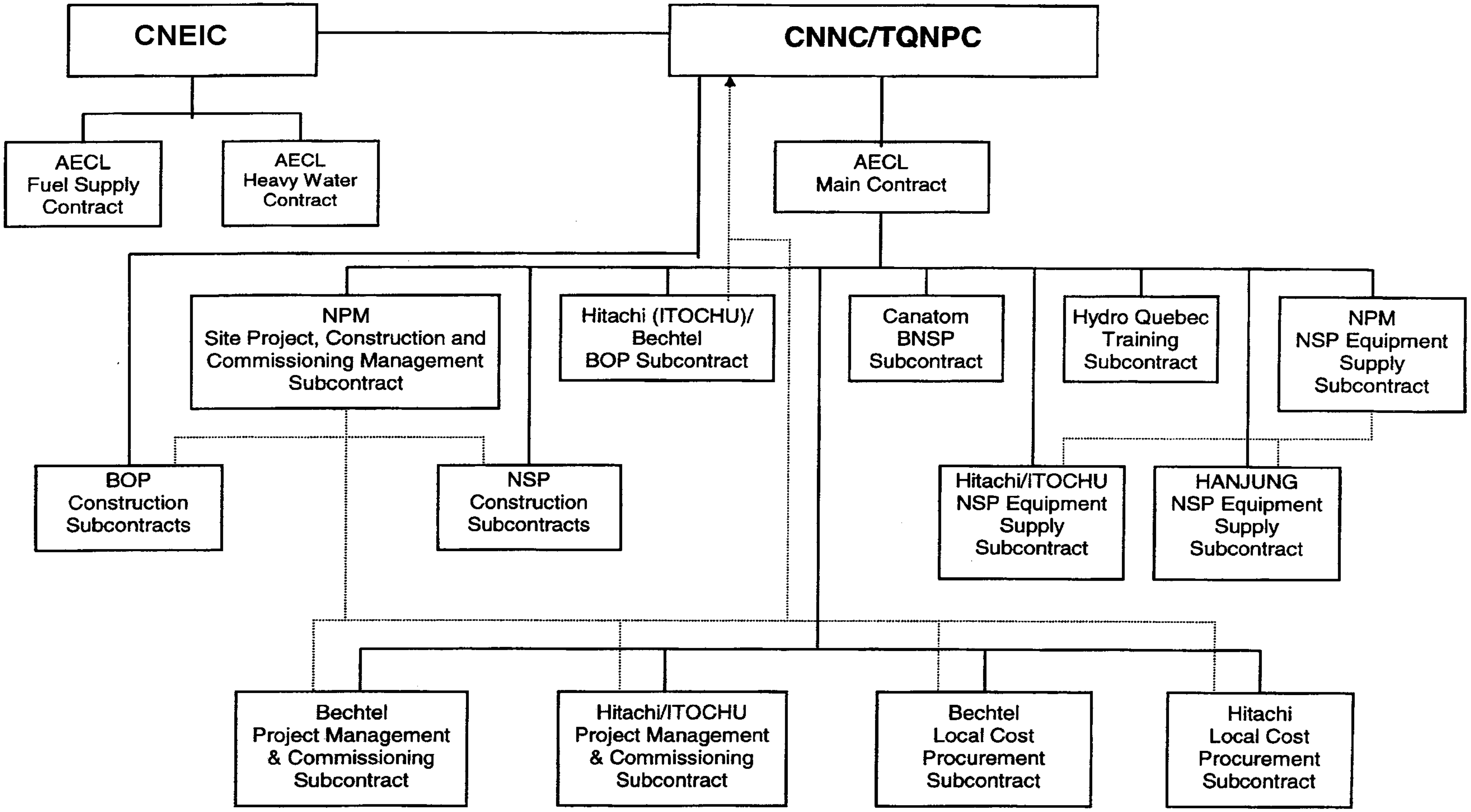


Fig. 2.1. Overall organization of the project and scope of supply (Qinshan).

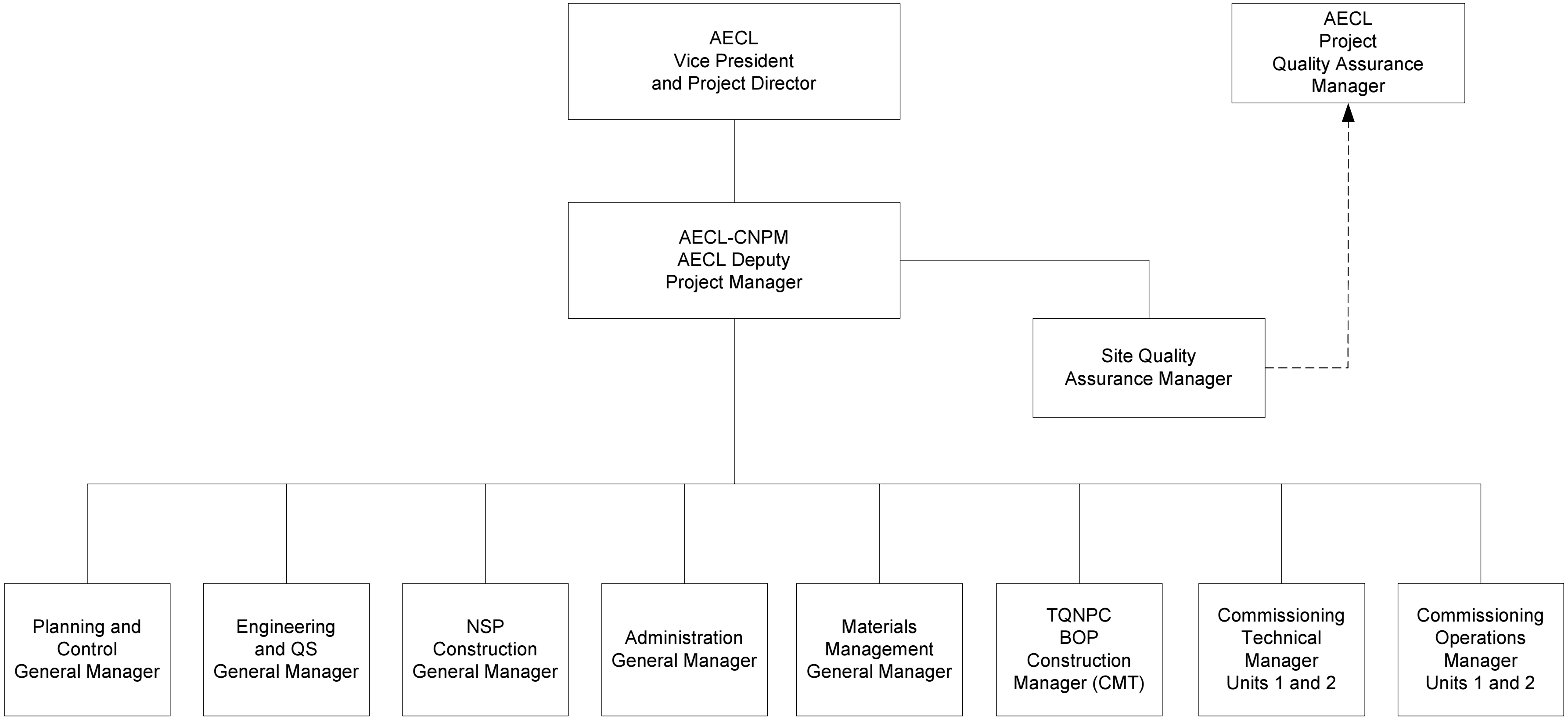


Fig. 2.2. Site project management organization (Qinshan).

2.2. Kashiwazaki-Kariwa

The owner (TEPCO) assumed the overall management of the project for both units in a split package contract approach. The main design and construction work was carried out by a joint venture of manufacturers (Toshiba, Hitachi and General Electric). The civil work was done by a joint venture of civil construction companies (Kajima, Hazama, Shimizu, Takenaka and Maeda). Radioactive waste treatment was assigned to a manufacturer joint venture (Toshiba, Hitachi).

- *Owner*: Overall project management; commissioning of the plant with support from suppliers, radioactive waste treatment system, light oil tanks, etc.

- *Main contractors*: Design, supply and installation (mechanical, electrical and I&C) of nuclear and conventional islands.

- *Site contractors*: Civil work.

The organization of the project and the scope of supply are graphically summarized in Fig. 2.3.

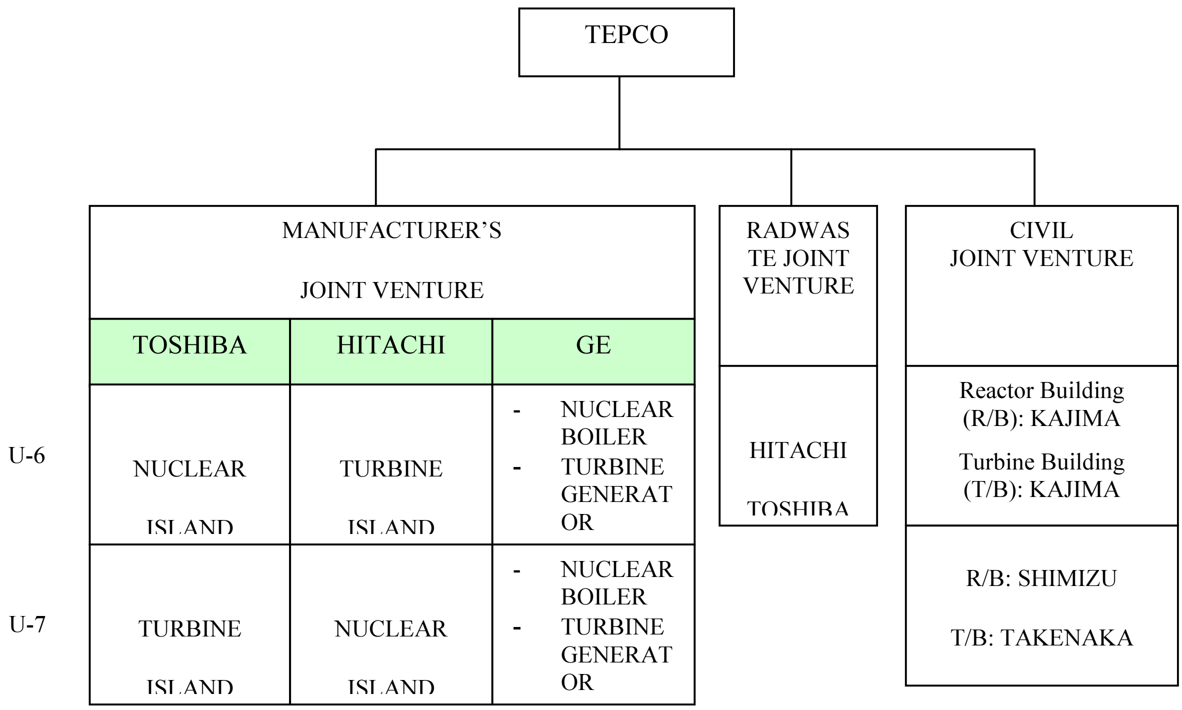


Fig. 2.3. Project organization and scope of supply (Kashiwazaki-Kariwa).

Table 2.1. Principal separate contracts (Kashiwazaki-Kariwa)

Main construction work	Company contracted	Remarks
Common radwaste treatment facility	Toshiba/Hitachi	Including installation work
Continuous condenser cleaning system	Taprogge	Including installation work
Auxiliary boiler	Hitachi	Including installation work
Condenser cooling tube	Kobe Steel, Sumitomo Light Metal Industries, Tiemet (U.S.A.)	Excluding installation work
Turbine overhead crane	Ube Industries	Including installation work
Building overhead crane for circulation water	IHI	Including installation work
Light oil storage tanks	Ishii Iron Works	Including installation work
Laundry facility extension	Tokyo Sensen Kikai	Including installation work
Main transformer	Toshiba/Hitachi	Including installation work
Switchyard construction work	Toshiba	Including installation work

Separate contracts were concluded for those equipment/works with fewer interfaces with the main equipment work and for which a competitive market existed (see Table 2.1).

2.3. Lingao

The owner, LANPC, carried out the overall management for each of the units in a split-packages contract framework: Nuclear Island (NI) and Conventional Island (CI) were supplied by foreign vendors (FRAMATOME and ALSTOM), with the participation of local designers (BINE and GEDI) in the design of civil parts and BOP was supplied by local companies. The construction for all three islands was carried out by Chinese companies except for the primary loop, which was performed by FRAMATOME.

- *Owner*: Overall project management, management of BOP and commissioning of the plant.

- *Main contractors*: Design and supply of NI and CI. Installation of the primary loop in the NI.

- *Local contractors*: Design of BOP; participation in the design of NI & CI; civil, mechanical (except the primary loop), electrical and I&C installation work.

The overall project structure, scope of supply and responsibilities are presented in Fig. 2.4.

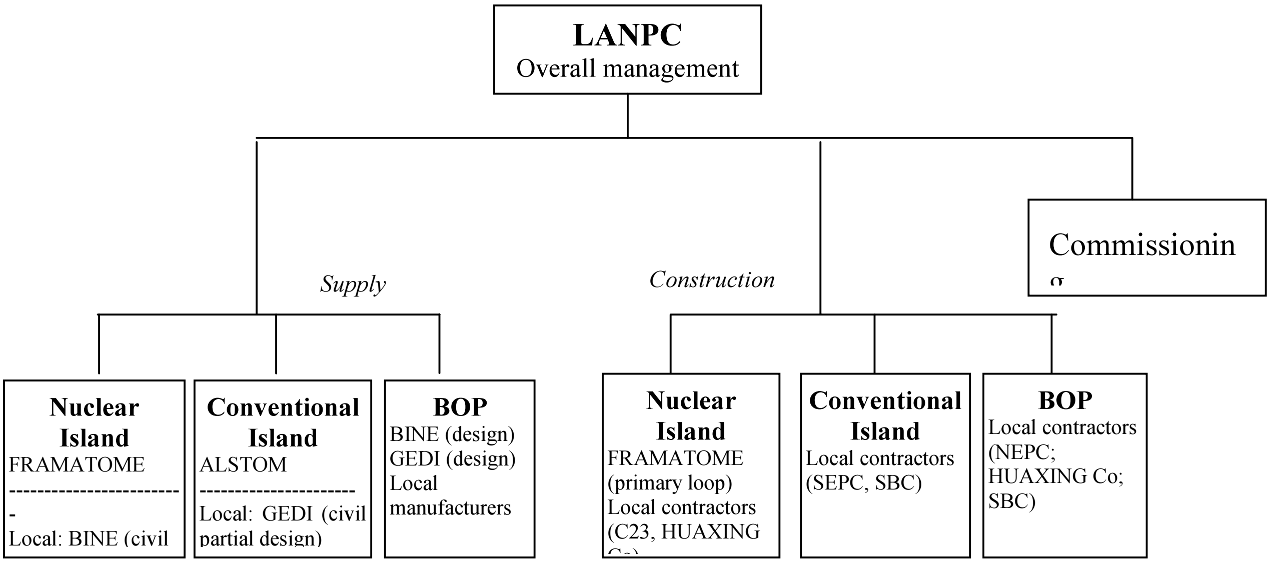


Fig. 2.4. Project organization and scope of supply (Lingao).

2.4. Yonggwang

The owner (KHNP) selected a multi package contractual approach and managed 6 major contracts (Nuclear Steam Supply System (NSSS), Turbo Generator (T/G), nuclear fuel, BOP, construction and non-destructive examination) with the support of an Architect-Engineer (A/E) - KOPEC.

- *Owner*: Procurement, construction management, commissioning and overall project management. Review and approval of drawings, specifications, manuals, other technical documents and provision of engineering and design criteria as required to properly completing the project work. Provision of inputs to the Safety Analysis Report (SAR) as outlined in the contract.

    - *KHNP Overseas Offices (Paris, New York)*: Expediting and transportation arrangements for the NSSS, T/G & BOP overseas procurement; quality surveillance of overseas suppliers; assistance and management of overseas trainees; other services as needed.

- *Main contractors*:

    - **Architect-Engineer**: Project management and engineering management support; owner's personnel training; support services to owner on procurement, construction & commissioning; and other related activities.

    - **NSSS supplier**: System & component design; equipment supply; provision of raw material specimens for LBB (Leak Before Break) analysis and other services (technical support, licensing and training).

    - **T/G supplier**: Equipment supply including: design, engineering & related information; tests; services; training for KHNP's personnel; and spare parts.

- **Fuel supplier**: Supply of the initial core fuel & related services (engineering, design, supply of the fuel and technical support services).

- **BOP suppliers**: Design, fabrication, inspection, testing, and delivery of BOP items.

- **Construction contractors**: Civil/architectural work, piping and cabling work, installation and erection of mechanical and electrical equipment, switchyard and other yard facilities, and commissioning support within their scope of work.

- **Non-destructive examination contractor**: establishment and operation of a field laboratory for NDE at the site, NDE evaluation and reporting to the owner.

The organization of the project and the scope of supply are graphically summarized in Fig. 2.5.

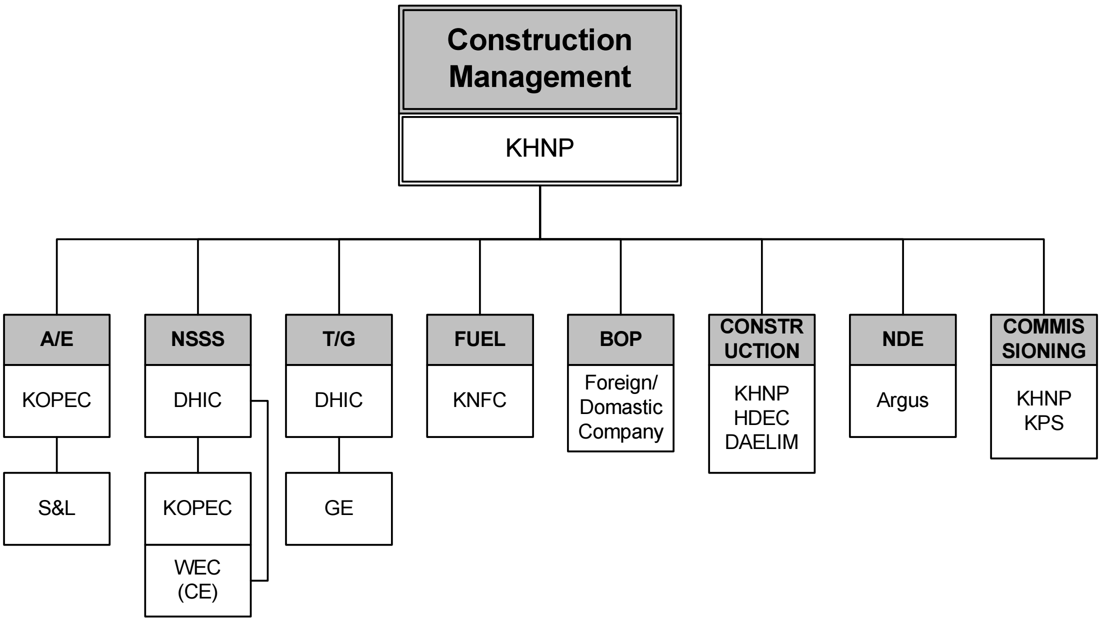


Fig. 2.5. Project organization and scope of supply (Yonggwang).

2.5. Tarapur

The owner, NPCIL, followed a multi-package contract approach for construction. There are 40 different types of EPC (Engineering Procurement Construction)/Procurement construction packages and about 100 major supply packages.

- *Owner* (NPCIL)

  - Provision of design support for nuclear systems

  - Procurement of the critical components like end shield, calandria, coolant channel components, steam generator, fuelling machine, primary coolant pump-motors, etc.

- Provision of construction management, commissioning and overall project management by the NPCIL's Site Project Management Team (SPMT). This includes review and approval of drawings, specifications, QA manuals and other technical documents. It provides design clarification / modifications as required to properly complete the project work. SPMT enforces QA through audits on quality system of package contractors.

- Preparation of all inputs for SAR.

- Acquisition of land.

- Provision of access roads.

- Provision of construction water supply (2.5 millions litres per day).

- Provision of construction power supply (33kv, 3 MVA).

- Provision of warehouses (for supply package only).

- Provision of land for package contractors for: offices, equipment storage, fabrication shop, labour camp, etc. Provision of educational facility to the children of major contractors on limited basis.

- Provision of training & qualification in important fields.

- Provision of safety coverage and training to contractors' employees.

- Provision of fire-fighting services.

- First aid centre (emergency medical facility).

- Provision of field supervision and overall QA coverage.

- Provision of design clarifications & resolution of interface hindrances.

• *Contractors*:

  - Establishment of labour camp.

  - Establishment of storage facilities.

  - Establishment of workshops.

  - Mobilization of equipment.

  - Pre-qualification of vendors.

  - Preparation of QA manuals, construction manual & procedures.

  - Training & qualification.

  - Maintenance of high degree of cleanliness and safety standards. Planning, scheduling and execution of works as per construction drawings and specifications.

- Provision of quality control and work inspection.
- Internal quality audits and self-assessment.
- Up keep of the records.
- Submission of monthly invoices.
- Commissioning of equipment.
- Testing of systems & circuits.
- Submission of as built drawings.
- Submission of construction completion documents.

The Tarapur project overall organization and scope of supply is shown in Figure 2.6.

2.6. Specific local environment

All 5 analysed projects are implemented either on multi-unit sites with an early built NPP in operation, or in the proximity of similar NPPs. To a certain extent, all of them took benefit of existing local infrastructures, previous experience, and, to a certain extent, of the know-how from the construction and commissioning of earlier projects:

- Qinshan III: This is the first Candu plant being built in China. It has in its proximity Qinshan phases I and II, both PWR type NPPs. The works at Qinshan II begun about one year before Qinshan III.
- Kashiwazaki-Kariwa: Already operating units at the site are of similar type (BWR).
- Lingao: This NPP is situated nearby Daya Bay NPP, having the same type and size PWR.
- Yonggwang: Previous units, in operation at the same site, are of similar PWR type.
- Tarapur: This plant is near the Tarapur Atomic Power Station (TAPS), a BWR type NPP, which has been under operation for the last 35 years. Initially Tarapur utilized the infrastructure created for TAPS. Also, the available experience and know-how from the construction and commissioning of earlier PHWR type nuclear power projects in India were made available by posting people from these projects.

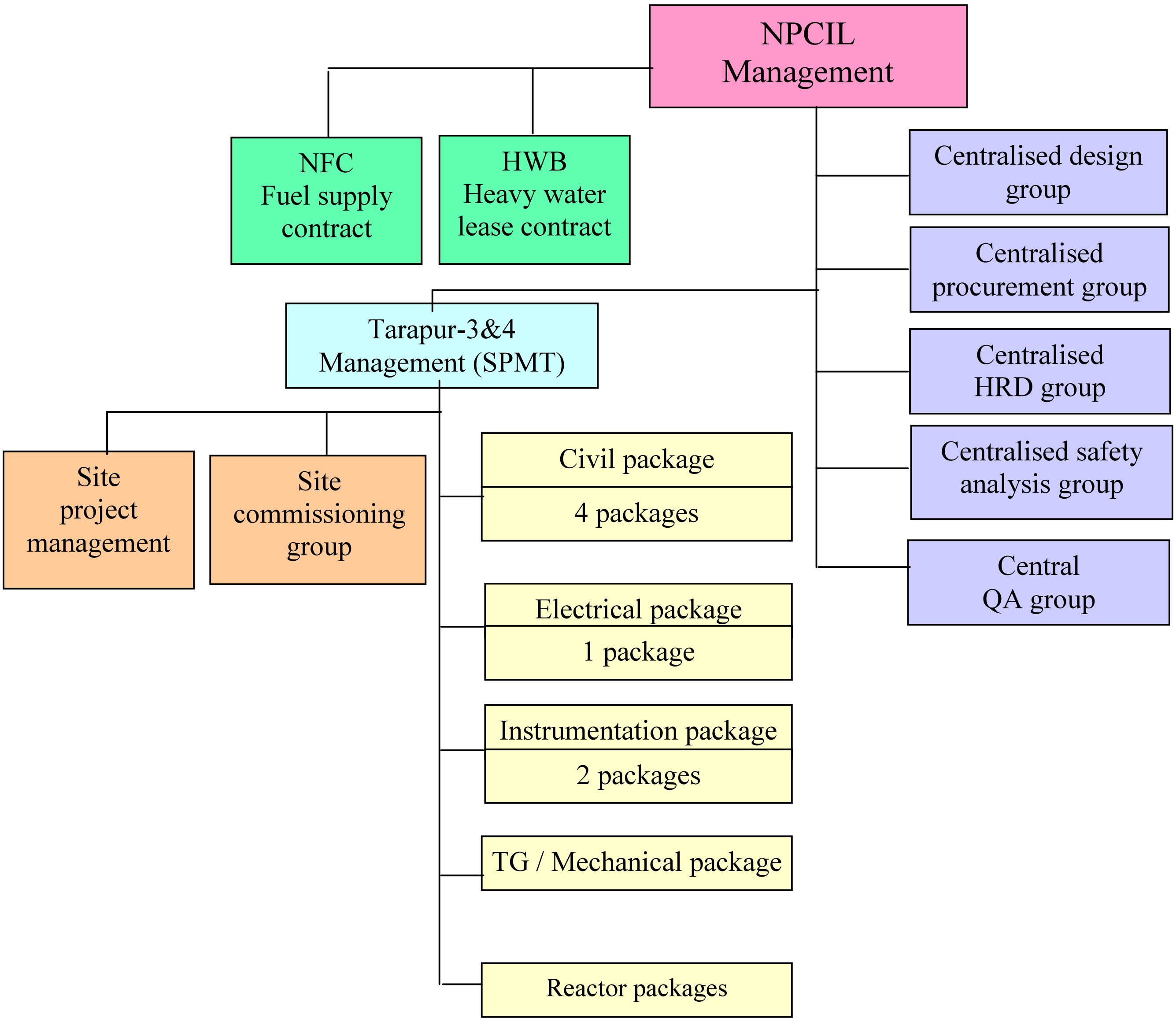


Fig. 2.6. Overall project structure and scope of supply (Tarapur).

CHAPTER 3. SAFETY & LICENSING AND REGULATORY ISSUES

Nuclear power can be a viable energy source only if it is safe and is also perceived to be safe by the public. Careful attention must be given to all activities that can affect nuclear safety throughout the siting, design, construction, commissioning, operation and decommissioning stages. Therefore, ensuring nuclear safety is a common goal of all participating organizations including the plant owner, vendors and the regulatory body.

Nuclear safety technologies have reached high standards in the world and the costs for implementing the safety requirements in design and licensing process constitute a significant portion of the electricity generation costs. Therefore, neither the quality objectives, nor the cost and schedule objectives can be achieved without good communication, co-operation and co-ordination between the regulatory body, the plant owner and other organizations participating in the project as it is illustrated by the five cases analysed in this document.

3.1. Responsibility for safety

The plant owner should be aware that he has the ultimate legal responsibility for nuclear safety. Hence it is imperative that the plant owner assigns the highest priority to nuclear safety throughout the life of the plant from concept to decommissioning.

The national regulatory body has the responsibility for ensuring that the public, plant personnel and the environment are protected against any adverse effects arising from the activities associated with nuclear power. Therefore, the regulatory body establishes safety regulations, assesses the SARs, and conducts regulatory inspection and enforcement to ensure the conformance of all project activities with the established national laws and regulatory requirements.

3.2. The licensing process

The licensing objectives for the regulatory body are to authorize actions and place conditions on the plant owner in order to have reasonable assurance that the public, plant personnel and the environment will not be subjected to the undue risks by the operation of the plant.

The licensing process is an on-going process, starting from concept, site preparation and continuing through design, construction, commissioning and operation of the NPP. The general process of licensing a nuclear power project is similar in many countries. The licenses include, in addition to the site authorization, the construction permit and the operation license. These licenses are directly requested by the plant owner to start construction and operation of a nuclear power plant and they are issued by the regulatory body.

In some countries the legal framework links safety and environmental licensing processes. It should be noted also that the “Convention on environmental impact assessment in a trans-boundary context” (the Espoo Convention), entered into force in 1997, requires that environmental impact assessments are extended across the borders between parties of the convention, when planned activities may cause significant adverse trans-boundary impacts.

The overall responsibility for co-ordination of the licensing process for the entire project remains with the plant owner. The plant owner should develop a licensing programme to meet the regulatory requirements, and present it to the regulatory body for review, comment and approval. The suppliers have to provide the plant owner with all necessary data and information for the license application. The plant owner co-ordinates the preparation of the SARs, follows the licensing process, and ensures the conformance of all project activities with the regulatory requirements and licensing commitments.

To perform the licensing application activities, the plant owner should establish a small licensing group with experts having technical and legal expertise. This owner's licensing group should develop close contact with the regulatory body as early in the project as possible, in order to fully understand the regulatory and licensing requirements and to avoid possible problems of misinterpretation. Regular meetings between the project management and the regulatory body should be implemented to ensure good communication and understanding during the whole licensing process. It is essential that the relationship between the plant owner and the regulatory body is one of mutual co-operation and assistance, as they share a common objective.

During the licensing process, it is possible to obtain expert assistance and advice from abroad, but the responsibilities of the plant owner and the national regulatory body cannot be delegated.

3.3. Regulatory positions and up-front licensing

Regulatory positions have an important impact on the implementation of the licensing process. The regulatory positions are reflected through various means such as

- Safety regulations and standards
- Review and assessment during the licensing process
- Regulatory inspection and enforcement
- Results of safety research and development

Up-front licensing, in which the regulatory requirements are agreed on between the regulatory body and the plant owner in advance of construction (and implemented in construction contracts, as applicable), will reduce the potential for regulatory induced construction schedule delays. By having the early engineering and the license acceptability in advance of the construction, the financial risk of the nuclear project will be also reduced.

The cases analysed in this document show that a clear definition, by the regulatory body, of all relevant requirements to enable issuing the licence right at the project planning stage and ensuring timely availability of qualified regulatory staff for technical review and regulatory inspection, helps to reduce the cost and the project schedule significantly.

Illustrative examples:

- ***Qinshan:*** the impact of licensing and regulatory issues on the project was minimized as the result of design upgrades identified by the owner (TQNPC) in pre-contract negotiations and incorporated into the contract. The principal licensing documents, Preliminary Safety Analysis Report (PSAR), required for construction license and Final Safety Analysis Report (FSAR), required for operating license, were produced by AECL on behalf of TQNPC, with input from TQNPC and subcontractors. TQNPC's and the regulatory's review comments were documented and addressed in a series of review meetings. AECL supported TQNPC and the Atomic Energy Control Board (AECB) trained Chinese regulatory representatives in Canadian licensing practices and processes. A close working relationship among the commissioning team members (comprising TQNPC and AECL participants) further minimized licensing issues.

o ***Kashiwazaki-Kariwa***: The basic design was completed before applying to government for the establishment permit. The design details were finalized before applying for the construction permit and the procurement started after receiving this permit. However the suppliers were notified before starting the basic design. Fig. 3.1 shows the licensing schedule.

