Inevitability of nuclear energy*

Raja Ramanna

The Indian Atomic Energy Programme that had been launched in the late 1940s, with the courageous vision of Homi Bhabha, had made remarkable progress during the fifties, sixties and till the mid-seventies, leading to the establishment of a comprehensive base of nuclear science, technology and engineering, and the setting up of nuclear power stations. After the Pokharan experiment in 1974, the programme had to face a hostile attitude from the Western powers, with the stoppage of flow of technology and equipment from the West. The programme had shown the resilience to face the challenge, and march ahead, developing a range of indigenous capabilities both within the Department and in the Indian industry, though with a certain loss in the momentum. The successful design, construction and operation of the 100 Mw(t) research reactor Dhruva in Trombay, and the successful commissioning of the Fast Breeder Test Reactor in Kalpakkam, with a unique plutonium–uranium carbide fuel of Indian design, are significant capability demonstrations in the latter phase. On the power front, the twin-unit power stations at Narora (UP) and Kakrapar (Gujarat) have shown excellent performance, with respect to plant availability and capacity factor. This article presents an assessment of the progress achieved so far, amidst the difficulties encountered. Factors accounting for the apparently slow pace of growth are discussed, and the public concerns regarding nuclear safety and safety regulations are also addressed.

In a situation where acute power shortages have become a fact of life, and difficulties can be foreseen in the development of coal and hydel resources (which are also limited in extent), the importance of pursuing the nuclear energy option is re-iterated. The need for unstinted government support to the program at this crucial stage is also emphasized.

NUCLEAR energy is a subject which started as a part of physics, chemistry, metallurgy and now I believe engineering plays the major role and it is the right time to address all the engineers about the difficulties and certain other important issues faced by our atomic energy programme.

I would now like to concentrate more on the philosophical and the problem sides of why a certain atmosphere has grown in the country, leading to statements like 'we should not go ahead too much with atomic energy, what we have done is sluggish, we have got stuck, etc.' Many of these are wrong statements, but we have to counter them by proper data, to understand why this sluggishness did come, as it did. There are very good reasons for all these and they fall well within the political plane of the whole world and our own industrial and financial situation. I would like to explain how this has unfortunately happened.

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There is a total isolation of the atomic energy development in India and the rest of the world except in as far as it goes on the negative side. We had an excellent start with Homi Bhabha, who had lot of connections in those days with foreign scientists of the period and, with this early start, he had hoped India would become totally self-reliant in this new field. This was to be so, even with the first reactor APSARA that was set up in 1955. Only the enriched fuel was imported and the rest of the reactor equipment, components – the electronics, engineering, etc. was all done in India. But I do recall that day, just a day before the reactor became critical, practically every part of the building was leaking. It was July and the rains were so heavy that there were leaks not from the top but through the walls. The tank was leaking as it has been built in a great hurry, but the main thing was that we got the reactor to go critical. I also recall the only thing that worked very well that day, something which I least expected, was the telephone call to Delhi to tell Pandit Nehru that the reactor had gone critical. In 1955, the nuclear domain was dominated by the physicists – Bhabha was a physicist. There were, however, many brilliant engineers and metallurgists who made this approach to self-reliance possible (see Box 1). When the Canadians offered to build a reactor of the Candu type, there was some discussion in 1955 between Bhabha and some of us who were around him. He was somewhat attracted by the British system called 'Dido' – a reactor which used enriched uranium. The Canadians had offered the heavy water system in the hope of building up strong business connection on power reactors for the future. For a while, Bhabha was for the enriched one, but he listened to us and accepted the heavy water system because we would be more self-reliant. I am talking about 1955 and we are now in 1997 – over this period of time, it seems that what we advised him was indeed the correct decision. As you all know, uranium enrichment is not a simple problem, though it is not a problem anymore. With the coming of the D_2O reactor, like the CIRUS reactor, which uses natural uranium, the next question was how we could become more self-reliant, especially with respect to fuel fabrication and reprocessing.

