Project Construction and Important Technical Innovation for Qinshan Phase Ⅲ (PHWR) Nuclear Power Plant

Third Qinshan Nuclear Power Co. Ltd, CNNC
(Haiyan County, Zhejiang Province, 314300, China)

Abstract: Qinshan Phase Ⅲ (PHWR) Nuclear Power Plant, the first commercial heavy water reactor nuclear power plant in China, was the biggest trade project performed between the governments of China and Canada. As the owner, the Third Qinshan Nuclear Power Company (TQNPC) persisted in independent innovation management during the project construction, commissioning and self-dependent operation, efficiently realizing the three controls of the project, i. e. quality control, schedule control and investment control, and persisted in technical improvement on the basis of digestion and absorption of CANDU-6 technology to improve the unit safety and reliability. The project construction practice has helped China's nuclear power project management to becomeprogrammed, computerized, standardized and internationalized management from the existing basis. After completion of the project, with unit safe and steady operation as the prerequisite, TQNPC performed several technical modifications and innovations to continuously improve the unit performance. In the area of staff development, TQNPC paid much attention to cultivation of corporate culture, strengthed staff training and built up a good circulating mechanism with staff training and project construction promoting each other. Further to "Zero Breakthrough" and a new step forward of locolization successfully realized in Qinshan Nuclear Power Plant and Nuclear Power Qinshan Joint Venture Company, the improvement and developemnt of nuclear power project management level in Qinshan Phase Ⅲ (PHWR) Nuclear Power Plant provided reference for promotion of nuclear power development in China and standardized management of introducing large imported project.

Key words: Qinshan Phase Ⅲ Heavy Water Reactor; nuclear power plant; project construction; technical innovation

1 Foreword

Qinshan Phase Ⅲ (PHWR) Nuclear Power Plant Project (hereafter "Qinshan Phase Ⅲ Project") was one of the national key projects during the 9^{th} Five-year Program, the first commercial heavy water reactor nuclear power plant in China, and the biggest trade project performed between the governments of China and Canada. As a proven CANDU-6 heavy water reactor nuclear power technology, it has many characteristics. In particular, the demand of separation work may be reduced as the reactor uses natural uranium as its fuel. The main purpose of introducing heavy water reactor nuclear power plant from abroad was to introduce the advanced nuclear power technology and management in order to promote the nuclear power development in China. In addition, heavy water reactor may produce isotopes such as cobalt-60, which is of great significance for military and civil combined nuclear industry in China.

Qinshan Phase Ⅲ Project enjoyed the warm solicitude from the leaders of China and Canada and full support from the parties concerned both at home and abroad. With the shortest construction period, good construction quality and several construction records in terms of the construction of similar nuclear power plant, the successful completion of construction of the 2 units was highly praised. After the 2 units were put into commercial service, with unit safe and steady operation as the prerequisite, TQNPC performed several

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technical modifications and innovations to continuously improve the unit performance.

The project construction practice of Qinshan Phase Ⅲ Project has helped China's nuclear power project management to become programmed, computerized, standardized and performed on international convention from the existing basis. Further to "Zero Breakthrough" and a new step forward of localization successfully realized in Qinshan Nuclear Power Plant and Nuclear Power Qinshan Joint Venture Company, the improvement and developemnt of nuclear power project management level in Qinshan Phase Ⅲ (PHWR) Nuclear Power Plant provide reference for promotion of nuclear power development in China and standardized management of introducing large imported project.

2 Project Overview

The proven CANDU-6 commercial heavy water reactor nuclear power technology is used in Qinshan Phase Ⅲ Project. The reference plant is Wolsong Unit #3 and Unit #4 in South Korea. 2 × 700 MWe nuclear power unit was constructed according to the Main Contract. The key indicators of the project are:

Reactor: Type CANDU – 6, horizontal pressurized tube heavy water reactor

Unit rated power: 728 MWe

Design life of the plant: 40 years

Average annual design capacity factor: 85 %

Construction period of the first unit: 55 months

The project is jointly invested and constructed by China National Nuclear Corporation (CNNC), China Electric Power Investment Group Corporation, Zhejiang Provincial Electric Power Development Corporation, Shenergy Company Limited and Jiangsu International Trust and State Property Management Group Corporation. As the owner, the Third Qinshan Nuclear Power Company Limited (hereafter "TQNPC") was responsible for site condition of the nuclear power plant, construction management of conventional island and balance of the plant (hereafter "BOP"), implementation of commissioning, production preparation and operation. Also, authorized by CNNC, TQNPC was responsible for project construction and management on behalf of China. As the General Contractor, Atomic Energy of Canada Limited (AECL) was responsible for design and supply of NSP and overall project management. The Bechtel China, Inc. (Bechtel) and Hitachi, Ltd. (Hitachi) formed BOP consortium and was responsible for design and supply of conventional island and balance of the plant. China National Nuclear Huaxing Construction Company (HXCC) and China Nuclear Industry 23rd Construction Corporation (CNI 23) undertook the responsibility of civil work construction and installation of NSP respectively. China Nuclear Industry 22nd Construction Corporation (CNI 22) and Zhejiang Thermal Power Company (ZTPC) were responsible for civil work construction and installation of BOP respectively.

On June 8, 1998, the first concrete for Unit #1 nuclear island main building base slab was poured, which marked the formal start of construction of the project. On December 31, 2002, Unit #1 was put into commercial operation, 43 days ahead of schedule specified by the Main Contract. On July 24, 2003, Unit #2 was put into commercial operation, 112 days ahead of schedule specified by the Main Contract. On September 22, 2005, Qinshan Phase Ⅲ Project passed the national as-built acceptance and the project was completely constructed.

Based on the design, construction and operation management experience of pressurized water reactor existing for several years in China, TQNPC learned in depth the CANDU-6 nuclear power technology during the contract negotiation and project construction, and made technical modifications and innovations on the basis of digestion and absorption of CANDU-6 technology, to have the first heavy water reactor nuclear power plant constructed in China meet the requirement of Chinese Nuclear Safety Code, adapt the Qinshan site characteristics, further improved the plant safety and reliability and reaches the international advance level of similar type of nuclear power plant in overall performance. The plant is the first heavy water reactor nuclear power plant with 40 years design life in the world.

During the project construction, as TQNPC always held the initiative and control powers, the controls of quality, schedule and investment were efficiently realized. The project construction and installation quality was good. The 2 units were put into commercial operation ahead of schedule. This achievement hit an all-time short-duration record in terms of the construction of CANDU-PHWR nuclear power plant worldwide. The project construction cost is approximately 10 % less than the budgetary estimate approved by the State.

During the unit commissioning, trial operation, operation and overhaul, the CANDU technology was promptly absorbed and mastered, each performance indicator of the unit reached the design requirement, the unit performance was improved through continuous modifications and the units were safely and steadily operating in 4 consecutive years, realizing remarkable operation performance. The completion of construction and commercial operation of the plant played an important role in mitigation of the situation of power electricity shortage in East China Area, obtaining significant economic and social benefits.

The National As-built Acceptance Commission concluded that every indicator of the project of Qinshan Phase Ⅲ nuclear power project met the design requirement, the project quality was good, the operation safe and reliable and the economic benefit excellent.

As of today, the 2 units of Qinshan Phase Ⅲ Project have experienced 2 overhauls respectively. The operation performance of the 2 units is good. In 2006, 10 indicators of Unit #1 excelled or equaled to 2005 WANO median and 9 indicators reached WANO advanced level while 10 indicators of Unit #2 excelled or equaled to 2005 WANO median and 8 indicators reached WANO advanced level.

