Present Situation and Mid- to Long-Term Outlook of Nuclear Power Development in China

Li Zhidong
Senior Researcher, Energy Data and Modeling Group, Energy Data and Modeling Center
Associate Professor, Department of Management and Information Systems Science, Nagaoka University of Technology

1. Issues and Purpose of the Study

Nuclear power development in China has attracted international attention. As nuclear power development in the world has been stagnant, international capital in the nuclear power field, mainly in developed countries, expects China to be the largest market in the 21st century as well as the place of next-generation reactor development and experimentation. On the other hand, there are concerns that such a rapid introduction of nuclear power relying on imported technologies, as in the past 20 years, may involve problems in such as security, cost competitiveness, and loss of job opportunities and cause a delay in the domestic development of nuclear power technologies, leading to a delay in nuclear power development in China. There are also a number of doubts such as why China pursues nuclear power generation despite its inability in domestic production and safety problems associated with waste disposal, although the country has great potential in terms of energy conservation as well as the development of renewable energy such as hydropower and wind power. China has thus been the focus of mixed attention with expectations, concerns, and doubts.

The purpose of this paper is to identify the current state of nuclear power development in China and provide the mid- to long-term outlook. In Section 2, the history of the nuclear industry is outlined and the present status of nuclear power development is analyzed. In Section 3, the mid- to long-term outlook of nuclear power development is provided based on various plans and predictions. Finally, in Section 4, the merits, demerits, and challenges of nuclear power development are examined.

2. Current State of Nuclear Power Development

Nuclear industry in China has a relatively long history of more than 50 years. As shown in Table 2-1, the China Institute of Nuclear Science was organized immediately after the establishment of the People's Republic of China in 1949. China concluded a Nuclear Cooperation Agreement with the former Soviet Union in 1955 and established a government agency in charge of nuclear power in 1956. Following the occurrence of antagonism between China and the Soviet Union, independent nuclear power development for military purposes started in 1960. China succeeded in testing an atomic bomb on October 16, 1964, a hydrogen bomb on June 17, 1967, and its first nuclear submarine was seen in September 1971.

Table 2-1. A Brief Chronology of China's Nuclear Power

Year	Changes in Major Nuclear Power Organizations and Status of Development in China
1949	People's Republic of China is founded (October 1). Chinese Academy of Science is established.
1950	Research Institute of Modern Physics is established in the Chinese Academy of Science.
1955	The Central Communist Party decides to develop a nuclear power industry (January 15). Sino-Soviet Nuclear Cooperation Agreement is signed (April).
1956	Ministry of Machine-Building Industry III is established as the competent authority for the nuclear industry (November).
1957	Research Institute of Modern Physics is reorganized into the China Institute of Nuclear Science (May).
1958	Ministry of Machine-Building Industry III is reorganized into the Ministry of Machine-Building Industry II (February). A 7-MW heavy-water reactor for research is constructed with the assistance of the Soviet Union.
1959	The Soviet Union unilaterally annuls the Nuclear Cooperation Agreement following antagonism between China and the Soviet Union.
1960	Soviet experts return from China, and China starts independent nuclear development mainly for military purposes.
1962	Uranium production starts in Hengyang, Hunan Province.
1963	Manufacturing of enriched uranium using the gaseous diffusion process starts in Lanzhou, Gansu Province.
1964	China succeeds in its first nuclear test (October 16).
1967	China succeeds in its first H-bomb test (June 17).
1971	China succeeds in its first nuclear submarine operation (September).
1972	Shanghai Nuclear Engineering Research and Design Institute is established for the development of nuclear reactors for peaceful use.
1973	Design of nuclear reactor for the Qinshan Nuclear Plant is started.
	Southwest Reactor Engineering Research and Design Center (present Nuclear Power Institute of China) and Southwest Physics Institute are established.
1982	Ministry of Machine-Building Industry II is reorganized into the Ministry of Nuclear Industry (May 4).
1984	National Nuclear Safety Administration (NNSA) is established in the State Science and Technology Commission as the competent authority for commercial nuclear safety (October).
1985	Construction of the Qinshan Nuclear Plant (300 MW), the first nuclear power plant in China, is started with an original design (March).
1987	Construction of the Daya Bay Nuclear Power Plant Unit 1, the second nuclear power plant in China, is started with equipment imported from France (August).
	The fast breeder reactor development project is incorporated in the Advanced Science and Technology Development Plan (Plan 863) of the State Science and Technology Commission (SSTC).
1988	The Ministry of Nuclear Industry is dissolved. The former China National Nuclear Corporation (former CNNC) is established as a state enterprise having administrative functions (September 15).
	China Institute of Nuclear Science starts the research and design of a fast breeder reactor (tank type; thermal output: 65MW; electrical output: 20MW).
1992	The State Council approves an experimental reactor project for a high temperature gas-cooled reactor (HTGR)
1993	Construction of the first 300 MW plant to be exported by China, to Pakistan, is started (August 1).
1994	China Atomic Energy Authority (CAEA) is established in the Commission of Science, Technology, and Industry for National Defense as the external relations organ of the Chinese government (January).
1995	Institute of Nuclear Energy Technology of Tsinghua University starts the construction of an experimental 10-MW high temperature gas-cooled reactor (HTGR, modular type).
1996	Construction of Unit 1 of the Qinshan Nuclear Power plant II, which introduces a 600-MW class PWR mostly developed by China, is started (June).
1998	National Nuclear Safety Administration is transferred from the State Science and Technology Commission to the State Environmental Protection Administration (March).
1999	Former China National Nuclear Corporation (former CNNC) is reorganized into China National Nuclear Corporation.
	China Atomic Energy Authority is reinforced as the competent authority for the peaceful use of nuclear power.
	China National Nuclear Corporation proposes its proprietary advanced PWR (1,000-MW class, CNP-1000) to the government and utilities as a standard model for domestic production
2000	The experimental high temperature gas-cooled reactor construction is completed and it reaches initial criticality (December).
2002	Civil engineering work for the experimental fast breeder reactor is completed (August 15). (It is planned to reach criticality and the rated output in 2005 and start commercial operation around 2030.)
2003	The high temperature gas-cooled experimental reactor is connected to the grid for the first time (January 7) and achieves the rated output (March 1).

