PREPARING FOR OUR TECHNOLOGY FUTURE*

ANIL KAKODKAR**

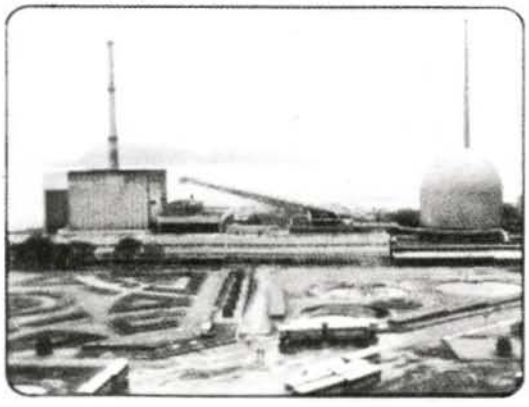
Introduction

I express my gratitude to all of you and IPA for the honour bestowed on me. Actually when I heard about this I found it a bit embarrassing as it appeared to me to be a felicitation within the house, as so many of you are from within the Department of Atomic Energy! But then I felt that it is not so, since the award is from the Indian Physics Association. When I accepted this date for receiving the award, I had not realized that today (11th May) happens to be the " National Technology Day". Keeping this in mind, I decided on the title of today's talk.

I sincerely feel that the continuous enhancement of tools for development of innovative technology and the presence of a very large and capable community which can carry the process forward, are two important prerequisites for a country to enhance its relative position in the current international world. I also believe that while we have done particularly well in the Atomic Energy program, the Space program and a few other programms, and that we have done extremely well in terms of developing national technological capability, we have miles to go in terms of creating an environment which will assure that the country attains the number one position in technological terms in different fields. I say this because if you want to be at the number one position, you have to have the ability to evolve new technologies ahead of anybody else.

While I think developing technologies which are not available for the national requirement or developing technologies so that you can reduce the cost of technology acquisition are very important features, (At least I am very proud of what has been achieved in several decades in terms of these features in India) I do not think we have too many examples of having developed some technology for the first time in the world. There may be only some cases here and there. Real innovative technology development capability is about doing or developing a very important technology ahead of others because only then do you really reap its benefit in terms of the relative position between countries. Today, I want to talk about this very important attribute that we must acquire and what is it that is necessary for us to be able to achieve this.

Clearly, this is not as easy as one might imagine, and particularly so in the Indian context where we have people conditioned with compartmentalized thinking. Technology development, on the other hand, is a long continuum which starts with a high quality education, an extremely high level of research, applied aspects of research as a follow up to the basic research in the field, going on the development of some technology and then making the technology robust and cost effective so that it can stand the competition in the market. Unless you are able to manage this entire continuum, it is not possible to develop innovative technologies. We see a lot of products being developed, but then they remain in the laboratories and



Dhruva (left) and CIRUS reactors at BARC

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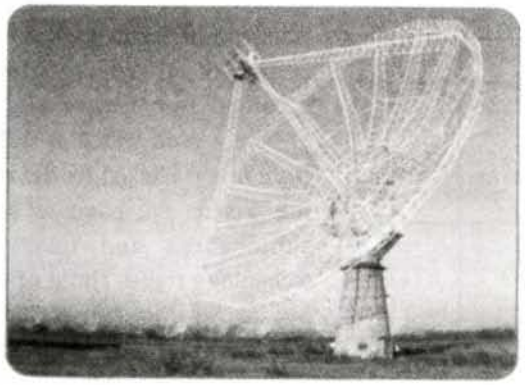
** When this lecture was delivered, Dr. Kakodkar Was Chairman, Atomic Energy Commission and Secretary to the DAE, Govt. of India. He has now retired and Dr. Srikumar Banerjee is now in this position.

do not reach the industry. Even after one has developed a technologically robust product, it does not imply that it will be successful in the market place for that is altogether a different ball game. I think the scientific community has to learn this and only when you establish this full continuum with a good handshake between stages of this relay, can we hope to realize this capability.

