QINSHAN CANDU PROJECT CONSTRUCTION EXPERIENCES AND LESSONS LEARNED TO REDUCE CAPITAL COSTS AND SCHEDULE BASED ON QINSHAN CANDU PROJECT IN CHINA

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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

SECTION **PAGE**

TABLES

FIGURES

TABLE OF CONTENTS

SECTION **PAGE**

APPENDICES

EXECUTIVE SUMMARY

This study report documents Qinshan CANDU Project construction experience as well as management strategies and approaches for the reduction of capital costs, including construction and start-up experience of evolutionary water-cooled reactors. The study was undertaken as an initiative of the International Atomic Energy Agency (IAEA) consultancy workshop held from 2002 October 16 to 18 at IAEA Headquarters in Vienna. The report covers the Qinshan CANDU units in China and provides an analysis of practical and achievable improvements to improve quality and reduce costs and schedules. The report also includes input from the Chinese construction contractors who in first-time construction of CANDU achieved several world records and the participation of Hitachi (turbine generator supplier of the Qinshan CANDU units), which is contributing its very successful modularization experience in Japan to the ongoing CANDU program.

The Qinshan CANDU®* Nuclear Power Plant (NPP), Qinshan Phase III is being built in Zhejiang Province, People's Republic of China by Third Qinshan Nuclear Power Company (TQNPC) as the owner and Atomic Energy of Canada Limited (AECL) as the main contractor. The most advanced tools and techniques for achieving optimum construction quality, schedule and cost were used. The commercial model of the Project was based on international financing for the associated design and equipment supply. Localization of construction and bulk materials was effective. Increased localization for future units is clearly feasible given the experience of Chinese industry and the commercial project model selected.

The introduction of new design and construction techniques was achieved by combining conventional AECL practices with working experiences in China. Successful application of advanced project management methods and tools will benefit TQNPC in operation of the station, and the Chinese contractors in advancing their capabilities in future nuclear projects in China and enhancing their opportunities internationally. TQNPC's participation in Quality Surveillance (QS) activities of Nuclear Steam Plant (NSP) and Balance of Plant (BOP) off-shore equipment benefited TQNPC in acquiring knowledge of specific equipment manufacturing processes, which can be applied to similar activities in China. China has established the capability of manufacturing CANDU fuel and becoming self reliant in fuel supply.

The two CANDU 6 units in China were based on a reference plant design of CANDU 6 in Korea. Improvements in design and construction methods allowed Unit 1 to be constructed in 51.5 months from First Concrete to Criticality - a record in China for nuclear power plants. AECL's initial assessment of replicating this project in China showed that the construction schedule could readily be reduced to 48 months and the capital costs, including IDC (Interest During Construction), reduced by almost one quarter. AECL is building on this experience and successful results of Qinshan CANDU NPP in its Advanced CANDU Reactor™ (ACR™)**

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* CANDU® is a registered trademark of Atomic Energy of Canada Limited (AECL).

** Advanced CANDU Reactor™ (ACR™) is a trademark of Atomic Energy of Canada Limited (AECL).

design, which will have an *N*th reactor capital cost of 1000$ US per kWe and a project schedule of 42 months.

The purpose of this review and study is to take real experience and feedback from the successful construction of 2 x 728 MWe CANDU units in China and move forward in assessing and developing future programs, projects and methods to reduce capital costs and schedules for nuclear power plants. The key factors are project management and project management tools, quality assurance, construction methods (including open top construction and heavy lifts), modularization, electronic documentation with configuration control that provides up-to-date on-line information, CADDS design linked with material management, specialized material control including bar coding, and planning, and accountability of activities to meet a challenging schedule and economic target.

ACRONYMS

ACR	Advanced CANDU Reactor
AECB	Atomic Energy Control Board
AECL	Atomic Energy of Canada Ltd.
AFS	Available-for-Service Certificates
AIM	Asset and Information Management (Intergraph software)
ASME	American Society of Mechanical Engineers
BNSP	Balance of Nuclear Steam Plant
BOP	Balance of Plant
BWR	Boiling Water Reactor
C & C	Co-ordination and Control (Schedule)
CADDS	Computer Aided Design and Drafting
CANDU	CANadian Deuterium Uranium
CCA	Commissioning Completion Assurance Certificates
CCP	Commissioning Control Point
CCR	Commissioning Clarification Request
CCW	Condenser Cooling Water
CED	Contract Effective Date
CEG	Commissioning Execution Group
CMMS	CANDU Material Management System
CMT	Construction Management Team
CNEIC	China Nuclear Energy Industry Corporation
CNI	Chinese Nuclear Industry
CNNC	Chinese National Nuclear Corporation
CNPM	Canatom NPM
CQOR	Commissioning Quality Observation Record
CRP	Commissioning Report
CSO	Commissioning Specification and Objective
CT	Commissioning Team
CW	Cooling Water
CWP	Construction Work Package
DDR	Deviation Disposition Request
ECC	Emergency Core Cooling

ECGD	Export Credits Guarantee Department
EPS	Emergency Power Supply
EWS	Emergency Water Supply
EDC	Export Development Corporation
E/P	Embedded Part
FSAR	Final Safety Analysis Report
HPECC	High Pressure Emergency Core Cooling
HXCC	Hua Xing Construction Company
IAEA	International Atomic Energy Agency
I&C	Instrumentation and Control
IDC	Interest During Construction
IFOS	In-Core Physics Calculation and Optimization of Fuel Management System
IntEC	Integrated Electrical and Control database (developed by AECL)
ISO	International Standards Organization
ITP	Inspection and Test Plan
J-EXIM	Export-Import Bank of Japan
LAN	Local Area Network
LOCA	Loss of Coolant Accident
LP	Low pressure
MMT	Materials Management Team
NCR	Non-conformance Report
NMAS	Nuclear Material Accounting System
NNSA	National Nuclear Safety Administration
NPP	Nuclear Power Plant
NSP	Nuclear Steam Plant
OM	Operating Manual
P/H	Pumphouse
PHT	Primary Heat Transport
PHWR	Pressurized Heavy Water Reactor
PRC	People's Republic of China
PSAR	Preliminary Safety Analysis Report
PWR	Pressurized Water Reactor
QA	Quality Assurance
QC	Quality Control
QS	Quality Surveillance

R & D	Research and Development
RFC	Release for Construction
S/B	Service Building
SCP	Standard Commissioning Procedure
SCR	Secondary Control Room
SDC	Shutdown cooling (pumps)
SFB	Spent Fuel Bay
SFTB	Spent Fuel Transfer Bay
SPMO	Site Project Management Organization
SQA	Site Quality Assurance
SSP	System Surveillance Plan
STAR	Chinese Quality organization overseeing NSP construction on behalf of owner
T/B	Turbine Building
T/G	Turbine Generator
T/H	Turbine Hall
T/O	Turnover
TRAK	Electronic document control system developed by AECL
TQNPC	Third Qinshan Nuclear Power Company Limited
U/G	Underground
US-EXIM	Export-Import Bank of the United States
VHL	Very Heavy Lift
WIS	Weld Information System
WMS	Work Permit Management System
WP	Work Plan
WR	Work Request
WTR	Water Treatment Plant
ZTPC	Zhejiang Thermal Nuclear Power Company

1. CONTRACT ORGANIZATION AND SCOPE

1.1 Background

The Qinshan CANDU Nuclear Power Plant (NPP) Qinshan Phase III, consisting of 2 x 728 MWe CANDU 6 units is being built in Zhejiang Province, PRC, by the Third Qinshan Nuclear Power Company (TQNPC) as the owner and Atomic Energy of Canada Limited (AECL) as the main contractor. TQNPC is the designated owner and implementer of the Project by the China National Nuclear Corporation (CNNC).

The Contract between CNNC and AECL was signed in November 1996 and became effective on February 12, 1997. The first concrete was placed on June 8, 1998 (Unit 1 was declared in-service December 31, 2002, some six weeks ahead of schedule). The scheduled in-service dates are: Unit 1, 2003 February 12 and Unit 2, 2003 November 12. The Reference Plant design is the Wolsong 3 and 4 CANDU 6 units in the Republic of Korea, with some specific design improvements. Qinshan III is an international project financed by China, Canada, Japan and USA

1.2 Contract Scope

The Project structure is illustrated in Figure 1-1. AECL is the main contractor and overall project manager for the owner TQNPC, working with international Project participants. The major participants and their roles are:

- TQNPC as owner prepares Site, provides permanent site facilities (offices, warehouse) and local staff to the AECL Site Project Management Organization, manages the Balance of Plant (BOP) construction by subcontract to Shanghai Nuclear Engineering & Research Institute, executes commissioning, manages licensing, provides Quality Surveillance (QS) of Nuclear Steam Plant (NSP) and BOP off-shore equipment during manufacturing, provides added Site QS of NSP construction through an independent QS company, and provides the first fuel load and initial heavy water fill.
- AECL designs and supplies the NSP, manages NSP construction, and provides guidance and direction to TQNPC for commissioning. As overall Project manager, AECL subcontracts to Canatom NPM (CNPM) for Site Project management and overall commissioning management, NSP equipment procurement and design of the Balance of Nuclear Steam Plant (BNSP). AECL also subcontracts to Hitachi in Japan and HANJUNG in Korea for supply of some NSP equipment. Hydro-Quebec as a subcontractor to AECL provides training of TQNPC plant management, operations and maintenance staff.
- The Bechtel/Hitachi Consortium as a subcontractor to AECL designs and supplies the BOP and provides technical assistance to TQNPC for BOP construction management.
- Chinese Construction Contractors perform the construction work. China Nuclear Industry-23 (CNI 23) and Hua Xing Construction Company (HXCC) as subcontractors to AECL perform NSP construction; China Nuclear Industry-22 (CNI 22) and Zhejiang Thermal Power Construction Company (ZTPC) as subcontractors to TQNPC perform BOP construction.

1.3 Project Organization

The Project organization is shown in Figures 1-2 to 1-5.

1.4 Contract Implementation

A key part of the success of the implementation of the Project was how the parties adapted to the Contract and their working experiences. TQNPC has the position that essentially all concerns were to be managed by AECL, as it was a “turnkey” type contract. AECL was new to China and while it managed NSP construction and entered into subcontracts with Chinese construction contractors, TQNPC paid the contractors. This was not a simple process to implement. TQNPC also managed BOP construction, with AECL having overall “project” Quality Assurance responsibility, as well as interfacing and coordination responsibilities on the Site work. In addition, commissioning was done under a joint team executed by TQNPC, with AECL providing guidance and direction. The parties learned to work in this dual reporting relationship and the roles of TQNPC and AECL evolved into an effective partnership, with respective responsibilities defined under the Contract.