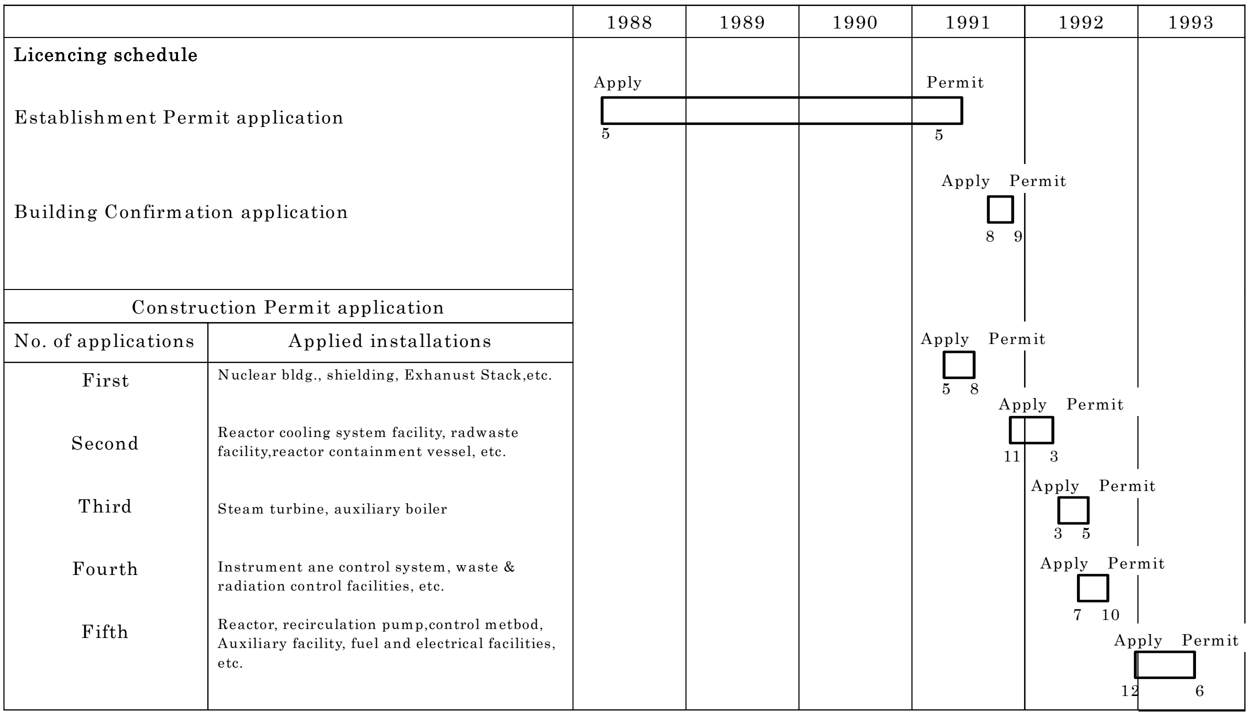


Fig. 3.1. Licensing schedule (Kashiwazaki-Kariwa).

o ***Lingao***: As LNPS was a duplication of Daya Bay except for some modifications, the safety review and assessment approach developed by the regulator consisted mainly of:

- The main focus was on modifications to the Daya Bay design.

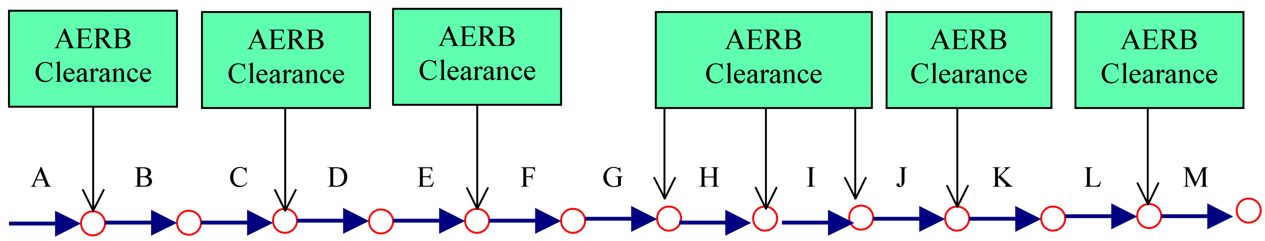
- Where the same design applied, if no significant safety issues, Daya Bay design review conclusions applied.

To smooth the safety review and licensing process, LANPC worked closely with the regulatory body to:

- Fully understand the regulatory and licensing requirements and avoid misinterpretation.

- Actively clarify, propose solutions and get approvals for issues not clearly defined in the regulations.

o ***Tarapur***: The owner, NPCIL, obtained safety clearance of site from Atomic Energy Regulatory Board (AERB). Subsequently an application was made to AERB for the construction authorization permit. This authorization is valid for 5 years. The construction activity at site can be started only after this clearance. The central design group obtains AERB clearance on all safety issues, for which the owner and the supply/erection contractors provide all input data well in time for analysis. NPCIL management ensures the conformance of all project activities with regulatory requirements and licensing commitments. AERB conducts regulatory inspection of construction activities normally three times in a year to ensure the conformance of all the project activities with the regulatory requirements. Effort has been made to define the stages of licensing by AERB. The planned stages of licensing at Tarapur are shown in Fig. 3.2.



A – Pre-project activity
B – Ground break
C – Confirm test & concrete mix qualification
D – First concrete & construction up to hydro test
E – Hot conditioning
F – Drain & dry
G – Fuel loading

H – Bulk D_2O filling
I – Approach to first criticality
J – Phase-B commissioning
K – Synchronization
L – Operation up to 90% full power
M – Full power operation

Fig. 3.2. Licensing process (Tarapur).

To ensure proper conformance to AERB guidelines, NPCIL carries out at least one headquarter audit followed by 4 local audits per year.

3.4. Impact of licensing on design of evolutionary reactors

The design of evolutionary reactors follows an approach, in which design improvements are made progressively, based on feedback from operating experience and updated licensing requirements. For example, in the Qinshan Candu project, a number of design improvements have been made to enhance the safety and performance of the plant and to meet the Chinese requirements. The major design improvements include: advanced plant display system in the main control room for enhanced human factors engineering incorporating better critical safety parameter displays, as well as a real time database, historical data and custom calculations; provision of a technical support centre adjacent to the Main Control Room (MCR) to facilitate effective assessment of emergency situations; design changes to buildings, structures and components to cater for tornado events; provision of a seismically qualified fire protection system after an earthquake; provision of duplicate valves for emergency water supply to the steam generators, to provide full redundancy and improve reliability for mitigation of seismic and other common cause events; and equipment design for a 40-year design life compared to 30 on the reference plant.

The licensing process for evolutionary designs should be handled following similar processes previously established.

CHAPTER 4. QUALITY ASSURANCE

The quality assurance (QA) programme is an interdisciplinary management tool that provides a means for ensuring that all work is adequately planned, correctly performed and assessed. It provides a systematic approach for accomplishing work with the ultimate goal of doing the job right the first time. The QA programme is a set of documents that describes the overall measures established by an organization to achieve management goals and objectives. These goals and objectives apply to every unit and individual within the organization.

The establishment and implementation of a QA programme are essential to the success of a nuclear power project. The basic general principles of QA are described in the following paragraphs and at the end of the chapter examples from the case studies are included[4].

The plant owner is responsible for establishing and implementing an overall QA programme to ensure that all project activities and processes (management, performance & assessment) are described in detailed plans & procedures, implemented by prescribed methods & techniques and documented in exhaustive records & reports. The QA programme also includes organizational structures, functional responsibilities, levels of authority and interfaces for those managing, performing & assessing the adequacy of work and qualification requirements for personnel, equipment & procedures. The final goal of all these efforts is the achievement of safe, reliable and economic production of electricity.

All constituent QA programmes established by other project participating organizations should be consistent with the owner's overall QA programme.

The owner may delegate QA functions to the main contractor or a consultant but the ultimate responsibility remains with the owner.

The QA programme is binding on everyone and its implementation is not the sole domain of any single organizational unit or individual. The QA programme can be effective only when the management, the staff performing the tasks and those carrying out the assessment, all contribute to the quality of the project in a concerted and cost effective manner.

4.1. Performance-based approach

A major factor influencing the positive trends in the performance of nuclear power plant construction and operation over the last several years has been the use of performance-based approach to quality assurance that places a greater emphasis on the effectiveness of programme implementation and process management in addition to documentation. Quality is achieved in a more effective, timely and productive manner when work is done "right the first time" rather than by finding and correcting non-conformances later. Therefore, the functions of the individuals and line organizations have gained importance in assurance of the quality of items and services while at the same time, the control and verification techniques are further improved.

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[4] The basic requirements on establishing and implementing quality assurance programmes related to the safety of nuclear plant can be found in the IAEA's Code 50-C-Q/Q1-Q14 (Quality Assurance For Safety In Nuclear Power Plants And Other Nuclear Installations) and Safety Guides Q11 (Quality Assurance In Construction) and Q12 (Quality Assurance In Commissioning).

Good practices in performance-based quality assurance programmes for nuclear power project construction include:

- Restricting number of documents for approval at higher management levels.
- Delegation of responsibilities down in the organization.
- Optimising multi levels of quality control measures among contractors.

4.2. QA Unit

The QA unit is established by the plant owner as an independent organizational unit at the pre-project phase of the nuclear power project and suitably modified and enlarged by the owner's project management organization during the construction stage.

The QA unit functions is an arm of and advisor to the project management in: establishing and implementing the overall QA programme; measuring the effectiveness of the management processes and work performance; and examining the conformance with the regulatory and licensing requirements. The QA unit is also, on behalf of the plant owner, responsible for assessing the effectiveness of the constituent QA programmes of the contractors.

The functions of the QA unit may also include:

- Review of the qualifications of the personnel, equipment and procedures employed by the line organization.
- Review of the inspection and test reports, etc. at the additional hold points and witness points determined by the site management.
- Provision of indirect control by monitoring of construction processes.
- Initiation of corrective actions and measures for non-conformances.

The relationship of the QA unit with other organizations and organizational units at the construction site is formally defined to ensure efficiency and functional independence.

4.3. Inspection personnel

Inspection personnel, or inspectors, are independent verifiers, who are not responsible for performing the work to be inspected but for assessing the quality of the concerned items and processes. The inspectors are required to be qualified in the relevant technical disciplines.

Inspectors can be part of the QA unit, however in some organizational structures, inspection functions are separated from the QA unit and placed within technical line organizations, such as those for construction, procurement, manufacture and commissioning and are then referred to as quality control (QC)[5].

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[5] Quality control: part of quality management focused on fulfilling quality requirements (ISO 9000:2000).

4.4. Assessment of effectiveness

The effectiveness of the QA programme is measured by the achievement of the project objectives. The effectiveness of the implementation of the QA programme is assessed through management self-assessment and by the QA unit. Both assessments focus on the performance objectives that the organization has determined in terms of quality, cost and schedule achievements. Assessment personnel also identify deficiencies or weaknesses in the organizational structure and in the project management.

4.5. Examples from recent projects

4.5.1. Qinshan

4.5.1.1. QA among TQNPC, AECL, Commissioning Team and Contractors

The main contractor, AECL, through the Site Project Management Organization (SPMO) was responsible for the overall QA programme at the Qinshan site. The primary responsibility for QA and QC rested with the construction contractors during construction and with the commissioning team (CT) during commissioning. SPMO Quality Surveillance[6] (SPMO QS) conducted QS activities on the NSP contractors. The Chinese quality organization, STAR, overseeing NSP construction on behalf of the owner, conducted QS on SPMO QS. SPMO QA was responsible for overseeing the construction contractors' QC and QA programs, as well as SPMO's QS and QA and the CT's QA programmes.

Significant improvements were achieved in the QA programme by the Construction Management Team (CMT) and the contractors, particularly in regard to programme implementation, as lessons learned during the construction and commissioning of Unit 1 could be applied to Unit 2 and resulted in less re-work, reduced costs and better QC.

4.5.1.2. Applicable codes, regulation and standards

SPMO Site Quality Assurance (SQA) was responsible for defining and ensuring the implementation of a QA programme for the construction phase of the Qinshan project, in accordance with CSA Standard CAN3 N286.3. SPMO's and the construction contractors' activities had to comply with their respective QA programs. SPMO reviewed the requirements of Nuclear Safety Regulation HAF-0404 to ensure that the requirements were met or exceeded by CSA N286.3.

In addition to the above, SQA was responsible for defining and, along with TQNPC, ensuring the implementation of a QA programme for the commissioning phase of the Qinshan project in accordance with CSA Standard CAN3 N286.4. SPMO reviewed the requirements of Nuclear Safety Regulation HAF-0405 to ensure that these requirements were met or exceeded by CSA N286.4.

4.5.1.3. Functions of SPMO with respect to the NSP Construction Contractors and CMT

The NSP construction contractor's and CMT's QA manuals were reviewed and accepted by SPMO SQA to ensure that they met project requirements. Each construction

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[6] Quality surveillance: the act of monitoring or observing to verify whether an item or activity conforms to specific requirements (IAEA-TRS-317, 1990).

contractor also prepared QA procedures to support the QA manual and submitted them to SPMO for acceptance. To assist the construction contractors and CMT, SPMO carried out information sessions defining the requirements for their QA manuals and supporting procedures. SPMO recommended that the construction contractors and CMT followed the basic format of the SPMO Construction Quality Assurance Manual to ensure consistency among SPMO, the construction contractors and CMT.

SPMO's responsibility included the review and acceptance of the CMT's QA Manual and procedures and auditing the effectiveness of BOP construction management for the implementation of the BOP Construction QA programme.

4.5.1.4. QA Audits

SPMO and CMT carried out QA audits of their own QA programmes, as well as of the construction contractors and their subcontractors and suppliers.

Internal QA audits were carried out by SPMO SQA to confirm that the SPMO had implemented the QA requirements specified in procedures and instructions, and that the QA programme was effective.

External QA audits of CMT's and NSP construction contractors' activities were carried out by SPMO to confirm implementation and effectiveness of their QA programmes, as described in their procedures and instructions.

TQNPC carried out QA audits of SPMO and CMT to verify the effectiveness of the respective QA programs. SPMO and TQNPC performed joint QA audits to the largest possible extent, including joint audits of the CT's QA programme.

4.5.1.5. Records

Records as required by applicable codes, standards, specifications, regulations and TQNPC were assembled and filed as history dockets for nuclear systems and as history files for non-nuclear systems by:

- The construction contractors during the construction phase of the project.
- The Commissioning Team during the commissioning phase of the project.
- SPMO.

History dockets and history files were also prepared for NSP equipment and materials. These permanent records were prepared by equipment and material suppliers and then reviewed and accepted by CNPM on behalf of AECL.

4.5.1.6. Trends

Trends in performance were analysed on a continuous basis and reported monthly to TQNPC. Any negative trends were immediately addressed with the responsible party. Actions taken are documented in minutes of meetings, correspondence, QA program reviews, monthly reports and through other means such as non-conformance reports and corrective action requests.

4.5.1.7. Equipment QS by TQNPC

AECL was responsible for the quality of the manufactured equipment. TQNPC had the right to conduct equipment QS and established representative offices & assigned qualified personnel in Canada, Japan and South Korea to this purpose. For QS related activities outside these regions, task-teams from TQNPC home office were organized, as needed, in accordance with the current conditions. The procedures developed for these activities include procedures for: procurement & review of manufacturing records, equipment QS, disposal of non-conformance reports (NCRs) & equipment acceptance and review of QA plan.

In accordance with the contract, equipment QS was carried out on 43 items of equipment that are critically important to the plant, such as T/G, main pump, etc.

TQNPC's equipment QS activities were further expanded to approximately 100 items of equipment through bilateral negotiations.

Equipment QS activities included:

- Review of manufacturers' qualification (selection of the manufacturer depended on the operation performance of related equipment in the reference plant, as well as other similar domestic and international projects).
- Review of AECL's management procedure for equipment procurement and QS (the review focused on procedures for the selection of subcontractors, control of subcontractors, disposition of NCRs and release of QA).
- Review of equipment technical specifications and quality plans: the review focused on conformance of technical specifications with standards & codes stipulated in the contract and the maturity & achievability of related technical processes. The owner also selected some witness and hold points, such as integrated performance tests, acceptance of historical files and final ex-works inspections.
- Participation in over 85% of the selected witness points.
- Inspection at unpacking of equipment on site (TQNPC mainly entrusted unpacking to the Commodity Inspection Bureau or the TQNPC/Local Contractor inspection during the receiving process).
- QA auditing on manufacturers.
- Disposition of technical issues for the major ones.

4.5.2. Kashiwazaki-Kariwa

Through a long experience of the NPP construction, TEPCO and suppliers have accumulated skills and tools for the QA program. TEPCO basic requirements for QA include: establishment of organizations and basic scheme for QA; systematic QC (for design, drafting, transportation, installation, etc.) according to the degree of importance of each component; systematic procurement control (obtaining approval for purchases of critical equipment, etc.) and auditing manufactures' QC.The supplies and works were classified in 7 classes according to their importance to reactor safety. There were a total of 286 Government's and 3718 TEPCO's (system-wise) inspections. Out of the TEPCO's inspection, 657 were at the factories and the balance at site.

A TEPCO site resident inspector was assigned at GE facilities for turbine-generator and NSSS components.

Due to their unique situation, for Units-6 & 7 additional QA programme was added as described in the sections below.

4.5.2.1. Full size verification tests

Full size verification test was one of the key tests during the ABWR development. Of all the tests, the Reactor Internal Pump (RIP) test was very special because it was confirmed and verified by the Government authority, "Nuclear Power Engineering Test Centre". Other major components and systems were developed and tested either by BWR Utilities Joint Study or by suppliers' own development programmes. More than 20 items were tested over 10 years in the framework of the Joint Study.

4.5.2.2. Design review

Design review is a widely accepted method when introducing new technology. ABWR went through a number of so-called "Juuten Sekkei" reviews (joint reviews by TEPCO and suppliers). For Kashiwazaki-Kariwa, Juuten Sekkei review was conducted on 28 areas, including components such as reactor pressure vessel, RIP and fine motion control rod drive and systems such as control rod drive system, heater drain pump-up system, water chemistry and lower drywell arrangement. A total of 175 meetings with TEPCO and suppliers were held over a period of two years and the results were presented to TEPCO's internal design review committee.

All concerns raised during the discussions were listed indicating when the function or the performance should be further confirmed during shop, pre-operational, or startup tests.

4.5.2.3. Design change control

Design change control was widely used by TEPCO, as it is known that the design change point is most susceptible to failure or miss-operation. All Kashiwazaki-Kariwa Units 6 and 7 systems and components were checked, from design change point of view, against either Kashiwazaki-Kariwa Unit 3 or 4 as the latest reference plant.

Design changes were classified into three levels:

- Class 1, "Significant", meaning that the failure of the component or system will result in plant shut down.
- Class 2, "Major", meaning that the failure will result in plant electrical output fluctuation.
- Class 3, "Minor", the result of failure is neither of the above.

Suppliers must do the classification, and items belonging to Classes 1 and 2 must be reported to TEPCO who confirmed the adequacy of the design, while Class 3 items were controlled by the suppliers themselves.

4.5.2.4. Product verification

It was common practice that all products must pass individual and/or combined tests before shipment. In case of Kashiwazaki-Kariwa Units 6 and 7 some additional tests were added such as RIP - RIP power supply — motor generator set combined test. This test was specially requested to confirm the RIP coast down characteristic with the motor-generator set.

Additional pre-operational and/or startup tests were conducted at site to confirm the functionality and/or performance of big systems.

4.5.2.5. Overall checkup at site

In addition to all the activities above, overall checkups at site during the commissioning test were finally conducted. During the commissioning tests, conducted at atmospheric condition, 20, 50, 7% and 100% power stages, the plant was shut down for a short period after each of the phases. An overall checkup was conducted before every reactor restart, and many types of checklists were prepared to ensure that the overall plant condition was complete.

4.5.3. Lingao

The owner, LANPC, took responsibility for the LNPS design and construction as well as plant's operation and is responsible for guaranteeing the plant's safe operation, staff's safety and environment protection. In order to meet all these requirements, LANPC established a QA programme, focusing on the different stages of the project such as preliminary works, design & construction, commissioning & trial and plant operation. It is based on HAF003 – The Rules for Nuclear Power Plant Quality Assurance and some other relevant guides.

The QA programme included all the required activities compulsory to the items, service and verification and had to be submitted to National Nuclear Safety Authority (NNSA) for review.

LANPC required all involved contractors to set up and implement a QA programme complying with the owner's QA programme and in accordance with their scope of work. The QA programme had to be submitted to LANPC for review within one month after contract signature.

4.5.3.1. Design Review

The design documents of the important systems and equipment of NI and CI that were modified on the basis of Daya Bay's experience were reviewed by the owner and EDF together, other documents were reviewed only by the owner..

The supply contracts for NI and CI requested that the documents submitted by the suppliers should be categorized as:

- Category A - identical with the DNPS's;
- Category B - modified based on DNPS's; and
- Category C - new documents.

The review was focused on documents in the categories B and C. The owner reviewed almost all NI civil and BOP design documents.

4.5.3.2. Equipment Manufacturing QS

LNPS's manufacturing QS consisted of three main aspects: the owner was in charge of the QS for the CI and BOP equipment that were manufactured in Europe; the QS for the NI equipment manufactured in Europe was contracted out to EDF, but the owner participated in the activities; the work for localized or indigenous equipment was contracted to a local company (SNPI).

Comparing with DNPS, three major improvements were made on equipment manufacturing QC surveillance in LNPS project:

- The number of witness points was increased from 20% to 70%.
- The regular (for NI equipment in Europe) and random reviews (for CI equipment in Europe and localized equipment) of manufacturer's NCRs resolution were reinforced.
- The survey of equipment manufacturing quality trend was strengthen, to find out suppliers' shortcomings in quality control and management so that the suppliers could be asked to take corrective actions keeping manufacturing quality under control.

4.5.3.3. Erection QC

The contractors set up an additional QC level organization in the working teams and focus was put on "self-check" function, which helped early finding and resolving the problems. These two levels of QC organization helped relieving the conflicts between the working team and the inspection entity and lowered the probability of misjudgement.

It was admitted that the system needed more QC inspectors, but this increase was fully compensated for as it ensured quality and had a direct impact on schedule and overall budget. Tables 4.1 and 4.2 show some statistical results of the QC inspections.

Table 4.1. Statistics of Inspection on NI Equipment Erection (Lingao)

Item Checked		**Quantity of Inspection**	**Non-conformities (NC)**	**NC Rate (%)**
Piping/ducting welds prefabrication		69 604	830	1.2
Supports prefabrication		29 241	152	0.5
Supports erection	Stage 1	39 737	543	1.4
	Stage 2	37 801	692	1.8
Piping/ducting erection		109 577	262	0.2
Piping/ducting compliance		632 systems	0	0
Primary cable tray		24 272 pieces	302	1.2
Secondary cable tray installation		16 899 pieces	123	0.7
Cable layout		8070 pieces	157	1.9
Cable terminal		14 568 pieces	146	1.2

Item Checked	Quantity of Inspection	Non-conformities (NC)	NC Rate (%)
connection			
Electrical device erection	16 380 sets	200	1.2
Mechanical equipment erection	2411	37	1.5
Ventilation pre-fabrication	5248	236	4.5
Ventilation erection	26 126	468	1.8
Instrumentation installation	20 746	21	0.1

Table 4.2. Statistics of Inspection on CI Equipment (Lingao)

Item Checked	Quantity of Inspection	Non-conformities (NC)	NC Rate (%)
Welds inspection	55 233	425	0.77
Site inspection	511 835	3033	0.59

4.5.4. Yonggwang

4.5.4.1. Division of responsibilities for QA

The Yonggwang project QA programme manual, prepared by the owner, KHNP, established the QA requirement to be implemented for the Yonggwang project. The entities participating in the design and construction of Yonggwang established their own QA programs to meet the requirements of applicable codes, regulations, standards, specifications, drawings and procedures as defined in KHNP's Yonggwang project QA programme manual.

These QA programmes were applied to those activities affecting the quality of safety-related items, safety-impact items and reliability-critical items as defined in the general design criteria and Yonggwang project QA program manual to ensure an acceptable level of confidence that the included structures, systems, and components can perform their intended functions.

All Yonggwang project participants were responsible for ensuring that the conduct of their activities is in strict compliance with the requirements of KHNP's and their own QA program manuals.

KHNP was ultimately responsible for assuring that all activities affecting quality such as design, procurement, fabrication, construction, testing and startup are accomplished in accordance with applicable regulations, codes, and standards.

KHNP maintained overall control of the contractors and suppliers by implementing the Yonggwang project QA programme to ensure that all QA requirements are met.

KHNP's Yonggwang project QA programme was implemented in accordance with the following documents:

- Project QA programme manual
- Project procedures manual
- QA procedures
- Quality surveillance manual
- Field QA manual /procedures
- Field QS manual /procedures
- Site internal procedures

4.5.4.2. Applicable codes, regulations, and standards

Article 26 of the Enforcement Decree of the Korean Atomic Energy Act, 10 CFR 50, Appendix B, and U.S. NRC Regulatory Guides in effect as of December 31, 1993, and the ASME Boiler and Pressure Vessel Code in effect as of December 31, 1993 applied to the Yonggwang project.

The QA program implemented for safety-related items applied the applicable elements of ASME NQA-1-1993 Edition, "Quality Assurance Requirements for Nuclear Facility Applications" to meet technical and quality requirements of contract documents.

For safety-impact items and reliability-critical items, QA requirements were applied to ensure that items or services as furnished and installed meet technical and quality requirements specified in contract documents.

4.5.4.3. QA by contractors and suppliers

- The contractors and suppliers established and implemented project QA programmes in accordance with the policy described in section 4.5.4.1 and additional requirements imposed by the applicable contractual documents.
- The contractors and suppliers imposed the same QA requirements on their own subcontractors, and required conformance to these requirements as much as they are concerned.
- The QA organizations of the contractors/suppliers reviewed and approved their subcontractors' QA programmes to ensure proper inclusion of the requirements. The selected subcontractors' QA programmes were forwarded to KHNP for information.
- The QA programmes established by KOPEC, DHIC, and KNFC were submitted to KHNP for approval before use in accordance procedure.
- The QA programmes and their revisions established by the BOP suppliers, construction and NDT contractors were submitted to KHNP for review.

- Implementing procedures/instructions of site construction and NDE activities such as QA procedures, work procedure, etc., were submitted to the KHNP site manager for review and approval.

4.5.4.4. Review and approval of QA programmes

- The KHNP General Manager, QA Department, was responsible for reviewing and approving the QA programmes submitted by KOPEC, DHIC and KNFC.

- The KHNP Site Manager, Construction Office, was responsible for reviewing and approving the construction and NDE contractors' QA procedures or field QA/QS manual and implementing procedures/instructions.

- Contractors and suppliers incorporated KHNP comments requiring resolution, into their programs and resubmitted them for final acceptance within 30 days or prior to conducting any safety-related, safety-impacted and reliability-critical activities.

- Any revisions to previously approved QA programs were submitted in the same manner as the original before the revisions were implemented.

4.5.4.5. QA implementation

The entities participating in the design, manufacturing, NDE and construction of Yonggwang implemented the approved QA Programs.

QA personnel involved in Yonggwang project were responsible for assuring that the appropriate QA programme was established and verified that activities affecting quality was correctly performed. The QA personnel possessed sufficient authority and organizational freedom, including independence from cost and schedule, to participate, observe, review, inspect and audit in identifying quality problems; to verify the implementation of solution to the problems; and to stop further work, if necessary.

4.5.4.6. Assessment

- KHNP periodically evaluated the implementation of the QA programmes of contractors and suppliers including subcontractors by QA audit, QA surveillance, inspection, review and other monitoring activities.

- Contractors and suppliers regularly assessed the adequacy of their QA programmes and assured effective implementation.

- Contractors and suppliers regularly evaluated the implementation of the subcontractors' QA programmes.

- Audit results performed by suppliers/contractors were reported to KHNP. Audit results performed by sub-suppliers /sub-contractors were reported directly to their respective prime contractors.

4.5.5. *Tarapur*

The project QA manual is based on NPCIL's "Topical QA Manual".

The manual puts particular emphasis on the construction of NPP with duly qualified personnel, and adopting duly qualified products & processes to achieve the specified quality requirements and incorporates all the useful feedback from previous projects. The Project Director has the responsibility for implementing the QA programme and delegated the authority to suspend the work if significant quality deviations are observed, to the head of the QA group. The QA manual provides for management self-assessment and for independent assessment by organizations beyond the site control. The QA manual requires preparation and implementation of well-defined procedures for all activities and work done.

All the package contractors are required to prepare implement and maintain an effective quality system complying with the project QA manual. NPCIL QA assessed the contractor's QA systems and their implementation.

CHAPTER 5. METHODS & FEATURES TO COMPLETE SITE CONSTRUCTION WORK ON SCHEDULE AND BUDGET

Site construction requires many overlapping activities in site preparation, civil works, mechanical erection, electrical installation and testing and includes placement of large quantities of civil construction materials (concrete, reinforcement, embedment, formwork) within a tight schedule. Apart from civil works, a multitude of component erection and installation activities are also under way, such as transporting, receiving, storing, handling, welding, cleaning, inspecting, testing, repairing and maintaining, etc. Many of these activities are interdependent and subject to high dimensional accuracy. Special technical skills, efforts and precautions are required.

Site construction is a very costly segment in project implementation. The achievement of shorter construction periods, through improved technology and construction methods can have a significant benefit on the net costs, prior to any production of electricity.

This chapter reviews the latest technologies, methods and processes that have been used in the construction of evolutionary water cooled reactors. The review is based on the 5 studied projects.

5.1. Design approach to facilitate construction

The ease, efficiency and cost effectiveness of construction of a nuclear power plant are key factors in improving quality and reducing the gestation period and cost. Design has a major effect on construction, as it determines the choices that are available to the construction organizations. If modules are to be used, for example, they must be incorporated into the design from the very beginning of the design process. Otherwise, there is very little chance that the construction organizations can use modular construction techniques.

For most of the analysed projects, design accounts for 6–10% of the total plant capital costs. A specific case is Yonggwang where due to standardisation design costs were reduced to 3.5–4% of the capital costs. Design has a significant impact on the total project costs and a sound design is the key to success of a nuclear power project.

It is good practice to assess the technical merits of all design and engineering options and establish a programme for improving the efficiency of construction through design at an early stage of the project. The programme should specify roles and responsibilities of the plant owner, design and engineering organizations in this regard and include policies, criteria and a set of implementation procedures.

The programme should integrate lessons learned and experiences accumulated from previous practices, both national and international. The programme should provide for incorporating advanced construction methods and techniques into design, implementing construction training to the project personnel, developing a database of lessons learned during the project implementation and establishing a system to measure the cost-benefit of the programme of design for facilitating construction.

5.1.1. Design tools

Computer modelling can be a very effective tool for both designers and constructors. The use of these tools has not only improved the quality of design and construction by identifying errors and weaknesses in advance, but it has also resulted in great savings in materials and man-hours so as to reduce the project construction time and costs.

The increasingly integrated design tools known as Computer Aided Design (CAD), Computer Aided Design & Drafting (CADD) or Computer Aided Engineering (CAE) are broadly used in the design and also in the construction and commissioning stages for establishing plant and building layouts. They are in addition used in the modularization process identifying structure and system interfaces; minimizing interferences; reducing the number of welds in components and piping systems; planning and sequencing construction activities; providing documents and other support to procurement; construction & commissioning activities (such as: releasing drawings; material management; configuration management and providing wiring, cabling, connection and equipment information). It is an essential technology for plant design and a very useful tool during construction and commissioning.