I recall the discussions at that time when the Canadians offered the first fuel load for the CIRUS reactor. We told them that we would produce half of the required fuel elements and that they could give us the remaining half. At a very friendly discussion on this matter, they said 'don't try fuel fabrication – it is a very difficult process much beyond you.' All this is in writing. Somehow, we were adamant and I would like to mention the name of Brahm Prakash, fine man that he was, who took up the challenge and, as it happened, produced the required fuel, which was better, in the sense that it failed less often than their own fuel, when it was tried out in the Canadian reactor. All this led to tremendous self-confidence. The Canadians were surprised and the other countries were worried.

Once you start making a complicated thing like the fuel, then there is no end to saying 'Why should we depend on others, let us make it here in India and not buy, but let our people make it here.' This is where I believe I like to express my admiration to the metallurgists who had a difficult job in doing many things for the first time. The theorists, of course, had shown their worth over many years. Though we did not have big computers at that time, all the work was done on small hand computers. Yet the calculations were dependable and sufficient. At that time, the Americans realized that they could not keep all atomic secrets to themselves. Earlier you may recall that the Americans would not even share the secrets with the British with whom they had worked during the war and more so with the French. Then, when the first Russian reactor went critical as also their bomb, they said Russians got the secrets through spies. I mention this because the person who was my guide for my Ph D thesis was arrested and sentenced to 10 years for passing on small quantities of Uranium 235 to the Russians. He was a very strong communist and that was the atmosphere at that time.

When China came along, the West began to realize that keeping secrets of the type did not make sense. The Eisenhower plan, which came into existence in the early fifties, was to control the use of atomic energy from becoming a weapon factory. The plan was that the US would build the reactor for power production and give the fuel, provided the reactor came under safeguards. It appeared very reasonable and Bhabha was attracted by it, but for some reason, the people in Delhi wanted to know whether safeguards meant that search would be restricted only to the reactor or to everything else. And from there started the big political problems we have had in the development of our atomic energy programmes. The suspicion of the West was based on the fact that we had put a small plutonium separation plant. At the earlier stages, the plant was not working very efficiently on all fronts, but we were learning an enormous amount because everything was being done for the first time. By the late fifties, pressures were being applied on us to sign the NPT. The conditions spelt in the NPT are different for different countries. The five weapon states can do anything, the rest must follow what they are told. While all this was going on, we carried out the peaceful nuclear explosion in 1974 at Pokharan. The fact remains that at the Geneva Conference III, there were big stalls both by the Russians and the Americans on the many peaceful uses of nuclear explosions, the oil explorations, in making large lakes and several other useful operations, to the extent that they invited some of our scientists to go and watch such explosions in America in a place called Rullison to show the usefulness of the method. They said it could even be done

Box 1.

Important elements energy self-reliance

- Infrastructure
- Raw material
- Technology
- Trained man power
- Finance

Vital issues

- Energy independence
- Energy security

If you do not take a programme with a fixed speed, the trained manpower becomes a lazy manpower, they lose heart. There must be a plan and the plan must be implemented especially in nuclear business, not just a five-year plan but a ten-year/fifteen-year programme and finance must be provided or else it becomes wasteful. If you are going to buy equipment from somewhere and not put them to use, this again becomes wasteful. Self-reliance is hence time-based. We have all the elements mentioned above except adequate funding. There is no need to stress on the importance of energy independence and energy security.

in other countries and had designed a plan to cut across the Kra peninsula which separates Malaysia and Thailand so that the ships could avoid sailing around Singapore and thus save time. This was all discussed at Conference in 1975 at Vienna. After we carried out the experiment in 1974, the whole world's attitude toward us changed and even the Canadians who were building for us, RAPP-1 and RAPP-2 reactors broke all connections with us. The agreement was a part of the turn-key system, but we were left alone to complete these projects.

Subsequent to our test in 1974, the nuclear embargo on us became very severe in that the embargo was to be on all machineries connected with atomic energy. This kind of NPT was sponsored by all the five nuclear-weapon states, and these very five countries had decided that they had their last word on the subject of atomic energy. They would decide on the future of atomic energy in all countries. Treaties were drawn up that, if one signed the NPT, it meant opening the whole country for inspection, not only for nuclear facilities, but on all other facilities required for an atomic energy programme. But we could not allow five countries to decide our future. We had just then become independent, after 200 years of slavery and though we were not politically strong to assert ourselves, the will to resist was there.

