Nuclear Power Developments in the Asia-Pacific Region

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SUMMARY. There are 438 nuclear power reactors operating in the world. Of these, 95 are in the Asia-Pacific region. Of the 36 reactors currently under construction in the world, 19 are in the Asia-Pacific region. Of the 44 planned reactors in the world, 36 are in this region.
At the start of the "New Nuclear Century" the Asia-Pacific region has become the main area for growth and innovation in nuclear power.
This paper describes the nuclear power developments in each country and examines the status of the construction programme and the planned projects. Countries included are China, India, Japan, Democratic People's Republic of Korea (DPRK), Republic of Korea, Pakistan and Taiwan. New projects include the HTR in China, ABWRs in Japan, KEDO in the DPRK and the APR in the Republic of Korea.

1. INTRODUCTION

During the last and current decades, the Asia–Pacific region has become the main area for growth in nuclear power, both for current construction and for firm planned projects.
This paper examines:

- The development of the nuclear power programme and the operating power stations.
- The status of the construction programme.
- The planned projects.

The region covered by this paper extends from Pakistan in the west to Japan in the east.

2. CHINA

Year	Nuclear electricity Production TWh	Nuclear Proportion
1999	14.1	1.15 %
2000	16	1.18%

OPERATIONAL POWER STATIONS

China has 3 operating nuclear power reactors with a total electrical output of 2167MWeN:

Qinshan 1

China's first nuclear power plant was built at Qinshan, Zejiang province. The 300 MWeN PWR was indigenously designed, based on submarine technology, with a reactor pressure vessel supplied by Mitsubishi (Japan). The plant first generated electricity in December1991. The reactor was shutdown from July 1998 to September 1999 for repairs to the lower reactor internals carried out with Westinghouse assistance.

Daya Bay 1 & 2

For the second power station, located 50 km from Hong Kong, China bought a standard 3 loop 900 MWeN French PWR from Framatome, with turbines supplied by GEC Alsthom. Construction started in 1987, and the plants began producing electricity in 1993 (unit 1) and 1994 (unit 2).

CURRENT CONSTRUCTION PROGRAMME

China's ninth 5 year national development plan (1996-2000) specified four 2-unit nuclear power stations with a total capacity of 6,370 MWe and these are all currently under construction. To accumulate experience in different types of reactor construction, a CANDU type reactor has been ordered from Canada, a PWR from France and a VVER from Russia. There is also one indigenous design PWR. Foreign contracts during the current construction programme included more technology transfer and more components built in China.

Qinshan Phase 2, units 1 & 2

Construction started in 1996 on these 600 MWeN, indigenous design PWRs – larger versions of the 300MWeN Qinshan 1. Mitsubishi supplied the pressure vessel for the first unit, but the second will be made in China. The turbines are from the Framatome subsidiary Thermodyn. The plant is due to commence operating in 2002/3.

Qinshan Phase 3, units 1 & 2

In 1996, a turnkey contract was signed with Atomic Energy of Canada (AECL) for the sale of two 700 MWeN CANDU 6 PHWRs. This is the first time China has chosen heavy water technology. Hanjung (Korea) is the subcontractor for the steam generators and the secondary plant is supplied by Hitachi (Japan). Construction started in 1998 and the plant is due on-line in 2003/4.

Lingao 1 & 2

This plant is essentially a replica of the existing Daya Bay French PWR which is sited just 1km to the east. Framatome again will supply the nuclear

island and Alstom the secondary plant. The contracts include specific technology transfer agreements between EdF and the operator. Construction started in 1997, and initial operation is due in 2002/3.

Tianwan 1 & 2

Russia is supplying two VVER-91, 950 MWeN PWRs for this new station located at Tianjin, Jiangsu province. Finland's Fortum participated in the design work and the reactor includes a number of safety features to meet the latest Russian and Finnish safety standards and IAEA recommendations. Siemens Power Generation Group (KWU) is contracted to supply the control and instrumentation equipment. Construction started in 1999 and the reactors are due on-line in 2004/5.

OTHER CONSTRUCTION PROJECTS

The Institute of Nuclear Energy Technology (INET) at Tsinghua University, Beijing has designed and built a 10 MWTh gas cooled High Temperature Reactor (HTR). This is a helium cooled, modular pebble bed reactor similar to the ESKOM project in South Africa. The reactor operates at an outlet temperature of 700°-950°c and of particular interest is its suitability as a source of high temperature process heat for heavy oil recovery and coal gasification. The reactor can also be directly coupled to a gas turbine allowing electricity generation at far higher efficiency (50%) than the 33% typically achieved by a PWR. Construction started in 1995 and the reactor was taken critical in December 2000.

