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India's Nuclear Power Industry Development: Necessity, Growth & Future Advancement

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Abstract: **Nuclear power is the fourth-largest source of electricity in India after thermal, hydroelectric and renewable sources of electricity. Nowadays India has 20 nuclear reactors in operation in six nuclear power plants, having an installed capacity of 4780 MW and producing a total of 29,664.75 GWh of electricity. India's domestic uranium reserves are small and the country is dependent on uranium import to fuel its nuclear power industry. In early 1990s, Russia has been a major supplier of nuclear fuel to India. Due to dwindling domestic uranium reserves, electricity generation from nuclear power in India declined by 12.83% from 2006 to 2008. Following a waiver from the Nuclear Suppliers Group in September 2008 which allowed it to commence international nuclear trade, India has signed bilateral deals on civilian nuclear energy technology cooperation with several other countries, including France, the United States, the United Kingdom, Canada and South Korea. India's nuclear power program has proceeded largely without fuel or technological assistance from other countries. Its power reactors to the mid-1990s had some of the world's lowest capacity factors, reflecting the technical difficulties of the country's isolation, but rose impressively from 60% in 1995 to 85% in 2001-02.**

Keywords: **Nuclear power industry, Uranium, Power reactors, Fuel**

1. INTRODUCTION

Nuclear power is the fourth-largest source of electricity in India after thermal, hydroelectric and renewable sources of electricity. As of 2012, India has 20 nuclear reactors in operation in six nuclear power plants,having an installed capacity of 4780 MW and producing a total of 29,664.75 GWh of electricity. while seven other reactors are under construction and are expected to generate an additiona l 6,100 MW.

India has been making advances in the field of thorium-based fuels, working to design and develop a prototype for an atomic reactor using thorium and low-enriched uranium, a key part of India's three stage nuclear power programme. The country has also recently re-initiated its involvement in the LENR research activities, in addition to supporting work done in the fusion power area through the ITER initiative[1].

India's domestic uranium reserves are small and the country is dependent on uranium imports to fuel its nuclear power industry. Since early 1990s, Russia has been a major supplier of nuclear fuel to India. Due to dwindling domestic uranium reserves, electricity generation from nuclear power in India declined by 12.83% from 2006 to 2008. Following a waiver from the Nuclear Suppliers Group in September 2008 which allowed it to commence international nuclear trade, India has signed bilateral deals on civilian nuclear energy technology cooperation with several other countries, including France, the United States, the United Kingdom, Canada. and South Korea. India has also uranium supply agreements with Russia, Mongolia, Kazakhstan, Argentina and Namibia. An Indian private company won a uranium exploration contract in Niger[2].

2. INDIAN NUCLEAR POWER INDUSTRY DEVELOPMENT

Nuclear power for civil use is well established in India. Its civil nuclear strategy has been directed towards complete independence in the nuclear fuel cycle, necessary because it is excluded from the 1970 Nuclear Non-Proliferation Treaty (NPT) due to it acquiring nuclear weapons capability after 1970. (Those five countries doing so before 1970 were accorded the status of Nuclear Weapons States under the NPT). As a result, India's nuclear power program has proceeded largely without fuel or technological assistance from other countries (but see later section).

Its power reactors to the mid-1990s had some of the world's lowest capacity factors, reflecting the technical difficulties of the country's isolation, but rose impressively from 60% in 1995 to 85% in 2001-02. Then in 2008-10 the load factors dropped due to shortage of uranium fuel. India's nuclear energy self-sufficiency extended from uranium exploration and mining through fuel fabrication, heavy water production, reactor design and construction, to reprocessing and waste management. It has a small fast breeder reactor and is building a much larger one. It is also developing technology to utilise its abundant resources of thorium as a nuclear fuel[3].

