Nuclear India – to be or not to be?

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Nuclear India was conceived before independent India, and has undergone similar ups and downs in its development. Multiple conflicting opinions, controversies and secrecy have been its constant companions. The end result is that the common citizens of the country are not sure if nuclear power is good or bad for them. This article is an effort to collate different opinions and facts on the nuclear issue from the point of view of electrical energy production.

Keywords: Atomic energy establishments, electricity production, India, nuclear power, reactors.

Birth and growth

THE genesis of nuclear energy in India started in 1944 when Indian scientists 'began to plan nuclear research and went on a tour of atomic energy research facilities in Britain, Canada and the United States.[1]' Anderson[1] has studied the Indian nuclear energy scenario for around four decades (Box 1). About this visit, he says: 'Revealing curiosity and awareness while visiting some of these facilities, they were questioned by American intelligence officers early in 1945 to uncover how much they really "knew".' He also reveals that even if the nuclear programme in India was not given much importance in the early days, 'not everyone was indifferent to India's usefulness to *their* interests, interests that were surely among the stimulants of the Indian nuclear program'.

The inspiration for India to develop its nuclear programme was that her scientists looked at nuclear power as a source of cheap energy. In 1945, the Tata Institute of Fundamental Research was established, following a letter from Bhabha (the founder of India's atomic energy programme) to the Sir Dorabji Tata Trust, proposing the creation of an institute devoted to fundamental research in physics. Ramamurthy[2], former Chairman of the International Atomic Energy Agency (IAEA) standing advisory group on nuclear applications, quotes from this letter: 'when nuclear energy has been successfully applied for power production, in say a couple of decades from now, India will not have to look abroad for its experts but will find them ready at home', and points out that this note was penned 'full one year before the world came to know the power of the atom, full three years before India became free from colonial rule, full 10 years before the production of commercial electricity from nuclear energy'.

In 1946, the Indian Atomic Energy Committee was created. It supported nuclear research and apportioned funds through the Atomic Energy Research Board. Plans for relevant institutions were made even before the bombing of Japan in 1945. Anderson comments: 'On the eve of India's Independence in 1947, more than a handful of her scientists understood the potentials and risks of nuclear weapons and nuclear power...[1].' Said Bhatnagar in the 1940s: 'I fully appreciate that India cannot be allowed to completely ignore this research and that we shall have to

Box 1. A book on nuclear energy in India.

Nucleus and Nation: Scientists, International Networks, and Power in India. Robert S. Anderson. The University of Chicago Press, Chicago, USA, 2010.

Many books and reports have been brought out on nuclear energy – why India needs it, why Indians are better off without it, how it would improve the economic status of the country and the available electricity status of the people ... A distinctive feature in Anderson's book is that it paints the nuclear scenario in India on a broader canvas of the changing (national and international) political, economic and social situations. It presents 40 years of research in an objective, comprehensive, well-organized and interesting fashion with appropriate and ample references, notes and quotes. It makes one appreciate that there is more to nuclear energy than pure science and the energy needs of the people.

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take very active steps to do something as it is going to be a very potent factor in industrial development of the world, and India cannot be a cipher in this direction.[1]'

In his narrative[1], Anderson calls Bhatnagar and Bhabha 'political scientists' and discusses how decisions affecting nuclear science were influenced by political connections. He also talks of the relationships, misunderstandings and individual opinions of scientist peers, how extreme poverty and expensive projects thrived side by side and of secrecy. Anderson[1] also points out how in November 1998, when the National Security Council (NSC) was created 'it was striking that scientists were no longer to be included in the inner circle of nuclear deliberations, a break with forty years' practice'. However, the present composition of NSC includes the Secretary of the Department of Atomic Energy (DAE) as well as the scientific advisor to the defence minister[3], both of whom may be scientists.

The Atomic Energy Commission (AEC) was set up in 1948, 'the first intermediary for foreign interest in India's nuclear development[1]' according to Anderson. The DAE was set up in 1954, of which the AEC became a part in 1958 (ref. 4). Politicians and scientists influenced decision-making during the creation of the Atomic Energy Regulatory Authority (AERA) in the 1970s: '… the prime minister's office objected to the DAE regulating itself, a captive regulator. Sarabhai opposed letting it leave the DAE family, whereas Sethna and Haksar accepted that it should go outside. Gandhi sided with Sarabhai, and the AERA remained inside DAE until it was made an independent statutory board in November 1983 (as the Atomic Energy Regulatory Board), finally resembling the atomic energy regulatory instruments in other countries.[1]'

In 2012, the Atomic Energy Regulatory Board (AERB) still reports to AEC, though promises have been made to make it truly autonomous – after the nuclear crisis in Fukushima and the subsequent call for an independent regulatory authority. Gopalakrishnan, former Chairman of AERB, notes: 'In India also, the nuclear regulator (AERB) does not have the comprehensive scientific and technological capabilities or in-depth experience required to carry out much of the safety analyses and evaluations needed. Therefore, almost 95% of the members in AERB's review and advisory committees are drawn from among retired employees of the Department of Atomic Energy, either from one of their research institutes like the Bhabha Atomic Research Center or a power generation company like the Nuclear Power Corporation of India Ltd. Having worked for 30 to 40 years in the Department of Atomic Energy (DAE) organisations before retiring, and continually enjoying all the retirement benefits from the DAE, including family medical support in their old age, the loyalty of most such review committee members is likely to be with the DAE and rarely can one expect impartial regulatory reviews from them. And yet, there are very few non-DAE national experts in nuclear engineering within the country, because the DAE has been systematically discouraging the higher institutes of engineering in India from starting and expanding post-graduate programs in nuclear engineering. While we wait to get this done over the next decade or more, we must insist that AERB elicits the help of ex-DAE personnel under a strict contract of service and code of ethics which minimise the chances of conflict of interest, somewhat akin to the formal understanding under which the French ASN and the IRSN co-operate.[5]'

The training school at the Atomic Energy Establishment, Trombay (now Bhabha Atomic Research Centre) was established in 1957. In the context of this training, Ramamurthy says: '…the near-total dependence on in-house training of its personnel had to some extent stunted the growth of nuclear education in the universities and other educational institutions.[2]' Steps are being undertaken to address this issue, including the establishment of the Inter-University Consortium for using DAE facilities, the Inter-University Accelerator Centre, and participation in international mega science projects by universities in collaboration with DAE[2]. Educational institutes such as the Indian Institute of Technology (IIT) Kanpur, IIT Madras, Manipal University and Jawaharlal Nehru Technological University offer Master's programmes in nuclear engineering (see http://www.iitk.ac.in/net/onp.htm). The Homi Bhabha National Institute has been established to foster in-depth capabilities in nuclear science and engineering (http://www.hbni.ac.in/).