We thus had to face all the challenges ourselves. Prior to all this, Bhabha died in a plane accident in January 1966. I mention Bhabha dying at this stage because if one looks at those countries which have progressed enormously in nuclear power like France, it shows how the will of the Government is essential to get things going. The French President, after the oil crisis, said 'we must try and avoid importing oil from outside and do everything to make the input of nuclear energy as high as possible'. Today, the share of nuclear power has reached 75–80% of the total power produced in France. But unfortunately, Indian will appeared lacking.

Once the will is gone, there will be criticisms galore, e.g.

(1) 'Look! India has only 2% of its power from nuclear sources, so it cannot support our power programmes in a large way';
(2) 'Nuclear power systems are always dangerous, they can become a bomb in the end like Chernobyl';
(3) 'We have so many other forms of energy, solar, etc. why use this source which causes radio-activity hazards. They must be closed down', etc.

There were many such criticisms emanating from the press and many more from the so-called environmentalists. When we built entirely by ourselves the big reactor DRUVA in Trombay, (a reactor which is much bigger than CIRUS reactor, and produces large fluxes of neutrons and is thus used not only for production of isotopes, but also to be in the forefront of neutron and nuclear physics, radio-chemistry and radio-biology) the criticisms in the press were that the design was wrong and it would never work, etc. As it turned out, it is the best reactor we have made and has worked continuously since criticality.

However, all these were statements, in a way, that led to slowing down of our operations. Criticism of this type depends on who is in power and their understanding of the situation. Panditji was all for science, Mrs Gandhi was to a certain extent so. She had certain faith in the self-reliant development of science, but I am not sure that after her this was the case. While nuclear power began to be discredited, it was realized that, in addition to generating power, there were many applications of great human value in medicine, in agriculture, in industries, in food preservation, etc. There were a lot of people quietly beginning to understand that these several uses were vital for modern society, but when it came to power there seems to have been a mental block. May be this was due to accidents of a special type abroad, but I think it was mainly due to the fact that a power reactor could be a source for weapon making.

Though we were completely isolated and had to operate under an embargo regime, it was only because of our early work, leading to self-reliance, we could go on. It was during these difficult days, our programmes began to be 'sluggish.' We had, however, been trained on self-reliance, so we started asking our industries for help. I am happy to say they rose to the occasion. BHEL produced the turbines. It was not without its troubles, for the blades used to crack and they had to learn much about servicing them. L&T and Cooper engineering did some good engineering jobs, but the fabrication of all the fuel elements and all the intricate parts were done in Trombay itself. Without the active participation of private industries, we would have been nowhere. It was very difficult for them to take on these jobs, as they had never done it before. They also knew it would cost them a lot of money, and may not give them profits. But for the challenging attitude taken by some of these industrialists, our entire atomic energy programme would have collapsed. Nowadays, if we go to an industrialist and ask him for various things, he will say, 'where are my profits, I will not take up anything which is not in the production line, I would not like to venture into new things, etc.' During this period, new technologies were developed at the Bhabha Atomic Research Centre (BARC) and the Nuclear Fuel Complex (NFC). Uranium metal and its alloys, the zircaloy and beryllium and an endless number of alloys of high quality became available (see Box 2 for an idea about uranium efficiency).

It was under these circumstances that the Tarapur reactors were operated and maintained. Their fueling has become a long story involving many countries and I will not dwell on it. The RAPP-1 & 2 reactors were also completed. After this, NAPP and KAPP reactors were

Box 2. Efficiency of uranium and how much energy is contained in it.

