India and the International Atomic Energy Agency

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Abstract: India is one of the founder members of the International Atomic Energy Agency. The sustained growth of its nuclear programme has accorded a unique distinction to India of being a developing country with strong foundations in advanced nuclear technology. This perspective of being a technologically advanced developing country has guided many of India's interactions on the IAEA platform.

Keywords: closed fuel cycle; high temperature reactor; India; innovative reactors; International Atomic Energy Agency (IAEA); nuclear; thorium.

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Biographical notes: R. Chidambaram is the Principal Scientific Advisor to the Government of India and a Homi Bhabha Chair Professor in the Department of Atomic Energy. He was the Chairman of the Indian Atomic Energy Commission during 1993–2000 and the Chairman of IAEA Board of Governors during 1994–1995.

1 A historical background

The foundation of Indian activities in nuclear science and technology was laid with the establishment of the Tata Institute of Fundamental Research in the year 1945, and the setting up of the Indian Atomic Energy Commission in 1948. Apsara, the first nuclear reactor in Asia, was dedicated to the nation in 1957, the year when the Atomic Energy Establishment Trombay (AEET) was born. AEET was rechristened Bhabha Atomic Research Centre (BARC) 10 years later. We are now in the Golden Jubilee year of this important event in the history of India's nuclear energy programme.

It seems to be a happy coincidence that the year 1957 also marked the beginning of another important phase in the history of nuclear energy in the world – the establishment of the International Atomic Energy Agency. Dr. Homi Bhabha, the founder of the Indian nuclear programme, was the President of the First 'International Conference on the Peaceful Uses of Atomic Energy' organised at Geneva. Indeed, it is a little known fact that Dr. Homi Bhabha was also instrumental in having the IAEA Headquarters located in Vienna, rather than in Geneva, where it was initially proposed. India was one of the 12 'founder' members who drafted the final version of the Statute of the Agency. In the 12-nation group, the Indian delegation came up with a complex but ingenious formula for determining the composition of the IAEA Board of Governors, that has stood the test of time (Fischer, 1997). India has been a member of the IAEA's Board of Governors since its inception. During the 40th anniversary celebrations of the IAEA, the then Director-General, Hans Blix, hosted a lunch, to which the members of the first Board of Governors of the IAEA and other nuclear pioneers were invited. It was eminently satisfying to me, as an Indian, to see the fondness and respect with which Dr. Homi Bhabha was remembered, more than 30 years after his tragic death in an air crash. I must also mention that, towards the end of my Chairmanship of the Board of Governors in 1995, my proposal to locate the bust of Bhabha outside the Boardroom was enthusiastically approved by the Board. Bhabha's bust now stands in the lobby along with those of Otto Hahn, which was there earlier, and of Kurchatov, which was added later.

2 A glorious milestone in the history of the IAEA

The award of the Nobel Peace Prize 2005 jointly to the IAEA, and its Director General, Dr. Mohamed ElBaradei, has been a fitting recognition of the immense contributions of the IAEA and Dr. ElBaradei in encouraging the peaceful and safe applications of nuclear energy and in applying safeguards to prevent diversion of nuclear materials from peaceful activities in any country, consistent with the country's commitments. This recognition is also a matter of pride to all the Member States of the Agency. Among all the bodies of the United Nations, IAEA is unique for its scientific character, which it should try to retain in the future. Dr. ElBaradei has added value by introducing the Scientific Forum at the time of the IAEA Annual General Conference. The other unique character of the Agency is that the decisions of the Board of Governors are taken, with rare exceptions, by consensus. The positive attitude of the IAEA senior personnel helps a great deal to ensure this. Dr. ElBaradei adds this attitude to his personal charm and his non-partisan approach to every issue. This is what has earned him universal respect among the Member States of the Agency.

3 Atomic energy and global sustainable development

Increasing energy demands, growing environmental concerns and depleting fossil fuel resources will pose the biggest global technological challenge for the task of achieving and maintaining sustainable development. Sustainable growth rates in developing countries, and sustained maintenance of quality of life in already developed countries, would also demand a shift from fossil fuel-dominated energy production because of the threat of global warming. There is strong evidence that most of the global warming over the last 50 years is attributable to human activities, particularly to energy consumption in the already-developed countries, and that these influences will continue to affect the climate throughout the 21st century, unless remedial action through rapidly increased use of nuclear power takes place. The eminent environmental scientist, Professor James Lovelock has said:

> "Even if they (the opponents of nuclear energy) were right about its dangers, and they are not, its worldwide use as our main source of energy would pose an insignificant threat compared with the dangers of intolerable and lethal heat waves and sea levels rising to drown every coastal city of the world. We have no time to experiment with visionary energy sources; civilisation is in imminent danger and has to use nuclear, the one safe, available energy source now or suffer the pain soon to be inflicted by our outraged planet." Lovelock (2004)

Sustainable development demands that energy resources must be available to meet humankind's expanding needs without environmental detriment. With this criterion, among the environmentally benign energy options, nuclear power is likely to progressively increase its contribution to the world energy supply during the next 50 years. While the extent of the predicted increase in world nuclear generation depends on the scenario assumed, a detailed study done by IAEA establishes a very high likelihood of a substantial growth in nuclear installed capacity within the next century (Langois et al., 2002).