Today atomic energy establishments span the country (Figure 1; http://www.dae.gov.in/) in spite of and boosted by its exclusion from international nuclear assistance, following the 'peaceful nuclear explosion experiment' (Operation Smiling Buddha/Pokhran I) conducted in 1974 and Pokhran II (Operation Shakthi) in 1998. The Indian nuclear power programme has three stages, as envisioned by Bhabha. The first stage involves natural uranium-fuelled pressurized heavy water reactors; the second stage features fast breeder reactors utilizing plutonium-based fuel and the third stage includes advanced nuclear power systems for utilization of thorium (http://www.dae.gov.in/publ/3rdstage.pdf). Considerable indigenous development has been made in keeping with this plan. The milestones achieved by DAE (http://www.dae.gov.in/milestone.htm), the annual report 2010–2011 (http://www.dae.gov.in/publ/ar1011/ar1.pdf) and the recent progress (http://www.dae.gov.in/press/founder2011.pdf) give an idea of how far we have come.

'The picture of the DAE in 1970 is one of an expanding and expensive empire involved in electronics, computers, satellites, rockets, and nuclear reactors, as well as basic research in physics, mathematics and biology. This expansion is contrasted with increasing public questioning about the contributions of the DAE to the economy… . By 1972 the DAE had become a very large and widely dispersed organization of almost 8,000 support

Figure 1. Atomic energy establishments in India. Source: http://www.dae.gov.in/publ/indmap.htm

staff on payroll, including 2,400 scientists; thousands more technical staff (e.g. machinists) worked on "continuous" casual labor pay. The reactor projects proceeded at high speed, to prove their completion and effectiveness.[1'] It is interesting to read the account by Anderson on the special cultures related to atomic energy projects (Box 2).

There are at present 20 nuclear power reactors operating in India with a total installed capacity of 4780 MWe. This represents about 3% of the total installed capacity. In the last financial year (2010–11), about 26,302 million units of electricity were generated from these nuclear reactors[6]. India stands at position 6 in terms of the number of reactors in operation worldwide (20 out of the 440

Box 2. Special cultures associated with atomic energy projects.

'… Kota for heavy water in Rajasthan had a special town near the lake, Tarapur for reactors in Gujarat had a special town too, Thumba in Kerala for rockets had a special housing project that was a large cosmopolitan community like a village. These projects grew like mushrooms, and though they resembled one another and resembled those towns for steel mills and for jet fighters and hydro dams, they were not everywhere the same, not identical though they all had electricity. In 1967 Taya Zinkin stressed the sociocultural differences between the British, German, and Russian steel project towns (Bhilai, Rourkhela), and the DAE projects experienced the same evolution and differentiation. Each had its special context, its starter's position, its distinctive character, its particular leaders and personalities. In these special DAE places, engineers and technicians enjoyed a status elevation because of their contact with the nucleus, their contact with the high sciences like physics. These DAE projects outside Bombay contributed naturally to the evolution of the different "epistemic communities" in the expanding department – some oriented to construction and operation, others looking ahead to new research and others to practical design in the next generation. Their ways of seeing and thinking gradually diverged and the family relationship, even as metaphor, eventually had less and less meaning. But still institutions referred to themselves as families, as the director of TIFR did in 1968.' (Source: Anderson[1].)

reactor units; http://www.iaea.org/cgi-bin/db.page.pl/pris.oprconst.htm), at position 3 in terms of the number of reactors under construction worldwide (6 out of 66 reactors; http://www.iaea.org/cgi-bin/db.page.pl/pris.opercap.htm) and held 2.85% nuclear share in electricity generation in 2010 (http://www.iaea.org/cgi-bin/db.page.pl/pris.nucshare.htm). The website of the World Nuclear Association (http://world-nuclear.org/info/inf53.html) gives details of the existing and proposed nuclear activities in India (Figure 2).

Future projections and criticisms

The plan is to increase the installed nuclear generation capacity to about 35 GWe by the year 2020 and to 63 GWe by 2032 (ref. 6). Tables 1 and 2 show projections for the installed electrical capacities and electricity generation respectively, in a fuel mix scenario up to 2052.

The future nuclear capacity estimates by DAE have been criticized, as previously projected energy targets have not been met. Raju notes: 'The DAE has been unable to meet targets even over the very short run. For example, in 2003, Kakodkar predicted that in about four years from now, DAE will reach an installed capacity of 6800 MWe. Six years later, nuclear capacity is only 4120 MW.[7]' Physicists, Raju and Ramana[8] also point out that: 'The first secretary of the DAE, Homi Bhabha, predicted that India would produce 18–20,000 megawatts (MW) of nuclear power by 1987; when 1987 came around, India's nuclear power production capacity was stuck at 512 MW – less than 3 per cent of Bhabha's projection.' On 21 April 2011, at the meeting of the Planning Commission, it was mentioned that 'the country needed an additional 1,00,000 MW of power during the 12th Plan period (2012–2017) and therefore capacity expansion should be undertaken keeping the safety measures intact.[9]' This 'capacity' refers to nuclear power.

The Indo-US nuclear deal

To enhance the speed and quantity of nuclear power production, much focus has been on international collaboration in recent years, particularly the Indo-US nuclear deal. The DAE[6] explains how international collaboration would help us: 'India has been pursuing a 3-stage nuclear power programme. The first stage which is already in the commercial domain comprises pressurized heavy water reactors that use natural uranium as fuel and heavy water as moderator and coolant. The second stage uses plutonium obtained by the reprocessing of the spent fuel of pressurised heavy water reactors (PHWRs). In this stage too India is firm footed and is on the verge of commercial domain. The third stage is based on conversion of thorium (of which India has vast resources) into uranium-233 (a man made fissile material) by its irradiation in uranium/plutonium reactors. The three stage programme has essentially a multiplier effect. A limited resource of fissionable material can be multiplied several fold through the 3-stage programme.'

'We have very modest uranium resources that even if mined fully, can support a limited installed capacity thus limiting the potential of the second and the third stage. For the immediate growth of installed nuclear capacity, we need to set up large capacity light water reactors through international co-operation. This will have multifold advantage. First, it will help increasing nuclear generation capacity on short term basis. Second, it will help in multiplying the nuclear generation capacity through setting up of breeder reactors which will employ Pu obtained by reprocessing of the spent imported fuel ensuring energy security to the country. Once the third stage enters into the commercial domain, we would be secured for energy supply for several centuries. Life time supply of uranium fuel for the imported reactors, right to reprocess the spent imported fuel and non-interference with our domestic programme are essential features of all our international collaboration endeavours.'

