EIR Science & Technology

India Looks to Next Energy Frontier: Fusion Power

The nation is committed to making nuclear power the backbone of its long-term power generation, while its fusion power research situates it to take the crucial next step. Ramtanu Maitra reports.

May 17—Last month, Indian Atomic Energy Commission (AEC) Chairman Dr. R.K. Sinha announced that the design for the thorium-fueled nuclear reactor, known as the **Advanced Heavy Water Reactor (AHWR)**, has been completed. The AHWR will form the third and final stage in India's fuel-cycle plan. A 300-MW prototype is scheduled to be built in 2016, and will start generating electricity by 2023. "To generate a single megawatt of electricity from this world's first thorium-based reactor, it would take at least 7-8 years," said Sinha.

Thorium, a fissionable fuel, is the second-most available element on Earth and abundant in India's coastal sands. No other country's scientists have done as much neutron physics work on thorium as have India's nuclear scientists. The positive results they obtained have motivated India's nuclear engineers to use thorium-based fuels in the more advanced reactors that will soon enter the construction stage.

But while thorium-fueled indigenous nuclear power plants will pave the way for India to produce the sizeable amounts of power it needs in the short term, the country needs to move forward quickly and decisively to set the stage for hydrogen-fueled nuclear fusion-based power generation as its bread and butter for the future.

IAEA

India is now building a 500-MW prototype fast breeder reactor (PFBR) at Kalpakkam (shown here), which is scheduled to go into operation later this year.

The key to any long-term economic and social stability is to generate power of the highest energy-flux density, such as nuclear fission and nuclear fusion, and to refrain from burning natural resources. That is also one of the keys to protecting and sustaining the environment for future generations.

As I will explain in the following pages, India is extremely well placed to lead the way in this area that is so fundamental to the country's prospects for future growth and development.

Dr. Homi J. Bhabha, the "father of India's nuclear program." India's Atomic Research Center in Mumbai is named for him.

A Three-Stage Nuclear Power Program

Guided by the late Dr. Homi Bhabha, widely regarded as the "father of India's nuclear program," India decided on a three-stage nuclear program in the 1950s, when its nuclear power research centers were set up. In the first stage, natural uranium (U-238) was to be used in state-of-the-art **pressurized heavy water reactors (PHWR)**. India has now built and made operational 18 such PHWRs, and five more are under construction.

In the second stage, it was envisioned that plutonium extracted from the spent fuel of the PHWRs would run fast breeder reactors. To do that, India needed to develop its own fast breeder reactor that could use plutonium-based fuel in the core, to breed both U-233 from thorium and Pu-239 from U-238 in the blanket. The Pu-239 and U-233 are needed as driver fuel in the AHWRs of stage three.

India is now building a 500-MW **prototype fast breeder reactor (PFBR)** at Kalpakkam, which is scheduled to go into operation this year. It will use **uranium-plutonium oxide (MOX)** with a thorium blanket to breed fissile U-233. The plutonium content will be 21% and 27% in two different regions of the core. The PFBR will take India's ambitious thorium program to stage two, and set the scene for eventual full utilization of the country's abundant thorium to fuel the reactors. Four more such fast reactors have been announced for construction by 2020.

In the third and final stage, AHWRs will be fuelled by a mix of U-233 and plutonium, which will be converted from thorium and U-238, respectively, by previously deployed and domestically designed fast breeder reactors. Another version of the AHWR will use low-enriched uranium (AHWR-LEU), along with thorium.

When India began the process of building the first PHWRs, the first-stage reactors, they had already been developed by other nations, Canada being the leader at the time. However, India had to develop on its own second- and third-stage reactors. The first of these second-stage reactors, the PFBR, and the breeder reactors that will follow, are intended to boost India's nuclear power generation capacity over the next three decades; but their crucial contribution will be producing the fuel for the third-stage nuclear reactors—the AHWRs.

Beside the PHWRs and the PFBRs now under development, India has two imported **Boiling Water Reactors (BWR)** in Tarapur, four 1,000-MW VVERs from Russia in Koodankulam, Tamil Nadu (one is now operational and a second is under construction, while two others are under contract), and six 1,650-MW EPRs under contract to be set up in Jaitapur, Maharashtra, by the French firm Areva. It can be said that India is now committed to making nuclear power the backbone of its long-term power generation scheme.