3 Main Characteristics of Project Construction and Management Innovation

3.1 Main Characteristics of Project Construction

3.1.1 Not simply replicating the reference plant, but re-modifying and re-innovating on the basis of digestion and absorption

Although Qinshan Phase Ⅲ Project was an introducing project, TQNPC established its clear project objective form the very beginning, i. e. the reference plant would not be simply replicated but the best CANDU-6 nuclear power plant in the world would be constructed, and efforts would be made to master heavy water reactor nuclear power technology through project practice. For this purpose, the following principles were made:

1) Chinese nuclear safety and environmental impaction code and standard must be met and the plant must suit the Qinshan Phase Ⅲ site characteristics;

2) Necessary design improvement must be performed based on operation feedback of CANDU unit to make all of the systems, overall function, quality and performance of the plant better than ones of the reference plant;

3) Effort shall be made to use the up-to-date and proven technology of the exporting country and the accumulated experience on pressurized water reactor in China to improve safety and reliability of the plant;

4) During construction, the proven new construction technology in international nuclear industry shall be used as much as possible.

According to the above principle, TQNPC organized its staff in digestion and absorption of CANDU-6 technology, coordinated discrepancies between Canadian and Chinese nuclear safety and environmental protection codes and made necessary design modifications to further improve the plant safety and reliability and made the overall performance of the plant reach the international advanced level of similar type of nuclear power plants. Many design modifications performed and some new technique and new equipment efficiently used during civil construction and equipment installation shortened construction duration while ensured project quality.

3.1.2 Not completely relying on foreign contractor, but always holding the initiative and control powers in project construction

TQNPC made it clear from the very beginning that it would not completely rely on the foreign contractor in project management, but would actively intervene project construction, hold initiative and control powers in project construction, exercise owner's right and ensure implementation of efficient surveillance over the foreign general contractor to ensure smooth progress of the project construction

Therefore, TQNPC affirmed in contract negotiation its surveillance and control powers over the entire project management, which provided the owner with legal basis in project management surveillance and control and ensured that TQNPC had sufficient powers in the areas of design review, equipment quality supervision, project quality and schedule surveillance and project investment management. During the project construction, TQNPC took strong measures to properly exercise various rights it had according to the Main Contract. In the area of design review, TQNPC performed many design modifications according to the codes and standards issued by Chinese authority to improve the unit safety and reliability; in equipment quality supervision, TQNPC timely issued stop-work orders for serious quality non-conformance and issued instructions for significant non-conformance for correction, which ensured project quality efficiently; in the area of project construction, cooperated with foreign contractors, several new construction techniques were implemented and several construction scheme modifications were raised and dealt with; during commissioning, several technical modifications were also performed. All of these laid a solid foundation for ensuring project quality, putting into commercial operation ahead of schedule and independent operation and maintenance of the units after turnover.

3.1.3 Joining the international track in project management through up-to-date computerized management platform

Since the advanced scientific management tools and software in the world were used in Qinshan Phase Ⅲ Project to build an up-to-date computerized management platform, the computer systems of the general contractor and sub-contractors were connected in the same net, which laid a foundation for application of modernized management technique and use of international advanced management software. The advanced computer system was used in the area of project schedule, document and drawing, material cable wiring data and etc. to aid management and to improve management level. Computerized management was realized in Main Contract surveillance, financial management, human resources management and etc. The company internal instructions, notifications, documents, materials and etc. were transferred through internal E-mail system, which greatly improved work efficiency and has become indispensable integral part for company normal operation.

The application of the following project management software and databases played a very important role in upgrading project management level:

The application of integrative schedule management software P3 efficiently realized project schedule dynamic management. All of the project activities were linked with resources (human resource, equipment and materials, construction machines and tools, payment of charges and etc.) required to perform the activities and the dynamic situation between plan and actual progress was reflected, which facilitated key path calculation, helped to analyze project bottleneck in advance and greatly improve efficiency of plan.

In area of logistic management, with help of CANDU Material Management System (CMMS), a total weight of more than 20 thousand tons of the structural steel could be tracked to whereabouts of even one steel piece. It also could be forecasted if equipment could arrive at the jobsite as schedule and be issued to installation and commissioning site.

In the area of integrative wiring, codes with complete information were given in integrated electric and control database (IntEC) for nearly 30 thousands of cables and hundreds of thousands of connectors, which was not only in favor of installation and commissioning but also facilitated operation and maintenance in the future.

The document and drawing management/distribution system (AIM/TRAK) realized computerized management and control of all the files in the project for the first time in the history of heavy water reactor construction, which greatly elevated access speed and distribution control efficiency and became an advanced model in electronic file management in China.

TQNPC also independently developed management software such as real time data management system (PI), work management system (WMS) and nuclear material management system (NMMS) for the plant. PI system helps the management staffs at various levels realize supervision of the operation status of the plant process system at its office computer; WMS may comprehensively manage all of the deficiencies and preventive maintenance works of the plant; NMMS realized overall process follow-up control of every fuel bundle (from arrival at the plant, to storage, loading and discharging from reactor and transfer of spent fuel) with computer for the first time in domestic nuclear power plant. At present, TQNPC is working hard to develop an integrated production management system platform (TEAM) to integrate all activities in plant production and management areas on one large platform so as to realize step-by-step the computerized plant operation management.

The construction, commissioning and operation data accumulated in the computerized platform provide convenient and valuable information for independent operation and maintenance.

3.2 Innovating Project Management and Driving Forward the Project

The project management of the imported nuclear power plant is very important in project construction. TQNPC always paid attention to the fact that the foreign general contractor was not relieved of its responsibility while the owner had sufficient power not only to actively participate in project management and ensure smooth realization of the three controls of quality, schedule and investment, but also to involve itself in technical areas such as design, equipment manufacture and project construction as deep as possible so as to digest and absorb technology, and cultivate and develop employees with high quality that could independently operate and maintain the plant.

3.2.1 Innovating cooperation mode by persisting self-reliance principle

A tendency often appears to rely on foreign contractor completely in large imported project. The owner tends to be in a weak position to learn and gradually master the technology until operation and perform common project quality surveillance. We already have had experience to independently design, construct, operate and manage pressurized water reactor nuclear power plant though we are not familiar with heavy water reactor nuclear power plant. Therefore, TQNPC paid much attention from the very beginning to researching and searching a cooperation mode to suit this actual situation.

In imported large nuclear power project, the Main Contract is one of the legal documents specifying power and responsibility of both parties. TQNPC selected and transferred crack staffs in project preparation phase, to make sufficient preparation in the areas of technology and contract terms and realized operable power in the contract. In the project management terms, the Contract specified that general contractor had to submit the owner in a timely manner the monthly progress report and quality trend report, and the owner had the right to access contractor project management system for project related information, which ensured the owner's real time right to learn the truth for the entire project management. The project management contract terms also specified a series of project management regular meeting, which ensured the owner's right to participate in project management. In the design and design review terms, the Contract specified the owner's right to review project concept design and detail design. In quality control terms, the Contract specified the owner's right to review qualification of safety important equipment suppliers of nuclear island and conventional island and supervise equipment manufacture quality. In quality assurance terms, the Contract specified that the quality assurance codes and guides issued by China National Nuclear Safety Administration (NNSA) had to be followed, which ensured the owner's control right in QA system of the entire project. The Contract also specified in owner supervision of project management that the owner had the right to issue stop-work order to the affected area in case that quality non-conformance seriously deviated from the contract requirement, which ensured the owner's right to dispose important issue. All these provisions legally ensured the owner's rights to supervise and control the entire project. As these provisions were specific and easy for operation, the owner seriously and reasonably exercised its rights in implementation of the project, which played a very important role in successful construction of Qinshan Phase Ⅲ Project.