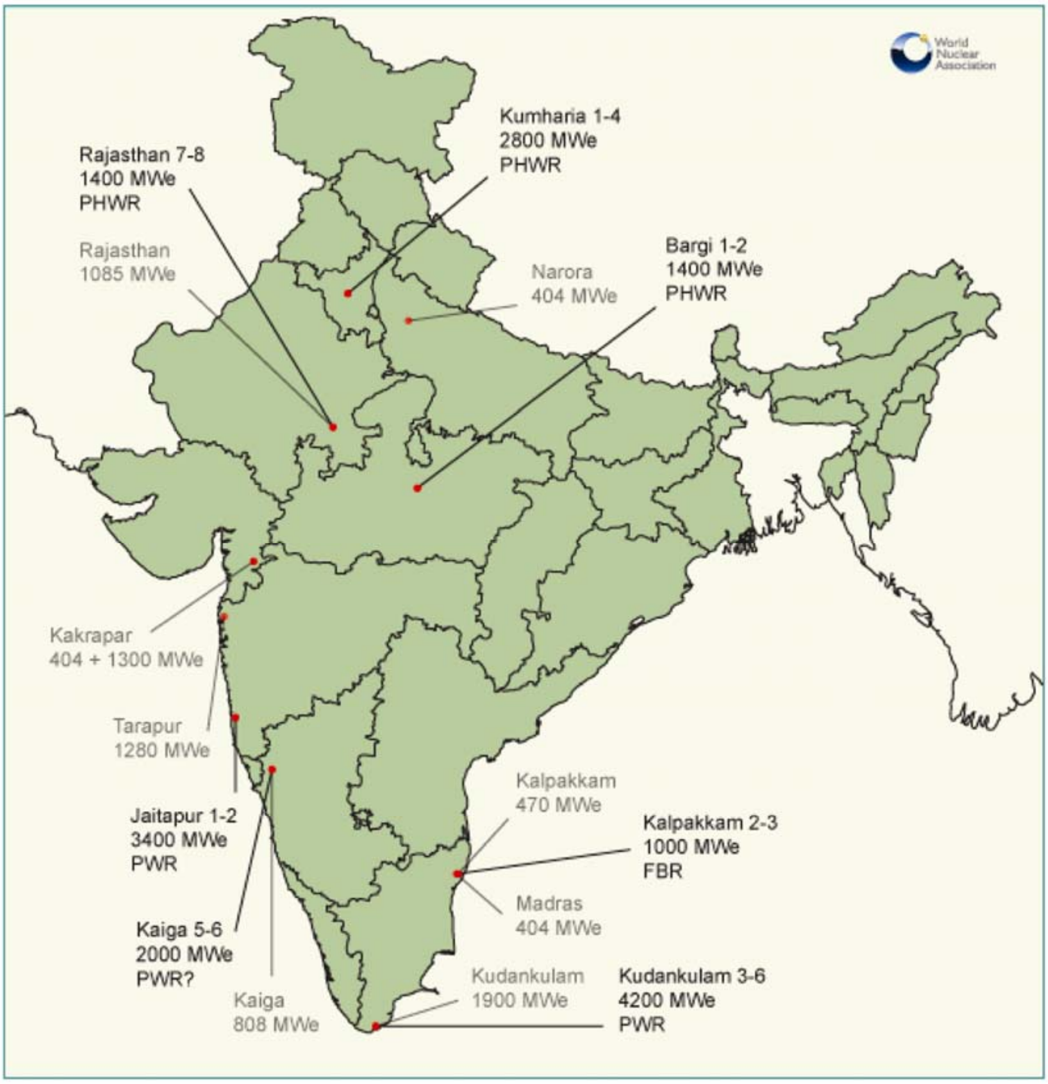

Figure 2. Planned nuclear power plants in India. Source: http://world-nuclear.org/uploadedImages/org/info/planned_nuclear_power_plants_in_india.png

Table 1. Installed electric capacities – fuel mix (including estimated captive power)

	Coal		Hydrocarbon		Hydro		Non-conv renewable		Nuclear		Total
Year	GWe	%	GWe	%	GWe	%	GWe	%	GWe	%	(GWe)
2002	71.92	51.84	32.81	23.65	27.78	20.02	3.5	2.52	2.72	1.96	138.73
2022	156	37	60	14	115	28	56	13	29	7	417
2032	266	41	101	15	150	23	68	11	63	10	648
2042	436	46	155	16	150	16	82	9	131	14	954
2052	615	46	204	15	150	11	100	7	275	20	1344

Source: Document 10: A strategy for growth of electrical energy in India; http://www.dae.gov.in/publ/doc10/index.htm

Kakodkar, former head of DAE, gave two lectures in 2008 and 2009, in which he 'claimed that if the nuclear deal went through and India was allowed to import a specified number of light-water reactors (LWR) and fuel, then the recycling of fuel from these reactors would lead to an installed capacity of 650 GW![7]' (see Figure 3). '... Kakodkar predicted that nuclear energy would provide more than 50 per cent of India's power generating capacity by 2050. Note that this is about 150 times the current nuclear power capacity of 4.12 GW that provides 2.64 per cent of the country's power generating capacity![7]' says Raju.

Table 2. Electricity generation – fuel mix (including estimated captive power generation)

Year	Coal TWh	Coal %	Hydrocarbon TWh	Hydrocarbon %	Hydro TWh	Hydro %	Non-conv renewable TWh	Non-conv renewable %	Nuclear TWh	Nuclear %	Total (TWh)	Per Cap Elec Gen (kWh)
2002	425.74	66.69	125.08	19.61	65.66	10.29	2.66	0.42	19.24	3.01	638.38	614
2022	957	44	369	17	460	21	162	8	206	10	2154	1620
2032	1630	47	618	18	600	17	197	6	441	13	3485	2454
2042	2673	49	950	18	600	11	237	4	978	18	5438	3699
2052	3774	47	1250	16	600	8	289	4	2044	26	7957	5305

Source: Document 10: A strategy for growth of electrical energy in India; http://www.dae.gov.in/publ/doc10/index.htm