The following examples illustrate the extent to which computer-aided design tools were used in the recent NPP projects:

- ***Qinshan:***
  - *3D CADDs* - The design information in CADDs tool (developed by AECL) was integrated with other electronic management systems for controlling and managing of materials and documentation. For the first time CADDs was used to issue formal construction documentation that satisfied the requirements of the QA program. The use of 3D CADDs in the design phase led to dramatic reductions in interferences among different design elements such as piping, cable trays, structural members and equipment. Using manual design techniques, such interferences in the past numbered in thousands for a major project and had to be corrected on the field, but with CADDS, they were substantially reduced.
  - *Integrated Electrical and Control database (IntEC)*: IntEC is a state of the art cabling and wiring system database developed by AECL. It provides wiring, cabling, connection and equipment information and includes live design and as-pulled data at site for all the wiring, cabling and connections. The design information in CADDs and IntEC was integrated with other AECL electronic management systems for controlling and managing materials and documentation and other project participants, including construction contractors, successfully used it.

- ***Kashiwazaki-Kariwa:***
  - *Three-dimensional CAD (3D-CAD)*: Hitachi has developed and customized this system based on own plant design practice. The system configuration is shown in Figure 5.1. The system contains a centralized engineering database, which includes small tubes, pipes and supports, enabling wide and effective data applications, e.g. preventive maintenance planning (accessibility, maintainability, etc.) and construction work planning (installation procedure, equipment set-on/carry-in, temporary scaffolding, etc.). This engineering database is very effective in plant design and construction but also in plant data management, preventive maintenance, and improving design, etc. (Figure 5.2.), and its widely practical use through the entire lifetime of a nuclear plant is greatly expected [3].

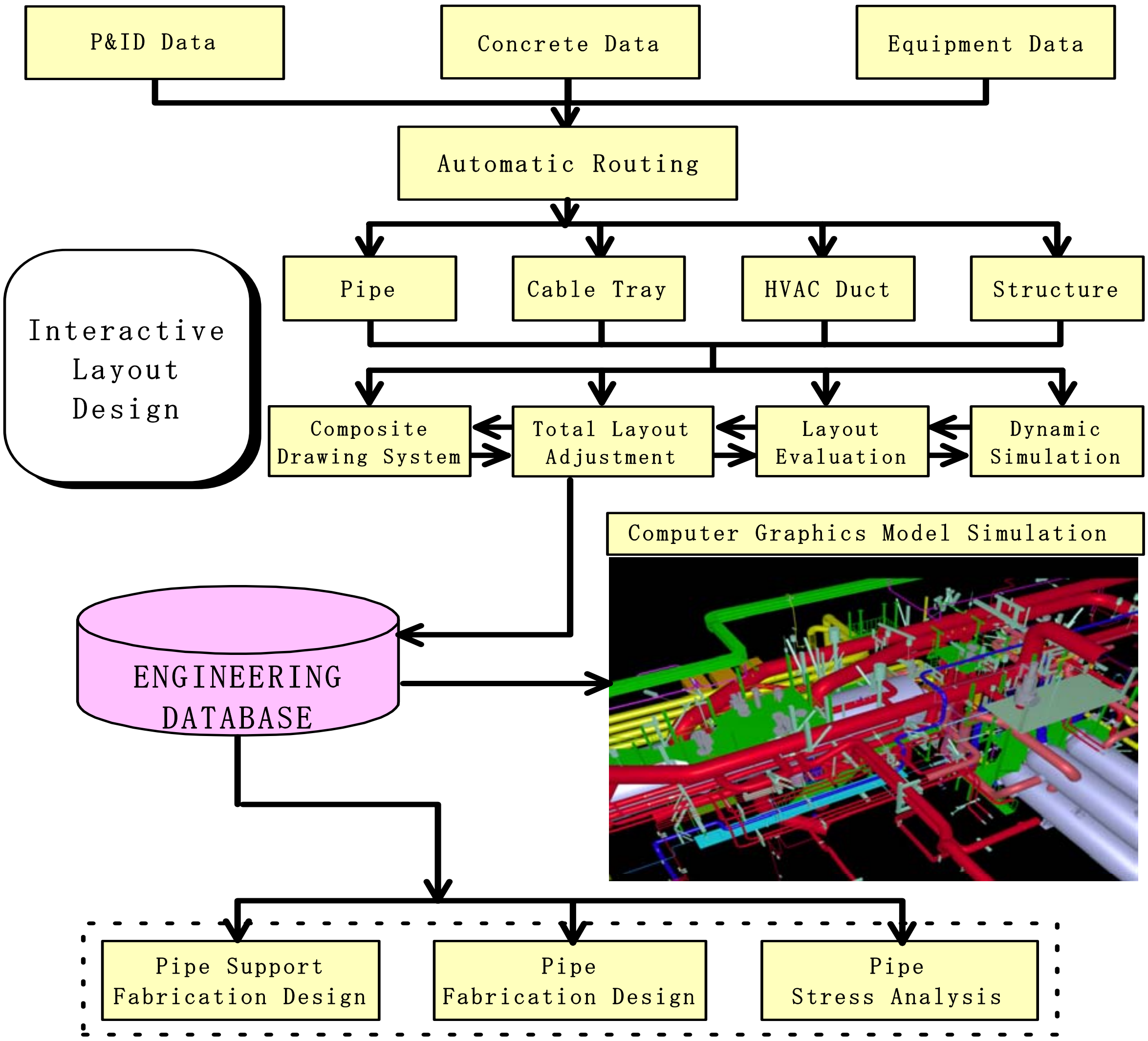


Fig. 5.1. 3D CAD configuration (Kashiwazaki-Kariwa).

- ***Tarapur:***

  - Up to the year 2000, all drawings for Units 3 & 4 were made manually. Later, all the drawings were prepared in AutoCAD, a powerful two-dimensional CAD tool. The three-dimensional feature of AutoCAD 2000 was used to prepare 3D models of the civil structure for better understanding. However, issue of general arrangements, isometric, detailed drawings etc. was done based on the two-dimensional functionality of AutoCAD.

  - In the year 2002, three-dimensional tools for plant design were used to identify the interferences in various buildings. Having seen the benefits of using 3D plant design tools, it has been planned that for all future units the complete plant will be modelled with 3D plant design software for controlling and managing drawings, documents, bill of material etc. It has also been seen that use of 3D plant design software in the design phase leads to dramatic reductions in interferences among different design elements such as piping, cable trays, structural members and equipment.

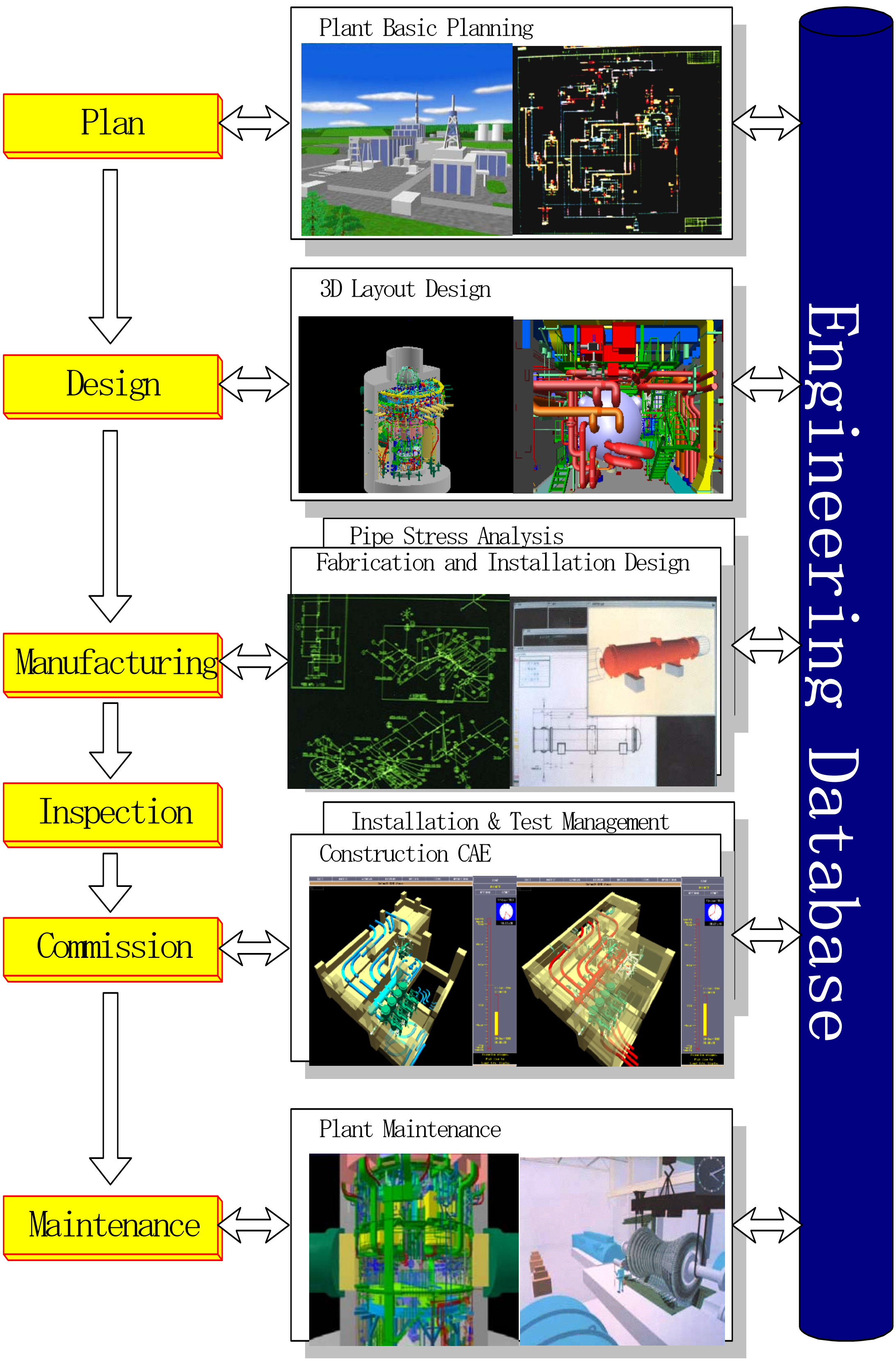


Fig. 5.2. Plant integrated 3D- CAD System (Kashiwazaki-Kariwa).

5.2. Improved construction techniques/methods

5.2.1. Open top construction

In the past, a major challenge to efficient construction has been the constraints on works carried out within the containment building. Historically, the reactor building or containment wall was constructed with openings left on the sides to allow entry of large equipment. The open top method allows work to be done from the top and from below, which increases work flexibility. Basically, by using the open top techniques a temporary roof with strategically located openings is placed on top and the permanent concrete dome of containment building is built later. A very heavy lift (VHL) crane (Fig.5.3) is used to place major pieces of equipment directly into their final positions through these openings, allowing significant schedule improvements. On completion of major equipment installation, the temporary roof is replaced by a permanent reactor concrete dome. Open top construction is increasingly used in conjunction with modularisation techniques (see next section).

Examples of the use of this technique are given below:

- ***Qinshan:***
  - About 70 pieces of equipment were set in place using the very heavy lift crane, including steam generators (220 tons each), pressurizer (103 tons), reactivity mechanisms deck (43 tons), feeder frames (40 tons each), fuelling machine bridges (16 tons each), dousing module (Fig. 5.4) and major heat exchangers.
  - A steam generator installation by the open top method[7] (Fig. 5.5) took only two days compared to two weeks taken by the traditional horizontal-access method.


Figs. 5.3. & 5.4. VHL crane lifting the temporary roof and dousing module (Qinshan).

[7] It is the first time this method is used for Candu 6.

Fig. 5.5. Steam generator installation (Qinshan).

- ***Tarapur*:**

  - As soon as the floor was cast and had acquired desired strength, all major equipments were lowered to their approximate location by heavy-duty crawler cranes. The equipment was protected by the temporary structure and civil work continued in the adjacent area including roof slab. Specific house keeping procedures were implemented for maintaining cleanliness near the equipment. This method resulted in a lot of savings of time due to parallel working along with the civil work. For previous projects, two additional years were needed after completing the civil work for equipment and piping erection. Actually, for Tarapur Units 3&4 utilizing the above technique, erection of equipment and piping takes only 6 months after completion of civil work. About 50 pieces of equipment were set in position using the heavy duty crawler crane e.g. moderator heat exchangers, pressurizer (103 tons), end shield (Fig.5.6), calandria (Fig 5.7), calandria vault top hatch central beam, primary circuit headers (20 tons each), fuelling machine columns & bridges, heavy water storage tank, bleed condenser, ECCS accumulators, major heat exchangers, stator generator etc.

Figs. 5.6. & 5.7. End shield and calandria installation (Tarapur).

  - Steam generators, being long lead-time equipment, could not be installed before dome closing. Thus, two openings provided in both the inner and outer containment for lowering steam generator (weighing 200 tons) were used (Figs. 5.8 & 5.9). With the help of heavy duty crawler crane the lowering of the steam generator to its vault was completed in only three hours as compared to more than one month taken earlier for the same operation. Subsequently, the shifting of the steam generator to its exact position was completed in just half a day by using a specially designed trolley.

Figs. 5.8. & 5.9. Steam generator installation (Tarapur).

5.2.2. Prefabrication and modularisation

A module is defined as a factory or workshop fabricated assembly consisting of structural elements, equipment and other items such as piping, valves, tubing, conduit, cable trays, reinforcing bar mats, instrument racks, electrical panels, supports, ducting, access platforms, ladders and stairs. Modules may also be fabricated and assembled at a workshop at the plant site.

Because of better facilities and less interferences from other activities, the factories or workshops provide more favourable conditions and environment for the achievement of higher quality & productivity and shorter schedules. Modularisation allows the mechanical erection or electrical installation to be carried out at off-site factories/workshops in parallel with civil works, thus reducing site congestion and improving accessibilities for personnel and materials, especially in the containment building, allowing for significant reduction of the schedule.

Large composite structures with steel-concrete walls or floors may be as well included in a module, but because of restrictions imposed by lifting or transporting, it is often necessary to pour the concrete into the walls after the modules have been put in final position.

The decision whether to apply the modular approach should be made during the early design stage. If positive, a modularisation plan should be established to allow this approach to be followed throughout the project, from the conceptual and detailed designs, engineering, procurement, fabrication, erection or installation, to completion of commissioning. The module designs should be planned with a series of consideration, such as:

- Definition of module envelope parameters.
- Integration of all relevant technical disciplines.
- Selection of installation and alignment tolerances.
- Standardization of modular specifications.

In addition, the design planning should also consider the necessary features of plant configuration to fit modularisation. An entirely new approach to plant and building layouts may be appropriate. Rectangular structures may reduce risks with the modular approach. Design should ensure sufficient access and lay down areas. Design inputs should include those from construction, operation and maintenance personnel to ensure that the plant can be well constructed and easily operated and maintained.

Issues, which must be considered in developing the modular construction plan, include:

- Module construction schedule driven by plant commissioning.
- Sequencing on-site movement, installation and testing of modules.
- Parallel conventional installation work in nearby areas.
- Appropriate use of on-site workshop(s) to support module installation.

Some sites do not have adequate access to navigable waterways for the shipment of large modules, which cannot be transported by road and rail. In these cases, shipping of parts of modules for final completion at the site may be more cost-beneficial, particularly where only a small amount of connection work at the plant site is involved. A workshop or even a comprehensive facility is needed for on-site assembly of modules. Some large facilities at the nuclear power project site include several workshops for mechanical, electrical and electronic works, non-destructive examination and for module fabrication and assembly. For example, at Kashiwazaki-Kariwa about 10 000 m^2 of workshops were used by Hitachi and at Tarapur about 25 000 m^2 of workshops are used by the contractors.

Prefabrication and modularisation were broadly applied in the analysed projects in combination with open top construction. Some selected examples are presented below:

- ***Qinshan***:
  - Lower dome was assembled and painted on the ground and lifted into position with a very heavy lift crane.
  - Using a dousing steel module (including piping, tanks, valves, electric and instrumentation) resulted in a 3 months reduction of schedule (Fig. 5.4).
- ***Kashiwazaki-Kariwa***
  - By using the so-called “Large scale modularising construction method” (used at Unit 7) the seven floors ABWR building was divided in three layers and constructed in three steps in a pre-assembly yard before the pieces were successively lifted into place by a giant crawler crane:

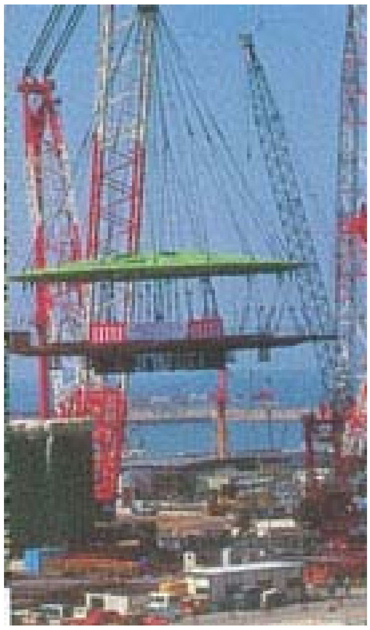
- The “Upper drywell super large scale module” was the heaviest and most complicated module. It consists of γ-shield wall, pipes, valves, cable-trays, air-ducts and their support structures, and weighs 650 tons (Figure 5.10).

Fig. 5.10. Installation of upper drywell super large scale module (Kashiwazaki-Kariwa).

- Two rooms of 300 and 440 tons each were successfully modularised with the combination of civil structures, rebar, mechanical and electrical equipments and parts (Fig. 5.11).

- The “Reactor building centre mat module” and the “Reactor concrete containment vessel (RCCV) top slab module”, two complex overcrowding parts, combining civil structures, rebar and mechanical equipment foundation, were formed into large modules in a yard adjacent to the reactor building, and lifted into position (Figs. 5.12, 5.13 and 5.14).

Fig. 5.11. Room module (Kashiwazaki-Kariwa).



Figs. 5.12. & 5.13. Integrated module of the centre mat (Kashiwazaki-Kariwa).

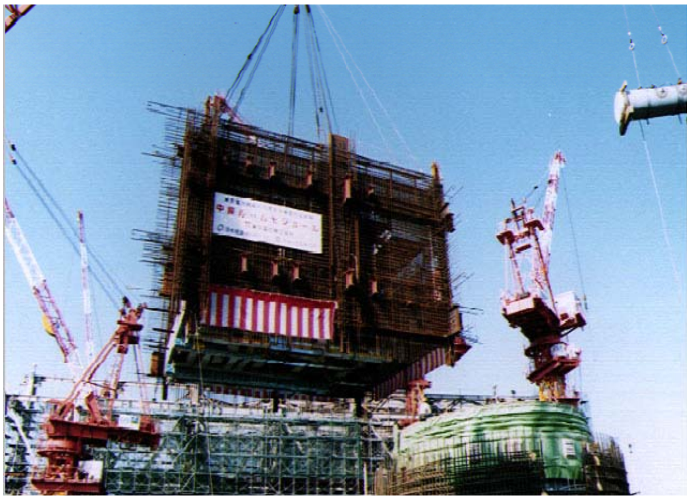


Fig. 5.14. Top slab module (Kashiwazaki-Kariwa).

- ***Lingao***:

  - Containment dome was assembled and installed as a single module (weight 143 tons, diameter 37 m, height 11 m). A new method called "ground assembly and top connection" provided for assembly of dome parts on the ground. During the steel liner erection all dimensions of the cylinder and girth were checked against the real size of the dome ensuring the success of the dome installation as a single module (Fig 5.15). Previously, the dome used to be assembled in two modules and their assembly in position took about 2 months.

Fig. 5.15. Lifting of dome module (Lingao).

- ***Tarapur****:*

    - Pre-fabrication of piping was increased to 60–70%, to compare with the earlier figure of 40%. Thus, field welding was reduced to 30–40%. This was made possible by handling the large piping spools segment with the help of crawler and tower cranes.

    - Calandria vault top hatch central beam is an example of modular construction. The steel module was fabricated by a leading vendor in Mumbai and transported to site. At site it was lowered in the reactor building with a heavy duty crane and grouted in situ.

    - Pre-fabricated liner module was used for construction of calandria vault and resulted in 2 to 3 months saving of time with respect to earlier projects.

5.2.3. Other construction techniques

5.2.3.1. All weather construction combined with parallel construction method

An “all-weather” cover dome may be put over the reactor building to protect the working place from weather conditions and to provides for temporary overhead crane and monorail hoists inside (Fig. 5.16). This method was used at Kashiwazaki-Kariwa Unit 6.

5.2.3.2. Use of Automatic Welding Equipment

Using automatic welding equipment is effective in maintaining high quality and in improving working environment at welding in narrow spaces. Table 5.1 shows the ratio of automatic welding and Figs. 5.17–5.18 illustrate the use of automatic welding at Kashiwazaki-Kariwa. Automatic welding equipment was used also for the welding of titanium tubes to the condenser tube sheet at Tarapur.

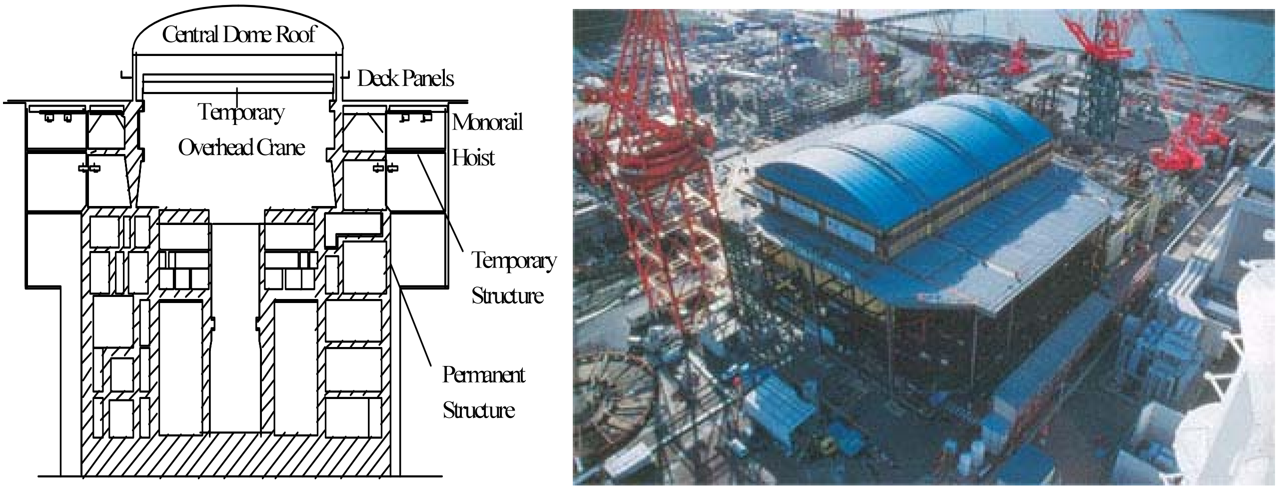


Fig. 5.16. All weather construction method (Kashiwazaki-Kariwa).

Table 5.1. Ratio of automatic welds (Kashiwazaki-Kariwa)

	Containment vessel	Piping	Lining vessel	Condenser body	Condenser tube
Unit 6	90%	20%	80%	50%	100%
Unit 7	21%(*)	35%	86%	90%	100%

(*) The large scale modularisation method was used for the installation of this unit, so most of the welds were performed in the shop.

Fig. 5.17. Automatic piping TIG welding (Kashiwazaki-Kariwa).

5.2.3.3. *Automatic scaffold elevating and horizontal rebar feeding machine*

These techniques have been developed in order to reduce the labour to installing rebar and to increase the precision of penetrations' positioning. They were used at Kashiwazaki-Kariwa Unit 6 (Fig 5.19).

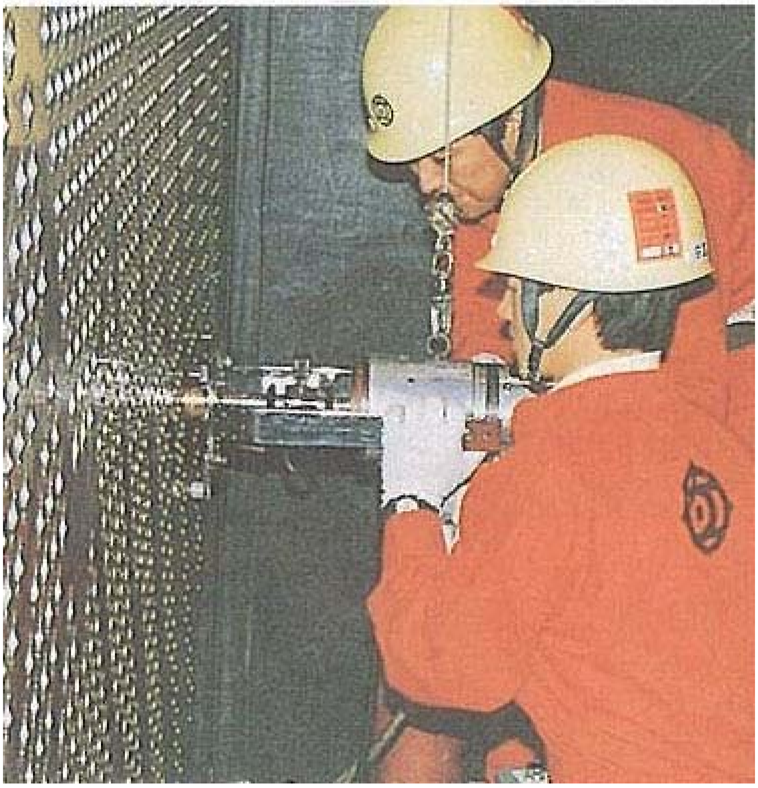


Fig. 5.18. Automatic welding of condenser tubes (Kashiwazaki-Kariwa).

Fig. 5.19. Automatic elevating scaffolding & horizontal rebar feeding machine (Kashiwazaki-Kariwa).

5.2.3.4. Automatic rebar assembly machine

The machine allows assembling of rebar into blocks through automated operations in accordance with rebar arrangement data that is loaded into the memory of the machine from a CAD model (Fig. 5.20). It was used for Kashiwazaki-Kariwa Unit 7 to increase the efficiency of assembling large amounts of rebar with a prefabrication type technique.

Fig. 5.20. Automatic rebar assembly machine (Kashiwazaki-Kariwa).

5.2.3.5. Pumping of heavy concrete

Pumping of heavy concrete may be done by properly designing the concrete mix using micro silica so as to have smooth pumping and flow in the pipes. This was used for calandria vault construction at Tarapur.

5.2.3.6. Shuttering

At Tarapur, using of left in shuttering in the slabs at elevations 115 and 130 m resulted in early release of areas for mechanical activities.

Use of Doka shuttering (Figs. 5.21 & 5.22) resulted in fast shutter erection and smooth surface finish and consequently saving in time with better quality.

Figs. 5.21. & 5.22. Doka shuttering installation in wall & slab (Tarapur).

5.2.3.7. Threaded coupler

Use of threaded coupler (Fig. 5.23) resulted in saving of time in reinforcement tying.

Fig. 5.23. Use of threaded coupler (Tarapur).

5.2.3.8. Round the clock working (Tarapur)

Round the clock working in critical areas of shop & plant erection may result in great timesaving. Fig. 5.24 shows the Tarapur site during the night shift, where the following time savings were made:

- 190 000 m^3 of soil excavation and 760 000 m^3 of rock excavation completed in only 6 months time.
- More than 500 000 m^3 concreting completed in 3 years with a peak concreting rate of 20 000 m^3 per month and average concreting rate of 14 000 m^3 per month.
- More than 14 000 tons structural steel erection job completed in just 2.5 years.
- Calandria vault concreting completed in 5.5 months compared to a target of 6.5 months.
- Inside containment dome concreting completed in 22 days compared to a target of 45 days.
- 100 m high ventilation stack completed in 60 days compared to a target of 150 days.
- End shield, calandria welding for Units 3 & 4 completed in 22 days and respectively 30 days compared to a target of 75 days.
- End shield ball filling for Unit 3 completed in 7 days compared to a target of 15 days.

5.2.3.9. Early development of infrastructure by package contractor

At Tarapur, about 10% mobilization advance was given to package contractors for the development of their infrastructure. This resulted in early completion of office premises with good communication network and better storage yard for equipment and consequently, the package contractors could give better output. Fig. 5.25 shows a partial bird eye view of Tarapur site.

Fig. 5.24. Night view of site activities (Tarapur).

Fig. 5.25. A bird eye view of area developed by package contractor (Tarapur).

5.2.4. Information technology supporting construction

It is common to use the Internet to link head offices with the site, and to link the owner with contractors and suppliers, etc., in real time to provide the latest versions of all design and construction documents. It was also common to manage the project documentation (including drawings, documents, correspondence and other project records) in electronic format on line, improving quality and efficiency and reducing costs. This was done in all studied projects.

The following are some examples of how information technology (IT) may support plant construction:

- Internet connection among participants (owner, contractors, designers manufacturers, etc.) to share project relevant information.

- 3D model and database shared by participants.

- Project management systems for the design, procurement, delivery installation and commissioning used for project planning, schedule control, cost control, management and review of design interface, document & archive management, commissioning and turn-over management.

- Auxiliary office information systems: electronic management of the project documentation (preparation, distribution, storage, retrieving, etc.).

5.3. Project management approaches

Project management is primarily concerned with the definition, direction, co-ordination and overall control of project implementation activities. Project management activities start with initiation of the nuclear power project and end with turnover of the completed and commissioned plant to the operating organization. Project management is essential for achieving the project objectives in terms of quality, cost and schedule.

A strictly defined relationship between the plant owner and his contractors, based on mutual competence and understanding, backed up by the experiences learned from the world good practices is the key to successful project management. In any case, the following two points should be clearly understood by all parties involved:

- The project manager of the plant owner has the authority and responsibility for overall supervision and control of the entire project.

- The common goal of all project participating organizations is the safe, reliable and economic construction and operation of the nuclear power plant.

The project manager is responsible for the cost, schedule and technical performance of the project and, assisted by a multi-disciplinary group of specialists, is in control of project activities such as design, engineering, procurement, manufacture, construction and commissioning. More details on project management for NPPs are given in [4].

5.3.1. Project planning and scheduling

Analysis of construction experience has led to an increased attention being paid to planning of project implementation, the quantity and quality of resources deployed and to the quality of outputs expected. The purpose of planning of project implementation is to ensure that the project objectives are achieved identifying, organizing and completing all tasks related to the nuclear power project. The planning of project implementation is vital to demonstrate an economic proposal with an acceptable level of risk to the project investors.

Within the overall project budget and duration, project management should define and plan individual expenditure and schedule targets for each major area of project activity, such as engineering, procurement, construction and commissioning. These plans should provide all participating organizations with a common understanding of the project objectives, scope, schedules, constraints, etc.

Based on the project implementation planning, other sub-programmes, e.g. engineering programme and procurement programme, can be prepared in detail and implemented subsequently to allow an early start of the site construction.

Brief descriptions of the way project planning and scheduling was done in the analyzed projects are given below:

- ***Qinshan:***

A level 2 Project Co-ordination and Control (C&C) schedule with 8500 events was developed, which sets the work requirements for all major project activities, including engineering deliverables (identified as release for construction), procurement (identified as delivery requirements), construction and turnovers, and commissioning.

This level 2 C&C schedule was produced within 6 months after CED. It was formally revised three times during the lifetime of the project to reflect actual progress and to incorporate improved sequences for construction and commissioning. Level 3 schedules were developed by supply and engineering companies within the first 12 months of the project and by construction and commissioning companies throughout the first two years, to comply with the overall level 2 C&C schedule.

Detailed level 2 and 3 schedules for engineering and supply were produced by area, using 3D CADDs and *Primavera* scheduling software and an integrated Qinshan deliverable system was generated detailing deliverables along with the budget, resources, schedule, status and responsible people. By the end of the job, a database containing more than 50 000 activities were produced by the contractors for the construction level 3 schedules.