We have been trying to establish this culture in the Department of Atomic Energy in a sustained manner over the years and I think we have been very successful. I want to bring to your attention some important developments which will convince you that the DAE programs have made a diference to the country. However, as I said earlier, it is not enough and we need to move forward. I wish to develop this theme further in the form of a case study because while one can always talk in general terms, it is instructive to do so in the context of the atomic energy program. This gives a message in terms of preparing our country for a technology future. Towards the end of the talk I will discuss what we need to do in general, and point out that there are many common elements, whether we are talking about nuclear energy or other forms of energy or about any other technology development. It is important to review the important elements which have contributed to our successes to date and then build on that so that we can achieve such an objective. If one looks at the DAE, it is an integrated system that translates nuclear and allied research into products of commercial and societal value. While this fact should be clear, at least to most of the audience here, I do not know how many of you are aware that today we are among the leading contributors to the global efforts in heavy water reactors, fast breeder reactors and in thorium related research. My colleagues in BARC and IGCAR (Indira Gandhi Centre for Atomic Research), have, in fact, done this data search and have compared scientific publications coming out of various countries and have found that India today stands at number one position in all these areas (viz., heavy water reactors, fast breeder reactors and thorium technology, which are the three main segments of our three stage nuclear power program). So we have done well in accordance our mission objectives. I made a presentation at Bangalore where I gave some statistics. These can be seen at the DAE website (*www.dae.gov.in*).



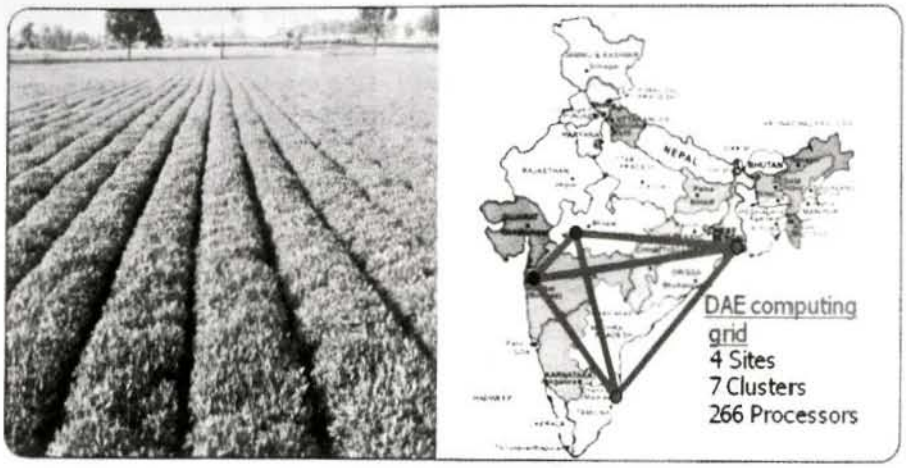
GMRT Radio-telescope at Pune

Advanced Centre for Treatment Education & Research Kharghar, Navi-Mumbai, a wing of TMRC.

Aside from the reactor technology, we have had success in many areas of basic and applied research. One can cite many examples, but in my opinion one that stands out is the Giant Meter-wave Radio Telescope (GMRT). It is an indigenous research facility which today has become a great attraction for researchers world over. About one hundred experimenters come to work in GMRT every year from outside India. What is exceptional about GMRT is that it is an instrument which is conceptually Indian and has been built by Indian in India. The GMRT has many noteworthy achievements to its credit, the most significant one being the recent discovery of a pulsar.

Take yet another atomic energy establishment, the Tata Memorial Centre which is of course a premier institute in the country for treatment, research and education in cancer. I would like to tell you that in the year 2006, TMC won a global award as the "outstanding cancer organization" for its excellence in "cancer control within and beyond India's borders". This award, given by the International Union for Cancer Control is a creditable global distinction.

India has been a major collaborator in many international scientific effort. Along with China, the European Union, Japan, Russia, South Korea and U.S.A, India is a member of the International Thermonuclear Experimental Reactor (ITER) project. It also has an observer status at CERN along with U.S.A. Japan, Russia, Turkey and Israel. Thanks to our association with CERN, we have contributed significantly to what is known as grid computing, which provides seamless and scalable access