(Source) Prepared by Li Zhidong based on relevant websites of Energy-china.com, China Nuclear Industry News, CNNC Website, etc..

Following the success in development for military purposes, China established the Shanghai Nuclear Engineering Research and Design Institute and launched the design of a reactor for power generation, the Qinshan Nuclear Plant (300 MW, pressurized water reactor (PWR)), in 1972. Ten years later, in 1982, the construction of the Qinshan Nuclear Plant was incorporated in the "Sixth Five-Year Economic and Social Development Plan (1981 – 1985)", which was the first five-year plan developed after the introduction of the "reform and opening-up" policy. The construction of the plant started in March 1985, and the plant started test operation in December 1991 and entered commercial operation in May 1994. China became the 30th country in the world to start nuclear power generation. This marked the end of the China's history of "being nuclear but not having nuclear power generation" and the start of the nuclear industry in its energy sector.

As shown in Table 2-2, with the construction of the Qinshan Nuclear Plant as a start, the Chinese government promoted nuclear power generation with a policy of "constructing nuclear power plants through concentrated and phased efforts" under the Seventh Five-Year Plan (1986 - 90), "constructing large- and middle-sized nuclear and other power plants according to schedule but placing priority on the construction of Qinshan II" under the Eighth Five-Year Plan (1991 - 95) and the Ten-Year Plan, "achieving remarkable progress in the commercialization of high technology, including nuclear power, and developing nuclear power generation moderately" under the Ninth Five-Year Plan (1996 - 2000) and the 2010 Plan, and "developing nuclear power generation moderately" under the Tenth Five-Year Plan. As a result shown in Table 2-3, the total nuclear power generating capacity as of the end of April 2003 was 8,700 MW with 11 units, including 5,400 MW with the 7 units that were in operation and 3,300 MW with the 4 units that were under construction. Table 2-4 shows the share of the nuclear power in the electricity power industry at 1.2% in terms of capacity and at 1.5% in terms of electricity generation as of the end of 2002.

In the field of technology development, China has placed its focus on PWR, which is the thermal neutron reactor technology that has been the mainstream in the world, and has realized the domestic production and export of 300-MW class reactors through the construction of Qinshan I, and then has almost fulfilled the domestic production of 600-MW class reactors through the construction of Qinshan II. Progress has been made in the domestic production of 1000-MW class reactors. In 1999, the largest nuclear power corporation in China, China National Nuclear Corporation (CNNC), proposed its proprietary advanced PWR (CNP-1000) to the government and utilities as a standard model for domestic production (Li Dingfan, 2000). Beside the domestic production of PWR, efforts have also been made in the development of a high temperature gas-cooled reactor. The State Council permitted an experimental reactor (10MW, modular type) project in 1992, and the construction started in 1995. After reaching criticality for the first time in December 2000, it was connected to the grid in January 2003 and achieved its rated power in March (Xinhuanet, March 3, 2003). Furthermore, development of a fast breeder reactor as a next-generation reactor was incorporated in the Advanced Science and Technology Development Plan of the State Science and Technology Commission (SSTC) in 1987. The research and engineering was started in the following year, and the civil engineering work for the experimental reactor was completed in August 2002 (tank type; thermal output: 65 MW; electrical output: 20 MW). It is planned that the initial criticality will be reached in 2005 and commercial operation will start in 2030 (China News Service, August 16, 2002, etc.).