- ***Kashiwazaki-Kariwa:*** The process of schedule preparation consisted of

  - Preparation of milestone construction schedule: timing of the construction start and duration time were determined based on power supply needs and on the cost-benefits analyses considering the following studies:

    - Major construction schedules (including key dates).
    - Study on the yard work concept (arrangement of large cranes, modularisation concept and arrangement of the yard).
    - Conceptual study for reducing schedules and improving construction method (module construction method).
    - Conceptual study of construction method specific to ABWR such as RCCV.

  - Preparation of yard work plan, which includes:

    - Yard work arrangement drawing at each construction stage.
    - Study on the yard occupation by cranes and temporary facilities etc.
    - Coordination between construction schedules of the reactor, turbine, other auxiliary buildings and outdoor structures.
    - Estimation of space requirements for temporary facilities.

  - Preparation of master construction schedule: modification of milestone construction schedule through the progress in the building and arrangement design, such as:

    - Integration of RCCV cylindrical section with reactor building.

  - Necessity of reinforcing steel structure due to single passage arrangement of T/B overhead crane.

- Preparation of sub-master construction schedule, including:Preparation of detailed construction schedule charts – mechanical, electrical and I&C (including modification of key dates).
  - Preparation of architectural work schedule charts — civil (including schedules of area transfer).
  - Work adjustments for area taking over and mismatch areas.
  - Modification of outdoor work schedule charts (including work procedure diagram).
  - Detailed study of construction methods applied to each building.
  - Equipment delivery scheme (including temporary opening).
  - Deck plate program.
  - Plan for use of sinking type forms.
  - Plan for use of temporary facilities.

Figures 5.26 & 5.27 present the management of the construction schedule before and respectively after the construction start.

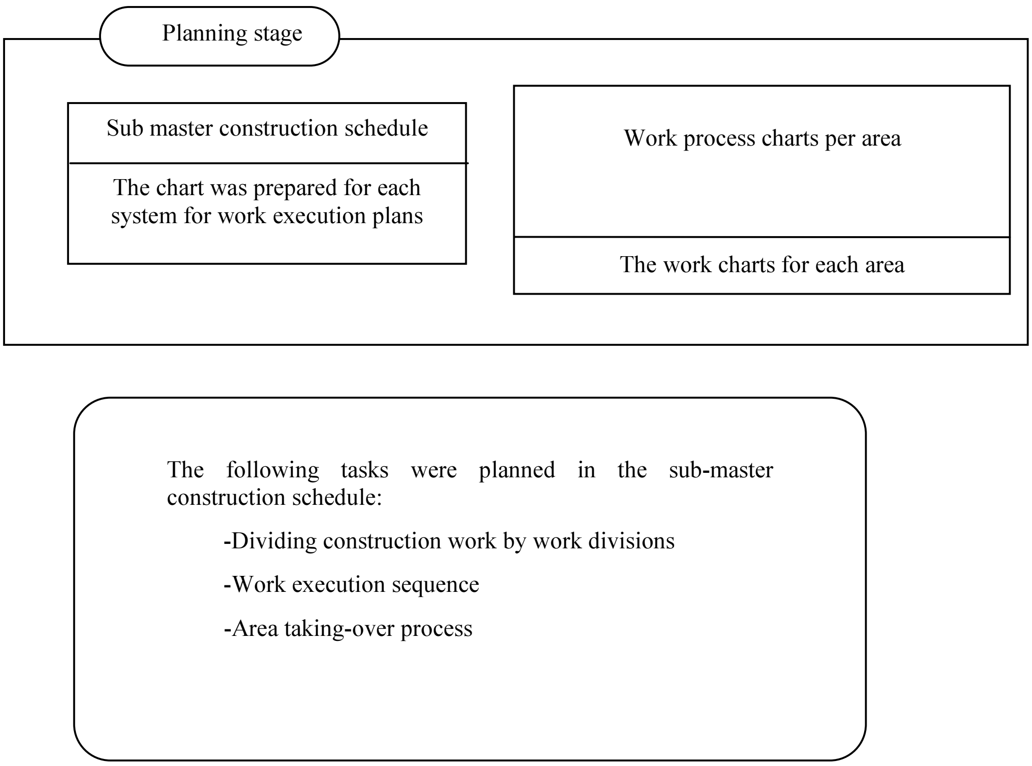


Fig. 5.26. Management of the construction schedule during the planning stage (Kashiwazaki-Kariwa).

After construction start

Installation stage: 3-month/3-week work construction schedule	Test operation stage: 3-month/3-week test operation schedule
The work charts for each area for daily work control	The system charts for daily system tests

Adjustments to make work execution easy (in conjunction with preparing the architectural construction work execution drawings)

-The work methods that could reduce interferences with machine work

-The work methods that enabled the construction period to be shortened

Fig. 5.27. Management of the construction schedule after the construction start (Kashiwazaki-Kariwa).

- ***Lingao***

There were developed 6 levels of schedule:

- The level 1 overall schedule contained the significant milestones and key activities of the design, procurement, civil works, erection and commissioning. It was prepared for each unit and covered the period from the first concrete to the end of performance test. There were a total of some 200 activities in the level 1 schedule and it was used as reference in the main design and supply contracts.

- The level 2 interface, coordination and management schedule was the core of project schedule control system. It included the main activities of design, civil works, erection and commissioning for NI, CI and BOP buildings, and was used to determine the interfaces and coordination between contracts. It was also the basis for development of level 3 schedules by the contractors.

- Level 3 schedules were prepared by contractors and reviewed by the owner. They included the start and end of construction dates for building or area, and the end of construction for the systems involved.

- Level 4 schedules were six-month rolling schedules, prepared by contractors as well. They detailed contractors' activities by building, area, elevation, system, discipline and work volume for the first 4 months and only a general schedule was provided for the last two months.

- Level 5 schedules were monthly schedules.

- Level 6 schedule were weekly schedules.

A yearly significant milestones schedule, consisting of twelve to sixteen milestones and a monthly list with control points, consisting of twelve to sixteen control points were developed. For each contract there were established key dates (control points), which facilitated the control and management of the interface schedule.

- ***Tarapur***

The Level 1 master project schedule was developed, containing about 500 activities and providing interface among contract packages. It clearly defined the following: completion of design; raising requisitions; placement of orders; delivery dates; erection completion; and testing and commissioning.

Level 2 schedule was developed based on sub-project concept and contained about 2000 activities. Each of the sub-projects represents sub-contracts finalized by major package contractors.

Level 3 schedule was developed by further breaking down the activity wherein system identification of activities was possible. It contained approximately 5 000 activities.

Level 4 schedules were developed for actual execution of the job. Here, floor-wise and area-wise schedules were made showing all the constraints. There were about 10 000 activities in level 4 networks. Target and actual schedules were compared regularly to identify problem areas and resolve issues.

Levels 3 and 4 schedules were made available on the intranet web site for reference and corrective action.

By properly defining the resource consumption, physical quantities and cash budget a target curve (mostly in the S-slope) was drawn and regularly compared with the actual progress to identify deviations and make corrective actions.

Level 1 to 3 schedules were developed within one month and level 4 schedules were developed two months later. From the above schedules a six-month window is sorted out and updated regularly. All constraints are indicated with required specific date for its resolution. This is regularly reviewed at all levels for updating and follow-up and finally reviewed every month by senior management from the corporate office.

An incentive amount was established for owner’s employees for progresses ahead of the schedule. Similarly, bonus and penalty clause was also introduced in critical package contracts. This motivated all the employees and contractors to achieve schedule reduction.

5.3.2. Design schedule

Reduced construction cost and duration are achieved if sufficient design and engineering expertise and efforts are utilized in the early stages of the project cycle. Experience shows that a minimum of 65 % of design and engineering information should be available prior to pouring the first reactor concrete in order to be successful. In this way the construction planning is made as an integral part of the design process.

The design activities can be generally divided into standard project design and site specific design. The standard project design includes the conceptual plant design as well as the detailed design necessary to ensure license ability and compliance with declared project cost and schedule. The standard project design should be as close to completion as possible before the start of construction. The site specific design includes the impact of the site conditions on the plant design, e.g. cooling water intake and out-fall structure and pump houses. This part of design may not be complete at the start of project construction and can be planned to meet the necessary construction milestones.

Ideally, the conceptual design should be completed before starting any construction. A minimum requirement is that for each area, the design is completed prior to start of construction in that area. It is very important to place contracts based on final drawings to avoid late changes. An early freeze of the design ensures early release for detailed engineering and procurement.

Completion of the necessary design and engineering in advance of the construction start will reduce the risk of construction delays and cost overruns. Integrated planning of engineering and construction is also a key to improvement of construction efficiency.

Other benefits of the completion of design prior to construction include the following:

- Availability of sufficient design information so that the safety and environment assessments can proceed as scheduled.

- Adequate time for preparation and completion of the licensing processes in a logical sequence.

- Availability of necessary information from manufacturers to ensure the erection and installation without interruption.

- Proper implementation of the manpower development programme for each discipline and for each period of the project.

Although details of the civil, mechanical and electrical activities may have been planned, certain flexibility should remain so that various changes could be effectively managed as they occur. For example, the final technical information of the long lead-time items is usually not available at the planning stage, although numerous data and commitments associated with the items are already provided by the supplier.

Two approaches for the design schedule, complying with the specific licensing process in force in the project's country, are presented below:

(a) Detailed design has to be available and submitted to support the application for the construction permit. Procurement can be started only after the construction permit is granted. This is the case in Japan:

  - ***Kashiwazaki-Kariwa***

    - Basic design completed before applying to government for the established permit.

    - Design details completed before applying to government for the construction permission.

    - Procurement started after receiving the construction permission from the government.

(b) Construction permit is given on the basis of the preliminary safety report, conceptual design and some other documents. In this case the detail design is finalized after the first concrete. However, the procurement process could begin before the construction permit is granted. For illustration, the status of the design at the pouring of first concrete is shown for the following projects:

- ***Qinshan***
    - Conceptual design completed.
    - Preliminary Safety Report (PSAR) issued.
    - Detailed design completed for works to be executed in a first phase (excavations; concrete pouring, etc.).
    - Technical specification completed for the materials needed.
- ***Lingao***
    - NI – 9% of the civil drawings issued.
    - CI – 3.7% of the civil drawings issued.
    - Main equipment ordered:
        - NI: reactor vessel, steam generators, pressurizer, etc.
        - CI: turbo generator, turbine hall cranes, Heating Ventilation and Air Conditioning (HVAC) equipment, main transformers, etc.
- ***Yonggwang***
    - Conceptual design completed.
    - PSAR issued.
    - Detail design: 30% completed.
    - BOP specifications: 19% finalized.
- ***Tarapur***
    - Design details were completed before applying to the regulatory for construction authorization permit.
    - First pour of concrete was taken up only after issue of all civil drawings needed for construction up to the ground level.

- Issue of embedded part drawings and reinforcement/concrete drawings was done six months and three months respectively before the construction.

- Advance procurement of long lead critical equipment was initiated before the first pour of concrete.

5.3.3. Construction schedule

The durations of the construction and commissioning (from the first concrete to the commercial operation date) for the analyzed projects range from 48 – 67.5 months.

Statistics drawn from IAEA's Power Reactor Information System (PRIS) indicate historical construction time span ranging from 33–42 months in the 'fifties to 48–300 in the first three years of the new millennium (Figure 5.28). It should be mentioned however, that PRIS includes about 40 nuclear power plant projects with delays of five or more years with respect to the originally scheduled commercial operation.

In comparison with historical PRIS data on construction duration, the analyzed projects (Table 5.2) are within the top performers of their generation in a generic context with much stronger regulatory requirements than in the early days of nuclear power.

Table 5.2. Construction durations

	Qinshan		Kashiwazaki-Kariwa		Lingao		Yonggwang		Tarapur	
	U1	U2	U6	U7	U1	U2	U5	U6	U3	U4
Construction duration [months]	55	58	48	48	60.5	61.5	58.8	61	64	67.5

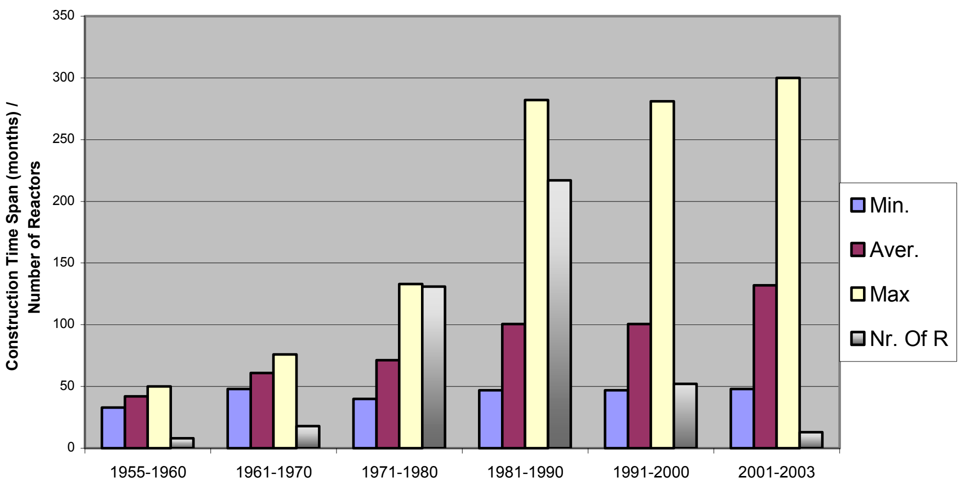
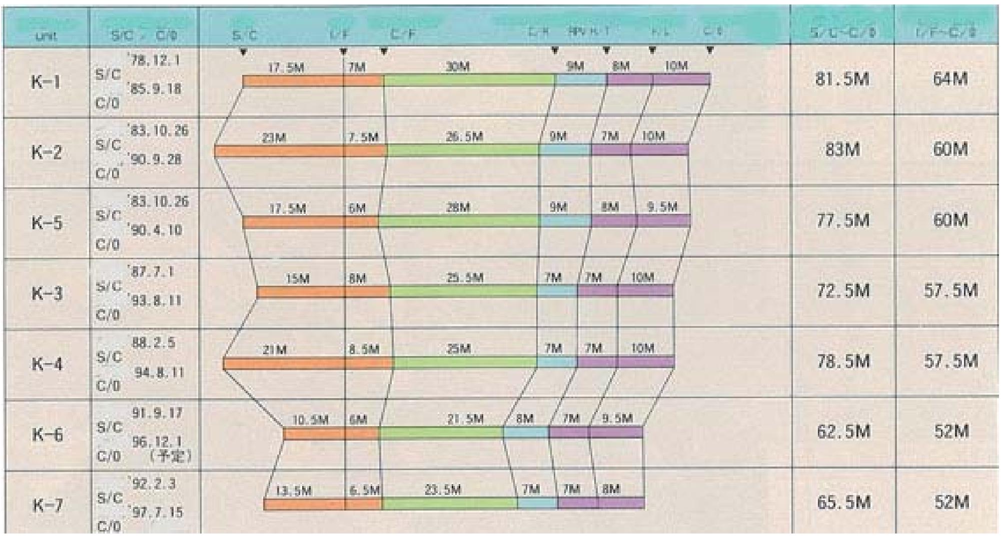


Fig. 5.28. Historical construction durations.

Fig. 5.29 shows the reduction of the construction schedule at Kashiwazaki-Kariwa with respect to the earlier units built on site. Table 5.3 presents Qinshan Unit 1 major contractual milestones.



Legend: S/C- Start of construction
I/F – Inspection of foundation
C/F- Completion of foundation mat
C/R- Completion of refuelling floor
RPV H/T- RPV First hydrostatic test
F/L- Fuel loading
C/O- Start of commercial operation

Fig. 5.29. Comparison of construction periods (Kashiwazaki-Kariwa).

Table 5.3. Construction key milestones (Qinshan Unit 1)

Key Milestones Unit 1	Contract Date	Actual Date
CED	12-Feb-97	12-Feb-97
First containment concrete	12-Jul-98	08-Jun-98
R/B slip form completed	12-Dec-98	23-Oct-98
Reactor moved into building	12-Mar-00	29-Nov-99
Moderator main circuit turnover	12-Dec-01	19-Oct-01
PHT main circuit turnover	12-Mar-02	19-Oct-01
Containment pressure test complete	12-Jun-02	26-May-02
Switchyard ready for station output	12-Jun-02	27-Jun-02
Start moderator D2O filling	12-Jul-02	31-Mar-02
Start fuel loading	12-Jul-02	18-Jul-02
Start PHT D2O filling	12-Aug-02	09-Aug-02
Authorization for criticality	12-Oct-02	18-Sep-02
First criticality	12-Oct-02	20-Sep-02
Approval to go to 100% power	12-Dec-02	17-Dec-02
Unit 1 complete (provisional acceptance)	12-Feb-03	05-Jan-03

5.3.4. Control of project progress

A successful nuclear power project is one that is designed, constructed, and put on line within the established schedule, budget and performance objectives. To this end control of project progress is one of the most fundamental functions of the project management. Control measures should be applied to both near term and long term tasks. Control therefore affects all partners and all phases of a project and it peaks during project execution. Control of project progress includes schedule & budget control and measuring progress.

Usually a schedule control system includes:

- A mechanism to report work performance and project progress.
- A process for changing, modifying and updating schedules.
- Measures to deal with contingency and adverse impact.
- Actions to capture schedule status and analyse trends.

If applicable, performance indicators are to be developed and used to measure and document the performance records of individuals and organizations.

A cost control system should define levels of authority and responsibilities of all managers and have a mechanism to report the cost performance and to take actions. The cost control system should describe:

- Cost breakdown structure and procedures.
- Process for obtaining approval for budget changes.
- Cost contingencies and how they will be managed.
- Measures to capture costs and evaluate cost performance.
- Some schedule and cost control features in the analysed projects are summarized below:
    - ***Qinshan***: Monthly updates by engineering, supply, construction and commissioning groups were inputted in the Level 2 C & C schedules, output was analysed, critical path and variance[8] analysis were performed. A separate monthly scheduling report, including the corrective actions taken when required, was issued to all project participants.
    - ***Kashiwazaki-Kariwa***: The construction supporting system developed by Hitachi included also a subsystem for the assessment of the work progress by material, building, area, system, and each sub-contractor (this system is described in section 5.3.5).

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[8] A variance is defined as any schedule or cost deviation from a specific plan. The budgeting and scheduling system variances must be compared together [5].

- *Lingao*: project cost control systems mainly consisted of cost control procedures, budgeting control, contract itemization control, contract commitment & payment control, cost control information and finance & financial risk management. The owner controlled design, procurement and construction schedules through levels of schedules and regular meetings. Flexible and logical adjustment was made to tailor the actual situation and ensure schedule implementation.

- ***Tarapur:***
  - Daily agenda for all commitments on day-to-day issues was made available on LAN and reviewed in the evening on daily basis.
  - Updating of commitments was done during the above meeting and constraints were resolved.
  - Weekly input is taken from each section for assessment of progress against target and weekly management information system report was sent to higher management for review and corrective actions.
  - Monthly management information system report was generated forecasting the trend of progress. Monitoring of the progress and corrective actions were initiated based on this report.
  - Six-month plans were generated by project management software listing all the constraints. The project management and the package contractor reviewed them periodically.
  - Package-wise report on actual versus target budget was also generated on a monthly basis for monitoring financial progress.

5.3.5. Management of information

It's a good practice to establish an Information Management System (IMS) to be used throughout the design, procurement, manufacture, construction, commissioning and the whole lifecycle of the plant. Due to the volume of information at a NPP, computerized IMSs are commonly used. This reduces administration time and storage space, improves correctness and efficiency of data management, and allows for instant access by personnel.

Available CADDs, computer databases and other computerized systems can be part of the IMS. In order to realize all the advantages that such systems and databases could provide to the site construction, it is necessary for the project management to work very closely with the design and engineering organizations from an early stage in the project.

Modern construction information management systems assist the construction manager and owner in managing project costs, schedules, workflow, communications, manpower and all documentation, with a completely electronic, paperless interface among all parties of the project team. Local Area Networks (LANs) are used to connect on-site representatives of the construction manager, design professional, contractor, and owner, and have additional capabilities for remote communications.

Each of the analysed projects had its IMS. Some of the main tools used at Qinshan, Kashiwazaki-Kariwa, Lingao and Tarapur are briefly presented below:

- **Qinshan**

    - *Asset Information Management (AIM) and TRAK integrated databases*: AIM is a documentation file manager that provides on-line access and archiving for all project participants. TRAK manages all project documentation (including drawings, documents, correspondence and other project records) in electronic format online, having improved quality and efficiency and reduced costs. TRAK accesses information from AIM to facilitate scheduling, issue, distribution and shipping of project deliverables and maintain the project document baseline. A key feature of AECL's internal production of design documents is electronic approval of documentation, which means that project official records can be electronic. This greatly simplifies storage, accessibility and upgrading, and facilitates configuration management during both construction and operations.

    - *LAN and Internet*: Real time status reports and documents are accessible to all project participants at all sites over LANs. The transfer of documents and drawings between Canada and site was also done electronically using the Internet. Two dedicated LANs were established:

        - LAN of CT with the following main functions: access or use of systems concerning the plant parameters LAN and project management LAN; Work Permit Management System to achieve control during commissioning and production; to manage work permits, work processes and regular tests; Work Package Database Management System to store basic information of various commissioning and maintenance work packages; to retrieve and trace the progress of work packages of each work execution group; In-core Physics Calculation and Optimisation of Fuel Management System; and Nuclear Material Accounting System.
        - LAN of the owner with the following functions: internal e-mail system; integrated company information management system (internal website); contract management system; accounting management system; personnel management system; etc.

    - *Weld Information System* developed by a constructor contractor to electronically record quality information for all pipe welds.

- **Kashiwazaki-Kariwa:**

Figure 5.29 shows Hitachi's organization of its construction supporting system. This system has project management functions like planning, execution, measurement and making corrections.

The construction support system is composed of seven subsystems:

(1) *Schedule planning system*: This system prepares three-month and three-week schedules based on the area schedules. This system is integrated with the work order and the inspection support systems and updates the schedule as the work order / inspection request is implemented. Design data such as the equipment number, construction-drawing number, and welding number could be taken through the document control system.

(2) *Document control system*: This system accepts, distributes & collects sub-contractor documents and manages obsolete documents. All this information is sent to the job site after processing and integrating in the Hitachi's offices. It manages also documents prepared on site and it is possible to retrieve a document image through Internet.

(3) *Material control system*: This system supports the management of goods delivered to the site. Each piece of material has a unique stock code number. This number is entered into the system based on design specification. The delivery date is entered into the system based on the contract documents. The system also manages the deliveries to the site contractors and has an inventory function.

(4) *Work order system*: The foreman issues a work order based on the three-weeks schedule, and after the supervisor and the chief supervisor approve the work order, he instructs the worker by a Personal Digital Assistant (PDA) or a work order sheet. The work results are entered by up loading from the PDA or by direct input to database. After the supervisor and the chief supervisor approve them, the inspection request data is transferred to QC section.

(5) *Inspection support system*: The person in charge of the inspection checks the data in the electronic data collected by the work order system and downloads to the PDA or prints the record sheet and then the inspection is executed. The inspection results are entered by up loading from the PDA or by direct input into the system, and stored in the database after the manager approves them.

(6) *Labour control system*: This system manages all field workers. Among other things it contains information on individual qualifications such as welding qualification and identifies employment opportunities.

(7) *Progress evaluation system*: It assesses the work progress by material, building, area, system, and each sub-contractor based on the data collected in the electronic form by the work order and the inspection support systems.

The database was distributed to the job site and the Hitachi office to facilitate the work and improve security. The components of the database were synchronized during the night. In addition, a local network similar to that at the head office was constructed at the site and all Hitachi's sub-contractors were authorized to use this network.

Administration of system users and permissions was managed by the labour control system. The registration with this system was mandatory for all workers on site. Work orders such as welding could be prepared and issued with the PDA and the approval request of the work order and record were also notified to individuals with electronic messages.

- ***Lingao***

  - The core of Lingao's project information system was a central information database set-up to follow up design, procurement, manufacturing surveillance, transportation, erection, site's commissioning and for the preparation of the operation, to meet the daily management's requirement.

  - An auxiliary office information system was established for the electronic management of all categories of documents (covering preparation, transmission, review, document 's storage and filing). This system was shared with all participants in the project.

- An integrated management system was set-up for the project based on the project information system, the financial management system and the auxiliary office information system to provide the different management levels with the necessary information.

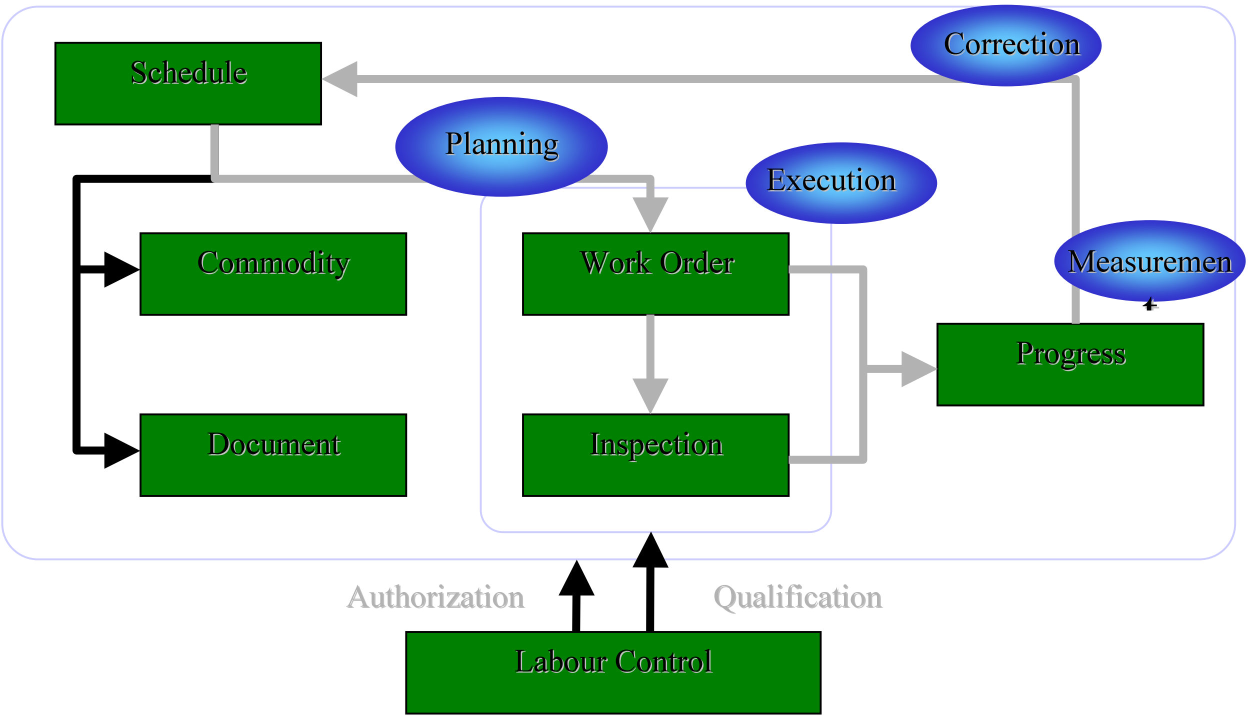


Fig. 5.30. Overview of Hitachi's construction supporting system (Kashiwazaki-Kariwa).

- ***Tarapur***

IT was used to the fullest extent for enabling quick reference of documents/drawings and providing proper communication network. Following example illustrates the role of IT in support of construction activities:

- All offices were connected through local area network using fibre optic backbone, thus enabling faster data communication. All sites including head quarter were connected through intranet web site using V-sat communication network.

- Owner, contractors, designers, manufacturers could communicate in electronic media for sharing project information. 3D modelling was shared with all the participants. Electronic management of project documents was enabled.

- Project schedule was prepared on project management software: Primavera Project Planner and M.S. Project and integrated. The information was made available on intranet web site.

- All Indian standards were made available on LAN.

5.3.6. Methods to subcontract material and construction works

5.3.6.1. Procurement Programme

To enable smooth construction of a NPP, a detailed procurement programme is to be established early enough. The programme includes procurement of the following:

- Necessary engineering documents in advance.
- Items, especially long-lead-time components, in advance.
- Services, such as civil, mechanical, electrical and I&C services in accordance with the project master schedule.

Procurement of an appropriate quantity of spare parts and consumables not only for construction and commissioning but also for the first period of operation and maintenance is recommended. Their technical specifications and procurement records should be retained. Lead-time and future availability should be key considerations in selecting such items.

In general, items should be delivered several months in advance of the erection or installation activities. The ways of transportation and the date of arrival at site should be specified and stipulated in the procurement contracts.

5.3.6.2. Procurement process

The procurement process shall ensure that engineering documents, materials, components, equipment and services are furnished to meet the requirements of the construction progress. A maximum and minimum inventory levels should be defined to control procurement of bulk material.

The procurement process should include implementation of QA requirements, such as supplier evaluation, control of processes, external audits, pre-shipment verification, and receiving inspection. QA documents, operation and maintenance manuals should form part of the delivery.

Pre-qualification and selection of manufacturers can save procurement time. Face to face contact between manufacturers and construction organizations should be encouraged. Environment qualification of items should be addressed where applicable. Delivery dates to site should be monitored, tracked and updated when needed. Receiving inspection should be performed, including review of material conditions and documentation.

Planning of procurement of items important to nuclear safety may need to consider placing resident inspectors of the plant owner at the manufacturer during the manufacturing process. The manufacturers should be required to report to the plant owner frequently and thoroughly. Clauses related to incentives and liquidated damages should be used in procurement contracts.

Some developing countries have experienced difficulties resulting from procurement of items from several countries originating in different quality standards. QA should provide measures to eliminate such conflicts.

The large volume of information during the procurement process should be entered, stored, managed and retrieved by a sophisticated system, such as a computer system. Some of procurement documents should form permanent records.