Plants using agricultural Mutant developed by BARC

DAE Computing GRID

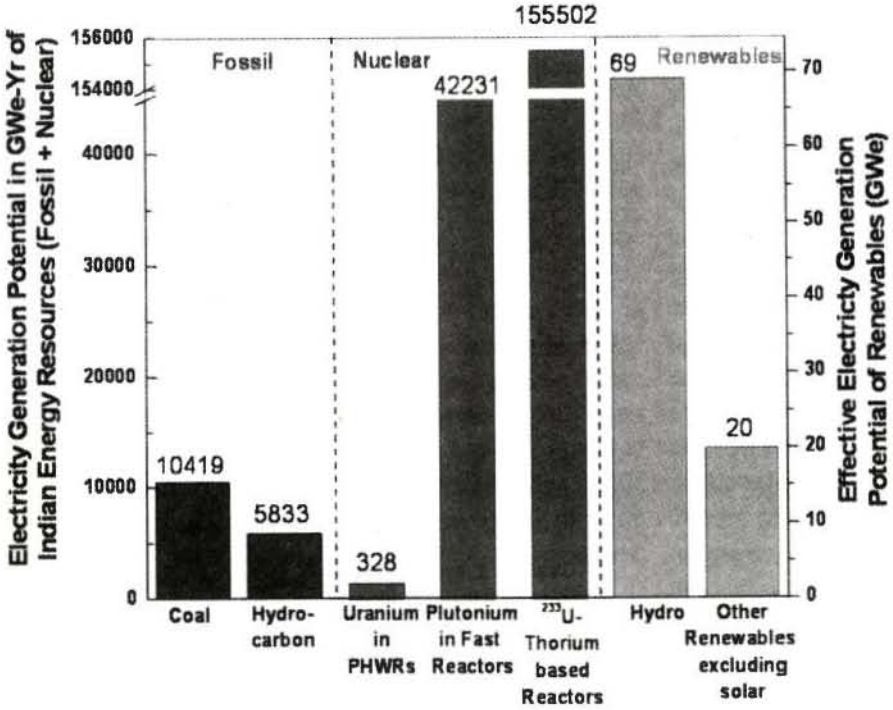


Fig. 1. Current Indian Energy Resources (Ref : A Strategy for Growth of Electrical Energy in India, DAE, 2004; Coal data from Report of the Expert Committee on Rado Map for Coal Sector Reforms)

	Source	Coal	Hydrocarbon	U in PHWR	Pu in FBR	Thorium
Years of depletion for electricity generation by a single source	Present Rate (697 Twh)	130	To be preferentially used for transport	4.12	211	>1950
	2052 Rate (7957 Twh)	11.5		0.36	18.5	>170

to wide area distributed computing resources.

A modest computing grid is already operational and is expanding. In terms of societal contributions, you have surely heard of the great development in agricultural mutants that has taken place at BARC. But many of you may not know that we annually contribute roughly 25% of the national ground nut and 22% of the national black gram production. I want to end this list with a quote from Siegfried Hecker, the former Director of the Los Alamos National Laboratory, during his testimony at the US Senate Committee on Appropriations (Sub-committee on Energy and Water Development) on April 30, 2008 : "*I found that whereas sanctions slowed progress in nuclear energy, they made India self-sufficient and world leaders in fast reactor technologies. While much of the world's approach to India has been to limit its access to nuclear technology, it may well be that today we limit ourselves by not having access to India's nuclear technology developments. Such technical views should help to advise the diplomatic efforts with India.*" The point I am making is that we have done well and we are rightfully proud of what we have achieved in technological terms. However, as we go along it becomes clear that we may have to take a path which is different from that traversed by the rest of the world. We have to pursue some ideas and take some technology routes ahead of others because our priorities are that much more. Our three stage program (see Box) was fine up to

