Asia's potential for nuclear power: where things stand today

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The following comprehensive review of the state of the nuclear industry in Asia demonstrates that the nations of the continent have little choice but to go nuclear.

Philippines: Will the phoenix rise?

The first nuclear reactor in the Philippines, a 605 MWe pressurized water reactor (PWR) at Napot Point near the city of Morong on the Bataan peninsula of Luzon island, sits idle, while in the increasingly impoverished cities of the archipelago, the number-one, high-ticket, hot-selling item is a diesel generator which can light up the home and provide for perhaps one ceiling fan. Such is the state of affairs in the Philippines, which was perhaps the most infrastructurally developed Asian country in the 1950s, outside of Japan. Today, the Philippines is lagging behind the five other member nations of the Association of Southeast Asian Nations—Indonesia, Thailand, Malaysia, Singapore, and Brunei. What happened to the Philippines Nuclear Power Plant 1 (PNPP 1) is what has happened to the country as a whole in the past ten years or so.

The PNPP 1 has been a victim of a massive anti-nuclear campaign that drew strength from the United States during the environmentalist-infested days of the Carter administration. The anti-nuclear démarches issued from Washington became enmeshed with Washington's obsession to get rid of the alleged dictator, then President of the Philippines, Ferdinand Marcos, and his allegedly dictatorial policies. The advent of the Reagan administration in 1981 did not change U.S. policy toward Manila. Earlier, the Carter administration had identified President Marcos as the brain behind building the PNPP 1. Rabid environmentalists joined anti-Marcos dissidents living within a stone's throw from the U.S. State Department. In 1986, President Marcos was physically removed from the Philippines and the PNPP 1 has gone into hibernation since.

A concert of howling wolves

The siting of the nuclear power plant in the first place had come under attack from the anti-Marcos dissidents residing in Washington. The PNPP 1 was designed and constructed according to the same codes and standards enforced by the U.S. Nuclear Regulatory Commission, which overruled the less stringent regulatory requirements suggested by the Philippines Atomic Energy Committee (PAEC). Some of these measures, implemented arbitrarily while the plant was under construction and when most of the safety and regulatory equipment had already been fabricated, delayed the construction further, stretching the construction time by eight years and increasing the cost by $1.1 billion.

In 1958, the Philippines government ratified the statutes of the International Atomic Energy Agency, and in the same year, the PAEC was established. In 1960, the Philippines government requested the IAEA to undertake a survey of the prospects for nuclear power in the Philippines, particularly the "economic and technical aspects of a nuclear power plant."

The IAEA report concluded that a nuclear power plant could be added to the Luzon power grid. In 1962, the Philippines government, aided by the United Nations Special Fund, commissioned the IAEA to do a feasibility study for setting up a plant on Luzon island. The report, submitted in 1965, recommended building nuclear power plants by the early 1970s. In 1968 the Atomic Regulatory and Liability Act was enacted and the Philippines government entered into a new international agreement with the U.S. government, which included building two nuclear power plants and the long-term supply of enriched reactor-grade uranium. Over the next decade, various studies were conducted to determine the optimal sites for nuclear facilities.

The Philippines government's decision to opt for nuclear power was spurred by its lack of energy resources, and further by the 1973 oil crisis. At that time, the Philippines depended on imported oil for 95% of its commercial energy consumption, and most of the oil came from the Arabian peninsula. Almost all electricity was generated by oil-burning power plants. It was estimated that a 600 MWe nuclear power plant would allow the National Power Corp. (NPC) to divert 6 million barrels of oil annually to meet the needs of other areas of the economy. NPC estimates also showed that using nuclear instead of coal would save the country $12.3 million annually.

Today, the PNPP 1 sits like a huge albatross around the neck of the Philippines economy. Recently, Westinghouse Electric and Burns and Roe Associates, the principal builders and designers, were cleared by a U.S. federal court in Newark, New Jersey, of civil bribery and conspiracy charges in connection with the building of PNPP 1. The suit was brought by the Philippines government under then-President Corazon Aquino. Current President Fidel Ramos had compromised all along with the same people who virulently opposed nuclear power, and pointed the finger at President Marcos as the source of all problems in the Philippines.

Pakistan: a reprieve

Like many other developing nations, Pakistan suffers acutely from a shortage of electrical power. Most of the cities in Pakistan undergo hours of power cuts affecting industries as well as commercial enterprises. Per capita electricity consumption in Pakistan is close to 150 kwh, which is about one one-hundredth of electricity consumption in the western countries and Japan. Since Pakistan does not have much coal, although it has rich reserves of natural gas, and since it has exploited most of its hydropower potential, there is no way that the country can survive without nuclear power.

Perhaps no other nuclear program in Asia was so influenced by the geopolitics of the Cold War days as Pakistan's. Twice the French had offered Pakistan nuclear reactors, and twice they went back on their word. The first offer was made by President Valéry Giscard d'Estaing to Pakistani Prime Minister Zulfikar Ali Bhutto in the 1970s. Subsequently, Giscard was armtwisted by U.S. Secretary of State Henry Kissinger to drop the offer. Later, during the first term of Prime Minister Benazir Bhutto, in 1989, French President François Mitterrand made a public speech committing to Pakistan two 900 MWe nuclear reactors, a promise which he later abandoned with much less fanfare.

In 1977, while in jail waiting to be hanged by a military general, Zulfikar Ali Bhutto wrote that Henry Kissinger had personally threatened him because of the Pakistani leader's efforts to obtain a fuel-reprocessing plant from the French.

Finally, after decades of inviting tenders to no avail, Pakistan has been offered a 300 MWe PWR by China. The China Zhongyun Engineering Corp., which is the builder on behalf of the China National Nuclear Corp., has begun civil works for the plant at Chashma. The CZEC has announced that it will supply the pressure vessel and is making arrangements for other components, following the ban by western suppliers on exports of key components to Pakistan.

Pakistan's only existing nuclear power plant, the Karachi Nuclear Power Plant (Kanupp), a 137 MWe CANDU pressurized heavy-water reactor set up from Canada in the early 1970s, long before computerization became part of design requirements, went through constant ups and downs. The normal upgrading of the plant could not take place, because the Canadians withdrew all support in 1976. As a result, Pakistan was forced to carry out all work on the plant by itself, and the lack of high-technology infrastructure in the country limited the work to maintenance and development of small systems. Now the plant has reached a point when serious and full-fledged technological upgrading is an absolute necessity. Kanupp was put under IAEA safeguards, as distinct from full-scope safeguards, in February 1983. Safeguards include the presence of cameras and computers to monitor fuel bundle insertion and withdrawal. According to available reports, Kanupp has been running at a very low efficiency.