In consideration of the fact that China has some experiences in construction and management of nuclear power plant, TQNPC adopted an attitude to actively cooperate with foreign contractor and undertook some project responsibility in its power through making full use of Chinese preponderant resources to reduce project cost and train Chinese management and technical staffs in specific practice of deep participation in project construction. For example, the owner promised in the Main Contract to be directly responsible for construction management of BOP, and implement construction management of BOP project under the condition that foreign contractor provided the related project design information, implemented level I and level II schedule control, and provided certain support. By this way, the foreign project management staffs were reduced and project cost saved. In addition, we could bring into play our advantages to be familiar with site condition and the construction experience of pressurized water reactor we had to modify construction scheme, save project investment as much as possible and expedite the project progress. We also undertook commissioning implementation of the plant with our own staffs under the precondition not to relieve the foreign contractor of its commissioning technical responsibility. This kind of cooperation mode did not change the overall responsibility of the general contractor in project design, equipment supply, construction and commissioning, but helped owner to play its role. This kind of cooperation mode was favorable in joint completion of the plant construction, commissioning, turnover and independent operation.

3.2.2 Innovating construction and installation management by signing construction contracts with contractor by both owner and general contractor

Particular construction contract signing mode was adopted in Qinshan Phase Ⅲ Project, i. e. NSP construction and installation subcontract was signed with the Chinese construction contractor by AECL/TQNPC, with AECL as the main signer and the owner as secondary signer while BOP construction and installation subcontract was signed with the Chinese construction contractor by TQNPC/ AECL, with the owner as the main signer and AECL as secondary signer.

The purpose of this kind of contract signing mode was to make TQNPC as the owner to be responsible for price negotiation of all construction contracts, payment of contract price and payment control under the condition that the general contractor was not relieved of its responsibility of technical management, schedule control and quality surveillance over the Chinese construction contractors, so as to make full use of domestic resources and construction experiences we had, greatly reduce project cost and directly and efficiently control the construction cost of the plant.

It was because of this mode of relationship among the 3 parties that had the owner participated in the project deeply and broadly and held in a favorable position to control the project. When general contractor performed strict quality management over the Chinese construction contractors (for example, issuance of stop-work order), the owner supported the general manager while when general manager intended to take strong measures (for example, replacement of certain construction contractor) that would cause serious impact to the project construction schedule, the owner coordinated the general contractor and took necessary measures (for example, to help the construction contractor improve its technical and planning management level by full use of domestic resources) to upgrade the construction contractor management ability to help the contractor reach the management requirement so as to ensure the project quality and schedule. By this way, not only proven management experience of the foreign general contractor was brought into full play, but the Chinese construction participants learned and absorbed the experiences of the foreign general contractor in construction and management of nuclear power plant and upgraded their construction and management level in nuclear power project.

3.2.3 Innovating design management by independent design review

Design is the first important work in a project. Strengthening design management and design review is one of the key links to ensure that the plant design meets the requirement in Chinese nuclear safety code and that the unit performance is better than that of reference plant. TQNPC seriously exercised its contractual design review right. After effectiveness of the Main Contract, TQNPC organized a design review team, made up of multiple-disciplines specialists from the company and the technical backup organization with the company chief engineer as the team leader. The responsibility of the design review team was design review, safety review, environment impact assessment report, and applications of construction permit and first fuel load. Efficient work had been done in this team, with organization management being smooth, overall plans made and all design works taken into consideration.

Strict design review was performed in the areas of the plant performance, main parameters, system configuration, function, equipment function, quantity, design specification and standard in order for the design to be in consistent with the contractual regulations and meet requirement in Chinese nuclear code and standard. This comprehensive and detailed design review might be considered as a pre-safety review conducted jointly by the owner and the backup organization and as an independent verification to a certain extent. It was because of this design review that the team became further familiar with CANDU-6 reactor design, that a technical center in project construction phase was gradually formed under the leadership of the company chief engineer, and that the young technical staffs were trained and developed into technical backbones and played important role in commissioning. The specialists from technical backup organization also became familiar with process system and plant overall performance after design review and a technical backup team was trained and developed for providing TQNPC with long term technical support.

3.2.4 Innovating equipment quality management by strengthening equipment manufactures supervision

Equipment manufacture supervision is one of the important links to ensure equipment quality and particularly important to the plant safety and performance. Since equipment in Qinshan Phase Ⅲ Project was contracted by Atomic Energy of Canada Limited and subcontracted by the companies in United States and Japan, there were some difficulties in equipment manufacture supervision by the owner.

In order to ensure equipment quality, the owner paid much attention to the selection of main contractor, requesting that the qualification of key equipment manufacturer must be accepted by the owner. The subcontractor was chosen also by owner consent. In addition, the owner tried every effort to participate in the equipment manufacture supervision. Through negotiation with foreign contractor, the main equipment supervision items of nuclear island and conventional island specified in the contract were extended from 40 to more than 200. A representative office was established in Canada and equipment quality supervision groups were set up in Japan and in South Korea. The experienced staffs were sent to the manufacturers for supervision and witness of important hold points during manufacturing of important equipment such as fuelling machine, calandria, steam generator, turbine generator, main pump and etc. according to inspection and test plan (ITP). As for equipment quality problem found during supervision activity, communication or negotiation would be conducted with foreign manufacturer according to equipment technical specification and associated standards. The equipment problems were generally dealt with on principle and de facto. For example, an error was found during manufacturing of Unit #2 steam generator thermal plate. The foreign manufacturer persisted that this error would not impact safety, while our staffs prevailed over all dissenting views and repeatedly communicated with foreign manufacturer on the basis of detailed technical analysis to force the manufacturer to discard as useless the original thermal plate and rework a new one according to technical specification until the first stop-work order was issued by the owner since commencement of the project.

A total of 533 supervision inspections were conducted by TQNPC during equipment manufacture supervision and 14 serious equipment quality deviations from standard were dealt. In more than 140 large equipment (50 ton or more/piece) installed in Qinshan Phase Ⅲ Project, none of unacceptable product was used in the project. Our staffs were further familiar with the heavy water reactor plant design and equipment property during equipment manufacture supervision, which laid a solid foundation for commissioning and operation.

3.2.5 Innovating commissioning management with system engineer as core

A commissioning management approach with system engineer as technical core was adopted by TQNPC. It would avoid responsibility confusion between discipline interfaces or responsibility shirking to divide the plant according to systems and the system engineer was full responsible for everything of the system.

System engineer responsibility approach divided management responsibility of every system to individual, realizing seamless connection with installation. As system engineers would continue to work in the plant technical management after commissioning, this approach ensured in management, technology and experience that the system engineer team could be considered as a technical team that mastered plant technical core to realize stable transition from commissioning to independent operation and seamless connection between commissioning and operation.

The foundation of system engineer approach is procedural operation, that is to say all activities shall be documented. Through issuance of technical document, system engineers plan and guide the test activities. Document is prepared beforehand and record is made after an event. The procedure preparation staff and the site implementation staff work independently, supervise and cooperate with each other to ensure completion of test activity with good quality. There was a plan as the guide, document as the foundation, supervision as the assurance and record as the basis for every activity.

System engineers sorted and analyzed commissioning results and records in a timely manner, prepared system commissioning progress report in each commissioning stage as required, and kept in the archives the technical documents generated from commissioning as required after completion of commissioning. Large numbers of commissioning data and records cumulated laid a good foundation for long-term production operation. The system commissioning progress report in phase also helped allowed high efficient safety supervision inspection.

The commissioning management approach with system engineer as technical core forced the technical core staffs participated in the plant work from commencement of the commissioning, which made the staffs trained sufficiently. The commissioning technical department with system engineer as the main body transited into technical support department responsible for technical support of unit maintenance, system modification and long and medium technical issue management, While commissioning implementation department transited into maintenance and operation department responsible for unit maintenance and operation, which laid a solid foundation for independent operation in the future.