3. NUCLEAR INDUSTRY DEVELOPMENTS IN INDIA BEYOND THE TRADE RESTRICTIONS

The Nuclear Suppliers' Group agreement which was achieved in September 2008, the scope for supply of both reactors and fuel from suppliers in other countries opened up. Civil nuclear cooperation agreements have been signed with the USA, Russia, France, UK, South Korea and Canada, as well as Argentina, Kazakhstan, Mongolia and Namibia. On the basis of the 2010 cooperation agreement with Canada, in April 2013 a bilateral safeguards agreement was signed between the Department of Atomic Energy (DAE) and the Canadian Nuclear Safety Commission, allowing trade in nuclear materials and technology for facilities which are under IAEA safeguards. A similar agreement is being negotiated with Australia. Both will apply essentially to uranium supply. The Russian PWR types were apart from India's three-stage plan for nuclear power and were simply to increase generating capacity more rapidly. Now there are plans for eight 1000 MWe units at the Kudankulam site, and in January 2007 a memorandum of understanding was signed for Russia to build four more there, as well as others elsewhere in India. A further such agreement was signed in December 2010, and Rosatom announced that it expected to build no less than 18 reactors in India. At least some of the new units are expected to be the larger 1200 MWe AES-2006 versions of the first two. Russia is reported to have offered a 30% discount on the $2 billion price tag for each of the phase 2 Kudankulam reactors. This is based on plans to start serial production of reactors for the Indian nuclear industry, with much of the equipment and components proposed to be manufactured in India, thereby bringing down costs[4].

Between 2010 and 2020, further construction is expected to take total gross capacity to 21,180 MWe. The nuclear capacity target is part of national energy policy. This planned increment includes those set out in the Table below including the initial 300 MWe Advanced Heavy Water Reactor (AHWR). The benchmark capital cost sanctioned by DAE for imported units is quoted at $1600 per kilowatt. In 2005 four sites were approved for eight new reactors. Two of the sites – Kakrapar and Rajasthan – would have 700 MWe indigenous PHWR units, Kudankulam would have imported 1000 or 1200 MWe light water reactors alongside the two being built there by Russia, and the fourth site was greenfield for two 1000 MWe LWR units – Jaitapur (Jaithalpur) in the Ratnagiri district of Maharashtra state, on the west coast. The plan has since expanded to six 1600 MWe EPR units[5].

4. NUCLEAR POWER GROWTH IN INDIA

India now envisages to increase the contribution of nuclear power to overall electricity generation capacity from 2.8% to 9% within 25 years. By 2020, India's installed nuclear power generation capacity will increase to 20,000 MW (2.0×10^{10} Watts, which is 20 GW). As of 2009, India stands 9th in the world in terms of number of operational nuclear power reactors. Indigenous atomic reactors include TAPS-3, and -4, both of which are 540 MW reactors. India's US$717 million fast breeder reactor project is expected to be operational by 2012–13. The Indian nuclear power industry is expected to undergo a significant expansion in the coming years, in part due to the passing of the U.S.-India Civil Nuclear Agreement. This agreement will allow India to carry out trade of nuclear fuel and technologies with other countries and significantly enhance its power generation capacity. When the agreement goes through, India is expected to generate an additional 25,000 MW of nuclear power by 2020, bringing total estimated nuclear power generation to 45,000 MW. Risks related to nuclear power generation and prompted Indian legislators to enact the 2010 Nuclear Liability Act which stipulates that nuclear suppliers, contractors and operators must bear financial responsibility in case of an accident.

The legislation addresses key issues such as nuclear radiation and safety regulations, operational control and maintenance management of nuclear power plants, compensation in the event of a radiation-leak accident, disaster clean-up costs, operator responsibility and supplier liability. A nuclear accident like the 2011 Fukushima Daiichi nuclear disaster would have dire economic consequences in heavily populated India as did the 1984 Union Carbide Bhopal disaster, the world's worst industrial disaster, covered extensively in Dominique Lapierre's 2009 prize winning book Five Past Midnight in Bhopal[6,7].

Indian President A.P.J.Abdul Kalam, stated while he was in office, that "energy independence is India's first and highest priority. India has to go for nuclear power generation in a big way using thorium-based reactors. Thorium, a non fissile material is available in abundance in our country." India has vast thorium reserves and quite limited uranium reserves. On 7 June 2014, Kudankulam-1 became the single largest power generating unit in India (1000 MWe)[8].

5. NUCLEAR POWER PLANTS

a. Flexibility

It is often claimed that nuclear stations are inflexible in their output, implying that other forms of energy would be required to meet peak demand. While that is true for certain reactors, this is no longer true of at least some modern designs. Nuclear plants are routinely used in load following mode on a large scale in France. Boiling water reactors normally have load-following capability, implemented by varying the recirculation water flow[9].

b. Life cycle

The nuclear fuel cycle begins when uranium is mined, enriched, and manufactured into nuclear fuel, which is delivered to a nuclear power plant. After usage in the power plant, the spent fuel is delivered to a reprocessing plant or to a final repository for geological disposition. In reprocessing 95% of spent fuel can be recycled to be returned to usage in a power plant.