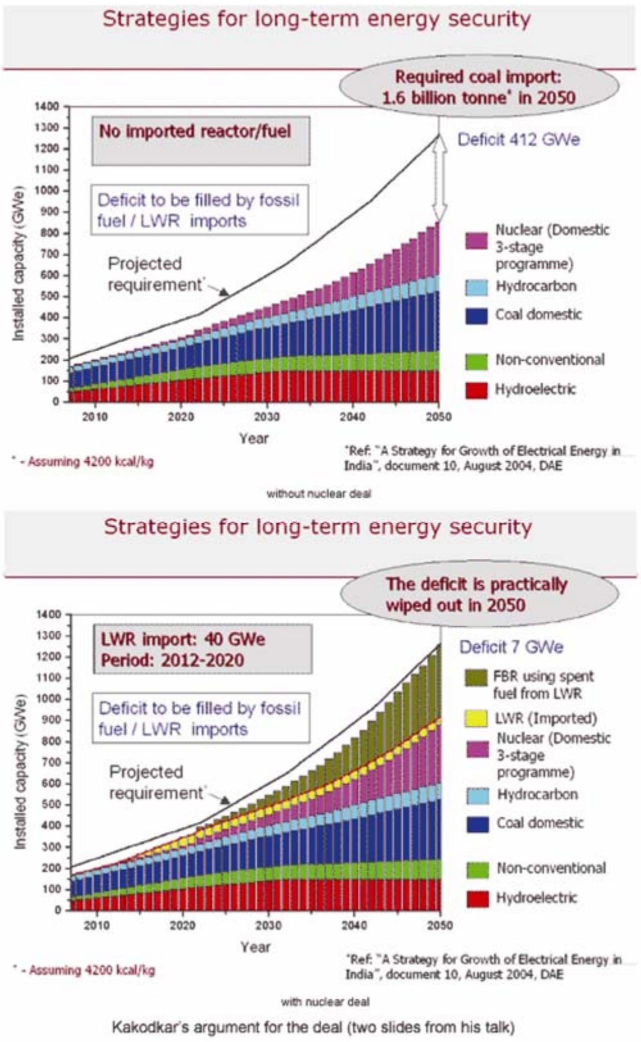

Figure 3. Meeting India's energy deficit through the nuclear deal. Source: http://rupe-india.org/48/atomic.html

When introducing the moratorium on *Bt* brinjal, Jairam Ramesh, the then Environment Minister, is reported to have said that there was no overriding urgency to introduce *Bt* brinjal, especially when the public sentiment was negative (http://www.tribuneindia.com/2010/20100210/main1.htm). Is there an urgency to expand nuclear power and that too with international collaborations? Kakodkar presented the effect of a 10-year delay in the import of these LWRs (40 GWe): 'the energy deficit in the year 2050 would be 178 GWe and the corresponding requirement for coal import will be 0.7 billion tonne.[10]'

But according to Gopalakrishnan[11], the DAE had framed a nuclear power plan prior to 2004 in which it had confirmed that '208,000 MWe of nuclear power can be generated in India by 2052 using Indian uranium resources, without having to import even a single reactor beyond the two Russian VVERs at Kudankulam, which were by then under construction'. He continues: 'The reason for bringing in imported reactors is neither technology driven nor is it for the economic benefit of the country. In the context of the need to maximize plutonium production from the first stage reactors to rapidly advance along the three-stage Bhabha Plan, it should be noted that the Indian PHWRs are the most efficient plutonium producers, far superior to the high burn-up LWRs which DAE is planning to import … we have the inherent indigenous ability to further extend the PHWR designs to 1000 MWe rating.'

Gopalakrishnan[11] goes on to mention that: 'Among the US objectives were the desire to bring several of our PHWR installations under IAEA safeguards, to revive the moribund US nuclear industry by selling US-design nuclear reactors to India, slow down and eventually stop India's indigenous nuclear programme based on the Bhabha Plan … .' Further, Sunita Narain[12], Editor of *Down To Earth*, comments on the Civil Liability for Nuclear Damages Bill that the Indian Government wanted to present in Parliament: 'The bill caps the operator's liability at Rs 500 crore per incident, with additional damages of approximately Rs 2,300 crore to be made good by the government. This amount is even less than what was paid in the case of Bhopal, a ridiculously low amount; this amount is a joke when it comes to a nuclear accident…US companies with an interest in the nuclear business desperately want India to pass this bill.'

The effort taken by India to keep foreign investors in good terms has been questioned. Raju and Ramana[8] ask: 'Why then would India rush to buy these exorbitant reactors from France? The answer was laid out clearly by Kakodkar … "we also have to keep in mind the commercial interests of foreign countries and of the companies there ... America, Russia and France were the countries that we made mediators in these efforts to lift sanctions, and hence, for the nurturing of their business interests, we made deals with them for nuclear projects"... In fact, the nurturing of foreign business interests has been of such importance to the Indian Government that it has often been willing to take away the rights of its own citizens ... the Government spent the entire 2010 monsoon session of Parliament passing a nuclear liability law whose primary purpose was to prevent victims from being able to sue suppliers for compensation in the event of an accident.' A remark by Nigam[13], in his book *Desire Named Development*, comes to mind: 'For when you invite capital from elsewhere, it comes with its conditions and it is bad "market economics" to say that we will not comply with such conditions.'

Another expert opinion is that the Indo-US nuclear deal is actually beneficial for the country. Rajaraman, Co-Chairman of the International Panel on Fissile Materials, says that the Deal would enable us to build more reactors and obtain the fuel required to operate them. It would also allow us to collaborate with other countries and lead to an improvement in our expertise. He discusses the implications of the Deal for India's energy and military programmes in a chapter in the book *Indo-US Nuclear Deal*[14]. He also indicates that 'While the nuclear deal is unquestionably beneficial to us, it is not going to solve all of India's energy problems, or even provide 20% of our energy requirements by the year 2030. We should be happy if even 10% of our electricity requirements in 2030 can be met by the nuclear sector.' He advises that the government '... must monitor the state of technology and cost alternatives like wind, solar and tidal power, as well as of environmentally improved versions of coal. The cost of reactor dismantlement and disposal of spent fuel must also be realistically included.[14]'

The Indo-US nuclear deal is one point of contention. Another is regarding the nuclear plant to come up in Jaitapur, which will be one of the largest in the world.

The case of Jaitapur

The Nuclear Power Corporation of India Limited (NPCIL) had signed an MoU with the French company AREVA for the supply of at least two European pressurized reactors (EPR) for Jaitapur. Gopalakrishnan[11] points out that a 700 MWe PHWR can be built in India within a capital cost of Rs 8 crore/MWe whereas a 1650 MWe, French EPR at Jaitapur would cost more than Rs 21 crore/MWe.

There have been remarks in the media that EPR is an untested technology and reports of the delays and consequent increase in costs of the EPRs in Finland. Responding to a query (in April 2011) as to why India is going in for LWRs when we are comfortable with PHWRs, Banerjee[15], Chairman of AEC, explained that LWRs have come to a kind of maturity and that 85% of the total nuclear power that is getting generated in the world is through these reactors and generally of much larger size. This is because the reactor concept is simple in this case; power can be continuously drawn from it with no interference. The heavy water reactors have a sophisticated design, but are much more complex.