FUTURE DIRECTIONS

In the 1990's, China built reactors of various types to gain experience, now they are moving to localisation and standardisation. Construction cost and unit price have to be optimised to make nuclear power more competitive.

The Shanghai Nuclear Engineering Research and Design Institute (SNERDI), the designer of Qinshan 1, and the East China Electric Power Design Institute (ECEPDI) are collaborating on the design of a standard 1000MWe PWR with the Spanish SEPI nuclear group. The reference plant is the Westinghouse 3 loop Vandellos 2 reactor in Spain.

From the experience with the Daya Bay and Lingao stations, further French designs are also likely to be considered.

Addressing the ninth National Peoples Conference in 2001, the Chinese Prime Minister, Zhu Rongji spoke of plans for "moderate development" of nuclear power over the next 5 years.

Projects that may be included in the tenth 5 year plan (2001-5):

- **Lingao**
  Two more 900 MWeN PWRs on this existing site in Guandong Province. Further Framatome technology transfer may be negotiated.
- **Sanmen**
  The original plan to build more reactors on the Qinshan site was rejected by local planners and a new site at Sanmen, just south of Qinshan in Zhejiang province was chosen. CNNC is proposing to build the first Westinghouse based 1000 MWe Chinese standard PWR here.
- **Haiyang**
  This PWR project is backed by China's State Power Corporation (SPC).

3. INDIA

Year	Nuclear electricity Production TWh	Nuclear Proportion
1999	11.448	2.65%
2000	14.21	3.14%

OPERATIONAL POWER STATIONS

India has 14 operating nuclear power reactors with a total installed electrical output of 2548 MWeN:

Tarapur 1 & 2

India's first nuclear power plant was a twin BWR supplied by the USA in 1969.

Rajasthan 1 - 4

The first units at this site are PHWRs based on the CANDU design with equipment imported from Canada and they began operating in 1972 and 1980. The last two units were completed in 2000 and these are the latest 202 MWeN indigenous design.

Kalpakkam 1 & 2

Unit 1 at the Madras Atomic Power Station, which began commercial operation in January 1984, was the first indigenously designed and built reactor. The second unit followed two years later.

The Narora, Kakrapar, and Kaiga sites each have two Indian standard PHWRs commissioned between 1989 and 2000.

CURRENT CONSTRUCTION PROGRAMME

Tarapur 3 & 4

Construction started on the twin PHWR Tarapur Atomic Power Plant (TAPP) in March 2000. These reactors are scheduled to achieve criticality in 2005 and 2006. The reactors are a scaled up version of the standard 220 MWe PHWRs and will each have a gross electrical output of 500 MWe.

PLANNED PROJECTS

Kudankulam
In 1988, India signed an agreement with the USSR for Soviet industry to construct two 1000MWe VVER-1000 units (PWRs) in India on a site at Kudankulam, in southern Tamil Nadu. After a lapse of ten years, the project was restarted in 1998 and a contract signed between the Nuclear Power Corporation of India (NPCIL) and Atomstroyexport (Russia) to commission the detailed project report. The report is expected to be completed in 2001. Construction is planned to start in 2002 with connection to the grid in 2005/6.
Kaiga 3 - 6
Four more 220 MWe PHWRs will be built on the existing site at Kaiga.
Rajasthan 5 - 8
Four 500 MWe PHWRs are planned for this existing site.

Fast Breeder Reactor
The design for the next stage of the fast breeder reactor programme, the 500MWe Prototype Fast Breeder Reactor (PFBR), is being carried out at the Indira Gandhi Centre for Atomic Research. Technology development is in progress in collaboration with Indian industry.

4. JAPAN

Year	Nuclear Electricity Production TWh	Nuclear Proportion
1999	303.255	34.6%
2000	304.866	33.8%

OPERATIONAL NUCLEAR POWER STATIONS

Japan has 54 operating nuclear power reactors with a total net electrical output of 44,301 MWeN.