Pakistan's troubles with nuclear suppliers started soon after India carried out its first peaceful nuclear explosion in 1974. Evidence has piled up that Pakistan has acquired the capability to produce nuclear weapons through smuggling in centrifuges for the purpose of enriching uranium to the weapons-grade level, provoking western nations to harden their hostile stance toward Pakistan's nuclear program. Western nations are showing no sign of climbing down from their ban of nuclear technology to Pakistan, a nonsignatory of the Nuclear Non-Proliferation Treaty, and Japan is contemplating withholding all economic aid unless Pakistan dismantles its nuclear weapons program.

But Pakistan has also found other uses for its nuclear program. It uses radiotherapy for cancer treatment and radioisotopes for diagnostics work in the health sector. Two new nuclear medical centers, in Lahore and Islamabad, opened during the 1980s. In the field of agriculture, Pakistan has utilized radiation to develop new crop strains, increasing agricultural yields significantly. Two nuclear centers, one at Faisalabad and the other at Tando Jam in Sindh, have been set up by the Pakistan Atomic Energy Commission to develop mutants of important cash crops using radiation technology.

China: positive on nuclear power

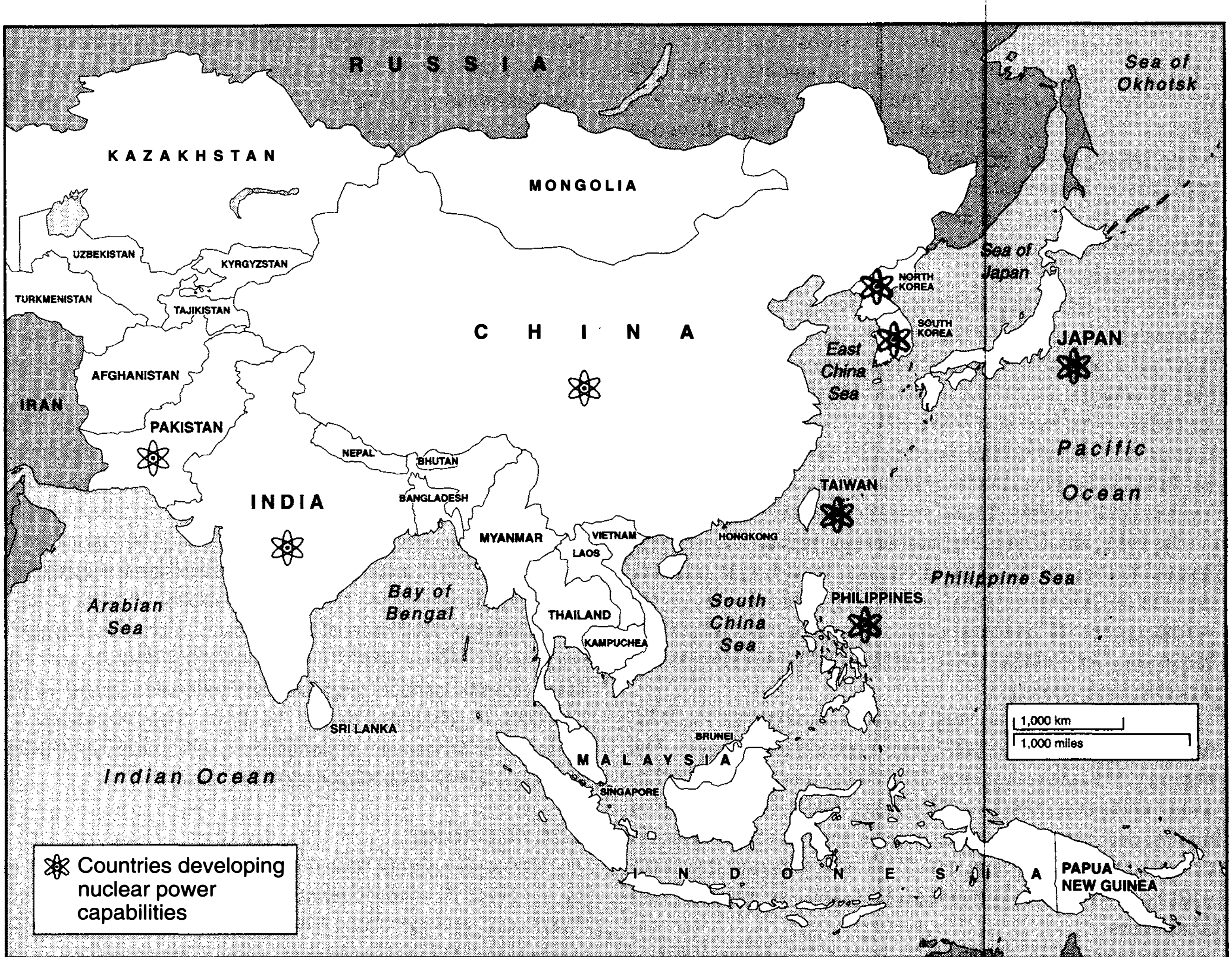
After years of deep slumber, the People's Republic of China is finally waking up to the necessity of establishing nuclear power as a major energy source for the future.

Today, China faces a serious energy crisis. Without nuclear power development, China faces a breakdown crisis. The

Glossary

ABWR: advanced boiling water reactor
APWR: advanced pressurized water reactor
ATR: advanced thermal reactor
BWR: boiling light water reactor
FBR: fast breeder reactor
HTR: high-temperature reactor
NHR: nuclear heating reactor
PHWR: pressurized heavy water reactor
PWR: pressurized water reactor
SGHWR: steam-generating heavy water reactor

Asia needs nuclear power



hectic economic activities of the Deng Xiaoping era are consuming crude oil at a rapid pace. China, the fourth largest producer of crude oil, has stopped exporting crude altogether, and, in 1993, was forced to import crude to meet domestic demand.

As of 1992, China had installed a generating capacity of 165 GWe, a sevenfold jump from 1970. Out of this 165 GWe, 0.3 GWe comes from nuclear, while hydropower contributes 40 GWe, and thermal, which is exclusively coal based, contributes the remaining 125 GWe.

But China faces serious problems in both the thermal and the hydroelectric subsectors. China's coal reserves are estimated at 967 billion metric tons. China already mines 1.1 billion metric tons annually. About 80% of the coal reserves are in the north, northeast, and northwest, and most are remote from population centers. Further exploitation of coal, besides the pollution factor, which is already serious, requires a drastic improvement of the country's rail infrastructure to transport it. Even to cope with the existing coal demand, China is negotiating with Australia for coal imports.

China's hydroelectric resources are also difficult to exploit and distribute. Estimated generation potential in the hydroelectric subsector is close to 380 GWe, of which China has exploited about 10%. The overwhelming bulk of the hydroelectric potential is located in the southwest in Tibet, far from population centers. China intends to increase capacity from 38 GWe to about 70 GWe by the year 2000. This will include the biggest hydroelectric station in the world, at Three Gorges on the Yangtze River, with a planned capacity of 17.86 GWe. The project, when completed, is slated to supply electricity to central and east China.