Regarding the doubt that it is an untested reactor, Banerjee remarked that 'it has been so standardized everywhere that it has gone past that doubt…', and also pointed out that 'any reactor process or reactor development is nothing but an evolutionary process'. He explained that the probability of core damage gets substantially reduced in the case of reactors with a large capacity; it is also economical. He emphasized that they would not be going ahead just with AREVA's words, but would be checking the safety mechanism themselves. He said that the first reactor will be coming up in Finland, the second in France, the third in China and by the time India gets it in 2018 or 2019, there will be several of them working in the world.

Protests have taken place in Jaitapur and more recently at Kalpakkam. There have also been public protests against proposed nuclear plants in Kovvada (Andhra Pradesh) and Mithi Virdi (Gujarat), some with political connotations. In Jaitapur, the local villagers have been protesting against the proposed plant, citing reasons of threat to health, livelihood and environment. A *yatra* from Tarapur to Jaitapur was organized in April 2011, in which many people were detained by the police and one person was killed during police firing. In spite of these protests, on 26 April 2011, the 25th anniversary of the Chernobyl nuclear disaster, the Indian Government announced its decisions: to make the results of the safety review public (a post-Fukushima review of India's nuclear plants had been commissioned), to constitute an independent regulatory board (the authenticity of the present AERB had been questioned as it reported to AEC, the body whose activities it was supposed to regulate) and to go ahead with the Jaitapur power plant.

These decisions have been questioned in a letter[16] dated 30 April 2011 by 80 well-known people in the country, including Amit Bhaduri (economist and professor emeritus, Jawaharlal Nehru University), Girish Sant (energy specialist, Prayas, Pune), K. Sujatha Rao (former Health Secretary, Government of India), L. Ramdas (former Chief of Naval Staff, India) and Ramachandra Guha (anthropologist and historian). The letter questions the disregard to the 'overwhelming opposition to the project by 40,000 local people and the larger public, the caution counselled by numerous experts, and the grave safety concerns raised by the still-unfolding Fukushima nuclear disaster in Japan', calls for projects like Jaitapur to be put on hold pending 'an independent, thorough and transparent review of our nuclear policy and installations by a broadly representative body, which includes non-DAE personnel and civil society representatives'. It also says that: 'the AERB's responsibilities and powers must be defined in advance and its members selected with exemplary prudence so that only persons with the highest integrity, impartiality, and commitment to the public interest are chosen by a broad-based collegium'.

A People's Tribunal conducted a non-governmental inquiry into the Jaitapur project, headed by Shah, former Chief Justice of the Delhi High Court and Pandit, former Justice. The local fishermen have reported that the environmental impact assessment (EIA) has not considered 'the impact on the two creeks in close vicinity of the project site.[17]' Shah has suggested that the Expert Appraisal Committee should ask for another EIA, while activists have criticized that the previous EIA has not dealt with 'long-term storage' of spent fuel[18]. 'In Jaitapur, at a public hearing for the EIA, inhabitants of the area overwhelmingly opposed the project. Expectedly, the environment ministry cleared the nuclear complex anyway, citing among other reasons the interest of "global diplomacy".' say Raju and Ramana[8].

Ramana and Rao[19] have examined the effectiveness of the EIA process for nuclear facilities in India. They discuss specific concerns: some nuclear facilities are exempt from the environmental clearance process; data regarding radiation baseline levels and future releases, which is the principle environmental concern with respect to nuclear facilities, are controlled entirely by the nuclear establishment; members of the nuclear establishment take part in almost every level of the environmental clearance procedure. 'For these reasons and others, the EIA process with regards to nuclear projects in India is of dubious quality[19].'

A comprehensive study was to be undertaken by NPCIL with five participating organizations 'to understand the possible effects of the Jaitapur Nuclear Power Project on the marine ecology and biodiversity in the area'. The study was to be completed in one year at a cost of ~ Rs 5.86 crore. Such a study has not been done before for the Jaitapur project[20]. Goenka, Executive Trustee of Conservation Action Trust, is reported to have said: 'This study should have been done as a part of the EIA … This [study] is going to be a waste of money and energy. One year down the line, whatever the result of the study, they are not going to stop the work on the project … Whatever the results of the study will be, they won't be factored in the environmental clearance.[18]'

Looking at Jaitapur from the seismicity point of view, is it susceptible to a Fukushima-type scenario? Valdiya, a specialist in tectonics and environmental geology, says: 'our plants are unlikely to be impacted by the earthquakes of the magnitude that rocked Japan.[21]' Kusala Rajendran[22], a seismologist, points out that: 'From the earthquake point of view, it is not located in an area where large earthquakes can occur …' She says that the likely tsunamigenic source to affect this site is Makran and that: 'one may take into account the possible inundation and wave height and use the worst case scenario for the plant design and location.'

In a recent article, Bilham and Gaur[23] discuss seismicity near Jaitapur and conclude that '…the apparent seismic quietness of Jaitapur does not mean that a severe earthquake cannot occur there'. They also point out: 'Since Jaitapur lies in the same compressional stress regime that has been responsible for generating both the $Mw = 6.3$ Latur and the $Mw = 6.4$ Koyna earthquakes in the past five decades, it can be argued that a similar sized earthquake could possibly occur directly beneath the power plant.' Have these considerations been taken into account in designing the power plant?

In spite of protests by the public and scientists, the Government had decided to go ahead with the Jaitapur plan. Recently, it has been decided that India will postpone purchase of EPR reactors from AREVA until after the current post-Fukushima nuclear safety tests have been satisfactorily completed (http://www.thehindu.com/news/national/article2468399.ece).

Whether Jaitapur or any other nuclear plant in the country, whether using international or national technologies, whether located in an earthquake-prone region or not, the question is 'do we need nuclear power to fulfil the energy requirements of the country?' Can this need be met through other less-risky sources such as solar?

Energy security and economic growth

Energy security is the 'equitable provision of available, affordable, reliable, efficient, environmentally benign, properly governed, socially acceptable energy services to citizens[24]'. Different sections of society see energy security differently. Brown and Sovacool[24] give some examples: for consumer advocates and users, it may be viewed as 'reasonably priced energy services without disruption … major oil and gas producers focus on the "security" of their access to new reserves, while electric utility companies emphasize the integrity of the electricity grid. Politicians dwell on securing energy resources and infrastructure from terrorism and war … scientists, engineers, and entrepreneurs characterize energy security as a function of strong energy R&D, innovation, and technology-transfer systems.'