Table 2-2. Government Plans, Achievements, and Literature Relating to Nuclear Power in China

Name of plan	Summary of the plan	Achievements, literature relating to the plan
Sixth Five-Year Plan (1981-1985)	Construct a 300-MW nuclear power plant.	Construction of Qinshan I started in March 1985.
Seventh Five-Year Plan (1986-1990)	Construct nuclear power plants through concentrated and phased efforts.	Construction of Daya Bay Unit 1 and 2 started in August 1987 and April 1988, respectively.
Eighth Five-Year Plan (1991-1995) and Ten-Year Plan (1991-2000)	Construct, expand, and re-equip large- and middle-sized nuclear plants (hydropower, thermal, and nuclear power) according to schedule.	No numerical targets. Deng Xiaoping's Discourse (1990): "We still should pursue the development of nuclear power."
	Place priority on the construction of Qinshan Power Plant II.	No new construction started.
Ninth Five-Year Plan (1996-2000) and Essentials of Long-Term Targets for 2010	Achieve a remarkable progress in the commercialization of high technology, including nuclear power.	No numerical targets.
	Develop nuclear power moderately.	Construction of 8 units (6,600 MW) at 4 sites started.
Tenth Five-Year Plan (2001-2005)	Develop nuclear power moderately.	No numerical targets.
Priority Energy Development Programs under the Tenth Five-Year Plan (Former State Development and Planning Commission)	Develop nuclear power generation moderately for early fulfillment of domestic production. Utilize the existing design, manufacturing, construction, and operation capabilities to the maximum; cooperate with foreign countries under the leadership of China; set a target of achieving competitive generating cost; and achieve domestic production of nuclear power generation equipment. In addition, actively support the development of new advanced reactors that are unique to China and lay the foundation for nuclear power development during the period of the Eleventh Five-Year Plan and after.	Views in the Research Report by the Planning Department of the Former State Development and Planning Commission (Zhu Baozhi, et al., 1999): Promote the development of nuclear power plants mainly in the southeastern coastal area and focus on the domestic production of equipment. Complete the ongoing construction projects successfully. Carry out preliminary preparations for the construction of nuclear power plants in Sanmen in Zhejiang Province, the plant III in Guangdong Province, Fujian Province, and Shandong Province in accordance with the domestic production policy based on independent design, independent manufacturing, independent construction, and independent operation.
	In addition to completing the ongoing nuclear power plant construction projects, start the construction of nuclear power plants with domestically produced equipment at an appropriate time during the period of the Tenth Five-Year Plan.	
Tenth Five-Year Plan for the Power Industry (former State Economic and Trade Commission)	Develop nuclear power moderately.	Views of Zhou Xiaoqian (2000) of the State Power Corporation of China: It is necessary to speed up the construction of nuclear power plants. The critical factor is domestic production. Targets for the total generating capacity are 20,000 MW in 2010 and 40,000 - 50,000 MW in 2020.
	Develop nuclear power plants moderately as a means of electric power development. Gradually start construction projects to drive domestic production of nuclear power generation equipment, and achieve the goals of domestic production based on independent design, independent manufacturing, independent construction, and independent operation step by step.	
Essentials of the Tenth Five-Year Development Plan for Peaceful Use of Nuclear Energy in China (China Atomic Energy Authority)	As the development of nuclear power is a driving force for the peaceful use of nuclear energy, moderate development of nuclear power is important to maintain research and development and production capacity in the nuclear industry, improve the energy structure, and develop relevant industries. Development of nuclear power and early fulfillment of domestic production will have a significant impact on the securing of scientific researchers in the nuclear power industry, improvement in the scientific and technological capacity, and favorable cyclic growth of the nuclear power industry, as well as on China's status as a great nuclear power.	Views of Li Dingfan (2000) of China National Nuclear Corporation (CNNC): (1) CNNC, as a huge military engineering corporation, establishes a policy of "integrating the military and civil technologies, developing nuclear power generation, adjusting the structure, emphasizing the efficiency and profitability, enhancing the management, and promoting the nuclear power industry through scientific and technological development" and promotes further development of the nuclear power industry in the 21st century. (2) CNNC proposes its proprietary advanced PWR (1,000-MW class, CNP-1000) to the government and utilities as a standard model for domestic production. The features of the reactors are: design life: 60 years; refueling cycle: 18 months; capacity utilization ratio: 87%; unit construction cost per kW: $1,500 or less; unit transmission cost per kWh: $0.05 or less; domestic production ratio: 75% or more; and probability of meltdown: 1:100,000 or less. (3) Start the construction of six to eight 1,000-MW class reactors by 2005. Increase the total generating capacity in 2020 to 40,000 MW by introducing an a
	The priority goals in the Tenth Five-Year Plan are: to unify the reactor type, develop and construct 1,000-MW class PWRs (pressurized water reactors); and to fulfill domestic production and standardization of 1,000-MW class nuclear power equipment. More specific goals are: (1) to introduce a system of development by "cooperating with foreign countries under the leadership of China" starting from the initial project and gradually moving towards independent design; and (2) to achieve a domestic production rate of 55% or more for the first two 1,000-MW class reactors and 70% for the third and fourth reactors.	
	Scale of development under the Tenth Five-Year Plan: Start new construction of 6,000-MW projects to the extent possible and increase the total nuclear power generating capacity to 15,000 MW by 2010.	
	Satisfy the location principle of "multiple units per site" and utilize existing nuclear power generation sites as much as possible. It is proposed to start projects in Guangdong Province, Zhejiang Province, and Shandong Province, respectively, and to introduce two 1,000 MW units in each of the projects.	