Significantly, it was Dr. Bhabha who insisted in the 1950s that atomic power should be the cornerstone of India's power generation; and, despite his mysterious death in 1966, and open opposition, if not outright sabotage, by the developed nations over the following decades, India did not stray from his original plan. Because of the delay, caused primarily by outside forces blocking supplies and trying to starve India of all nuclear-related items, 450 million people in India still live without electricity. Without access to electrical power, their capabilities and potentials have been forcibly suppressed, and the blame for that heinous act should be shared widely, particularly by those who deliberately resorted to devious means over several decades to undermine India's nuclear power program.

The China Lesson

Before the 1980s, when China plunged into rapid economic development, the situation in that country was similar to that of India. Although China had been part of the nuclear weapons club since the 1960s, and thus had access to all nuclear-related equipment and material, that country did not have the basic infrastructure necessary to develop a full-fledged nuclear power program. That came later, after Deng Xiaoping decided that it was time for China to "walk on both legs," i.e., pursue all-around economic and technological progress.

Since the 1990s, China has been setting up electrical power generation stations, mostly coal-fired, at breakneck speed. Since neither China nor the world had the capacity to supply China with the dozens of nuclear reactors that would meet some of its power generation demand, Beijing opted for burning dozens of millions of tons of coal on a daily basis to generate electrical power. The result is an unfolding ecological disaster.

China's massive power generation program using coal at an unsustainable rate was premised on its requirement to enhance and widen its manufacturing base to seize the world market and provide employment to its millions of people. And, indeed, it succeeded in both areas. But this success has come at the cost of destroying vast stretches of China's inland water sources, its air, and even its precious and limited arable land. China's Ministry of Environmental Protection and Ministry of Land and Resources recently pointed out in a joint report that about 16.1% of the country's soil is polluted. Most alarmingly, about 19.4% of the farming land is polluted, according to the report. Unregulated growth, aided by burning coal in massive amounts to generate power, has resulted in industrial waste contaminating land around factories and mines, while automobile exhaust is polluting the air along the country's main highways.

China has a limited amount of arable land—about 112 million hectares and shrinking (about 13% of the total land area). Although it has very high crop yields, China is now wholly dependent on imports for a percentage of basic cereals to feed its population. As more and more agricultural land is being polluted and becoming unusable, it is likely that China's dependence on food imports will increase, and the country will be looking to lease lands in various Third World countries to grow food for China's consumption—a bad situation, indeed.

Can China move out of this trap? It is not likely in the short term. China is now caught in its self-created "Catch-22" situation. It must carry on; it has to maintain its growth rate. But since the country will need decades to acquire the capability to build nuclear reactors in bulk and generate nuclear power at an adequate rate, it means that more coal, mined from all across the world, will be used to create more electrical power—and pollution. To clean up the mess that has already been created, massive amounts of resources will be necessary in the coming years. Such remedial plans are already on Beijing's drawing board.

The problem of burning millions of tons coal on a daily basis to generate power affects the infrastructure in many adverse ways. A 1,000-MW coal-fired power needs about 6,600 tons of coal daily. The amount varies slightly according to the quality of coal used. There are more than 2,300 coal-fired power stations worldwide (7,000 individual units), and approximately 620 of these power stations are in China. And many hundreds more are already on China's drawing boards.

Coal-fired power generation does not simply make the air less breathable, it initiates other problems as well. For instance, vast amounts of water are needed to clean these millions of tons of coal every day for burning. The polluted water needs to be cleaned up, a part of the process that China has put aside for now. In addition, handling these vast amounts of coal on a daily basis is extremely burdensome: The coal needs to be shipped from the ports or mines to the coal washeries to get it ready for burning. For China, that entails lugging in dozens of millions of tons of coal every day, 365 days a year, to feed these hungry burning ovens. Those amounts may soar in the coming years.

The process does not end there. Burning vast amounts of coal also produces vast amounts of fly ash—which is full of acidic chemicals ready to pollute the land, clog the waterways, and kill all living things in the water—so an almost equal amount (in weight) of fly ash then has to be carried to the dumping grounds. What that means is that a large section of China's railroads

Government of India/Dept. of Atomic Energy

India has been engaged in desalination research since the 1970s. This demonstration plant was set up in 2002, at the Madras Atomic Power Station (MAPP), Kalpakkam, Tamil Nadu.

will remain tied up hauling in coal from the ports and mines to inland destinations where the power plants are located and then hauling the fly ash out.

China has walked into a terrible trap. Its energy policy is a case study in unsustainable "development" which India must recognize and, while there is still time, decisively avoid—by deliberately putting a priority on stepping up its nuclear power generation capabilities.