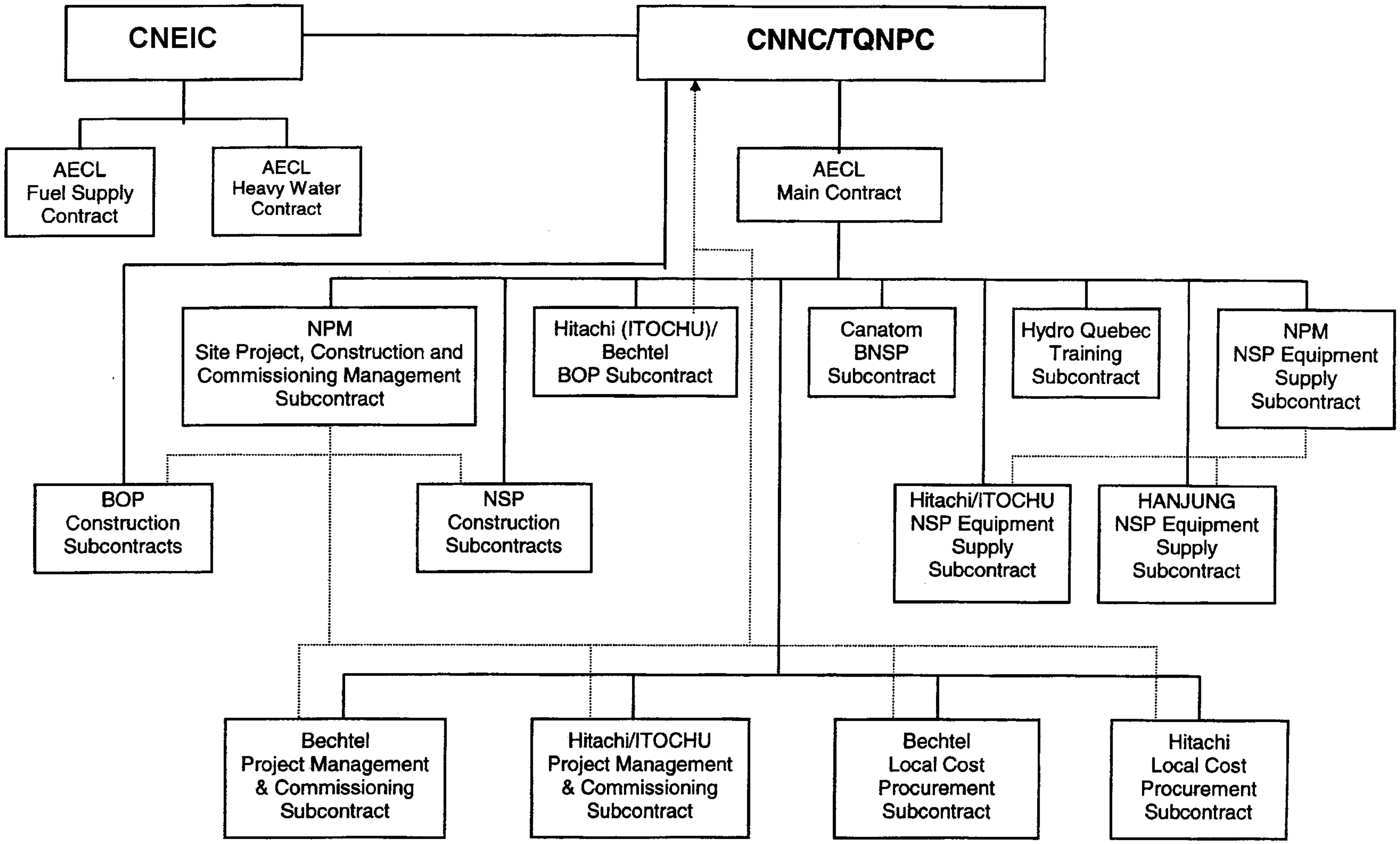


Figure 1-1 AECL Overall Project Contract Structure

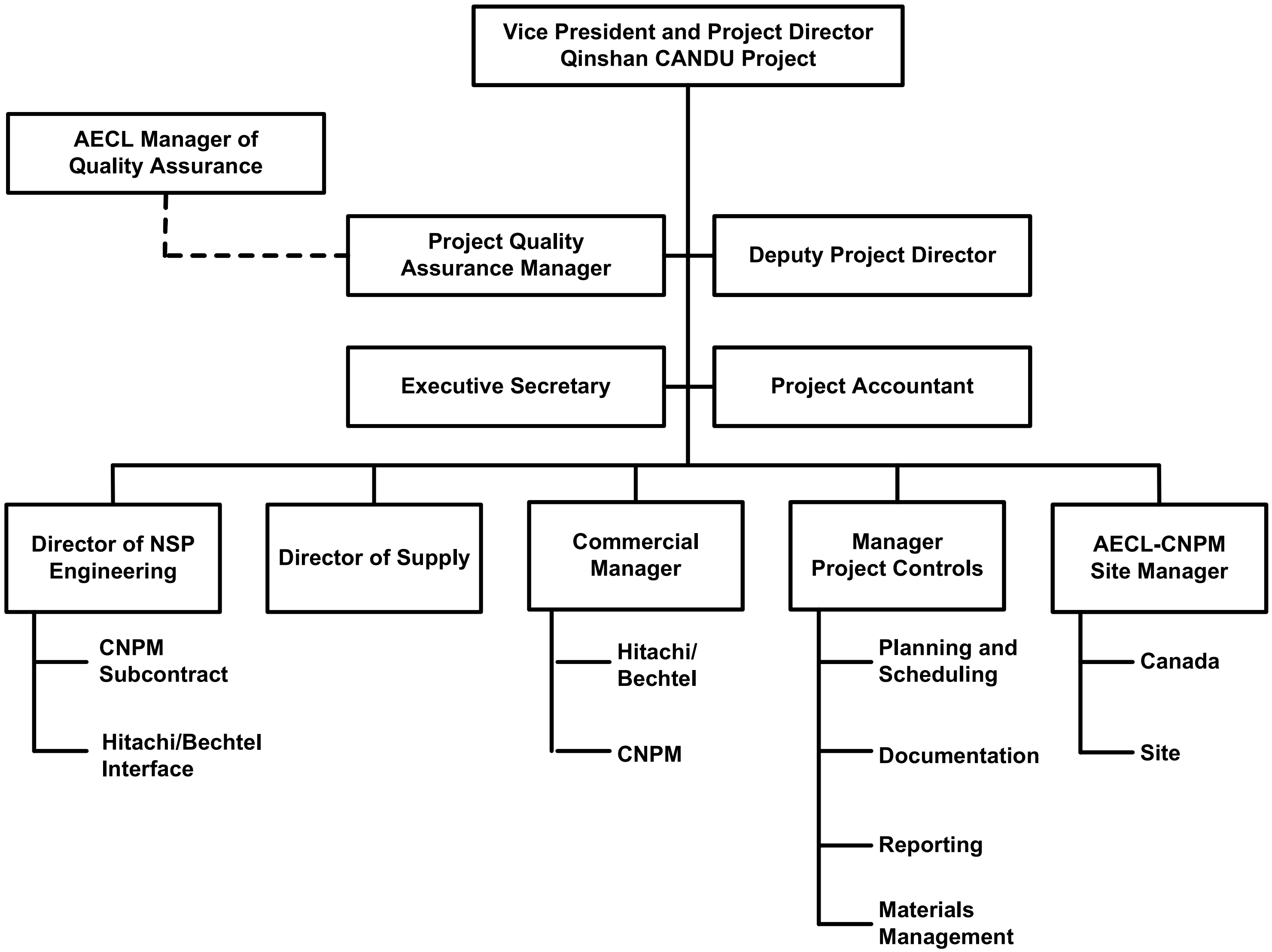


Figure 1-2 AECL Qinshan CANDU Project Organization

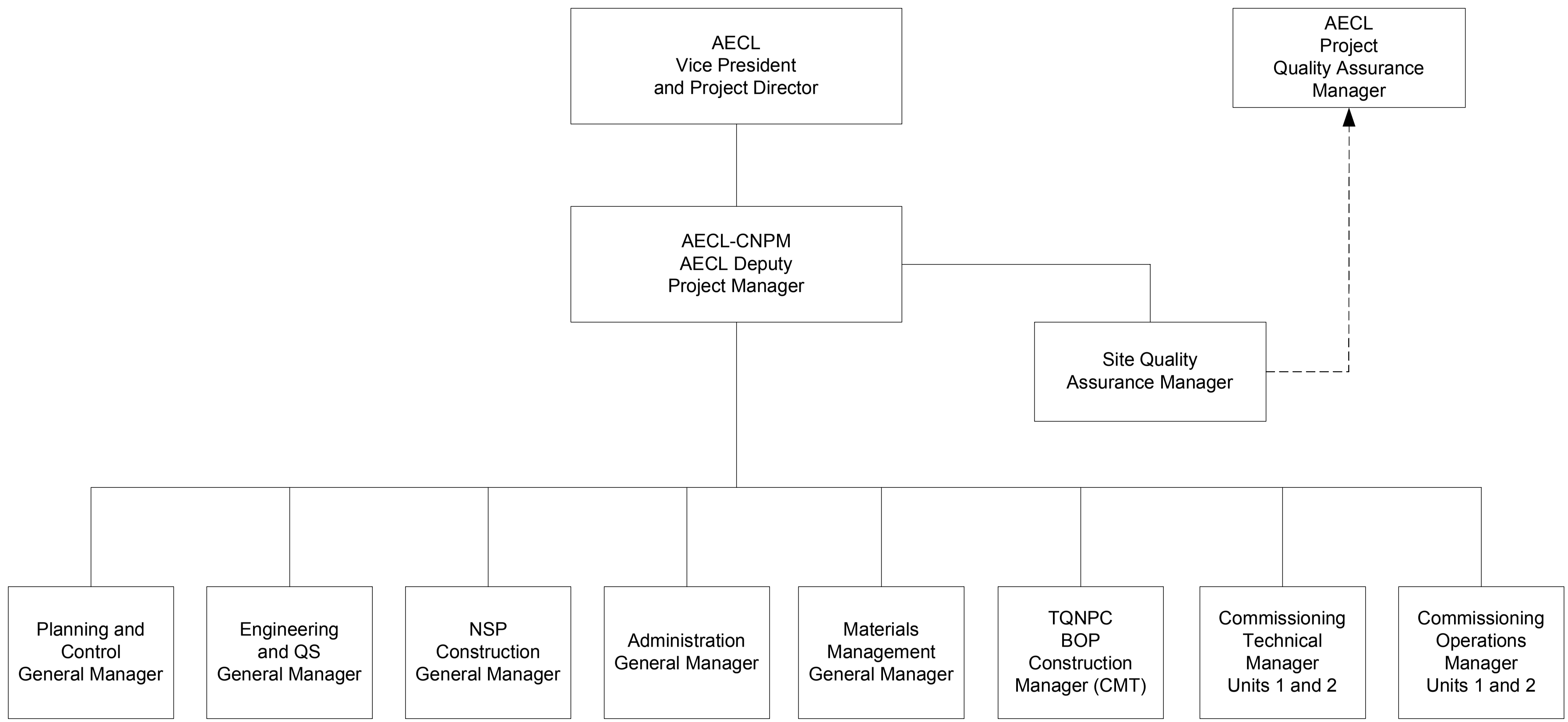


Figure 1-3 Site Project Management Organization

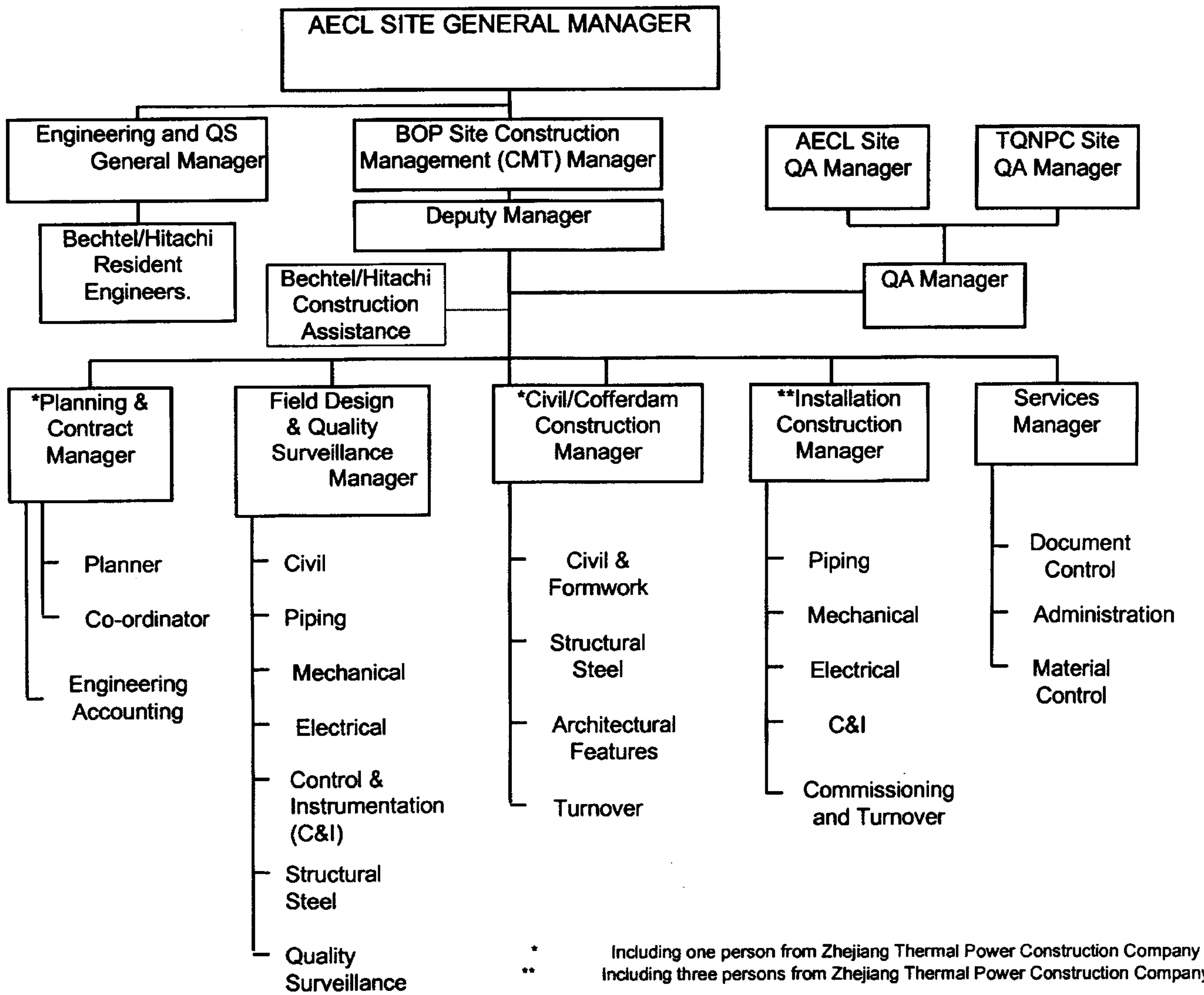


Figure 1-4 BOP Site Construction Management Organization

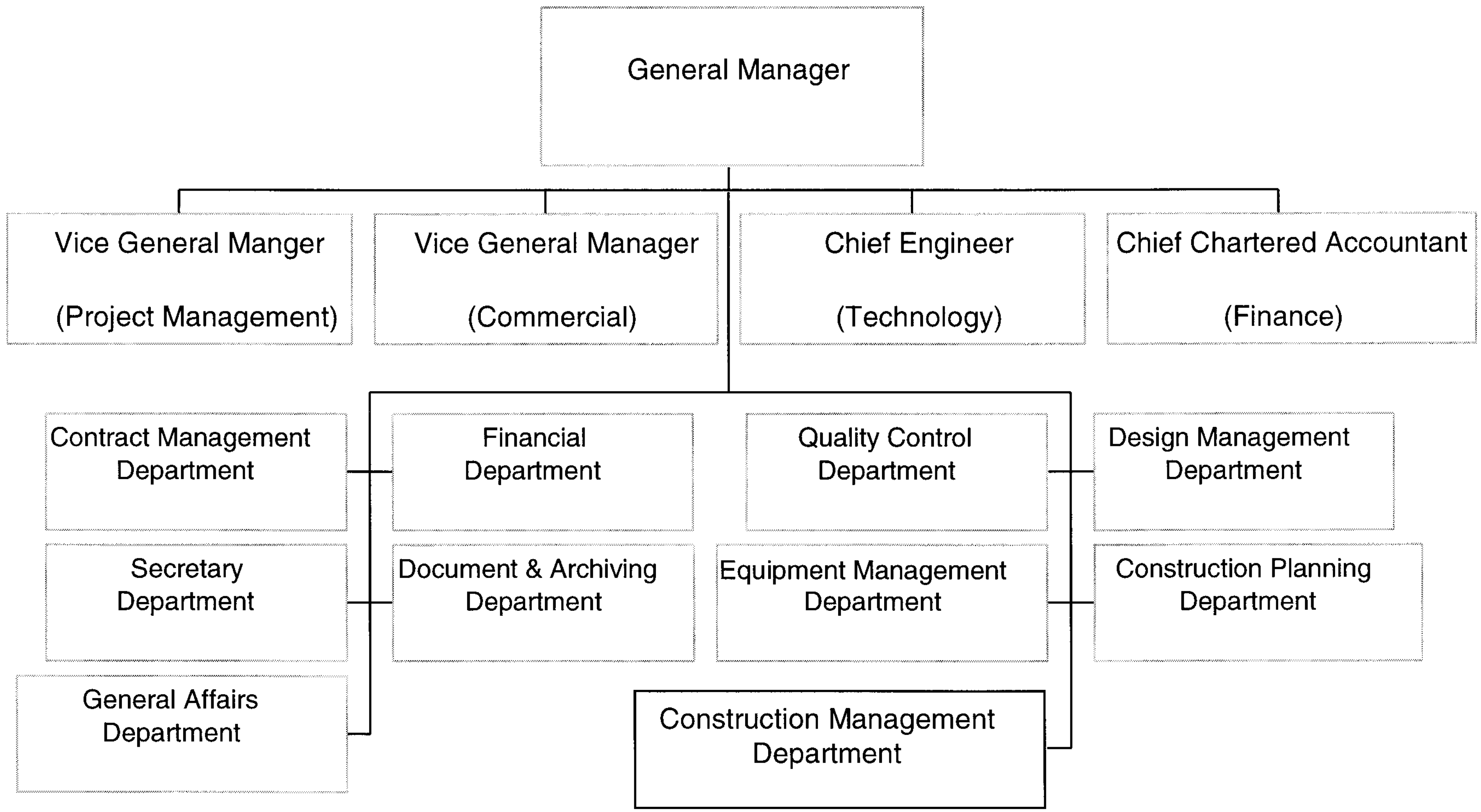


Figure 1-5 Qinshan CANDU Project – TQNPC Construction Organization

2. PROJECT COSTS

The project was based on maximizing the extent of financing, as reflected in the Contract model and scope. The Contract and major subcontracts were lump sum and unit cost, which reduced risk to the owner.

AECL arranged full financing of the foreign scope through the export credit agencies of EDC (Canada), US-EXIM (USA) and J-EXIM (Japan), including 85% of foreign content, plus 15% for local scope and Interest During Construction (IDC).

The dollar values of the financing are as follows:

EDC - Canadian financing	$ 1228 M (Cdn.)
EDC - Canadian financing for Korean supply	$ 123 M (US)
US EXIM - United States financing	$ 192 M (US)
J EXIM - Japan financing	$ 223 M (US)
ECGD - UK financing for European supply	$ 43 M (US)
TOTAL	$1228 M (Cdn.); $581 M (US)

3. LICENSING AND REGULATORY

3.1 Licensing and Regulatory Issues

Licensing and regulatory issues were minimized as the result of upgrades identified by 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 provided by TQNPC and subcontractors. TQNPC and regulatory review comments were documented and addressed in several series' of review meetings. AECL supported TQNPC and the Atomic Energy Control Board (AECB) trained Chinese regulator 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.

The National Nuclear Safety Administration (NNSA) supervises the safety of all nuclear facilities in the People's Republic of China (PRC), independently exercising the right of nuclear safety supervision. The safety permit system is implemented in PRC for nuclear facilities, with NNSA responsible for the approval and issuing of such safety permits. Submission of nuclear safety licensing documents for Qinshan Phase III Unit 1 satisfied the following regulations of NNSA:

a) Six (6) months before the site is finally selected for nuclear power plant the would-be operating company shall submit to NNSA plant site safety-related documents as listed in the "Nuclear Power Plant Feasibility Study Report".

b) Twelve (12) months before the placement of nuclear island foundation concrete, the would-be operating company shall submit to NNSA "Nuclear Power Plant Construction Application", "Preliminary Safety Analysis Report" and other safety-related documents. The company cannot start construction without obtaining the Construction Permit for the specific nuclear facilities.

c) Twelve (12) months before the first loading of nuclear fuel into the reactor core, the nuclear power plant shall submit to NNSA "Application for First Fuel Loading of Nuclear Power Plant".

d) Before operating the nuclear facilities the operating company shall submit to NNSA the "Application for Nuclear Power Plant Operation Permit", "Final Safety Analysis Report" and other related documents. Without obtaining documents allowing for fuel loading and commissioning, the operating company cannot start fuel loading or commissioning. Only after getting the "Nuclear Power Plant Operation Permit" can the nuclear power plant be put into official operation.

- To apply for a "Nuclear Power Plant Construction Permit" the following documents shall be submitted:
  1. Approval of "Nuclear Power Plant Feasibility Study Report"
  2. Approval of "Nuclear Power Plant Environmental Impact Report"
  3. "Nuclear Power Plant Preliminary Safety Analysis Report"
  4. "Nuclear Power Plant Quality Assurance Program" (for the period of design and construction)

- To apply for “First Fuel Loading Permit of Nuclear Power Plant” the following documents shall be submitted:
  1. “Final Safety Analysis Report”
  2. Approval of “Nuclear Power Plant Environmental Impact Report” (one month before first fuel loading)
  3. “Nuclear Power Plant Commissioning Program”
  4. Certificate for the qualification of Nuclear Power Plant operating personnel (one month before first fuel loading)
  5. “Emergency Program of the Nuclear Power Plant Operating Company” (six months before first fuel loading)
  6. “Nuclear Power Plant Construction Progress Report” (six months before first fuel loading)
  7. “Nuclear Power Plant In-Service Inspection Program”
  8. Pre-service inspection results (one month before first fuel loading)
  9. “Nuclear Power Plant Commissioning Report before First Fuel Loading” (one month before first fuel loading)
  10. Certificate permitting the nuclear power plant to possess nuclear material (one month before first fuel loading)
  11. List of nuclear power plant operation procedures (one month before first fuel loading)
  12. “Nuclear Power Plant Maintenance Program (six months before first fuel loading)
  13. “Nuclear Power Plant Quality Assurance Program (commissioning period)
- To apply for the “Operation Permit of Nuclear Power Plant”, the following documents shall be submitted:
  1. “Final Safety Analysis Report” revised by the nuclear power plant
  2. Approved “Nuclear Power Plant Environmental Impact Report”
  3. “Nuclear Power Plant Commissioning and Test Run Report after Fuel Loading”
  4. “Nuclear Power Plant Quality Assurance Program” (operation period)
- Issuing dates of Unit 1 Main Licenses/Permits
  1. Qinshan Third Nuclear Power Plant Construction Permit: June 7, 1998
  2. Qinshan Third Nuclear Power Plant First Fuel Loading Approval: July 18, 2002
  3. Release for the control point of Unit 1 first criticality: September 17, 2002
  4. Release for the control point of Unit 1 100% full power: December 17, 2002

3.2 Licensing Impact on Design

The CANDU design follows an evolutionary approach, in which design improvements have been made progressively, based on feedback from operating experience and updated licensing requirements. On the Qinshan CANDU Project, a number of design improvements have been made to enhance the safety and performance of the plant and meet Chinese requirements.

The major design improvements include:

1) The Plant Display System (a major improvement to the Main Control Room) has been provided for enhanced human factors engineering. It incorporates better critical safety parameter displays, as well as a real time database, historical data and custom calculations.

2) A technical support centre has been provided adjacent to the Main Control Room to facilitate effective assessment of emergency situations and provide support to operators, without undue interference with Main Control Room activities. Provision for interfacing with the off-site emergency response centre has also been added. These changes were introduced to address Chinese regulatory requirements.

3) Design changes to buildings, structures and components were made to cater for tornado events. Safety assessments were performed to demonstrate that the required safety functions of safe shutdown, heat removal and containment had been met.

4) A seismically qualified fire protection system has been implemented to meet Chinese regulatory requirements for fire suppression capability in the reactor building after an earthquake.

5) Emergency power supply has been provided to the fans of the seismically and environmentally qualified local air coolers in the reactor building to enhance the control of hydrogen in containment for a site design earthquake 24 hours after a Loss of Coolant Accident (LOCA).

6) Duplicate valves have been provided for emergency water supply to the steam generators, to provide full redundancy and improve reliability for mitigation of seismic and other common cause events.

7) A stainless steel liner has been provided for the spent fuel bay instead of the epoxy liner used in earlier plants, to eliminate leakage from the bay during plant life.

8) Demineralized water is used in a number of clean-up systems to reduce the quantity of spent resin from the liquid waste management systems.

9) More than 10 modifications have been adopted for the sea water intake pump house: velocity caps have been placed on the inlet section of the square culvert pipe, sodium hypochlorite has been injected into the velocity caps, CCW and RSW pump sea water contact parts have been made from sea water and silt-resistant material, and sea water pipes have been lined with polymer cement mortar. There are connecting pipes and isolation valves among circulating water main outlet pipes for each unit in the sea water intake pump house.

10) One hundred % condensate polishing system has been added.

11) Design of extra long propeller blade and two low pressure casing cylinders have been adopted for the turbine LP last stage propeller; low elevation layout of the turbine generator reduces electric consumption of the condenser cooling pump.

12) ^{14}C sampling monitoring system has been added for each Unit.

13) Equipment has been designed for a 40-year design life, rather than the 30 on the reference plant.

In addition to these design changes for enhanced safety, the nuclear design, which had been based primarily on Canadian regulatory and design standards, was assessed to demonstrate compliance with relevant Chinese codes and standards for nuclear design and operation.

From the overall plant performance aspect, the Qinshan CANDU project incorporates an improved thermal cycle to produce the largest power output (728 MWe) compared to similar CANDU reactors, including the reference plant.

The Qinshan CANDU Project represents the latest design of its class, with much improved safety and power output.

4. SCHEDULES

The heart of the Qinshan planning and scheduling management was a detailed 8500-activity Level 2 (Project Co-ordination and Control [C&C] schedule), which set the work requirements for all major project activities, including Engineering deliverables (identified as Release for Construction – RFC), Procurement (identified as Delivery Requirements), Construction and Turnovers, and Commissioning. These Level 2 C&C schedules were produced within 6 months of CED. The Level 3 schedules were developed by engineering and supply organizations within the first 12 months of the Project. The construction and commissioning Level 3 schedules were developed throughout the first two years. The individual subcontractors produced their own Level 2 and 3 schedules to comply with the overall Level 2 C&C schedule. The Level 2 C&C schedule was formally revised three times over the life of the Project to reflect actual progress and incorporate improved sequences for construction and commissioning.

A major challenge of working was to introduce and then successfully implement Level 3 planning. AECL, with TQNPC support, provided training and hands-on teaching to the construction contractors to produce Level 3 schedules that were integrated among the contractors and that matched the activities in the Level 2 C&C schedule.

AECL, Bechtel and CNPM produced detail Level 2 and 3 schedules for engineering and supply schedules by area, using 3D CADDS, *Primavera* scheduling system and an integrated Qinshan Deliverable System that detailed deliverables along with the budget, resources, schedule, status and responsible people. By the end of the job, a database containing more than 50000 activities had been produced by the contractors for the Construction Level 3 schedule.

Monthly updates by the engineering, supply, construction and commissioning groups were provided in order to update the Level 2 C&C. The output was analyzed, and the critical path and variance analysis were produced. A separate monthly scheduling report, including the corrective actions taken when required, was issued to all Project participants.

5. CONSTRUCTION SCHEDULE AND MAJOR MILESTONES

Qinshan Unit 1 was based on a 72-month schedule, followed 9 months later by Qinshan Unit 2. It is to be noted that Unit 1 achieved In-Service 43 days ahead of schedule. Figure 5-1 provides major Project milestone data.