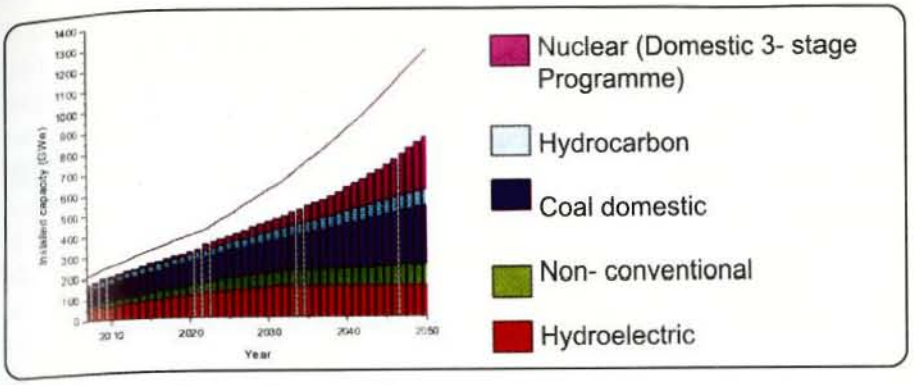


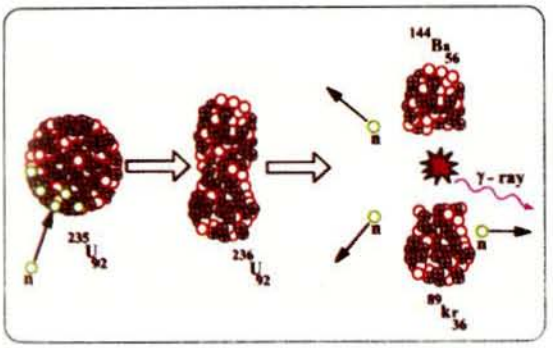
Fig. 2. Projected Electrical Energy Requirement and Domestic Supply. After taking into account all available indigenous sources for electricity production the deficit in 2050 will be around 400 GWe (Source : A Strategy for Growth of Electrical energy in India, Document 10, DAE, August 2004).

the first stage but for the second stage and the third stage, we need the route I have just mentioned. There are people who are still debating whether fast reactor development should be done now or later, whether it will work or not. We cannot afford that luxury and must develop fast reactors and that too with great speed. The thorium story is very similar. There are fuel cycles technologies which connect the heavy water reactor to the fast reactor and to the thorium reactor, and the rationale for our following this path will be clear from the data in Fig. 1 and the table following. The figure shows the electricity generation potential of various energy resources, while the table indicates the number of years any one of the resources would last if used alone (i) at the current rate and (ii) at the rate projected for 2052.

It is very clear that India just does not have enough energy resources to support our estimated electricity requirements by the middle of the century. At the rate of consumption projected in 2052, our coal deposits would last us for just 11 years, uranium in PHWR (Pressurized Heavy Water Reactors) for not even 1/3 of an year and plutonium in fast reactors for about 18

Nuclear Power Reactors

In a nuclear reactor, energy is harnessed for power production primarily through fission of uranium, thorium and plutonium, with uranium being the most common fissile material today. In a fission reaction, a heavy nucleus splits into smaller fragments, releasing energy in the process. The energy appears as kinetic energy of the fission fragments, gamma radiation and heat.



Natural uranium consists of 98.275% of ^{238}U, 0.72% of ^{235}U and 0.005% of ^{234}U. Most of the nuclear energy in the world is produced by fission of ^{235}U. An isotope of uranium ^{233}U, which does not naturally occur but can be produced by exposing thorium to neutrons, is also fissionable. The process of fission is initiated by capture of a slow (thermal) neutron by uranium nucleus. When the parent nucleus breaks up into fragments, additional neutrons are produced, which can be used to produce a chain reaction. However, to control a chain reaction, excess neutrons are removed by inserting *control rods* containing neutron absorbing material. Further, in a thermal reactor, the remaining neutrons are thermalized by making them collide with low mass *moderators* such as water, heavy water or graphite. A fast reactor, on the other hand, does not require a moderator. The heat generated in the core of a reactor is removed for being used to heat water to generate steam and eventual generation of electricity. Based on heat removal mechanism, the reactors are of two types, viz. **Boiling Water Reactor** (BWR) and **Pressurized Water Reactor** (PWR).

In a BWR, water in pipes circulates inside the core. This causes water to boil and become steam, which in turn, is used to drive a turbine. After this the water is cooled and is returned to the core. As the water enters the core, there is a possibility of its becoming radioactive.

In a PWR, the coolant is kept under high pressure to raise its boiling point and avoid significant steam formation in the core. The heat is transferred through a heat exchanger to a secondary coolant, which is used to drive the turbine. As the secondary coolant does not enter the core, it does not become radioactive.

years. You can see that we are an energy deficient country. Our hydrocarbon deposits are not of any significant amount and will be used primarily for transport. Hydro-power of course will be there as it is a renewable source but it will contribute a very limited amount, about 69 GWe year per year, which is going to be a very small fraction of the total electricity production by the middle of the century. Solar energy is an important input and even in the Department of Atomic Energy we have come to the conclusion that we must work on harnessing solar energy economically. It is an enormous resource but the challenge is to be able to exploit it at a viable cost. Today, on the other hand, we can exploit nuclear energy at a competitive rate.