To generate 12,000 (units) kWh, we consume approximately :

Oil	1 ton
Coal	1.5 tons
Natural gas	1.11×10^3 CuM
Uranium	0.06 kg

(Source: British Petroleum)

Table 1. Operating performance (1996–97)

Unit	Generation (MUs)		Availability factor %	Capacity factor %
	Target	Actual		
TAPS-1	665	424*	38	30
TAPS-2	975	648**	59	46
MAPS-1	500	752***	53	51
MAPS-2	810	1233	84	83
NAPS-1	1209	1377	75	71
NAPS-2	1218	1449	78	75
KAPS-1	1201	1593	90	83
KAPS-2	992	1593	90	83
Total	7570	9069		

*TAPS-1 was under annual shutdown from July 1996 up to mid-January 1997, for refuelling, carrying out mandatory regulatory inspection of core shroud and other systems.
**TAPS-2 started generation from June 1996 after annual shutdown from September 1995 to May 1996, for refuelling, carrying out mandatory regulatory inspection of core shroud and other systems.
***MAPS-1 started generation from September 1996, after annual shutdown from April to August 1996, for mandatory regulatory inspection of coolant channels.

Table 2. Operating performance (1995–96)

Unit	Generation (MUs)		Availability factor %	Capacity factor %
	Target	Actual		
TAPS-1	960	1108	90.14	78.87
TAPS-2	680	445**	35.60	31.65
MAPS-1	905	1136	79.59	76.07
MAPS-2	995	274**	18.79	18.38
NAPS-1	1222	1295	75.31	66.99
NAPS-2	1226	1457	81.07	75.40
KAPS-1	1225	1115	73.47	57.07
KAPS-2	737	1152*	84.70	70.07
Total	7950	7982		

*KAPS-2 commenced commercial operation from 1 September 1995, includes 365 MUs during infirm power period.
**They were under shutdown for mandatory regulatory inspection.

built entirely by us and are now working at high capacity factors.

It was at this stage that we had to think of a more sophisticated system like the breeder reactor. Another question which I am always asked was about the cost of nuclear power.

From the Tables 1 and 2 it can be seen that all the reactors, except RAPS-2 which is undergoing coolant channel replacement, are functioning with availability factors of 80 to 90% and capacity factors of something little less than that. During the last few months, RAPS-1, MAPS-1, MAPS-2, NAPS-1, NAPS-2, KAPS-1 and KAPS-2 are working at high capacity factors. A few days ago, I had been to Kakrapar as I had never been there. The reactor and the site is a sight to see. An important aspect of atomic power is the disposal of the waste and this is where the regulatory board plays an important role in all countries. About this time, the rise of anti-nuclear lobby had become significant. Some of its concerns were based on ignorance but it is, perhaps, not without some influence of foreign elements.

These excellent operating figures are making people ask newer types of questions. Now people ask where is the hold-up? Why is our contribution only 2%? It is said that NPC has earned a profit of about 300 crores this year. What happened to the money? Is it fed back to build 500 MW stations or is it set against payment of interest towards public borrowing? Why do we have to import Russian reactors at this stage? It is true that Rajiv Gandhi and I disagreed completely on the import of Russian reactors, but now, I feel, I was wrong and we should have imported these reactors for a very strange reason. It just happens that the government is quite willing to get reactors on delayed payment from foreigners but is unable to give money for building our own 500 MW reactors. And a stranger thing that happened was that, in earlier planning meetings all that the finance and the planning commission would say to our request was 'buy some components of long manufacturing cycle time and keep them ready till we can finance the whole project.' So far, several crores of rupees worth of components have been bought and kept ready but the last operation to build the actual reactor was always met with the reply 'No money' and the matter oscillates between Finance and the Planning Commission. I believe this is done as a part of the governance that you have two bodies always at variance, to postpone the issue when the government is unable to take a decision. This is what puts atomic energy into such a difficult position to take the appropriate step into the next century. For those who believe that there are other methods of providing bulk power at a reasonable cost, Box 3 will show the situation.

The new argument advanced by the government is 'we do not have money to give you, but then go to the public, they will provide you with the money. And when a little later you make money because the reactors are working well, you can return their borrowings'. You will all appreciate that, with a small installed capacity base, it is almost impossible to fund further expansion, leave

Box 3. Renewable energy development.