Qinshan CANDU Project
Contractual Milestones

Milestone	Contract Date	Actual Date
UNIT 1		
Contract Effective Date	12-Feb-97	12-Feb-97
Start Excavation below Grade	12-Mar-97	10-Mar-97
PSAR Issued to TQNPC	12-May-97	18-May-97
Construction Licence	12-Jun-98	07-Jun-98
First Containment Concrete Unit 1	12-Jul-98	08-Jun-98
Reactor Building Slipform Completed Unit 1	12-Dec-98	23-Oct-98
Condenser Delivered to Site Unit 1	12-Jun-99	25-Jun-99
Calandria, Press.Tubes Delivered to Site Unit 1	12-Aug-99	18-Jun-99
Reactor Moved into Building Unit 1	12-Mar-00	29-Nov-99
Turbine Building Enclosed & Ready For T/G Unit 1	12-Apr-00	06-May-00
Turbine/Generator Delivered to Site Unit 1	12-May-00	14-Apr-00
Ready for Steam Generator Installation Unit 1	12-Jul-00	08-Jul-00
Steam Generators Delivered to Site Unit1	12-Sep-00	13-Jun-00
PHT Pump Volutes (2of4) Delivered to Site Unit 1	12-Sep-00	24-Mar-00
FSAR Issued to TQNPC	12-Nov-00	10-Nov-00
Control Centre Ready for Equipt Instal'n Unit 1	12-Jan-01	28-Sep-00
First Station Control Computer Del'd to Site U1	12-Mar-01	16-Oct-00
Station Service Bus Energised Unit 1	12-Apr-01	17-Apr-01
Instrument Air Compressors,Dryers in Service U1	12-May-01	30-Aug-01
Water Treatment Plant in Service	12-Jul-01	24-Sep-01
Moderator Main Cicuit Turnover Unit 1	12-Dec-01	19-Oct-01
Recirc.Cooling Water in Service Unit 1	10-Jan-02	08-Jul-02
Raw Service Water in Service Unit 1	11-Jan-02	10-Jun-02
Chilled Water in Service Unit 1	23-Jan-02	23-Apr-02
Condenser Cooling Water in Service Unit 1	08-Feb-02	23-Apr-02
PHT Main Circuit Turnover Unit 1	12-Mar-02	19-Oct-01
F/M Heads Delivered to Site Unit 1	12-Apr-02	16-Oct-01
Turbine, Generator Ready for Reactor Steam U1	12-Apr-02	26-May-02
PHT Hydrotest Complete Unit 1	12-Apr-02	09-Feb-02
StandBy Generator Tests Complete Unit 1	10-May-02	06-Jul-02
Containment Pressure Test Complete Unit 1	12-Jun-02	26-May-02
Switchyard Ready for Station Output Unit 1	12-Jun-02	27-Jun-02
Fuel Load Licence Unit 1	12-Jun-02	18-Jul-02
D2O Supply Tanks Filled Unit 1	12-Jun-02	16-Mar-02
Start Moderator D2O Filling Unit 1	12-Jul-02	31-Mar-02
Start Fuel Load Unit 1	12-Jul-02	18-Jul-02
Start PHT D2O Filling Unit 1	12-Aug-02	09-Aug-02
Authorization for Criticality Unit 1	12-Oct-02	18-Sep-02
First Criticality Unit 1	12-Oct-02	20-Sep-02
Approval to go to 100% Power Unit 1	12-Dec-02	17-Dec-02
Unit 1 Complete (Provisional Acceptance)	12-Feb-03	05-Jan-03

Figure 5-1 Major Milestones

Qinshan CANDU Project
Contractual Milestones

Milestone	Contract Date	Actual Date
Unit 2		
First Containment Concrete Unit 2	12-Jan-99	25-Sep-98
Reactor Building Slipform Completed Unit 2	12-Jun-99	02-Feb-99
Condenser Delivered to Site Unit 2	12-Feb-00	15-Jan-00
Calandria, Press.Tubes Delivered to Site Unit 2	12-Mar-00	21-Jan-00
Reactor Moved into Building Unit 2	12-Sep-00	21-Jun-00
Turbine Building Enclosed & Ready For T/G Unit 2	12-Oct-00	07-Dec-00
Turbine/Generator Delivered to Site Unit 2	12-Nov-00	15-Oct-00
Ready for Steam Generator Installation Unit 2	12-Jan-01	01-Sep-00
Steam Generators Delivered to Site Unit2	12-Mar-01	19-Jan-01
PHT Pump Volutes (2of4) Delivered to Site Unit 2	12-Mar-01	02-Nov-00
Control Centre Ready for Equipt Instal'n Unit 2	12-Jul-01	18-Jan-01
First Station Control Computer Del'd to Site U2	12-Sep-01	16-Apr-01
Station Service Bus Energised Unit 2	12-Dec-01	21-Oct-01
Instrument Air Compressors,Dryers in Service U2	12-Feb-02	05-Jun-02
D2O Supply Tanks Filled Unit 2	16-Mar-02	16-Mar-02
Moderator Main Cicuit Turnover Unit 2	12-Sep-02	31-May-02
Chilled Water in Service Unit 2	12-Oct-02	10-Dec-02
PHT Main Circuit Turnover Unit 2	12-Dec-02	05-Jul-02
F/M Heads Delivered to Site Unit 2	12-Dec-02	17-May-02
Turbine, Generator Ready for Reactor Steam U2	12-Jan-03	26-Dec-02
PHT Hydrotest Complete Unit 2	12-Jan-03	27-Nov-02
Containment Pressure Test Complete Unit 2	12-Mar-03	30-Jan-03
Switchyard Ready for Station Output Unit 2	12-Mar-03	
Fuel Load Licence Unit 2	12-Mar-03	
Start Moderator D2O Filling Unit 2	12-Apr-03	
Start Fuel Load Unit 2	12-Apr-03	
Start PHT D2O Filling Unit 2	12-May-03	
Authhorization for Criticality Unit 2	12-Jul-03	
First Criticality Unit 2	12-Jul-03	
Approval to go to 100% Power Unit 2	12-Sep-03	
Unit 2 Complete (Provisional Acceptance)	12-Nov-03	

Figure 5-1 Major Milestones (continued)

6. DESIGN AND PROCUREMENT ACTIVITIES BEFORE PLACEMENT OF FIRST CONCRETE

The main design and procurement activities before placement of first concrete are shown in Appendix A.

7. QUALITY ASSURANCE PROGRAM

7.1 Quality Assurance System among TQNPC, AECL, Commissioning Team and Contractors

In its capacity as the main contractor, AECL (through SPMO) was responsible for the overall Quality Assurance Program at the Qinshan Site. The primary responsibility for quality assurance and quality control rested with the construction contractors during construction and with the commissioning team (CT) during commissioning. SPMO Quality Surveillance conducted quality surveillance activities on the NSP contractors. STAR, on behalf of the owner, conducted quality surveillance on SPMO QS. SPMO Quality Assurance was responsible for overseeing the construction contractors' Quality Control and QA programs, as well as SPMO's QS and QA and the Commissioning Team's QA programs.

Significant improvements occurred in the Quality Assurance program of the CMT and the contractors during the execution of the Qinshan Project, particularly in regard to program implementation. Improvements also occurred as a result of lessons learned during the construction and commissioning of Unit 1. These lessons were applied to Unit 2 and resulted in less re-work, reduced costs and better quality control. These lessons may be applied to future projects and expanded further, to improve quality, reduce re-work and achieve greater cost reductions.

A description of the overall site QA Program under SPMO's responsibility is found in Appendix B.

7.1.1 General Responsibility to TQNPC

SPMO Site Quality Assurance (SQA) was responsible for defining and ensuring the implementation of a Quality Assurance Program for the construction phase of the Qinshan CANDU Project, in accordance with CSA Standard CAN3 N286.3. SPMO's activities and the construction contractors' activities must 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 Quality Assurance Program for the commissioning phase of the Qinshan CANDU Project in accordance with CSA Standard CAN3 N286.4. SPMO reviewed the requirements of Nuclear Safety Regulations HAF-0405 to ensure that these requirements were met or exceeded by CSA N286.4.

7.1.2 SPMO Responsibility to the NSP Construction Contractors and CMT

Each construction contractor and CMT was responsible for establishing quality assurance programs in accordance with CSA N286.3. NSP construction contractor and CMT QA manuals were reviewed and accepted by SPMO SQA to ensure that they met Project requirements. Each construction 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 follow 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 Quality Assurance Program.

7.1.3 Quality Assurance Audits

SPMO, CMT and construction contractors carried out QA audits of their own QA programs, the Commissioning Team and the quality programs of their subcontractors and suppliers. Audits of the Commissioning Team were performed jointly with TQNPC.

a) Internal QA Audits - SPMO SQA carried out QA audits to confirm that the Site Project Management Organization had implemented the QA requirements specified in procedures and instructions, and that the QA Program was effective.

b) External QA Audits - SPMO carried out audits of CMT, ZTPC (for one contract only) and NSP construction contractors' activities to confirm implementation and effectiveness of their QA programs, as described in their procedures and instructions.

c) TQNPC QA Audits - 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 as much as possible, including joint audits of the Commissioning QA program.

7.1.4 Records

These include records required by applicable codes, standards, specifications, regulations and TQNPC.

These records are assembled and retained as History Dockets for nuclear systems and as History Files for non-nuclear systems by the construction contractors during the construction phase of the Project, by the Commissioning Team during the commissioning phase of the project and by SPMO. History Dockets and History Files are also prepared for NSP equipment and materials. These permanent records are prepared by equipment and material suppliers and then reviewed and accepted by CNPM on behalf of AECL.

7.1.5 Trends

Trends are analyzed on a continuous basis and reported monthly to TQNPC. Any negative trends are 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.

7.1.6 Equipment Surveillance by TQNPC

AECL is fully responsible for the manufacturing quality of the equipment, while TQNPC possesses the right of conducting equipment surveillance.

7.1.6.1 Surveillance Actions/Measures for Equipment Quality

TQNPC established representative offices in Canada, Japan and South Korea for equipment quality surveillance and assigned qualified personnel, including the recruiting of related experts. For the witness of other important equipment outside of the above three regions, domestic delegation from the TQNPC home office may be organized in accordance with the actual conditions.

Management procedures for equipment surveillance are prepared as follows:

- Management Procedure for Equipment Quality Surveillance
- Management Procedure for Equipment Procurement and Review of Manufacturing Recordings
- Procedure for the Disposing of Equipment NCRs and DDRs
- Management Procedure for Equipment Acceptance
- Procedure for the Review of Quality Plan

7.1.6.2 Scope for Equipment Surveillance

Equipment quality surveillance for 43 items of equipment in accordance with the contract such as T/G, main pump, etc., which are critically important to the plant.

TQNPC's equipment surveillance activities have been further expanded to approximately 100 items of equipment through bilateral negotiations.

7.1.6.3 Implementation of Equipment Surveillance

1) Review of the manufacturer's qualification
   The selection of the manufacturer depends on the operation performance of related equipment in the reference plant, as well as other similar domestic and international projects.
2) Review of AECL's management procedure for equipment procurement and quality surveillance
   The review focuses on the procedures for the selection of subcontractors, control of subcontractors, disposition of NCRs and release of quality assurance.
3) Review of equipment technical specifications and quality plans
   The review focuses on the conformance of technical specifications with standards and codes stipulated in the Contract, and the maturity and achievability of related technical processes. The owner also selects some witness points and hold points, such as integrated performance tests, acceptance of historical files and final ex-work inspections, etc.
4) Witness
   TQNPC participated in over 85% of the witness points selected.
5) Unpacking inspection of equipment delivered to site
   TQNPC mainly entrusted unpacking to the competent Commodity Inspection Bureau or the TQNPC/Local Contractor inspection during the receiving process.
6) QA audit on manufacturers

7) Disposition of technical issues
   With regard to major technical issues, decisions were made by the management of both parties demanding the meeting of related requirements by manufacturers.

8. METHODS AND FEATURES TO COMPLETE THE WORK ON SCHEDULE AND ON BUDGET

8.1 Construction Issues

The major challenge of this first CANDU Project in China was construction by new contractors not familiar with AECL or international practices. AECL recognized that it would have to use and enhance its most modern management systems and tools to ensure success of the Qinshan Project. Timesaving elements such as open top construction and modular construction for major components were successfully implemented. The strong focus on project and construction management and partnership among TQNPC, AECL, subcontractors and the Chinese construction contractors was a success.

Key features of the Site include four undersea intake ducts averaging 50 meters long. These ducts were constructed in water having a high silt content and current velocities reaching 4 meters per second with the inflow of the tide into Hangzhou Bay where the Qinshan Site is located. A major challenge for both BOP and NSP was the localization of structural steel design, fabrication and erection, as most experience in China had been with concrete structures.

A special task was to build retaining walls around the Site, which is surrounded by water on three sides to create sufficient real estate for the two units. This made execution and co-ordination of work difficult and greatly increased the need for planning and co-ordination among the contractors.

8.1.1 Degree of Prefabrication/Modularization

Prefabrication and modularization were effective in ensuring the timely completion of construction. The lower dome was fully assembled on the ground, painted and lifted into position using a very heavy lift crane. This major element of work enabled significant progress to be achieved on the installation of the reactivity deck and related components inside the Reactor Building. Construction of the lower dome *in situ* would have required suspension of reactivity deck installation for safety and protection of the equipment below. This resulted in a significant time saving for the Project. Another module was the dousing steel along with all piping, tanks, valves, and electrical and instrumentation, which resulted in a 3-month net saving over previous projects.

8.1.2 Open Top Construction

In the past, a major challenge to efficient construction has been the work restrictions within the containment building. Historically, the Reactor Building or containment wall was constructed with openings left in the sides to allow entry of large equipment. To facilitate access at Qinshan Phase III, a temporary roof with strategically located openings was placed on top of each reactor building (open top construction). A very heavy lift crane supplied by TQNPC placed major pieces of equipment directly into their final positions through these openings, gaining significant schedule improvements. A steam generator installation by the open top method took only two days against the two weeks taken by the traditional horizontal-access method. About 70 pieces of equipment were set in place using the heavy lift crane, simplifying access and allowing work to start or continue in other areas, thus reducing labour and risks associated with installation.

Steam generators (220 tons each), temporary roof (150 tons) pressurizer (103 tons), reactivity mechanisms deck (43 tons), feeder frames (40 tons each), fuelling machine bridges (16 tons each), condenser lower shells (270 tons each), turbine generator stator (280 tons), deaerator (90 tons) and major heat exchangers were among items installed using the heavy lift crane. On completion of major equipment installation, the temporary roof was replaced by a permanent reactor concrete dome. The open top method allowed work to be done from the top and from below, which increase~~d~~ work flexibility. Future use and experience with open top planning will result in further schedule reductions for CANDU projects.

8.1.3 Information Technology and Engineering Tools

TQNPC as owner supported the use of the new electronic tools, which contributed substantially to the successful management of the Project. Qinshan CANDU features optimized state-of-the-art information and engineering tools and systems, including:

a) Three-dimensional Computer Aided Design and Drafting Systems (3D CADDS)

AECL had used CADDS technology in some parts of its CANDU reactor designs, but had not previously used this tool to produce Released for Construction design. A QA program and procedures for production were developed to enable CADDS to be used to issue formal construction documentation that satisfied the requirements of the QA program. The design information in CADDS was integrated with other AECL electronic management systems for controlling and managing materials and documentation. Material information extracted from CADDS, for example, carries a stock code number and a physical description, which are linked with AECL's CANDU Material Management System (CMMS).

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 the thousands for a major project and had to be corrected in the field, but with CADDS, they are substantially reduced.

b) CANDU Material Management System (CMMS)

CMMS identifies and tracks equipment and material from design through to construction and operation of the station. CMMS is described in Section 11.

c) Integrated Electrical and Control (IntEC) database

IntEC is a state-of-the-art cabling and wiring system database developed by AECL. It was successfully used by Project participants, including construction contractors. IntEC provides wiring, cabling, connection and equipment information and includes live design (in Canada and USA) and as-pulled data (at Site) for all the wiring, cabling and connections. Design information in CADDS and IntEC is integrated with other AECL electronic management systems for controlling and managing materials and documentation.

d) Asset Information Management (AIM) and TRAK integrated databases

Configuration and control of documentation (which includes documents and drawings) are priorities for complex engineering projects. The AIM (Asset Information Management)/TRAK system for managing Project documentation provides all Project participants with a common and real time view of all design and construction documents.

AIM is a documentation file manager that provides on-line access and an archive for all Project participants. TRAK manages all Project documentation (including drawings, documents, correspondence and other Project records) in electronic format on line, which has improved quality and efficiency and reduced costs. TRAK accesses information from AIM to facilitate the scheduling, issue, distribution and shipping of Project deliverables and maintain the Project document baseline.

The AIM/TRAK system provides revision control and gives the owner a real time official document baseline for the project and the operating station. 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.

e) Local area networks (LANs) and Internet

Real time status reports and documents are accessible to all Project participants at all sites through Local Area Networks (LANs). The transfer of documents and drawings between Canada and Site is also done electronically using Internet technology.

f) LAN of Commissioning Team

The LAN of the CT has the following functions:

- Access to or use of systems concerning the plant parameter LAN and project management LAN
- Work Permit Management System (WMS): to achieve control during commissioning and production; to manage work permits, work processes and 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 Optimization of Fuel Management System (IFOS)
- Nuclear Material Accounting System (NMAS)

g) LAN of TQNPC Administration

The LAN of TQNPC Administration has the following functions:

- Internal E-mail system
  About 1000 e-mail addresses have been established for transmission of shared information and meeting schedules, and for consultation and communication
- Integrated Company Information Management System (internal home page)
  To hierarchize, classify and/or authorize all the shared information such as meeting minutes, company regulations, management procedures, work plans/reports, etc.
- Correspondence and Document Management System
  To classify, retrieve and trace all correspondence among TQNPC, AECL, related contractors and other organizations
- Contract Management System

- Accounting Management System
- Personnel Management System
- Document and Archives Management System
- Equipment Management Supporting System

h) Construction Contractor CNI 23 (nuclear installation contractor) developed a Weld Information System (WIS) to electronically record quality information for all pipe welds.

8.1.4 Project Management

There was a strong focus on project and construction management and partnership. TQNPC worked hand in hand with AECL expatriate staff in all areas, including engineering, construction and material management. TQNPC took the lead in commissioning, with AECL providing guidance and support. Particular emphasis was placed on setting up effective processes and procedures to ensure quality. Sensitivity to and understanding of Chinese culture and practices were considered in all aspects of the Project. A Chinese-speaking Deputy Project Director was assigned to the Qinshan Site to facilitate and ensure successful communications. With strong field supervision, construction times of 18 days for Unit 1 and a world record of 14 days for Unit 2 were achieved for the reactor buildings containment walls. Fuel channel installation took 69 days for Unit 1 and 64 days for Unit 2, which were better than durations achieved on past CANDU projects. The effective partnership among TQNPC, AECL and the Chinese Construction Contractors played a critical role in the success of the Project.

8.15 Construction Photographs

March 1999 – VHL – Temporary Roof

June 1999 – Unloading Calandria

July 2000 - U1 Steam Generator Installation

November 2000 – Dousing Module Lift

April 2001 – Temporary Roof

September 2002 – A Bird's Eye View of Qinshan CANDU Project

9. METHOD TO SUBCONTRACT MATERIAL AND CONSTRUCTION WORKS

The Chinese construction contractors were responsible for providing skilled resources, management and supervision, planning of work and quality program. Site Project Management Organization (SPMO) provided overall management of NSP construction and technical assistance to the construction contractors to reinforce their planning, develop Level 3 schedules, develop catch-up programs, schedules and plans, develop and use production indicators to manage bulk works, assist contractors in subcontracting specialized activities such as structural steel design and fabrication, improve organization of contractors for better communications and increased productivity, develop quality procedures, assess training programs and update as needed, assist contractors in complying with worker qualifications and certificates, assist contractors in setting up and executing check and test programs that represented an increase in their traditional scope, and assist and monitor the contractors in the setting up and carrying out industrial safety and worker safety programs.

The Project construction scope was divided into a series of Construction Work Packages (CWPs). Individual general works subcontracts were established for mass excavation, pipe prefabrication, ready mix concrete production, temporary construction utilities, and inland transportation. The plant building and system CWPs were established by craft disciplines and compiled into two civil and two installation subcontracts, one each for the Nuclear Steam Plant (NSP) and the Balance of Plant (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 subcontractors priced the works on a CWP basis, which permitted firm prices to be established for a large percentage of the scope. Other works where only preliminary information was available were based on fixed unit prices and provisional sums for the different commodities.

AECL and Bechtel/Hitachi supplied the majority of the material and equipment separately, with the exception of mainly concrete, rebars and steel.

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. Interrelationship with the construction schedule was readily available and produced accurate labour and cost monitoring and forecasts throughout the implementation of the construction works.

Quantity reconciliation between contract value and actual quantity installed was regularly kept up-to-date and contract values were adjusted accordingly. Contractors were paid based on the actual quantity installed.

Figure 9-1 shows the Site construction interface.