Today, nuclear energy supplies one-sixth of the world's electricity in 30 countries. While more than half of the world's 443 nuclear power reactors are located in North America and Western Europe, only about 10% are located in developing countries (ElBaradei, 2004). The largest future growth is expected to occur in India and China.

With the present-day nuclear technology, mainly based on thermal reactors with open fuel cycles, the global resources of uranium, produced at a cost of up to US$80 per kg, will be exhausted by the middle of the 21st century, even if its consumption rates remain the same as they are today. Use of nuclear fuel in a closed nuclear fuel cycle, involving fast breeder reactors, would hugely increase the availability of global fuel resources to the nuclear power industry.

It is obvious that, for long-term sustainable supply of nuclear fuel resources, nuclear energy technology will have to aim for more effective utilisation of the world's nuclear fuel reserves, uranium and thorium. This requires closing the nuclear fuel cycle, and using breeder reactors as an important component of a nuclear energy system.

At present only a few countries, India, France, Japan and the Russian Federation, have a clearly defined policy to recover plutonium and other fissile material from the spent nuclear fuel and use this precious material to fuel other reactors, constituting what is called a 'closed nuclear fuel cycle'. At least for the time being, others are following an 'open fuel cycle' implying no reprocessing of spent nuclear fuel. Such a policy is mainly dictated by consideration of the current availability of cheap natural uranium to these countries, coupled with a philosophy in some of these countries linking the production of the man-made fissile materials to their possible diversion for making nuclear weapons. It must, however, be mentioned that the plutonium in the stored spent fuel (Pu-239 has a half-life of 24,000 years) can be recovered as needed on a future date; in fact more easily because other short-lived radioactivities would have died down by then, making reprocessing relatively easier.

4 Atomic energy as a facilitator of India's energy independence

Energy is an important factor contributing to the social and economical development of nations. Per-capita electricity consumption is an important measure of development, particularly for developing countries. It also contributes, directly and indirectly to the UN Human Development Index (HDI). For India to become a 'developed' country in the fullest sense of the term, the per capita consumption of electricity should increase at least by a factor of eight to 10 (Chidambaram, 2001). This would require an installed electricity generation capacity of about 1300 GWe (Grover and Chandra, 2004). The generation of power of such magnitude, using fossil fuel resources alone, will contribute to nearly 2 tonnes additional carbon dioxide production per person on earth. It is thus self-evident that, considering the global dimensions of fossil fuel resource sustainability and the need for environmental protection, a major part of the energy mix in India will have to be non-fossil. Another important fact to be kept in view is that the aforementioned projected Indian capacity is nearly 40% more than the current installed electric generation capacity in the USA, and nearly ten times that of the installed capacity in France. Looking at the sheer magnitude of the need, and the associated logistics and economic aspects, it is also obvious that a major fraction of the energy resources needed for a large country like India, must be derived from domestic supplies, as far as possible.

This brings me to the issue of availability of domestic fuel resources in India. At present about 87% of electricity generation in India comes from the use of fossil fuels. The contribution of thermal power plants operating on coal is about 67% while those on hydrocarbons (oil and gas) is about 20%. Even though the present trend will continue in the near future, the known available domestic fossil resources may not last for more than a few decades. The impact of rising oil prices and their impact on the prices of other fossil fuels must also be considered.

India has one of the world's largest deposits of thorium, and only a small fraction of the world's uranium reserves. With a nuclear energy system based on the once-through fuel cycle in Pressurised Heavy Water Reactors (PHWR), its uranium resources are currently estimated to have an energy potential of only about 328 GWe-year. With the use of fast breeder reactors and thorium this energy potential will be increased nearly 600 times (Grover and Chandra, 2004). While the full potential of renewable resources including hydro and non-conventional sources is being exploited, it cannot be used as a primary option. Therefore, in the Indian energy mix, the contribution of nuclear energy resources, which have enormous potential, has to be increased significantly to satisfy the long term energy needs of India. In addition to electricity generation, one can foresee a progressively growing need to develop alternatives to fossil fluid fuels (oil and gas) for transportation applications. Nuclear energy is eminently suited for producing high temperature process heat for several water-splitting processes for producing hydrogen.