Wind farms		
Capital cost	:	Rs 30,000/kW
Generation	:	Rs 3.15/kWh
Solar photo-voltaic		
Capital cost	:	Rs 1,10,000/kW
Generation	:	Rs 11.7/ kWh
Solar thermal		
Capital cost	:	Rs 90,000/kW
Generation	:	Rs 7.9/ kWh
Bio-mass gasifier		
Capital cost	:	Rs 7,500/kW
Generation	:	Rs 1.49/ kWh

alone meeting the interest burden of public borrowings. This is how we all get into a debt trap. An important buyer of electricity is the farmer. You know farmers have high priority. Somehow, we are told to give electricity but not collect the tariff from them. So give free electricity. Well, if you don't collect money, what do they do when you give them something free? They will use it carelessly and inefficiently. Their pumps will be working at 10% efficiency, because the farmer buys the cheapest pumps available. In other countries, pumps work at 85% efficiency. Thus, in our country, all this electricity which we produce with great difficulty is converted into low grade heat and wasted in inefficient systems.

I mention all these things because I think really the engineers are those who should look into this aspect of political interference in what should be a strictly economic matter. I do not know if when a government says, give priority to agriculture, it would mean providing free electricity.

I have no direct connections with atomic energy for many years, but I certainly know, from living in Bangalore, how much the power situation can deteriorate.

Suppose you suddenly decide and the government has the will to go into nuclear power in a big way in the next century, i.e. 20% of all power by the year 2015 or 2020, what are the preparations necessary? These are two-fold. One is to work towards a totally fail-safe system and the other is that the safety is supervised by the Atomic Energy Regulatory Board (AERB) whose main business is supervision and not design and maintenance. The latter is the business of the operation group.

The government is considering a new structure in which the AERB, with an independence of its own, will work with the Nuclear Power Corporation (NPC). But it has to be essentially positive in its approach. It should

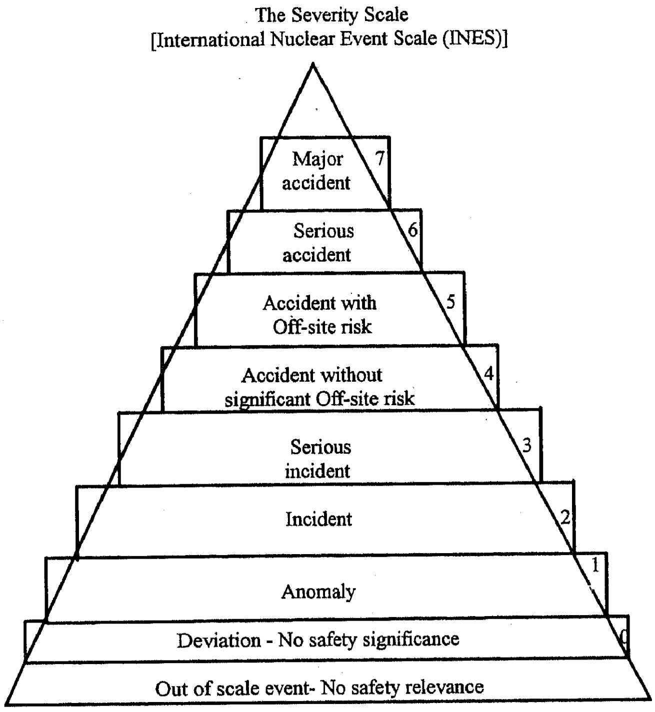


Figure 1. Indication of the internationally accepted scale for grading various types of accidents that occur in nuclear plants. Chernobyl is graded as 7, Narora fire graded as 3 though the fire occurred in the conventional portion of the nuclear plant and had no implication on the safety of the nuclear portion.

also be not forced by anyone to say 'yes' or 'no'. It requires this structure and tradition. And that is what the Deve Gowda's government was planning to do and I am sure the new Prime Minister will follow the same philosophy and the AERB will remain as a very independent body to check on all possible types of accidents, but with the spirit that they are essential there to help in the generation of safe power. One can always create a structure and say 'No' to everything, then nothing will happen and no development takes place.