The Integrated Energy Policy Report of India (2006) defines 'energy security' as: 'We are energy secure when we can supply lifeline energy to all our citizens irrespective of their ability to pay for it as well as meet their effective demand for safe and convenient energy to satisfy their various needs at competitive prices, at all times and with a prescribed confidence level considering shocks and disruptions that can be reasonably expected.[25]' In the context of this definition, the cost-effectiveness of

Box 3. Concerns about cost.

'In May 1969 Sarabhai and Sethna had been asked about the price of a unit of electricity from Tarapur: Sarabhai said it would be 5.6 paise, which was the generating cost, and Sethna said the generation *cost* would be 5.6 paise but the sale *price* would be 6.5 paise; "as a result there was considerable confusion in Parliament, in the scientific community, and in the media." (Parthasarathi, *Technology at the Core*, p. 18). Parthasarathi questioned Sethna again about the cost of power and learned that the AEC's calculation was made without considering the cost of enriched fuel to be imported from the US and with the Tarapur reactor capital cost held at Rs 770 million (what the Parliamentary Committee was told, but lower than was actually spent). Sethna then said that if the International Atomic Energy Agency cost methodology, which covered all costs including fuel, safety, waste handling, and disposal, as well as decommissioning, were used, the price would go up: "he implied that it would raise the cost of power from our reactors to 'unacceptable' levels," at about 8 paise per unit, higher than the cost of thermal power in the grid, which was then close to 5.6 paise and the reason Sarabhai quoted that price' (Ibid, p. 19). (Source: Anderson[1].)

nuclear power has been under question right from the start (Box 3). Ramana also points out that today, nuclear power is not an economically competitive choice (MIT study, 2003; ref. 26).

Nuclear batteries are also being looked into. These are cheaper, smaller and produce less power than conventional power plants, and are easily transportable. They can be used to power small towns, desalination plants or commercial ships, and can augment renewable energy sources. But some groups are concerned about the risk of proliferation and increased nuclear waste (http://www.time.com/time/magazine/article/0,9171,2050039,00.html). Brown and Sovacool[24] say that 'Research and development into autonomous, long-lived small nuclear power plants that do not require refuelling could provide safe and reliable electric power to remote locations'.

Anderson' notes: 'Though warned about underestimating the opportunity costs of nuclear power... , a great many other energy initiatives could have been pursued with the same money, and it might have been possible to study and develop other sources of energy. Surprisingly there was no sustained push in solar power, which could have provided for India's two big energy uses—night light and cooking—for about eight months of the year. This gap arose because solar power had little value to industry, and India's energy system was an industry-first planning priority; only in the late 1960s did mid-level planners realize that modern agriculture was also going to need energy, and not just from electricity but also from petroleum.[1]' In a recent article, Sukhatme indicated that renewable energy sources stretched to their full potential can at best contribute 36.1% (in 2070) of the total electricity needs of the country, and that nuclear energy would be the major player[27].

The DAE[6] provides an explanation on the need for nuclear power: 'If one has a serious look at the demand and supply of electricity scenario in India in the coming decades and analyses it in terms of various resources (including solar and other renewables) one comes to the conclusion that nuclear energy is an inevitable option and should be an essential component of electricity planning. We have large sections (nearly 40%) of our population deprived of any electricity.' (See ref. 28.) 'Today the per capita electricity consumption is a meagre 700 kWh per person per year, which is quite low compared to the global average (about 2700 kWh) and far too low compared to that of the OECD countries (about 8000 kWh per person per year).

'As per Planning Commission, for increasing the per capita electricity consumption to about 5000 kWh and also to achieve an economic growth of 8–9% in the coming decades, we will have to increase the total installed capacity of electricity in the country by 8–10 times by 2050. Contribution of renewable resources (including hydro, solar and others) can only be 10–12% of this. Meeting the rest of this target only through fossil resources will require about 4.7 billion tonnes of coal to be burnt every year (about four times the present US coal consumption for electricity generation). This poses two problems – first availability of such large quantities of coal, and second the exorbitant amount (~ 7.7 Gte) of carbon dioxide emission associated with it. Nuclear energy being emission free becomes an inevitable option for meeting these ambitious but necessary requirements of electricity in India.

'The ideal approach to meet these targets is: (a) to exploit all renewable resources to their maximum with special attention to develop solar and (b) gradual increase in the share of nuclear so as to minimize the dependence on the fast depleting fossil resources. Thus, it is not only worth but rather essential to obtain energy from nuclear. Of course, it has to be done in a safe manner. As far as the risk associated with nuclear resources is concerned, it may be noted that nuclear is one of the safest resources as proved by a study of the World Nuclear Association, according to which the fatalities per TWh generation of electricity are 883 for hydro, 342 for coal, 85 for gas and 8 for nuclear.'

In order to increase the gross domestic product (GDP), widely seen as an indicator of progress, India has to escalate electricity supply. Does GDP truly reflect progress of the nation and welfare of its people? Nigam[13] has pointed out that GDP can continue to rise even when the nation is at war and its people are suffering from poverty. The Human Development Index (HDI) may better assess growth, according to materials scientist Chokshi. HDI takes into account life expectancy, literacy, education and standard of living and shows that we do not really need so much energy consumption as indicated by GDP[29]. Even in the early days, 'Amid the sophisticated missiles and reactors, there was still malnutrition, preventable disease, and unsafe drinking water', points out Anderson[1].

Chokshi says that a substantial expansion in nuclear power will enable its contribution to raise from the current value of ~ 3% to ~ 6%. This amount can be obtained by reducing transmission and distribution losses (> 25% in India compared to ~ 5% globally), conserving energy, enhancing efficiency, using renewables, and decentralizing power generation and installing smart grids[29].

Carbon emissions and nuclear power

Ramamurthy[30] indicates: 'As far as the power needs are concerned, we are a country of energy shortages. We also have a large aspiration driven population. We rely on substantial import of hydrocarbons. At the global level, we are committed to a global reduction of CO_2 so that we leave behind a livable earth for our children .... We cannot afford to say NO to nuclear power at this stage hoping that some renewable energy will be found ...'.

An analysis of the fuel-mix scenarios developed, using a programming model, to study the options available to meet India's projected energy needs shows that the two scenarios, namely (i) coal-based development and (ii) maximize nuclear, which result in higher energy outputs at 1702 and 1700 Mtoe respectively, are also the ones which cause greater CO_2 emissions at 5118 and 5054 Mt respectively. An 'accelerated renewables' scenario gives 1351 Mtoe of energy and 3591 Mt of CO_2 emissions[31].