On the other hand, China has extensive deposits of uranium in seven regions throughout the country, totaling 57,000 tons. As a result, China is planning to base its nuclear program on uranium as fuel. Reports indicate that China has uranium deposits large enough to support its nuclear program and provide uranium for enriching purposes for export as well.

But until recently, China has not taken advantage of this resource to meet its energy needs.

In 1964, China first exploded an atomic bomb and joined the privileged group of the nuclear weapons club. In so doing, China also acquired some technological benefits, in the form of uranium ore prospecting, mining, and processing, fuel element fabrication, spent fuel reprocessing, and radioactive waste management. It also developed nuclear technology applications in agriculture, medicine, and industry. However, China went that far and no farther. Nuclear power for commercial use remained derailed by the economic follies of Maoist China.

In 1976, following the Cultural Revolution, which almost decimated the country's entire scientific community, China drew up a plan for a civilian nuclear program, including a plan to acquire a series of imported PWRs. Chinese leaders agreed to order two 900 MWe PWRs from Framatome, the French firm then building reactors as a Westinghouse licensee. In 1979, however, facing serious problems in accumulating foreign exchange, China cancelled the order.

In 1980, the China Nuclear Energy Industry Corp. was formed within the Ministry of Nuclear Industry, to promote the sale of Chinese uranium and enrichment services on the world market. It also sold research reactors and offered to take spent fuel elements from foreign utilities for storage and possible reprocessing.

The first civilian nuclear program, announced in 1978, had two strategies and both were kept alive officially. The Ministry of Nuclear Industry favored the promotion of indigenous nuclear industry development, while the Ministry of Energy and Water Resources was for foreign involvement in China's nuclear program. The 1978 program compromised, with a call for two indigenous projects and two using imported reactors.

The two indigenous projects were a 300 MWe PWR to be located at Qinshan, and a 125 MWe heavy water reactor to be located in Henan province. The projects to be imported involved discussion between the Jiangsu provincial authorities and Framatome for two 900 MWe PWRs for Sunan and separate discussions between the Guangdong provincial authorities and GEC/NNC (U.K.) for two 900 MWe PWRs for Daya Bay, close to Hongkong.

At a 1981 meeting of the Chinese Society of Electrical Engineering in Suzhou city, Wang Ganchang, an academic, suggested that China could build nuclear power stations with capacities of 2,000 to 4,000 MWe by 1990, and 15,000 MWe by the end of the century. To reach this capacity would require the installation of two to four reactors of 1,000 MWe each over the next nine years, and another 11 to 13 to be completed within the following decade.

Wang's speech gave the impression that China was in the process of developing large nuclear reactors of a 1,000 MWe capacity. This, however, contradicted what Cao Banxi, deputy director of the Ministry of Nuclear Industry, had told Japanese reporters in 1980. Cao Banxi had said that China was developing two kinds of reactors, a pressurized reactor with an output of 300 MWe (the kind China has decided to supply to Pakistan) to be built in Shangai in three to five years, and a heavy-water reactor which has remained on the drawing board. Subsequently, the Chinese authorities commissioned a 300 MWe PWR at Qinshan on the coast at Hangzhou Bay, 126 km southwest of Shanghai in Haiyan county, Zhejiang. The reactor went critical in October 1991; it was connected to the East China Power Network on Dec. 15, 1991, and reached full power in July 1992.

In 1984, a Nuclear Power Leadership Group was formed, under the chairmanship of then-Vice Premier Li Peng, to coordinate the activities of the Ministry of Nuclear Industry and the Ministry of Water Resources and Electric Power involved with nuclear power and the various bureaus and committees that had been set up.

In 1986, the nuclear power program was recast. The Ministry of Water Resources and Electric Power, which was dragged into the program because of its foreign experience, formally handed over its responsibilities for civilian nuclear power construction to the Ministry of Nuclear Industry. In September 1988, a further reorganization saw the formation of a state corporation, the China National Nuclear Corp., which incorporated most of the Ministry of Nuclear Energy's nuclear activities, while the Ministry of Energy and Resources transferred its responsibility on nuclear power to the Ministry of Electric Power. All these reorganizations are believed to represent a consolidation of Chinese indigenous efforts to develop its nuclear power program.

The beginning

Under the eighth and ninth five-year plans, drawn up by the State Planning Commission, the Ministry of Energy Resources, and the China National Nuclear Corp. (CNNC), it was estimated that by the year 2000, China will have some 6,500 MWe of nuclear-based commercial power generation capacity, and that a further 8,000 MWe would be under construction at that time. However, due to a paucity of funds and other factors, only Qinshan 1 (300 MWe and operating), and two more units in Qinshan (each 600 MWe), and Guangdong I and II (each 900 MWe) at Daya Bay (Guangdong I is already hooked into the grid system), totaling 3,300 MWe, will be in operation by the year 2000. CNNC projects that another 8,000 MWe of additional nuclear power generation will come from among the planned stations listed in **Table 1.**

Reports indicate that the CNNC has already identified a site for the Guangdong 2, which eventually will house four 1,000 MWe units and is often referred to as the Dongping site. These nuclear plants will be imported from abroad, and it has been reported that Framatome and a Westinghouse/Mitsubishi Heavy Industries consortium have already been contacted. The Liaoning plants are expected to house two 1,000 MWe Russian VVERs from Atomash, based upon the

TABLE 1

Nuclear plants under commission, under construction, and ordered as of January 1994.

Philippines
PNPP 1, 620 MWe (to be commissioned in 1995)

Pakistan
Kanupp 1, 137 MWe, near Karachi
Chasnupp 1, 300 MWe, at Chashma (under construction)

China
Guangdong 1, 900 MWe in Daya Bay
Guangdong 2, 900 MWe in Daya Bay (to be commissioned)
Planned:
Guangdong (two 1,000 MWe units)
Liaoning (two 1,000 MWe units)
Sanmen (two 1,000 MWe units)
Fujian (two 600 MWe units; or two 1,000 MWe units)
Jiangxi (two 300 MWe units)
Qinshan 3, (two 600 MWe units)
Qinshan 1, 300 MWe in Zhejiang province (to be commissioned)