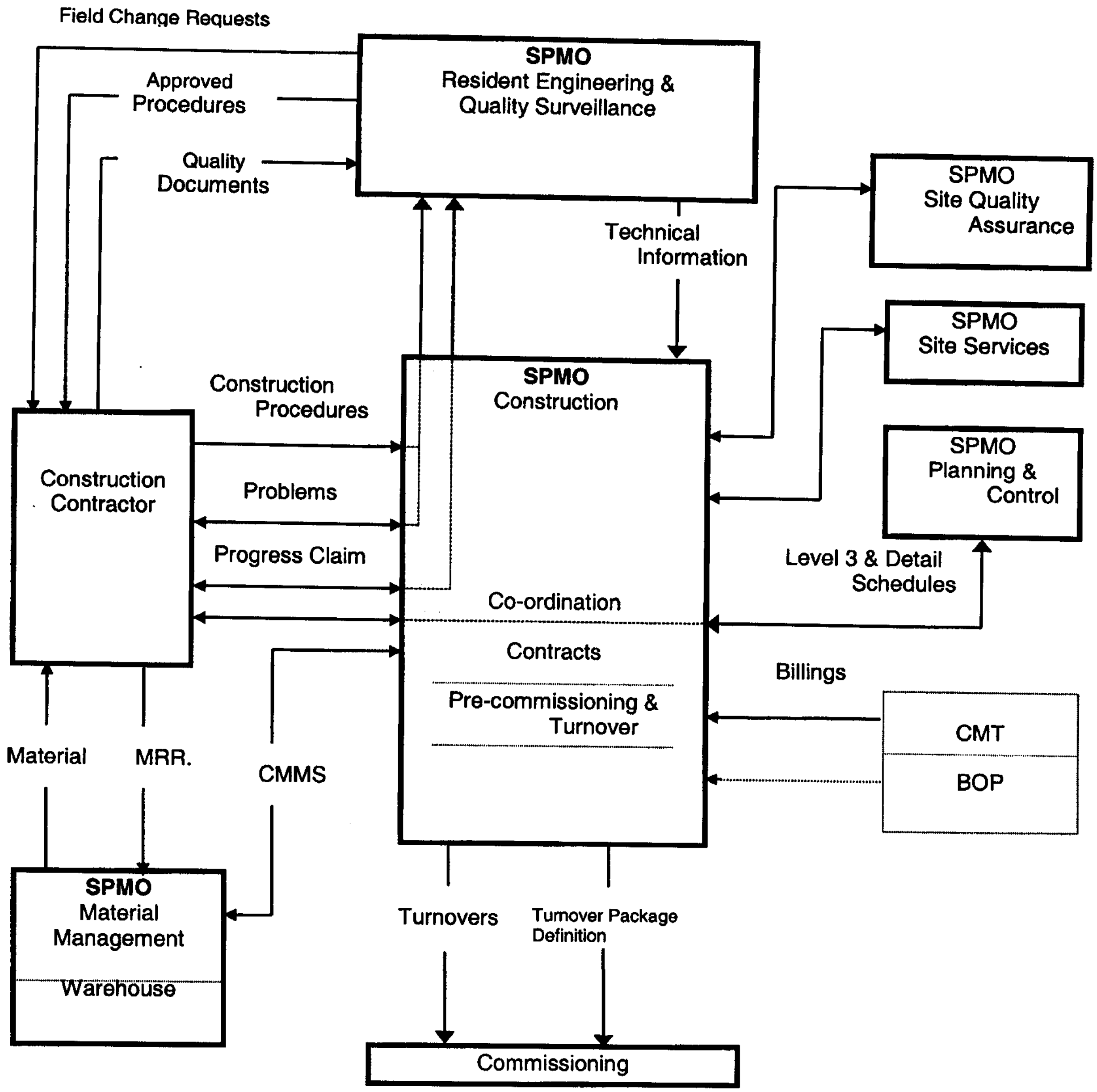


Figure 9-1 Construction Interface Flowsheet

10. RESOURCES AND QUANTITIES

10.1 Manhours

The availability and use of construction labour resources were planned and managed primarily by the construction contractors, with support and direction provided by TQNPC and AECL. The use of both skilled and unskilled labour in the construction works generally resulted in sufficient resources being able to carry out the work to meet schedule requirements. On occasion, the management teams of TQNPC and AECL worked with the construction contractors to evaluate and re-allocate the skilled labour resources necessary to support the critical path works. The construction contractors expended approximately 34 million labour hours on the construction activities for the two-unit station. Based on the work done on Unit 2 compared to Unit 1, it is anticipated that the construction experience gained on the Qinshan CANDU Project by the local construction contractors will result in a net reduction of 10-15% labour hours for a replicated CANDU plant in China. Figure 10-1 gives a summary of the construction labour resources used on the Qinshan CANDU Project. Figure 10-2 provides an overview of the labour distribution during the peak construction period.

The detailed planning of the required labour resources was performed in conjunction with the development of the construction work package (CWP) 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 labour resource profiles. On the basis of the labour profiles and the activities of the Level 2 and 3 schedules, the assignment and management of the labour 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 labour 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 labour resources.

Figures 10-3 to 10-5 provide an overview of the civil program; Figures 10-6 to 10-8 give an overview of the installation program.

10.2 Cubic Metres of Concrete and Nuclear Piping

The construction contractors successfully placed 1/2 million m^3 of concrete, fabricated and erected 25000 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.

