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Nuclear Power in India: An Inevitable Option for Sustainable Development of a Sixth of Humanity

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Introduction

India is the world's largest democracy with a population of about 1.045 billion and low per capita income. In recent years, it has witnessed an impressive growth rate in GDP. The development aspirations of its populace demand that this growth rate be sustained for a long enough time so as to enable them to have a decent quality of life. This requires matching growth in the availability of energy. Further, the development process is also driving, as expected, a shift in energy use from non-commercial energy sources to commercial sources, particularly electricity. This phenomenon is similar to what has been witnessed by the developed countries in the West. But the situation in India is more complex because of the high density of its population.

Let us look at some data. Electricity generation in the fiscal year 2001-02 was about 515 billion kWh from electric utilities [1] and about additional 120 billion kWh were generated by captive power plants [2]. On a per capita basis, this works out to be 610 kWh per year. In the countries comprising the Organisation for Economic Cooperation & Development (OECD), the corresponding figure is about 10 000 kWh [3]. India's population is expected to rise to 1.5 billion by the year 2050. If we assume that the development aspirations of the people of India would call for per capita electricity generation of about 5000 kWh per year, the country has to plan to have total electricity generation of about 7500 billion kWh per year. This is about 12 times the generation in the fiscal year 2001-02. Electricity generation of this magnitude calls for a careful examination of all issues related to sustainability, including diversity of energy supply sources and technologies, security of supplies, self sufficiency, security of energy infrastructure, effect on local, regional and global environments and demand side management.

In India, the Central Electricity Authority (CEA) undertakes periodic electric power surveys (EPS) to make projections of the energy requirements of the country. These estimates guide the planning process for capacity addition in the country. CEA released its report on the 16th electric power survey in January 2001 and projected energy requirement to increase from 529 014 million kWh in 2001-02 to 1 317 644 in 2016-17. *Table 1* gives further details [4]. Installed capacity on 31 March 2002 was about 104 935 MWe [5].

The concept of sustainability calls for the exploitation of available resources to improve the quality of life of people without harming the interests of future generations, both from the point of the availability of resources and of the degradation of the environment beyond the inherent corrective capability of natural processes. While the environmental burden has to be kept within the limits of self-correction and be geographically well distributed, people's development aspirations have to be given a place of supreme importance in all decision-making processes. After all, 'poverty is the biggest polluter' and is the source of several conflicts.

Fuel resource position

Against this background, let us examine India's fuel resource position and where the nation is headed with regard to the utilisation of this resource for meeting energy requirements. At present, coal is the mainstay of power generation in India. Today more than 70% of power generation is through the burning of coal. The quality of coal available in India is poor, with ash content in the range of 35 to 50%. With an estimated coal reserve [6] of 221 billion tonnes and extremely limited availability of oil and gas, coal will continue to be the mainstay of power generation in India for a long time.

India has a large hydro potential and only a part of this potential has been exploited. All issues related to exploitation of this resource need to be addressed and the full hydro potential needs to be harnessed expeditiously. Displacement of people in a country with a high population density is a major issue and is particularly acute in case of hydro power development. Renewable resources are very important, as they are geographically dispersed and in several areas have good potential. They should be tapped to meet the energy demands of small communities. Unfortunately, at the present level of technology, renewables cannot be used for central power stations and remain very expensive due to high capital costs and their low availability factor [7]. Renewables have additional problems arising from seasonal variations.

Role of nuclear power

Against this backdrop, one may now analyse the importance of nuclear power, which in recent years has been making an increasing contribution to electricity supply and is poised to expand in the years to come. The programme profile spelled out by the Department of Atomic Energy envisages the use of domestic uranium resources in Pressurized Heavy Water Reactors (PHWRs), followed by the recycling of spent fuel in Fast Breeder Reactors. PHWR technology is already in the commercial domain, with a good record of safe operation of nuclear power reactors and several PHWRs are under construction. A detailed Project Report for a 500 MWe Prototype Fast Breeder Reactor has been finalized. Pre-project activities are already in progress and the approval for the main project construction is being processed. Recycling of plutonium obtained from the reprocessing of spent fuel gives us a very large energy resource. While the domestic programme is progressing rapidly to further expand the installed nuclear generation capacity, we have also sought to set up Light Water Reactors based on imported technology. The start of construction of two 1000 MWe nuclear power reactors at Kudankulam in Tamil Nadu is a step in this direction. Technologies to exploit the vast thorium reserves in the country are under development at the Bhabha Atomic Research Centre (BARC). A 300 MWe Advanced Heavy Water Reactor with very innovative safety features has been designed for this purpose.

Nuclear power is thus a well-established technology in India with very significant potential for avoiding the burning of large quantities of poor quality coal. Given the large population (one-sixth of the world) and the highly inadequate availability of electricity at present, nuclear power in India can contribute to both the development of a large fraction of world population and also to the protection of the global environment. Given the uranium and thorium resources of the country, this has inevitably to take place through the use of Fast Breeder Reactors and thorium reactors, which can tap the full energy potential in nuclear fuel materials through the use of recycling technologies.