By contrast, a nuclear power plant requires very little fuel—a tiny fraction of what a coal-burning power plant requires. In the case of thorium-fueled nuclear power plants, the fuel requirement will be even less. Why? Because, unlike the pressurized and boiling water reactors that burn about 1% of their fuel before going non-critical, and require refuelling once a year, thorium-fueled power plants can burn more than 90% of the loaded fuel and would thus require refuelling only once in 30 years or so. This means that the overall waste per reactor lifespan will be a fraction of what we have to deal with in the present generation of uranium-fueled reactors. These were the major reasons (besides, of course, India's abundant reserves of thorium) that Dr. Bhabha and Indian scientists opted for this unique three-stage nuclear power generation program.

Nuclear Desalination: Its Time Has Come

With such an advantage in hand, besides laying the foundation for an ecologically sustainable and vast power generation capacity, India should soon be ready to build in bulk, and set up small, sealed thorium-fueled nuclear power plants of 75-MW capacity, or less, all along our 8,000-km coastline, stretching from West Bengal to Gujarat, to provide power to the communities and desalinate water for drinking and other uses.

Nuclear desalination uses the excess heat from a nuclear power plant to evaporate seawater and condense the pure water. It can also make brackish inland water potable. According to experts, small nuclear power plants strung like a necklace along peninsular India's coast can supply the water needs of the population on a daily basis. Indeed, this could be the harbinger of India's "blue revolution."

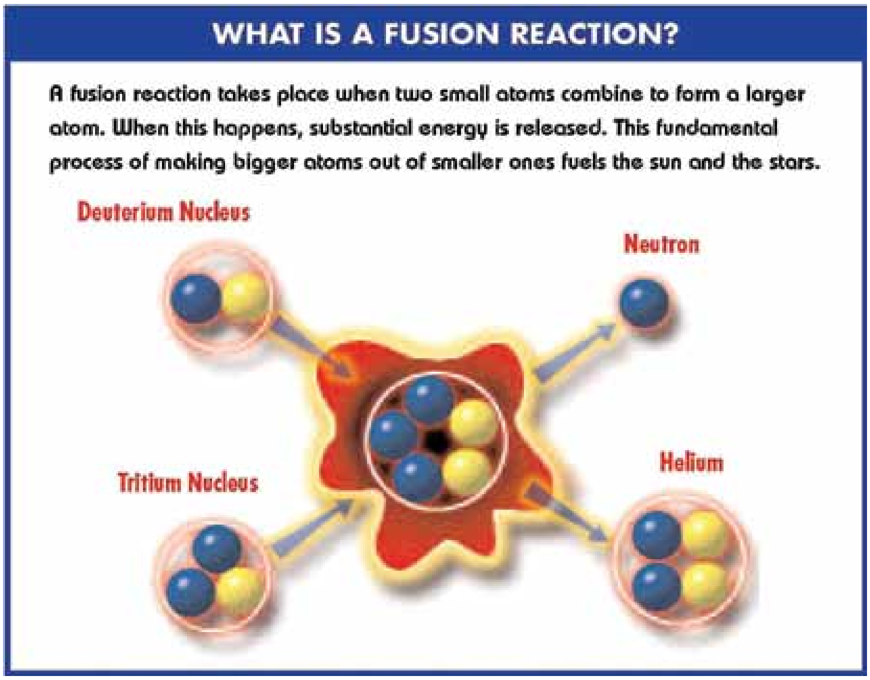
FIGURE 1

India

This is not uncharted territory. The first nuclear desalination plant in the world, the BN-350 fast reactor at Aktau, in Kazakhstan, established during the Soviet Union, and now decommissioned, successfully supplied up to 135 MW of electrical power while producing 80,000 m^3/day of potable water over some 27 years—about 60% of its power being used for heat and desalination. In Japan, some 10 desalination facilities linked to pressurized water reactors operating for electricity production yield about 14,000 m^3/day of potable water.

India has been engaged in desalination research since the 1970s. In 2002, a demonstration plant coupled to twin 170-MW nuclear power reactors (PHWR) was set up at the Madras Atomic Power Station (MAPP), Kalpakkam, Tamil Nadu. This hybrid Nuclear Desalination Demonstration Project (NDDP) comprised a **reverse osmosis (RO)** unit with 1,800 m^3/day capacity and a **multistage flash (MSF)** unit of 4,500 m^3/day, plus a recently added barge-mounted RO unit. This is the largest nuclear desalination plant in the world based on hybrid MSF-RO technology using low-pressure steam and seawater from a nuclear power station.