So the point is, the world says that there is plenty of uranium and we need not be concerned about energy production. That is of course true at this time as far as the rest of the world is concerned. However, after another 30 or 40 years even that statement is not going to be true. It strange that some 10 years back several countries which were producing nuclear power had decided not to recycle and several others had decided not to build nuclear powers stations. Today, the countries which decided not to build power stations have decided to start building power stations, and countries which had decided not to recycle have admitted that they will at least recycle partially. This view will certainly change further as the energy crisis become more and more acute. So eventually the world is bound to be in the same situation in which we find ourselves today. The world will develop the technologies necessary for coping with this situation tomorrow. Do we wait till that time, and then suffer because of energy shortages or do we go ahead and develop these technologies for ourselves? I think we are in a position to do so and it is a pity that while even the world thinks that we have the required capability, there are many in India who do not have the same faith in our ability. We need to shed that diffidence and get on with the job, because time is of importance. There is no point in saying there is plenty of thorium, we will get the technology for using it in the long run. The question is will we survive till such time if we suffer so much due to energy shortage? It is, therefore, important to solve energy problems in a timely manner regardless of whether the rest of the world is moving on that path or not. If you want follow this path, we need to be self reliant, except that we are not just talking about self reliance in terms of replicating a technology which has been developed elsewhere. We are now talking about being self-reliant in terms of technology which has not been developed elsewhere in the world. That is the difference and we must realize it.

Now, thanks to the opening up of the civil nuclear co-operation, there is this other extreme reaction. People think that with the international civil co-operation open,

Among the thermal reactors, the most common is the **"Light Water Reactor"** (LWR). These reactors use ordinary water (H_2O) as moderator and coolant. These reactors use enriched uranium-235 (3 to 5%) as fuel. They are cheaper to maintain as they can run for 12 to 18 months without change of fuel.

Pressurized Heavy Water Reactors (PHWR) use natural uranium (0.7% U-235) as fuel and heavy water (D_2O) as the moderators coolant system. Originally a Canadian design, this has been popular in India because of its use of natural uranium. The reactor is also commonly known as CANDU (Canada Deuterium Uranium) reactor. PHWRs are well suited for efficient production of plutonium which is produced by absorption of the fast neutrons produced in a fission reaction ${}_0^1n + {}_{92}^{238}U \rightarrow {}_{94}^{239}Pu + 2\beta^-$. The plutonium generated by this procees can be fed to a Breeder Reactor.

A **Breeder Reactor** produces more fissionable material than it consumes. The core of a fast breeder reactor consists of an inner part which contains the fission fuel consisting of enriched $^{235}UO_2$ and $^{239}PuO_2$ and an outer part which consists of U-238, depleted uranium and ^{232}Th in some combination. The fast neutrons that are produced during fission of the inner part is captured by the outer layer to breed fissionable plutonium and U-233. Thus the reactor breeds more fuel than it consumes, which accounts for the name. No moderators are used in the reactor as the neutrons should not be slowed down (hence the name Fast Breeder Reactor or FBR). This is also the reason why the primary coolant used is not water which could slow down neutrons. The usual coolant used in the primary loop is liquid sodium. A thermal breeder reactors employs thorium-232 as the fuel and converts it to U-233 which is capable of sustaining a chain reaction.

Interested readers may look up the information material for laymen available at the website of WANO *http://www.world-nuclear.org/info/inf32.html*. Also available in this website is a list of terms which are commonly used in discussion of the uranium industry and the nuclear fuel cycle ; *http://www/world-nuclear.org/info/inf51.html.*

–S Kailas

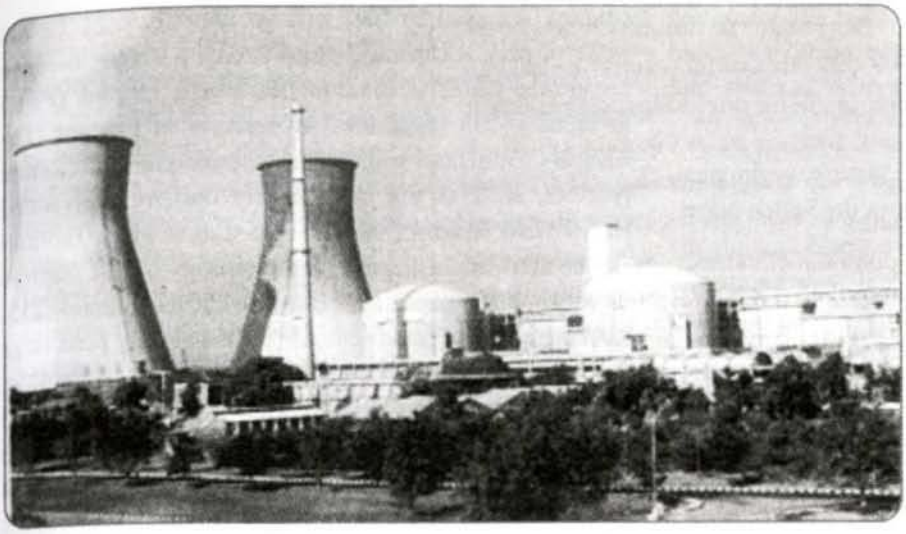


Fig. 3. A view of the Kakrapar Atomic Power Station.