4 Important Technical Improvements and Effect

Though proven CANDU-6 technology was used in design and construction of Qinshan Phase Ⅲ Project, TQNPC made clear from the beginning of negotiation of the Main Contract that the plant could not be simply duplicated according to reference plant, necessary technical improvements should be performed and full considerations given to improvement of unit performance based on the world nuclear power technology development trend and CANDU-6 nuclear power plant operation experience feedback and in reference of the successful experience on pressurized water reactor we mastered so as to improve unit safety and reliability. During the project contract negotiation and construction, a total of 99 design changes were suggested, including 52 technical improvements, of which, 21 technical improvements were used for the first time in

CANDU-6 reactor, which made the design of Qinshan Phase Ⅲ Project reach the world advanced level. During construction design and construction scheme review, a total of 11 important construction scheme improvements were suggested and some new construction techniques were used in the construction, which not only assured project quality and shortened construction duration, but also saved great deal of investment. Even during commissioning, commissioning technical modification was performed, which laid a solid foundation for unit safe and steady operation.

The 9 important technical improvements were presented below.

4.1 Optimization of Function of Main Control Room and Modification of Human Engineering

Since design of CANDU-6 heavy water reactor nuclear power plant was finalized at end of 1970s, some of the functions could not meet the human engineering requirement. Before Qinshan Phase Ⅲ Project was commenced, AECL had already developed CANDU-9 (900 MWe) concept design and took the initiative to suggest adopting CANDU-9 technology to add Plant Display System (PDS) (100 inch large screen) and new designed alarm system (the status information and alarm is automatically separated to restrain meaningless alarm signal, and the signals were automatically ordered according to importance of nuclear safety and operation safety) in the Main Control Room. This new technology was used in the project with no additional cost. In addition, the following improvements were raised.

Key safety parameter system should be added to have the key safety parameters of the plant displayed collectively and on levels according to its importance, i. e. reactivity control of the reactor, core cooling and thermal transfer of heat transport system, integrity of core cooling system, activity monitoring system and containment integrity so as to facilitate the operator to promptly assess the plant safety status in normal operation, transient, accident and post-accident conditions, and fastest find the related parameters when accident occurs and analyze the accident cause. This is the first design in CANDU nuclear power plant.

For lessons learned from Three Mile Island accident, a technical support center should be added, which would not only provide associated supporting specialists with a shelter in case of accident, but also would provide connection interface between emergency commanding center and environment monitoring and provide the technical support staffs with a shelter for emergency rehearsal.

The historical data storage time should be extended from original designed 6 min to 24 h. During commissioning and operation, TQNPC further developed and extended the historical data storage time, and connected them with the company LAN, through which, the operation parameters for previous day could be accessed, which provided further support for data access and accident analysis.

The above improvements improved function of the Main Control Room and human engineering and received good feedback from operators from MCR.

4.2 Improvement of Feeder Material

During the period from 1995 to 1996, Canadian G-2 and Point Lepreau plants (both CANDU-6 reactors) found that the corrosion rate of feeder exceeded the design set value, which failed to meet the requirement of 30 years design life. A heavy water leak accident due to break of feeder occurred in Point Lepreau Plant in 1996. TQNPC as the owner paid much attention to this issue as 40-year design life of Qinshan Phase Ⅲ Project would not be met due to this issue.

Through negotiation, the foreign contractor proposed to increase the chromium content of SA106B carbon steel pipe to 0.2 ~ 0.4 wt% from the original ~ 0.02 wt% and promised to verify the material improvement through engineering test to ensure 40 years design life. TQNPC performed strict review and control of the test. The main result of the test showed that FAC corrosion rate was reduced about 60 % and the service life was extended to 58 years (2 inch tube) and 67 years (2 inch tube) when chromium content was increased from 0.013 wt% to 0.24 wt%. The actually measured wall thickness of feeder was 0.15 mm larger than designed value and the material chromium content was 0.33 wt%, larger than 0.24 wt% of the material used in the test, which added proper safety margin and met 40 years design life.

This new design was used for the first time in CANDU reactor. This design scheme was adopted in Romanian Cemavoda #2 Unit, the CANDU-6 reactor constructed after Qinshan Phase Ⅲ Project.

4.3 Process Modification of Radioactive Liquid Waste Processing System

The radioactive liquid waste discharging concentration in Qinshan area approved by the state is $\leqslant 1\times 10^{-8}$ Ci/L($1\text{Ci}=3.7\times10^{10}$ Bq) while the discharging concentration of CANDU reactor is 2.1×10^{-6} Ci/L, 210 times higher than the approved discharging concentration. If the liquid waste processing system is designed according to original AECL discharging standard, the waste resin generated from liquid waste processing will be increased 100 times the original quantity to reach the concentration discharging standard for Qinshan area.

After analysis by our staffs, it was found that the main cause of quick failure of low activity liquid waste resin bed was due to high total dissolved solid (TDS), and the main cause of high TDS was high salt content of domestic water in decontamination water. Therefore, we requested AECL to change the decontamination water of mixture of domestic water and demineralized water to demineralized water and to add sampling points for low activity liquid waste system in Reactor Building (R/B) and Service Building (S/B) respectively, so as to realize strict classification and respective collection of wastewater.

After modification, the radioactive waster resin generated is greatly reduced. This design is used in CANDU nuclear power plant for the first time.

4.4 Development and Preparation of Technical Specification and Source Terms Report of CANDU-6 Reactor

4.4.1 Preparation of technical specification of CANDU-6 reactor

In operation practice of CANDU nuclear power reactor in Canada, the Operation Policies and Philosophies (OP&P) is used in the plant as the top technical document. If conditions not specified in OP&P or deviation from OP&P occurs during operation, the review and approval by the site representative of nuclear safety authority is needed sometimes and sometimes the review and approval by the general manager of the plant is needed. By this way, it is a little random. Modification in a short time may cause inconsideration and safety hidden trouble. In addition, it is not consistent with the requirement in Chinese nuclear safety code. After more than 2 years unremitting hard work by TQNPC and AECL, the developed operation technical specification obtained approval by NNSA, and has become an operation technical specification with advanced format, content and requirement used for the first time in heavy water reactor nuclear power plant in the world. NNSA has highly commented this result and some CANDU-6 nuclear power plants in foreign countries requested TQNPC to exchange views on the operation technical specification.

4.4.2 Development of source terms report of CANDU-6 reactor

AECL had never performed radioactive source terms research for CANDU-6 unit before Qinshan Phase Ⅲ Project. In order to meet environment assessment requirement for Qinshan Phase Ⅲ Project and to establish target value in effluent discharging management, TQNPC requested in the Main Contract that AECL perform research work of radioactive source terms for CANDU-6 unit under normal operation condition to meet Chinese environment protection code and standard. AECL revised the radioactive source terms report for 8 times based on the comments by Chinese specialists to perfect the report. As shown in the preface of the report, AECL specialists stated that AECL was dependent on radioactive release measured value in the past. These measured values reflected the performance reached by the plant but not theoretical values. As consideration of the performance of CANDU-6 reactor plant in the past was taken into the source terms report on Qinshan Phase Ⅲ Project and some adjustments were made based on the design modification of Qinshan CANDU Nuclear Power Plant, the data provided by the source report may be used to anticipate the performance of the 2 units in the future.

4.5 Important Improvement of Construction Scheme

More than 10 construction design improvements were performed, new technique and new equipment were introduced and developed and successfully applied in the project practice during construction of Qinshan Phase Ⅲ Project, which made great contribution to the controls of quality, schedule and investment of the project.