Nuclear electricity generation is based on light water reactors of which there are 29 BWRs and 23 PWRs. The last reactor to be connected to the grid was Onagawa 3 BWR on 30 May 2001.
A 148MWeN prototype Advanced Thermal Reactor (ATR) has been operating at Fugen since 1979. This is a heavy water moderated light water cooled reactor designed for both uranium and plutonium fuel. Construction of a 600MWe demonstration ATR was planned for Ohma, but this was dropped in 1995.
Construction of the 250MWe prototype fast reactor Monju began in 1985 and the plant eventually began generating electricity in 1994. Near to the end of the commissioning tests in 1995, the reactor was shutdown due to a sodium leak in the secondary cooling loop when a thermocouple pocket failed. The reactor has not yet been restarted. In December 2000, the Japan Nuclear Cycle Development Institute (JNC) applied for preliminary consent for a full safety examination of Monju as a step towards a restart. JNC want to restart Monju to verify the technology, improve the economics and confirm the practical use of a Fast Breeder Reactor (FBR) for the future. The application for the safety licence and approval of the plant modification to guard against further sodium leakage was submitted by JNC in June 2001.

CURRENT CONSTRUCTION PROGRAMME

There are 3 reactors under construction in Japan with a total installed net capacity of 3,696 MWeN:

- **Hamaoka 5 (Chubu)**
  1325 MWeN ABWR in Shizuoka Prefecture. Construction began in March 1999 and operations should start in 2005.
- **Shika 2 (Hokuriku)**
  1304 MWeN ABWR in Ishikawa Prefecture. Construction began in August 1999 and operations should start in 2006.
- **Higashidori 1 (Tohoku)**
  1067 MWeN BWR . Construction began in December 1998 and operations should start in 2005.

PLANNED NUCLEAR POWER STATIONS

There are firm plans for twelve reactors to be constructed with a total installed net electrical output of 15,858 MWeN:

Station	MWeN	Type	Grid date
Fukushima 7	1325	ABWR	2006
Fukushima 8	1325	ABWR	2007
Tomari 3	900	PWR	2008
Ohma	1350	ABWR	2008
Tsuruga 3	1500	APWR	2010
Tsuruga 4	1500	APWR	2010
Shimane 3	1375	ABWR	2010
Higashidori 1 (TEPCO)	1330	ABWR	2010
Higashidori 2 (TEPCO)	1330	ABWR	2010
Higashidori 2 (TOHOKU)	1320	ABWR	2011
Kaminoseki 1	1320	ABWR	2012
Kaminoseki 2	1320	ABWR	2015

5. DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA (DPRK)

The DPRK has no operating nuclear power reactors.
In 1994, the DPRK agreed to halt their nuclear development programme in return for the supply of

two US designed LWRs under international safeguards. To assist in meeting energy needs, 500,000 Te of heavy fuel oil a year is supplied for electricity and heating until the first reactor is completed. The first reactor was due to begin producing power in 2003, but due to political and economic delays this is unlikely to be before 2007. The governments of Japan, the Republic of Korea and the USA signed the agreement on the establishment of the Korean Peninsular Energy Development Organisation (KEDO) on 9 March 1995. Further governments have subsequently joined the organisation, including Australia in September 1995.

The site for the nuclear power plant is at Sinpo, South Hamgyong province, 160 kilometres north of the demilitarised zone. The reference plant is the Ulchin 3 &4 1000MW Korean Standard Nuclear Plant (KSNP), an advanced version of the ABB-CE System 80 PWR.
In 1996, the Korea Electric Power Corporation (KEPCO) was designated the prime contractor for the turnkey project. Site preparation started in 1997.

On 15 December 1999 KEPCO and KEDO signed the contract for the design, construction and commissioning of the two power reactors. The value of the turnkey contract is US$4.6 billion. South Korea has agreed to pay $3.22 billion (70% of the cost). This has to be reimbursed by North Korea in instalments over 17 years after a three-year grace period upon completion of the project. Japan is contributing $1 billion, with the remainder being provided by other KEDO members. The project delays have been due to the complex financing and the difficulty in agreeing protocols for contact between North and South Korea. Another major issue which delayed the contract signing was project liability. The matter was shelved by agreement to enable the contract to be signed, but has to be resolved before nuclear fuel is delivered on site.
KEPCO signed a contract with HANJUNG in December 1999 for the supply of the nuclear steam system including the reactor vessels and steam generators.
The preliminary works contract was completed and preconstruction site work started in February 2000. On 22 December 2000, a contact to build the two reactors was signed by KEPCO and a consortium of four South Korean companies. The companies and their share in the project are Hyundai Engineering and Construction (50%), Dong Ah Construction (20%), Daewoo (15%) and Korea Heavy Industries (15%).

In February 2001, KEDO applied to the North Korean Regulators for a construction certificate. KEDO submitted the preliminary safety analysis report and an environmental report.