The main features of the procurement processes in place at Qinshan, Lingao and Tarapur are briefly presented below:

- ***Qinshan***
  - Construction scope was divided in Construction Work Packages (CWPs). Individual general subcontracts were assigned for: mass excavation, pipe prefabrication, ready mix concrete production, temporary construction utilities, and inland transportation. Plant building and system CWPs were established by craft discipline and compiled into two civil and two installation subcontracts (one each for the NSP and BOP).
  - AECL entered into the subcontracts covering the general works and the NSP civil and installation works with local contractors selected with the agreement of TQNPC. TQNPC entered into subcontracts for the BOP.
  - The Chinese construction contractors were responsible for providing skilled resources, management and supervision, planning of work and quality program.
  - SPMO provided overall management of NSP construction and technical assistance to the construction contractors to reinforce their planning: develop schedules, catch-up programs & plans and develop and use production indicators to manage bulk works. Also SPMO assisted contractors to: subcontract specialized activities such as structural steel design and fabrication; improve organization for better communications and increased productivity; develop quality procedures; assess training programs and update as needed; comply with worker qualifications and certificates; set up and execute check and test programs that represented an increase in their traditional scope; and set up and carry out industrial safety and worker safety programs.
  - Pricing the work by the subcontractors was done on CWP basis, which permitted firm prices to be established for a large percentage of the scope. Since each subcontract firm pricing was established at a low level breakdown within each CWP, the subcontractor-estimated labour resources were more accurately established and available. AECL and Bechtel/Hitachi supplied the majority of the material and equipment separately, with the exception of mainly concrete, rebars and steel. Interrelationship with the construction schedule was readily available and produced accurate labour & cost monitoring and forecasts throughout the implementation of the construction works.
  - Quantities reconciliation between contract value and actual quantity installed were regularly kept update. Contractors were paid based on the actual quantity installed.
  - Fig. 5.31 shows the construction interface worksheet

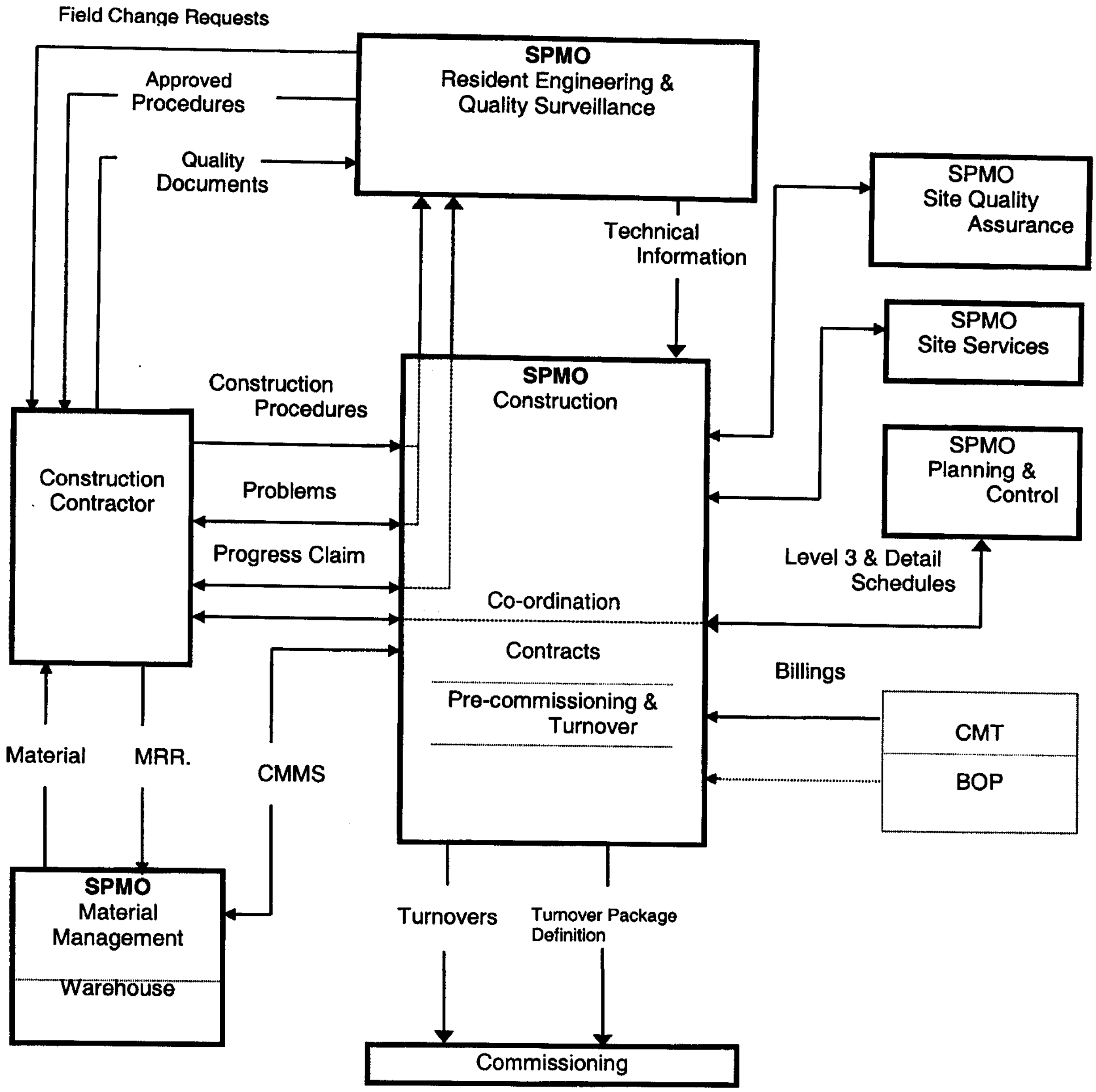


Fig. 5.31. Construction interface flowsheet (Qinshan).

- o ***Lingao***

  - Civil construction works were divided in NI and CI civil works. Both were completed by local companies.
  - Installation works were divided in NI, CI and BOP. NI installation was divided in 10 work packages. One (installation of the primary loop) was given to FRAMATOME and the others to a domestic contractor. CI and BOP installation work were given also to local companies.
  - Payment was performed in accordance with the progress of the work.

- *Tarapur*
    - Total procurement and construction scope was divided in packages.
    - Supply packages were given for long-lead equipment and they were awarded through a two part tendering process.
    - Supply & erection and EPC packages were awarded to pre-qualified vendors.
    - Main issues considered in the qualification process included: financial status, resources, quality & safety organization, ISO certification, feedbacks regarding credentials, pre-occupation, infrastructure backup and in-house design support.
    - Sub-contracting by major package contractor was allowed with the approval of project management.
    - Civil construction work was divided in 4 major packages.
    - Single package for electrical work was awarded.
    - All instrumentation work was awarded in the form of two mega-packages.
    - Mechanical works were awarded in about 30 packages according to expertise available with the Indian manufacturers.

5.3.7. Other management issues

During analysed projects implementation a strong focus was also on the following aspects:

- Effective partnership between owner and main contractor(s).
- Setting up effective processes and procedures to ensure quality.
- Sensitivity to and understanding of local culture and practices in all aspects of the project, including language problems.

5.4. Material management

The objective of material management is to ensure that the variety, quantity and quality of materials meet site construction requirements and are available according to schedules or when urgently requested.

A material management system usually relies on a computerized database, which maintains material inventory and controls inventory location.

The material management system also includes a material identification system. Alphanumeric stock codes designated during the design stage function as a unique identification number of materials or items. The stock code is tracked and traced in all documents for design, procurement, transportation, storage, construction, commissioning, operation and maintenance.

A material management system includes basically the following functions:

- Receiving/inspection: Unloading & inspection of incoming materials for identity, completeness, quality and condition of the material and as well the related technical documents, provision of inputs to the computerized database.

- Site storage: Storage and preservation of materials in accordance with manufacturer's instructions, as well storage of associated document and update of information in the computerized database.

- Distribution to construction/commissioning: Release of the materials as needed in accordance with procedures; provision of inputs to computerized database.

- Contingency procurement: The needs for materials are normally identified well in advance by design and are purchase by the procurement unit. However for urgent contingency needs material control could initiate requests to procurement group.

A brief presentation of the main features of Qinshan's material management system is given below as an example of the scope covered and tools used.

- ***Qinshan***

  - Scope of Qinshan's material management system includes: Co-ordinating; planning and scheduling of heavy lift and transportation movements; calibration of instruments; managing the receiving process of all materials including receiving inspection; implementing a bar coding system for tracking and control of materials; assisting owner in establishing proper storage conditions in various warehouses for levels A/B/C storage; developing qualified local suppliers; managing the material substitution programme; establishing a programme for hazardous material storage and handling; and training local staff and construction contractors on computerized management systems. The traffic and supply function included handling of major equipment (eight steam generators, two reactivity mechanism decks, two calandria, two pressurizers, two degasser-condensers, four airlocks, various heat exchangers, eight feeder frame assemblies, two turbine generators, and various cranes). Management of materials at site was carried out by the SPMO Materials Management Team (MMT), consisting of 8 expatriate staff and 70 local staff at peak.

  - The heart of the system is the Candu Material Management System (CMMS). Material management starts from the moment a designer identifies a design element in 3D CADDS or IntEC, and continues with procurement management, storage and release of materials during the lifetime of the station. Since CMMS is integrated with 3D CADDs, accurate material identification is achieved, which is particularly important for materials requiring QA documentation and traceability. CMMS is also used to create bills of material. Supplier, forecast and actual schedule, release, shipment and cargo information is also added.

  - An enhancement made at Qinshan was that items were bar coded and input to CMMS as they arrived at site. Issuing of materials to contractors using the same bar coding and online linkage to CMMS gave good material tracking and control.

- CMMS also supports on-going plant operation and maintenance, by detailing the status of each item by stock code number and tag number.

5.5. Site infrastructure preparation and management

Site infrastructure preparation and management during the construction stage includes planning, acquiring, construction and maintenance of all provisional site buildings, facilities and systems, as well as a residential area and the necessary social infrastructure. Detailed planning of site infrastructure usually considers the type of contract, construction schedule, delivery and transport of large equipment, and availability of all other necessary resources. Usually, preparation of the site infrastructure is started at least six months before the start of construction of the reactor building.

Site specific conditions, such as those listed below, have a considerable influence on the infrastructure planning:

- -Siting conditions, such as topography, soil and rock, earthquake, etc.
- -Whether conditions, such as wind, temperature, humidity and precipitation.
- -Qualified craft manpower available in the vicinity.
- -Local industrial infrastructure, such as power and water supply, and status of traffic.
- Selected examples of the site infrastructure preparation and management for the studied projects are given below:
    - ***Qinshan***
        - The transportation and logistical support for the project presented some major challenges, in that all materials and equipment (including the very large equipment such as the calandria, boilers, and condenser sections) from across the world would have to come through Shanghai. Due to road and bridge restrictions, this equipment was moved by barge from Shanghai and by heavy multi-wheel-transporters from the local dock to site at about 2 km. The approximate tonnage via barge was 27 000 tons. About 1500 tons of materials were air shipped. Strict processes, procedures and controls, with frequent audits by the QA department, contributed to the overall success of the program.
        - Warehouses:
            - Indoor 12 200 m2, out of which off-site 5800 m2 (within 1 km from the in-site storage).
            - Outdoor 51 500 m2, out of which 28 500 in-site storage and lay down area.
        - Offices and archives: The owner provided the main site offices at the commencement of the project. These were built as the permanent office facilities for the operating stations. This advanced planning resulted in good

facilities for the project management team of main contractor and owner personnel who were also housed in the same building. In addition, this building also housed the main document control archives and computer facilities for the project.

- Accommodations:

  - Expatriate accommodation was provided about 15 minutes from the site. There were about 180 apartments consisting of 3, 2 and 1 bedrooms, bathroom, living room, dining area, and kitchen (120m^2 for a 3 bedroom apartment).

  - A Canadian standard school was established, with six expatriate teachers. The Canadian curriculum covered Grades 1 to 8, with older children going to boarding school in Canada.

  - The compound also had a gymnasium, recreational centre with fitness centre and bar with pool tables, swimming pool, basketball court, clinic and restaurant. Internet and cable television were also provided.

  - During the construction peak of the two units, there were about 180 AECL expatriate staff on site, along with about 8000 combined construction and other contractor staff and TQNPC.

o ***Kashiwazaki-Kariwa***

- Total size of the site temporary yard used within or outside the site is shown in Table 5.4. Details for the yard used by Hitachi are indicated in Table 5.5. Figure 5.32 shows the site infrastructure used by Hitachi.

o ***Lingao***

- As Lingao is nearby Daya Bay NPP, some of the common facilities could be shared to make better use of human resources, warehouse, offices; buildings, archive and staff accommodations, resulting in lower costs. Given below are some examples:

  - Warehouses: The equipment inventory stored in the warehouses is 20% less than that for Daya Bay. The total storage surface is 20% smaller than the one for Daya Bay. Accordingly, the investment on warehouse facilities is 40% less.

  - Offices**:** During the construction period the offices built for Daya Bay construction stage were used and two additional permanent office buildings were built for the operation department.

Table 5.4. Site temporary yards (Kashiwazaki-Kariwa)

[m^2]

		U-6	U-7
Mechanical	In-site	98 100	
	Out-Site	128 900	
	Total	227 000	
Building	In-site	54 000	60 200
	Out-Site	14 200	16 300
	Total	68 200	76 500
Civil	In-site	96 700	
	Out-Site	18 700	
	Total	115 400	
Total	In-site	309 000	
	Out-Site	178 100	
	Total	487 100	

Table 5.5. Site temporary yard used by Hitachi (Kashiwazaki-Kariwa)

		Area [m$^{2]}$	Remarks
In-site (Around Office Area)	Office Area	2500	
	Warehouse & Stockyard	30 000^2	
	Workshop	10 000^2	
	Parking Area	5500^2	
	Sub total	48 000^2	
Out-site	Accommodation	12 000^2	
	Stockyard	34 000^2	
	Sub total	46 000^2	
Total		94 000^2	

- *Tarapur*
  - The planning for movement of over dimensional consignment (ODC) was done well in advance.
  - A sea route was finalized for transportation of steam generators, end shields and imported equipments.
  - The warehouses (9354 m^2 indoor and 15 000 m^2 outdoors) were provided by the owner. Package contractors developed 50 000 m^2 of closed storage yard and 200 000 m^2 of open storage yard.
  - Offices were provided for owner's construction and commissioning staff in16 shacks and a part of permanent warehouse. Package contractors have developed their own offices.
  - Storage capacity was provided for 27 000 documents and drawings in the archives. Also the archive was equipped with scanners, printers, LAN, 240 GB storage space, A0 colour plotter, etc.
  - Accommodation was provided at a distance of about 12 km from site for owner's employees (250 construction staff and about 600 O&M staff). About 11 ha land was allocated at a distance of about 4 km from site for the labour camp. During peak construction, 250 owner's construction employees and about 8000 contractor's manpower were hosted.

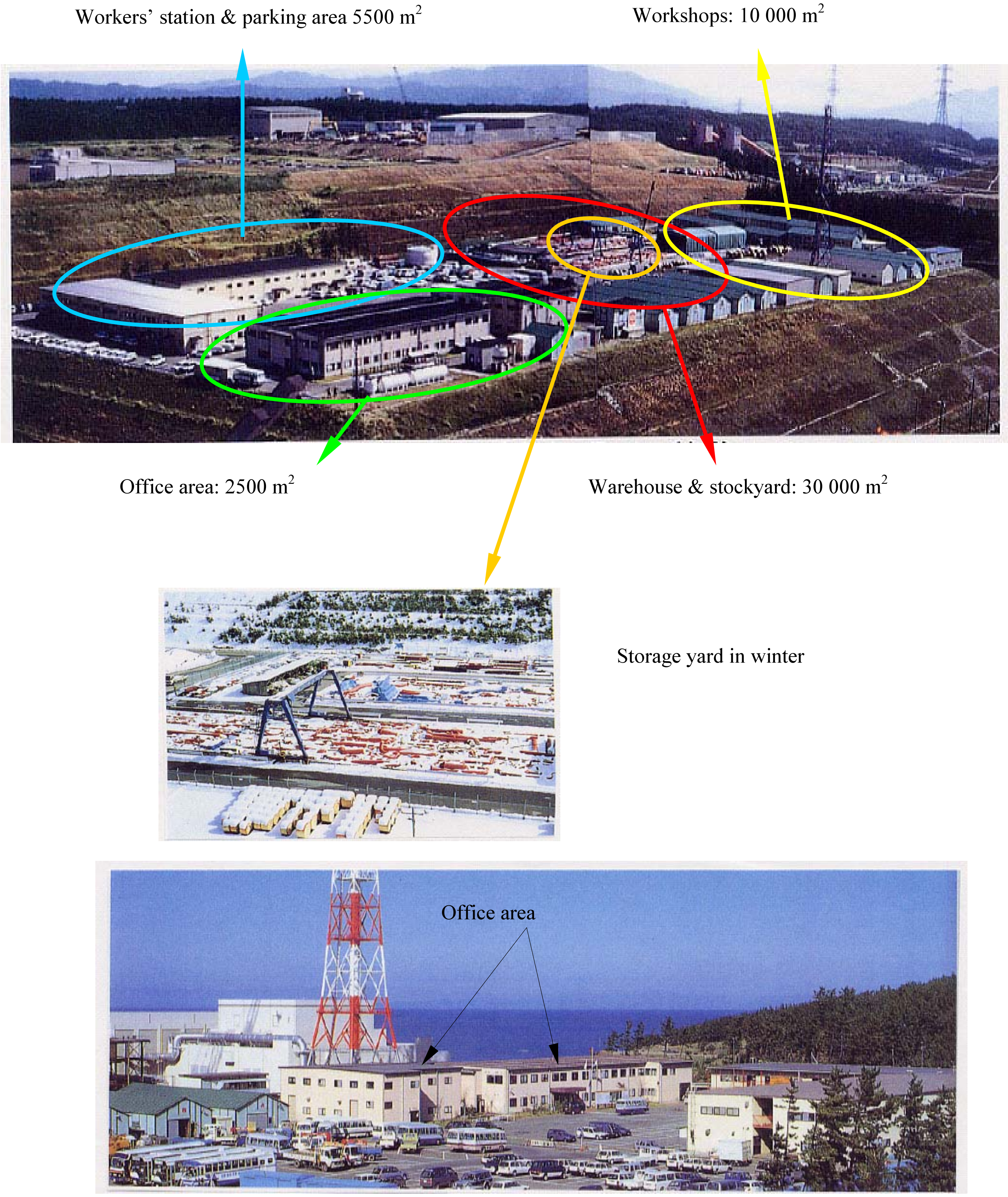


Fig. 5.32. Site infrastructure used by Hitachi (for both Kashiwazaki-Kariwa units).

CHAPTER 6. MEASURES TO REDUCE COMMISSIONING PERIOD

Before a nuclear power plant is put into commercial operation, the functional adequacy of the installed components, systems and the plant as a whole must be tested to demonstrate that the plant can be operated safely and reliably. Some commissioning activities may coexist with construction or operation activities.

The main objective of commissioning is to confirm that the design intents of the components, systems and the plant as a whole are achieved. Commissioning objectives also include optimisation of the plant system functions, verification of the operating procedures, getting the operating personnel familiar with the plant systems, and producing the plant initial startup and operating historical records.

Some commissioning tests may be performed by commissioning groups well ahead of the formal turnover of the entire plant to the commissioning organization. At the end of the commissioning stage, the tested systems and the complete plant are turned over to the operating organization.

Generally, the contract strategies will determine the nature of the commissioning management. In the turnkey approach the main contractor normally manages the commissioning organization. In the non-turnkey approaches the commissioning organization is likely to be directly managed by the plant owner, sometimes with the help of an A/E organization.

This chapter provides an overview of plant commissioning, illustrated with selected examples, and describes the methods and approaches to reduce the commissioning period used in the reviewed projects.

6.1. Plant commissioning

6.1.1. Test programme

The test programme for the nuclear power project is usually established during the design stage. The test programme covers all required tests, including equipment tests before installation, tests of installed components and systems, and the plant power tests. The whole test programme is, in fact, implemented by both the construction and the commissioning organizations respectively. The project management should develop a clear policy that allocates responsibilities of the project participating organizations for implementation of the test programme during the construction and commissioning stages.

Tests should be performed according to test procedures, which are established in accordance with QA requirements and include applicable quality standards, technical specifications and acceptance criteria. The test procedures should describe the scope of testing, indicate the test prerequisites and precautions, provide detailed guidance for conducting tests and include methods for evaluation of test results in conformance with design requirements.

The design organizations are responsible for formulating the test objectives, acceptance criteria and for evaluating the test results. Unexpected test results or occurrences should be analysed and immediate corrective actions taken. Retests should be prescribed if necessary.

6.1.2. Commissioning programme

Project management is usually responsible for establishing of a commissioning programme to ensure that all tests, from component tests, system tests, pre-operational tests up to power tests, can be performed in a logical sequence by qualified personnel with calibrated equipment according to approved procedures.

The commissioning programme should be drawn up at least six months in advance of the commencement of commissioning activities. Each commissioning test procedure should be finalized at least six weeks before the start of the relevant system test in order to have enough time available for preparation of the test equipment and documents.

The following documents, which should be provided by the construction organizations and included in the turnover packages, are necessary for development and finalization of the commissioning testing procedures:

- System description.
- System flow diagrams.
- Component operation instructions.
- Design and construction reports.

Training requirements and test equipment should be defined at an early stage to ensure that qualified personnel and suitable equipment are available in accordance with the project schedule. Nuclear and industrial safety provisions should be included in the commissioning programme, such as:

- Fire prevention and fire fighting.
- Control of radiation exposure and waste.
- Housekeeping and cleanliness of areas and systems.
- Management of accident and injured persons.

6.1.3. Commissioning organization

There is usually an overlap between the commissioning stage, the construction stage and the operational stage. Three kind of works coexist as described below:

- Final installation and completion of the plant,
- Continuous performance of the commissioning tests,
- Operation of the plant to support commissioning.

Moreover, those participating in the commissioning tests and supporting activities may also include personnel from the construction and operating organizations, and representatives from designers, manufacturers, QA units and regulatory body.

The commissioning organization usually includes a number of commissioning groups for testing of different systems and the overall plant. A commissioning group is usually a composite team, made up of construction and operating personnel from, for example, the equipment supplier, main contractor, A/E and the plant owner. Upon completion of the commissioning tasks, these people will generally return to their original organizations.

The commissioning manager should formally take over the overall responsibility for the entire plant from the site manager normally prior to the first hot functional test.

Operation of the plant systems and the entire plant during commissioning should be performed by suitably trained and qualified operating personnel, provided by the operating organization and integrated into the commissioning programme. The following services are also necessary to be provided by the operating organization to the commissioning organization:

- Maintenance, including personnel and workshops.
- Support services such as water chemistry and radiological protection.

The commissioning organizations at Qinshan, Kashiwazaki-Kariwa and Tarapur are presented below:

o ***Qinshan***

Division of responsibilities

Overall commissioning, operation and maintenance of each unit up to its provisional acceptance were under the responsibility of an integrated CT, consisting of about 1000 TQNPC staff (for two units), plus about 45 expatriates to provide guidance and direction. TQNPC and AECL staff worked under the direction of the AECL Project Director and TQNPC General Manager respectively. The reporting relationships between the CT, AECL Project and the TQNPC Operations Organization are illustrated in Fig. 6.1. The CT was formally set up 24 months prior to fuel load.

The expatriate staff together with TQNPC staff and supported by design engineering staff (AECL for NSP and Bechtel-Hitachi Consortium for BOP) solved the technical problems discovered during commissioning. The designers were responsible for making the final decision and performing the design changes necessary to resolve any equipment performance-related issues.

AECL was responsible for:

- Provision of guidance and direction to TQNPC, including defining the organization, staffing, QA program and procedures, commissioning program and acceptance criteria, planning and scheduling, troubleshooting problems, review and acceptance of major test results and the assurance of commissioning completion in accordance with the specified requirements.

- Provision of on the job coaching and mentoring of TQNPC staff, and in some cases direct supervision, to meet quality and schedule requirements.

- Coordination of the turnover of systems from construction to commissioning and resolution of any related problems.

- Interface coordination among its sub-contractors, for NSP.

TQNPC was responsible for:

- Training of all commissioning, operations and maintenance staff.

- Preparation of detailed commissioning documents.

- Obtaining regulatory authorizations of the operating staff to meet the licensing requirements by fuel load.

- Obtaining all the necessary licenses and permits required for the commissioning programme.

- Procurement of heavy water, nuclear fuel and other consumables except for what was specifically covered in the AECL scope of supply.

- Assuring that the work performed by BOP contractors met the commissioning requirements (TQNPC's CMT).

- All operations-related activities to support commissioning including health physics and radiation protection, chemistry, nuclear safety and training (under the guidance and direction of AECL).

Commissioning organization

The CT was divided into four distinct functions:

- *Commissioning technical function* consisting of six separate departments: namely NSP Process, NSP I&C, Fuel Handling, Electrical, Common Services and Thermal Cycle. They were responsible for the development and implementation of a commissioning programme for the Qinshan NPP to demonstrate that plant structures, systems and components met their design requirements before they were declared available for service.

- *Commissioning execution function* consisting of six Commissioning Execution Groups (CEG) for each Unit and Maintenance Department, one corresponding to each of the six Commissioning Technical Groups. They were responsible for performing field commissioning as defined by the Commissioning Technical Departments using the resources of the Operating and Maintenance Departments.

- *Production function* consisting of five separate departments: namely Operating, Maintenance, Chemistry Control, Health Physics and Nuclear Safety. The Operating and Maintenance Departments are responsible for performing normal plant operation and maintenance and for executing field commissioning. The Chemistry Control Department performed normal chemistry analysis and control functions, and supported commissioning activities. The Health Physics Department performed normal radiation protection, dosimetry, industrial safety and emergency preparedness functions, and supported commissioning activities. The Nuclear Safety group was responsible for developing the reactor physics and thermo-hydraulics commissioning programme during Phases A, B, and C and for providing technical support to commissioning execution/operating staff to conduct these tests.

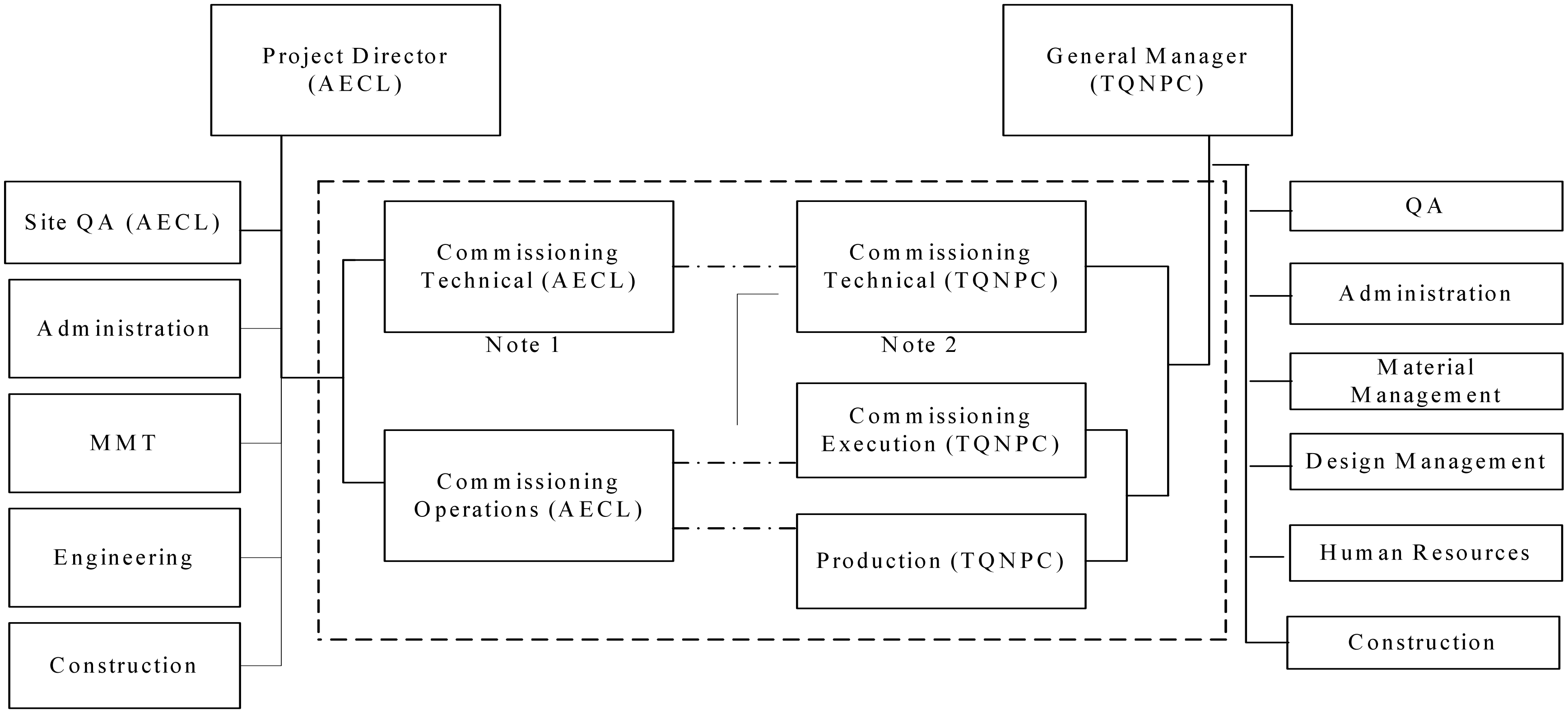
- *Planning function* responsible for developing the optimised integrated commissioning logic based on level 2 commissioning procedures (CP2s). This was then used to schedule the turnover of systems from construction to the maximum extent practicable. Planning was also responsible for developing and implementing a computerized database for work management system to schedule field execution of commissioning activities as well as emerging breakdown work. Planning issued a weekly plan that formed the basis for daily plan for commissioning execution groups to perform fieldwork.

Typical commissioning organizations are shown in the following figures:

- Figure 6.2 shows the Integrated Unit 1 and 2 CT and Operations Organization.
- Figure 6.3 shows a typical Commissioning Technical Group.
- Figure 6.4 shows a typical CEG.

o ***Kashiwazaki-Kariwa and Tarapur***

Figures 6.5 and 6.6 show the commissioning organization charts at Kashiwazaki-Kariwa and Tarapur.



Note 1: The AECL Commissioning and Operations organization provides guidance and direction to TQNPC Commissioning and Operations organizations and has a reporting relationship to AECL Project Director.

Note 2: The TQNPC Commissioning Technical, Commissioning Execution and Production Organization perform the Commissioning and have a reporting relationship to the TQNPC General Manager.