A nuclear reactor is only part of the life-cycle for nuclear power. The process starts with mining . Uranium mines are underground, open-pit, or in-situ leach mines. In any case, the uranium ore is extracted, usually converted into a stable and compact form such as yellowcake, and then transported to a processing facility. Here, the yellowcake is converted to uranium hexafluoride, which is then enriched using various techniques. At this point, the enriched uranium, containing more than the natural 0.7% U-235, is used to make rods of the proper composition and geometry for the particular reactor that the fuel is destined for. The fuel rods will spend about 3 operational cycles (typically 6 years total now) inside the reactor, generally until about 3% of their uranium has been fissioned, then they will be moved to a spent fuel pool where the short lived isotopes generated by fission can decay away. After about 5 years in a cooling pond, the spent fuel is radioactively and thermally cool enough to handle, and it can be moved to dry storage casks or reprocessed[10].

c. Conventional fuel resources

Uranium is a fairly common element in the Earth's crust. Uranium is approximately as common as tin or germanium in Earth's crust, and is about 35 times more common than silver. Uranium is a constituent of most rocks, dirt, and of the oceans. The fact that uranium is so spread out is a problem because mining uranium is only economically feasible where there is a large concentration. Still, the world's present measured resources of uranium, economically recoverable at a price of 130 USD/kg, are enough to last for "at least a century" at current consumption rates.

This represents a higher level of assured resources than is normal for most minerals. On the basis of analogies with other metallic minerals, a doubling of price from present levels could be expected to create about a tenfold increase in measured resources, over time. However, the cost of nuclear power lies for the most part in the construction of the power station.

Therefore the fuel's contribution to the overall cost of the electricity produced is relatively small, so even a large fuel price escalation will have relatively little effect on final price. For instance, typically a doubling of the uranium market price would increase the fuel cost for a light water reactor by 26% and the electricity cost about 7%, whereas doubling the price of natural gas would typically add 70% to the price of electricity from that source. At high enough prices, eventually extraction from sources such as granite and seawater become economically feasible[11].

d. Breeding

As opposed to current light water reactors which use uranium-235 (0.7% of all natural uranium), fast breeder reactors use uranium-238 (99.3% of all natural uranium). It has been estimated that there is up to five billion years' worth of uranium-238 for use in these power plants. Breeder technology has been used in several reactors, but the high cost of reprocessing fuel safely requires uranium prices of more than 200 USD/kg before becoming justified economically. As of December 2005, the only breeder reactor producing power is BN-600 in Beloyarsk, Russia. The electricity output of BN-600 is 600 MW — Russia has planned to build another unit, BN-800, at Beloyarsk nuclear power plant. Also, Japan's Monju reactor is planned for restart (having been shut down since 1995), and both China and India intend to build breeder reactors.

Another alternative would be to use uranium-233 bred from thorium as fission fuel in the thorium fuel cycle. Thorium is about 3.5 times as common as uranium in the Earth's crust, and has different geographic characteristics. This would extend the total practical fissionable resource base by 450%. Unlike the breeding of U-238 into plutonium, fast breeder reactors are not necessary — it can be performed satisfactorily in more conventional plants. India has looked into this technology, as it has abundant thorium reserves but little uranium[12].

e. Fusion

Fusion power advocates commonly propose the use of deuterium, or tritium, both isotopes of hydrogen, as fuel and in many current designs also lithium and boron. Assuming a fusion energy output equal to the current global output and that this does not increase in the future, then the known current lithium reserves would last 3000 years, lithium from sea water would last 60 million years, and a more complicated fusion process using only deuterium from sea water would have fuel for 150 billion years. Although this process has yet to be realized, many experts and civilians alike believe fusion to be a promising future energy source due to the short lived radioactivity of the produced waste, its low carbon emissions, and its prospective power output.

f. Solid waste

The most important waste stream from nuclear power plants is spent nuclear fuel. It is primarily composed of unconverted uranium as well as significant quantities of transuranic actinides (plutonium and curium, mostly). In addition, about 3% of it is fission products from nuclear reactions. The actinides (uranium, plutonium, and curium) are responsible for the bulk of the long-term radioactivity, whereas the fission products are responsible for the bulk of the short-term radioactivity.