It has been pointed out that even though nuclear stations do not emit greenhouse gases at the point of production, 'over their whole lifecycle, that is, from fuel production, decommissioning and waste storage, nuclear power does add to the greenhouse effect[32]'. There exists a debate on the amount of carbon emissions from the complete nuclear fuel chain. The estimates range from 1.4 to 200 g/kWh (ref. 26).

There would also be a need for geological repositories to dispose the spent fuel (an example is the Yucca Mountain in Nevada). Parthasarathy, DAE Raja Ramanna Fellow, mentions that: 'For disposing high level waste construction of deep geological repositories is accepted universally as a workable solution ... with today's spent fuel or vitrified high-level waste, extra layers of protection come from the multi-barriers of stable ceramic material, encapsulation, and depth from the biosphere that are designed to prevent any movement of radioactivity for thousands of years. A stable geological formation, within which the waste will be disposed, also constitutes a highly reliable barrier.[29]' But O'Keefe *et al.*[32] explain that 'This involves disposing waste in rock, clay or salt 500–1000 m deep ... there are many uncertainties about deep geological storage as little is understood about the impacts of storing radioactive materials for very long periods.'

In a paper entitled 'Balancing risks: nuclear energy and climate change' (http://www.princeton.edu/mae/people/faculty/socolow/Daedalus-Socolow-Glaser-Fall-2009-pp-31-44.pdf), Socolow and Glaser put forth four questions which require discussion and give tentative answers for them. One of the questions is: 'Will the nuclear power cure for climate change be worse than the disease?' and their answer is: 'Every "solution" to climate change can be done badly or well. Done badly, it can be worse than the disease. Making climate change the world's exclusive priority is therefore dangerous. It results in an overemphasis on speed of transformation of the current energy system and a dismissal of the very large risks of going too fast. Looming over energy efficiency is the shadow of excessive regimentation; over renewables, land-use conflicts (with food, biodiversity, and wilderness values); over carbon dioxide capture and storage, the environmental abuses that continue to characterize the fossil fuel industries; and over geoengineering, granting excessive authority to a technocracy. Looming over nuclear power is nuclear war. The upper limits of climate change are terrifying, amounting to a loss of control of the climate system as positive feedbacks of various kinds set in. Nonetheless, at this moment, and conceding that such calculations can only embody the most subjective of considerations, we judge the hazard of aggressively pursuing a global expansion of nuclear power today to be worse than the hazard of slowing the attack on climate change by whatever increment such caution entails. If over the next decade the world demonstrates that it can do nuclear power well, a global expansion of nuclear power would have to be – indeed, should be – seriously re-examined.'

Safety concerns

An analysis by Parikh[31], former member of the Planning Commission, Government of India, shows that a pessimistic scenario of 208 MW of nuclear power installed capacity in 2050 is possible, assuming that 'the FBR technology is successfully demonstrated by the 500 MW PFBR currently under construction, new Uranium mines are opened for providing fuel for setting up additional PHWRs, India succeeds in assimilating the LWR technology through import and develops the Advanced Heavy Water Reactor for utilising Thorium by 2020'. But, are India's fast breeder reactors (FBRs) safe? Kumar and Ramana[33] mention that fast reactor programmes have been shelved in many countries due to safety concerns. Their study 'finds that the PFBR is not designed to protect against a severe Core Disruptive Accident (CDA) and the DAE makes favourable assumptions that it has not justified. Even slight variations in their assumptions could have consequences far worse than acknowledged by the DAE and could overwhelm the PFBR containment.[33]'

Regarding the safety analysis of nuclear reactors in India, Munshi[34], one of the associated faculty members of the Nuclear Engineering and Technology Programme at IIT Kanpur, talks about the steps involved: 'Accidents are simulated using "computer codes" licensed by USNRC in USA and AERB in India. Design of nuclear reactor is approved if key parameters (e.g. pressure, temperature, fuel integrity) are predicted to be within prescribed limits.' A review committee was set up on 19 March 2011 to review the safety of nuclear power plants in India in the light of the earthquake and tsunami in Japan. Bishnoi[35], Member-Secretary of the Committee, explained that the Committee would review: (i) Capability of Indian nuclear power plants to withstand earthquakes and other external events such as tsunamis, cyclones and floods. (ii) Adequacy of provisions available to ensure safety in case of such events, both within and beyond design basis.

In a recent address, Banerjee indicated that: 'Many of the recommendations of the safety reviews conducted by the NPCIL task forces and by AERB have already been implemented. A road map has also been prepared for implementing the remaining recommendations. It has been decided to invite IAEA missions, namely, Operational Safety Review Team (OSART) and Integrated Regulatory Review Service (IRRS), for peer review of safety of nuclear power plants, and of the regulatory system respectively. The emergency response and preparedness measures have been further strengthened in all our nuclear facilities' (http://www.dae.gov.in/press/founder2011.pdf). But, there have been widespread objections that a thorough review has not been done (for example, see ref. 16).

During another lecture, Banerjee explained that the disaster at Fukushima could have been prevented to a great extent by the passive safeguard systems incorporated in the design of the advanced heavy water reactor (AHWR) in India[15]. But do all of the imported and existing reactors have these features? Can our existing and proposed nuclear power plants withstand an earthquake or tsunami similar to those that occurred in Japan? The DAE[6] says: 'Seismically and tsunamigenically, India and Japan are just not comparable. In India except for the two reactors at Narora (which lie in seismic zone 4), all the existing and proposed nuclear power plants are in seismic zone 3 or 2. A nuclear plant at a given location in India is always designed and constructed taking into consideration among many other things, the seismicity of that location. Similarly, an ocean based fault nearest to a nuclear power plant in India – the Makaran fault in the Arabian Sea is about 900 km away from Tarapur. The possible tsunami scenario at a place is also taken into consideration while putting up a nuclear power plant at that location. The Bhuj earthquake of 2001 and the tsunami of 2004 are testimony to the capability of Indian Nuclear Power Plants to withstand such natural calamities.'

Munshi[34] also notes that: 'Our reactors are located in a much "lower" seismic zone as compared to Fukushima plants so the question of such a disaster does not arise.' Here one must take note of the statement by Valdiya, that our seismic zonation maps are not up to date[21]. He says: 'It is ironic that our laws (or regulations) forbid free access to academies of the Survey of India topographic maps on the requisite scale of many crucial regions. Even if one were to delineate the faults in such maps (obtained somehow), these maps cannot be published.[36]' He explains how the as-yet-unmapped faults, lineaments and fractures could trigger seismic activity: 'If the faults are reactivated abruptly and the strain relaxed spasmodically, or if the blind faults reach the surface and rupture the ground, there would be earthquakes, preceded and followed by shocks of lesser magnitude.[21]' 'Reactivation of active faults would pose danger to the stability of the structures built.[36]' says Valdiya. Rajendran[37] indicates that: ' … it is important that we generate a first approximation inventory of active faults, identified on the basis of seismological, geological and geophysical studies'. He also says: '… Peninsular India, a stable continental interior, may contain potential seismogenic structures that are yet undetected.' Harinarayana *et al.*[38] point out that 'The recent major devastating earthquakes in India – Bhuj earthquake in Gujarat, Jabalpur earthquake in Madhya Pradesh and Latur earthquake in Maharashtra – have changed the notion that stable continental regions of India are not prone to major earthquakes and have demanded more stable examination of the stress accumulation.'