4.5.1 Slipform construction technique of reactor containment perimeter wall

The advanced slipforming technique was adopted in the construction of reactor containment perimeter wall of Qinshan Phase Ⅲ Project, different from the formwork technique used previously in construction of containment perimeter wall of pressurized reactor. The formwork was continuously jacked hydraulically and the concrete pouring of containment perimeter wall was finished quickly and with high quality. This achievement has hit an all-time short-duration record (14 d and 4 h) in the history in terms of construction of similar nuclear power plant. The construction of containment perimeter wall was a success with concrete quality and wall uprightness meeting design requirement. Verified by containment integrated leakage rate test, the structural strength and airtight of containment perimeter wall of the 2 units met the design requirement, of which, the leakage rate of Unit #2 in airtight test, only 0.132 % reactor volume/day (the design indicator: 0.5 % reactor volume/day), was the least leakage in similar nuclear power plant worldwide.

4.5.2 Application of maritime multi-function movable work platform in water intake project

There are 4 intake ducts in pumping station's water intake and all are underwater reinforced concrete structures. As construction would be performed at estuary of Qiantang River, natural conditions were abominable, which would bring great difficulty to construction. After investigation, the construction scheme with maritime multi-function movable work platform was adopted. The maritime multi-function movable work platform is a new hydraulic self-elevated platform with a square frame and 4 legs. It has several functions such as underwater drill and explosion, underwater component installation, underwater concrete pouring and maritime orientation. It is suitable for bad environment of 5 m/s water velocity of flow and construction can be performed even at 26 m of water depth. The technical features of the maritime multi-function movable work platform had never been reported In China and it was used for the first time in nuclear power plant in China. The application of maritime multi-function movable work platform in construction of water intake project overcame various natural condition's deterring factors and ensured smooth completion and met the quality requirement of the project.

4.5.3 Installation of heavy equipment in R/B with top-open method

There are 18 main process equipments (above 30 ton/each in weight) in R/B in CANDU-6 reactor nuclear power plant, with a total weigh being 1 657 tons. If these equipments could not be put in place promptly, large space would be occupied in the congested R/B, hindering construction of other disciplines. After discussion between both parties, it was agreed to adopt "Open Top" lifting construction technique with available 800 T crane at the site, i.e. to directly lift the heavy equipments such as steam generator in place from the building top before closure of the top. This construction technique changed the conventional technique that movement and installation of main equipment in R/B would not start until closure of dome, made efficient use of interlapping period of civil construction and installation, shortened installation duration of main equipments and laid a good foundation for the project to be completed ahead of schedule. The "Open Top" lifting technique was used for the first time not only in construction of nuclear power plant in China but also in construction of CANDU-6 reactor nuclear clear power plant in the world.

4.5.4 Pipe prefabrication modularization

Pipe installation work takes large percentage in CANDU-6 heavy water reactor installation. Pipe installation progress and its quality directly affect construction period and engineering quality of the whole nuclear power project. Qinshan Phase Ⅲ pipe prefabrication process changed the production pattern where one group finishes all work procedures. Instead, each procedure is divided into several independent steps, which are performed separately by special groups. This type of plant flow process fully utilizes limited resources, shortens construction period, enhances production efficiency and facilitates smooth progress.

4.5.5 Seawater pump house earth and stone excavation and large cofferdam construction scheme improvement

Large cofferdam is a waterpower engineering structure designed by foreign contractor that is about 110 m × 6 m and top elevation +7.2 m. Its bottom crosses four seawater square ducts. Its function is to excavate and construct seawater pump house under non-water conditions. We reviewed the design and found if it is constructed according to original design it certainly will delay construction period of other buildings and will bring potential risk of site flooded by seawater. After discussion it was proposed to first construct a small cofferdam (2.5 m W, elevation +5.5 m) in the large cofferdam design position as a component of the large one, thus the construction under water is changed into dry construction, the original prefabricated pipe duct now is changed into concrete duct placed in site, which guarantees construction period and smoothes site excavation of other buildings and ensures construction safety. The scheme greatly advanced construction, saved more than 1.1miliion US $ in investment.

4.5.6 Outfall construction scheme improvement

Outfall is composed of inlet well and discharging duct. The discharging duct is 5.5 m × 5.5 m in external dimension with inner hole of 4.1 m × 4.1 m, and the pipe inside wall elevation is 77.3 m (equivalent to Yellow Sea elevation of −10.7 m). In foreign concept design, the discharging duct penetrates into sea 120 m, and the duct in deep sea is in silt that is more than 10 m deep. The scheme shortcoming is that it did not provide the method to guarantee the stability and reliability of the duct. Based on the experience in nuclear power station construction in the area, Chinese experts proposed to reduce the discharging duct to 15.6 m, cancel the section which penetrates into the sea to avoid construction in silt and to safely and reliably set the duct on rock base. The physical model test indicates the proposal is not only feasible but also beneficial. The improvement of this construction scheme shortened the construction period and saved the investment. The more important, it guarantees safety in duct use during station operation.

4.6 Design Modification to Improve Safety

TQNPC paid great attention to safety in contract negotiation, design review and safety review. Whenever safety issue is found not to meet the requirements in Chinese codes and standards, TQNPC insisted on AECL improvement to ensure station safety.

4.6.1 Improvement to add seismic requirements

Design seismic requirements for heating, cooling and air conditioning systems in secondary control area were added. Air conditioning unit, electric heating unit, all manual dampers, shutters and building roofs are designed seismically DBE class "A" to ensure habitability under event conditions.

The originally designed fire water U pipeline in reactor building is changed to O type, and additional inlet pipeline from fire water pool to reactor building was added besides the original fire water pipeline, so there are two inlet pipelines from water pool to R/B, which not only meet redundancy requirement in Chinese code but also meet seismic requirements.

TQNPC also proposed that the safe class local air cooler LAC 1-16 in containment should be directly fed by emergency power EPS, which ensures the system design safety requirements under various event conditions.

4.6.2 Design improvement of spent resin storage tank

In reference station, the spent resin storage tank was designed to have two concrete storage tanks coated with epoxy resin inside installed in auxiliary building as radioactive spent ion exchange resin storage time is as long as station service life. Considering the fact that epoxy resin will generate brittle fracture due to ageing in late days of its life, the radioactive water in the tank may penetrate into underground water through concrete wall, which in turn will result in environmental pollution, TQNPC proposed that epoxy resin coating should be changed into stainless steel to enhance tank safety and reliability, and add designs such as spent resin loose bubbling and spent resin transport pipe joint per Chinese environmental protection code. The improvement allows long time stored spent resin to become loose to facilitate its disposal when required. It is the first time for such improvement to be implemented in CANDU-6 unit.

4.6.3 Addition of redundant valves in emergency water supply system PV7 and PV41

Emergency water supply system is an important safety support system in station second group of safety systems, and PV7 and PV41 are two important valves that are constantly closed and only open with air loss. The original design did not meet redundancy requirements of single failure criteria. TQNPC requested AECL to change the separate PV7 and PV41 in emergency water supply system to a valve combination to satisfy design requirements of single failure criteria in Chinese code, so as to increase station prevention capacity against severe accidents and to more reliably guarantee safety functions in accident conditions.

4.6.4 Improvement of cable tray fire separation in safety system

In the original design, the distance between some cable tray of group 1 and group 2 safety support systems in reactor building was less than 6 m that did not conform to CAN/CSA – N293-M87 CANDU *Nuclear Power Plant Fire Fighting* which stipulates cable tray arrangement for two groups of safety support systems shall have at least 6 m distance of horizontal separation, or one group must be enclosed in fire barrier with 1 hour fire rating.

After comprehensive analysis and comparison, TQNPC added fire jacket on cable tray and sleeve, having the cable tray physically fire separated. After completion of construction, effective fire separation barrier between cables of group 1 and group 2 safety support systems was established, which satisfied fire requirements for CANDU nuclear power plant.

4.7 Improvement of Reliability and Maintainability of Seawater System

Seawater at the reference station contains little sand, while seawater in Hangzhou bay is cloudy and contains much sand. Sand erosion severely affects reliability of system equipment operation. Besides, seawater system and circulating cooling water system copies the design of reference plant i. e. some pumps and related pipes and valves are connected by cross around pipe which makes part of equipments unmaintainable. Considering importance of seawater system for station safety and economic operation, TQNPC organized its technical staffs in consistent technical improvements on seawater system.

