India Will Construct Four Fast Breeder Nuclear Reactors

by Ramtanu Maitra

In the announcement Jan. 31 of its plan to build four 500-megawatt fast breeder reactors simultaneously, Dr. Baldev Raj, director of the Indira Gandhi Centre for Atomic Research, made evident that India is finally giving its almost-50-year-old nuclear program a much-required push. Raj's announcement was issued just days after Russian President Vladimir Putin, during his Jan. 25-26 visit to New Delhi, promised the delivery of four more 1,000-MW pressurized light water reactors to India (see *International*).

Russia has already supplied India with two large nuclear VVER-1000 (V-392) pressurized light water reactors, under a Russian-financed $3 billion contract. The units are now being built in Koodnakulam, Tamil Nadu, and will be commissioned late in 2007. Russia will supply all the enriched uranium fuel, but India will reprocess the spent fuel and keep the fissile plutonium for its fuel use.

India's Atomic Energy Establishment was set up at Trombay, near Mumbai, in 1957, and later renamed the Bhabha Atomic Research Centre (BARC) in recognition of the pioneering contribution made by India's premier nuclear scientist, Dr. Homi Bhabha.

A Fuel-Centric Program

From the outset, the nation's nuclear power program was designed to meet fuel independence. India's uranium resources are modest, with 54,000 tons identified as reasonably assured resources (much of which has since been depleted by the first-stage reactors), and another 23,500 tons as estimated additional resources *in situ.* It is likely that more uranium reserves will be found in the future, but the fact remains that India, with a billion-plus population and correlated demands, cannot base its entire power future on uranium.

On the other hand, India has reserves of at least 290,000 tons of thorium—about one quarter of the world's total reserves. These findings helped India to develop a three-stage nuclear power program in 1957: The first two stages were considered as necessary stepping-stones to usher in the thorium-fuel-based reactors in the third and final stage.

In the first stage, natural uranium (U-238) was used in pressurized heavy water reactors (PHWRs). In the second stage, the plutonium extracted from the used fuel of the PHWRs was scheduled to be used to run fast breeder reactors (FBRs). The plutonium would be used in the FBRs in 70% mixed-oxide (MOX) fuel to breed uranium-233 in a thorium-232 blanket around the core. In the final stage, uranium-233, a fissile material bred from thorium-232, will power India's future nuclear reactors. FBRs will also have a blanket of natural uranium, which would breed the plutonium required for mixed-oxide fuel to run future FBRs.

To a large extent, India has completed the first stage. Although a few more Pressurized Heavy Water Reactors have been planned, it already has 12 small (varying from 220-MW to 235-MW) and two mid-sized (490-MW) nuclear power reactors in commercial operation. India also has two boiling water reactors supplied by the United States in the 1960s.

These PHWRs use natural uranium (99.3 percent U-238 and 0.7 percent U-235) as fuel and heavy water (deuterium oxide, D_2O, which India manufactures) as moderators. These reactors followed the design of the Canadian reactors, CANDU. As of now, six more nuclear reactors are under construction in India. Four of these are PHWRs of smaller capacity (235-MW), while two are larger 1,000-MW VVER light water reactors supplied by Russia, which use enriched uranium as fuel and light water as a moderator.

Other than the two Russian reactors now under construction, the first two reactors came from the United States, followed by two others from Canada. The two that the United States supplied were the Tarapur 150-MWe Boiling Water Reactors (BWRs) built by General Electric and exported to India in the early 1960s on a turnkey contract in 1968, before the advent of the Nuclear Non-Proliferation Treaty. These were originally of 200-MWe capacity. The reactors were scaled down in power because of recurrent problems, but have run well since. They have been using imported enriched uranium and are under International Atomic Energy Agency safeguards.

The two small Canadian PHWRs at Rawatbhata in the state of Rajasthan, started up in 1972 and 1980, and are also under safeguards.