Korea
KNU 1, 565 MWe at Kori
KNU 2, 605 MWe at Kori
KNU 3, 630 MWe at Wolsung
KNU 5, 900 MWe at Kori
KNU 6, 900 MWe at Kori
KNU 7, 950 MWe at Yeonggwang
KNU 8, 950 MWe at Yeonggwang
KNU 9, 920 MWe at Uljin
KNU 10, 920 MWe at Uljin
KNU 11, 950 MWe at Yeonggwang (to be commissioned in 1995)
KNU 12, 950 MWe at Yeonggwang (to be commissioned in 1996)
KNU 13, 663 MWe at Wolsung (to be commissioned in 1997)
KNU 14, 950 MWe at Uljin (to be commissioned in 1998)
KNU 15, 950 MWe at Uljin (to be commissioned in 1999)
KNU 16, 663 MWe at Wolsung, ordered

Taiwan
Chinshan 1, one 636 MWe unit, northern Taiwan
Chinshan 2, one 636 MWe unit, northern Taiwan

Taiwan *(con't.)*
Kuosehng 1, one 985 MWe unit, northern Taiwan
Kuosehng 2, one 985 MWe unit, northern Taiwan
Maanshan 1, one 951 MWe unit, southern Taiwan
Maanshan 2, one 951 MWe unit, southern Taiwan
Yenliao 1, one 1,000 MWe unit, under construction
Yenliao 2, one 1,000 MWe unit, under construction; a proposal for four 1,000 MWe units has been cleared

India
Tarapur 1, 160 MWe
Tarapur 2, 160 MWe
Tarapur 3, 470 MWe (to be commissioned in 2000)
Tarapur 4, 470 MWe (to be commissioned in 2001)
Rajasthan 1, 207 MWe
Rajasthan 2, 207 MWe
Rajasthan 3, 220 MWe (to be commissioned in 1997)
Rajasthan 4, 200 MWe (to be commissioned in 1997)
Madras 1, 220 MWe
Madras 2, 220 MWe
Narora 1, 220 MWe
Narora 2, 220 MWe
Kakrapar 1, 220 MWe
Kakrapar 2, 220 MWe
Kaiga 1, 220 MWe (to be commissioned in 1996)
Kaiga 2, 220 MWe (to be commissioned in 1996)

Japan
Hamaoka 1, 515 MWe
Hamaoka 2, 806 MWe
Hamaoka 3, 1056 MWe
Hamaoka 4, 1092 MWe
Shimane 1, 439 MWe
Shimane 2, 790 MWe
Tomari 1, 550 MWe
Tomari 2, 550 MWe
Shika 1, 513 MWe
Tokai 1, 159 MWe
Tokai 2, 1080 MWe

Japan *(con't.)*
Tsuruga 1, 341 MWe
Tsuruga 2, 1115 MWe
Mihama 1, 320 MWe
Mihama 2, 470 MWe
Mihama 3, 780 MWe
Takahama 1, 780 MWe
Takahama 2, 780 MWe
Takahama 3, 830 MWe
Takahama 4, 830 MWe
Ohi 1, 1120 MWe
Ohi 2, 1120 MWe
Ohi 3, 1127 MWe
Ohi 4, 1127 MWe
Genkai 1, 529 MWe
Genkai 2, 529 MWe
Gankai 3, 1127 MWe
Genkai 4, 1127 MWe (to be commissioned in 1997)
Sendai 1, 846 MWe
Sendai 2, 846 MWe
Fugen ATR, 148 MWe
Monju 280 MWe (only commissioned for a liquid metal fast breeder reactor as of now)
Ikata 1, 538 MWe
Ikata 2, 538 MWe
Ikata 3, 538 MWe (to be commissioned in 1995)
Onugawa 1, 497 MWe
Onugawa 2, 796 MWe (to be commissioned in 1995)
Fukushima Daiichi 1, 436 MWe
Fukushima Daiichi 2, 760 MWe
Fukushima Daiichi 3, 760 MWe
Fukishima Daiichi 4, 760 MWe
Fukushima Daiichi 4, 760 MWe
Fukushima Daiichi 6, 1,067 MWe
Fukushima Daini 1, 1,067 MWe
Fukushima Daini 2, 1,067 MWe
Fukushima Daini 3, 1,067 MWe
Fukushima Daini 4, 1,067 MWe
Kashiwazaki Kariwa 2, 1,067 MWe
Kashiwazaki Kariwa 3, 1,067 MWe
Kashiwazaki Kariwa 4, 1,067 MWe (to be commissioned in 1994)
Kashiwazaki Kariwa 5, 1,067 MWe (to be commissioned in 1994)
Kashiwazaki Kariwa 6, 1,067 MWe (to be commissioned in 1996)
Kashiwazaki Kariwa 7, 1,315 MWe (to be commissioned in 1997)

December 1992 agreement between the two countries. The Liaoning project is expected to be a turnkey project, carried out by Atomenergoexport of Russia and paid for by exports from China after the station starts operating.

Additionally, a conference in Hangzhou in December 1992 unfolded a plan for a "nuclear island." Maotou Island in Sanmen Bay, 65 km north of Jiantiao in Zhejiang province, has reportedly been selected as the site. The nuclear island will accommodate 10,000 MWe of nuclear power-generation capacity.

The Shanghai Nuclear Research and Design Institute has reportedly been performing feasibility studies on two possible sites in Jiangxi province, and it was reported that a site at Maozidingshan, Pengze county, in the northern part of the province, has been selected.

At the same time, China is taking the lead internationally in the field of the gas-cooled "pebble-bed" high temperature reactor (HTR), pursuing a program of reactor construction and technology development which is practically unique in the world today. Modular HTR plants, which can produce high-temperature process heat for industrial use as well as electricity, are destined to play a crucial role in coming applications of nuclear energy throughout the developing sector. As a high-priority project of the government's advanced technologies program, an experimental 10 MW HTR module is being built at the Qinghua University Nuclear Research Center near Beijing. This unit, based on the German "pebble-bed" HTR technology, is scheduled to begin operation in 1998. Facilities are now under construction for fabrication of the spherical fuel elements for this and future larger HTR reactors. In addition, the Qinghua Center has developed a low-temperature nuclear heating reactor (NHR) technology, for district heating, desalination, and other applications. A 5 MW test version has been successfully operated and work is going ahead to develop a 200 MW version for domestic use and export.

In the area of the fuel cycle—mining and processing, enrichment, fuel fabrication, reprocessing, and waste management—China is well developed. The enrichment plant at Lanzhou, in Gansu province, was decided upon back in the 1950s. The plant has since been enlarged, but it does not meet the amount of China's exports annually. Unofficial reports indicate that China has set up other enrichment plants in Sichuan and Shaanxi provinces. There are also reports that the CNNC is developing a gaseous centrifuge plant and is negotiating with Russia to buy a 200,000 SWU/year centrifuge enrichment plant the same size as that of the Lanzhou plant.

India: Bhabha's vision derailed

After years of preparation, the Indian nuclear program is retreating, at a time when the country is reeling due to lack of power. For all practical purposes, the nuclear program has been shoved into a corner, starved of funds. While this antinuclear policy has been quietly carried out, reports indicate that by the turn of the century, India's peak power demand will be about 50% more than the grids can supply.