4.7.1 Modification of gate board in seawater pump house

The gate board to separate seawater was designed by Bechtel. The original design was reinforced steel concrete structure. Due to its improper structure the gate board had severe leakage when it dropped and could not meet the system separation requirement. In addition, as it was difficult to drop and hoist, there existed hidden safety trouble.

TQNPC independently made modifications that a wholly welded steel gate board was utilized, on which six underwater oil jacks were installed, to compress rubbers to stop water in top and side. Automatic hook connection and disconnection device was used in gate board underwater installation and hoist and corresponding seawater corrosion proof measures were taken at the same time. The modified steel gate board has little leakage in air face. The weight of gate board is only 12 t that ensures safe lifting by 32 t monorail hoist and automatic hook connection and disconnection device reduces risk of underwater work. Operation indicates the new gate board is far superior in advance and practicability to original one thus guarantees system maintainability.

4.7.2 Physical separation of seawater pump house

The seawater pump house is shared by two units. Each unit has two condenser cooling water (CCW) pumps and four raw service water (RSW) pumps. Each reinforced steel concrete wall separates two units, and RSW pump houses and CCW pump houses for two units. However, these walls extend from pump house base floor to motor floor, and are lower than normal high tide level. When high tide comes, if any pump of the two units severely leaks, the whole pump house may be submerged by seawater, causing full stop of two units.

In view of unit safe operation, TQNPC independently made modifications that additional physical separation wall was installed between units #1 and #2 and between RSW and CCW systems of two units, and a three 3.2 m high concrete walls were constructed at the motor floor. The technical modification eradicated potential safety risk and guarantees station safe operation and equipment safety in seawater pump house.

4.7.3 Addition of RSW stand-by cooling system

RSW system is designed to supply cooling water for RCW system. Based on characteristics of heavy water reactor, RSW system is required to continuously run after reactor shutdown to remove reactor core decay heat. However, the original design did not take isolation maintenance of some equipment into consideration.

To improve system maintainability, TQNPC studied reference plant modification and decided to add RSW stand-by system by connecting CCW pump outlet header and RSW side of two RSW heat exchangers with a 24-inch pipe. When RSW system stops for maintenance, cooling water could be taken from CCW system so that the capability of removing residual heat is available after plant and RSW system shutdown. After completion of the modification, conditions for RSW system maintenance during unit overhaul is provided.

4.7.4 Technology improvement of RSW system second screen

RSW system is equipment cooling water and stand-by heat sink system and its reliability directly affects unit safe operation. Besides traveling screen, the system is equipped with second screen to remove impurity in seawater. The original second screen was chain driven with rotating scrapper. In the early days of plant operation, failures such as chain drop, leakage, screen blockage and axle-box wear frequently happened that reduced system reliability and greatly increased maintenance manpower and cost.

TQNPC independently modified the second screen that the chain driven screen is now directly driven by speed reduction gear box through external electrical driven facility, which directly avoids silt rotation device erosion and wear caused in seawater. The modified second screen never failed as above and its operation performance has greatly increased.

Operation experience proves that the above modification improved seawater system maintainability, put seawater system early failure under effective control and enhanced system reliability, thus guarantees safe and economic operation of the 2 units.

4.8 Addition of Reverse Osmosis in Water Treatment Plant

Base on characteristics of raw freshwater in Qinshan area that in fall or winter seawater reversely flows in water intake, which drastically increases salt concentration in raw water, the normal operation can hardly be maintained as water supply could last just several hours if water is treated only by ion exchange.

In view of this factor, TQNPC proposed in design period that reverse osmosis (RO) and superfine filter device should be added before ion exchanger in water treatment plant. Thanks to the technical improvement with RO operation, even during low water season production of ion exchanger exceeds 2 000 m^3, various needs for demineralized water during commissioning and trial operation were satisfied.

4.9 Technical Improvement of Reactor Physical Start-up

As common practice for CANDU reactor, commissioning test is divided into four stages: A, B, C and D. Reactor physical start-up and commissioning items mainly are concentrated in first criticality and low power physical test in stage B and in power ascension and thermal commissioning test in stage C. Tests in stage B take about 4 weeks, while tests in stage C take about 2 months. Therefore, there exist issues such as too long time test, inaccurate test data and repeated test.

Mainly depended on Chinese technicians, TQNPC independently made the following improvements: gadolinium was used instead of boron as additive poison in moderator; lifting regulating rod but not absorber rod was used when criticality reached; criticality estimate and extrapolation was improved; computer aid program was developed for criticality estimate; reactor start-up procedure under ionization chamber effective conditions was improved; reactivity measurement scheme for liquid zone control unit was improved through standard born package injection of instrument pipeline of moderator pump; channel flow verification technology was improved; correction calculation program was developed to improve zone superpower protection detector correction method; 6 computer data processing and analysis software programs for physical start-up and operation were developed.

The improvements increased accuracy for both test expectation and test data, avoided repeated tests, reduced commissioning time and enhanced safety of physical testing.

Thanks to the above technical improvements, not only the unit safety and reliability have been enhanced, but also Chinese staffs accelerated process of mastery of CANDU nuclear power technology, which laid solid foundation for independent operation.

5 Independent Operation and Management, and Consistent Improvement and Innovation

Whether production and independent operation and management would successfully follow construction completion is an important symbol that reflects we have digested and absorbed heavy reactor nuclear power technology. From the beginning of contract negotiation, TQNPC attached great importance to this issue and established high standard in the main contract that after unit commissioning is completed and is operated at full power for 100 h the unit will be handed over to Chinese party for independent management and operation. Since project construction started, TQNPC has begun preparations for independent operation. Comprehensive monitoring and control were implemented during construction period and the employees got familiar with systems and equipment characteristics through commissioning. Meanwhile the organization structure was established and perfected. A scientific documentation system was also established to guide various production activities. All these guarantee independent operation and independent overhaul. During independent operation management, not only the unit performance was improved, but also TQNPC culture characterized by nuclear power was evolved, which contributed to good performance in safe production and operation management.

5.1 Smooth Transition from Commissioning to Production

Per Chinese nuclear safety code and guideline and IAEA requirements for project management, TQNPC carried out production preparation based on project actuality. According to principle of vertical management and authorization at different levels, the company organization structure was established and adjusted appropriately at different stage of nuclear power station to guarantee successful production preparation, commissioning and operation management. Project construction and production preparation went ahead in parallel, which guaranteed construction successful progress.

It is very important to have employees with high quality to promote progress of various works. During project construction, TQNPC transferred technical staffs with experience in pressurized water reactor operation management and nearly 300 university and college graduates recruited in 1997 and 1998 for production preparation training. Technical staffs received training on foreign language, nuclear power basic knowledge, CANDU-6 station systems and equipment element. Some technical staffs went abroad to participate in commissioning training at reference plant and participated in training at foreign CANDU-6 unit. Completing training, they rapidly absorbed, digested and gradually mastered CANDU-6 heavy water reactor nuclear power technology through activities such as design review, equipment manufacture supervision, project quality supervision, commissioning and trial operation, and formed a strong force, which laid a solid foundation for smooth transition from commissioning to production.

To achieve station independent and safe operation, TQNPC attaches great importance to the plant management and gradually enhanced management level from implementation enhancement to management standardization, from management standardization to management refinement. A set of comprehensive and scientific documentation system is built up to guide various production activities and make work conducted in accordance with procedures, standardization and systemization.