6. REPUBLIC OF KOREA

Year	Nuclear Electricity Production TWh	Nuclear Proportion
1999	97.817	42.8%
2000	103.501	40.7%

The Republic of Korea has 16 operating nuclear power reactors with a total electrical output of 12,970 MWeN.
Nuclear electricity generation is based on water reactors of which there are 4 PHWRs and 12 PWRs.

The first Canadian CANDU reactor was constructed by Atomic Energy of Canada (AECL) on the Wolsong site in 1982. Since then, a further three CANDU reactors have been built on this site, with the last one connected to the grid in 1999. There was an increasing Korean involvement in the projects. For Wolsong 2, KEPCO led the commissioning programme and Wolsong 3 & 4 had 50% of the plant manufactured in Korea. Hanjung manufactured the calandria for Wolsong 4.

Two PWRs were supplied by Framatome for the Ulchin site and connected to the grid in 1988/9. There have been no further major projects with French companies.
Six PWRs were purchased from Westinghouse. Kori 1-4 went into service over the period of 1977-85 followed by Yonggwang 1 & 2 in 1986.
After this initial period gaining PWR experience, Korea looked for technology transfer on the next projects. A contract was signed with Combustion Engineering (CE) USA in 1987 and Yonggwang 2 & 3 were based on the CE system 80 PWR design. Yonggwang 3, commissioned in 1994, was the first "Made in Korea" power reactor. These reactors became the reference plants for the Korean Standard Nuclear Power Plant (KSNP) series of 1000MWeG (950MWeN) units.

Ulchin 3 & 4 were the first two KSNP PWRs. Construction started in 1992 and they were connected to the grid in January 1998 and December 1998.

Over a period of 21 years, Korea had moved from turnkey contracts, through component manufacture to self-sufficiency and a standard reactor.

CURRENT CONSTRUCTION PROGRAMME

There are four reactors under construction in Korea with a total capacity of 3800 MWeN All the reactors are of the KSNP design in this phase:

Reactor	Type	MweN	Grid date
Yonggwang 5	KSNP	950	2002
Yonggwang 6	KSNP	950	2002
Ulchin 5	KSNP	950	2004
Ulchin 6	KSNP	950	2005

LONG TERM PROGRAMME

According to the "5th Long-term Plan for Electric Power Demand and Supply" which was finalised in January 2000, eight more nuclear reactors will be constructed by 2015. Kori 1 (2008) and Wolsong 1 (2013) are due to be decommissioned during this period making a total of 26 operating reactors in 2015.

The KSNP is based on the 1000 MWe Combustion Engineering system 80 unit. In 1992, a four-phase programme commenced to design an evolutionary reactor based on the KSNP but of larger capacity. This was known as the Korean Next Generation Reactor (KNGR) and was originally 1300 MWe. General requirements included a plant lifetime of 60 years, a construction period of 48 months and a 20% electricity cost advantage over competitive energy sources. During phase one 1992-4, Advanced Light Water Reactor (ALWR) designs were examined and the reactor type selected. In Phase two, the basic design was developed and completed in 1999. During the current phase three, the design will be optimised and finalised. Phase four will see the construction of the first KNGR. In 1997, Combustion Engineering (now Westinghouse and part of the BNFL group) signed three 10 year contracts with KEPCO for technical co-operation, Hanjung licensing and support for the KNGR project.

In August 2000, KEPCO announced plans for two more 950 MWeN KSNPs. The reactors will be located near to the existing Kori site and the units will be named Shin-Kori 1 & 2 (New- Kori).

In April 2001, plans for a further six reactors were finalised. Two more 950 MWeN KSNPs will be built at a site previously known as Bonggil. As this is close to Wolsong, the site is now to be known as Shin-Wolsong. Wolsong is the site of all the PHWR CANDU reactors, but there are no plans at present to build further reactors of this type.

The KNGR is now called the Advanced Pressurised Water Reactor (APR) and the capacity is uprated to 1400 MWeG. The first APRs will be New-Kori 3 & 4. Two more APRs were included in the plans with the site yet to be decided.

Planned Reactors

Reactor	**Type**	**MWeN**	**Grid Date**
Shin-Kori 1	KSNP	950	2010
Shin-Kori 2	KSNP	950	2011
Shin-Wolsong 1	KSNP	950	2009
Shin-Wolsong 2	KSNP	950	2010
Shin-Kori 3	APR	1350	
Shin-Kori 4	APR	1350	
APR 3	APR	1350	
APR 4	APR	1350	

7. PAKISTAN

Year	Nuclear Electricity Production TWh	Nuclear proportion
1999	0.69	1.1%
2000	1.081	1.65%

Pakistan has 2 operating nuclear power reactors with a total electrical output of 425 MWeN.

