# Nuclear energy: Emerging trends

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*The Royal Society and The Royal Academy of Engineering have jointly studied the role of nuclear energy in generating electricity and have concluded that it is vital to keep the nuclear option open. The study refers to the status of nuclear electricity in France, where it is sold at an economic price, and says that it would be irresponsible to abandon nuclear energy in UK. Signals emanating from other countries also point to likely revival of interest in nuclear power. Considering India's resource position, large-scale development of nuclear power is inevitable to ensure long-term energy security.*

TO achieve socio-economic growth, it is necessary to have a reliable supply of energy at a cost affordable by the populations requiring growth. The developed countries have already ensured a very high standard of living for their citizens and most of their energy needs are met by commercial energy sources, with electricity contributing a major share. Per capita electricity consumption in developed countries is very high, of the order of 10,000 kWh per year. Developing countries have very low per capita energy consumption, and their share of non-commercial energy is much higher than the developed countries. (Wood, charcoal, agricultural and animal residues and derived fuels are non-commercial energy resources. They are also referred to as biomass.) Per capita electricity consumption in developing countries is very low, a few hundred kWh per year. (For example, in India for the year ending 31 March 1999, per capita electricity generation was 450 kWh/year and metered consumption less by about 25%.) As a result, in the years to come, we are likely to see a very fast growth in the electricity generation in developing countries, while growth in the developed countries will be much slower. Many growth scenarios have been postulated, but overall conclusions are clear that one cannot continue to be profligate as far energy usage is concerned. All the countries have to examine various issues to find an optimum solution considering their fuel resource position, technical competence of local industry, availability of trained manpower at all levels, state of regional as well as global environment and overall economics of the country.

At present fossil fuels play a dominant role in energy production and there are two very important issues associated with the use of fossil fuels. One is the influence on environment and the other is the time period for the depletion of the fossil fuels, which can be estimated by dividing the reserves with the rate of production. On both these issues alarm bells have been sounded. Oil production would probably decline before coal[1]. Deterioration in the state of environment, because of the emission of carbon dioxide, which is continuously increasing since the beginning of the industrial revolution, has led to the formulation of the Kyoto Protocol, which alone is not sufficient. The per capita carbon emission by the developed countries is above 10 tonnes per year, while the corresponding figure for India is only about 1 tonne per year, and for China, it is above 2 tonnes per year. Imagine the situation when populous countries like India and China start producing carbon dioxide at a rate which on per capita basis equals that of the developed countries!

Strategies have to be formulated to ensure sustainable development so that future generations are ensured a standard of living, which is better than that of the present generation. We need to address many issues to achieve the goal of sustainable development. How to identify the fuel resources needed to sustain ever-increasing energy demand? What technologies are best suited to a country, given its technology base, fuel resource position and availability of skilled manpower and finance? These aspects are being debated all over the world by organizations and individuals at the national as well as the international level. It is now obvious that the present profligate approach towards the use of natural resources or what is referred to as 'business as usual' approach, is not sustainable and all efforts including energy conservation and improvement in energy intensity are needed for socio-economic growth of the developing countries so as to provide an equitable standard of living to the citizens of all the countries.

Analysis of global energy resources indicates that oil and gas will last for part of the 21st century and coal a while longer. However, renewables and nuclear resources would last for a very long time. Renewable resources are virtually inexhaustible, but at the current

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stage of technology development, but for hydro, they are not suitable for large-scale electricity production. Thus for long-term sustainability, it is necessary to go in for nuclear electricity. However, nuclear electricity evokes an intense debate, particularly in developed countries, with a very high standard of living, whose citizens are unable to visualize the scenario which may result from non-availability of plentiful electricity. Announcements have been made in some of the developed countries about closing down of nuclear power plants in the future. In reality, governments are finding it difficult to close down plants which are operating well. In addition, studies conducted by learned organizations point out to the inevitability of nuclear energy on a long-term basis. One such study was published recently by The Royal Society and The Royal Academy of Engineering[2]. The study concludes that there is a need for setting up new nuclear plants in the United Kingdom and recommends a carbon tax and major investment in research and development in all energy sectors by creating an international fund. The following paragraphs summarize the main findings of the study.