There is no good reason that things should have come to such a pass. India's nuclear power development efforts began in the 1950s when Dr. Homi Bhabha, the first head of India's Atomic Energy Commission and the motor behind building up infrastructure for future nuclear power generation, outlined a three-phase program for India. Bhabha's outline encompassed development and application of natural uranium-fueled heavy water reactor technology on the model of the CANDU, mastery of reprocessing technology, and development of breeder reactor technology, using plutonium as the fuel initially, and a thorium-based fuel system later.

At the heart of the Indian program was the aim of indigenization of nuclear power projects. Dr. Bhabha's direction of the atomic energy community was guided by his conviction that achieving self-reliance in all aspects of the technology was essential. In 1957, the Electronics Corporation of India Ltd. was set up with the know-how developed at the Tata Institute of Fundamental Research, a premier research center established in 1945, and at the Bhabha Atomic Research Center, Trombay. Development of know-how in mining and refining of uranium ore led to the establishment of the Uranium Corporation of India Ltd. in 1967.

Three research reactors, the Apsara, Cirus, and Zerlina, were developed by 1962. Besides providing data which gave nuclear physicists a clearer idea about the controlled nuclear reaction, the research reactors facilitated the development of highly skilled scientific manpower. The successive research reactors became training grounds for generating qualified scientific and technical manpower, as well as facilities for conducting research in the frontier areas of basic science. Later, India developed three other research reactors: Purnima, a zero-energy fast reactor commissioned in 1972 for studies in fast reactor physics; R5, a high-flux reactor; and a natural uranium heavy-water moderated 100 MW reactor for production of isotopes for special applications, and also for development of power technology. Perhaps the most important research reactor for India was Purnima 2, which went critical in 1984 with about 500 grams of uranium-233.

Uranium-233 is a man-made fissile isotope of uranium produced by irradiation of thorium-232 in a reactor. It is chemically separated, just as plutonium-239 is produced from uranium-238. This material was produced using the CIRUS research reactor. The Purnima 2 reactor is unique from two standpoints. First, it is the first such reactor to exist in the world, and, second, the long-range program for nuclear power in India is to be based upon conversion of thorium-232 to uranium-233, for use in thermal or breeder reactors. The Bhabha Atomic Research Center research program concentrated on problems associated with the fabrication, irradiation, and reprocessing of thorium, and the experimental neutronics associated with the use of uranium-233 in reactor systems.

The Indian program, based on thorium, will exhibit in the coming years power demonstration using thorium-232, plutonium-239, and uranium-233. Instead of building a reactor to exhibit this, it will be achieved through partial loading of thorium in an existing reactor. Analysis has shown that it is possible to achieve a self-sustaining thorium-uranium-233 fuel cycle in a pressurized heavy-water reactor. For the power demonstration, about 40 channels of a pressurized heavy-water reactor will be loaded first with thorium-plutonium mixed oxide, and later with thorium-uranium-233 mixed oxide fuel. The fuel will be analyzed for actual breeding.

Despite India's scientific achievements, the transfer of nuclear power into broad use for industrialization has stagnated, not only because of inadequate funds, but also because of fuel problems. Total available natural uranium reserves are small. Reasonably assured resources amount to about 29,000 tons, while additional estimates account for another 24,000 tons. This ore is low grade, and with low uranium content (only half of the average uranium content of ores exploited around the world). But, at the same time, India possesses the world's largest thorium deposits, in the form of monazite, in the beach sands of Kerala on the southwestern coast. Monazite makes up about 1.5-3.5% of these beach sands, and thorium makes up about 9% of the monazite. Easily extractable resources of thorium amount to at least 320,000 tons. India has already demonstrated that uranium-233 can be produced from the Kerala beach sands.

In opting for pressurized heavy-water reactors, and not the commonly used pressurized or boiling light-water reactors, the fuel consideration played a major role for India.

The other important aspect of India's overall nuclear program is developing the fast breeder reactor. In the mid-1980s, the Fast Breeder Test Reactor was commissioned at Kalpakkam, in the southern state of Tamil Nadu. The reactor has a capacity to generate 40 MW of thermal power, equivalent to 13 MW of electricity. The FBTR's design was based on the original design of the French fast reactor Rapsodie. Following FBTR, it is expected that the focus will shift to the development of a 500 MWe Prototype Fast Breeder Reactor. The original program suggested that the PFBR would be ready by the year 2000, but this target will not be met.

Although the Indian program called for building pressurized heavy water reactors, the first two nuclear reactors that were commissioned for commercial use in India were boiling light water reactors (BWRs), using enriched uranium as fuel. India negotiated the purchase of these reactors from General Electric in the 1960s. In 1964, work began on the Tarapur Atomic Power Plants (TAPP 1 and TAPP 2), which consisted of two 220 MWe boiling water reactors. The plants went into operation in 1969, becoming the first commercial nuclear power generators in Asia and in the developing world. The plant was built as a turnkey project, though there was a significant involvement of Indian personnel in designing, constructing, and commissioning the project.

In 1961, India and Canada jointly undertook a study to build commercial power plants using CANDU-type reactors. The first CANDU heavy-water-moderated pressurized water reactor was then being built in Canada. In 1962, Indian authorities decided to build two 235 MWe PHWRs of the CANDU type, fueled by natural uranium. India then entered into an agreement with Canada on the construction of the power plants, with the premise that Canada would transfer technology in the process.

In 1964, with Canadian help, the construction of the Rajasthan Atomic Power Plant 1 (RAPP 1) started, and three years later RAPP 2 began. Poor industrial infrastructure within India and the unproven commercial quality of the PHWR caused immense delays. Finally, in 1973, RAPP 1 was commissioned. But long before many problems were solved, the Canadians walked out of the project, in protest against India's nuclear test in 1974. Although RAPP 2 was commissioned in 1979, its many technical problems have made it an unreliable power source.

Since RAPP 2, which was about 70% indigenous as concerns its capital cost expenses, India has commissioned six more 235 MWe PHWRs. Today almost 95% of the PHWRs are indigenous. India has also succeeded in closing a Fuel Complex TAPP 2, and also fabricates natural uranium fuel for all PHWRs. Heavy water required for moderation in the CANDU-type PHWRs that India builds is now manufactured indigenously. India has four heavy-water manufacturing plants, and latest reports indicate that South Korea has contacted India for the purchase of heavy water. The Indian surplus is due to the slowdown of its nuclear program.

On the downstream end, India built a power reactor fuel-reprocessing plant at Tarapur in 1977. It was designed to reprocess oxide fuels from the TAPP and RAPP plants and has a capacity of 100 tons of uranium per year. Because of the refusal of the United States to sanction reprocessing of the TAPP fuel, India has not reprocessed it. However, the 30-year contract has come to an end, and it is likely that agreement on the TAPP fuel will be reached between Washington and New Delhi.