Fig. 6.1. Integrated TQNPC/ AECL Commissioning Team (Qinshan)

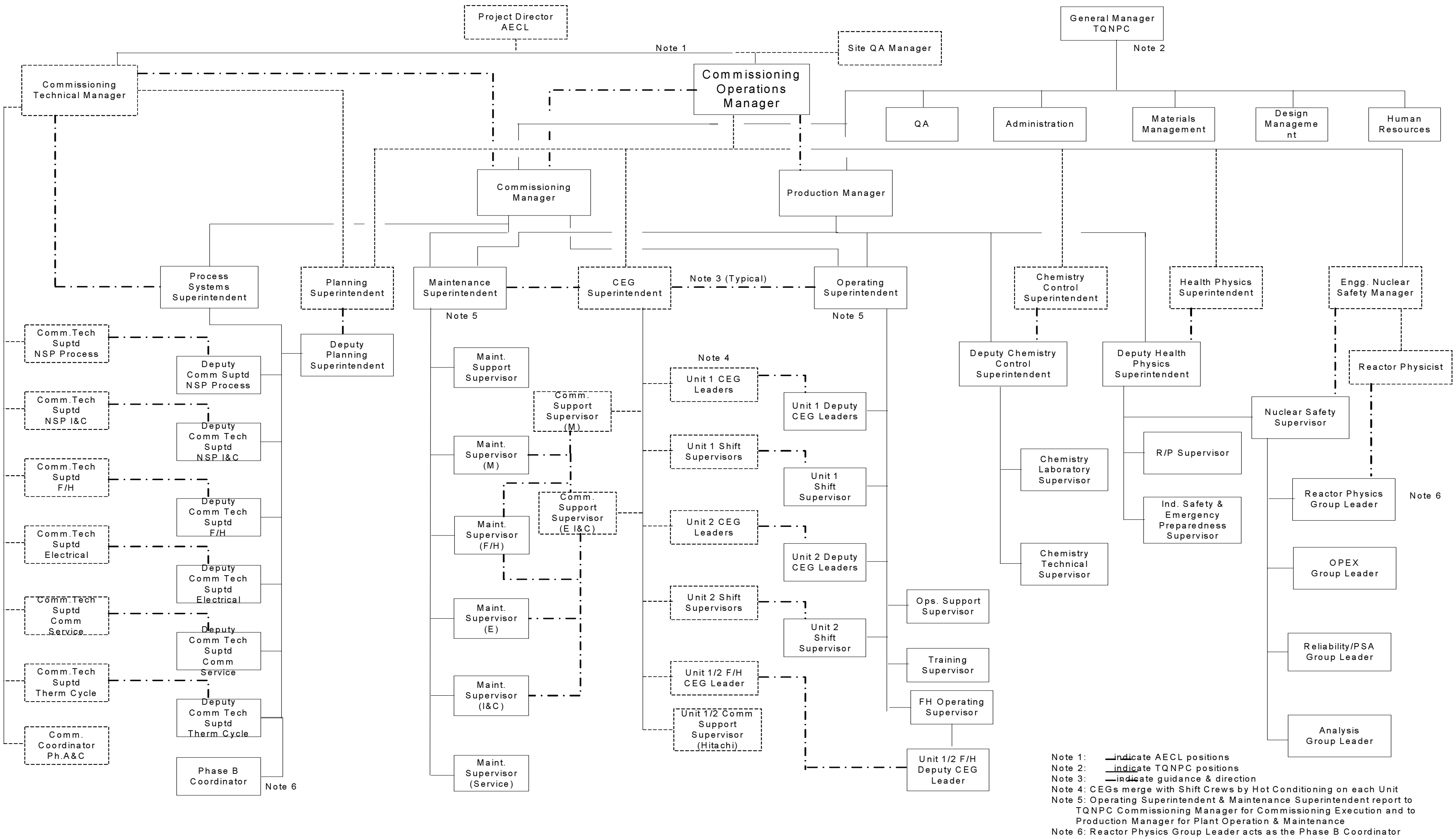
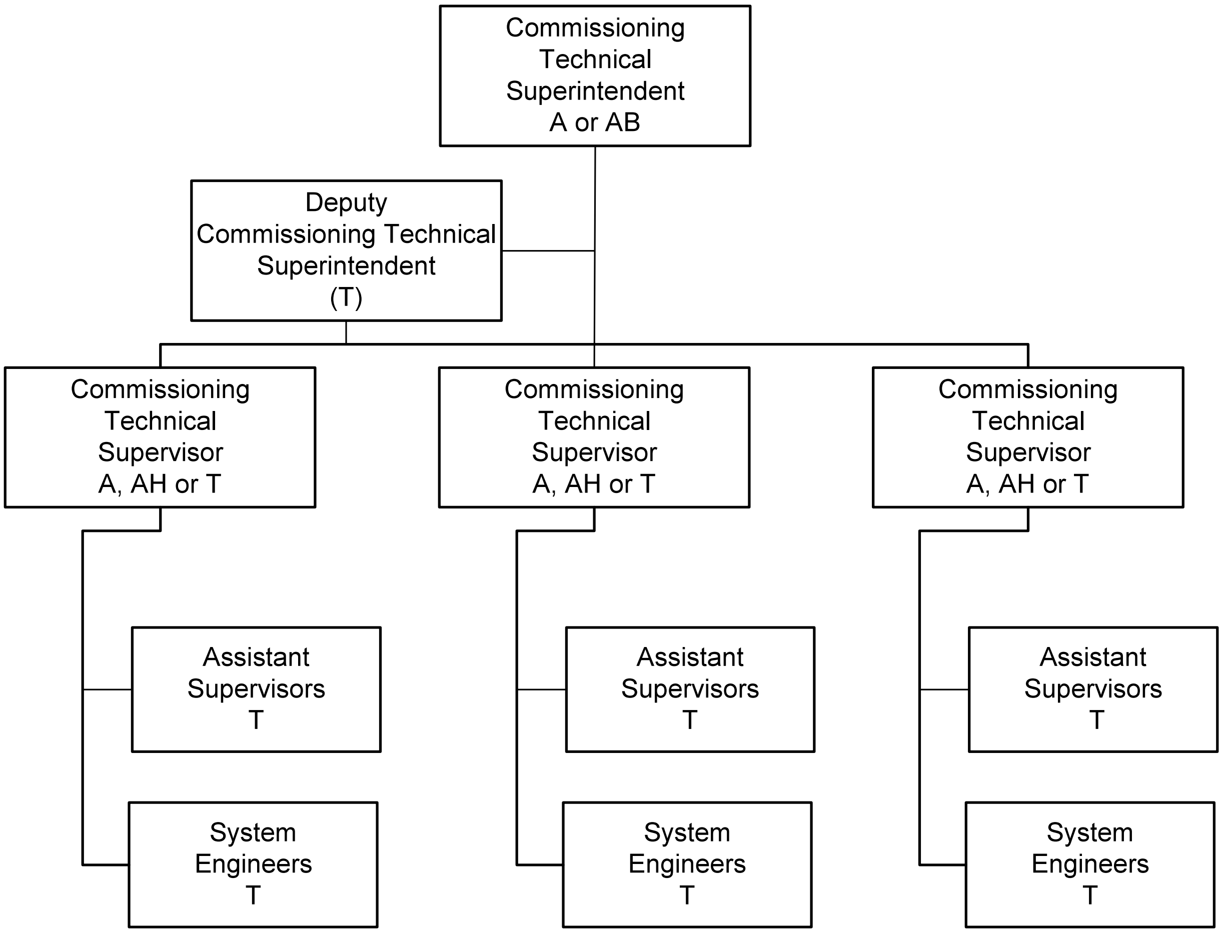
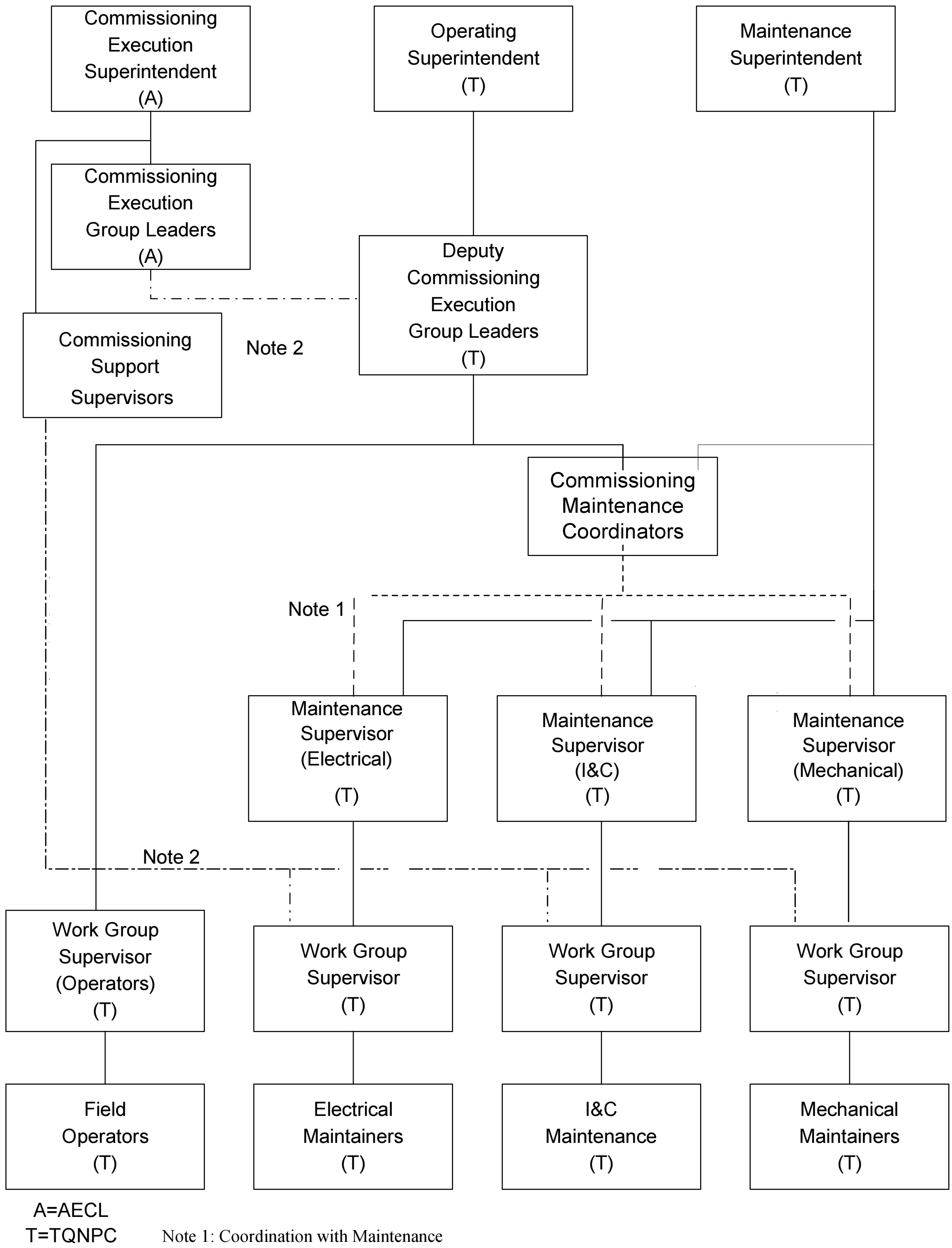


Fig. 6.2. Integrated Unit 1 & 2 Commissioning Team Organization (Qinshan).



A = AECL
T= TQONP
AB= Bechtel seconded to AECL
AH = Hitachi seconded to AECL

Fig. 6.3. Typical Commissioning Technical Group (Qinshan).



Note 1: Coordination with Maintenance

Note 2: Guidance and Direction

Note 3:Planning-Operating-Maintenace Work Flow Interfce

Fig. 6.4. Typical Commissioning Execution Group (Qinshan)

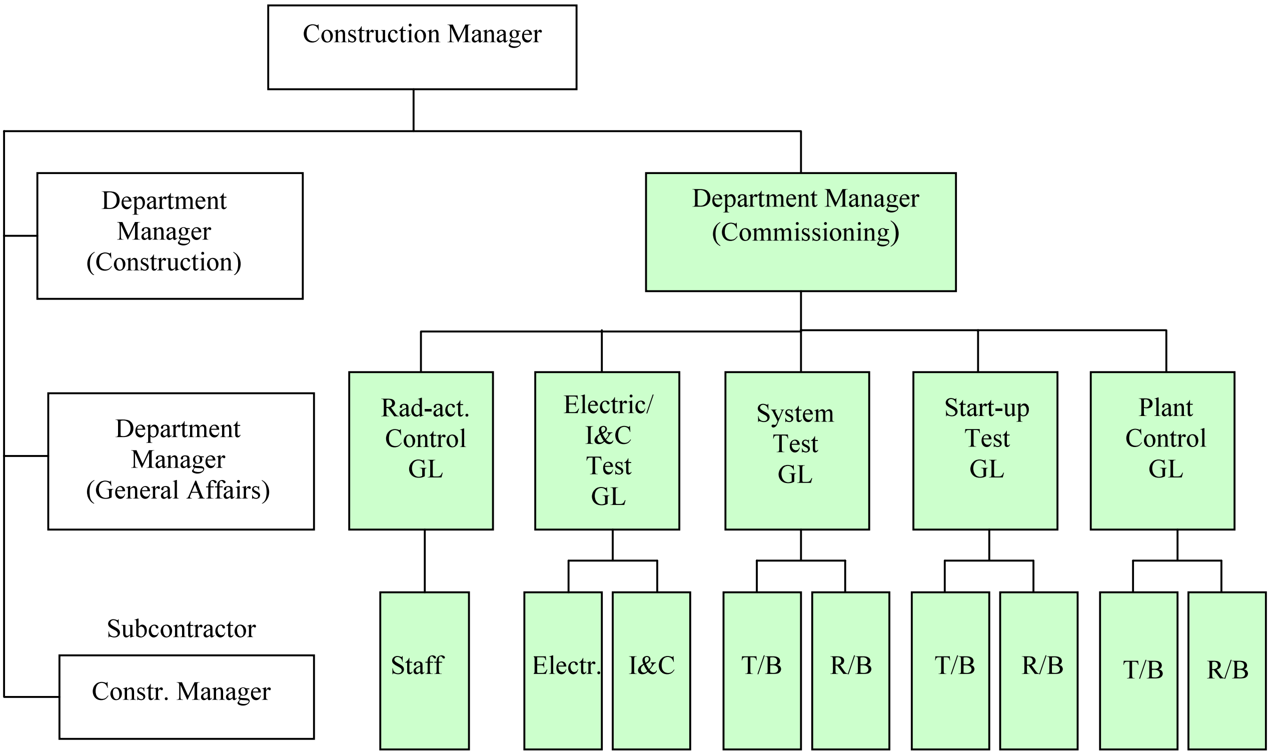


Fig. 6.5. Commissioning organization (Kashiwazaki-Kariwa Unit 7).

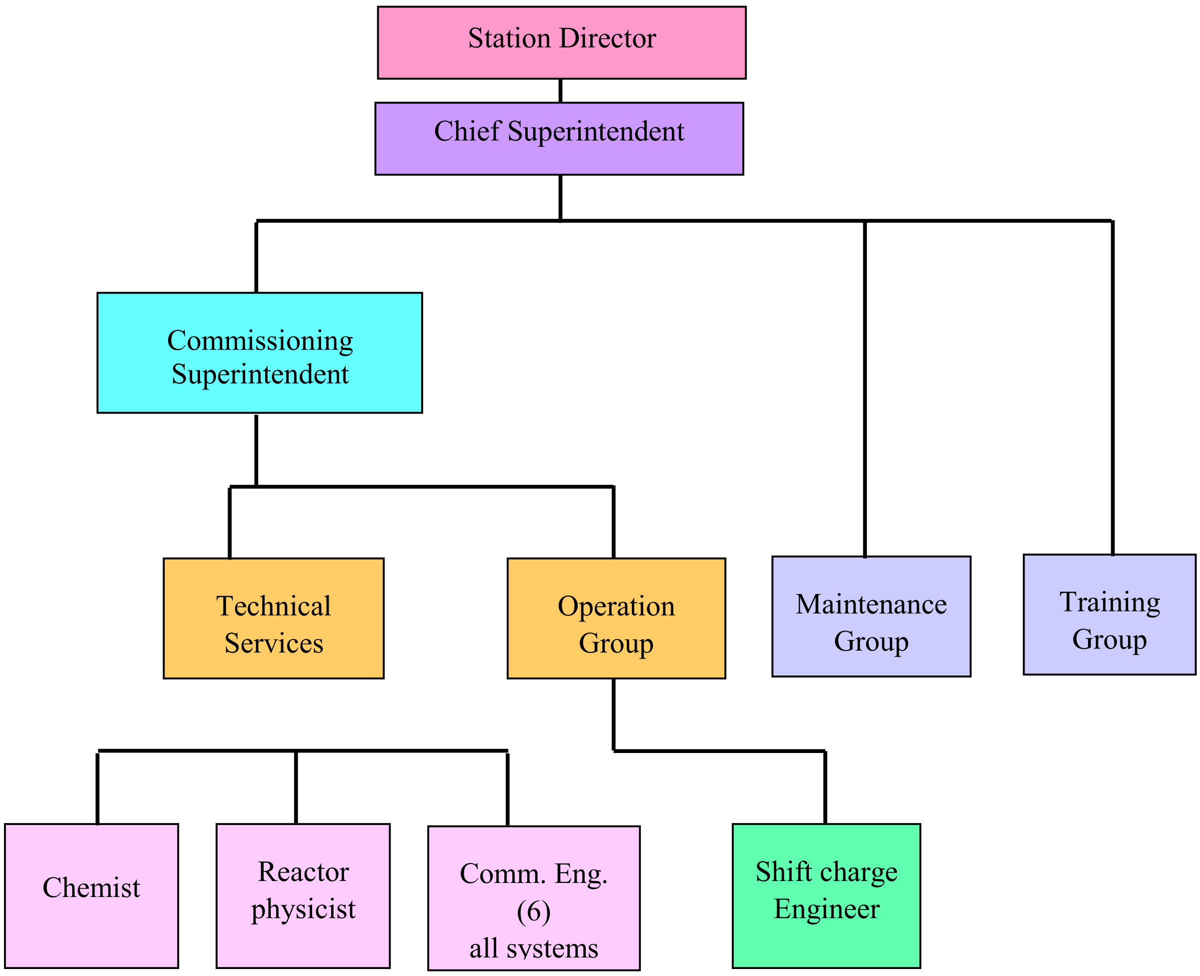


Fig. 6.6. Commissioning organization (Tarapur).

6.1.4. Planning and scheduling

Commissioning tests should be effectively planned and scheduled in line with the installation and completion of the plant components & systems and in accordance with the project master plan and master schedule. The plant systems are usually grouped into well-defined sub-systems that can be tested together in a step by step manner. The commissioning plan and schedule should be developed by personnel experienced in construction and commissioning, and approved by the operating organization.

The schedule for individual component or system testing should specify all required elements, and include as a minimum the following:

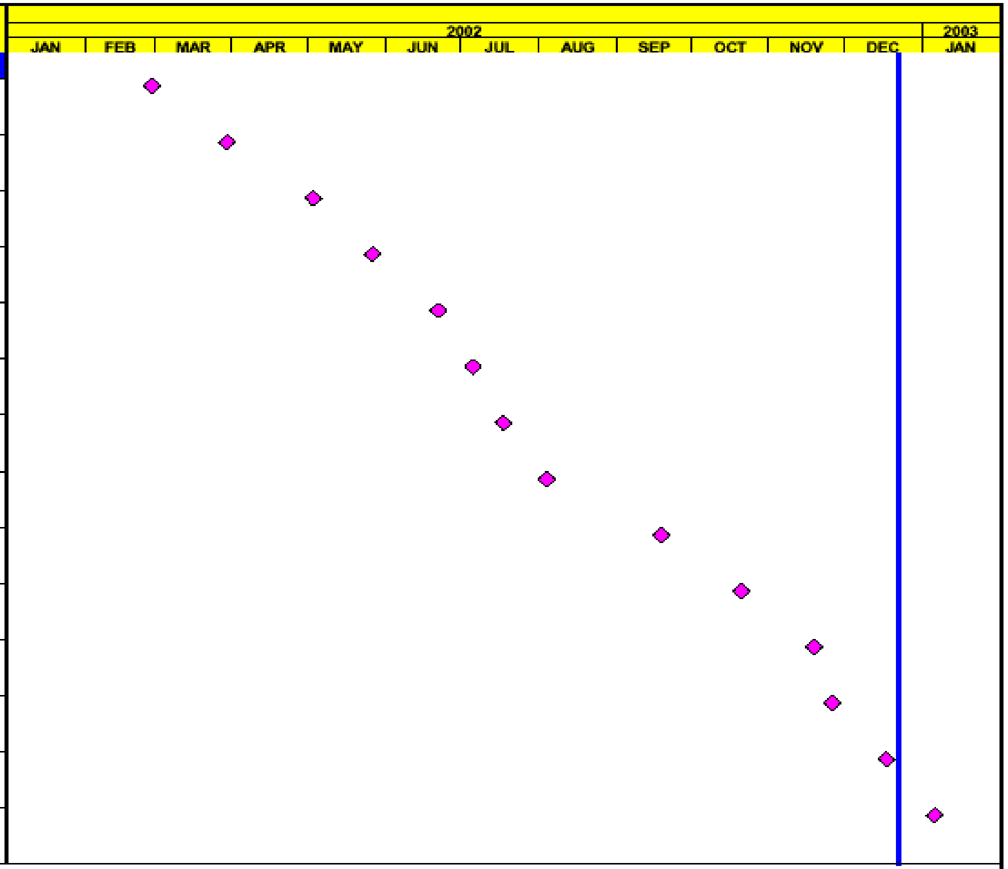
- Systems required supporting the individual system testing.
- Group or team responsible for conduct of the testing.
- Support services provided by the plant owner and other organizations.
- Review and acceptance of the test results.
- Turnover packages and turnover point.

Early planning is required for development of qualified manpower, for preparing test procedures in advance and performing tests in accordance with the commissioning schedule. The planning should also ensure that necessary tools, instruments and special equipment are provided at the required time.

Planning of the logical test sequence after fuel loading, should be agreed on and approved by national regulatory body. Each step of the power increase should be carefully planned, tested, reviewed, adjusted, and authorized to continue up to 100 % rated power. The whole process and test results should be accepted by all parties and documented as the plant permanent records.

Fig. 6.7 presents the main commissioning milestones for Qinshan Unit 1.

Activity Description	Actual Finish
1 Qinshan Unit # 1	
AD - Aquire and Store D2O	27FEB02
MD - Moderator System Fill With D2O	29MAR02
LT - Reactor Building Leak Rate Test	02MAY02
HC - Hot Conditioning	26MAY02
AF - Aquire and Store Nuclear Fuel	21JUN02
PF - Power Failure (Loss of Class 4 Power Test)	05JUL02
LF - Load Fuel	17JUL02
HD - Heat Transport system Fill With D2O	03AUG02
CR - First Reator Criticality	18SEP02
PI - Power Increas For First Synchronization	20OCT02
PP1- First Synchronization	18NOV02
PP2-Raise Power above 45%	25NOV02
PP3-Raise Power above 95%	17DEC02
PA - Provisional Acceptance	05JAN03



Start Date	12FEB97	Early Bar	CM3M Sheet 1 of 1
Finish Date	05DEC03	Progress Bar	QINSHAN CANDU PROJECT
Data Date	23DEC02	Critical Activity	UNIT 1 COMMISSIONING
Run Date	14JAN03 16:04		

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Fig. 6.7. Main commissioning milestones (Qinshan-Unit 1).

6.1.5. Phases of commissioning programme

The commissioning programme should be divided into successive phases to ensure the completion of all commissioning tests and the control of the logical test sequence. A formal review should be performed after completion of tests in each phase. The review will make a quick judgement of the test results to determine whether the tests in the succeeding phase should continue or should be modified.

The following are examples, which suggest that the commissioning programme be divided into four phases in order to better define the objectives of each of them.

Example 1

Phase A - Pre-Operational Tests

This phase covers all tests of individual equipment, components and systems. These tests are performance-based, mainly for demonstration of the achievement of the proper functions described in the design documents.

The commissioning test of the electrical supply system is performed in this phase, either prior to or in parallel with other system tests.

Phase B - Hot Functional Tests I (without Fuel Loading)

During this phase, the reactor coolant system is operated for the first time together with the reactor auxiliary and other systems. During the course the reactor coolant system obtains the operating pressure and almost up to the operating temperature by running the reactor coolant pumps. The nuclear power plant is demonstrated to be operated safely to the extent possible without the nuclear steam generation.

For acceptance of the essential equipment and systems at the end of this phase, inspections should be performed:

- Components of the reactor coolant system and the residual heat removal system.
- Boron injection functions in the nuclear auxiliary systems.
- Instrumentation and control equipment and systems.

The final inspections made at the end of Phase B are the prerequisites for initial core loading.

Phase C - Hot Functional Tests II

Phase C begins with the initial core loading. During the whole phase the reactor is kept in the sub critical mode.

The hot functional tests continue but with the whole reactor core and the complete core instrumentation to demonstrate the operability and safety of the entire nuclear power plant before the start of the nuclear operation.

Phase C is to end immediately before the reactor initial criticality.

Phase D - Plant Overall Nuclear Tests

Phase D starts from initial core criticality and contains a step by step approach covering all commissioning tests up to the full power testing of the reactor. The power ranges are designed at 0–30 %, 30–80 % and 80–100 % of the reactor full power.

Within the 0–30 % power range the steam is, at first, discharged through the bypass system into the turbine condenser. After the required steam quality is achieved at 30 % of the reactor power, the turbine generator is then synchronized and the generated electrical power is fed into the grid.

The objective of this phase is to demonstrate the proper function of the plant at each of the individual power ranges. All relief and safety valves and the protection systems are well adjusted accordingly to ensure that all tests are carried out under the specified operational conditions and limits.

Since a series of secondary systems and the turbine generators are operated with load for the first time, the commissioning scope is much larger than those in the previous phases.

When full power is reached and no further probative tests are required, a number of demonstrative tests are performed to guarantee safe and reliable operation of the plant before it is turned over to the operating organization.

Example 2

This example is different from the previous, in that it uses a different definition of the phases of the same full process. In this approach Phase A ends just before the reactor becomes critical, Phase B includes criticality, and all tests done with the reactor at zero power. Phase C includes increasing the reactor power, first steam in the turbine, raising reactor power to 25%, 50%, 75% and 100%, first synchronization. Phase D includes warrantee and performance tests.

As an illustration, commissioning phases for Tarapur are given below:

- ***Tarapur***
  - Phase A: In this phase, following activities are done:
    - Hot conditioning of the primary heat transport (PHT) system with light water.
    - All light water commissioning
    - Electrical system commissioning
    - Draining & drying of PHT system.
    - Fuel loading
    - Flushing of moderator system with D_2O
    - D_2O addition in PHT system
    - Filling demineralised water in calandria vault

- Phase B: Following activities are conducted in this phase:
  - Bulk D_2O addition in moderator system
  - Approach to criticality
  - Low power physics experiments — up to 0.1% of full power (FP)
- Phase C: Rising of power in stages to FP

6.1.6. Turnover to operation

Turnover (T/O) is generally an administrative action by which responsibility for physical, economic control and for safety of the plant systems, areas and the whole plant is transferred from commissioning to the operating organization.

The operating organization should be responsible for establishment of the system turnover procedures, which should clearly identify the participants, responsibilities, duties and documents necessary for the T/O process. T/O documents should describe boundary deficiencies and exceptions existing at the time of T/O in comparison with commissioning programme and test procedures.

The operating organization should receive all of the complete and update system T/O packages on time, including changes and revisions of the commissioning programme and testing procedures. The operating organization should carefully review the T/O documents and assess the test results.

T/O should be made with a minimum of, or no, exceptions. Resolving exceptions is a much larger effort than working to make a complete system T/O. Decision for acceptance of additional exceptions should be made at the upper management level. T/O exceptions should be tracked and corrected in a timely manner.

Responsibilities for closing the exceptions after T/O should be clearly defined, including performance and control of the construction work and commissioning testing on the incomplete components or systems.

The system T/O and the area or room T/O should be distinguished. The system T/O, which may cross through several areas or rooms, should be given first priority. The area or room T/Os can be delayed because the process of getting administrative clearances for keys and others can become very cumbersome and time consuming.

6.2.Examples of measures to reduce commissioning duration

The main measures aimed to reduce commissioning duration at the studied projects are presented in the following sections.

6.2.1. Qinshan

- *Appointment of system engineers:* The commissioning technical process was based on the concept of a system engineer responsible for all aspect of commissioning a plant system or a group of systems. Each system engineer was responsible for preparing commissioning documentation, interfacing with engineering and construction on design and/or T/O issues, providing technical support for field execution of commissioning procedures, assessing test results, and preparing commissioning reports, commissioning completion certificates and commissioning history dockets. In addition, the system engineer was responsible for preparing operating manuals, test procedures, system surveillance plans and preventive maintenance programs. A key factor in the execution of field procedures was the extent to which system engineers provided field support to maintenance and operations staff. System engineers were required to provide extensive technical support in the field to explain the CP4s and troubleshoot problems.

- *Establishment of commissioning control points (CCPs)*: A total of 14 CCPs were established in order to check and confirm that the plant systems required to support their release were duly commissioned and the results documented. Seven of these (marked with '*') were set as hold points for the regulatory to formally release before commissioning could proceed further. The CCPs are:

  (i) Acquire D_2O
  (ii) Acquire new fuel*
  (iii) Load D_2O into moderator*
  (iv) Reactor building leak rate test
  (v) Hot conditioning of main heat transport
  (vi) Loss of class IV test
  (vii) Load fuel*
  (viii) Load heavy water into heat transport systems
  (ix) Criticality*
  (x) First synchronization to 25% full power*
  (xi) Raise power to 50% full power and above*
  (xii) Raise power above to 100% full power *
  (xiii) Continued operation at 100% full power
  (xiv) Provisional acceptance

- *Close interface with engineering:* To address any design related issues, a formal Commissioning Clarification Request (CCR) process was established. CCRs were responded to by engineering and closed out by the system engineers. Typical issues covered design and manufacturers' documentation clarification and minor design corrections, which were resolved by engineering field change requests.

  For issues related to equipment performance, a Commissioning Quality Observation Record (CQOR) process was implemented to disposition defective or damaged equipment discovered during commissioning. An engineering assessment determined whether the component should be repaired or replaced. Commercial responsibility was arrived at separately. Where parts were not readily available in stores, Unit 2 materials were transferred to Unit 1 through a formal material transfer process. The replacement materials were later repaired or replaced for use in Unit 2.

- *Establishment of commissioning documentation:* For each system, a Commissioning Specifications/Objectives document (CSO) was prepared to define the design and analysis requirements that had to be demonstrated during physical commissioning checks and tests. The CPs were prepared at three levels of detail:

- Level 2 and 3 procedures defined the overall program, interfaces and logic, and
- Level 4 procedures defined the detailed procedures to execute fieldwork. These procedures were deliberately prepared at a higher level of detail than at other stations in order to increase the level of procedural compliance in the largely inexperienced commissioning execution groups.

In addition, 135 Standard Commissioning Procedures (SCPs) were prepared to cover repetitive type of checks on mechanical, electrical and I&C equipment. Work Plans (WPs) covered more complex tests where several systems were involved. Work Requests (WR) were issued to allow each work package to be scheduled and implemented in the field by the execution teams and to provide feedback to the system engineers along with a report of the work done.

Once the fieldwork was done and results assessed, the system engineers prepared a Commissioning Report (CRP) to formally document the results by comparing them against the acceptance criteria specified in the CSO document. Finally, the status of commissioning for each system was reviewed to ensure that the system would meet the technical and performance requirements for each of the 14 CCPs. Table 6.1 shows the commissioning and operating documentation prepared for Unit 1.

Table 6.1. Commissioning and operating documentation for Unit 1 (Qinshan)

Document Type	**Number**
Commissioning Specifications/Objectives (CSO)	154
Commissioning Procedures (CP2)	154
Commissioning Procedures (CP3)	161
Commissioning Procedures (CP4)	2979
Work Plans (WP)	233
Commissioning Reports (CRP)	275
Available-for-Service Certificates (AFS)	282
Commissioning Completion Assurance Certificates (CCA)	107
Work Requests	23 855
Operating Manuals (OM)	124
Safety related Systems Tests	339
System Surveillance Plans (SSP)	195

- *Close interface with construction:* Major construction interfaces included the T/O of systems and management of open items. Key elements of the T/O process included preparation of T/O scope definition by commissioning, and an agreement on scope of construction check and test program. Wiring and functional loop and logic testing was performed by the construction contractor under AECL supervision in order for any errors to be detected and resolved before system T/Os. The T/O process was well managed with preliminary T/O packages prepared three months prior to scheduled dates and final open item review meetings within two weeks of the T/O date. A key factor in acceptance of T/Os was the criteria for categorizing open items as those required before T/O versus those to be completed after T/O. Provided that bulk of the commissioning work could proceed, open items were scheduled for completion T/O. Open item management after T/O was done through the Commissioning Work Permit system.

- *Optimisation of commissioning schedule*

  - In 1998 a generic set of CP2 was developed based on experience and feedback from previous CANDU projects. This information was integrated into the Generic CANDU 6 Commissioning Schedule.

  - In 1999 a small group of commissioning staff was assembled to review Qinshan specific design information and revise these CP2 to make them Qinshan specific. This new information was used to revise the generic CANDU 6 schedule and the Qinshan specific schedule was established along with the necessary T/O profile required to achieve it. This new information was incorporated into the project C&C schedule. Some conflicts were identified with existing T/O dates and where possible, Construction adjusted their program to try and achieve the required dates.