Sources: Prepared by Li Zhidong based on the following:

1. Five-Year Economic and Social Development Plans approved in National People's Congress meetings and relevant long-term plans.
2. Former State Development and Planning Commission "Priority Energy Development Programs under the Tenth Five-Year Plan"
3. Former State Economic and Trade Commission "Tenth Five-Year Plan for the Power Industry"
4. China Atomic Energy Authority "Essentials of the Tenth Five-Year Development Plan for Peaceful Use of Nuclear Energy in China"
5. Deng Xiaoping(1990) "Take the Opportunity to Solve Development Problems," The Analects of Deng Xiaoping, Vol. 3
6. Zhu Baozhi, et al. (1999) "Research on the Energy and Transport Development Projects and Production Distribution under the Tenth Five-Year Plan in China"
7. Zhou Xiaoqian (2000) "Future Development of the Power Industry in China"
8. Li Dingfan (2000) "Development of Nuclear Power Industry and Enhancement of National Power for People's Prosperity"

Table 2-3. Status of Nuclear Power Plants That Are in Operation or under Construction in China (As of the end of April 2003)

Name	Location	Unit No.	Output (10 MW)	Reactor type	Procured from	Start of construction	Commercial operation	Remarks
Daya Bay	Guangdong Province	Unit 1	90	PWR	France	Aug-87	Feb-94	In operation
		Unit 2	90	PWR	France	Apr-88	May-94	In operation
Qinshan I	Zhejiang Province	Unit 1	30	PWR	Domestic production	Mar-85	Apr-94	In operation
Qinshan II	Zhejiang Province	Unit 1	60	PWR	Domestic production	Jun-96	Apr-02	In operation
		Unit 2	60	PWR	Domestic production	Apr-97	2003 (planned)	Under construction
Qinshan III	Zhejiang Province	Unit 1	70	CANDU	Canada	Jun-98	Dec-02	In operation
		Unit 2	70	CANDU	Canada	Jun-98	November 2003 (	Under construction
Ling-ao (I)	Guangdong Province	Unit 1	100	PWR	France	May-97	May-02	In operation
		Unit 2	100	PWR	France	May-97	Jan-03	In operation
Tianwan (Lianyungang) (I)	Jiangsu Province	Unit 1	100	VVER	Russia	Oct-99	2004 (planned)	Under construction
		Unit 2	100	VVER	Russia	Sep-00	2005 (planned)	Under construction
Total	4 provinces	11 units	870	Mainly PWR	Mainly overseas			
Including: In operation		7 units	540					
Under construction		4 units	330					
Including: Domestic production		3 units	150					
Imported		8 units	520					

Note: PWR means pressurized water reactor.
VVER (Vodo-Vodyanoi Energetichesky Reaktor) = WWER (Water-Water Power Reactor) is a Russian-type pressurized water reactor.
CANDU (CANadian Deuterium Uranium) is the pressurized heavy water reactor developed in Canada.
Sources: Prepared based on Energy-china.com, People's Daily, Economic Daily, China Nuclear Industry News, ATOMICA, etc.