Despite India's pioneer role in nuclear development in underdeveloped countries, the nuclear program today is in the grip of a bureaucracy whose commitment to India's industrialization is questionable. The private sector, whose contribution to the nuclear power plants does not go beyond supply of non-strategic items, is also less than enthusiastic about setting up nuclear plants. The government's unaccountable secrecy and lack of will to build nuclear power plants has made the people vulnerable to the gossip and rumors spread widely and effectively by various anti-nuclear groups at home and abroad.

In fact, the opposition to nuclear power is growing, and the Kaiga nuclear power plant, which is now under construction in the state of Karnataka and is being starved of funds, has become the target of environmentalist demonstrations.

There were also innumerable attempts made by the western powers to slow down, if not abort, India's nuclear power program, through restriction of technology transfer. The Canadians' 1974 walkout, without transferring the reactor technology as promised by contract, caused a great deal of difficulty in meeting the schedule for installation of nuclear plants. Even today, non-governmental organizations abroad issue reports claiming that Indian nuclear power plants are run shoddily and have been health hazards. These NGOs are supported within India by such organizations as Kalpvriksh and Narmada Bachao Andolan, which campaign against development projects and are trying to build political movements around anti-dam, anti-nuclear, and such other issues. The failure of the government at every level to counter these irrational and rabble-rousing campaigns has pushed the nuclear program to a corner—to the tremendous detriment of the Indian economy.

Taiwan: slowing down perceptibly

Among the Pacific Rim countries in Asia, Taiwan is a major nuclear power reactor customer. However, after an

TABLE 2
Profile of Asian nations

Country	Total population (in millions) 1992	Percent of labor force in industry 1990	Per capita energy consumption (kg oil equivalent) 1991	Urban population as a percent of total population 1992	Percent contribution of nuclear energy to total electricity generation 1992
Pakistan	124.9	20	243	33	1
Sri Lanka	17.7	21	177	22	0
India	880.1	11	337	26	4
Nepal	20.6	1	22	12	0
Bangladesh	119.5	13	57	18	0
Bhutan	1.6	3	15	5	0
Myanmar	43.7	9	—	25	0
Thailand	56.1	11	438	23	0
Vietnam	69.5	12	—	20	0
Laos	4.5	7	42	20	0
Cambodia	8.8	7	—	12	0
Indonesia	191.2	14	279	30	0
Philippines	65.2	16	218	44	0
Singapore	2.8	35	6,180	98	0
Malaysia	18.8	28	1,070	45	0
China	1,187.4	14	602	28	1
North Korea	22.6	30	—	59	—
South Korea	44.1	36	1,940	74	60
Taiwan	20.7	32	—	74	45
Japan	124.5	34	3,550	77	24

Sources: UNDP; Statistical Yearbook of the Republic of China

initial burst, its nuclear power development program has been dormant for almost a decade.

Taiwan has three operating nuclear plants, with two units in each plant with a generating capacity of 5100 MWe. Taipower, the constructor and operator of the country's nuclear plants, has completed a reorganization of its nuclear management in preparation for the construction of two 950-1350 MWe PWRs at Yenliao, now called the Lungmen project. Bids were invited for the nuclear island and initial fuel, although the government has not yet given its approval.

Taiwan's nuclear reactors are all imported from the United States. The first four reactors were BWRs. The third plant, Manshaan, has PWRs. Although the reactors were supplied by Westinghouse Electric Corp., the plants are considered to be the product of a team effort. Taipower handled most of the plant construction, with Sinotech Engineering Consultants, Inc. the contractor on site during the basic construction period.

Despite the head start Taiwan had in nuclear power development, the program did not take off as projected in the late 1970s. In 1982, the plan to build the fourth plant was set aside with the claim that slow economic growth would lower demand for electrical power. However, figures for the first six months of 1982 showed that electrical power consumption had surged ahead at a 6-7% rate. At that point, there were hopes that the plant would be revived and Taipower would tender the postponed units. In 1984, Taipower had also urged mandating eight more reactors by the year 2000. At that time, it was envisaged that the seventh unit would be commissioned in 1993, with a similar-capacity reactor unit commissioned each year thereafter through the year 2000. But Taipower and pro-nuclear forces met with strong opposition. Taiwan's dilly-dallying in expanding nuclear power-generating capacity is reflected in the growing criticism of Taipower for its alleged poor handling of the nuclear units. There are rumors that Taipower will now be privatized.

Indonesia: nuclear power revived

Indonesia does not have a nuclear reactor generating commercial power, and there is no nuclear power plant under construction. The good news is that after decades of soul-searching, the Indonesian government has finally decided to back President Suharto's 1984 statement during the inauguration of the 30 MW research and training reactor center at Serpang, near the capital city of Jakarta, that Indonesia had "no other alternative but to go nuclear." A feasibility study by the Japanese firm Newjec, working for BATAN, the Indonesian National Atomic Energy Agency, has been completed, with the conclusion that work on a nuclear power plant could begin in 2004. The site identified is the Muria peninsula, on the island of Java. On paper, at least, there is a full-fledged nuclear power generation program, which proposes a chain of 12 nuclear power stations over the next 25 years. These time-frames can be highly deceptive; in 1982, the Indonesian government promised to have the first nuclear power station in operation by 1996! The latest report indicates that at the earliest Indonesia can have its first nuclear reactor in operation by 2010.

Indonesia is actively developing its power sector. Under its 1994-99 development plan, Indonesia aims to increase the state-owned power utility Perusahaan Umum Listrik Negara's 13,000 MWe capacity by 11,700 MWe, or 90%. One-third of this is to be privately financed. Its Paitan power complex, where eight coal-fired generating plants are to be built with a generating capacity of 4,000 MWe, is as large as they come anywhere in the world. Two-thirds of the complex is to be built and paid for by private consortia that will sell their electricity to the national grid.

Nuclear power has been under consideration since 1968, but in an archipelago of 12,000 islands floating on oil, nuclear power was not the obvious route.

A feasibility study for the first nuclear power plant indicated that coal-fired plants using coal from Bakit Asam, Indonesia's premier coal field, would generate electricity at about 10% higher cost than a CANDU-type pressurized heavy-water reactor. The report, decidedly favorable to going nuclear, was submitted to the government in 1980, and the Energy Resources Technical Committee made its recommendation to the Energy Board at the end of that year. But in 1981, the board decided to scrap the plan and postpone construction of Indonesia's first nuclear power plant indefinitely.