## The study by the Royal Society

The study emanates from the conviction that global warming is a real phenomenon. Consequences of global warming are emerging with some clarity from the climate models and 'are likely to prove to be significant and overall, deleterious'. Here the series of world climate conferences starting in 1979 have had a progressively increasing impact on world opinion. The United Nations Framework Convention on Climate Change (UNFCCC) adopted at Rio de Janeiro in 1992 and subsequently followed by the Kyoto Protocol of December 1997 were immensely important first steps. In spite of receiving international attention, global warming is a complex issue and calls for a holistic approach for a solution. It is an issue where time has to be measured in decades and therefore calls for creative thinking to find solutions with no risk to future generations.

The fossil fuels are considered most economical sources of energy, but their use does not consider all the true costs. The emission of $CO_2$ to the atmosphere as if it were a free sink is the main cost component externalized from the cost calculations, particulate emission is another. In the case of nuclear electricity, cost of waste disposal is accounted for. There is a need to reduce usage of fossil fuels due to the following three factors.

- The eventual exhaustion of fossil fuel supplies.
- Most of the known gas and oil supplies are located in the middle-east, Russia or the Former Soviet Union (FSU). It raises the possibility of reduced availability for the rest of the world.
- There is a need to stabilize the amount of $CO_2$ in the atmosphere to avoid global climate change.

Of these three factors, global climate change is by far the greatest immediate threat. To understand all issues involved, the report urges 'that the climate modelling and measuring should be given the fullest support, both within UK and via collaborative agreements, internationally'.

The world population is growing and is likely to be between 8 and 12 billion by the year 2100. The energy demand of developing countries will determine the rate of energy growth requirement worldwide and one may expect the energy demand relative to the 1995 figures to at least double by the year 2050, and to rise by a factor of five by the year 2100. Therefore the efforts to conserve energy and to improve energy generation efficiency need full support. Renewable energy resources need to be understood and encouraged in spite of their low contribution to the present energy needs. The study also examines the issue of carbon sequestration, which may be described as 'catching' the carbon dioxide and 'hiding' it by appropriate means for a long period and calls for research and development to establish the feasibility, cost and safety of this approach.

At the end of 1998, there were 437 nuclear reactors operating in 32 countries globally and suppling 16% of the world's electricity. A major share of the world's nuclear capacity is located in OECD (Organization for Economic Co-operation and Development) countries, where it supplied 24% electricity. The study says, 'With regard to nuclear energy installations in Europe, North America, or elsewhere when based on designs in these regions, we have no reservations on the grounds of safety. We recognize no rational reason for seeking a retreat from its usage'. It seems authors of the study want to exclude reactors such as RBMK of Russian design. The study examines the following facets:

- Cost of nuclear electricity
- Waste disposal
- Public perception
- International implications – the possibility of proliferation.

The cost of nuclear electricity depends on a number of factors including the size of the programme. This has been demonstrated in France, where a large number of plants of basically similar design have been built and nuclear electricity contributes 80% of France's electricity needs. Nuclear energy has not been subsidized in France; it is sold at an economic price. The report concludes 'that the cost of nuclear electricity need not prove to be a barrier to the retention or expansion of the industry in UK'.

Mineral sources from which uranium mining can be carried out economically are limited and the current international cost of uranium is around $ 40/kg. As high-grade ores are consumed this could rise, but as the fuelling cost is a small fraction of the nuclear electricity, it would not greatly affect economics. However to ensure long-term availability of fissile material, it is necessary to follow the breeder-route. This requires reprocessing of the spent fuel to recover fissile materials, but with regard to reprocessing the study is inconclusive. It does acknowledge the fact that reprocessing is a way to ensure long-term availability of fissile material and that reprocessing produces one-eighth of the volume of high level waste than that produced by direct disposal. On the other hand, intermediate level waste is three times more voluminous. The study goes on to say that until an ultimate waste disposal option is decided, costs are bound to be debatable. Either case, viz. direct disposal or reprocessing followed by plutonium recycling, does not have a large impact on the cost of the final product – the cost per kWh of electricity generated. Long-term waste disposal is a problem and the option of deep geological storage has been examined in detail. The study recognizes the need for additional basic research to resolve the issues involved and recommends that investigations be carried out for a proposed repository site.

The study stresses the importance of public confidence in the safety of nuclear technology and goes on to say that leadership by politicians is of critical importance. Communication of issues involved in a complex technology like nuclear is a challenge for scientists as well as planners. All communications 'have to be bilingual – they have to make sense both to the source and to the intended recipients of the information provided'.

With regard to immediate future, the study says, 'Our own perception in the light of all the uncertainties, is that it would be irresponsible to abandon nuclear energy in UK, to the currently expected extent of reducing nuclear capacity by a total of 70% by 2020, without taking a new hard look at the options'. The report supports the conclusion reached by the Trade and Industry Committee of UK 'that new nuclear power plant may be required in the course of the next two decades'.