FIGURE 2



US Department of Energy (2001)

Why Nuclear Fusion?

Considering India's steadfast commitment to bringing its three-stage nuclear power generation program to fruition, one may ask why the nation should opt for nuclear fusion. The key to nuclear power—both fission and fusion—is their high energy-flux density, which enables the society to use this source of power to perform all known industrial and manufacturing activities using very little fuel. Moreover, both nuclear fission and fusion are clean sources of energy and do not encumber the country's infrastructure unduly.

The nuclear fission reaction requires a critical mass of the substance (i.e., the smallest amount of fissile material for a nuclear chain reaction to take place) and a relatively slow neutron to split the atom. No significant amount of energy is needed to initiate the process. By contrast, a nuclear fusion reaction requires a significant input of energy, enough to bring two nuclei so close that nuclear forces become active and the nuclei "fuse" to release energy. But there is an important difference between the two nuclear processes, which gives an advantage to fusion.

In addition to having measurably higher energy-flux density than fission, nuclear fusion uses isotopes of hydrogen for fuel, which does not require the mining and processing that is associated with fission fuels. We know that fusion powers the Sun and stars, as hydrogen atoms fuse together to form helium, and matter is converted into energy. Heated to very high temperatures, hydrogen changes from gas to plasma, in which the negatively charged electrons are separated from the positively charged atomic nuclei (ions). Normally, fusion is not possible because the strongly repulsive electrostatic forces between the positively charged nuclei prevent them from getting close enough together for fusion to occur.

However, if the conditions are such that the nuclei can overcome those forces to come within close range of each other, the attractive nuclear force (which binds protons and neutrons together in atomic nuclei) between them will outweigh the repulsive (electrostatic) force, allowing them to fuse. Such conditions can occur when the temperature increases, causing the ions to move faster and eventually reach speeds high enough to bring them into close contact, at which point they can fuse, causing a release of energy.[1]

New Developments

In the Sun, massive gravitational forces create the right conditions for fusion, but on Earth, they are much

1. "Nuclear Fusion Power," World Nuclear Association, February 2014.

harder to achieve. Fusion fuel—different isotopes of hydrogen—must be heated to extreme temperatures in the order of 100 million degrees Celsius, and must be kept dense enough, and confined long enough, to allow the nuclei to fuse. The aim of the controlled fusion research program is to achieve "ignition," which occurs when enough fusion reactions take place for the process to become self-sustaining, with fresh fuel then being added to continue it.

For decades now, scientists around the world have been carrying out experiments to develop the equipment and methods to generate sustainable power through fusion. The lack of interest of governmental authorities, who are guided by various existing energy lobbies, have deliberately and consistently stymied their efforts. Recently, however, things have begun to change.

Scientists have been pursuing two ways to achieve nuclear fusion. One uses lasers and is called **inertial confinement fusion (ICF)**; the other deploys magnets and is called **magnetic confinement fusion (MCF)**. Recent reports indicate that at the Lawrence Livermore National Laboratory in California, Omar Hurricane and his colleagues at the National Ignition Facility who opted for ICF, have made a significant breakthrough (with the help of 192 high-energy lasers) in the pursuit of commercial fusion power.

The most critical part of the reaction for Hurricane's team was the shape of the fuel capsule. Made from a polymer, it is about 2 mm in diameter—about the size of a pin head. On the inside it is coated with deuterium (2H) and tritium (3H)—isotopes of hydrogen—that are frozen into a solid state.

This capsule was placed inside a gold cylinder, at which the 192 lasers were fired. The lasers hit the gold container, which emits X-rays that heat the pellet and make it implode instantly, causing a fusion reaction. According to Debbie Callahan, a co-author of the study, "when the lasers are fired, the capsule is compressed 35 times. That is like compressing a basketball to the size of a pea." By firing 192 lasers at a fuel pellet the size of a pin head, and compressing it 35 times to produce the pressure and heat needed to start a fusion reaction, the scientists succeeded in producing slightly more energy than the fuel absorbed from the lasers—a breakthrough after years of setbacks and slipped timescales.[2]

In addition to the success at Lawrence Livermore, groundwork has advanced significantly in achieving magnetic fusion, which is the way the Sun produces nuclear fusion. Arguably the more advanced strand of research, MCF is the basis of the **Joint European Torus (JET)** experiment located at the Culham Centre for Fusion Energy (CCFE) in the U.K. In 1997, the JET team achieved a major breakthrough, generating a world record 16 MW of fusion power. But for lack of interest from a world busy with speculative financial rackets, the news didn't get the attention it deserved. In 2017, the team will attempt to break its previous record in a new series of tests, says Prof. Steve Cowley, director of CCFE and chief executive of the United Kingdom Atomic Energy Authority.