In 2005, four sites were approved for eight new reactors. Two of the sites, Kakrapar and Rawatbhata, are to have 700-MWe indigenous PHWR units; another is to have imported 1,000-MW light water reactors (LWRs) alongside the two being constructed by Russia at Koodankulam, and the fourth is a new site for 1,000-MW light water units, at Jaitapur in the Konkan region. It is likely that the four Russian 1,000 MW VVERs promised by President Putin will be located at Koodankulam and Jaitapur.

BARC

The Bhabha Atomic Research Centre in Trombay, India. A new Advanced Heavy Water Reactor, using thorium, "the fuel of the future," will be built here.

The Second Stage

In addition to the six reactors now under construction, in 2002 the Department of Atomic Energy issued approval to start construction of a 500-MW prototype fast breeder reactor at Kalpakkam in the state of Tamil Nadu, and this is now under construction. The unit is scheduled to be operating in 2010, fueled with uranium-plutonium oxide (the reactor-grade plutonium is extracted from the spent fuel of existing PHWRs). It will have a "blanket" around the reactor core with thorium and uranium to breed fissile U-233 and plutonium respectively. This will take India's ambitious thorium fuel-based nuclear program to stage 2, and set the scene for eventual full utilization of the country's abundant thorium to fuel reactors.

On Jan. 31, Dr. Baldev Raj announced the formal ushering in of that second stage of nuclear power development, when he told reporters that the Department of Atomic Energy will simultaneously construct four more breeder reactors of 500 megawatts each, including two at Kalpakkam. India's first 20-MW Fast Breeder Test Reactor at Kalpakkam attained criticality on Oct. 18, 1985, making India the sixth nation having the technology to build and operate a fast breeder reactor (others were the United States, United Kingdom, France, Japan, and the then-U.S.S.R.).

The site for the other two fast breeder reactors has not been firmed up yet, but it is likely, at least according to the Tamil Nadu political authorities, that the other two would also be situated in the state of Tamil Nadu. Electricity generated from the prototype fast breeder would be sold to the Tamil Nadu State Electricity Board at Rs.3.22 (about 7.5 cents) per watt-hour unit.

If all goes according to schedule, the Department of Energy expects all four fast breeder reactors to be on line by 2020. Dr. Raj, addressing the reporters at the end of a workshop on research opportunities for physicists, said, "By 2020, we will have totally five breeder reactors and we will be the world leader in breeder technology."

Breeder Fuel Development

The new breeders, whose estimated cost would be close to $550 million each at the present dollar-rupee exchange rate, would first use mixed uranium-plutonium oxide as fuel, and later switch over to metallic fuel. "We can breed much faster with the metallic fuel," Raj said. "By 2020, the technology of making the metallic fuel will be ready."

The technology for mixed oxide fuel is very similar to that of uranium oxide used in thermal (nuclear) reactors. "Using oxide fuel will help us to fine tune and perfect other areas of the breeder reactor technology," said S.B. Bhoje, the director of the Indira Gandhi Centre for Atomic Research in Kalpakkam. Nonetheless, the objective is to switch over to metallic fuel because it has an advantage over mixed oxide fuel in the area of breeding ratio. Breeding ratio is the amount of extra plutonium produced in a reactor that can be used to start a new reactor.

Breeder technology works on the principle of self-sustenance and the ability to produce more plutonium than it actually consumes to produce power. The breeding capability of a reactor is measured by the time it takes to reproduce (double) the fuel which it has burned up in operation. Uranium-plutonium oxide mix provides a breeding ratio of 1.1 (ten years to double), while the metallic fuel can breed as high as 1.4 to 1.5, bringing the doubling time down to seven years or less. The doubling time becomes paramount if, and when, the country goes on overdrive to commission new reactors.

The Third Stage

Although the Department of Atomic Energy's announcement of the four fast breeder reactors ensured the advent of the second stage, India already last year began work on the Advanced Heavy Water Reactor (AHWR)—the third-stage reactors. The AHWR will use thorium, the "fuel of the future," to generate 300 megawatts of electricity, up from its original design output of 235 megawatts. The reactor will have a life of 100 years, and may be built on the campus of India's main nuclear research and development center, the Bhabha Atomic Research Centre (BARC) at Trombay.