Regarding tsunamis, Kusala Rajendran[22] explains that the tsunamigenic sources that can affect India are: (i) the Sumatra–Andaman and (ii) the Makran subduction zones. '… we can only identify the potential sources, but not the time. We certainly cannot predict that an earthquake/tsunami would or would not happen. In the scenario that two likely sources exist in the neighborhood, we have to raise our level of alert and caution.'

The impacts of the 1986 Chernobyl disaster are still not clear – many figures are quoted: 'around 50 people engaged in the immediate emergency and recovery operations' died (Yukiya Amano, Director-General of the International Atomic Energy Agency)[39]; 'Chernobyl may ultimately cause some 270,000 cancer cases, more than 90,000 of which could prove fatal' (Greenpeace)[39]; 'Chernobyl had long-term impacts on human health and the environment, including the contamination of large tracts with various radioactive elements. An area of over 3,000 sq. km (almost 80 per cent the size of Goa) still remains officially evacuated because it is contaminated with a radioactive element called cesium-137. A surrounding region that is thrice as large is designated as an area of strict radiation control, requiring decontamination and the control of intake of locally grown food. It takes 30 years for the radioactivity from cesium-137 to halve ...' (Raju and Ramana)[8].

The effects of radiation range from genetic (risk of radiation exposure to reproductive organs that can be passed onto progeny), somatic (in case radiation damages molecules of living matter) and in utero (spontaneous risk of foetal abnormalities)[32]. Interviews with workers at Japanese nuclear power plants revealed that: 'radiation levels would be so high that workers would take turns approaching a valve just to open it, turning it for a few seconds before a supervisor with a stopwatch ordered the job to be handed off to the next person.[40]'

The wastes from nuclear power plants can be low level waste (LLW), intermediate level waste (ILW) and high level waste (HLW), with increasing degrees of radioactivity in that order. Prolonged exposure to strontium-90 and cesium-137 found in low-level liquid waste (which, in India, is released though smokestacks and reaches nearby water sources) may result in leukaemia and elevated risks of cancer (http://www.indiafutureofchange.com/featureEssay_D0043.htm).

Ramana and Kumar[41] describe some accidents at Indian nuclear power plants and mention that this evidence shows 'the lack of priority given to nuclear safety by the DAE' and it 'suggests that the organisation has not developed the capability to reliably manage hazardous technologies'. They also point out: 'The largest study of nuclear workers, carried out by a large team of researchers and headed by a team from the International Agency for Research on Cancer (IARC), retrospectively examined the health records of over 400,000 workers in 15 different countries and demonstrated that a small excess risk of cancer exists, even at doses lower than typically mandated by radiation standards ... At the typically mandated radiation standards, workers could receive up to 100 mSv over five years. This would, according to the IARC study, lead to a 9.7% increased mortality from all cancers excluding leukaemia and a 19% increased mortality from leukaemia (excluding chronic lymphocytic leukaemia).'

Contradictory statements are presented by Parthasarathy: '… no genetic effects were found among the thousands of children born to the atomic bomb survivors at Hiroshima and Nagasaki… Allegation of diseases in the villages near Jaduguda, birth defects in the villages near Rajasthan Atomic Power Station (RAPS), blindness and other ailments of cattle near Pokhran site, accidental overexposures of workers at various sites, cattle deaths near Tarapur Atomic Power Station due to leak from the Waste Immobilization Plant (WIP), intake of tritiated water by many workers at Kaiga Generating Station … each of these have been investigated thoroughly; there were scientific explanations.[29]'

Parthasarathy also clarifies that the radiation from man-made radio-nuclides is exactly the same form as that emitted from naturally occurring radiaoactive materials (alpha, beta or gamma radiation). He points out: 'The annual dose limit to radiation workers recommended by the International Commission on Radiological Protection is 50 mSv. Many people in New Jersey and Pennsylvania get more radiation from radon in a week than anybody ever got at Three Mile Island. (Gerald Nicholls in *Newsweek*, 18 August 1986).[29]'

To be or not to be?

Such opposing and confusing information keeps comes out, and the lay person (still?) looks up to scientists and the Government to give him accurate information on whether a nuclear plant in his vicinity is safe for his health, whether a power plant that comes up in the land that he has given up will improve his food and livelihood security, whether there is a risk of radiation contamination of his water, air and land. But there has been no transparency or clarity in the multi-opinion reports that have been coming out in various media. On the one hand while Kalam[42], former President of India, says: 'Invincible nuclear security can be accomplished by every nation individually and collectively through eternal vigilance, continuous expansion of new energy technology options, coherence, dynamism and strength, freedom, indestructibility and self sufficiency ...', Ramana[43] says 'Catastrophic nuclear accidents are inevitable, because designers and risk modelers cannot envision all possible ways in which complex systems can fail.'

While one opinion questions the prudence of going ahead with nuclear power given the associated risks (leukaemia and thyroid cancer; pollution of groundwater, soil and air; loss of lives and property) in case of nuclear power plant failure, another opinion is that nuclear power is a must for the economic growth and electricity needs of the country, and that it is sufficient if precautions are taken in the design and location of these plants incorporating the lessons learnt from the Fukushima accident.

While some people are of the opinion that due to the high risk posed by nuclear power as witnessed in the case of Three Mile Island and Chernobyl, one should reconsider its use, others point out that just because there have been accidents, we have not abandoned nuclear power but have learnt from their review and incorporated changes. Brown and Sovacool[24] mention: 'The partial meltdown of a reactor core at Three Mile Island Unit 2 in 1979 resulted in the creation of the Institute of Nuclear Power Operations to promote excellence in utility operations of nuclear power plants. The core destruction and resulting contamination at Chernobyl Unit 4 in Ukraine in 1986 resulted in the formation of the World Association of Nuclear Operators to maximize the safety and reliability of nuclear power plants worldwide.'

This split in opinions continues and has been magnified by the triple disaster in Japan – earthquake–tsunami–nuclear plant damage.

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