Since then, however, Indonesia has poured money into coal-fired power plants and gas-fired plants, the latter for medium-term solutions. Indonesia, which used to export gas and was earning about $4 billion annually in recent years, was using liquefied natural gas domestically in such industries as steel, fertilizers, and cement plants. But exploding demand for electricity and Jakarta's inability to opt for nuclear power forced Indonesia to use the gas fired in northeast Java for power generation. In Java alone, there are an estimated 5 trillion cubic feet of recoverable resources in offshore fields. This is enough to generate about 5,500 MW of combined-cycle power plants for 20 years.

Meanwhile, the coal lobby in Indonesia is pushing ahead with large coal-fired plants. Citing the Paitan project, they claim that coal will meet Indonesia's long-term fuel needs. There is plenty of coal: an estimated 34 billion tons, mostly in Sumatra and Kalimantan.

The present feasibility report recommending nuclear power development has come under attack from the environmentalists. The country's largest greenie group, Walhi, is protesting the location of the first nuclear plant, proposed near an inactive volcano on the northern coast of central Java. Walhi's campaign draws sustenance from geological experts who cite the case of Mount Pinatubo, a volcano in the Philippines which remained inactive for almost 700 years, before erupting in 1992. Mount Muria, the central Java volcano, has been inactive for 340,000 years. The Indonesia Atomic Energy Authority also pointed out that nuclear is the only way the enormous energy requirements of the Java Bali grid, where 70% of Indonesia's 180 million people live, can be met.

South Korea: Nuclear program shows strength

South Korea and Japan, both Pacific nations, belong to a different league altogether. With a large industrial economy to support and little power generation resources available, the policymakers in those two countries realized years ago that options for power generation were limited and a transition to nuclear-based power generation was an absolute necessity. Were it not for nuclear power, the future of both these countries would be very bleak indeed.

According to the Asian Development Bank's Energy Planning Unit, South Korea has a gross theoretical capability to generate 3,000 MW of hydropower, of which 2,232 MW of capacity has already been installed, and a meager reserve of 751 million tons of recoverable coal. South Korea continues to import oil and burn a substantial amount of it, along with domestic coal, to produce electricity. However, the unsustainability of a long-term electricity-generating program based on coal and oil propelled policymakers toward nuclear.

As a result, Korea will soon be the Asian nation which has the fastest-growing nuclear power installation program. According to available reports, in the second half of this decade, South Korea will start up seven new units, three of them are 700 MWe CANDU PHWRs and four are 1,000 MWe PWRs. South Korean authorities also plan to install six more 1000 MWe PWRs and one more CANDU, and all of these will be operating by 2010.

South Korea's program was not smooth sailing, however. Its nuclear power plants were charged with having "significant safety flaws" in 1982 by a confidential World Bank report, the "Levy Report." The report was triggered by the fact that South Korea had run up a $40 billion foreign debt and yet, to the dismay of the World Bank and the International Monetary Fund, showed no signs of changing its nuclear course. The World Bank demanded that South Korea slow down its growth rate and lower its power generation target; the Levy Report succeeded in putting the brakes on the development of nuclear power. South Korean authorities have scaled back the original program in the post-2000 period, which would have seen eight PWRs and three CANDUs go on line in the first decade of the next century.

Korea is now pursuing an indigenization program. The process has been slow and carried out primarily through technology-transfer programs. The Korea Electric and Power Co. (KEPCO), the agency in charge of power generation, transmission, and distribution throughout South Korea, built a fuel fabrication plant in the 1980s and is moving to create an indigenous capability in manufacturing power plant equipment. The Korea Heavy Industries Corp. plant, located at a sheltered anchorage in Masan Bay, is presently manufacturing heavy components such as primary circuit vessels and generator stators.

But Korea's efforts to develop a complete nuclear fuel cycle have not met with success. The principal blame lies not with KEPCO or any other agency, but with the geopolitics of the Cold War. Vowing to keep Pacific and Pacific Rim countries free of plutonium, the United States has acted consistently as a barrier to South Korea's fuel cycle plans. When Kori 1 started operating commercially in 1978, the Carter administration, committed to opposing nuclear power development, imposed a reprocessing embargo on all enriched uranium shipped from the United States. South Korean engineers took the embargo as a serious threat to their program. Insisting that the fuel cycle be closed, and that reprocessing be allowed as a consequence, Korean atomic energy authorities moved away from their U.S. suppliers, and placed orders for KNU 9 and KNU 10 with the French reactor manufacturer Framatome. But this did not help the Koreans to close the fuel cycle. Since the late 1980s, Korea has focused on two reactor types, ABB CE's System 80 and AECL's CANDU, and with successive contracts, Korean suppliers have contributed a greater proportion of the work. KEPCO has signed contracts with India's Department of Atomic Energy for the supply of heavy water for its CANDU plants.

South Korea's track record on nuclear non-proliferation is immaculate. It had joined the International Atomic Energy Agency by 1957. In 1975, South Korea ratified the Nuclear Non-Proliferation Treaty, and in the same year reached an agreement with the IAEA for the application of safeguards as recommended in the treaty.

Japan: from strength to strength

Japan now has the world's largest nuclear power construction program, and considering its growing power requirements and the competitiveness of its products, nuclear power has come to be the bread and butter of Japan's future power program.

In 1992, the 41 commercial nuclear power reactors operated at an average capacity factor of 73.6%. The same year, Ohi 4 (1,180 MWe PWR) started commercial operation, fuel loading began at Hamaoke 4 (1,137 MWe BWR) and Shilka 1 (540 MWe BWR), and construction started on Kashiwazaki Kariwa 7 (1,356 MWe ABWR), and Tokai 2 (1,100 MWe BWR). Plans were announced by Tohoku Electric for Onagawa 3 (825 MWe BWR), by Choguku Electric for Shimane 3, and by Kyushu Electric for six more 1,100 MWe reactors, two at Sendai and four at a new site at Kushima. The local municipality approved Japan Atomic Power's plans to build two 1,350 MWe advanced pressurized water reactors (APWRs) at the Tsuruga site. Tokyo Electric Power, Toshiba, Hitachi, and General Electric have sped up their "post ABWR" to meet the target date of operation by 2010. Mitsubishi demonstrated a full working prototype of an advanced PWR control room.

In the present-day context, these figures might seem to indicate that Japan has really sped up its nuclear power development program, but in reality this is not so. Close to 7,000 MWe of new nuclear capacity will be added to the Japanese grid before the next century, but this represents something of a slowdown for the Japanese program: In the previous ten years, 20 new units went into commercial operation, adding close to 13,000 MWe to the grid.

In 1955, when the country's Atomic Energy Act went into force, the emphasis was to start research immediately for the development and utilization of atomic energy for generation of electrical power, agricultural development, medicine, and industry. Ravaged by war, and the victim of two atomic bomb strikes, Japan realized that in order to revive as an economic power, it must have plentiful energy at a low cost. The clean nature of nuclear power was taken into consideration in calculating the cost of construction and recurring maintenance cost of the environment. Since the country was bereft of coal or oil, Japan's business and government leaders began as early as 1953 to formulate a program to develop nuclear power.