ITER Tokamak and Indian Tokamak

JET's ring-shaped "tokamak" magnetic confinement chamber design is also at the heart of the **International Thermonuclear Experimental Reactor (ITER)**, a $20 billion project that aims to demonstrate that fusion can work at a power-plant scale. ITER (Latin for "the way" or "the road") is an international nuclear fusion research and engineering project, which is currently building the world's largest experimental tokamak nuclear fusion reactor, adjacent to the Cadarache facility in southern France. A truly international effort, ITER involves 35 nations, many of which are building complex components that are then shipped to France for assembly.

Once completed, ITER is expected to release 500 MW of power from a 50-MW input and, as many hope, might even achieve ignition. ITER is scheduled to be fired up by 2017.[3]

India is one of the seven partners (along with the European Union (EU), the United States, Russia, China, South Korea, and Japan) working to demonstrate the viability of nuclear fusion on the scale of a power station. As the host-partner of ITER, the EU is the largest contributor, with a 34% stake. India has taken up 9%, which will be executed by the Gandhinagar-based ITER-India, a division of the Institute of Plasma Research (IPR). All seven partners will contribute in kind by bringing components to the project. Twenty-three Indian scientists are part of the ITER project to produce electricity from nuclear fusion.

---

2. Akshat Rathi, "Giant leap for nuclear fusion as lasers blast new route to ultimate energy source," *The Conversation,* Feb. 12, 2014.

3. Duncan Jefferies, "Back to the future: are we about to crack energy fusion?" *The Guardian,* May 7, 2014.

"Indian companies—both in the public and private sectors—with capabilities in nuclear and space industries are being awarded contracts," says Shishir Deshpande, ITER-India project director. Nine large components, amounting to almost a tenth of the project, will be fabricated and sourced from India. The biggest of these, the cryostat—a 3,800-ton pressure chamber the size of a 10-story building—was awarded to Larsen & Toubro (Mumbai) in August. The component, worth more than $160 million, is being built in India and will be shipped to France in sections.

Peter Ginter

India is one of seven nations working on the International Thermonuclear Experimental Reactor (ITER), a $20 billion project which aims to to demonstrate the viability of nuclear fusion. Here, Indian technicians work on the assembly housing the gas-feed system.

Beginning December 2015, the first of the ITER cryostat's components will arrive at the Cadarache site from India. The 54 segments that constitute the cryostat are among the largest and heaviest of the whole tokamak assembly. They will have to be pre-assembled into four sections before being transported to the Assembly Building.

For L&T president M.V. Kotwal—a board member and head of heavy engineering, who also spearheads the company's ambitions in the nuclear industry—the ITER-India contract is a chance to further establish the company's reputation and enhance its engineering capabilities. L&T has sunk about $300 million into a forge shop at Hazira through a joint venture with the Nuclear Power Corporation of India (NPCIL). ITER-India awarded an earlier contract, for the shielding vessel, to Bangalore-based Avasarala Technologies. It is also working closely with TCS and Inox India for cryogenics; ECIL for power electronics; and several other vendors.[4]

India's participation in ITER is not only a firm step in the right direction, it came about because of India's own limited, but useful, fusion program, which began in 1989 at the Institute for Plasma Research (IPR) in Gandhinagar. That year at IPR, India's first tokamak, called ADITYA, was commissioned. It was designed and mainly fabricated in India. The main objective of this experiment was to reliably operate a tokamak at high temperature and plasma current. ADITYA has been upgraded several times to enhance its performance and undertake diagnostics work to get a better understanding of high-energy plasma physics.

The experience garnered from ADITYA over the years has helped Indian scientists move to the next phase, which is to build and operate the next-generation tokamak, called **Steady State Tokamak (SST-1)**. When commissioned, SST-1 will operate in long pulses and will be using superconducting magnets to produce a strong magnetic field of 3 Tesla. The objective will be to set the stage for commercial generation of fusion power, and for that, long pulses and steady-state plasma are essential. The issue at stake is the duration of plasma current, which must remain sustainable for at least a few hours. The tokomak will be using superconducting magnets, a large-scale cryogenic system, high-power radio frequency (RF) systems, etc. SST-1, however, will not be producing any energy from fusion and will be using hydrogen plasma, instead of deuterium-2H and tritium-3H, a radioactive isotope of hydrogen.

4. Ibid.