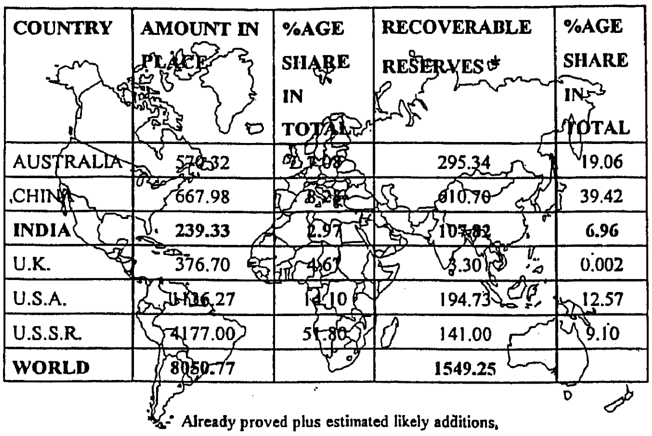
As we know, atomic energy accidents are of various types (Figure 1). Principally, one is the conventional side where the turbine generators may go bad and give rise to a fire as it happened at Narora, or the heat exchangers and valves in the nuclear side, which could develop some leaks. When it comes to civil engineering buildings, I am sure you engineers, have your own set up for saying whether a building is safe or not. But the one that happened in Kaiga is the most unfortunate, because it has held up the momentum of our activity. The roof came down and this has nothing to do with the nuclear matter and that it should have fallen down, despite the fact that we are a civil engineering country, is somewhat strange. Unfortunately, we had a system by which we

Table 3. World hydro electric potential (average flow conditions)

Country	Theoretical capacity (usable MW)	Percentage of the total
China	330,000	14.60
USSR	269,000	11.91
USA	186,700	8.26
India	70,000	3.09
Japan	49,600	2.19
Pakistan	20,000	0.85
All other countries	1,335,800	59.10
World total	2,261,100	100.00

Source: World Energy Conference (SER) 1974.

Table 4. World coal resources and reserves at the end of 1987 (billion tonnes) (Source: World Energy Conference 1989.)



COUNTRY	AMOUNT IN PLACE	%AGE SHARE IN TOTAL	RECOVERABLE RESERVES*	%AGE SHARE IN TOTAL
AUSTRALIA	570.32	[illegible]	295.34	19.06
CHINA	667.98	[illegible]	610.70	39.42
INDIA	**239.33**	**2.97**	**107.82**	**6.96**
U.K.	376.70	4.67	3.30	0.002
U.S.A.	1136.27	14.10	194.73	12.57
U.S.S.R.	4177.00	51.80	141.00	9.10
WORLD	8050.77		**1549.25**	

*Already proved plus estimated likely additions.

Table 5. Proved oil reserves at the end of 1990 (billion tonnes)

Country	Quantity (billion tonnes)	% Share of total	
USA	4.3	3.4	
Mexico	7.3	5.2	Latin America
Venezuela	8.5	5.8	
Abu Dhabi	12.1	9.1	
Iran	12.7	9.2	
Iraq	13.4	9.9	Middle East
Kuwait	13	9.4	
Saudi Arabia	35	25.5	
USSR	7.8	5.6	
China	3.2	2.4	Asia
India	1.1	0.8	
Total	118.4		

Table 6. Proved natural gas reserves at the end of 1990

Country	Quantity (trillion CuM)	% Share of total
USA	4.7	4
Abu Dhabi	5.2	4.3
Iran	17	14.3
Saudi Arabia	5.1	4.3
USSR	45.3	38
China	1	0.8
India	0.7	0.6
Total world	119.4	
Billion ton	107.5	

Source: BP statistical review of World Energy, 1991.
Proved reserves: More than trebled over the past two decades.

Table 7. World uranium reserves at the end of 1987 (thousand tons)

Country	Recoverable reserves up to $80 per kg	Percentage of the total
Australia	470	28.00
South Africa	324	19.33
Niger	171	10.20
Brazil	163	10.20
Canada	148	9.70
USA	117	6.98
Namibia	94	5.60
France	50	2.98
India	35	2.09
Others	104	6.20
Total	1,676	

China 2000*; USSR 5000*.
*, Speculative.
Source: World Energy Conference 1989 (SER).