With the Atomic Energy Act in place, the government established three pivotal organizations to carry out its vision. The Atomic Energy Commission was established in 1956, as one of the advisory organizations for the prime minister, for the purpose of carrying out the national policy of atomic energy research, development, and utilization. The Science and Technology Agency (STA) was established in May of the same year as an extraministerial bureau of the Prime Minster's Office, with the purpose of encouraging science and technology. The Atomic Energy Bureau was formed soon after to accelerate R&D and the utilization of nuclear energy; and the Nuclear Safety Bureau was formed to administer safety matters as a sub-organization within the STA.

The third most important organization, the Japan Atomic Energy Research Institute, was established in June 1956. Today, JAERI's responsibility is not limited to research and development; it also runs the Takasaki Radiation Chemistry Research Establishment in Gumma Prefecture and the Osaka Laboratory for Radiation Chemistry in Osaka Prefecture.

But the real motor force behind Japan's earlier nuclear power development came from the Ministry of International Trade and Industry (MITI) and Keidanren, Japan's business federation, as Japan's business leaders saw the benefit that the nation's industrial sector would reap if such an advanced technology were implemented.

Once the commitment was made, Japanese authorities forged ahead. Although a well-coordinated environmentalist movement did curb their efforts to a certain extent, the authorities countered the anti-nuclear lobby with a well-organized educational program, which saw thousands of engineers and technicians, loaded with literature and pamphlets explaining the nature of nuclear power, spending years roaming around the interior of Japan and holding village meetings.

The success of nuclear power, besides the nature of the technology itself, was due to the stress on constant improvement laid down by JAERI. Japan has already pioneered the "advanced" boiling water and pressurized water reactors. An advanced boiling water reactor (ABWR) design team comprised of Hitachi and Toshiba Atom (Sweden) and AMN (Italy) formed the basis for the ABWR development. Six Japanese BWR-using utilities headed by the Tokyo Electric Power Company, the single largest power-generating company in the world, together with GE, Hitachi, and Toshiba, set up the necessary framework for developing the technology, as well as carrying out a parallel research program in the early 1980s. Kashiwazaki Kariwa 6, which is expected to be installed in 1996, is the first ABWR, with a generating capacity of 1,315 MWe. A number of ABWRs are also in the pipeline. Among the main features of the ABWRs are: increased rated power output (1,300 MWe-plus) to facilitate maximum utilization of Japan's restricted land area; improved core and fuel design; use of internal recirculation pumps; use of electrically operated (as opposed to hydraulically operated) fine-motion control rod drives, and use of pre-stressed concrete primary containment vessels.

The advanced pressurized water reactors (APWRs) have completed the research and developmental stage, which began with the formation of a conglomerate of Japanese utilities along with Westinghouse of the United States. The basic aims were to enhance the continuous operation period (make it longer than 12 months), shorten periodic inspection times, provide improved control and protection systems, reduce occupational exposures, reduce radioactive waste volume, and, generally improve power output availability and reliability. Among the primary features of the Japanese APWR design is its large capacity (1,350 MWe-plus) using a lower power density core. This will enable 18 months of continuous operation at 75% load factor (equivalent to 13.5 months at 100% load factor). Other features include the use of water moderator displacement rods to attain a saving in both uranium and fuel cycle costs of about 20%, according to available estimates. The first two APWRs, 1,420 MWe each, are being built by Mitsubishi Heavy Industries in collaboration with Westinghouse. These APWRs will be built at Tsuruga, where two nuclear units (one of 341 MWe and the other of 1,115 MWe) already exist.

Another type of power reactor, which the Power Reactor Nuclear Fuel Development Corp. is developing in parallel with the fast breeder reactor in Japan, is the heavy-water-moderated boiling light-water advanced thermal reactor (ATR). The purpose of the ATR is to utilize depleted uranium and recovered plutonium efficiently, to conserve natural uranium. The 165 MWe FUGEN (prototype reactor) was set up in March 1979 for study. Subsequently, it has been announced that the Electric Power Development Corp. is going to build a 606 MWe ATR near Ohma. This will be a scaled-up version of the FUGEN reactor.

The ATR is, in essence, very close to the SGHWR, designed as a plutonium burner, and the initial core will have MOX (mixed oxides of uranium and plutonium) with a plutonium content of 2.5%. Reload fuel will have a plutonium content of 3.1%. As this MOX fuel can use recycled uranium without enrichment, as well as plutonium reprocessed from light-water reactor spent fuel, the ATR conserves uranium and takes care of plutonium produced in the light-water reactors.

The Ohma reactor is a national project and the components will be manufactured jointly by the main Japanese reactor vendors. At present, site preparation has been completed and construction has begun.

JAERI has also designed a high-temperature gas-cooled reactor using prismatic fuel elements (similar to the U.S. General Atomic design). A 30 MW demonstration reactor is now under construction at the Oarai Research Establishment and is scheduled to go critical in 1998.

While emphasizing the ABWR, APWR, and ATR, Japan has virtually turned its back on the FBRs. Japan's 280 MWe MONJU prototype FBR went critical in the early 1990s, but a start on the construction of the second experimental FBR was delayed until 2005. Among the reasons given for the delay were cost, other countries' decision to stop studying the FBR, and public concern about plutonium.

Although the enriched uranium supply in the world is abundant and is expected to remain so for a few more decades, Japan's decision to move to a plutonium economy is as much a decision to make good use of the nuclear fuel generated in the country as it is a decision to resolve the ticklish plutonium issue.

Japan has planned to create an independent nuclear fuel cycle by the early years of the twenty-first century. The country's energy plan has specified the use of mixed oxide fuel. In an interview with the journal of Japan's Power Reactor and Nuclear Fuel Development Corp. (PNC), Sabaro Kukichi, who heads the company's Policy Planning Division, stressed that "MOX and not plutonium is PNC's true fuel for the future." The benefits of using MOX fuel are many, Kikucki said, but the most important is the fact that it delivers more energy for less cost. "Using mixed oxide fuel, U-238 combined with Pu-239 in a fission reactor, we can produce 60 times as much energy as by using U-235." MOX is also presently in consideration in a number of other countries.

The development of nuclear power in Japan is ultimately centered around Japan's willingness to make available reactors to developing countries. *Nihon Keizai Shimbun*, a daily, reported recently that Japan is planning to develop safe, low-cost, electricity-generating nuclear reactors for Chi, Toshiba, and Mitsubishi, among others, for the development of such light-water reactors. Tokyo's plan is to counter Russian reactors, which are easy to use for the production of nuclear weapons.