Table 2-4. Position of Nuclear Power in the Power Industry in China

	Generating capacity			Generated electricity		
	Total (GW)	Nuclear power (GW)	Share (%)	Total (TWh)	Nuclear power (TWh)	Share (%)
1990	137.9	0.0	0.0	621.3	0.0	0.0
1991	151.5	0.0	0.0	677.5	0.0	0.0
1992	166.5	0.0	0.0	754.2	0.0	0.0
1993	182.9	0.0	0.0	836.4	0.0	0.0
1994	199.9	2.1	1.1	927.9	14.0	1.5
1995	217.2	2.1	1.0	1,006.9	12.8	1.3
1996	236.5	2.1	0.9	1,079.4	14.3	1.3
1997	254.2	2.1	0.8	1,134.2	14.4	1.3
1998	277.3	2.1	0.8	1,157.7	14.1	1.2
1999	298.8	2.1	0.7	1,233.1	14.8	1.2
2000	319.3	2.1	0.7	1,368.5	16.7	1.2
2001	338.0	2.1	0.6	1,478.0	17.4	1.2
2002	353.7	4.4	1.2	1,640.0	25.0	1.5

Note: Figures for 2002 are preliminary estimates.
Sources: Prepared based on "China Statistical Yearbook" for each year and "Electric Power of China" Vol.36, No.2 (2003).

3. Mid- to Long-Term Outlook of Nuclear Power Development

In China, a number of nuclear power plant construction plans and conceptions are in progress centering on the coastal areas to meet the rapid economic growth and massive power demand following the introduction of the reform and opening-up policy. Many of them were proposed by the middle of the 1990s. These plans vary in their levels of progress, such as having obtained government approval, waiting for the approval, completing the site locating, having the equipment and capital procurement in view, and progressing only in terms of conception. See Table 3-1 for a complete list.

Table 3-1. Status of Operation, Construction, Planning, and Examination of Nuclear Power Plants in China (As of the end of April 2003)

	No. of units	Capacity per unit (10 MW)	Total capacity	
To start operation by 2005.	11		870	
In operation as of the end of April 2003	7		540	(1) To be authorized before the Ninth Five-Year Plan.
Daya Bay	2	90	180	
Qinshan I	1	30	30	(2) Having the major purpose of solving electricity shortage.
Qinshan II-1	1	60	60	
Qinshan III-1	1	70	70	(3) Low domestic production ratio and high import ratio.
Ling-ao (I)	2	100	200	
To start operation between May and December 2003	2		130	(4) Importing countries and reactor types not unified.
Qinshan II-2	1	60	60	
Qinshan III-2	1	70	70	(5) Concentrating on the three provinces in the southeast coastal area.
To start operation in 2004	1		100	
Tianwan (I)-1	1	100	100	
To start operation in 2005	1		100	
Tianwan (I)-2	1	100	100	
To come to the planning and examination stage by March 2003	26		2,300	(1) To be considered in the Tenth Five-Year Plan.
Potential domestic production projects under the 10th 5-Year Plan	8		800	(2) Having the major purpose of fulfilling domestic production.
Sanmen (Zhejiang Province)	2	100	200	
Yangjiang (I, Guangdong Province)	2	100	200	(3) The reactor type is likely to be unified to PWR.
Haiyang (Shandong Province)	2	100	200	(4) Import of equipment is unlikely.
Hui'an (Fujian Province)	2	100	200	(5) Concentrating on the southeast coastal area.
Other projects in application or under examination	18		1,500	(1) Succeeding projects after the fulfillment of domestic production.
Qinshan IV	2	100	200	
Tianwan II	2	100	200	(2) Possible introduction of an advanced PWR.
Ling-ao II	2	100	200	(3) The reactor type is likely to be unified to PWR.
Yangjiang (II, III, Guangdong Province)	4	100	400	(4) Import of equipment is unlikely.
Jinzhouwan (Liaoning Province)	2	100	200	(5) While concentrating on the southeast coastal area, introduction in midland areas is also likely.
Jiujiang (Jiangxi Province)	2	30	60	
Hainan (Hainan Province)	2	30	60	
Fuling Baitaozheng (Chongqing)	2	90	180	
Total	37		3,170	

Sources: Prepared based on relevant literature, including "Fifty Years of Energy in China," "Report on Energy Development in China 2001," "Essentials of the Tenth Five-Year Development Plan for Peaceful Use of Nuclear Energy in China," "Tenth Five-Year Plan for the Power Industry," "Priority Energy Development Programs under the Tenth Five-Year Plan for National Economy and Social Development," "Essentials of the Tenth Five-Year Plan for National Economy and Social Development of China," Song Renqiong, et al. "Brilliant 40-Year History of the Nuclear Power Industry in China," Energy-china.com, People's Daily, Economic Daily, and China Nuclear Industry News

All the four units with a total capacity of 3,300 MW that are under construction as of the end of April 2003 are expected to be completed and start commercial operation by 2005. Together with the seven units (5,400 MW) that are already in operation, the total nuclear power generating capacity in 2005 will be 8,700 MW.