Long-term scenarios about growth of nuclear electricity generation are full of uncertainties, as issues involved are too complex. The issues include new concepts and technologies for renewables, environment impact, public perception about nuclear energy. They are being debated from a position of personal conviction rather than on hard facts. The study calls for funding of non-fossil energy research at the international level in a co-operative mode. Current funding for the issues like nuclear energy, renewables and carbon sequestration, is inadequate. The study criticizes the intention of the Chancellor of Exchequer to introduce a climate change levy on the business of energy. The report suggests that levy would be much more effective if it were based directly on net $CO_2$ emitted rather than on the amount of energy supplied. In summary, the report says that to meet both the energy requirements and the commitments to limit greenhouse gases, it is necessary for UK to ensure that the nuclear option remains viable.

## Other opinions

In the recent past, signals emanating from many other sources also point towards a likely revival of interest in nuclear power. In the United States initiatives approved and already underway[3] are:

- Nuclear Energy Research Initiative (NERI), which supports peer-reviewed nuclear science and engineering research.
- Nuclear Energy Plant Optimisation (NEPO) programme aimed at long-term operation of the existing fleet of 103 commercial LWRs in the USA.
- Funds for university reactor fuel assistance and to counteract the slow decline in the number of graduates from the nuclear science and engineering programmes.

Though no new reactors are proposed in the USA, life of existing reactors is being extended. The application for life extension of six nuclear plants has already been moved and the first license renewal application has already been approved. In Sweden, where public pressure demanded phasing out of nuclear plants at the beginning of the eighties by a margin of two to one, public opinion now favours nuclear power and there are calls for a new referendum on nuclear energy, though one reactor has been shut down[4,5]. More recently, in the light of the policy of the German Government that it will phase out nuclear power, 570 German Academics have signed a memorandum in favour of the continued use of nuclear power[6].

Countries in Asia are continuing to plan and construct nuclear power plants. These include India, China, Japan and South Korea. 'Asian commitment to nuclear power is motivated by a number of considerations: keeping the nuclear power on the list of options available to meet the rapidly rising demand for electricity; reducing energy import dependence; improving air quality; reducing greenhouse gas emissions; benefiting from the technological spin-offs of high technology; easing energy supply logistics[7].'

## Nuclear programme in India

Let us examine the fuel resource situation in India (Table 1). We have reasonable coal reserves – more than 200 billion tonnes. Out of this, mineable reserves are only about 73 billion tonnes. All forms of energy have their merits and their constraints. While coal-based stations will continue to play a major role for many years to come, they are likely to pose serious problems in future arising out of transport of large quantities of coal across the country and environmental problems related to disposal of ash and emission of greenhouse gases and acid gases. Fuel Map of India published by Central Electricity Authority in August 1998 recognizes that the fuel handling and transportation facilities need to be augmented to optimize the use of indigenous resources. It goes on to say that indigenous production rate is not sufficient to meet the requirements and 14–15 million tonnes of coal may have to be imported during the 9th plan. Now depending upon the pattern of usage and the postulated growth rate, one can forecast how long the coal deposits will last. Estimates differ, but coal is not likely to be sufficient even for the next century. Our oil and natural gas reserves would have run out much earlier. Hydro-potential is renewable and must be exploited to the maximum but this may be resisted because of issues like displacement of people and possible effects on ecology. Non-conventional sources like solar, biomass and wind will play useful roles but are not suited for building high capacity power plants. Large-scale development of nuclear power is thus inevitable. A comparison with our neighbour China is very interesting. Its coal reserves are 5 times as large as ours. It is the largest producer of coal in the world. Its hydro potential is also quite large. Still to ensure energy supply security it is following a twin track policy aimed at developing indigenous nuclear reactors and is also shopping abroad for nuclear power reactors.