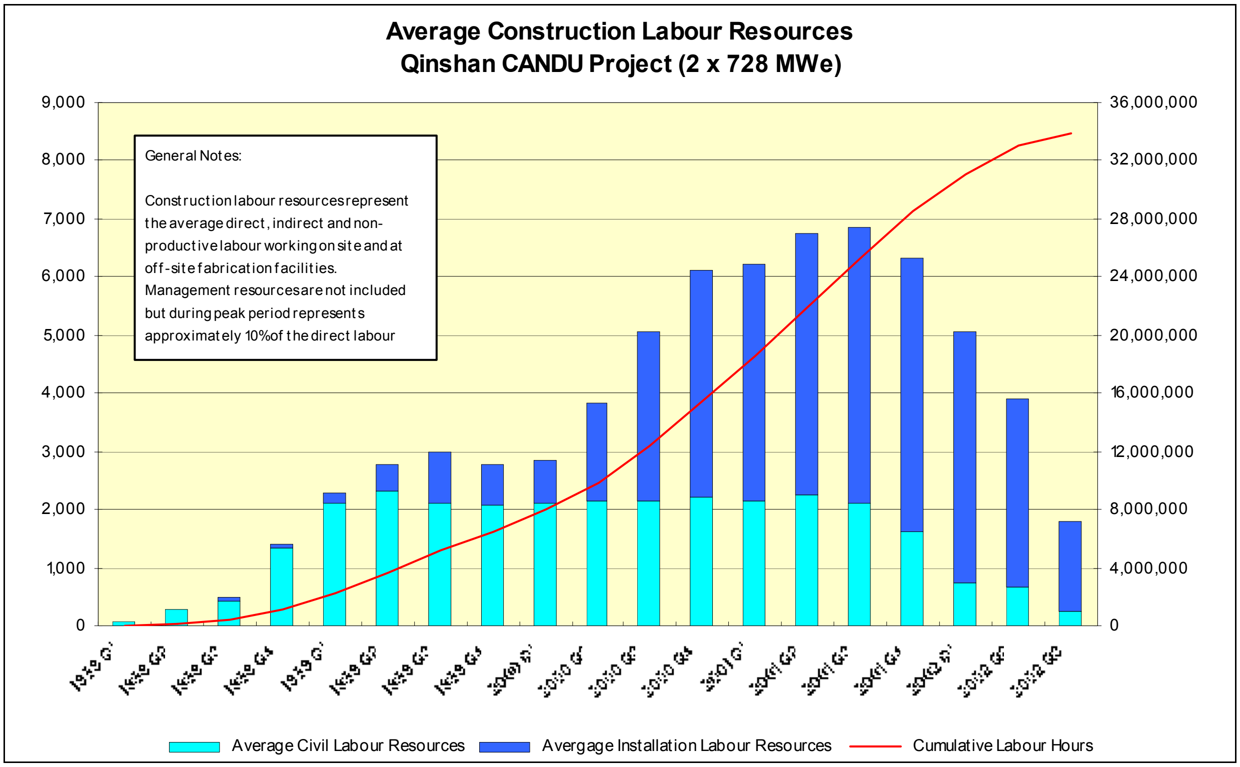


Figure 10-1 Average Construction Labour Resources

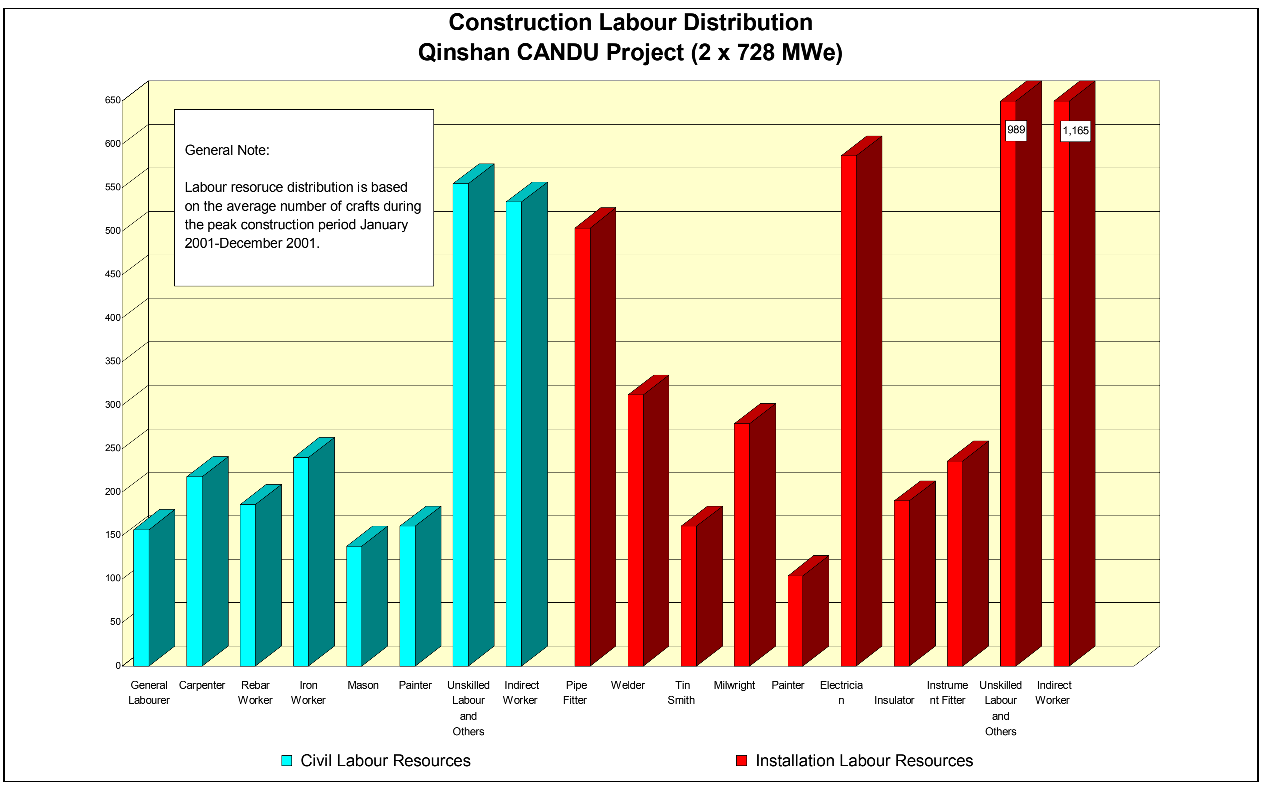


Figure 10-2 Construction Labour Resources

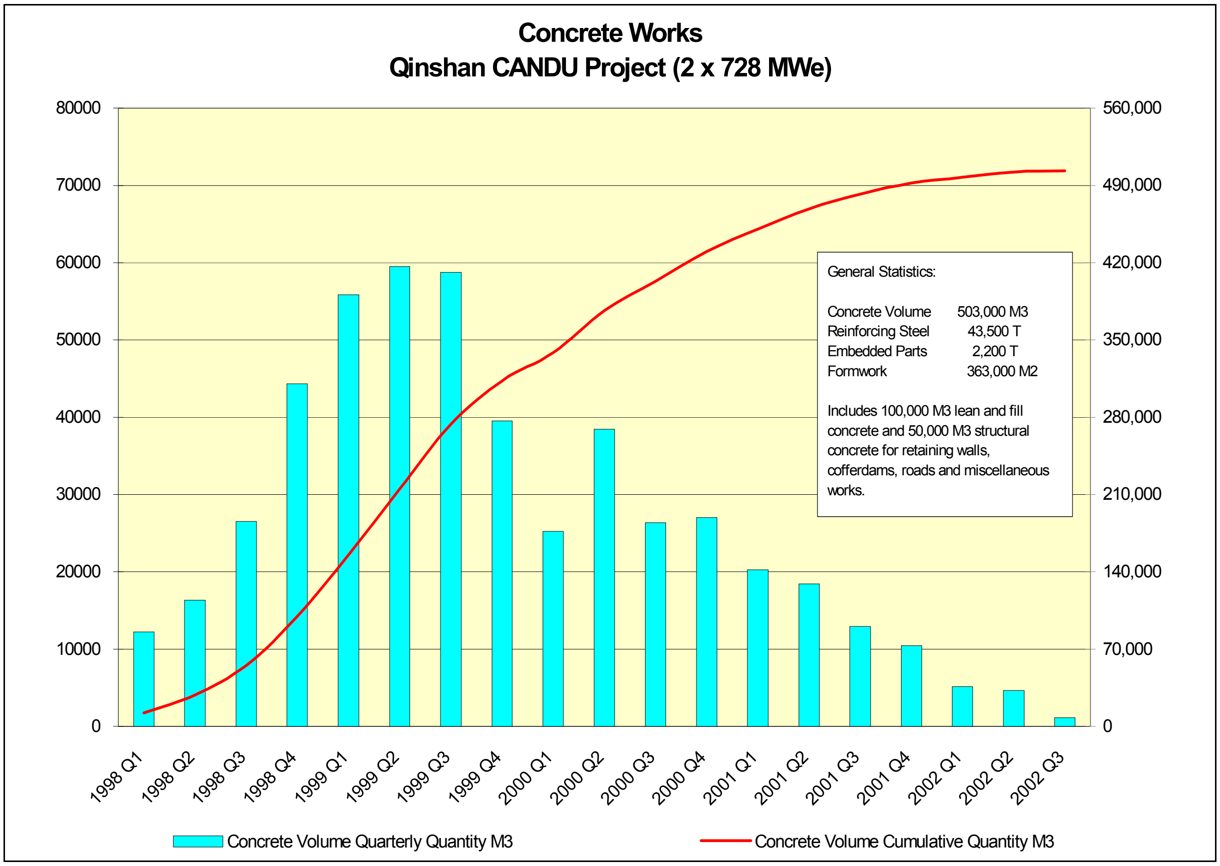


Figure 10-3 Concrete Works

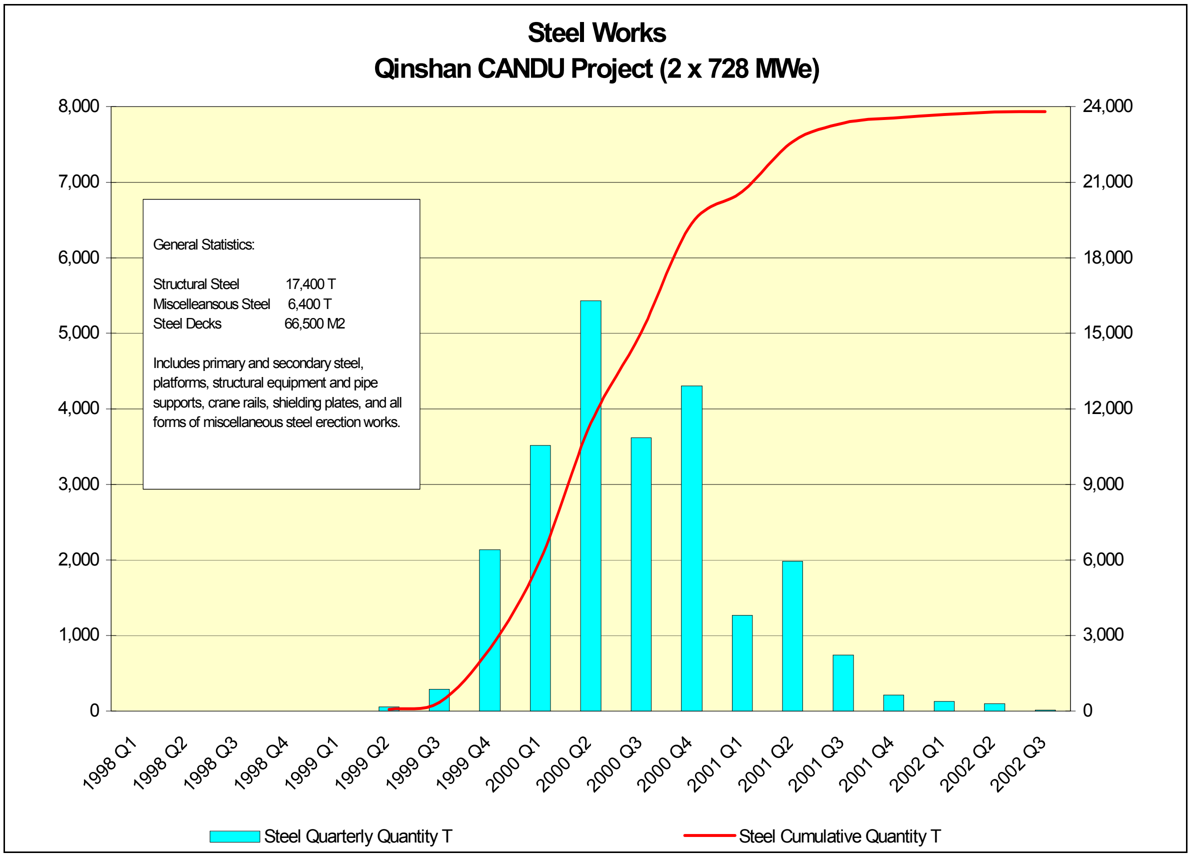


Figure 10-4 Steel Works

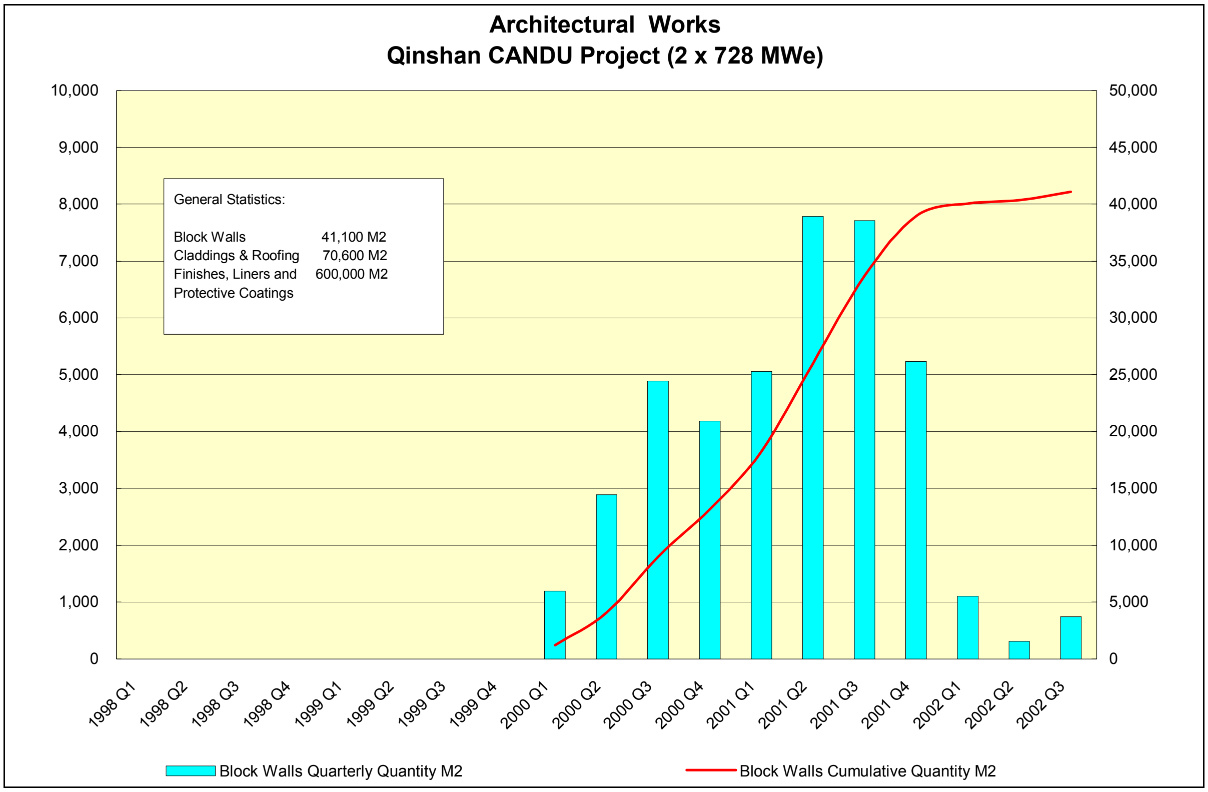


Figure 10-5 Architectural Works

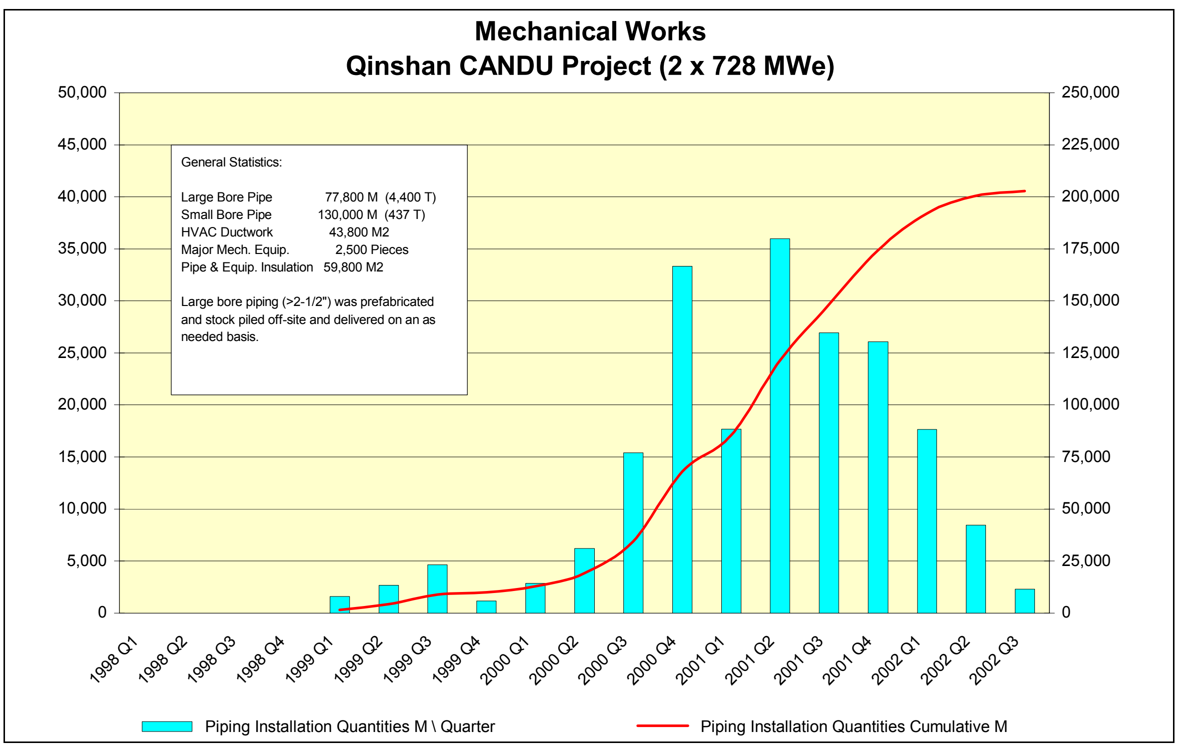


Figure 10-6 Mechanical Works

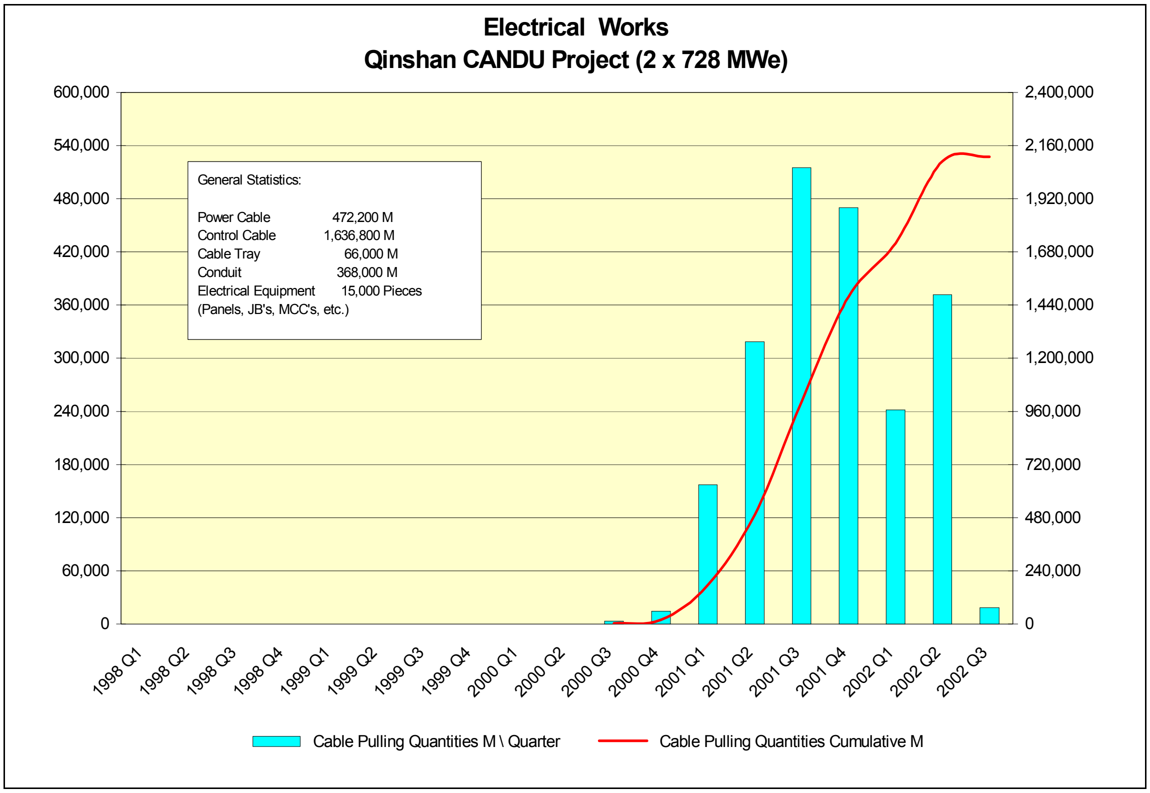


Figure 10-7 Electrical Works

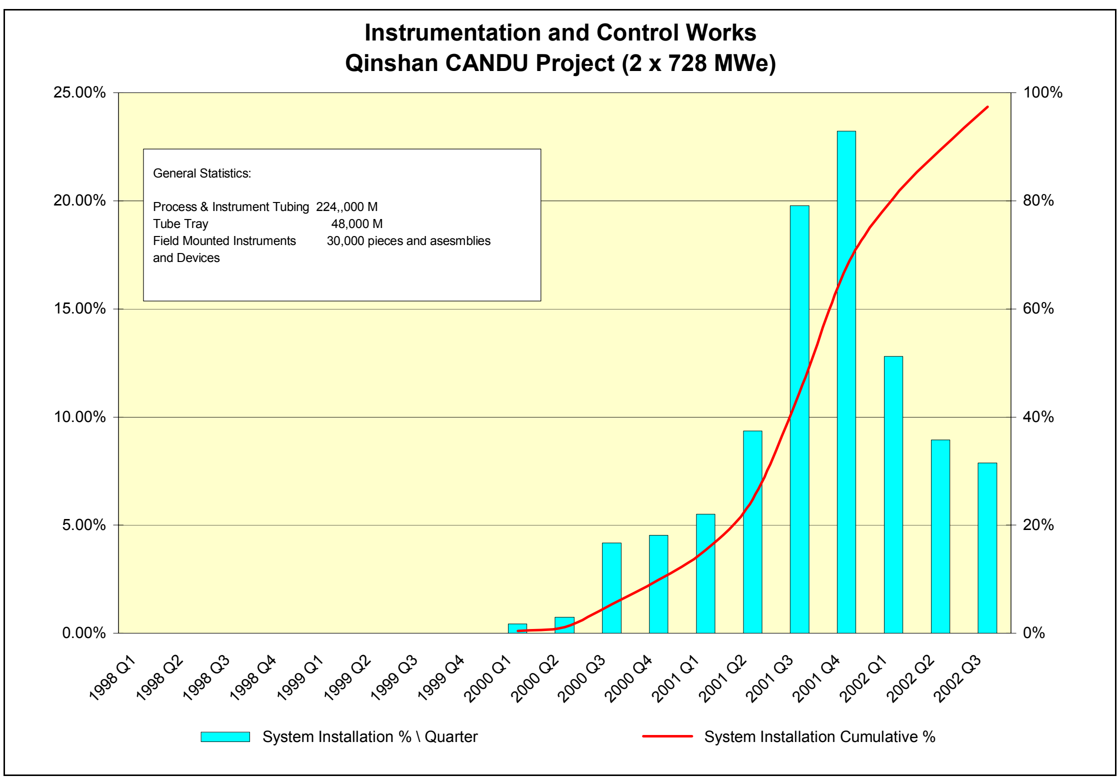


Figure 10-8 Instrumentation and Control Works

11. MATERIAL MANAGEMENT

Management of materials at Site was carried out by the SPMO Materials Management Team (MMT). The team consisted of 8 expatriate staff and 70 local staff at peak. Responsibilities included: 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 TQNPC in establishing proper storage conditions in various warehouses for levels A/B/C storage, developing qualified local suppliers, managing the material substitution program, establishing a program 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).

The Chinese construction contractors made especially effective use of these new tools and methods in managing materials and producing CWPs on an area basis. Preservation data were kept up-to-date and consolidated to ensure proper records. Calibration shops were set up using the latest tools.

The heart of the operation is the CANDU Material Management System (CMMS). Material management starts from the moment a designer identifies a design element in 3D CADDS or IntEC, right through to managing procurement, storage and issue 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 quality assurance documentation and traceability. The CADDS demand generates the engineering quotation request, which then becomes the tender and purchase order. 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 on-line linkage to CMMS gave good material tracking and control.

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

12. SITE INFRASTRUCTURE AND MANAGEMENT

12.1 Infrastructure

Because of the small site and hard granite rock that precluded later blasting, a decision was taken early to construct the permanent service trenches to prevent risk of possible damages during later construction.

The transportation and logistical support for the Project presented some major challenges, in that all materials and equipment from across the world would have to come through Shanghai. This included the very large equipment such as the calandria, boilers, and condenser sections. It was decided that due to road and bridge restrictions, this equipment would have to be moved by barge from Shanghai and by heavy multi-wheel transporter from the local dock to Site. The approximate tonnage via barge was 27000 tons, with an additional 1800 containers. This was augmented with air shipments of about 1.5 million kg, all of which were moved safely and in record time. Strict processes, procedures and controls were applied, with frequent audits by the QA department, which contributed to the overall success of the program.

12.2 Warehouses

Initial establishment of the site infrastructure was a challenge due to the small size of the site footprint. In order to build the warehouse and material and equipment support facilities, TQNPC had to remove an extra section of the mountain that bordered the site. This provided sufficient on-site storage space for a 6400 m^2 warehouse building and a 4-story office support building. This building also houses the instrument calibration facilities and provides special storage for instrumentation. Having the calibration facilities close and within the warehouse complex reduced the amount of moving and handling of instruments, thus reducing the potential for damage.

The total on-site external storage facilities comprised a 28500 m^2 equipment and material laydown area. Within this area, four large concrete pads were installed to facilitate storage of some very heavy pieces of equipment. This enabled equipment to be landed safely. Additional off-site external storage was also required and provided by TQNPC, amounting to about 23000 m^2, providing a grand total of 51500 m^2 of outdoor storage.

A further three warehouse facilities were also provided consisting of a combined area of 5800 m^2. These facilities were located off-site but within ¼ mile of the main warehouse, which when combined with the on-site indoor storage, provided a grand total of 12200 m^2.

12.3 Offices and Archives

TQNPC 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 AECL and TQNPC 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.

12.4 Accommodations

Expatriate accommodation was provided about 15 minutes from the Site in a compound overlooking Hangzhou Bay and within walking distance of Haiyan. There were about 180 apartments consisting of 3, 2 and 1 bedrooms, bathroom, living room, dining area, and kitchen. The size of 120 m^2 was consistent with western standards and provided the families with a comfortable setting.

To meet the needs of the Canadian community, 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. These facilities became the hub for the expatriate community. Internet and cable television were also provided.

12.5 Personnel on Site

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.

13. COMMISSIONING ORGANIZATION INCLUDING MEASURES TO REDUCE THE COMMISSIONING PERIOD

13.1 Function

Commissioning was carried out by an integrated commissioning team consisting of about 1000 TQNPC owner's staff to commission two units, plus about 45 expatriates to provide guidance and direction. Two hundred and thirty-two TQNPC staff were trained in Canada at the Gentilly-2 CANDU Power Plant.

13.2 Division of Responsibilities

AECL provided guidance and direction to TQNPC, which carried the responsibility for performing commissioning as well as supporting operating and maintenance functions in accordance with the technical and schedule requirements. The "guide and direct" role included defining the organization, staffing, quality assurance 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. In addition, the "guide and direct" role covered on-the-job coaching and mentoring of TQNPC staff, and in some cases direct supervision, to meet quality and schedule requirements. The integrated Commissioning Team is responsible for overall commissioning, operation and maintenance of each unit up to its Provisional Acceptance. 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 are responsible for making the final decision and performing the design changes necessary to resolve any equipment performance-related issues. AECL was responsible for coordinating the turnover of systems from Construction to Commissioning and solving any related problems. For NSP, AECL was responsible for interface coordination among its sub-contractors, while TQNPC's Construction Management Team (CMT) was responsible to assure that the work performed by BOP contractors met the Commissioning requirements.

The expatriate staff worked with over 1000 TQNPC and contract staff in an integrated Commissioning Team. About 20 % of the TQNPC staff had previous experience, with the rest hired directly from fresh graduates in engineering or technical school. TQNPC hired about 370 supplementary contract staff (about 100 in technical and the rest in maintenance) with previous experience to enhance the overall experience level of the team to meet the requirements of commissioning, operation and maintenance during the Commissioning period. Initially, TQNPC provided 232 staff for NSP pre-job training in China, CANDU training in Canada and commissioning training in Korea followed by on the job training in Qinshan.

Under the guidance and direction of expatriate staff, TQNPC staff

- prepared the detailed commissioning, operating and maintenance procedures
- performed commissioning and supporting operations and maintenance-related activities
- evaluated commissioning results
- prepared commissioning reports and commissioning completion assurance documents

TQNPC was responsible for

- training all commissioning, operations and maintenance staff
- 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 program
- supply of heavy water, nuclear fuel and other consumables except for what was specifically covered in the AECL scope of supply

Under the guidance and direction of AECL, TQNPC was also responsible for all operations-related activities to support commissioning including Health Physics and Radiation Protection, Chemistry, Nuclear Safety, Training.

Following the turnover of a system or a structure from Construction, its care, custody and control during commissioning was transferred to TQNPC. However, AECL continued to be responsible for the whole unit until its Provisional Acceptance from the point of overall performance in accordance with the design requirements.

13.3 Commissioning Organization and Staffing

The Commissioning Team was an integrated organization of TQNPC and AECL staff under the direction of the AECL Project Director and TQNPC General Manager respectively. The reporting relationships between the Commissioning Team, AECL Project and the TQNPC Operations Organization are illustrated in Figure 13-1.

The Commissioning Team is divided into four distinct functions:

1) Commissioning Technical function consisting of six separate departments: namely NSP Process, NSP Instrumentation and Control I&C, Fuel Handling, Electrical, Common Services and Thermal Cycle. They are responsible for the development and implementation of a Commissioning Program for the Qinshan Nuclear Power Plant to demonstrate that plant structures, systems and components meet their design requirements before they are declared available for service.
2) Commissioning Execution function consisting of six Commissioning Execution groups for each Unit and Maintenance Department, one corresponding to each of the six Commissioning Technical Groups. They are responsible for performing field commissioning as defined by the Commissioning Technical Departments using the resources of the Operating and Maintenance Departments.
3) 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 performs normal chemistry analysis and control functions, and support commissioning activities. The Health Physics Department performs normal radiation protection, dosimetry, industrial safety and emergency preparedness functions, and support commissioning activities. The Nuclear Safety group is responsible for developing the reactor physics and thermalhydraulics commissioning program during Phase A, B, and C and for providing technical support to commissioning execution/operating staff to conduct these tests.

4) Planning function responsible for developing the optimized integrated commissioning logic based on Level 2 commissioning procedures (CP2). 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 13-2 shows the Integrated Unit 1 and 2 Commissioning Team and Operations Organization;
- Figure 13-3 shows a typical Commissioning Technical Group
- Figure 13-4 shows a typical Commissioning Execution Group (CEG).

The Commissioning Team was formally set up 24 months prior to fuel load. The distribution of staffing over the commissioning period is shown in the Figures 13-5, 13-6 and 13-7.

13.4 Measures to Reduce the Commissioning Schedule

13.4.1 Appointment of System Engineers

The commissioning technical process is 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 turnover issues, providing technical support for field execution of commissioning procedures, assessing test results, and preparing commissioning reports, commissioning completion certificates and commissioning history dockets. 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.

13.4.2 Establishment of Control Points

A total of 14 Commissioning Control Points (CCPs, listed below) 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 NNSA to formally release before commissioning could proceed further.

The CCPs are:

1. Acquire D_2O
2. Acquire New Fuel*
3. Load D_2O into Moderator*
4. Reactor Building Leak Rate Test
5. Hot Conditioning of Main Heat Transport

6. Loss of Class IV Test
7. Load Fuel*
8. Load Heavy Water into Heat Transport Systems
9. Criticality*
10. First Synchronization to 25% Full Power*
11. Raise Power to 50% Full Power and Above*
12. Raise Power Above to 100% Full Power *
13. Continued Operation at 100% Full Power
14. Provisional Acceptance

13.4.3 Establishment of Commissioning Documentation

For each system, a Commissioning Specification document (CSO) was prepared to define the design and analysis requirements that had to be demonstrated during physical commissioning checks and tests The Commissioning procedures were prepared at three levels of detail: Level 2 (CP2) and 3 (CP3) procedures defined the overall program, interfaces and logic, and Level 4 (CP4) defined the detailed procedures to execute fieldwork. CP4 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. The 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 Commissioning Control Points (CCP). Table 13-1 shows the commissioning and operating documentation prepared for Unit 1.

Table 13-1
Commissioning and Operating Documentation for Unit 1

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	23855
Operating Manuals (OM)	124
Safety related Systems Tests	339
System Surveillance Plans (SSP)	195

13.4.4 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.

13.4.5 Close Interface with Construction

Major construction interfaces included the turnover of systems and management of open items. Key elements of the turnover process included preparation of turnover 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 turnovers. The turnover process was well managed with preliminary T/O packages prepared 3-months prior to scheduled dates and final open item review meetings within 2 weeks of the turnover date. A key factor in acceptance of turnovers was the criteria for categorizing open items as these required before turnover versus those to be completed after turnover. Provided that bulk of the commissioning work could proceed, open items were scheduled for completion turnover.

Open item management after turnover was done through the Commissioning Work Permit system.

13.4.6 Optimization of Commissioning Schedule

In 1998 a generic set of Level 2 (CP2) procedures 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 at Sheridan Park to review Qinshan specific design information and revise these CP2 procedures 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 turnover profile required to achieve it. This new information was incorporated into the Project C&C schedule. Some conflicts were identified with existing turnover dates and where possible, Construction adjusted their program to try and achieve the required dates.

Turnover of the electrical distribution systems occurred in 6 months (6 months later than defined in the C&C) and turnover of the service water systems occurred 3 months late. These systems should normally be fully operational to support commissioning of the Primary Heat Transport (PHT) and related critical path systems. With turnover 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 programs 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 programs were continuously reviewed to identify possible work-arounds. 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 programs. Meetings were also held 3 times per week at the Manager/Superintendent level to identify and track all significant issues affecting the program.