Table 8. World thorium reserves at the end of 1986 (thousand tons)

Country	Recoverable reserves up to $80 per kg	Percentage of the total
Brazil	551.01	18.46
Canada	440.00	14.75
India	400.00	13.41
Turkey	400.00	13.41
USA	400.00	13.41
Venezuela	300.00	10.06
Others	492.00	16.50
Total	2983.01	100.00

Source: OECD 1986.

could appoint any number of committees to examine why it fell down and if each one takes several months to give a report, there is something wrong with our regulatory system. Indeed, the best way to stop activity is to have two committees to give opposite views. Between them, the game can go on for a long time. There is another procedure that they have in government, and that is to use a 'space' expression, to send it into 'orbit', which means you send the file from one ministry to the

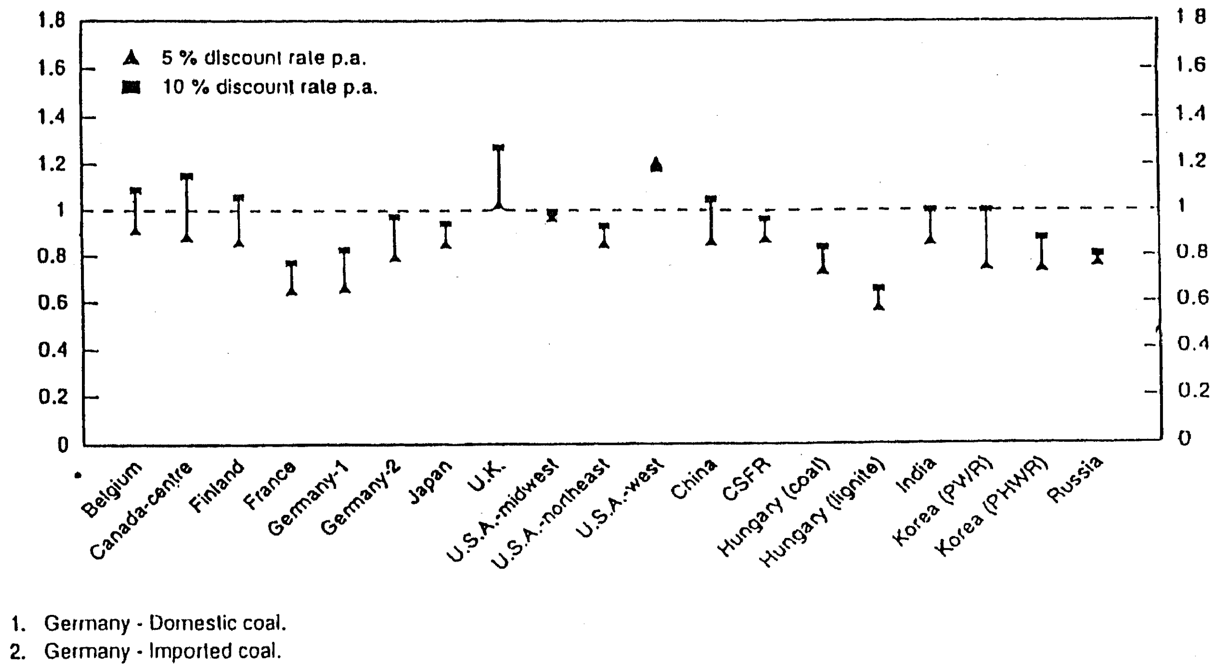


Figure 2. Ratio of tariff of coal to nuclear power for different countries.

Table 9. Reserves – Energy sources (India)

	Recoverable quantity	% share in world total
Coal	107.82 billion tons	6.96
Oil	1.10 billion tons	0.80
Natural gas	0.7 trillion CuM	0.60
Uranium	35 '000 tons	2.09
Thorium	400 '000 tons	13.41
Hydro	70,000 usable MW	3.09

Source: World Energy Conference.

Table 10. Tariff P/kWh

Nuclear		Comparable thermal	
TAPS	63 P/kWh	Nasik	90 P/kWh
MAPP	82 P/kWh	Ramagundam	90 P/kWh
		Neyveli	104 P/kWh
NAPP	152 P/kWh	Dadri thermal	185 P/kWh
KAPP	215 P/kWh	Kawas gas	195 P/kWh

other, for their comments and it may or may not even come back.