Kanupp

Pakistan's first power reactor, Karachi Nuclear Power Plant (Kanupp), a small 125MWeN natural uranium fuelled PHWR located 30km west of Karachi, began operating in 1971. Canadian General Electric supplied the Candu type reactor on a turnkey basis.

Following India's 1974 nuclear explosion, Canada imposed a ban on spare parts, fuel and technical services. The operation of this plant has since been based on indigenously produced fuel and mostly locally manufactured parts.

Chasnupp 1

In 1989 it was announced that China had agreed to supply a 300 MWeN PWR to Pakistan. The contract for an improved version of China's indigenously designed Qinshan 1 was signed in 1991 and construction of the Chasma Nuclear power plant (Chasnupp) by the China National Nuclear Corporation began in 1993. The reactor was taken critical on 3 May 2000, synchronised to the grid on 13 June and handed over to the Pakistan Atomic Energy Commission (PAEC) on 25 September. The plant is located 32 km south of the city of Mianwali in Punjab. Chasnupp was formally inaugurated in March 2001 at a ceremony attended by Liu Jibin, Minister for COSTIND, the leading Chinese nuclear decision making body.

CONSTRUCTION PROGRAMME

There are no reactors at present under construction in Pakistan.

FUTURE DIRECTIONS

Chasma was modelled on the 300 MWeN Qinshan 1 reactor. (For Qinshan phase two, China is building a larger 600 MWeN version that is due to start operations in 2002). At the Chasma inauguration ceremony, outgoing PAEC chairman Dr Ishfaq Ahmad said Pakistan would proceed as early as possible with another unit and would again look to China for assistance. The key factor will be the financial arrangements.

8. TAIWAN

Year	Nuclear Electricity Production TWh	Nuclear proportion
1999	37	25%
2000	37	23.64%

Taiwan has 6 operating nuclear power reactors with a total electrical output of 4884 MWeN. Four General Electric BWRs and two Westinghouse PWRs are in operation at three sites – Chinshan, Kuosheng and Maanshan.
Construction work on the first station, Chinshan, began in 1972. The last reactor to begin commercial operation was Maanshan in 1985. Taiwan involvement in all these projects was limited to local manufacture of small components and civil construction.

CONSTRUCTION PROGRAMME

Plans for the Lungmen nuclear power station on the Yenliao peninsula, in northeast Taiwan were first announced in 1980. These plans were deferred due to a slow down in the growth of electricity demand. The plans were deferred again during the late 1980s because of the Chernobyl accident in 1986 and a turbine fire at Maanshan 1 in 1985 that shutdown the plant for over a year.

Lungmen was included in the 1990 Six Year Development Plan, and although a strong antinuclear lobby had developed, government permission to go ahead was received in 1991, partly due to predicted power shortages. The preconstruction funds were released in 1992. Initial bids on a turnkey nuclear island basis were rejected, and rebidding on a components basis invited. Eventually in May 1996 General Electric won the contract to construct two Advanced Boiling Water Reactors (ABWR). The turbine contract was later awarded to Mitsubishi Heavy Industries (MHI).

The Atomic Energy Council (AEC) issued the construction permit in 1999 after a two-year safety review and the first concrete was poured in March 1999.

After 55 years of rule by the Nationalist Kuomintang (KMT) party, the Democratic Progressive Party (DPP) leader, Chen Shui-bian won the presidential election in March 2000 and pledged to scrap the project. A government committee set up in August to review the project could not reach consensus. In October, the cabinet decided to cancel the project citing concerns about the welfare of future generations. Construction was 30% complete when Taipower issued a notice to formally suspend the work.

The Taiwan Court of Grand Justices in January 2001 ruled that the premier's action was flawed stressing the necessity for legislative approval. The KMT majority Legislative Yuan passed a resolution calling for work to be resumed and in February the Executive Yuan reinstated the budget. The order to restart construction was given after 3 months suspension.

CONCLUSIONS

Several countries in the Asia-Pacific region have major nuclear power construction programmes. China has an indigenous construction programme and is also buying different types of reactor for experience. India has an established PHWR programme. Japan continues to build large, advanced design water reactors and the Republic of Korea has a well-established standard reactor programme. Pakistan and Taiwan have no indigenous build programmes but have bought reactors from China and the US (General Electric) respectively.
The Asia-Pacific region now and in the current reactor planning period which extends up to ~2010 is the main area in the world for new nuclear power plant projects.