TQNPC documentation system mainly is composed of production procedure and technical procedure. Production procedure is divided into four classes and 18 categories. Class 0 - national code, standard and nuclear safety guideline; class 1 – plant operation quality assurance program and final safety analysis report; class 2 – plant policy and instruction; class 3 – implementation procedure, interface procedure and departmental procedure. According to work type, 18 categories respectively are administration management, security and fire prevention, training, quality assurance, operation, chemistry, nuclear safety, document and archives, design management, fuel management, maintenance, purchase management, production, technology and information, emergency, industrial safety, radiation protection. Per project schedule requirements, all management procedures were prepared, checked and reviewed between October 1999 and May 2003 to guarantee production requirements and standardize plant procedure-oriented operation mode. Technical procedure covers commissioning procedure, operation procedure and maintenance procedure, which specify plant equipment, system operation, test and inspection and address of various abnormalities.

In production preparation, TQNPC always set prompt mastery of CANDU technology and early realization of independent operation management as a goal. Correct implementation of the measures made the plant a successful commissioning, turnover after 100 h operation at full power and independent operation management, realizing smooth transition from commissioning to production.

5.2 Capability to Independently Carry out Overhaul

Early from the project start, TQNPC set independent overhaul as its target. To realize this target, Overhaul Preparation Program was worked out and maintenance system was established during production preparation, specifying guidelines that "TQNPC is independently responsible for maintenance management, maintenance technology preparation and control for mechanical, electrical and instrument control specialty, routine maintenance plan and coordination; for quality control of maintenance implementation; fully responsible for maintenance of instrument control system and relay protection; fully responsible for maintenance of refueling system; responsible for maintenance of key electrical and mechanical equipment; and maintenance of common electrical and mechanical equipment are sent out for maintenance".

According to requirements in Overhaul Preparation Program and taking experience of domestic and foreign nuclear power stations, TQNPC gradually established maintenance management system and procedure as planned, and consolidated and enhanced theoretical level of maintenance staffs through maintenance document preparation. With help of self- developed maintenance management software such as work management system and work permit system, the maintenance workflow was further standardized thus effectively controls maintenance work process.

Commissioning and maintenance practice tempered maintenance staffs and strengthened their confidence. When trial operation came, TQNPC can independently undertake maintenance work for almost all important and key equipments as instrument and control equipment, main pump mechanical sealing, charging pump mechanical sealing and fueling machine.

Soon after unit provisional acceptance, TQNPC started to prepare for first overhaul. Work was conducted according to overhaul plan, and time feedback from site prompted plan network control. All these helped overhaul completed on schedule. Thanks to effective overhaul organization and management, four unit overhauls succeeded. After overhaul, the unit performance increased year by year, which proves that it is correct for TQNPC to set independent overhaul as target at the project start and to repeat practice until capacity to independently carry out overhaul is obtained.

5.3 Good Practice Worth Spreading to International Peers

During trial operation after the stable transition from commissioning to running, TQNPC timely and appropriately adjusted organization structure, department responsibility and management procedures to adapt them to requirements for operation stage. Meanwhile, TQNPC established a five year plan for enterprise development taking world advanced nuclear power station as the goal, took a series of measures in nuclear safety culture, staff awareness and personnel behavior to upgrade personnel performance and operation management level.

In March 2005 IAEA dispatched experts to Qinshan for a 17 day-operation safety review. OSART group commented so: "The station has a strong superincumbent safety culture, as TQNPC has a group of young experienced staff who underwent orientation period; management and staff are open minded, they were active in coordination with experts during review; the counterparts were frank and open, they looked for deficiencies and good practice together with us." The experts choose 11 good practices in TQNPC and recommended them to the peers in the world. For example:

(1) Establish and improve Human Performance Improvement Plan for shift crews

To ensure the units for safe and stable operation and give full play to operation duty activity, the performance indicators for operation duty are objectified. The indicators cover 16 items such as periodic test and switchover, work request, work permit, equipment safety measures, routine work quality nonconformance, work error transparency, team cooperation satisfaction degree. Quantitive assessment is applied for operation work so that work volume and performance of each shift is comparable. Assessment items are adjusted and optimized based on unit operation, staff experience and level increase. WANO Tokyo Center considered the operation shift performance indicators assessment as good practice for nuclear power plant operation management and recommended it to world nuclear power industry.

(2) Human Performance Enhancement Plan has been push to perform

To stress and reinforce correct behavior and timely propose and execute the personnel performance upgrade plan so as to reduce human errors. In the plan an operator work is divided into five main aspects, each duty each round at least 2 tasks are selected by the field duty supervisor for tracking the whole process and finding defects therefrom; he sums up them when the tasks are completed. Thus not only the site operator 's behavior is improved but also the supervisor technical ability and management capability can be enhanced.

TQNPC makes full use of the opportunity to organize exchange between its staff and experts with rich operation experience so that they could learn good practice in international nuclear power industry to widen visual field and find gap, which can greatly promote their work.

5.4 Consistent Technical Improvement and Continuous Enhancement of Operation Performances

Facing design and equipment problems in the commissioning and operation period, according to the Chinese nuclear safety laws and codes, national and industry technical standards, based on further enhancement of operation safety and reliability, TQNPC has made technical modifications on equipment, system and structure which consistently has increased unit operation performance. Patent application for four technologies were accepted by SIPO of PRC, now the approval is pending.

5.4.1 Addition of shutdown system data acquisition function (patent pending)

The reactor is equipped with two sets of independent shutdown systems that work on different principles. The original designs of systems have no data acquisition function which cause difficulties in analyzing and identifying failure causes in abnormal events. On the other hand, the panels in the main control room display some parameters but with bigger errors.

In view of these issues TQNPC added a set of independent parameter monitoring system for each shutdown system which collects parameters of shutdown systems at high speed facilitating operators to monitor. The parameter monitoring systems of these two shutdown systems do not interfere with each other and they can perform self- diagnosis and alarm. Based on analog indicators for monitoring parameter, high precision digital display was added along with shutdown parameter margin alarm function.

After putting into service the parameter acquisition system provides operator with more accurate parameter display, improves plant status monitoring capacity and transient analysis capacity for plant status and enhances plant safety and economic benefits. It is an initiative improvement in the heavy water nuclear power stations.

5.4.2 Improvement of damaged fuel bundle inspection and positioning method (patent pending)

The damaged fuel bundle positioning system identifies fuel channel where a damaged fuel bundle locates by measuring delayed neutron number generated by decayed fission product ^{137}I and ^{87}Br in coolant. The previous methods could only find that a damaged fuel bundle exists in the discharge channel fuel bundle cluster (4 ~ 8 bundles) but could not identify its accurate position so that it is easy to lead to misjudgment.

TQNPC made the following modification: position the channel position where damaged fuel bundle is located based on the historical trend of fuel channel delayed neutron counting, then position the damaged fuel bundle through gamma dose change in discharge pool room. In the newly developed damaged fuel discharge process, every time when fuel/changing gear discharges a pair of fuel bundles, it is able to firstly restrict the damaged fuel bundle to a pair of fuel bundles by means of the above-said method and then find the damaged one out of this pair of doubtful fuel bundles, thus positioning the single damaged one.

The improved positioning method has increased the positioning capability so that now it can be used to accurately identify the single damaged fuel bundle which effectively prevents misjudgment.

5.4.3 Isolating system with ice plug (patent pending)

In the heavy water reactor process system there is such a case for safety or economic reason that it is necessary to isolate a system but the related parts of system could not be isolated, e.g., as the reactor is full of fuel bundles the main heat transmission system has to be filled with water any time and can not be isolated. In this case isolating a system with ice plug is an effective method.

From 2001 on TQNPC started to develop ice plug technology, and make practice and application, now it has the capability to fabricate ice plugs on 1/4 ~ 6 in (1 in = 25.4 mm) pipes. So far TQNPC has applied ice plugs for about 200 times, developed tens kinds of ice plug fixtures for different use facilitating plant maintenance work.