The potential projects currently under consideration are 26 units with a total capacity of 23,000 MW. The Chinese government has set a policy of “developing the nuclear power generation moderately” in the Tenth Five-Year Plan with the goal of fulfilling domestic production. Accordingly, the China Atomic Energy Authority, the competent authority for the peaceful use of nuclear power, has plans to start the construction of six units with a total capacity of 6,000 MW by 2005. On the other hand, China National Nuclear Corporation expects the construction of six to eight units with a capacity of 6,000 - 8,000 MW (Li Dingfan, 2000). Given a construction period of about six years, at least four units with a capacity of 4,000 MW, or eight units with a capacity of 8,000 MW at the maximum, will be completed by 2010. The total nuclear power generating capacity in 2010 may then be 12,700 - 16,700 MW.

The remaining 18 to 22 units with a capacity of 15,000 - 19,000 MW may start operation by 2015 if the construction is started between 2006 and 2010. Then, 37 units with a total capacity of 31,700 MW may be in commercial operation in 2015, but at this point there is little likelihood of that. If domestic production progresses successfully, it is likely that the construction of four to six units, or eight units at the maximum, will be started.

Table 3-2 shows the outlook prepared by relevant authorities, including the above-mentioned outlook for 2015.

While there are differences in the predictions of nuclear power generating capacity in 2010 ranging from 8,600 to 20,000 MW, it is reasonable to predict about 15,000 MW. As for 2020 onward, China National Nuclear Corporation (CNNC) presented, in 1994, a ambitious prediction of rather large-scale development with a capacity of 64,000 - 84,000 MW in 2020, 135,000 - 170,000 MW in 2030, and 300,000 - 350,000 MW in 2050, but it recently revised the values downward to 40,000 MW or more in 2020 (Zhao Renkai, 1994; Li Dingfan, 2000). On the other hand, predictions by overseas organizations are significantly lower than those by Chinese organizations. IEA (2002) predicts 21,000 MW in 2020 and 31,000 MW in 2030. DOE/EIA/USA (2001) has presented extremely low predictions of 21,000 MW at the maximum, or as low as 11,000 MW in 2020.

Without considering the value judgment of whether or not to introduce nuclear power generation, the author thinks that there is a possibility that the nuclear generating capacity will increase to 31,000 - 51,000 MW in 2020 and 50,000 - 90,000 MW in 2030, provided that the average annual economic growth is maintained at 6% or higher until 2030, that the domestic production expands successfully, and that no major radioactive contamination accidents or movements against nuclear power will occur. It is unlikely that all of the conditions listed above will not be satisfied, however, any of them may be missed. Even so, it is unlikely that the Chinese government will reduce the present scale of development, because it will aim to raise the level of research and development that has already lagged behind, to secure human resources, and maintain its status as a nuclear power. Consequently, it is predicted that the nuclear generating capacity in 2030 will not be less than 40,000 MW.

Table 3-2. Outlook for Mid- to Long-Term Nuclear Power Generating Capacity Introduction in China

	2000	2005	2010	2015	2020	2030	2050
Capacity range (MkWh)	2.1-2.7	5.3-8.7	8.6-20	9.6-32	11-51	31-90	120-240
(1) Task Group (November 1996)	2.7		20		40-50		120-200
Standard case	2.7		20		40		120
High-progress case	2.7		20		50		200
(2) Academy of Engineering (May 1997)	2.1		20		40		120-240
Standard case	2.1		20		40		120
High-progress case	2.1		20		40		240
(3) China Energy Research Institute (February 1999)	2.1	6.7	16.7	26.7	36.7	56.7	
(4) China National Nuclear Corporation (2000)	2.1	8.7	14.7-16.7		40-		
Standard case	2.1	8.7	14.7		40		
High-progress case	2.1	8.7	16.7				
(5) State Power Corporation of China (November 2000)	2.1		20		40-50		
Standard case	2.1		20		40		
High-progress case	2.1		20		50		
(6) EIA/DOE/USA (2001)	2.167	5.3-6.6	8.6-11.6	9.6-18.7	10.6-20.7		
Standard case	2.167	5.922	9.587	11.587	18.652		
High-progress case	2.167	6.587	11.587	18.652	20.652		
Low-progress case	2.167	5.257	8.587	9.587	10.587		
(7) IEA(2002)	2.1		11		21	31	
(8) China Atomic Energy Authority (2003)	2.1	8.7	15				
(9) Wu Jingru (April 2003)	2.1	8.7	13.7	23.7	40		
(10) Li Zhidong	2.1	8.7	12.7-16.7	16.7-31.7	20.7-50.7	40-90	
Standard case	2.1	8.7	14.7	22.7	30.7	50	
High-progress case	2.1	8.7	16.7	31.7	50.7	90	
Low-progress case	2.1	8.7	12.7	16.7	20.7	40	

Sources:

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2. Academy of Engineering “First Draft of the Comprehensive Report on the Energy Strategy for Sustainable Development in China” 1997
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4. China National Nuclear Corporation (Li Dingfan) “Development of Nuclear Power Industry and Enhancement of National Power for People’s Prosperity” CNNC Website, 2000
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6. EIA/DOE/USA, International Energy Outlook 2001
7. IEA, World Energy Outlook 2002
8. China Atomic Energy Authority, “Essentials of the Tenth Five-Year Development Plan for Peaceful Use of Nuclear Energy in China,” Energy-china.com, 2003
9. Wu Jingru, “There Will Be a Great Development in the Coming 20 Years,” Energy-china.com, 2003
10. This paper

4. Merits, Demerits and Challenges of Nuclear Power

According to the research report by the State Council Development Research Center "Research on the Development and Policies of Nuclear Power Industry in China," there has been controversy in China over the merits, demerits and policy lines relating to the introduction of nuclear power generation (Lu and Xiong, 2000). As far as the author knows, however, there is plenty of literature relating to the "merits," but little literature about the "demerits" and evidence of the "controversy" has been published.

As is evident from the introduction of nuclear power generation being incorporated in the government programs, pronuclear has been the mainstream in China. The grounds for such opinions can be summarized as below (Wang Qingyi, 1988; Song Renqiong et al, 1995; Jiang Xinxiong, 1998; Li Dingfan, 1999, 2000; Lu and Xiong, 2000; "Essentials of the Tenth Five-Year Plan for Peaceful Use of Nuclear Energy in China", etc.).

First, nuclear power is essential to secure electricity supply and energy security. While the concern for electricity supply was predominant until the middle of the 1990s when electricity supply was in short the emphasis has shifted to energy security since the latter half of the 1990s as the energy security problems became more tangible. Second, nuclear power is a clean and safe energy source and contributes to the resolution of air pollution and global warming problems. Third, in the tightening environment surrounding nuclear testing after the end of the Cold War period, it is necessary for China to promote the development of technology and human resources through nuclear power development in order to improve its status as a nuclear power. The economics of nuclear power generation was also stressed as one of the grounds to support nuclear power; it has turned to be a drag on the pronuclear since the virtual privatization of the former China National Nuclear Corporation and the liberalization of the power industry.

Although the support for the introduction is mainstream, there is controversy over the lines of introduction; that is, whether or not to keep the pace of introduction with the progress in the expansion of domestic production. This question is examined below, looking back on the history of the past 20 years (See Tables 2-1 and 2-2).

All 11 reactors currently in operation or under construction were planned or additionally approved by the middle of the 1990s. The Qinshan Power Plant I, whose construction started in 1985 under the Sixth Five-Year Plan (1981-1985), was constructed mainly with domestic equipment. The domestic production ratio is 95% on a component basis and 70% on a value basis (CNNC Website). The Daya Bay Power Plant (PWR 900 MW, 2 units), whose construction started in 1987 and 1988 with reactors imported from France, was not included in the Seventh Five-Year Plan (1986-1990), but it is guessed that the project had a purpose of acquiring technology. The fact that Qinshan Power Plant II, whose construction started in 1996, was based on the design of Daya Bay Power Plant supports this guess (Ding Yan, 2002). The Eighth Five-Year Plan (1991-1995) provided that the government would "place priority on the construction of Qinshan Power Plant II" mainly with domestic equipment. It is thus assumed that the Chinese government aimed at expanding domestic production from an early stage in the introduction of nuclear power and chose the "steady-going lines" to introduce nuclear power in step with the progress in domestic production.

In a talk with high government officials on December 24, 1990, Deng Xiaoping stated his views that "We should take every opportunity to resolve the problems involved in development" and "We still should pursue nuclear power development" ("The Analects of Deng Xiaoping, Vol. 3"). These remarks meant that, under the domestic circumstances where the demand for energy, especially electricity, was rapidly increasing with the rapid economic growth and the international circumstances that nuclear power development in the world had been stagnant and international capital in the nuclear power field was trying to find a way out in the Chinese market, China should take this opportunity to promote nuclear power development (Song Renqiong, et al., 1995). Following these remarks, the development of nuclear power generation progressed faster than the expansion of domestic production, and the policy shifted from "steady-going lines" to "rapid expansion lines." The ambitious outlook by the former China National Nuclear Corporation mentioned above may be attributable to such a situation. Of the eight reactors whose construction started in or after 1996, six reactors, other than the two in Qinshan II under the Eighth Five-Year Plan, were additionally approved and imported from France, Canada, and Russia, two from each country.