The use of thorium-based fuel cycles has been studied for about 30 years, but on a much smaller scale than uranium or uranium/plutonium cycles. Basic research and development has been conducted in Germany, India, Japan, Russia, the U.K., and the U.S.A. Test reactor irradiation of thorium fuel to high burn-ups has also been conducted, and several test reactors have either been partially or completely loaded with thorium-based fuel.

As of now, India is the nation by far the most committed to the use of thorium fuel, and no other country has done as much neutron physics work vis-à-vis thorium as Indian nuclear scientists have done. The positive results obtained in the neutron physics work have motivated the Indian nuclear engineers with their current plans to use thorium-based fuels in more advanced reactors now under construction.

From the technological angle, one reason that thorium is preferred over uranium-238 is because the breeding of the fissile uranium-233 from thorium is more efficient than the breeding of plutonium from uranium-238. The thorium fuel creates fewer non-fissile isotopes, and therefore there is less spent fuel per unit of energy generated. In addition, thorium dioxide, the form of thorium used for nuclear power, is a highly stable compound—more so than the uranium dioxide typically used in today's fuel. Also, the thermal conductivity of thorium dioxide is 10 to 15% higher than that of uranium dioxide, making it easier for heat to flow out of the reactor fuel rods. In addition, the melting point of thorium dioxide is about 500 degrees celsius higher than that of uranium dioxide, and this gives the reactor an added safety margin if there is a temporary power surge.

The construction of the AHWR will mark the beginning of the third phase of India's nuclear electricity generation program. The fuel for the AHWR will be a hybrid core, partly thorium-uranium-233 and partly thorium-plutonium. The AHWR will be a technology demonstrator for thorium utilization.

Nuclear Power to Make Potable Water

In addition to wanting nuclear for power generation and the use of isotopes for industrial, agricultural, and medicinal purposes, Indian nuclear authorities have now come to accept the usefulness of waste heat from nuclear reactors for desalination of water. India is a water-short nation, but much of its southern part is surrounded by seas. There should not be any reason why these areas remain water-short.

Delivering the inaugural address at the Indian Nuclear Society conference at Kalpakkam in 2003, President A.P.J. Abdul Kalam had stressed the need for finding a lasting solution to the water crisis around the world. He said: "Desalination of seawater to produce fresh water appears the best, with 97 percent of the Earth covered by ocean. This could produce perennial supply of fresh water."

President Kalam, a rocket scientist who is known as the "Father of India's Rocket Program," then pointed out that India has begun looking at the use of nuclear power for desalination of seawater. There is already a desalination demonstration plant set up at Kalpakkam, using nuclear waste heat for the multi-stage flash process that produces 4,500 cubic meters a day. "These plants can be scaled up ten times from the present configuration without any difficulty," he said.

Two methods of desalination—reverse osmosis and multi-stage flash—have been demonstrated at the Bhabha Atomic Research Center. Joining voices with President Kalam, the then-Tamil Nadu chief minister Jayalalitha urged the Department of Atomic Energy to set up a large number of smaller desalination plants all along the Tamil Nadu coast using the Kalpakkam experience.

In fact, the Tamil Nadu government has approved the installation of 45 desalination plants in various locations of the Ramanathapuram district at a cost of Rs 5.3 billion, and the installation work has been entrusted to Bharat Heavy Electricals Limited (BHEL), a government of India undertaking. Out of 45 plants, two major ones are at Narippaiyur and in Rameshwaram (300,000 liters per day). The remaining 43 smaller plants (20,000 to 300,000 liters per day capacity) have been designed for treating brackish water from the bore well sources.

The importance of nuclear power for desalination of water to provide clean water to the parched throats and parched land will grow. In a message to readers, publisher and editor-in-chief of the Delhi-based quarterly magazine *World Affairs,* J.C. Kapur, said: "One of the most significant contributions to the cause of energy security would be to design and develop self-contained nuclear power units of 50-100 MW capacity, based on fast breeder reactor technology and using thorium as fuel. It could dramatically increase the availability of electrical power in factories, for infrastructural development and in millions of rural communities and settlements worldwide."