  - T/O of the electrical distribution systems occurred 6 months later than defined in the C&C and T/O of the service water systems occurred three months later. These systems should normally be fully operational to support commissioning of the PHT and related critical path systems. With T/O of the PHT occurring in October 2001, it meant both the support systems and major process systems had to be commissioned in parallel.

  - In order to recover the lost time, all programmes with negative float were scheduled 7 days per week, and in many cases, extended hours as well. Temporary power and cooling solutions were identified and implemented where practical and commissioning programmes were continuously reviewed to identify possible work-around. The schedule was updated each month and new short term objectives and strategies were developed based on actual progress. New critical paths were continually evolving. Daily and weekly planning meetings were held with the work groups to communicate current priorities and programmes. Meetings were also held three times a week at the manager/superintendent level to identify and track all significant issues affecting the programme.

  - The commercial operation of Unit 1 was achieved in 20.5 months after the first energization of the station service transformer, considerably shorter than comparable experience at other CANDU 6 Units. This achievement was the result of the following main factors:

    - Excellent co-operation and teamwork within the integrated TQNPC/AECL Commissioning Team.

    - Focus on resolving technical issues and on working around problems.

- Great support from senior management in AECL, Bechtel, Hitachi, TQNPC and the contractors. Commissioning issues always received first priority.

- Commissioning staff, both expatriate and TQNPC, worked hard and smart with great dedication and motivation.

- Good planning, work management, co-ordination and effective troubleshooting process.

- Working according to a well documented commissioning QA programme to achieve high quality standards.

- Earlier involvement of CT system engineers in the system T/O activities in order to familiarize with the systems and identify potential system problems.

- Learning from a good experience feedback programme during commissioning.

6.2.2. Kashiwazaki-Kariwa

During commissioning, the following test and inspection are performed:

- Verification: To confirm that the actual manufactured and installed components demonstrate their design performance and functions. Examples: Flow-induced vibration (FIV) measurement test of core internal structures; structural integrity test of RCCV; verification and integrity validation of the digital type safety protection. The first two are first of a kind (FOAK) design tests

- System tests: To confirm system performance and functions before fuel loading. Example: ECCS core injection test.

- Startup tests: To confirm plant safety and operability. Examples: Recirculation pumps trip test, all main steam isolation valves closure test.

- Pre-use inspections: Inspections of the regulatory authorities.

To reduce the commissioning duration the following are considered

- Deletion of test items such as

    - Verification tests for FOAK (first of a kind) design.

    - Test items possible to verify during system tests.

    - Preliminary test items for next stage tests.

- Reduction of power stage numbers from four steps (25%, 50%, 75%, 100%) to three steps (25%, 75%, 100%).

- Optimisation of maintenance work during the planned shutdown.

6.2.3. Lingao

- Overall training and authorization of the commissioning personnel: Individual training plans were developed for the personnel based on their experiences and background. Training courses included commissioning management and techniques applied in the ongoing projects home and abroad, on-site training in thermal power stations under construction in China, specific training at manufacturers' institutes' premises, in-house commissioning authorization. Training and authorization prior to job assignment ensured commissioning effectiveness and quality.

- Complete commissioning management information system: The commissioning team initiated the development of a commissioning and handover management information system since June 1998 and put it into operation in 1999. The system included all the information related to commissioning and handover management such as documentation, human resources, handover, project targets, tools, and feedbacks. It was a common working platform for all commissioning staff and other relevant departments.

- CT's planning system consisted of the followings:

  - Key project points: yearly and monthly key points and key points for the overall commissioning and for different commissioning phases.
  - Commissioning critical path schedule
  - Level 3 schedule (commissioning overall schedule).
  - Level 4 schedules (individual systems test schedules).
  - Weekly schedule (CT regular meeting schedule).
  - Three-day rolling schedule (overall test schedule).
  - Specific schedules (for item such as Diesel engine test, etc.).

  The level 3 schedule was developed by CT considering the End of Erection Status Report (EESR) as the starting point of commissioning. On this basis and considering the major project milestones, such as cold and hot functional tests, containment pressure test, etc., CT prepared the critical path schedule to control the progress and interfaces for individual system test schedule (level 4). All these ensured effective control and co-ordination of the commissioning.

- To reduce the potential human injuries and equipment damages during commissioning, CT prepared risks analysis based on the characteristics of commissioning activities at different commissioning stages. Test supervisor were requested to prepare Risks Analysis Sheet (RAS) ahead of performing the tests, RAS, being part of the application to get tests permits. For important tests or risky works (like power supply switchover test, transient tests at 50% and 100% rated power), test supervisor or work supervisor, in addition to filling RAS, met with the on-duty shift engineers, control room operators and other relevant people and clarified the steps, possible risks and necessary measures. Where needed rehearsal on the simulator was done. Finally, rector and turbine trips during commissioning of LNPS were significantly reduced if compared with the Daya Bay Nuclear Power Station.

6.2.4. Tarapur

- Two and a half years before the plant criticality, a commissioning group of 78 engineers was established under the responsibility of an operation & maintenance team at site. Half of them were taken form other project/stations having vast experience of commissioning & operation of the plant.

- Commissioning engineers were participating in construction & testing activities right from the beginning so that their observations were incorporated.

- A vigorous training programme was arranged for the commissioning group to give a better understanding of the system.

- Early initiation of licensing process for operating staff.

- Early availability of technical specifications.

- Commissioning activities are included in the scope of package contractors. Thus, their manpower was available for commissioning under the guidance of owner's commissioning group.

- Table 6.2 summarizes the commissioning documentation issued for Tarapur.

Table 6.2. Commissioning documentation (Tarapur)

Document type	**Number**
Commissioning procedure in the owner's scope	247
Commissioning procedure in package contractor's scope	124
Operation flow sheets	247
System training manual	22
Operating manual	22
Technical specification	1
Off site emergency preparedness plan	1

CHAPTER 7. FACTORS TO BE CONSIDERED FOR FUTURE PROJECTS TO FURTHER REDUCE THE SCHEDULE

Building on the experience accumulated and lessons learned during the implementation of the reviewed projects the main actors identified areas and topics where future improvements would further contribute reducing construction and commissioning schedule. This chapter summarizes and presents these aspects in two sections: factors common to all projects reviewed and project specific ones.

7.1. Common factors

- Use of a single point project team that actively controls the finance, schedule, and quality of the project through audits and updates. The team should be experienced and have the flexibility and ability to make adjustments during implementation. The team should be established at the early stage of the project.

- Factors that have been found to aid flexibility during implementation are: 3D CADD modelling of complete plant with as much details as possible including piping etc, good communication which can be aided by electronic documents on a common network, open top construction and modularisation.

- Local participation should not exceed local expertise. One should not expect suppliers to train themselves. Training in scheduling techniques, QC and procedures, etc. is a very important part of project management responsibilities.

- There is a strong benefit in finishing design before start of construction and integrating procurement, construction and commissioning requirements with upfront design.

- In general, small incremental design advances usually end up costing more than they save. It is recommended to implement design changes in planned stages rather than as they become available.

- Pre-qualification of contractors including a design audit. QC should be explained and agreed to beforehand.

- Division of contracts into functional blocks (i.e. pump house, etc.) where possible, rather than by civil, mechanical, electrical.

- Making available modern facilities and infrastructures on the site as early as possible.

- The project management should be given the full authority to successfully complete the project within the project budget and schedule.

- Work (detail engineering, procurement of long delivery material, civil works) should be done to the extent possible before the signature of contract.

7.2. Project specific factors

o ***Qinshan***

The schedule from CED to In Service for the Qinshan Phase III Project Unit 1 was 72 months. On future CANDU 6 projects, AECL expects that it should be possible to reduce this to 60 months, based on the lessons learned on Qinshan CANDU Project in China. Table 6.3 summarizes the schedule reduction:

Table 6.3. Summary of schedule reductions (Qinshan)

	Q3 Contract Month	Q3 Actual Month	Q3R* Planned Month
Contract Effective Date	0	0	0
First Concrete	17	16	12
In Service	72	70.5	60 + 6 month contingency

* Qinshan III CANDU Replication

To achieve this objective the following actions are considered:

- Early finalization of engineering deliverables. Delivery of design drawings and specifications to site, in clean conditions, well in advance of construction.
- Acceleration of yard services work. Design for yard services must be finalized at CED.
- Increase of modularisation applications where possible.
- Close monitoring of engineering and procurement level 3 schedules and early action to counteract delays.
- Issue of early purchase orders to get supplier drawings that affect the design as early as possible.
- Improving equipment and material deliveries to better suit construction sequencing. A better definition of bulk material requirements and deliveries is required.
- Increasing use of 3D CADDS for planning and construction sequences.
- Starting of excavation at CED. The excavation construction contract should be signed in advance. Making available detailed design for the excavations in advance of CED.
- Breakdown of the level 2 C&C bulk activity (cables, panels etc.) into as many details as possible to identify priorities.
- Enhancement of construction level 3 schedules to define the optimum construction sequences. Civil and installation planning groups must work together to define the overall construction level 3 schedule.
- Acting immediate when schedule dates fall behind (especially in engineering, procurement and civil work).
- Incorporation of room or area T/Os into the level 3 schedules.
- Integration of CMMS access and material status within the site-planning group.
- Enhancement of schedule visibility during construction. Critical paths to be known by all, including home office engineering and procurement groups.

- Earlier start of structural steel fabrication and erection.
- Earlier start of pipe fabrication.
- Review of spare parts requirements in light of actual experience.
- Development of resource-levelled schedules.
- Earlier completion of level 4 commissioning procedures.
- Earlier detailed level 2 commissioning schedules to match the project conditions.
- A combined commissioning and construction team to carry out checkout and T/O activities.
- Vendor support linked to purchase order of equipment to provide for shorter commissioning, training, and better problem resolution.

o ***Kashiwazaki-Kariwa***

- Engineering/licensing schedule: reduction of the design period through standardization of plant design.
- Construction Schedule: reduction of construction time through:
  - Increased composite modularisation (Fig. 7.1).
  - Increased prefabrication.
  - Application of steel-concrete structure (Figs. 7.2 and 7.3).
  - Inspections' rationalization (reduction of hold points).
  - Better communication through IT.

Figs. 7.4 and 7.5 present the estimated impact of new construction techniques on the schedule.

Composite module (Large-scale module) = Building elements + Equipments & piping, duct

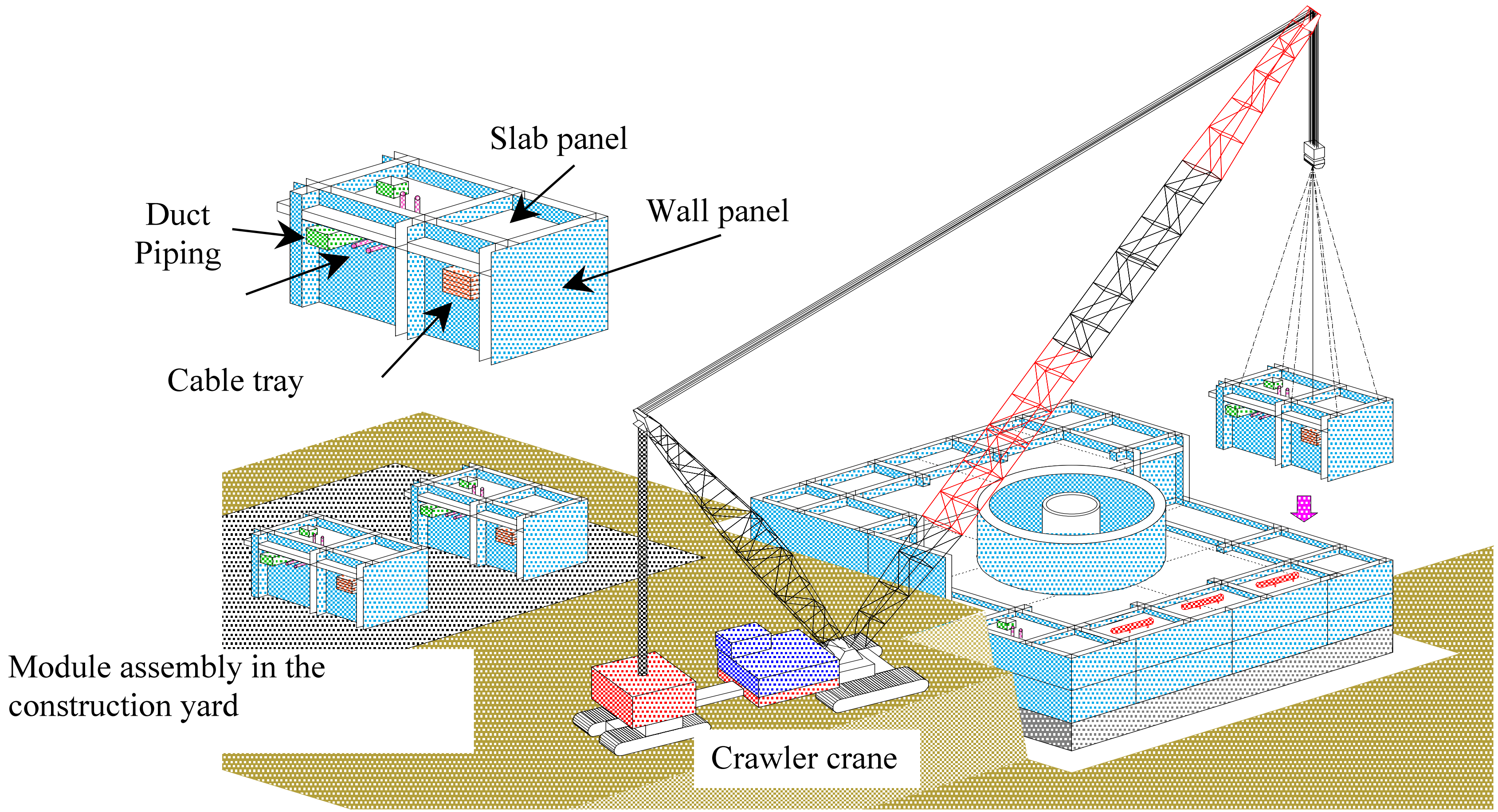
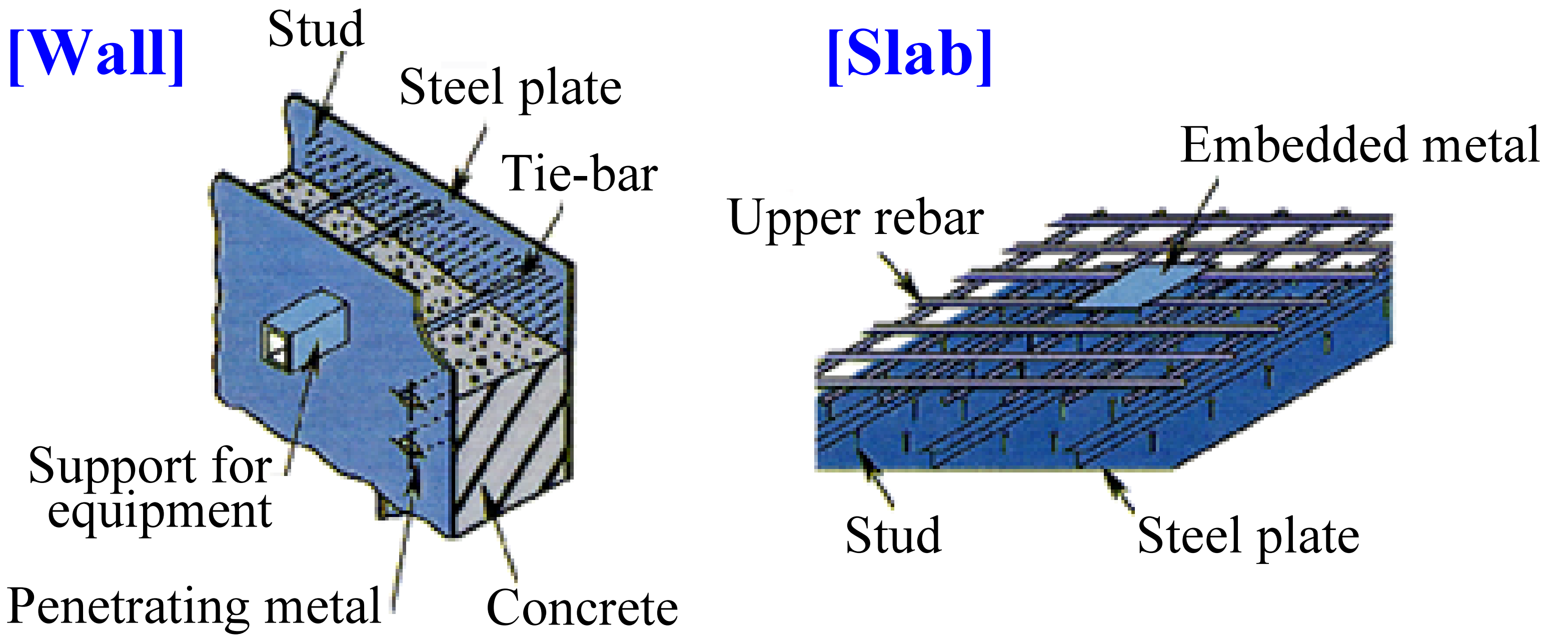


Fig. 7.1. Increased composite modularization (ABWR - study).



The parts to which SC will be applied :Foundation mat, PCV , Building elements (slabs and walls) - critical parts which affect the whole construction period)

Fig. 7.2 Steel plate reinforced concrete (SC) structure (ABWR - study).

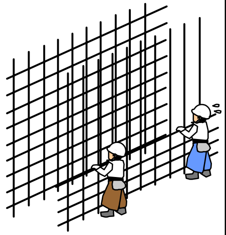
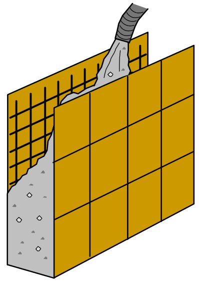
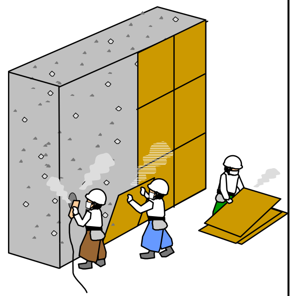
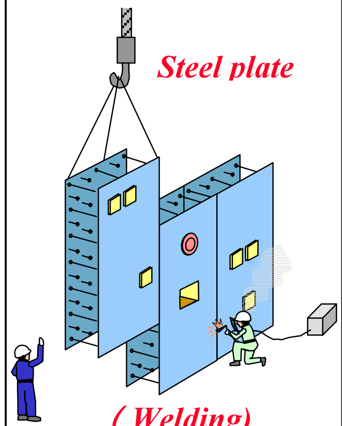
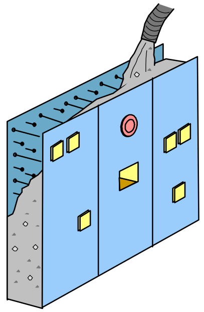
Work / Structure	Rebar arrangement	Formwork (assembling)	Placing concrete	Formwork (removal)
RC				
Total 28days	13days	7days	4days	4days
SC	—			—
Total 14days	-	10days	4days	-

Fig. 7.3. Advantages of steel plate reinforced structure (ABWR - study).

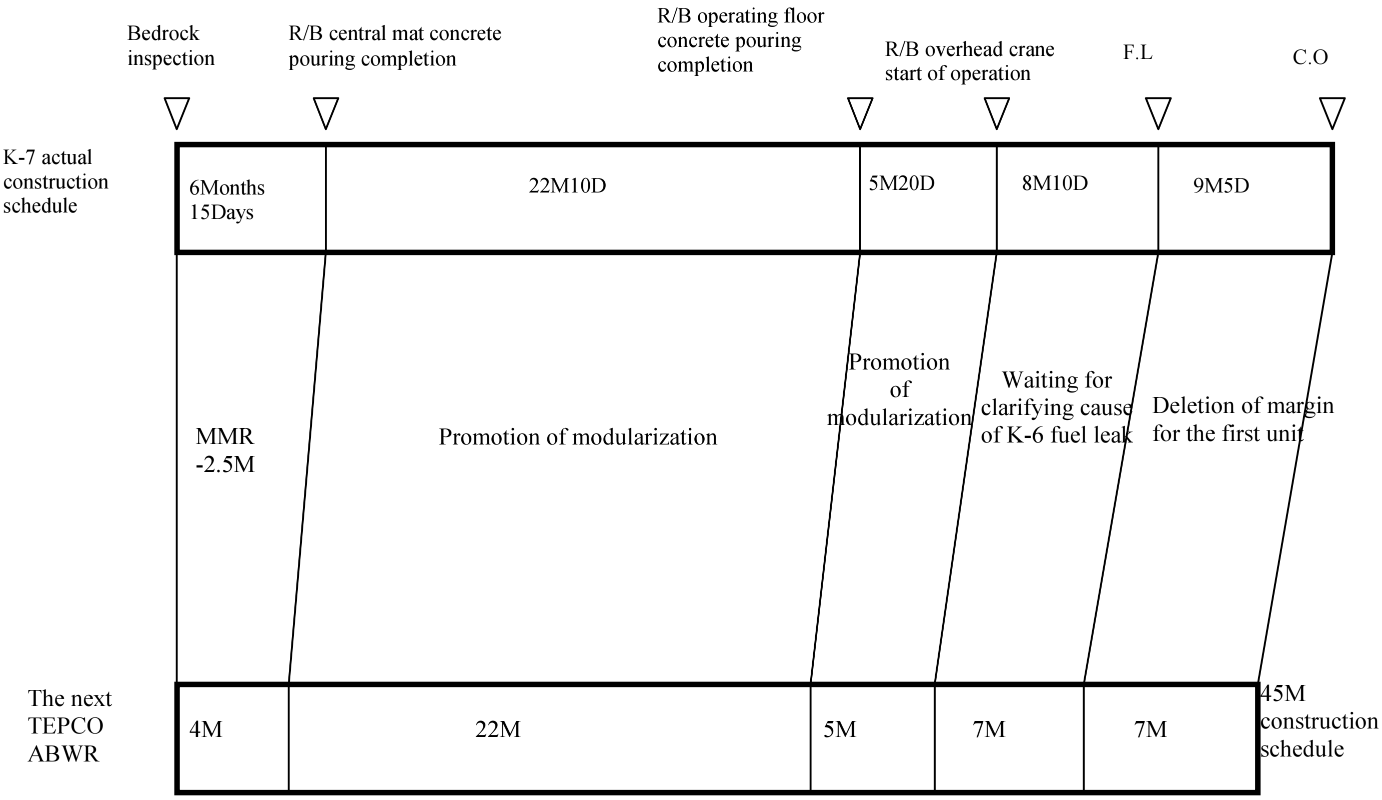
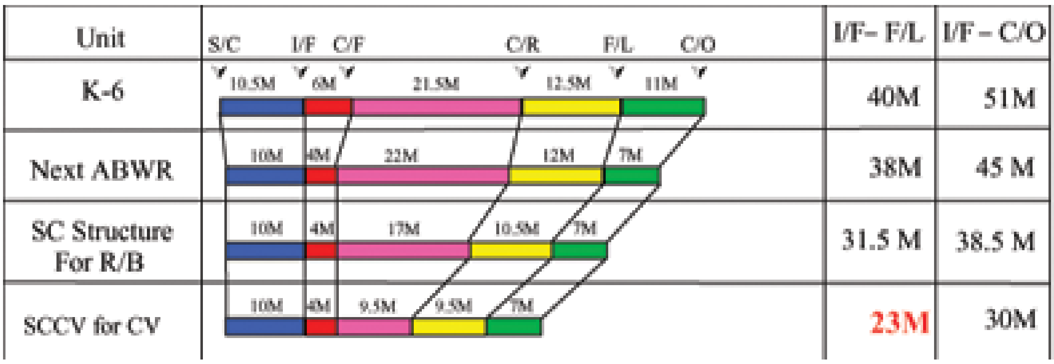


Fig. 7.4. Construction schedule for the next ABWR (projection).



Legend: SCCV – Steel concrete containment vessel

Fig. 7.5. Impact of new construction techniques on schedule (ABWR - study).

- ***Lingao***

  - Adopt mature technology and make a good use of the present experience.
  - Reinforce and keep on improving on project civil works design to guarantee drawing submission in accordance with the schedule.
  - Optimise the construction and its management (including the increase of the overlap between civil works and erection to reduce the critical path).
  - Increase prefabrication and modularisation.

- Optimise the equipment supply and its installation.
- Speed up the response to the site requirements.
- Add adequate manpower and facilities as needed.
- Include in the periodic assessment of the contractors aspects such as manpower mobilization, internal management, fabrication capability and construction equipment, to identify the shortcomings and require correction when necessary.

o ***Tarapur***

NPCIL plans to reduce the construction of the plant to about 30 months. To achieve this objective the following steps are considered:

- Design & Procurement
  - Complete plant design will be made using 3D model software and issue of all drawings and bill of materials controlled by this software.
  - Modular design for all floor slabs will be adopted for the building to allow early release of areas for mechanical, electrical and instrumentation activities.
  - All drawings and specifications will be made available at site 9 months before the first pour of concreting.
  - Order for long delivery equipment such as steam generator, end shield, calandria, fuelling machines, column & bridge, fuelling machine, coolant channel components etc. will be finalized before the contract effective date.
  - Percentage of shop welding will be increased to 80% as to minimize field welding to 20% only. This aspect should be addressed during design stage.
  - Equipment of critical nature will be procured with alternate contingency plan prepared right from the beginning.
  - Level 4 schedules for engineering, procurement and construction activities will be made ready at CED and progress will be closely monitored.
  - Pre-qualification of vendors will be done before the CED. Pre-qualification criteria will have more weight for sound quality organization, safety organization, financial status in the last 5 years, adequate modern/mechanized plant & machinery and manpower resource availability.
- Construction
  - Excavation package contract will be awarded at CED and this package will also include access road, station road, and crane hot-spot work to provide proper access for proceeding with modular construction.
  - All pre-project activity (infrastructure work) including land acquisition & rehabilitation and contractor’s workshop, labour camp etc. should be completed before CED.

- Detailed level 4 schedules should be prepared before CED. Six-month plan will be prepared based on these schedules for monitoring & speeding up.
- Corrective action should be initiated immediately when the trend of actual progress shows delay in overall schedule.
- Matter related to release of rooms and terminal points should be resolved in daily meeting.
- Resource based schedule should be developed.

CHAPTER 8. CONCLUSIONS

The experience shared within this document clearly reflects the fact that the duration of the NPP construction can be considerably reduced with good management and improved processes and technologies.

The following common major areas/considerations, where further improvement and development might result in additional reduction of construction period and capital costs, have been identified:

(i) Design/Engineering:

- 3D CADD modelling of complete plant with as much details as possible integrated with material and documentation control.
- Finishing design before start of construction and integrating procurement.
- Construction and commissioning requirements with upfront design.

(ii) Procurement & construction:

- Use of open top installation in combination with prefabrication and modularisation.
- Doing as much as possible prior to the signature of the contract (detail engineering, procurement of long delivery material, civil works).

(iii) Local participation should not exceed local expertise.

(iv) Availability of modern facilities and infrastructures on the site as early as possible.

(v) The project management should be given the full authority to successfully complete the project within the project budget and schedule.

(vi) Use single point responsibility assignment to the project team that actively controls the finance, schedule, and quality of the project through audits and updates. The team should be experienced and have the flexibility and ability to make adjustments during implementation. The team should be established at the early stage of the project.

(vii) Increased use of the IT project management tools to further reduce the manpower, to assure the consistency with licensing documents, share electronically design and other info among participants and to establish the basis for configuration management.

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ABBREVIATIONS

A/E	Architect-Engineer
ABWR	Advanced Boiling Water Reactor
AIM	Asset Information Management
BOP	Balance of Plant
CAD, 3D CAD	(3-Dimensional) Computer Aided Design
CADD	Computer Aided Design and Drafting
CAE	Computer Aided Engineering
C&C	Coordination and Control
CCA	Commissioning Completion Assurance Certificate
CCP	Commissioning Control Point
CCR	Commissioning Clarification Request
CE	Combustion Engineering
CED	Contract Effective Date
CEG	Commissioning Execution Group
C/F	Completion of Foundation mat
CI	Conventional Island
CMMT	Candu Material Management System
CMT	Construction Management Team
CNPM	Canatom NPM
C/O	Start of commercial Operation
COD	Commercial Operation Date
CP	Commissioning Procedure
CP2	Commissioning Procedure level 2
CQOR	Commissioning Quality Observation Record
C/R	Completion of Refuelling floor

CRD	Control Rod Drive
CRP	Commissioning Report
CSO	Commissioning Specifications/Objectives document
CT	Commissioning Team
CWP	Construction Work Package
DHIC	Doosan Heavy Industries and Construction
DNPS	Daya Bay Nuclear Power Station
ECCS	Emergency Core Cooling System
EPC	Engineering Procurement Construction
F/L	Fuel Loading
FMCRD	Fine Motion Control Rod Drive
FOAK	First of a Kind
FP	Full Power
FSAR	Final Safety Analysis Report
GE	General Electric
HRD	Human Resources Development
HVAC	Heating, Ventilation and Air Conditioning
HWR	Heavy Water Reactor
HWB	Heavy Water Board
IAEA NUSS	IAEA's Nuclear Safety Standards
I&C	Instrumentation and Control
I/F	Inspection of Foundation
IMS	Information Management System
IntEC	Integrated Electrical and Control database
IT	Information Technology
LAN	Local Area Network

LBB	Leak Before Break
LNPS	Lingao Nuclear Power Station
LWR	Light Water Reactor
MCR	Main Control Room
MMT	Material Management Team
MRR	Material Receiving Report
NC	Non-Conformity
NCR	Non-Conformity Report
NDE	Non-destructive Examination
NDT	Non-destructive Testing
NFC	Nuclear Fuel Complex
NI	Nuclear Island
NPP	Nuclear Power Plant
NSP	Nuclear Steam Plant
NSSS	Nuclear Steam Supply System
ODC	Over-dimensional Consignment
OP	Operating Procedures
PDA	Personal Digital Assistant
PHT	Primary Heat Transport
PHWR	Pressurized Heavy water Reactor
PRIS	Power Reactor Information System
PSAR	Preliminary Safety Analysis Report
QC	Quality Surveillance
QS	Quality Control
RAS	Risks Analysis Sheet
R/B	Reactor Building

RC	Rebar reinforced Concrete
RCCV	Reactor Concrete Containment Vessel
RIP	Reactor Internal Pump
RPV	Reactor Pressure Vessel
SAR	Safety Analysis Report
SC	Steel plate reinforced Concrete
S/C	Start of Construction
SCP	Standard Commissioning Procedure
SPMO	Site Project Management Organisation
SPMT	Site Project Management Team
TAPS	Tarapur Atomic Power Station
T/B	Turbine Building
T/G	Turbo Generator
TIG	Tungsten Inert Gas
T/O	Turnover
VHL	Very Heavy Lift
WP	Work Plan
WR	Work request

Annex

RESOURCES

To illustrate NPP project complexity and the huge amounts of resources (man-hours/staff, materials, etc.) that have to be managed to get the project completed, some of the resources involved in the analysed projects are presented within this annex.

It should be noted that these projects are of different types and implemented in different environments. The information within this annex should not be used to make comparisons between vendors/utilities, countries and projects.

I.1. Qinshan:

The availability and use of construction labor resources were planned and managed primarily by the construction contractors, with support and direction provided by TQNPC and AECL. The construction contractors expended approximately 34 million labor hours on the construction activities for the two-unit station. Fig. A.1.1 gives a summary of the construction labor resources used on the Qinshan CANDU Project. Fig. A.1.2 provides an overview of the labor distribution during the peak construction period.