5.4.4 Development and application of corrosion inhibitor for cooling water system (patent pending)

The conventional island of each unit has 14 cooling water systems. For chemical control of the systems the designer merely specified pH values and did not provide the description of corrosion inhibitor and its concentration range for us. There is limited experience in this field in nuclear power industry at home and abroad. In 2002, TQNPC developed molybdenum compound corrosion inhibitor suitable for the above cooling water system. Operation practice shows that the corrosion inhibitor greatly reduces cooling water system corrosion rate and total iron and suspended matters maintain at low level, it has good corrosion inhibiting effect and anti corrosion function even at higher temperature. Take demineralized water, for example, at 85 ℃ after the inhibitor is put into A106 carbon steel corrosion rate is just 0.001 4 mm/a, corrosion inhibiting rate reaches 99.58 % much lower than 0.125 mm/a in Chinese standard.

5.4.5 Research and modification for increasing overall rated capacity

The turbine for Qhinshan phase Ⅲ is Hitachi TC4F-52, single shaft three cylinders, four-ended reheat condensing impulse turbine, and the guaranteed rated capacity of unit is 728 MWe.

At provisional acceptance the rated capacity of unit did not reach the design-guaranteed value (about 1 % lower) due to Hitachi's reasons. The two parties handled it per the contract provisions. From 2002 to 2005 Hitachi spent more than 10 million US $ on modification but the power of unit has not been increased noticeably yet, finally Hitachi gave up further efforts. In September 2005 Qhinshan phase Ⅲ heavy water reactor nuclear power station passed the national completion acceptance, the rated capacity of unit was determined as 720 MWe due to the above reasons.

In early 2006, TQNPC established a key problems tackling group mobilizing Chinese technical resource to handle them in combination of analyzed and tested station thermal data, found main factors affecting the rated capacity of unit, worked out modification scheme and reconstructed #2 unit during the second overhaul #2 unit as follows: optimized MSR second stage reheating steam flow which increased the rated capacity of unit by 2. 8 MWe; regulating valve was added on bleeder heater air pipeline which increased the rated capacity of unit by 0. 8 MWe; drain pipeline modification increased the rated capacity of unit by 0. 6 MWe; air leakage at turbine LP diaphragm increased the rated capacity of unit by 1. 2 MWe. Performance test indicated the rated capacity of # 2 unit reached 728. 01 MWe.

Besides the above improvements, in view of unreasonable design of power systems and improper selection of equipment, the power systems were modified and optimized, radiation protection system was modified, safety and reliability of ventilation and refrigerating system were enhanced, system configuration was optimized.

5.4.6 Cobalt-60 isotope production research

Due to the core structure of CANDU heavy water reactor and reactor physical features during operation the regulating rods are inserted into the core, after the stainless steel regulating rods are replaced with ^{59}Co regulating rods, ^{59}Co in core strong neutron field in the receives radiation, captures a neutron and transforms into cobalt-60. Therefore, CANDU heavy water reactor has advantageous conditions of producing cobalt-60 radiation source, and will not basically affect normal generation and safe and stable operation.

TQNPC and Shanghai Nuclear Engineering Research & Design Institute (SNERDI) have started design and safe analysis of replacement of stainless steel regulating rods with ^{59}Co regulating rods in reactor and receipt of radiation and transforming to cobalt-60, they have made corresponding modifications on reactor. Other works such as manufacture technology for target and handling facilities in spent fuel pit is in preparation.

TQNPC plans to replace cobalt regulating rod assembly each cycle (18 months) which can complete during planned overhaul period without affecting generation time. Two reactors are expected to produce industrial cobalt of 6 milion Ci each year. After putting into service they will change the present status that China mainly depends on import of cobalt-60, and bring great economic and social benefits.

5.4.7 Independent spent fuel dry storage research

According to the design, each unit is equipped with a spent fuel storage pit with storage capacity of 10 years. The pit needs an area for handling equipment and transport road, thus its actual storage volume can't withstand 8-year use.

Through researches, it is found that site spent fuel dry intermediate storage is a common method for heavy water nuclear power stations in the world. Presently there are three technologies for CANDU reactor spent fuel dry storage: dry concrete storage container (DSC) by Ontario Electrical Company, concrete silo by AECL and MACSTOR module.

In 2004 TQNPC started this project and entrusted SNERDI with analysis and research of technical scheme, siting and feasibility for spent fuel temporary storage facility. After much discussion with experts TQNPC intends to adapt MACSTOR-4 scheme. Compared with other methods the scheme has better shield and thermal diffusion capability, good leak tightness, less occupation space and less cost. Recently completed or will be constructed CANDU reactor spent fuel dry storage facilities such as ones in Cernavoda (Romania) and Wolsong (South Korea) applied the technology for spent fuel dry storage.

Progress for TQNPC spent fuel dry storage project is going ahead smoothly. Now the feasibility report has been worked out and submitted to NNSA for construction application and the earth excavation for storage site started.

With consistent technical improvements TQNPC has got one fruit after another. Through Qinshan Phase Ⅲ construction, especially commissioning, independent operation and maintenance, we have basically mastered CANDU technology. In future operation, we will continue to push forward technical improvements to enhance unit indicators. TQNPC will make every effort to stride forward for entering advanced rank in world nuclear power industry.

6 Conclusions

During project construction of Qinshan Phase Ⅲ we have improved Sino-foreign cooperation pattern, consistently enhanced capability to independently construct nuclear power station. We have adhered to independent principle and owner's monitoring and control right over project; rapidly absorbed and mastered international advanced experience and technology on nuclear power based on Chinese nuclear power engineering experience; effectively exercised control over engineering quality, progress and investment through management innovation, and conducted engineering management according to international practice; digested and absorbed CANDU-6 technology, applied advanced and ripen technology, made technical improvements, further enhanced unit safety and reliability, achieved outstanding effects.

Based on existing management experience on nuclear power engineering project management, taking advantage of opportunity of cooperation with large foreign companies we have changed management concept and innovatory management means and method, successfully established management system on effective control over engineering based on international convention, and enhanced management level. Through Sino-Canadian cooperation, CNNC has set up a comprehensive set of systems from contract negotiation, construction, commissioning, operation to fuel manufacturing, fostered a group of international nuclear power engineering construction and management personnel, accelerated the growth of production operators. More importantly, it has fostered many professionals who act on international convention, mastered nuclear power technology and have the capacity of managing project who have became backbone force in Chinese nuclear power construction, thus CNNC has provided valuable experience for new nuclear power projects.

Successful construction of Qinshan Phase Ⅲ engineering has accumulated valuable experience for Chinese nuclear power construction and management of introduced project, Chinese party and state leaders fully affirmed the success. In 2005, the President of China Hu Jin-tao praised "the great success TQNPC achieved through Sino-Canadian joint construction is a successful model in cooperation between Chinese and Canadian enterprises." Canadian opinion commented that Qinshan Phase Ⅲ engineering is realized mainly by Chinese, is a successful story for Chinese. Qinshan Phase Ⅲ engineering success explored management pattern of china and foreign countries joint construction of on nuclear power station, thanks to that Chinese nuclear power project management level rose greatly. Qinshan Phase Ⅲ project is a successful model in peaceful use of nuclear energy for China and Canada which witnessed cooperation and friendship between Chinese and Canadian people.

After the units putting into commercial operation based on experience summarization TQNPC continues to make technical optimization and improvements to consistently enhance unit operation performance, to create greater economic and social benefits. Operation performances are outstanding after the units putting into service. From station completion to December 2006, the station has be operated safely for 3 years in succession and brought profit in 3 years. Accumulated generation reached 4 000 MW·h equivalent to 1.36 million T of coal which greatly reduced environment pressure and brought noticeable economic, social and environmental benefits.

(cont. on p. 134)