For a large country like India, it is strategically as well as economically important to avoid depending excessively on imports for meeting its requirements of energy resources. Speaking on the eve of India's Independence Day on August 14, 2005, the President of India Dr. Abdul Kalam differentiated between the concepts of Energy Security and Energy Independence and highlighted the importance of the latter in the following words:

"Energy Security rests on two principles. The first, to use the least amount of energy to provide services and cut down energy losses. The second, to secure access to all sources of energy including coal, oil and gas supplies worldwide, till the end of the fossil fuel era which is fast approaching. Simultaneously we should access technologies to provide a diverse supply of reliable, affordable and environmentally sustainable energy.

Energy Security, which means ensuring that our country can supply lifeline energy to all its citizens, at affordable costs at all times, is thus a very important and significant need and is an essential step forward. But it must be considered as a transition strategy, to enable us to achieve our real goal that is – Energy Independence or an economy which will function well with total freedom from oil, gas or coal imports.

Energy Independence has to be our nation's first and highest priority. We must be determined to achieve this within the next 25 years, i.e. by the year 2030."

5 The Indian roadmap

The Indian nuclear power programme, based on closed fuel cycles, consists of three stages, which are drafted to optimally utilise the modest indigenous uranium reserves and abundantly available thorium reserves.

In the first stage, natural uranium is used as a fuel to operate the PHWR. The plutonium, generated from ^{238}U in the first stage is recovered and reprocessed from the spent fuel of these PHWRs. This recovered plutonium is used as a fuel in Fast Breeder Reactors to initiate the second stage of the programme. The Fast Breeder Reactors, while generating electricity, multiply the fissile material inventory. In the Fast Breeder Reactors, the fissile material plutonium is bred from ^{238}U and ^{233}U, an isotope of uranium, is generated from thorium (^{232}Th). In such reactors more fissionable material (plutonium and uranium-233) is produced than is consumed. Finally, the thorium-^{233}U based fuel will be used in advanced reactor systems in the third stage of the Indian nuclear power programme.

At present India is operating 15 reactors, out of which 13 are PHWRs, representing the first stage of the Indian nuclear programme. As a component of the second stage, the Fast Breeder Test Reactor (FBTR) has been in operation at Kalpakkam since 1985. This reactor uses a unique indigenously developed mixed carbide fuel that has already seen a burn-up exceeding 150,000 MWD/Te. India's first commercial fast reactor, the 500 MWe Prototype Fast Breeder Reactor (PFBR) is under construction. In preparation for the third stage of thorium utilisation, several programmes for the irradiation of thorium bearing fuel in research reactors as well as PHWRs have been completed. Challenges associated with the fuel cycle of thorium-based fuels are being progressively addressed through a large R&D programme.

India currently has an intense level of activity in the nuclear power field, with the highest number of reactors (eight) under construction in the world today.

6 The new challenges

Like any other technology, nuclear technology has been and will continue to evolve and innovate to meet new requirements, and to become more efficient and competitive in the market place. In order to fully realise the potential of nuclear energy to meet the large and varied energy needs in the next 50 years, advanced nuclear energy systems are required. Considering the possibility of a multifold increase in the global population of nuclear energy systems required for this purpose, and the fact that a large fraction of these systems may need to be deployed in countries with little or no local infrastructure to support nuclear technology, some of the important requirements envisaged to be fulfilled by these advanced, or so-called next generation, nuclear energy systems are:

- improved economic competitiveness compared to the alternative energy systems available for deployment in the same time frame and geographical region
- further enhanced levels of safety consistent with the larger population of these systems, many of which may need to be sited close to population centres
- proper management of the inventory of long-lived wastes, with the objective of minimising this inventory
- proliferation-resistance (after, of course, defining ‘proliferation’ properly and focussing on *genuine* proliferation concerns taking into account the present ground realities (Chidambaram, 2001))
- establishment of links of nuclear energy with other important technologies like desalination and hydrogen generation.

Recent international initiatives such as the IAEA’s INPRO (International Project on Innovative Nuclear Reactors and Fuel Cycles) and the USA led Generation-IV programme, have further elaborated many of these requirements to provide guidelines for the design and development of advanced nuclear energy systems. India is an active member of INPRO, and has contributed to the preparation and revision of the IAEA document containing these guidelines.

7 Indian innovative reactors

India is in the forefront of the countries currently developing next generation nuclear energy systems, with the design and development of the Advanced Heavy Water Reactor (AHWR) and the Compact High Temperature Reactor (CHTR).