Nuclear power programme

The first stage of the nuclear power programme, comprising setting up of Pressurised Heavy Water Reactors (PHWRs) and associated fuel cycle facilities, is already in the commercial domain. The technology for the manufacture of various components and equipment for PHWRs in India is now well established and has evolved through active collaboration between the Department of Atomic Energy (DAE) and the industry. Twelve PHWRs are operating and six PHWRs comprising a mix of 540 and 220 MWe rating are under construction. As we gain experience and master various aspects of the nuclear technology, performance of our plants is continuously improving. The average capacity factor of the plants operated by the Nuclear Power Corporation of India Limited (NPCIL) has steadily risen from 60% in 1995-96 to 85% in the year 2001-02.

The second stage envisages the setting up of Fast Breeder Reactors (FBRs) backed by reprocessing plants and plutonium-based fuel fabrication plants. In order to multiply the fissile material inventory, Fast Breeder Reactors are necessary for our programme. A higher power-generating base through Fast Breeder Reactors is also needed to establish the use of thorium on a large scale in the third stage of our programme. A 40 MWt Fast Breeder Test Reactor (FBTR) has been operating at the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, since attaining first criticality on 18 October 1985. FBTR uses a unique and indigenously developed mixed uranium carbide-plutonium carbide fuel, which has functioned extremely well up to the current burn up of about 100 000 MWd/t. The FBTR has provided valuable experience with liquid metal Fast Breeder Reactor technology and the confidence to set up a 500 MWe Prototype Fast Breeder Reactor (PFBR). The PFBR design is now ready and, with several full-scale components already manufactured by Indian industry, is well poised for start of construction. Pre-project activities are already in progress at Kalpakkam near Chennai.

The third stage will be based on the thorium-uranium-233 cycle. Uranium-233 is obtained by irradiation of thorium in PHWRs and FBRs. An Advanced Heavy Water Reactor (AHWR) is being developed at Bhabha Atomic Research Centre (BARC) to expedite transition to thorium-based systems. The reactor physics design of AHWR is tuned to generate about 75% power from thorium. A detailed project report for this reactor has been made and the construction of this reactor is planned to start in the year 2004.

To jump start the nuclear power programme, two Boiling Water Reactors were set up at Tarapur near Mumbai in the late 1960s. These reactors are still in operation. In a similar manner, in parallel with the indigenous self-reliant three-stage programme, we are planning to set up Light Water Reactors. The ongoing construction of two 1000 MWe units at Kudankulam in technical cooperation with the Russian Federation is a step in this direction.

Status of nuclear technology in India

Nuclear power technology in India has reached a state of maturity and the Department of Atomic Energy continues to take steps to further its development. These steps are aimed at further improving the safety and availability of operating stations, reducing the gestation period of plants under construction by using innovative management techniques, cost optimisation and development of new reactor systems. For example, repair technologies have been developed to improve the availability factor of nuclear power plants. Some of the repair jobs completed successfully include *en masse* replacement of coolant channels, end-shield repair, and calandria inlet manifold management. One of the components of the project gestation period is the time taken between hydrotest to commercial operation and NPCIL has been able to reduce it from 854 days for a plant (KAPS-2) commissioned in September 1995 to 161 days for a plant (RAPS-4) commissioned in December 2000. To further shorten the gestation period, for the plants now under construction, the practice has been adopted of contracting out packages of activities rather than single activities. This approach simplifies coordination, and therefore increases the speed of execution of various works.

Indian industry is geared to manufacture equipment needed for the setting up of nuclear power plants. Plants for the production of heavy water, fabrication of fuel and mining of uranium are under the direct control of the Department of Atomic Energy and their performance during recent years has been excellent. Heavy water plants are working at full capacity and continuously implementing measures to conserve energy. India’s experience in managing the back-end of the fuel cycle is also noteworthy. Fuel reprocessing started in India early in the programme based on indigenous efforts. At present, India has three reprocessing plants to extract plutonium from spent fuel, the first at Trombay, the second at Tarapur and the third at Kalpakkam. With total protection of the environment as an overriding consideration, management of the radioactive waste in the fuel cycle has received high priority in India’s nuclear programme right from its inception. Facilities for managing intermediate- and low-level wastes have been set up and are operating successfully alongside every nuclear facility in the country. To treat high-level waste from reprocessing plants, a waste immobilisation plant has been set up at Tarapur incorporating hi-tech features such as complete remote operation and maintenance. A facility for interim storage of vitrified waste has also been built nearby. For ultimate disposal of high-level waste, research on setting up an underground waste repository is in progress.

With regard to the new reactor systems, IGCAR is working on the design and technology development of fast reactors, while BARC is working on the Advanced Heavy Water Reactor and other technologies for thorium utilisation.

India has prepared a road map to develop accelerator driven sub-critical systems (ADS). As a first step towards this, a project to build a 100 MeV, 10 mA CW Proton Linac has been initiated. A compact high temperature reactor is being developed. Laboratory scale work on fusion power is being pursued. The steady-state superconducting Tokamak (SST-1) being build in Gandhinagar, is expected to be completed in the year 2003. *Table 2* gives a summary of the total Indian programme.