all our problems are solved. That, I think, is a very disastrous approach or attitude. If you look at the figure (Fig. 2), the continuous black curve is the projected electricity generation requirement over next few decades arrived at on the basis of a fairly detailed study. The numbers may look large, but in reality, they are likely to be under estimates. (I know for a fact that the Planning Commission has undertaken a study of the energy requirement of the country till 2030 and their numbers are larger.) The figure also shows what we can do with different energy resources which are at our disposal. We have only considered such energy generation methods which can produce electricity in a proven and commercially viable manner. These numbers are optimistic as we have simply accepted the claims made by various segments of their capabilities. Even with this, there is a big gap between the demand and the generation potential of all methods combined together. You know that even today we are importing a lot of hydrocarbons but that is more as primary energy and here I am talking only about the electricity. Even for electricity, we are importing a certain fraction of our energy form outside and this is bound to increase. For the year 2050, in terms of electricity deficit, it is estimated that there would be a shortfall of around 400 GWe. Mind you, we have accounted for all the domestic energy resources. This deficit can only be met by import. If we want to import, let us say coal, it amounts to an import of 1.6 billion tons of coal annually. This is a mind boggling quantity of coal which will choke all our ports and our transportation system. So we are moving towards a fairly unsustainable situation. We need to aware of it today because the solution to these things takes time.

I also want to point out again that the projections made for the three stage program are also optimistic. It has been assumed that we will develop the fast reactor in the way we have planned and that we will develop the recycle technology in the way we have planned and that we would reach the projected output of 273 GWe by 2050. You may note that 273 GWe is roughly twice the total electricity that we produce today. That's the challenge which we must meet. But then we need to bridge the gap. We could bridge this gap if we had 3 or 4 times the amount

Three-stage Nuclear Power Programme of India

The three stage nuclear power programme of DAE is rather unique to India and is based on the Uranium and Thorium resources available in the country. it has been planned based on a closed fuel cycle concept, requiring reprocessing of spent fuel from every reactor, to judiciously reutilize all available fissile material for peaceful purposes. The first stage comprises the commercial deployment of Pressurized Heavy water Reactors (PHWRs) based on natural Uranium and Heavy water. While the less abundant ^{235}U undergoes fission generating energy, the most abundant ^{238}U gets converted to fissile ^{239}Pu. The Pu can be extracted by reprocessing the spent fuel from the first stage. In the second stage, the fast breeder reactors (FBR) which use fuels based on ^{239}Pu will be built. These reactors in addition to enhancing the nuclear power, will also be used to convert the fertile Thorium to fissile ^{233}U, thereby multiplying the inventory of fissile material. Reprocessing of the spent fuel is vital for the efficient utilization of Pu and U. The third stage of the programme will be based on the fissile ^{233}U produced in the second stage and the vast resources of fertile ^{232}Th and the Th-^{233}U cycle. An advanced Heavy Water Reactor (AHWR) is being planned to gain useful experience in using thorium based fuels and to expedite the transition to thorium based systems for long term energy security. In addition, for large scale utilization of Thorium, the DAE also has plans to develop Accelerator Driven sub-critical Reactor System (ADS) in future.

–S Kailas

of uranium than what we actually have. It is also interesting to observe that if we bridge this gap once, we would have bridged it forever because breeder reactors and thorium would allow you to do so.