The AHWR is a 300 MWe, vertical, pressure tube type reactor cooled by boiling light water and moderated by heavy water. The reactor is fuelled with $(^{233}U\text{-}Th)O_2$ together with $(Pu\text{-}Th)O_2$. AHWR is nearly self-sustaining in terms of ^{233}U. The design of AHWR is fine-tuned towards deriving most of its power from thorium based fuel, while achieving a negative void-coefficient of reactivity.

AHWR incorporates several advanced features to increase its safety, reliability and economics. One of the most significant safety features of this reactor is its reliance on natural circulation based heat removal under normal operation and shutdown conditions.

The CHTR is a ^{233}U-thorium fuelled, lead-bismuth eutectic alloy-cooled and beryllium oxide-moderated reactor. This reactor has been designed to have a long core life of 15 years. The reactor will have several advanced passive safety features to enable its operation as a compact power pack in remote areas not connected to the electrical grid. The reactor is being designed to operate at 1000°C, to also facilitate demonstration of technologies for high temperature process heat applications such as hydrogen production from water. CHTR would serve as a prototype technology demonstrator reactor in the direction of fulfilling these objectives.

8 India and the IAEA

When India started its nuclear power programme in the late 1960s, the industrial capability in the country was extremely limited. Manufacturing of sophisticated nuclear components and structures meeting the necessary high technological standards was not possible. The induction of the nuclear power programme facilitated the progressive involvement of the Indian industry towards assimilation of the required technologies and subsequently taking up manufacture of nearly all the critical components of nuclear reactors within the country itself. The indigenous R&D capability developed within the Department of Atomic Energy facilitated the results of in-house development being transferred to the industry to create the required infrastructure. The withdrawal of international technological support and imposition of restrictive technology control regime from 1974 onwards, brought into focus the urgency of developing self-reliant capabilities in all areas concerning nuclear energy. As a consequence, the industrial capabilities received the boost required to come up to international standards for the manufacture of complex and high precision components and systems. Special nuclear materials, such as zirconium alloys and associated products, heavy water, control rod materials etc., were developed in the country. This enhancement in the industrial capability led to spin-offs in several areas.

Apart from the technological aspects associated with nuclear power generation, a large programme to harness the other allied benefits of atomic energy, particularly the utilisation of radioisotopes have progressed in parallel. The programmes for application of radioisotopes in the field of agriculture, medicine and industry have been very successful. For example, more than 45% of blackgram cultivated in India uses mutant seed varieties developed in BARC.

India has the unique distinction of being a major developing country with a developed status as far as nuclear energy is concerned. This developing country perspective, with a sound technological foundation, has been at the root of several important contributions made by the country in IAEA forums. The Indian approach to some of the important issues before the Agency has been to pilot the cause of the immediate needs and aspirations of the developing countries. During the period when I was the Chairman of the IAEA Board of Governors, an important initiative was taken to establish an International Working Group on Advanced Technologies for Heavy Water Reactors. Following the establishment of this International Working Group (later rechristened as the Technical Working Group – TWG) immensely beneficial cooperative research programmes in the field of inter-comparison of thermal hydraulic codes of HWRs and inter-comparison of methods for carrying out flaw detection in pressure tubes were carried out with prominent Indian contributions.

India is also one of the founder members of IAEA's International Project on Innovative Reactors and Fuel Cycles (INPRO) and has played a major role in the preparation of IAEA's documents containing the methodology for evaluation of innovative nuclear energy systems, and associated manuals. India is the only country today with an active programme to link a large commercial nuclear power plant with a desalination unit, and is considered a leading nation in the field of nuclear desalination. In the area of thorium utilisation, similarly, India has been treated as a leader in the world, and has contributed to several IAEA activities pertaining to international information exchange and coordinated research in this very important field.

There are two approaches for International Cooperative R&D:

- full concepts (e.g. Generation IV, ITER model)
- enabling technologies (e.g. IAEA CRPs).

Both the approaches have their merits, and both can co-exist. Full concepts provide a more focused approach for developing a few well-defined products expeditiously. Enabling technologies provide a flexible and cost-effective basis for eventually facilitating the development of a large range of products to cater to different regional requirements, with a capability of leveraging the strengths available in a large number of international institutions.

Every country has to make technology choices with a national perspective. This requires Technology Foresight, which attempts to select the 'critical technologies' needed for a country's development at any point of time. Many countries consider nuclear technology as a critical technology in this context. The mission of IAEA should be to help establish what I call 'Coherent Synergy' among the nuclear-related activities of institutions, governments and industry in the world.

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