The attached diagram shows the dates of various CCP's achieved for Unit 1. With reference to first energization of the station service transformer, Unit 1 commercial operation was achieved in 20.5 months, considerably shorter than comparable experience at other CANDU 6 Units. This achievement is 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 working around problems.
- Great support from senior management in AECL, Bechtel, Hitachi, TQNPC and the Contractors. Commissioning issues always received number 1 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 to a well-documented Commissioning QA program to achieve high quality standards.

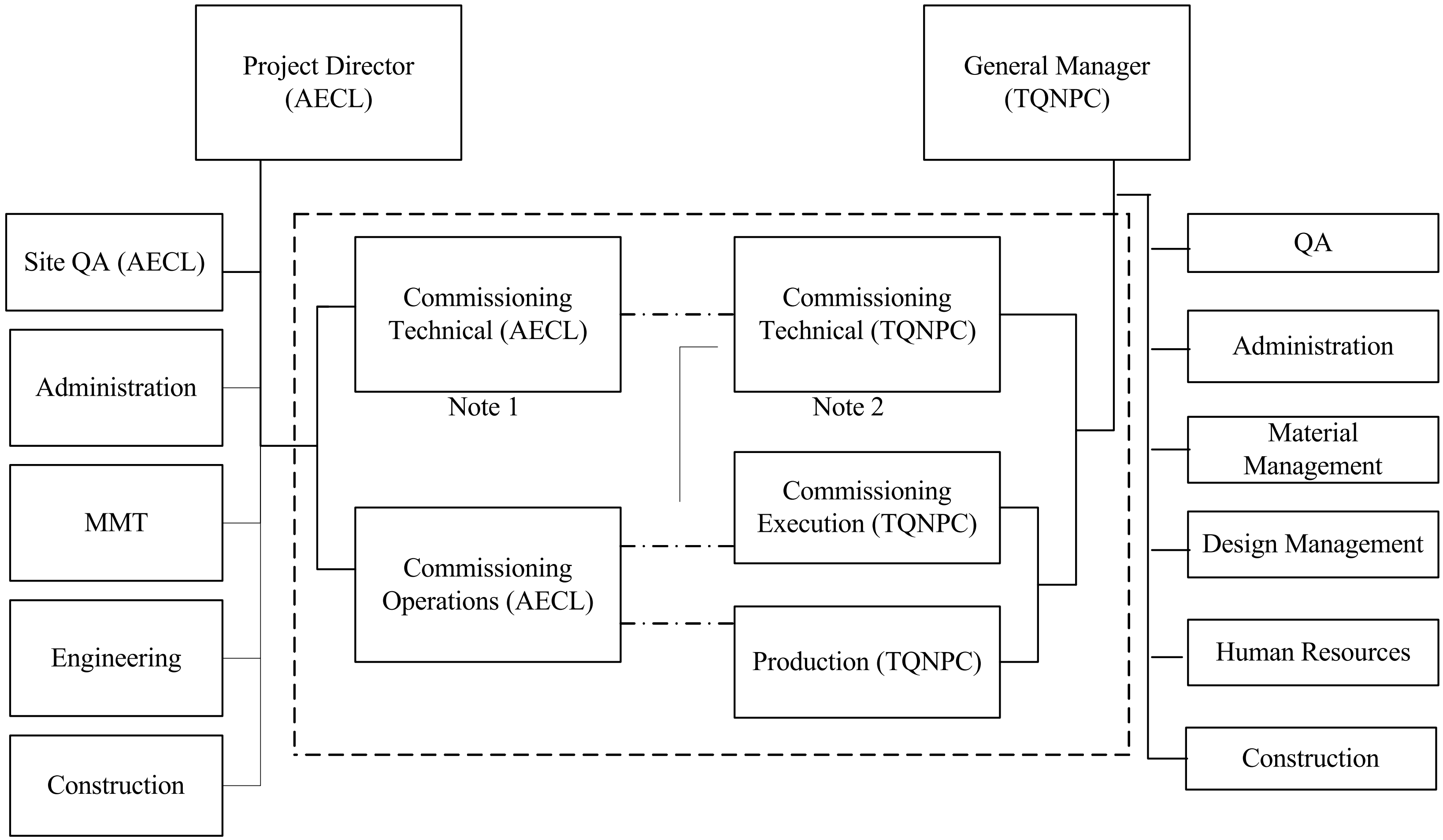
- Earlier involvement of CT system engineers in the system turnover activities in order to be familiarize with the systems and identify protential system problems.
- Learning from a good experience feedback program during commissioning.

13.4.7 Improvements in Future Commissioning Programs

The Commissioning Program at Qinshan was a success due to the excellent team established by TQNPC and AECL. Items that could contribute to an even shorter schedule include:

- Earlier completion of level 4 procedures
- Earlier detailed level 2 commissioning schedules to match the project conditions
- A combined Commissioning and Construction team to carry out check-out and turnover activities
- Vendor support linked to purchase order of equipment to provide for shorter commissioning, training, and better problem resolution.

The excellent results obtained on Qinshan CANDU Phase III can be improved further by these actions, which are generic in nature and suitable for most projects.



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 performs the Commissioning and has a reporting relationship to the TQNPC General Manager.

Figure 13-1 Integrated TQNPC/ AECL Commissioning Team

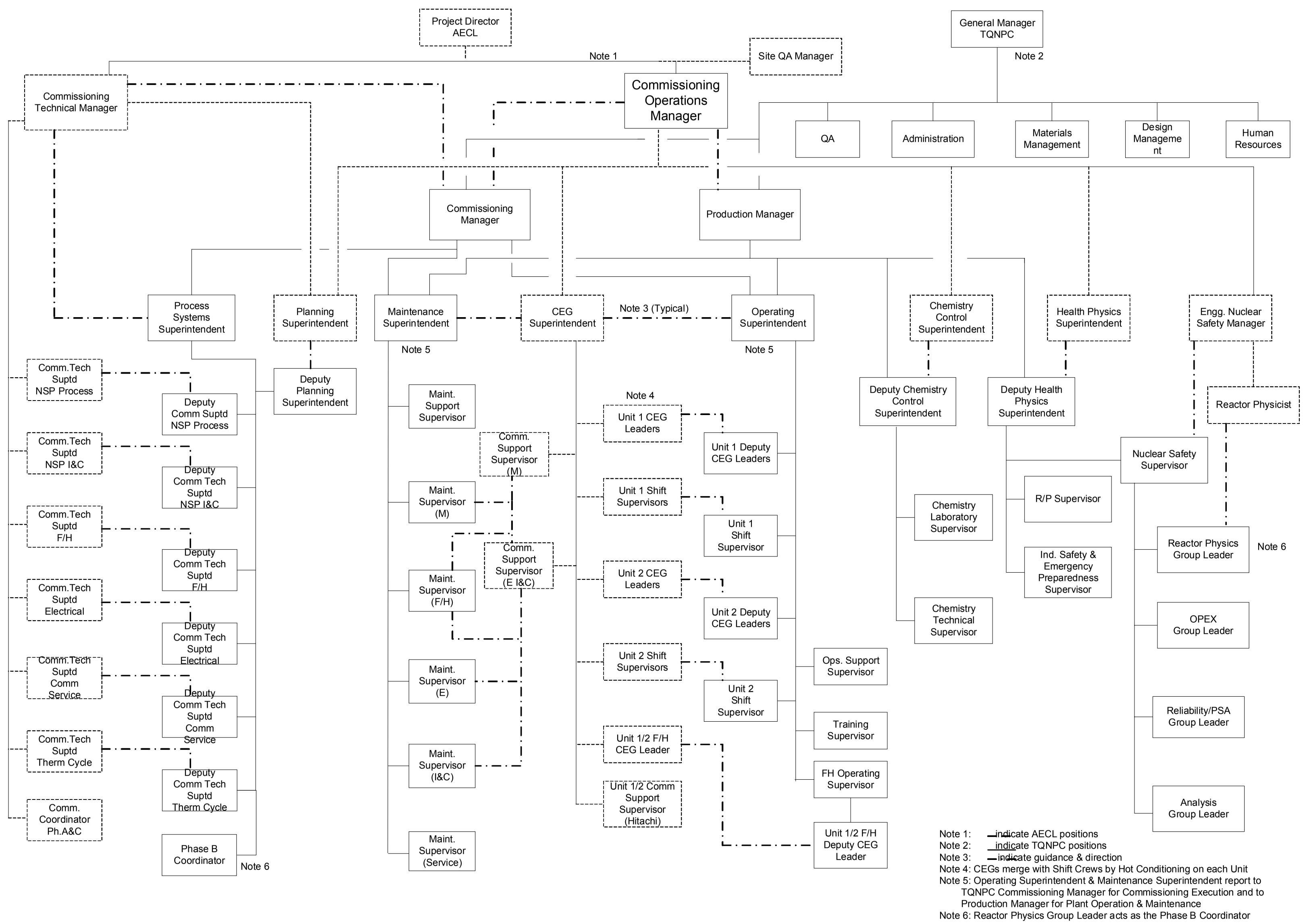


Figure 13-2 Integrated Unit 1 & 2 Commissioning Team Organization

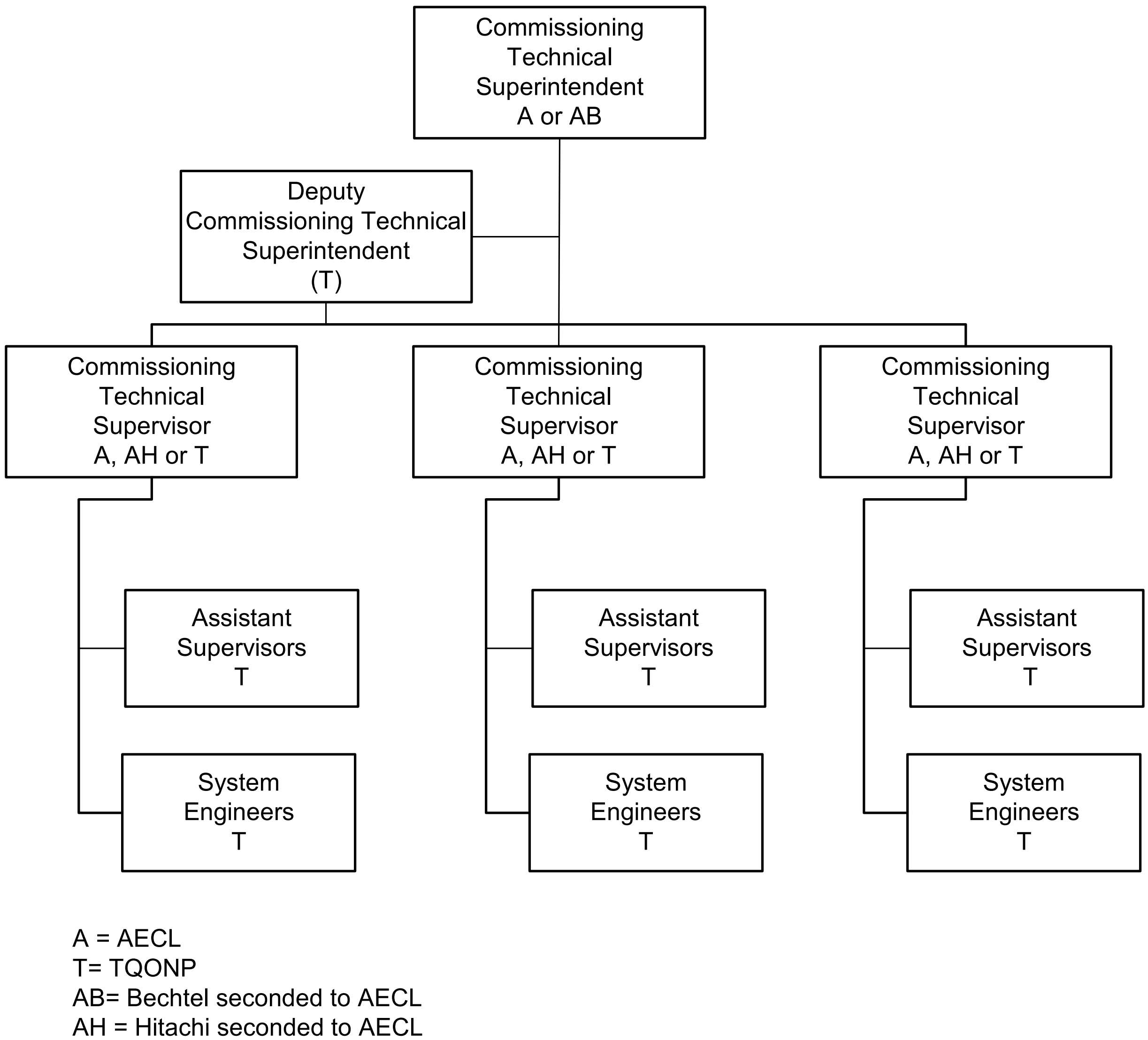
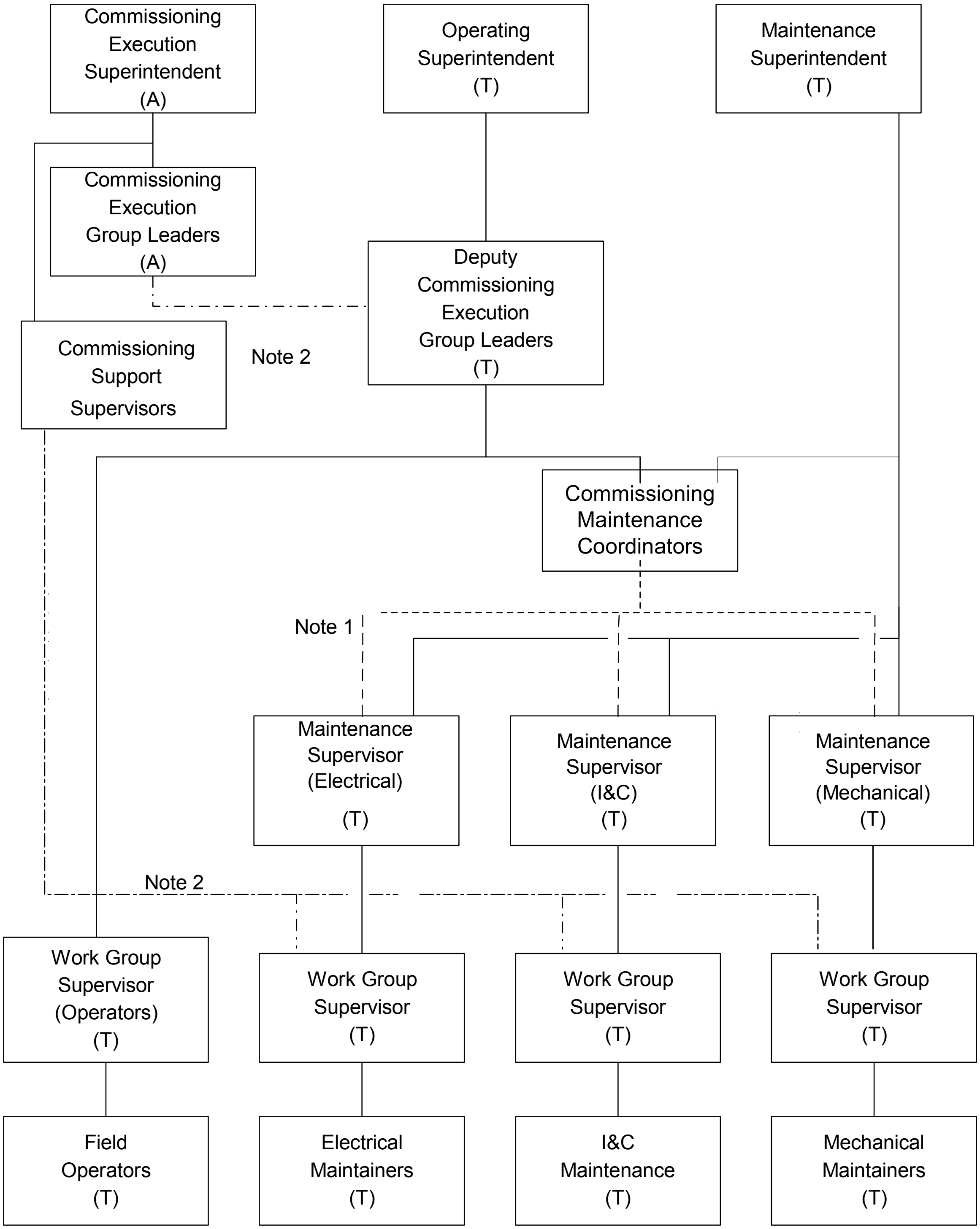


Figure 13-3 Typical Commissioning Technical Group



A=AECL
T=TQNPC

Note 1: Coordination with Maintenance
Note 2: Guidance and Direction
Note 3:Planning-Operating-Maintenace Work Flow Interfce

Figure 13-4 Typical Commissioning Execution Group

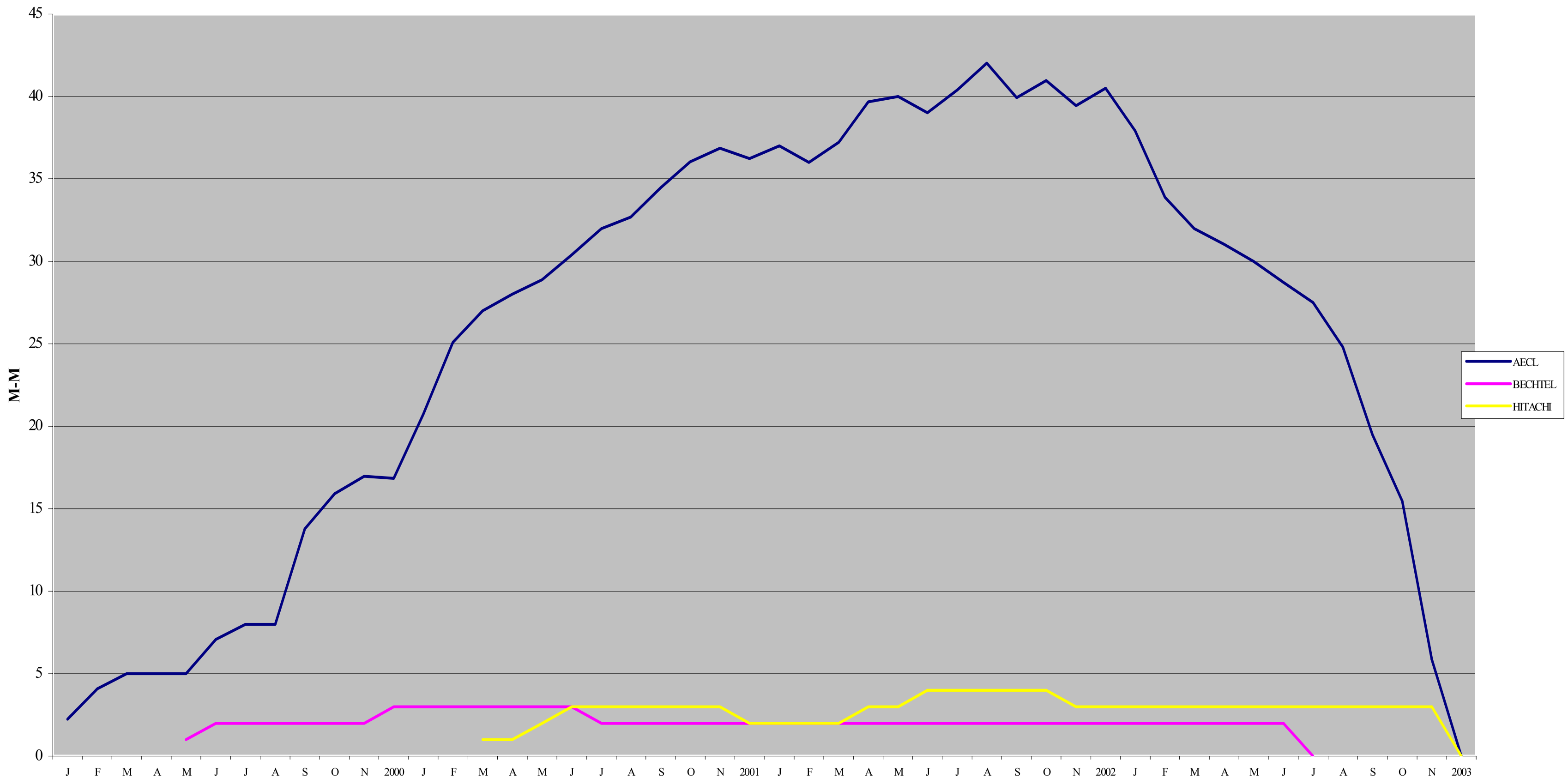


Figure 13-5 Commissioning Expatriate Staffing (Technical and Operations)