Initially, for the first stage of the three stage program, we have to import or use uranium from the Indian mines. Once we get into the recycle mode, we would multiply the power capacity. The power capacity will grow because in a fast breeder reactor you grow independent of any additional uranium – the same uranium which is used for setting up 10,000 MWe of PHWR capacity will lead to power capacity of 273 GWe through recycle in fast reactor. If you back calculate to find what needs to be done to bridge the 400 GWe gap, you need to set up 40,000 MWe of light water capacity. Thus we would have closed that gap without having to import any further fuel from anywhere. In fact, it will make India energy independent and not just technology self reliant. Such tremendous advantage can be realized once you have mastered the three stage nuclear power program. You can transpose the domestic technology on to the spent fuel which will come out from the light water reactors and grow and it will then be possible to close the gap. To repeat, what this means is that if you do your technology development right, you not only get additional power in terms of immediate requirements of electricity generation but you in fact have a chance of making India eventually independent of external inputs. It is important of do this in a timely manner. For example, if 40,000 MWe by 2020 doesn't happen and say it takes 10 more years, this would mean that the start up will get delayed. Obviously the exponential growth later will still be there, but it will not be able to bridge this gap by 2050. It means that a 10 year delay in this part would still leave us with about 178 GWe deficit, which in turn would mean that we will have to still import 0.7 billion tons of coal annually. This of course is less than our initial estimate of 1.6 billion tons, but it is still very large. So timely implementation is of great importance. Note that our aim would be to bring to bear our own technology on the additionality through import to realize the energy independence. In the process we also consolidate our leadership on fast reactor and thorium technologies through our own efforts and be ready to offer them to others who would surely need them after sometime.

Now I will digress a little bit here because I thought I must answer a question which is often asked ; "We have plenty of thorium and then why is it that we are not able to meet our national requirement using thorium right now ?" We discussed the three-stage process which is fundamental to the nuclear power development of the country. We need to start with an initial base of 10,000 MWe of PHWR capacity, which is only a trigger, because it can then sustain a chain of fast breeder reactors (FBR) to breed U-233 using the vast reserves of thorium (Th-232). U-233, in turn, will fuel the next generation of thorium reactors, such as the indigenously designed Advanced Heavy Water Reactor (AHWR). The scale at which Thorium can be used would depend on the capacity of fast reactors in which Thorium can be converted to Uranium – 233. Looking at our large scale needs we obliviously need large fast reactor capacity to be brought in place for this purpose. The three stage programme thus needs a sequential implementation. Let us ask as to what is the right time to introduce thorium? Detailed calculations have shown that thorium can be deployed on a large scale about three decades after the introduction of fast breeder with short doubling time. What if we do it earlier? We say to ourselves, forget about the fast breeder reactor; we have PHWRs, we have plenty of thorium and we know we have done a lot of irradiation of thorium in PHWRs. So we start introducing thorium in PHWRs or for that matter let us look for a more efficient reactor where thorium can deliver best results say, for instance, a molten salt reactor (A suitable candidate for our purpose doesn't exist as yet. It is a reactor in which nuclear energy production and reprocessing can be done together using molten salt as medium). If we do that, our studies show that the power capacity actually peaks only at 36 GWe and we cannot get more than that. 36 GWe is negligibly small compared to the energy requirement that we have. That is the rationale for doing things in the sequence of a three stage program. You cannot put the cart before the horse. That is the only way you can build a large nuclear power program.

We have done well on this developmental path in the sense that we have been recognized as the global leader in fast reactors and we have been also recognized as global leaders in PHWR technology. If you want some pointers, in Kakrapar (near Surat, Gujarat), a unit of NPCIL (Nuclear Power Corporation of India, Ltd.) was adjudged to be the best performing PHWR in the world in its class, during the period October 2001 to September 2002 by World Association of Nuclear Operators (WANO).

In 2003 and 2007 two of the senior Indian operators of our nuclear power stations have also been awarded the Nuclear Excellence Award of WANO. Further, the CANDU owners group had this to say : "*NPCIL PHWRs showed a major improvement in the gross capacity factor in 2002 exceeding the United States light water reactor performance by almost 1%*". So we have reached

somewhere! Unfortunately, we do not have enough uranium. This has resulted in our reactors running at partial capacity whereas we could actually generate much more energy. We have to of course continue to look for domestic Uranium deposits within the country through augmented exploration programme. Larger the resources of uranium that we can mobilize, larger will be the initial thermal reactor capacity and in turn better would be our ability to make larger contribution to national electricity needs with faster introduction of Thorium. As far as fast reactors are concerned, Russia is the only other country with a FBR under construction/operation larger than the 500 MWe of PFBR that we are constructing.