To return to India's nuclear fuel resources, our uranium deposits are limited, while thorium deposits are large. Uranium-238, the dominant isotope of uranium is a fertile material and cannot make a reactor critical by itself and has to be converted to fissile plutonium-239. The process of conversion takes place in a nuclear reactor and spent fuel from thermal reactors contains plutonium-239. On discharge from the reactor, spent fuel can be dealt with in two ways. The first one termed 'open cycle', consists of treating the entire spent fuel as waste and disposing it as such. With this approach only 2% of the energy potential exploitable from uranium is utilized. To avoid this colossal waste, a 'closed fuel' cycle involving reprocessing of spent fuel to separate plutonium and uranium-238 has to be pursued. Besides recovering valuable fissile material, reprocessing helps to sort out the wastes according to their activity levels and their decay period, thereby assisting waste disposal and minimizing environmental impact. Similarly thorium is a fertile material and has to be converted to a fissile material, viz. uranium-233. To ensure long-term energy security for the country, we have chosen to follow a 'closed cycle' approach. Pursuit of the closed cycle approach calls for setting up of reprocessing plants and breeder reactors. We have taken cognisance of these facts, viz. our resource position and need for ensuring long-term energy security and accordingly formulated a three-stage nuclear power programme[8].

Table 1. India's energy resource position

| Resource | Amount | Potential (GWe – yr) |
|---|---|---|
| Coal[9] | 206 billion tonne (total) | 41,000 |
| | 75 billion tonne (proven) | 15,000 |
| Oil[9] | 0.75 billion tonne | 300 |
| Natural gas[9] | 692 billion $m^3$ | 250 |
| Hydro[10] | 84 GW at 60% PLF | 84 GW at 60% PLF |
| Uranium[11] | 78,000 tonne metal | In PHWRs – 420 |
| | | In FBRs – 54,000 |
| Thorium[11] | 518,000 tonne metal | In Breeders – 358,000 |
| *Non-conventional*[12] | | |
| Wind | – | 20 |
| Small hydro | – | 10 |
| Total solar insolation | – | 600,000 |
| Ocean thermal, sea wave and tidal | – | 79 |

Assumptions for potential calculation in Table 1.
For coal, oil and gas: Complete source is used for electricity generation with thermal efficiency, $\eta$ = 30% and calorific value for coal = 5000 kcal/kg, oil = 10,200 kcal/kg and gas = 9150 kcal/$m^3$.
For nuclear fuel: Fuel burn up in PHWRs = 6700 MWD per tonne and $\eta$ = 29%. FBRs can use 60% uranium with $\chi$ = 42%. Breeders can use 60% thorium with $\eta$ = 42%.

The first stage, comprising setting up of Pressurized Heavy Water Reactors (PHWRs) and associated fuel cycle facilities is already in the industrial domain. The speed at which our nuclear power programme can move forward is no longer limited by technology or the country's industrial infrastructure, but by the availability of funds.

The second stage envisages setting up of Fast Breeder Reactors (FBRs) backed by reprocessing plants and plutonium-based fuel fabrication plants. In order to multiply fissile material inventory, FBRs are necessary for our programme. Multiplication of fissile inventory is also needed to establish a higher power base for using thorium in the third stage of our programme. As a first step, a 40 MWt Fast Breeder Test Reactor (FBTR) was set up and it attained criticality in 1985. FBTR has provided valuable experience with liquid metal FBR Technology and the confidence to embark upon the design and technology development of a 500 MWe Prototype Fast Breeder Reactor (PFBR). Detailed design of the PFBR is in advanced stage. Construction work on this is expected to start in the last year of the Ninth Plan (2001–2002). This will be located at Indira Gandhi Centre for Atomic Research (IGCAR) 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 to expedite transition to thorium-based systems. In addition, it will enable us to sustain some of the heavy water technologies, which we have already acquired. The reactor physics design of AHWR is tuned to generate about 75% power in thorium, and is to maintain negative void coefficient of reactivity under all operating conditions. Under an ongoing project, a detailed project report for AHWR is being prepared and will be completed by the end of the 9th five-year plan. The construction of the reactor will be launched after obtaining the necessary clearance.

## Concluding remarks

In conclusion, one may say that for long-term sustainability of economic growth, nuclear power is inevitable. The presently operating nuclear reactors continue to contribute towards the electricity needs of the world. Countries in Asia are planning to set up nuclear power plants and therefore, in the immediate future one can expect growth of nuclear electricity in Asia. At the global level, there may be some reduction in the nuclear electricity, but it is likely to be followed by a revival. While the Department of Atomic Energy in India is pursuing research necessary to exploit nuclear energy, there is no comparable institute to explore other energy technologies. There is a definite need to set up an Energy Technologies Research Institute in India to examine all technology options, particularly those which are directed towards improving existing technologies and those which are necessary to exploit emerging energy resources such as gas hydrates. To provide energy security to the nation, we have to follow an approach formulated to exploit all available energy resources, without taking strong positions about any one of them.

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