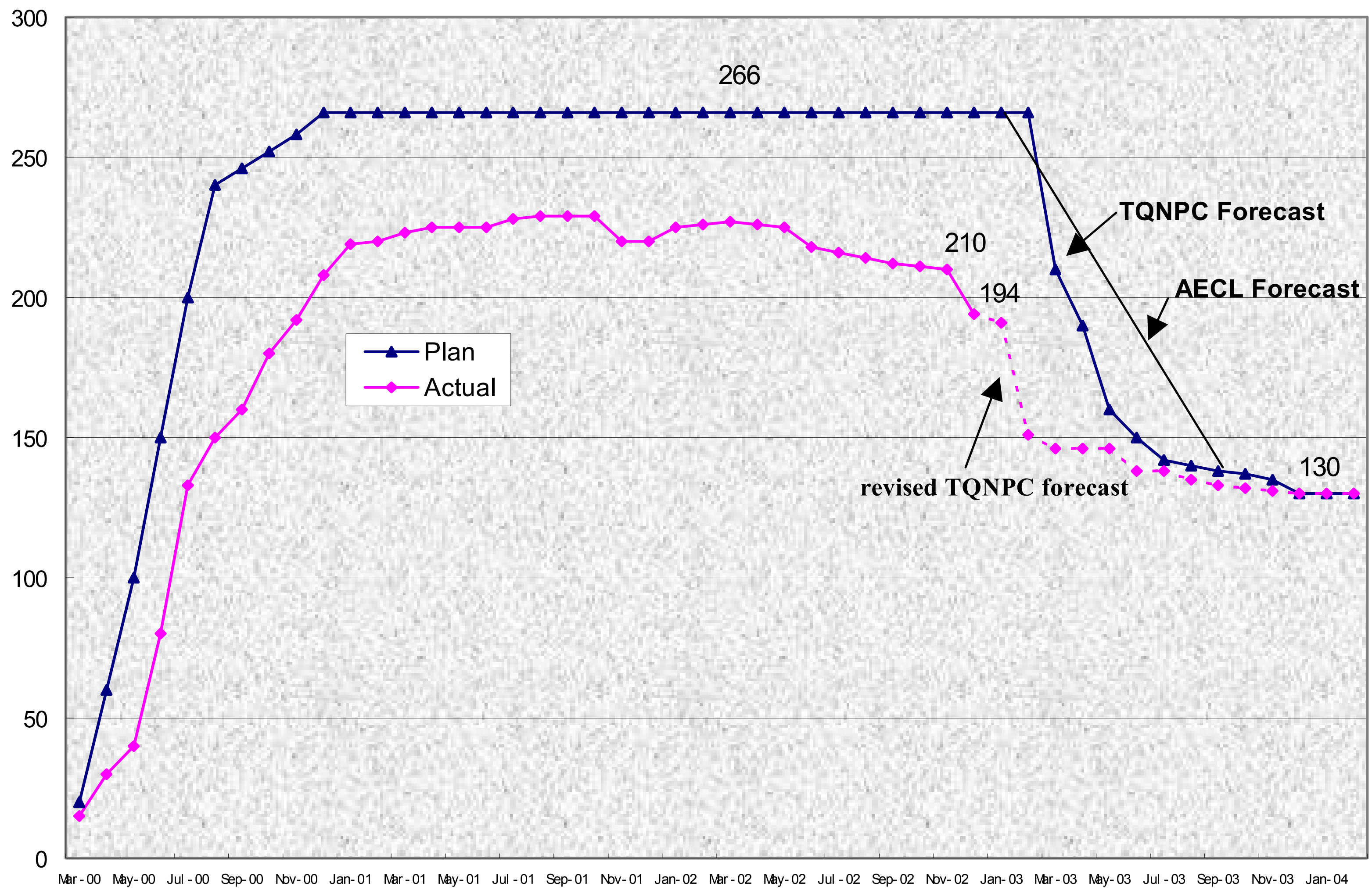

300
250
200
150
100
50
0
266
210
194
130
Plan
Actual
TQNPC Forecast
AECL Forecast
revised TQNPC forecast
Mar-00
May-00
Jul-00
Sep-00
Nov-00
Jan-01
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04

Figure 13-6 TQNPC Commissioning Technical Staff (including Planning)

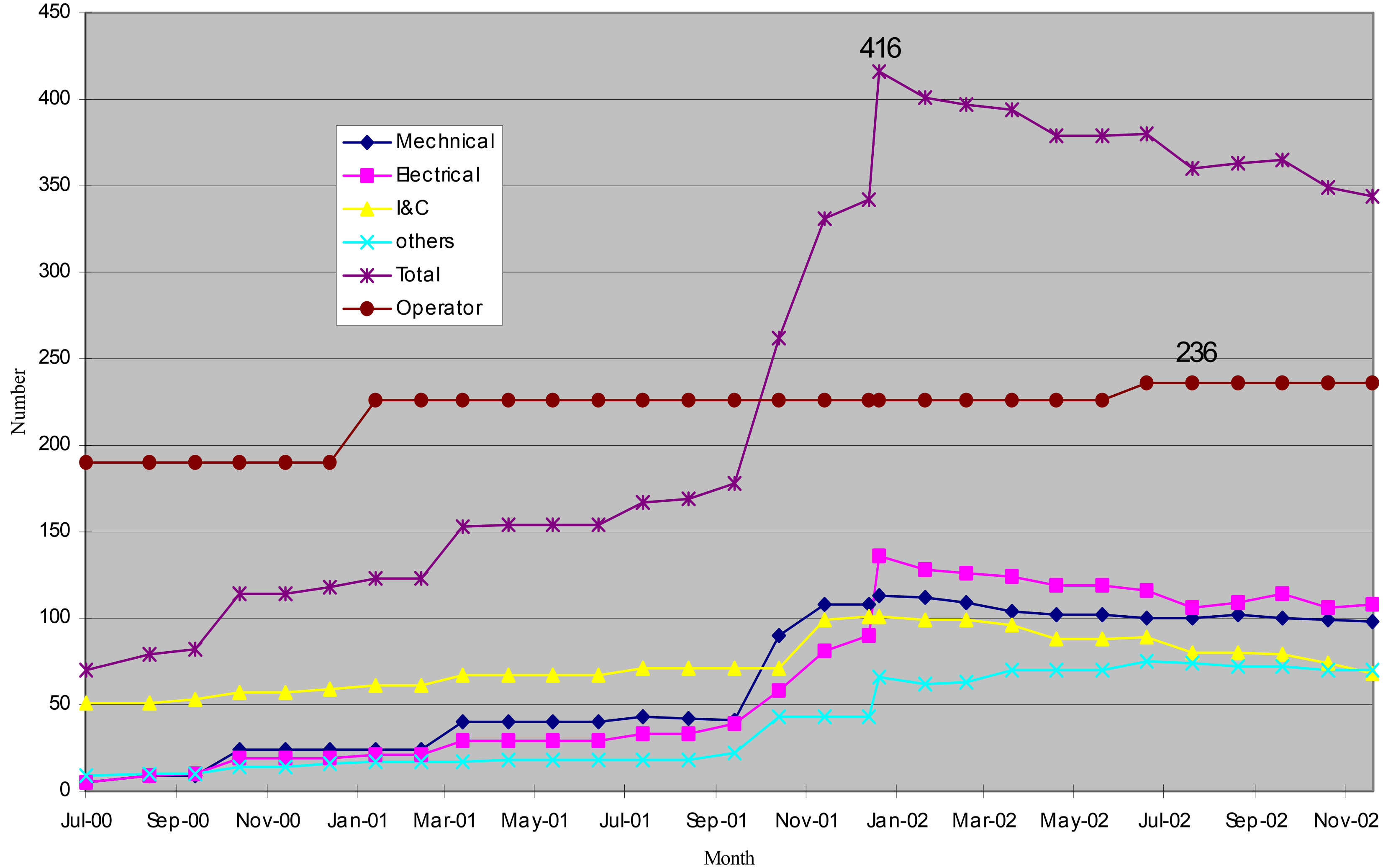


Figure 13-7 TQNPC Commissioning Execution Staff (Operators and Maintainers)

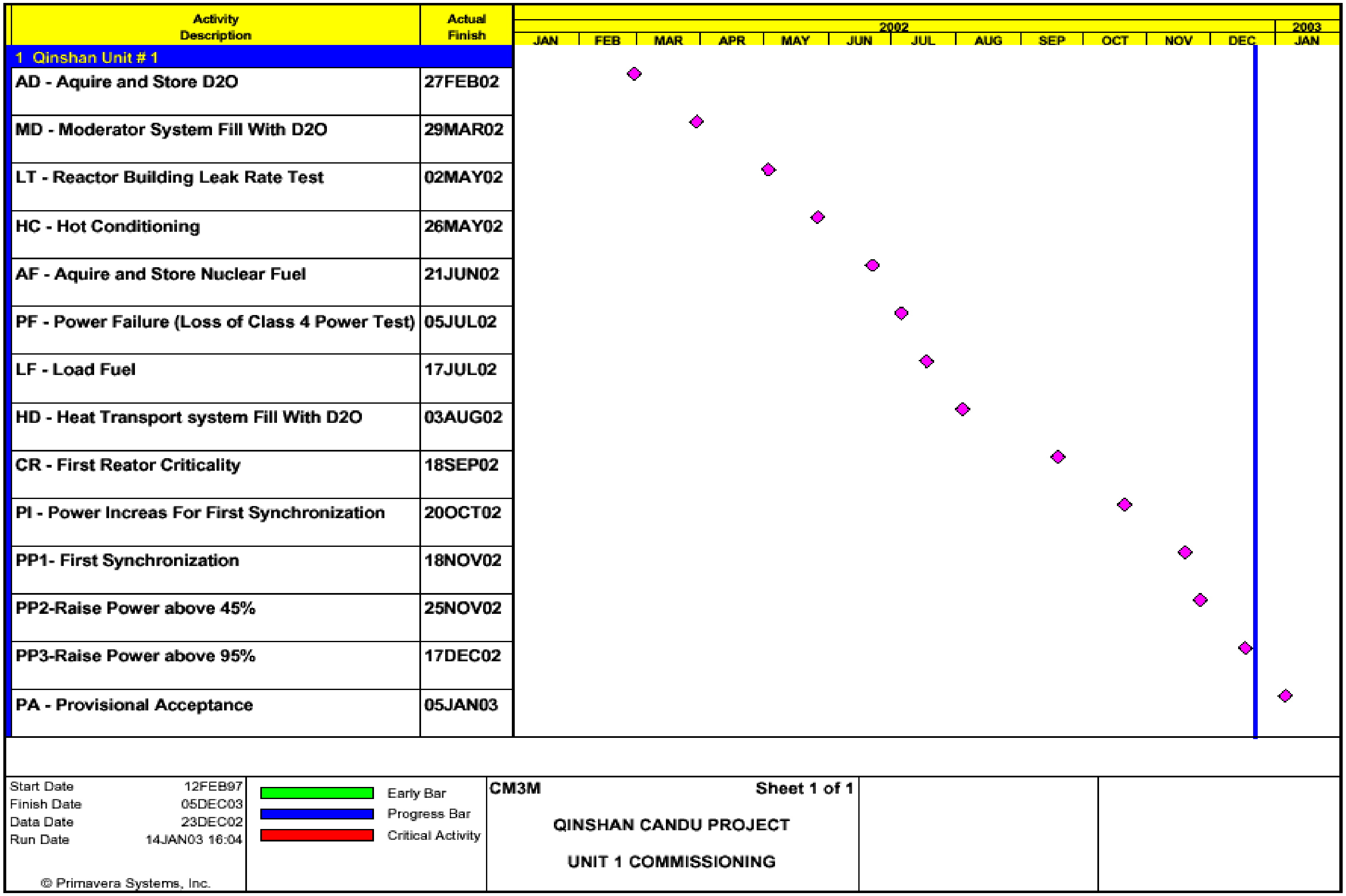


Figure 13-8 Unit 1 Commissioning Milestones

14. AECL STUDY: LESSONS LEARNED ON QINSHAN 3 TO REDUCE THE SCHEDULE ON FUTURE REPLICATED PROJECTS

14.1 Planning and Control

The schedule from CED to In Service for the Qinshan Phase III Project Unit 1 was 72 months. On future CANDU 6 projects, it should be possible to reduce this to 60 months with no contingency allowance, based on the lessons learned on QINSHAN CANDU Project in China. The table below summarizes the schedule reduction:

	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 CANDU Replication

To achieve this objective the following actions are suggested:

- Act immediately when schedule dates fall behind especially in Engineering, Procurement and Civil work.
- Finalize engineering deliverables earlier. Design drawings and specifications must be on site in clean condition at least 9 months before construction.
- Improve equipment and material deliveries to better suit construction sequencing. A better definition of bulk material requirements and deliveries is required.
- Detail the Level 2 (C&C) bulk activity (cables, panels etc.) to identify priorities.
- Enhance 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.
- Closely monitor the engineering and procurement Level 3 schedules and act upon delays early.
- Have an expatriate planner assigned to each contractor's management organization.
- Incorporate Room or Area turnovers into the Level 3 schedules.
- Start excavation at CED. The excavation construction contract should be signed in advance. Detailed design must be available in advance.
- Integrate CMMS access and material status within the site planning group.
- Enhance schedule visibility during construction. Critical paths to be known by all, including home office Engineering and Procurement groups.
- Accelerate yard services work. Design must be finalized at CED.

- Enter into early Purchase Orders to get supplier drawings that affect the design as early as possible.
- Increase modularization applications where possible.
- Accelerate structural steel fabrication and erection.
- Accelerate pipe fabrication.
- Review spare parts requirements in light of actual experience.
- Increase use of 3D CADDS for planning and construction sequences.
- Develop resource-levelled schedules.

15. AECL'S STUDY: FURTHER IMPROVEMENTS IN DESIGN AND CONSTRUCTION

15.1 Evolutionary Improvements

AECL is developing the Advanced CANDU Reactor (ACR), which is an evolution of the very successful CANDU 6 design operating in five countries: Canada, Korea, Argentina, Romania and China. The most recent CANDU 6 project at Qinshan in China successfully demonstrated the use of the open top, modularization and heavy lift concepts to reduce costs and scheduling. From a technology aspect, starting with a new layout and drawings, improvements in technology and side-by-side design and construction, planning provides for the optimum product in terms of cost, scheduling and constructability. Specific design and construction details of the ACR are provided in Appendix C.

AECL is undertaking a 45-month basic engineering program and supporting research and development (R & D) program to develop the ACR product to ensure that the cost, schedule, safety and licensing requirements defined by the market will be achieved.

ACR achieves substantial reduction in capital cost by using light water coolant, slightly enriched uranium fuel and a tight heavy water-moderated lattice. The use of light water reactor coolant and the smaller moderator sharply reduces the inventory of heavy water in the moderator, giving a major cost reduction. The more compact core also results in a reduction in the size of the reactor shield tank assembly and the number of fuel channels to generate the same reactor power as in CANDU 6. For example, the ACR-700 with a gross output of 731 MWe is similar to that for CANDU 6 but it requires only 286 fuel channels compared with 380 channels for CANDU 6. This channel reduction combines with other design simplifications such as the use of two steam generators instead of four in CANDU 6 and the less complex interface between the emergency core cooling (ECC) and the heat transport (HT) system, since they both contain light water, resulting in a small reactor building for ACR-700. Substantial economic benefits are also achieved by operating at a higher coolant and steam turbine supply pressure and temperature, resulting in higher thermal/electric conversion efficiency.

15.2 Constructability

The ACR is designed with constructability considerations as a major requirement during all project phases, from the concept design stage to the detail design stage. This necessitates a much more comprehensive approach in including constructability considerations in the design to ensure that the construction duration is met.

The overall construction strategy comprises the open top construction technique using a very heavy life crane and parallel construction activities, with extensive modularization and prefabrication, all of which were successfully implemented and proven on the Qinshan CANDU Project. In addition, significant applications of construction technology are being implemented; e.g., large volume concrete pours, prefabricated rebar, use of climbing forms, composite structures, prefabricated permanent formwork, automatic welding, and utilization of the latest electronic technology tools such as 3D CADDs modelling to yield a very high quality product. Integration of 3D CADDs models and scheduling tools such as *Primavera* allowed development of actual construction sequences and an iterative approach to schedule verification and improvement. Modularization and prefabrication are major features of the ACR design to achieve the project schedule. For the reactor building, approximately 80% of the volume is installed as modules or prefabricated assemblies. This ensured that critical path durations are achieved.

To achieve the shorter schedule, the construction method/strategy was defined very early in the concept phase of the design, as it has a major impact on the construction schedule. This strategy was then included in the design requirements and considered in the plant layout as the design of the new product progressed.

The layout of the reactor building was developed taking the construction method into consideration to ensure full integration of the plant layout with the proposed method of construction. When the layout of a system is developed, a particular area/volume within the reactor building in which to fit the particular system is identified.

Details on construction strategy are found in Section C.1.4 of Appendix C.

15.3 BOP Optimization

The conventional BOP for the ACR-700 was developed jointly by AECL and Hitachi, Ltd., of Japan. The steam turbine for the ACR-700 is based on Hitachi's TC4F-52 impulse type. The turbine consists of one single-flow high-pressure cylinder and two double-flow low-pressure cylinders in a single-shaft tandem-compound arrangement, with direct coupling to the generator. There are two external two-stage moisture separator reheaters working in parallel to remove moisture and to reheat the high pressure turbine exhaust steam. The turbine generator, condenser and feedwater heating plant are based on proven designs; a characteristic that has minimized associated R&D work.

15.4 The Right Economics

The estimated capital cost for a replicated ACR-700 plant is US $1000/kWe.

15.5 Capital Cost

The reference plant design was developed with close attention to equipment specification and cost. Because AECL has had a continuous record for active CANDU projects, it has an extensive and up-to-date database of equipment and material costs. In addition, by working closely with manufacturers to establish realistic estimates for innovative components, an accurate plant cost estimate has been established.

Key factors leading to capital cost reduction are:

- Reduced heavy water and heavy water systems
- Reduced core size
- Improved turbine cycle
- System and component simplification

- Improvements in product delivery

15.6 CANDU 6 to ACR Cost Evolution

Elimination of D_2O and associated systems:	7.5%
Reactor size reduction:	6%
Improved turbine cycle:	7%
System and component simplification:	10%
Design for reduced construction cost:	4%
Improvements in product delivery technology:	5.5%

15.7 Construction Schedule: ACR/CANDU 6 Schedule Comparison

Recent CANDU construction projects have established a record of meeting challenging schedule targets. The Wolsong 2, 3 and 4 CANDU 6 units in Korea were completed on time in 1997, 1998 and 1999 respectively. Qinshan 1 was completed ahead of schedule and 2 is in commissioning and ahead of schedule. Because of the design and engineering innovations included and because of the use of state-of-the-art project delivery technology, significant further schedule improvements are achievable. The ACR eliminates the previous heavy water commissioning steps for the coolant system and associated auxiliaries and also emphasizes layout for streamlined construction, in particular a highly modularized design. By preparing the complete reactor building design from the beginning in the form of drop-in modules, the total project schedule can be substantially reduced. The critical paths through such a schedule run through a limited number of large components.

For the ACR-700, a project schedule of 48 months has been developed for the *N*th replicated unit, with a 36-month construction period duration from First Concrete to Fuel Load.

Modularization and prefabrication are ideal techniques for doing work in parallel. Multiple modules are fabricated in a shop while the civil work is progressing, ready to receive the modules. Using these techniques will

- significantly reduce direct construction labour costs
- reduce conventional shoring and scaffolding
- shorten durations of critical activities
- improve access
- allow work to be completed away from the final construction area
- improve safety

Appendix C provides more details on ACR design and construction.

16. SUMMARY COMMENTS

The Qinshan CANDU Project in China was very successful for both the Chinese and Canadian participants. An effective partnership between China and Canada allowed the use of new technology and methods in CANDU construction, which were proven by actual results in construction and demonstrated the way for continued cost reductions in future CANDUs.