I would like to end by saying that I have given you a fairly open account of everything. I have hidden nothing, but being out of the organization, I may have left something out, but not out of any secrecy. There is no other energy source which will give you large amounts of power using a small amount of fuel and space. If you want to be an industrial country and speak about being an equal to China and Japan, you cannot do this without a surplus of power and only nuclear can give you this in large quantities. If we assume imaginary difficulties and see red herrings, like, for example, earthquakes, we have the case of Japan, a country of many big earthquakes who design their buildings against such catastrophes from the start. It is only necessary that there has to be somebody to check that this has been provided for. This is where a regulatory authority becomes essential. I am sure one would like to have suggestions on safety of the construction of buildings, safety of electrical systems and finally nuclear safety by a special body knowledgeable about nuclear matters generally. One also requires safety against delay in decision making. Delay is the biggest enemy of progress. While we have computers which work faster and faster, the reports take longer and longer to prepare. Unless there is a reason why you want to delay things, it can be very dangerous to the nation. Sometimes, the delays may be purposefully planned by those who do not wish to see us progress. I will not go further into it and make comments which I cannot support. But we would like to warn people like us to be aware of these unnecessary committees and discussions. I have said to the media that danger and progress are interconnected. Sometimes, poets or novelists, based on misleading information, tend to romanticize the danger aspect. To minimize the former and accelerate the latter is the business of the engineers.

Tables 3–9 give data on various energy resources like hydro, coal, gas, uranium and thorium. Our oil extraction process is rather low, about 20% *vis-á-vis* about 80% elsewhere. Improvement in extraction efficiency would bring in significant energy savings. With respect to uranium and thorium, we have limited uranium resources but abundant thorium. Those who have lot of uranium have no interest in the use of thorium. Those who have less of uranium and lot of thorium like India, should work towards the fast breeder. The recoverable uranium reserves (35,000 tonnes) will support 10,000 MW-PHWR while the recoverable thorium reserves (400,000 tonnes) equivalent to 600 bn tonnes of coal will support 350,000 MW-FBR.

Table 10 and Figure 2 give data on costs. The unit energy cost from recent plants is higher due to higher input cost and incorporation of several safety features. The OECD data shows that the nuclear cost is cheaper in comparison to coal. We should specially take note of the situation in France.

Finally, I make a few suggestions about planning for power reactors for the next century following Sarabhai's earlier proposal. I think we must create industrial complexes around power stations and use up all the power there to avoid long-distance transmission where losses go up to even 30% (mostly by theft). The maintenance of the lines is also a specialized science. Domestic supply must be treated as a separate demand.

Research as a career – A study of factors influencing choice

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For a dynamic R&D organization the values and attitudes of its researchers are crucial. Do our young researchers exhibit a keen desire to take up research as a career? The following sample study probes this important aspect of R&D through the responses of our young researchers.

RESEARCH as a career has been the topic of discussion elsewhere in the world. Generally it is perceived that a scientist opts for this profession consciously in preference to others. The spirit of inquiry, the thrill of unravelling the mysteries of Nature and, now, finding out new things that may bring economic/social betterment to fellow beings and himself/herself seem to constitute the motivation to undertake Research & Development (R&D). Do our young researchers make a determined bid to enter the portals of R&D institutions with research as a career in their minds or do they gravitate there buffeted by circumstances beyond their control? Why is the number of personnel actually engaged in R&D so small? The declining trend of expenditure on R&D as a percentage of GNP (ref. 1) with the resultant decline in the attractiveness of science as a career is of serious concern especially when we claim to have a large reservoir of S&T personnel. Opinions[2,3] on the university research scenario have been expressed by academicians. Yet no answers to the above and related questions have been obtained based on analysis of authentic data from research workers. A study of the attitudes of young scientists at the research fellow (RF) level was therefore deemed necessary. These RFs are selected and placed by the Human Resource Development Group (HRDG) of CSIR in universities and higher technological institutions of their choice to pursue research. In terms of the number of fellowships and range of disciplines covered, HRDG accounts for the largest collection of young scientists undertaking R&D. Being one of the largest, it is imperative for CSIR and other funding agencies to know whether these fellows and associates really aspire for scientific research, choose research as a career and whether they find themselves motivated to continue.

The data was acquired from a sample of RFs on an individual basis through a questionnaire, inquiring about their decision to pursue research, their views regarding the prospects of scientific research as well as theoretical

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