The Ninth Five-Year Plan (1996 - 2000) set forth a policy of promoting the commercialization and moderate development of nuclear power, implying a return to the "steady-going lines." Since then, existing import projects that had obtained additional approval were not abandoned, but any new import projects have not been approved. In the meantime, the Qinshan Power Plant II (2-loop, 600 MW, 2 units) was constructed following the model of the Daya Bay Nuclear Power Plant (3-loop, 1,000 MW, 2 units), with a domestic production ratio of 56% on a value basis (Ding Yan, 2002; China Youth Daily, August 5, 2002). Furthermore, the design of the 1,000-MW class advanced PWR (CNP-1000) as a standard reactor for domestic production was almost completed (Li Dingfan, 2000). In the Tenth Five-Year Plan (2001 - 2005), the "steady-going lines" policy to pursue the moderate development of nuclear power was reconfirmed.

"Essentials of the Tenth Five-Year Plan for Peaceful Use of Nuclear Energy in China" pointed out major problems in the peaceful use of nuclear power as follows: "the lack of leadership in the long-term development plan caused slower progress in the development of nuclear power technology and the domestic production of equipment; China falls behind advanced nations in terms of the scale of industry and the level of technology; and there is a serious shortage of funds for basic research and technological development, the equipment is old, there are significant outflows of human resources, and there are relatively large differences in the principal technologies as compared with developed countries." These may be the major reasons for returning to the "steady-going lines" emphasizing domestic production.

Other points that cannot be ignored are the economic effects and economics. Of the total RMB 99 billion (1,500 billion yen) investment in the construction of the eight nuclear power plant units (6,600 MW) whose construction started in or after 1996, 60%, or RMB 59.4 billion (900 billion yen) was paid overseas (Li Dingfan, 2000). This was a great loss to China, which was undergoing declining economic growth after peaking at 14.2% in 1992 and suffering unemployment as social problem. In terms of economics, the unit construction cost of imported power plants is $1,800 to 2,000/kW, significantly higher than that of the Qinshan II at $1,330/kW (Li Yongjiang, 2002). Domestic production is essential to secure the economic effects and reduce the unit construction cost and unit generation cost.

Although there is little official literature that openly opposes the introduction, there are some, including the author, who express the view that the introduction should be considered more prudently (e.g. Fu Bingjun, Institute of Geology and Geophysics, Chinese Academy of Science, December 19, 2002).

First, China should give priority to exploiting its great potential in terms of both energy conservation and the development of renewable energy. The energy utilization efficiency in China is generally 20 - 40% lower than that in developed countries (Li Zhidong, 2003). As for renewable energy, China is estimated to have 380 GW of developable hydropower resources, but the development rate in 2001 was only 21.8% on a capacity basis. Although developable wind power is estimated at 250 GW, wind power generation capacity is only 0.35 GW at present. Utilization of solar energy has lagged farther behind.

Second, unsolved problems relating to nuclear power safety remain, in particular the safe disposition of high-level waste. It is doubtful whether any radioactive pollution caused by an accident in uranium mining, processing, transportation, reactor operation, or waste disposal can be prevented. In addition, underground storage of high-level waste is under consideration as a means of disposition, but the possibility of causing trouble to coming generations cannot be ruled out.

Third, it is necessary to reconsider whether nuclear power will contribute to energy security or not. As can be seen in Japan, any accidents or concealing of problems might give rise to movements against nuclear power and cause an electricity supply crisis.

Fourth, the economics of nuclear power has not been fully confirmed. In Guangdong Province, where the Daya Bay Nuclear Power Plant is located, the unit transmission cost for nuclear power is RMB 0.53 - 0.54/kW, 32.5 - 35.0% higher than that for thermal power, which is RMB 0.40/kW, and 12.8 - 14.9% higher than that for the total power including nuclear power, which is RMB 0.47/kW (Zhou and Zhang, 1999; Wang, et al., 1999).

According to the State Council Development Research Center's research report, "Research on the Development and Policies of Nuclear Power Industry in China," it is pointed out that under the present economic conditions the nuclear power industry will not be able to achieve autonomous development on a commercial basis and requires focused support measures, such as favorable tax treatment, favorable financing, and a quota purchase system (Lu and Xiong, 2000). According to "Essentials of the Tenth Five-Year Plan for Peaceful Use of Nuclear Energy in China," the Chinese government set a future goal of reducing the unit transmission cost for nuclear power in the coastal areas that are far from coal production centers, to a level that is comparable to that for the coal-fired power having desulphurization equipment, through the expansion in domestic production. These costs do not, however, include those for the disposition of high-level waste. There is a project under consideration to construct a high-level waste disposal facility in the Northwest Gobi Desert Area (Northern Mountain), which will cost several ten billion RMB for the construction only (Shi Ding, 2003). If the high-level waste disposal cost including those for the construction and maintenance is taken into account, the economics of nuclear power generation will further worsen.

These challenges also apply to nuclear power development throughout the world, but they are especially critical to less-developed countries such as China.

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Contact: info-ieef@tky.ieej.or.jp