Current countries with an active NPP program are in Asia – China, Korea and Japan and also India, all of which participated in the IAEA workshop. The business model in China features the "company" concept with a board of directors and the shareholders being government state companies. Deregulation of electricity sales and production are in progress. Given the major experience and capabilities already existing in China, future NPPs will most likely be managed by the Chinese owner companies, with increasing localization. China is moving to develop its own 1000 MWe PWR and AECL is promoting the CANDU PHWR as an attractive partner to the PWR program, due to its fuel cycle flexibility and its ability to use fuel from PWRs. In the long term, as the world nuclear renaissance progresses, countries will adapt or resume nuclear programs. The key to these programs will be low-cost and competitive NPPs with short construction schedules.

This paper has outlined the CANDU experience in China and the evolutionary steps being taken based on the real experience and successful results from the Qinshan CANDU Project to provide competitive CANDU NPPs to support the expanding electricity demands in the future marketplace.

Appendix A
Design and Procurement Activities before Placement of First Concrete

- Activity Description
- NSSS input to PSAR
- Issue PSAR to TQNPC
- RFC NSP Detail Exc'n (S/B, HPECC, SCR/EPS, EWS)
- RFC BOP Tech Specs – Concrete Construction
- NSP Conceptual Design Submission
- RFC – Mass Excavation Outline Layout Drawing
- RFC NSP Tech Specs – Concrete Structures
- RFC R/B Subbase Concrete Structures
- RFC Preliminary P/H Cofferdams
- BOP Input to PSAR
- RFC BOP Tech Specs – Concrete Furnish
- RFC R/B Detail Excavation
- RFC NSP Tech Specs – Concrete Production
- RFC R/B Post Tensioning
- NSP/BOP Trenches and T/B – WTP Tunnel Excavation
- RFC P/H Excavation – Initial (+/- 88)
- RFC P/H Excavation Final
- RFC R/B Baselab Concrete and Formwork
- RFC R/B Perimeter Wall Concrete Structure
- RFC R/B Baselab E/Ps and Reinforcing Steel
- Construction Permit - Application, Review, Issue
- RFC-CW Structures Excavation – Initial
- RFC Preliminary BOP Excavation Design
- RFC R/B Perimeter Wall E/Ps and Rebar
- RFC-R/B Grounding and Lightning Protection
- RFC NSP Tech Specs – Grounding and Lightning Protection
- RFC BOP Detail Excavation

- BOP Conceptual Design Submission 1
- RFC R/B Strain Measurement Devices
- RFC S/B Embedded Parts
- RFC Four Intake Duct Sections under P/H Cofferdam
- RFC BOP Tech Specs – Grounding (symbols/notes/details)
- RFC R/B Internals 93-98m E/Ps
- RFC R/B Internals 100-117m E/Ps
- RFC R/B Internals above 117m E/Ps
- RFC-CW Structures Excavation – Final
- RFC Info for Proc/Plan'g Rebar T/H
- RFC R/B 100m Slab Concrete and E/P
- Site Lighting Electrical (cancelled, but issued)
- RFC – Final BOP Excavation Design
- RFC R/B and S/B Epoxy Finishes
- RFC Retaining Walls – Concrete Structures
- RFC R/B Internals 93-98m Concrete Structures
- RFC R/B SFTB Steel Liner
- RFC S/B A-E3, 5-8 SFB Steel Liner
- RFC – Retaining Walls Excavation Design
- RFC(S) Tanks Area – Grounding/Lightning Protection
- RFC Tech Spec for U/G Piping
- RFC BOP Tech Specs – Struct/Misc/Secondary Steel Sup/Fab
- RFC-CW Ducts Concrete Structures Onshore
- RFC(S) Tr'fr Area – Grounding/Lightning Protection
- RFC(S) T/B Structural Steel Main Columns and Trusses
- RFC Outfall – Concrete Structures Onshore
- RFC(S) T/B and Annex – Lightning Protection
- RFC Proc. Info for Rebar. Perim walls 87-104m
- RFC S/B A-E3, 5-8 (all Elev.) SFB Conc/Rebar/Fmwk
- RFC R/B Temporary Roof
- RFC BOB Tech Specs – Pipe Fab and Installation

- RFC(S) BOP Tech Specs – Lightning Protection
- Information for Proc/Plan’g – T/G Block Conc
- RFC(S) TAuxB K-N; 5-17 Grounding/Lightning Prot.
- RFC(S) Outfall E/Ps
- RFC NSP Tech Specs – Steel Liners
- RFC Tech Spec BNSP Pipe Installation
- RFC BOP Tech Specs – Siding and Roofing
- RFC(S) T/B E/P (Below 87m)
- RFC Aux Bay - Conc Base Mat (Below 87m) incl mtls
- RFC P/H Conc Basemat w/ Embedded Pipe
- RFC RSW Installation Yard (CW Inlet)
- RFC Info for Proc/Plan’g E/Ps T/B
- RFC S/B F-K, 13-17 below 93m Conc/Rebar/Fmwk
- RFC S/B – Grounding and Lightning Protection
- RFC S/B U/G and Embed Pipe Fab and Installation
- RFC R/B Basement Structural Steel
- RFC R/B Intls 93-100m Pipe Fab (to ext interface)
- RFC Proc Info for P/H Rebar
- RFC Calandria Vault Conc Structure (incl E/P)
- RFC(S) T/H N-T, 5-17 87m-Top – Grounding
- RFC Tech Specs SNSP Pipe Fabrication
- RFC NSP Tech Specs - Structural Steel
- RFC S/B F-K, 13-17 93-100m – Conc/Rebar/Fmwk
- RFC T/H – Conc Base Mat (Below 87m)
- RFC TAuxB and T/H – Conc Base Mats (<87m)
- RSW/RCW
- RFC R/B Internals 100-117m Concrete Structures
- RFC BOP Tech Specs – Masonry
- RFC BOP Tech Specs – Doors
- RFC BOP Tech Specs – Arch’l Features
- NSP/BOP Road Layout and Storm Drainage

- RFC R/B Externals – Cable Gallery and Shielding Walls
- RFC R/B Externals – Concrete Cable Gallery
- RFC R/B Domes and Ring Beam E/Ps and Rebar
- RFC Vault Steel Liner
- RFC NSP Tech Specs – Pipe Fabrication
- RFC BOP Tech Spec – Structural Steel Erection
- RFC R/B Internals above 117m Concrete Structures
- RFC CCW Duct Crossover
- RFC S/B G-K, 8-13 below 93m Conc/Rebar/fmwk
- RFC S/B F-K, 13-17 100m Slab
- BOP Conceptual Design Submission 2
- RFC T/B and S/B U/G Drainage
- RFC(S) Balance of T/B Structural Steel
- RFC S/B G-K, 8-13 93-100m Conc/Rebar/Fmwk
- RFC T/B and S/B U/G Drainage
- RFC(S) BOP Tech Specs – Pipe and Equipment Installation
- RFC D_2O Tower – Conc Subtruct 93.9 (incl E/Ps)

Appendix B
Quality Assurance Program

B.1 General Responsibility to TQNPC

SPMO SQA works closely with TQNPC QA personnel. Monthly QA co-ordination meetings are held to discuss and resolve quality issues raised by either SPMO or TQNPC. TQNPC regularly attends and participates in SPMO's audits of construction contractors and the Commissioning Team (CT). TQNPC and SQA have also initiated Quality Monitoring of CT activities. A Quality Monitoring Plan is prepared each month and is executed jointly by staff from SPMO and TQNPC. Findings are reported each week and corrective actions are taken by the CT on an on-going basis. This has resulted in continuous improvement to the Construction and Commissioning Quality Assurance Programs.

B.1.1 SPMO Responsibility to the NSP Construction Contractors and CMT

After acceptance of the construction contractors' QA manuals and supporting quality procedures, SPMO carried out QA evaluations and audits to ensure the effective implementation of the requirements defined by the construction contractors' quality manuals, procedures, and applicable quality standards. Audits were scheduled to ensure that all applicable elements of the construction contractors' QA programs were audited annually. The frequency of quality audits for each element was determined by the work underway, as well as by the effectiveness of implementation of the quality program. Additional evaluations were carried out when specific concerns arose. One example of this is preservation, whereby evaluations were carried out in both the NSP and BOP when it became evident that the construction contractors were not taking adequate measures to ensure that equipment and materials were being properly preserved while in their care and custody. As a result of these audits and evaluations, there were fewer preservation problems as the Project progressed. This, in turn, reduced re-work and reduced costs since it was not necessary to procure and re-install replacement equipment and materials.

As a result of efforts on the part of TQNPC and SPMO, CMT and the BOP contractors became more diligent in identifying non-conformances, thereby ensuring that the non-conformances were reviewed and properly dispositioned by the responsible parties. Properly documented non-conformances reduced re-work and costs, since qualified staff corrected problems immediately. This improved "quality awareness" minimized re-work, reduced down time and will benefit these companies on future projects.

B.1.2 Quality Assurance Audits

a) General - Quality Assurance audits are the most important preventive activities of Quality Assurance. Audits were carried out to confirm that quality assurance requirements as specified by each construction contract and the Commissioning Team were effectively implemented, to identify deficiencies in program implementation and to initiate corrective actions in order to resolve the observed deficiencies. Over 100 audits have been carried out by SPMO thus far on the Project. This aggressive audit program resulted in the effective identification and resolution of problems.

b) Internal QA Audits - Deficiencies observed during the audits were identified, documented, and promptly reported to the appropriate level of management for correction. Follow-up activities, including verification, were conducted to ensure that corrective action had been implemented in a timely manner and that it was effective.

c) External QA Audits - Deficiencies observed during the audits were identified, documented and promptly reported to the appropriate level of management for correction. Follow-up activities were conducted to ensure that corrective action had been implemented in a timely manner and that it was effective.

B.1.3 Records

Records essential to provide documented evidence that items and services met specified requirements and that the Construction and Commissioning QA Programs had been effectively implemented have been produced and retained.

They are reviewed and accepted by SPMO QS (for NSP) and CMT QS (for BOP), transferred to SPMO Document Control, and eventually transferred to TQNPC for retention in the TQNPC QA Vault.

In addition to the above, records are maintained of all internal and external Quality Assurance audits conducted by SPMO. These records are available in both electronic and hard copy format. Electronic versions of the audit reports are available in AIM. Hard copies are currently being maintained by SQA but these copies will be turned over to the owner at the end of the commissioning phase.

B.2 Main Quality Activities

B.2.1 Quality Surveillance by SPMO

The SPMO Construction Quality Assurance Program required that quality surveillance be carried out on the work of each Construction Contractor. Quality Surveillance (QS) is the responsibility of SPMO Engineering and Quality Surveillance Division. Quality Surveillance is the process that is used by SPMO QS to ensure that:

- The contractor planned and performed inspection activities according to an Inspection and Test Plan (ITP)
- All non-conformances were identified and dispositioned
- Drawings, specifications, codes, standards, regulations and procedures were followed
- Documentation, which includes quality records, is in place
- Contractor History Dockets/Files are acceptable to SPMO

To initiate this surveillance, construction contractors submitted Inspection and Test Plans (ITPs) for SPMO's acceptance and identification of both SPMO and TQNPC/STAR witness and hold points before work commences. These plans specified the inspections and tests that the Construction Contractor must carry out to ensure that work met specified requirements.

B.2.2 Quality Control by Construction Contractors

The construction contractor's quality control (QC) group planed and performed the inspections and tests in accordance with the Inspection and Test Plan. Quality Control is the inspection process used by the construction contractors to:

- Inspect the installation/fabrication in accordance with the ITP, procedures, technical and quality requirements
- Conduct all testing activities as defined by the ITP
- Interpret and review test results
- Initiate and then re-inspect nonconformances after disposition
- Assemble quality records of inspections and tests for the History Docket/File
- Ensure that History Dockets/Files are correct and complete prior to issue to SPMO

SPMO developed quality surveillance plans based on the contractors' Inspection and Test Plans. SPMO Quality Surveyors surveyed or witnessed significant construction contractor inspections and tests to ensure that the construction contractors were performing them effectively to achieve the specified quality requirements.

B.2.3 Quality Supervision Activities for Equipment Manufacture

AECL, through Canatom NPM, performed quality surveillance at equipment manufacturers to ensure, as applicable, that:

- Inspections, tests and examinations were carried out in accordance with the accepted inspection and test plans/checklists.
- Inspection status was maintained and items were properly identified.
- Qualification of suppliers was maintained through audits and quality system verifications.
- The correct revision of applicable specifications, drawings, standards and procedures was used.
- Qualified personnel executed the work.
- Environmental and seismic qualifications were complete and acceptable.
- Measuring and testing equipment was calibrated.
- Data and test results were accurately recorded and evaluated.
- Non-conformances were properly documented and controlled.
- History Dockets/Files were correctly compiled and released.

- Equipment and materials met all specified requirements
- Packaging and marking were correct and meet Project requirements.
- Equipment and materials were released.

B.3 Quality Assessments

B.3.1 Quality Assessment for Construction

Construction contractors' QA programs improved dramatically during the course of the Qinshan Phase III Project. Initial efforts were directed toward documenting the QA programs (QA Manual plus procedures). Once documented, the QA programs were "tested" to determine the extent of application. This required extensive efforts on the part of SPMO and the construction contractors. One of the most difficult challenges was in instituting international quality practices, such as documenting non-conformances. This became much easier once the benefit of these practices was acknowledged by the contractors. The lessons learned on Qinshan Phase III can now be applied to other projects both in China and abroad.

Improvements were also made from the construction of Unit 1 to that of Unit 2. The following are some examples:

- Build Clean program – a more comprehensive program was developed for Unit 2, resulting in much fewer incidences of foreign materials in the piping system.
- Cleanliness levels were significantly improved on Unit 2, particularly the dust levels in panels and other sensitive electronic components. This required significant interface management, since all contractors were involved.
- Assembly of cable penetration seals was improved on Unit 2. Additional field engineering, verification and construction supervision activities were undertaken. These efforts resulted in a significant reduction to the Reactor Building leak rate for Unit 2.

The contractors' QC function was strengthened, resulting in earlier problem definition and quicker corrective action.

B.3.2 Quality Assessment for Commissioning

When commissioning activities began, many of the staff were young and inexperienced. Although the AECL staff had extensive experience gained during the commissioning of previous CANDU plants, their numbers were quite low, representing about 5% of the entire Commissioning Team. There was some indication in the beginning that procedures were not being followed and processes were not well documented.

However, TQNPC staff learned quickly and endeavoured to follow procedures. Significant inroads were made as the commissioning work proceeded. This was aided to a large extent by the Quality Monitoring activities of TQNPC and SPMO staff.

As a result of the continuous Quality Monitoring activities, Commissioning Team staff became diligent in following procedures and in completing the necessary records. This, in turn, resulted in less damage during commissioning and better control of the commissioning process. Since better records are available, it will be much easier to diagnose problems during future operational activities.

B.3.3 Quality Assessment for Equipment Manufacture

NSP equipment was grouped into about 410 Purchase Orders, out of which 28 orders were designated major equipment. All of this equipment has now been shipped. Suppliers of all the equipment were qualified to the specified requirements and their documentation; inspections and tests were monitored to varying degrees. All equipment was final inspected and QA released to ascertain its conformance to specified requirements.

All suppliers were qualified. They were qualified by various means, including auditing by AECL/CNPM and qualification by other parties such as ASME and ISO registrars.

All NSP equipment and materials that were supplied on the Qinshan Project fully complied with all specified requirements. During execution of the Project, a number of quality improvements and corrective actions were implemented. The following are some generic corrective actions taken during the fabrication of NSP equipment:

- In order to reduce packaging and handling damage, packaging and handling processes were improved, inspection activities were reinforced and tilt and impact indicators were installed on crates for sensitive equipment.
- Improvements were implemented on the cleanliness of the test loops and test water quality for some major pumps, including PHT and SDC pumps.
- The legibility of History Dockets and History Files was improved, and suppliers became more vigilant in the proper assembly of permanent records.

Appendix C
ACR Design and Construction

C.1 Design and Construction

The ACR reactor design is based on the modular concept of horizontal fuel channels surrounded by a heavy water moderator, the same as with all CANDU reactors. The prime objectives of new features and design improvements incorporated into ACR are cost reduction and enhanced safety.

The use of the CANFLEX fuel bundle design enables ACR to operate to higher fuel channel and bundle powers with reduced risk in fuel failure and to achieve about three times the fuel burn-up of natural uranium. The ACR design also builds on the proven characteristics of the CANDU system, including: simple, economical fuel bundle design and on-power fuelling; passive shutdown systems in separate cool, low-pressure moderator; back-up heat sink capability, and relatively high neutron efficiency.

C.1.1 Containment/Calandria

The ACR reactor building is a steel-lined, pre-stressed concrete structure that provides biological shielding and an environmental boundary. Because of the lower design leak rate from containment, the exclusion area radius for the siting of ACR can be as small as 500 meters, significantly reducing site area requirements. The ACR containment free volume is sufficiently large and design pressure is higher than that for CANDU 6.

A smaller calandria vessel contains the moderator and simpler reactor internal components. The use of 54-element CANFLEX fuel bundles in lieu of the traditional 37-element fuel bundle increases fuel operating margins. The increased design margins in the pressure tubes allow an increase in reactor coolant operating pressures and temperatures in the heat transport system design. This combines with a higher pressure and temperature of the turbine main steam to provide a higher thermal efficiency than the existing CANDU plants.

C.1.2 System Improvements

The design requirements for the ACR control centres have been reviewed and optimized. The Main Control Room is designed for all design basis accidents, including external events such as an earthquake or extreme external events, whereas the secondary control area is required only for an event such as a major fire or hostile takeover, which requires an evacuation of the Main Control Room. For the Main Control Room, the equipment and panels that are required for all the design basis events are appropriately hardened and qualified. For the secondary control area, the ability to ensure continued reactor shutdown and maintain emergency long-term heat sinks and safety parameter monitoring are provided.

C.1.3 Operational Enhancements

The ACR design has incorporated an advanced control centre. The control centre features standard panel human-machine interfaces that provide an integrated display and presentation philosophy and includes the use of a common plant display system for all consoles and panels. The control room human factors design builds on the improvements made at Qinshan in the wide screen displays and safety parameter analysis and displays.

A powerful and flexible annunciation system provides extensive alarm filtering, prioritizing and interrogation capabilities to enhance staff recognition of events and plant state. A systematic plan has been set up and is being implemented in the ACR to improve the interface between the operator and the plant systems.

C.1.4 Application of Construction Strategy

a) Open Top Construction

Very heavy lift (VHL) cranes similar to the Qinshan project have made it feasible to leave the top off the containment structure and install the internals through the "open top" construction method. The reactor assembly will be the heaviest lift made with the VHL crane and, as such, defines the size of crane required. There is no longer a requirement for a temporary opening in the reactor building wall for equipment installation.

The reactor assembly concept developed for ACR-700 includes a calandria and integrated shield tank supported on four feet, stabilized by four horizontal seismic pads to the reactor vault wall. The reactor assembly also includes fuel channels, lower feeders and reactivity mechanism deck being assembled prior to installation. From a construction point of view, this is a good arrangement as it simplifies the civil program by not requiring complex work to be done embedding the calandria shield tank assembly in the civil structure, as required for the conventional CANDU 6 design.

b) Parallel Construction

The key to short construction schedules is the paralleling of activities that are traditionally done in series. This is why modularization is so effective, as it allows the module fabrication to start at Contract Effective Date and continue in parallel with the civil program for reactor building containment and internal structure. The internal structure is designed as thirteen vertical installation compartments that can be filled up with modules functioning as parallel independent work areas.

c) Module Development

Modularization for ACR-700 is achieved through a multi-disciplinary team. For each module, a module project engineer is responsible for the layout of the piping systems and optimizing and coordinating input from all disciplines for the design. Since modular design is compact to optimize space utilization and constructability, operation and maintenance review is critically important. Operations and Maintenance input and review by a specialist have become part of the module design work process. One hundred and five civil and process modules have been incorporated into the reactor building.

d) Construction Technologies

ACR is using several up-to-date construction technologies on ACR:

- Large volume pours

- Prefabricated rebar
- Use of climbing forms
- Use of composite structures
- Use of prefabricated permanent formwork
- Use of automatic welding

As on Qinshan, 3D CADDs is being used to develop construction sequences to match the schedule through links with *Primavera*. In addition, 3D CADDs provides a high quality output with minimal field interferences due to clash checking capabilities.