The detailed planning of the required labor resources was performed in conjunction with the development of the CWPs scopes of work for the individual construction contracts. Craft hours were assigned to the detailed quantities of work contained in the scope packages so as to determine the overall labor resource profiles. On the basis of the labor profiles and the activities of the Level 2 and 3 schedules, the assignment and management of the labor resources were carried out successfully by the construction contractors.

The constricted site footprint together with the fast-track construction schedule required the construction contractors to significantly overlap the various crafts working on the Site at any one time. During the peak construction period of January 2001 to December 2001, the average construction labor force numbered approximately 7000. The use of a second shift on critical path work during this period enabled the construction contractors to have further flexibility in managing their labor resources. Figs A.1.3 to A.1.5 provide an overview of the civil program and Figs. A.1.6 to A.1.8 give an overview of the installation program.

The construction contractors successfully placed 0.5 million m^3 of concrete, fabricated and erected 25 000 tons of steel, installed 200 kilometres of pipe, pulled 2000 kilometres of power and control cable, and installed some 2500 pieces of major mechanical equipment.

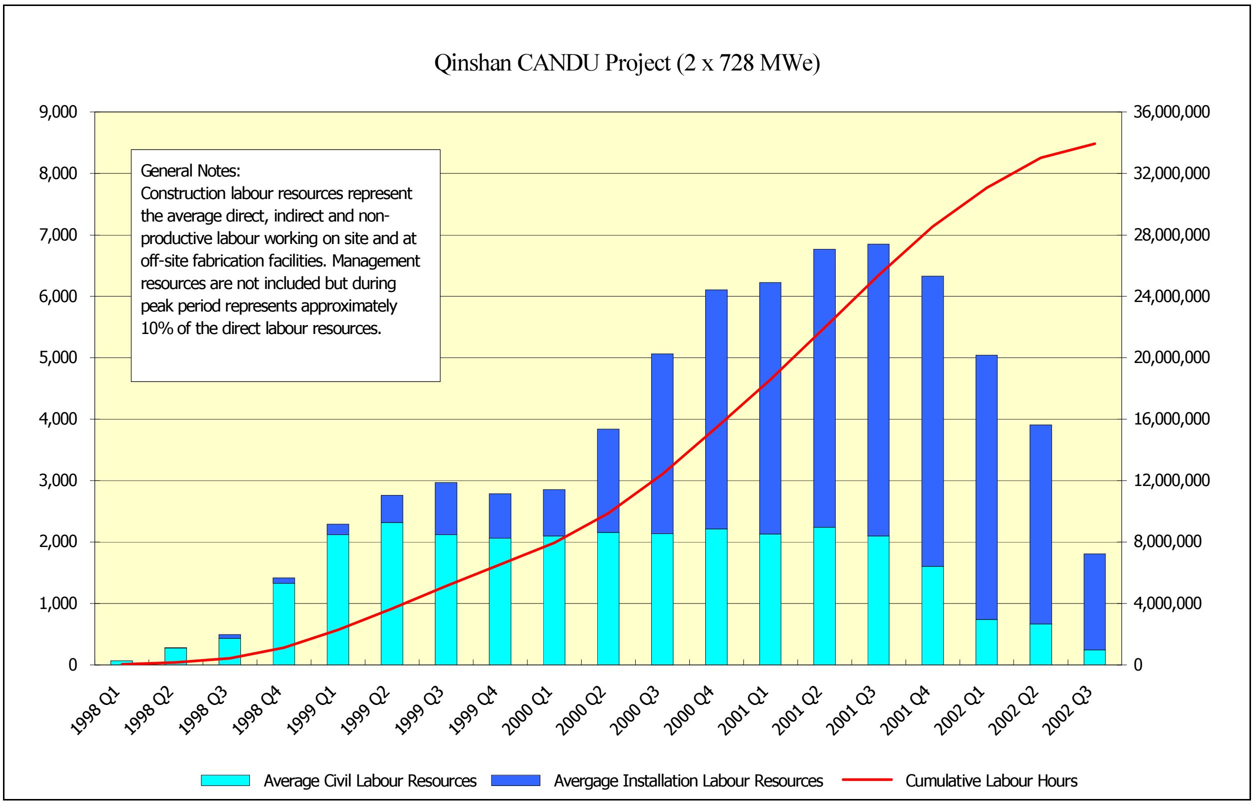


Fig. A.1.1. Average construction labor resources (Qinshan).

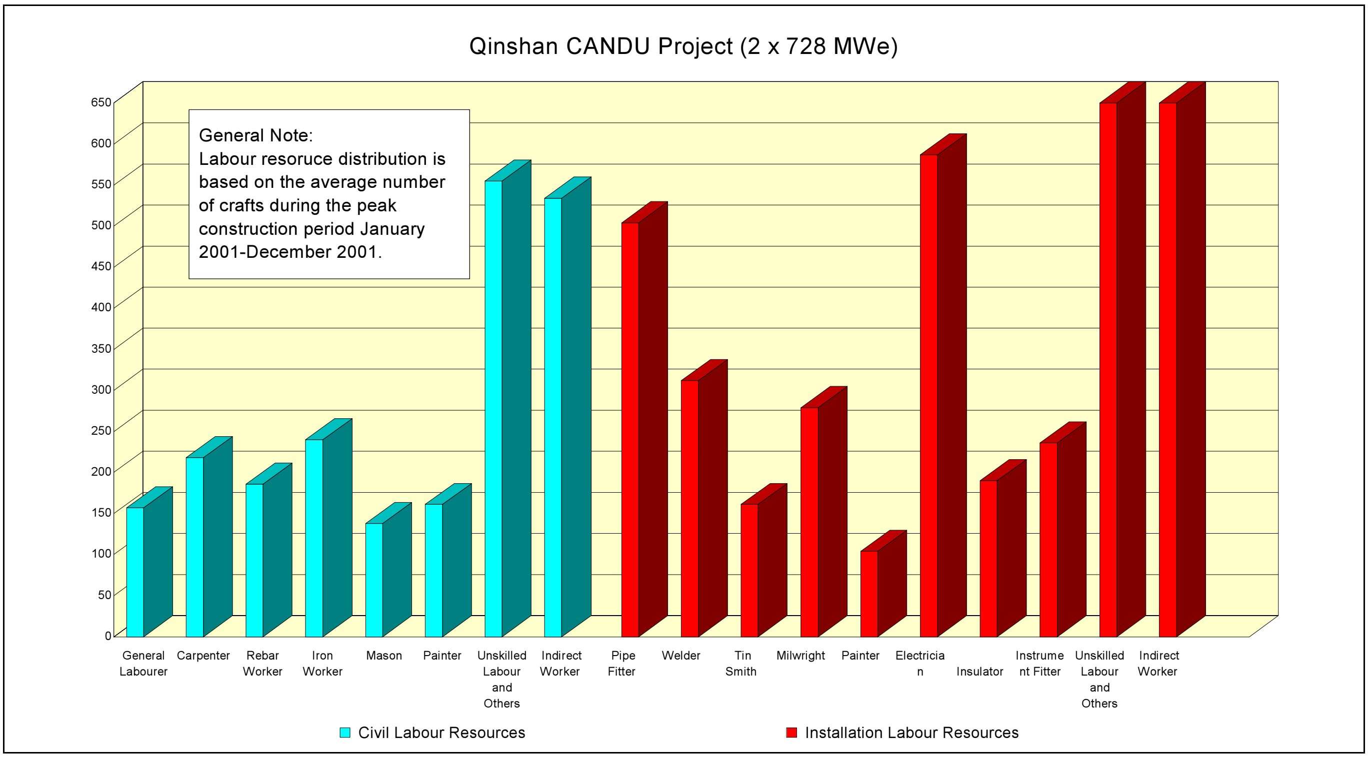


Fig A.1.2. Construction labor resources (Qinshan).

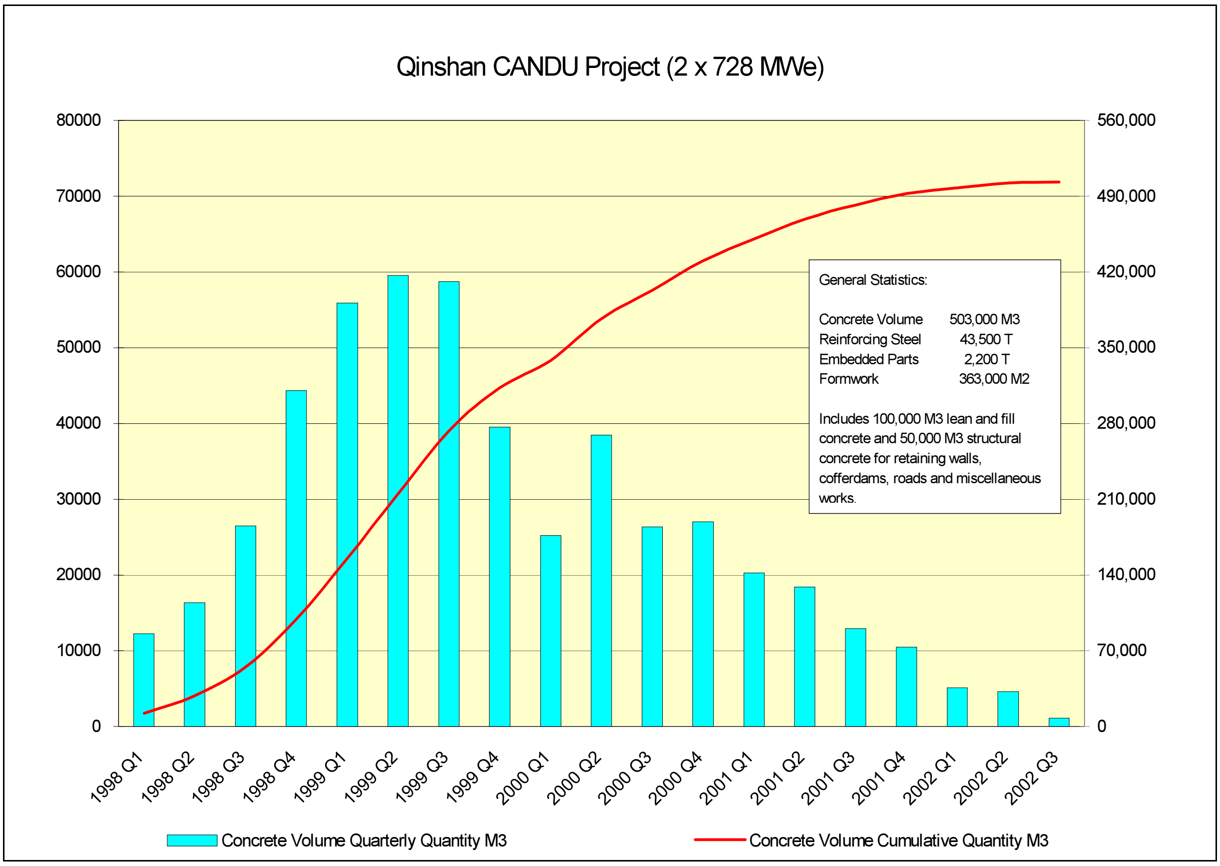


Fig. A.1.3. Concrete works (Qinshan).

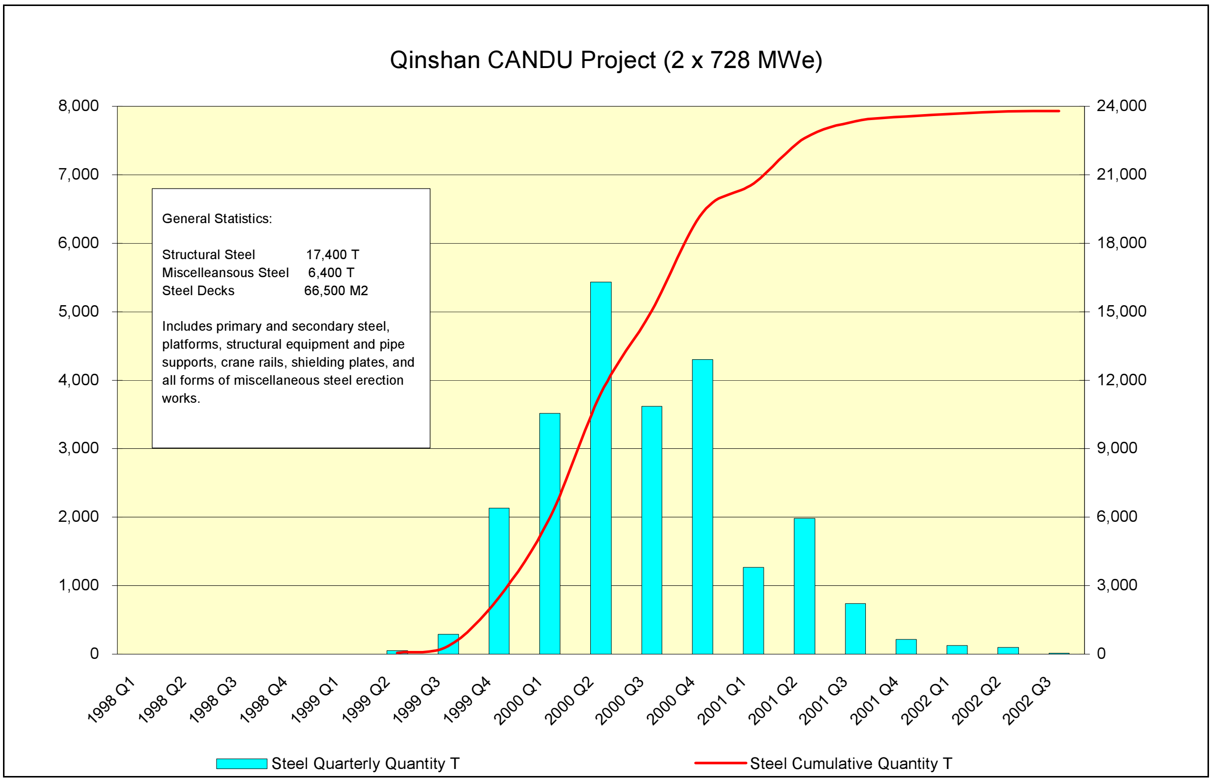


Fig A.1.4. Construction labor resources (Qinshan).

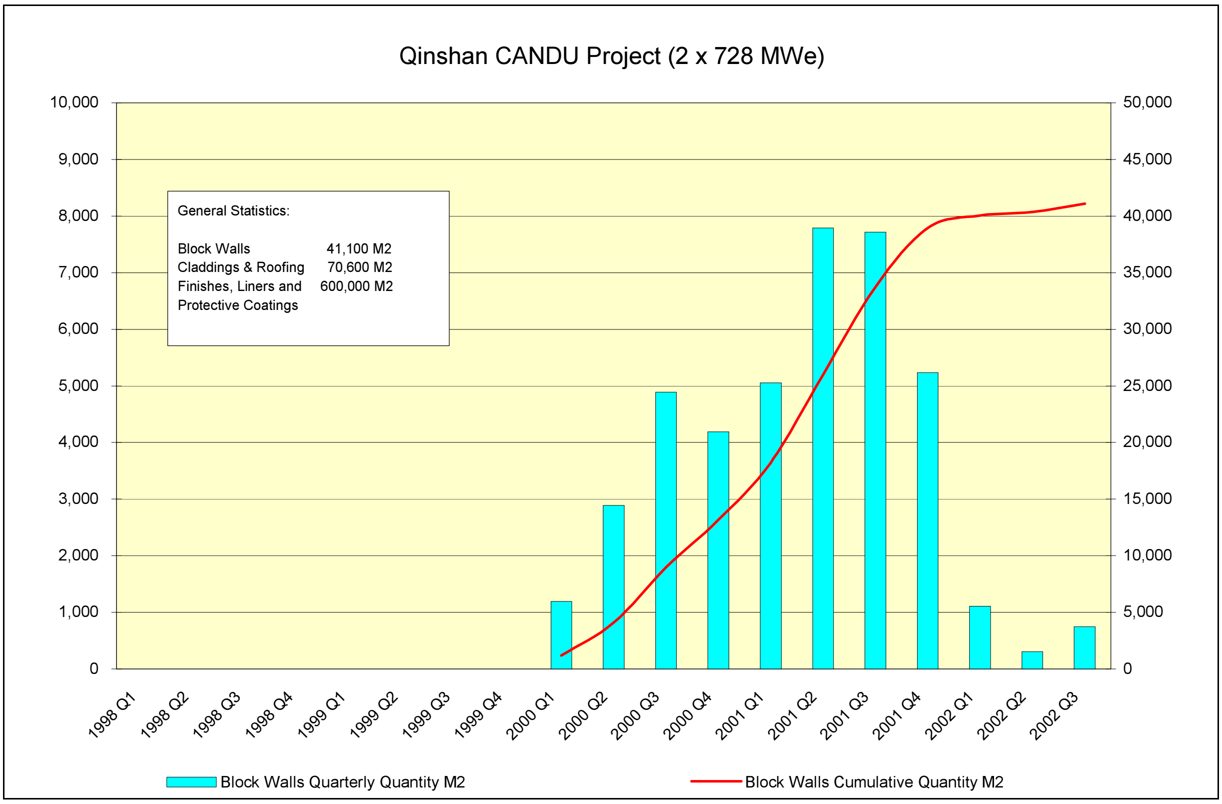


Fig. A.1.5. Architectural works (Qinshan).

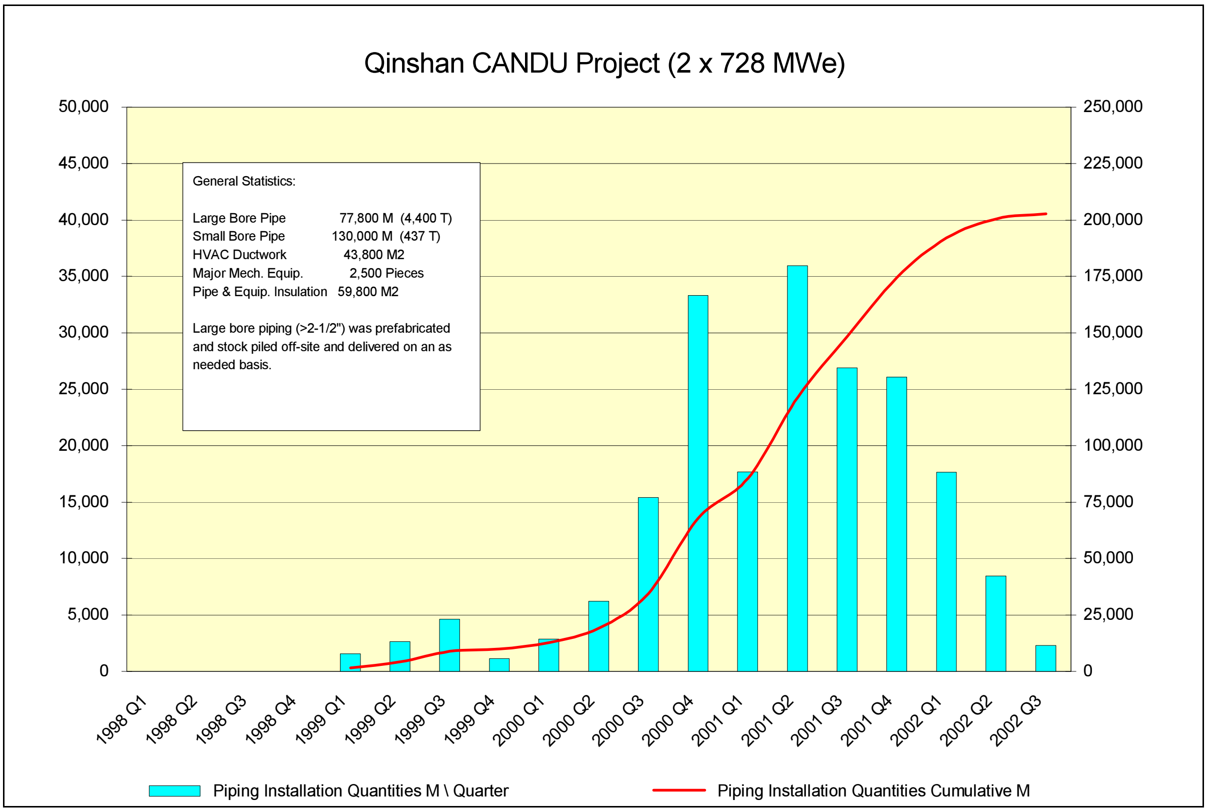


Fig. A.1.6. Mechanical works (Qinshan).

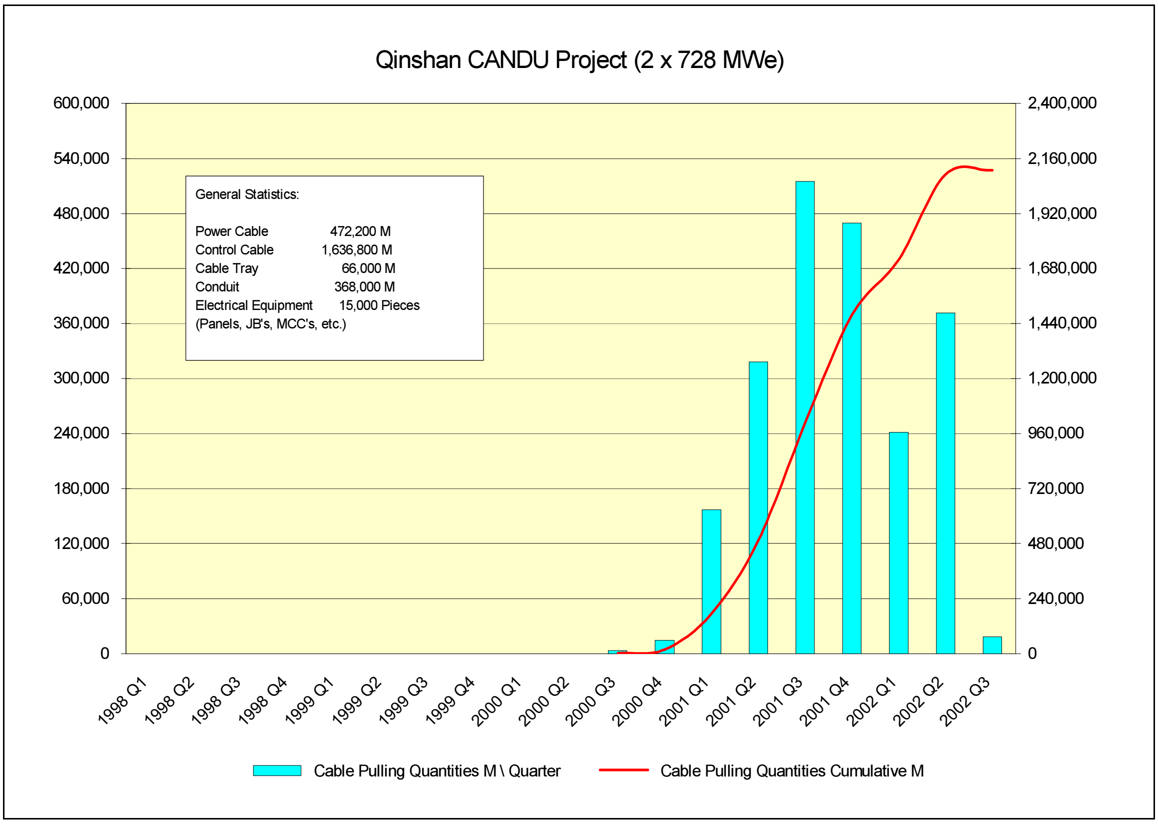


Fig. A.1.7. Electrical works (Qinshan).

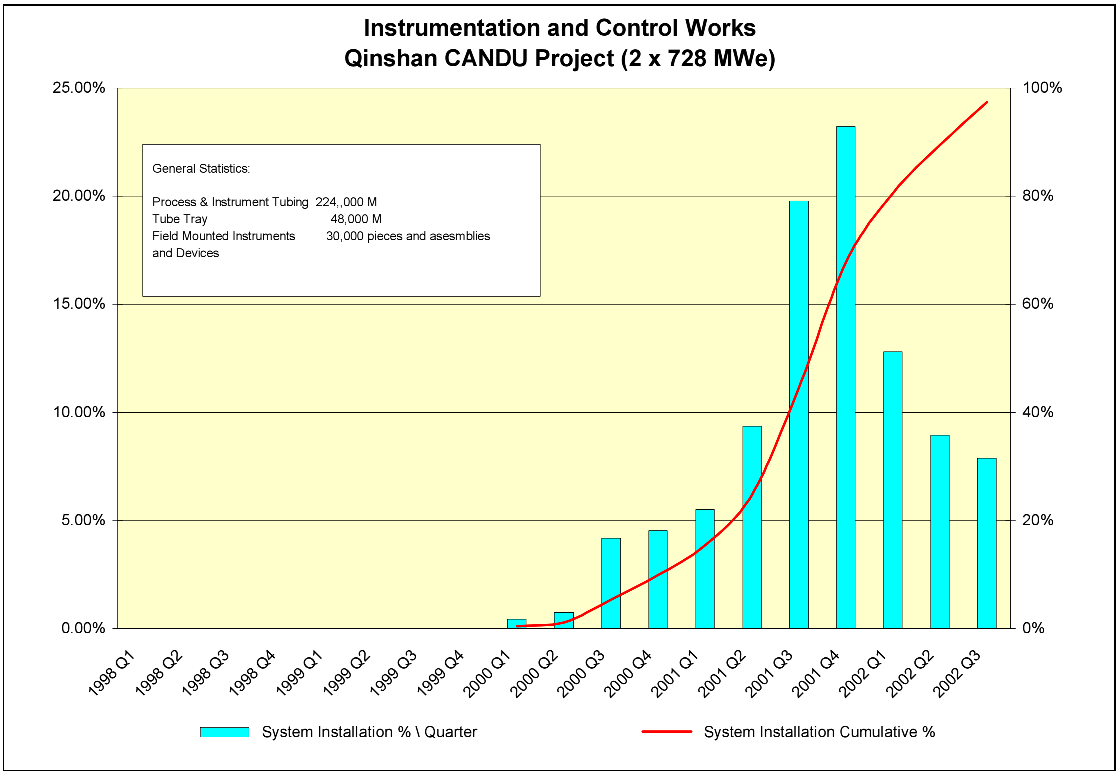
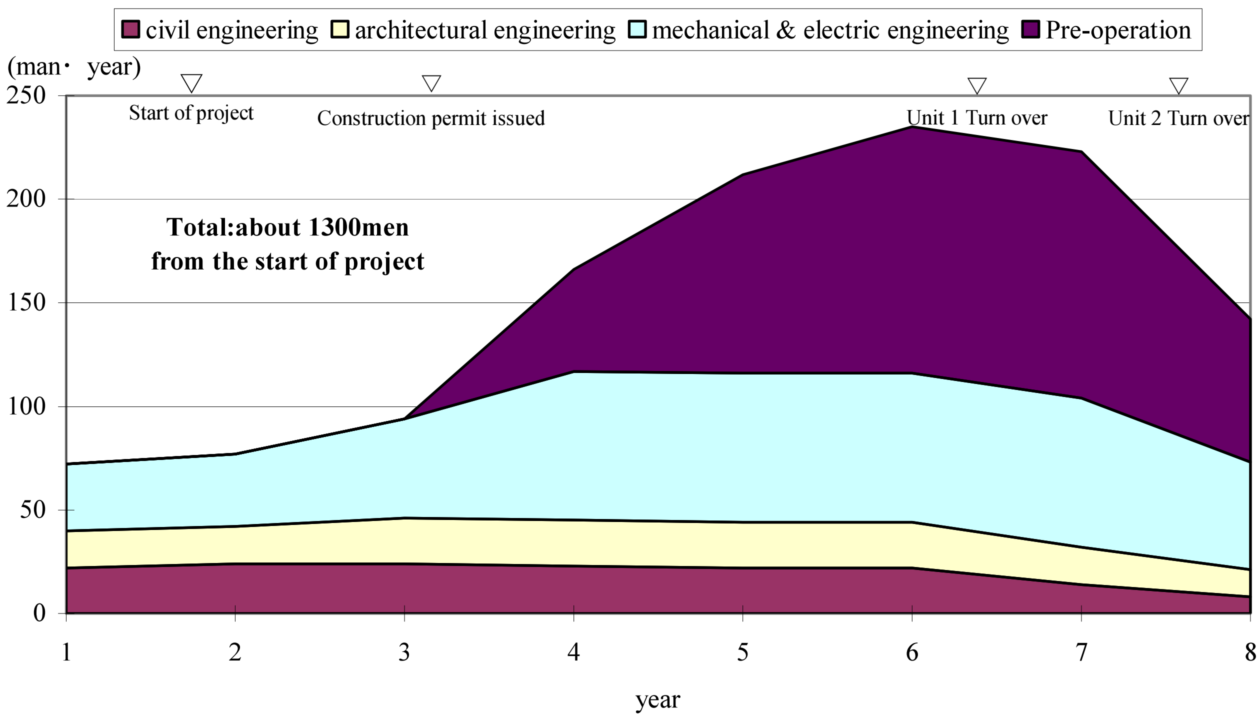


Fig. A.1.8. Instrumentation and control works (Qinshan).

I.2. Kashiwazaki-Kariwa

Figure A.2.1 shows the owner's human resources needs. Other resources utilized are given below:

- Manpower - construction [man-hours]: U6: 14 400 000; U7: 10 800 000.
- Materials:
  - Piping [tons]: U6: 11 000; U7: 6000.
  - Valves [pieces]: U6: 11 000; U7: 8000.
  - Concrete [m^3]: U6: 200 000; U7: 167 000.



Note: For twin ABWR plant: about 1,300 men-year, out of which: mechanical & electrical (average57, max 72); architect (19, 22); civil (20, 24); administration (61, 82)

Fig. A.2.1. Owner's project management team (Kashiwazaki-Kariwa).

I.3. Lingao

- Manpower [man-hours/unit]:
  - Early and marine works: 829 400.
  - Civil works: 16 567 100.
  - Erection works: 16 786 400.

Note: It was reported that the number of foreign experts was reduced significantly if compared with Daya Bay.

- Materials
  - Concrete [m^3 /unit]
  - NI/ Nuclear Auxiliaries within BOP: 120 000.
  - CI/ Auxiliaries within BOP: 110 000.
  - Nuclear piping [meters/unit]: 110 000.

I.4. Yonggwang

- Manpower (man-hours for two units):
  - Contractors: 26 900 000.
  - Owner: 3 400 000.
- Materials
  - Concrete: 590 000 m3.
  - HVAC ducts: 1100 tonnes.
  - Large size pipe: 26 000 spools (115 000 liner meters).
  - Cable pulling: 4 400 000 linear meters.
  - Valves: 23 000 pieces.

I.5. Tarapur

- Manpower: 4 million man-hours of owner's staff and 90 million man-hours of package contractor are estimated to be used for Units 3&4 construction.
- Equipment and material:
  - One 15 000 tons heavy duty crawler crane, one 7000 tons crawler crane, 15 crawlers cranes of 10 tons each.
  - Six batch plants with a total capacity of 155m^3/h, 2 chilling plants with a total capacity of 4.25 m^3/h, 8 concrete pumps, 7 concrete placer booms, 17 concrete transit mixer.
  - About 200 welding sets, 4 automatic welding sets, 50 gas cutting sets, 100 grinders, etc.
  - Concrete: 560 000 m^3.
  - Instrumentation tubing: 120 km.
  - HVAC ducts: 52 0000 m^2.
  - Cable pulling: 2160 km.

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