To summarise, India has developed expertise in every aspect of nuclear technology and is presently undergoing a major expansion of its nuclear power programme, both in terms of the commercial deployment of present-day technologies as well as bringing in newer technologies. The necessary industrial and R&D infrastructure is in place to facilitate this process.

Safety of nuclear power

India has accorded a prime position to safety in all its activities. We have gained close to 200 reactor years of operating experience with a good record of safety of operating personnel, the public and the environment. Safety measures in all our activities are in conformity with the norms stipulated by an independent regulatory body, the Atomic Energy Regulatory Board (AERB). These norms are also in line with the international standards. Safety is also an important subject for research and development, and dedicated groups are involved in continuous monitoring and upgrading of systems based on our own experience and experience elsewhere.

Human resources

Human resources development has been given importance right from the day the programme was initiated in the country. Adequate training facilities have been set up within the department to provide specialized training in nuclear-related areas. A training school to impart one-year orientation courses in nuclear science and engineering has been functioning since the late 1950s. Many new schemes have been introduced in recent years to further augment the training facilities. In addition, India's education system is fully geared to provide the manpower needed to provide input to the training programmes of the Department of Atomic Energy.

Economics of nuclear power

Unit energy costs of nuclear power are comparable to power from coal at locations away from coal pits. Nuclear Power Corporation, which builds, owns and operates nuclear power stations, is a triple A-rated company and has been highly commended for its excellent commercial performance, both in building power plants as well as in their operation.

High capacity factors, low discount rates and reduced capital costs are factors, which make nuclear power more attractive, and conditions in India have become more favourable in terms of these parameters over the years. Further, with its low variable costs, nuclear power improves its relative economics with years of operation of the power plant.

Future programme

Considering that India has a mature technology base and that the economics of nuclear power are favourable in several parts of the country, DAE has formulated a programme for increasing installed nuclear capacity. This programme envisages setting up about 20 000 MWe installed capacity by the year 2020. Details are given in *Table 2*. One interesting aspect is that planners and many energy experts agree that the programme, as proposed, is modest and needs to be uprated. However, the Department of Atomic Energy wants to pursue a cautious approach and to move in a stepwise manner before adopting higher goals.

Concluding remarks

India's fuel resource position calls for the development and deployment of a nuclear power programme to meet long-term energy needs in a sustainable manner. The technology resources needed to pursue the nuclear power programme are in place for the programmes being pursued at present, and also to be pursued in near future. For programmes beyond this, research and development is in full swing and it is being ensured that human resources to pursue these aims will be available as and when needed.

REFERENCES AND FOOTNOTES

1. Personal communication, CEA, May 2002.
2. PowerLine, November 2001, p10. This is based on the assumption that all (recognized and unrecognized) captive power plants operated at a capacity factor of 50% during the fiscal 2001-02.
3. World Energy Outlook - 2000: Highlights, p48, International Energy Agency, Paris.
4. PowerLine, February 2001, p24
5. Personal communication, CEA.
6. Government of India, Ministry of Coal, Annual Report 2001-02.
7. The Renewable Energy Act in Germany guarantees levels of payment for electricity produced by renewable resources and fed into the grid. Guaranteed rates for 2002 are solar (48.1 Euro cents per kWh), wind (9), biomass (10.1) and so on. Notice the high values even in a country where a lot is being done for renewable resources. See 'Common Ground', February 2002, p9 for further details.

Table 1. Sixteenth electric power survey estimates

Region	Energy requirements (million kWh)				Peak load (MW)			
	2001-02	2006-07	2011-12	2016-17	2001-02	2006-07	2011-12	2016-17
North	157 466	220 820	308 528	429 480	25 307	35 540	49 674	69 178
West	168 401	224 927	299 075	395 859	26 502	35 523	46 825	61 966
South	142 980	194 102	262 718	354 599	22 784	31 017	42 061	56 833
East	53 586	69 467	90 396	117 248	9229	11 990	15 664	20 416
North-East	6404	9501	14 061	20 756	1272	1875	2789	4134
Islands	176	280	444	702	38	60	94	148
Total	529 014	719 097	975 222	1 318 644	85 132	115 705	157 107	212 725

Table 2. Nuclear power plants – present status and future plans

Plants under operation: **2720 MWe**
14 reactors at 6 sites viz.,
Tarapur, Rawatbhata, Kalpakkam,
Narora, Kakrapar and Kaiga

Plants under construction: **3960 MWe**
2 x 540 PHWR at Tarapur
2 x 220 PHWR at Kaiga
2 x 220 PHWR at Rawatbhata
2 x 1000 VVER at Kudankulam

Plants likely to commence in the current financial year:
1 x 500 PFBR

Future plans:
One AHWR having a rating of 300 MWe and a mix of 500 MWe FBRs, 680 MWe PHWRs and 1000 MWe LWRs so as to reach a total of about 20 000 MWe by the year 2020.