g. High-level radioactive waste

After about 5 percent of a nuclear fuel rod has reacted inside a nuclear reactor that rod is no longer able to be used as fuel (due to the build-up of fission products). Today, scientists are experimenting on how to recycle these rods so as to reduce waste and use the remaining actinides as fuel (large-scale reprocessing is being used in a number of countries). A typical 1000-MWe nuclear reactor produces approximately 20 cubic meters (about 27 tonnes) of spent nuclear fuel each year (but only 3 cubic meters of vitrified volume if reprocessed). All the spent fuel produced to date by all commercial nuclear power plants in the US would cover a football field to the depth of about one meter. Spent nuclear fuel is initially very highly radioactive and so must be handled with great care and forethought. However, it becomes significantly less radioactive over the course of thousands of years of time. After 40 years, the radiation flux is 99.9% lower than it was the moment the spent fuel was removed from operation, although the spent fuel is still dangerously radioactive at that time.[51] After 10,000 years of radioactive decay, according to United States Environmental Protection Agency standards, the spent nuclear fuel will no longer pose a threat to public health and safety.

When first extracted, spent fuel rods are stored in shielded basins of water (spent fuel pools), usually located on-site. The water provides both cooling for the still-decaying fission products, and shielding from the continuing radioactivity. After a period of time (generally five years for US plants), the now cooler, less radioactive fuel is typically moved to a dry-storage facility or dry cask storage, where the fuel is stored in steel and concrete containers. Most U.S. waste is currently stored at the nuclear site where it is generated, while suitable permanent disposal methods are discussed.

As of 2007, the United States had accumulated more than 50,000 metric tons of spent nuclear fuel from nuclear reactors. Permanent storage underground in U.S. had been proposed at the Yucca Mountain nuclear waste repository, but that project has now been effectively cancelled – the permanent disposal of the U.S.'s high-level waste is an as-yet unresolved political problem. The amount of high-level waste can be reduced in several ways, particularly nuclear reprocessing. Even so, the remaining waste will be substantially radioactive for at least 300 years even if the actinides are removed, and for up to thousands of years if the actinides are left in. Even with separation of all actinides, and using fast breeder reactors to destroy by transmutation some of the longer-lived non-actinides as well, the waste must be segregated from the environment for one to a few hundred years, and therefore this is properly categorized as a long-term problem. Subcritical reactors or fusion reactors could also reduce the time the waste has to be stored. It has been argued[who?] that the best solution for the nuclear waste is above ground temporary storage since technology is rapidly changing. Some people believe that current waste might become a valuable resource in the future.

According to a 2007 story broadcast on *60 Minutes*, nuclear power gives France the cleanest air of any industrialized country, and the cheapest electricity in all of Europe. France reprocesses its nuclear waste to reduce its mass and make more energy. However, the article continues, "Today we stock containers of waste because currently scientists don't know how to reduce or eliminate the toxicity, but maybe in 100 years perhaps scientists will… Nuclear waste is an enormously difficult political problem which to date no country has solved. It is, in a sense, the Achilles heel of the nuclear industry… If France is unable to solve this issue, says Mandil, then 'I do not see how we can continue our nuclear program. Further, reprocessing itself has its critics, such as the Union of Concerned Scientists.

h. Low-level radioactive waste

The nuclear industry also produces a huge volume of low-level radioactive waste in the form of contaminated items like clothing, hand tools, water purifier resins, and (upon decommissioning) the materials of which the reactor itself is built. In the United States, the Nuclear Regulatory Commission has repeatedly attempted to allow low-level materials to be handled as normal waste: landfilled, recycled into consumer items, et cetera. Most low-level waste releases very low levels of radioactivity and is only considered radioactive waste because of its history.

Following the March 2011 Fukushima nuclear disaster in Japan, populations around proposed Indian NPP sites have launched protests that had found resonance around the country. There have been mass protests against the French-backed 9900 MW Jaitapur Nuclear Power Project in Maharashtra and the 2000 MW Koodankulam Nuclear Power Plant in Tamil Nadu. The Government of West Bengal refused permission to a proposed 6000 MW facility near the town of Haripur that intended to host 6 Russian reactors. But that now is disputed: it's possible for Bengal to have its first nuclear power plant at Haripur despite resistance. A Public-interest litigation (PIL) has also been filed against the government's civil nuclear programme at the Supreme Court. The PIL specifically asks for the "staying of all proposed nuclear power plants till satisfactory safety measures and cost-benefit analyses are completed by independent agencies".But the Supreme Court said it was not an expert in the nuclear field to issue a direction to the government on the nuclear liability issue[13].

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