I will now quickly list some challenges. We know the PHWR capacity will have to go up to 10,000 MWe. We are already at around 4,400 MWe in terms of reactors which are already operating and those under construction. So eight more untis of 700 MWe will take us to 10,000 MWe target. But once you have access to international uranium, and, since we know that the PHWR will compete well, we can set up more units running on imported uranium. Tomorrow, when we have light water reactors, the spent fuel from light water reactors will produce plutonium but there will also be left over uranium which would contain enough uranium 235 to be actually the fuel, in fact, better fuel than natural uranium as it will contain between 0.9% to 1.1% of U-235. From the spent fuel that will arise from the PWR, we can send plutonium to the fast reactors but we can also send reprocessed uranium back to the heavy water reactors. So, it looks to me that we can set up another 12 or 14 more PHWRs if we go by the reprocessed uranium route and more through use of imported uranium. So our target has to be a massive deployment of 700 MWe PHWRs, which will be of domestic design which can run on natural uranium, slightly enriched uranium or reprocessed uranium.

The 220 and 540 MWe PHWRs which are operating and for that matter even the 700 MWe reactor which is coming up can also form the basis of our exports. I was in Beijing a few weeks ago. There were at least four different presentations which expressed that the Indian PHWR could be potential candidates for some of the emerging markets. I was very pleased to hear that they look at not just our PHWR but also have interest in AHWR. This is the global expectation about India. We should think of these reactors as export models, again fueled by either reprocessed uranium or natural uranium. The Indian industry can in fact become a major hub for the equipment supply chain, for both the Indian PHWR in India and abroad and CANDU reactors abroad.

Many of you might have heard that AECL has signed an MOU with Larsen & Toubro. What for? I think the business people understand these things far better. We are actually very efficient in terms of supplying plant life management services, re-tubing etc. NPCIL has to its credit several large scale re-tubing of reactors done at a price which is a fraction of a price which prevails in Canada and other places. There are companies which are coming to India and exploiring whether India can participate in this repair market abroad.

About PWRs, just because we are going to import PWRs, it does not mean that there are no technological issues. First of all, we are talking of parks of light water reactors. At each place we want to set up 6 or 8 units, so there is massive construction to be done and it will be the Indian industry that will do the construction. The vendors have recognized that if they have to succeed in India, they have to bring the capital cost down and make their proposals more competitive with what is available in India. That can happen only if the manufacturing of major equipments is done in India, at least progressively. That is why we see a lot of commercial activity between Indian companies and foreign vendors. We should become a major manufacturing hub, not just for PHWRs but also for PWRs. It is good not only for the Indian domestic program but also for creating a sizeable export potential. This is an example how technology can empower the country.

Having done all that, we need to also ensure that we have an indigenous PWR as we are not going to depend on foreign PWRs for all time to come. NPCIL is in fact very close to putting and Indian PWR design on the table so that we develop capability in this area. This is how it has happened elsewhere. Look at France. It started with initial collaboration with Wastinghouse and today France is a leader. Likewise, Japan started by having a collaboration with Westinghouse and GE and today it is a leader in the field. The Korean story is the same. We should have that ambition. As a matter of fact, we already possess all basic elements of PWR technology. The same thing is true of fast reactors, PFBR is there and we will repeat the same design. There are several further technology objectives because we have to keep the doubling time to an absolute minimum. Only then will the capacity will grow at a fast rate. There are developed countries in the field but we are going to race ahead of them. The same thing is true with thorium – again we are going to be ahead of rest of the world as we master the technologies needed for the third stage.

We also talk about AHWRs, about other thorium systems which may, in fact, be more optimum for use in

the third stage. We are now talking about ADS (Accelerator Driven Systems). We are talking about them for two reasons. The three stage program will allow us to go to a very high level of generation capacity, but will we be content to remain at that level – reaching a steady state with no growth potential ? I think that growth potential aspect will always remain important, and if we want to support growth potential with thorium we have to bring in external non-fission neutron and that is where accelerator driven system is important. It is also important form another perspective. Through these systems, we can reduce the radio-toxicity of long lived waste and in fact, countries like France and United States are now talking about at least a policy directive for R&D to reduce the radio-toxicity of high level waste to a level less than the radio- toxicity of a Uranium mine in a time span of 300 years. This is a very important statement ! Imagine, if they realize that 30-40 years from now, one of the main issues connected with the use of nuclear power will vanish. No longer will we need to manage radio active waste beyond the institutional life – a core issue with waste management.

How do we develop this technology? There is a lot of work going on at BARC, at RRCAT and other places; internationally also, there is lot of work going on. A typical project cost for a 1,000 MWe unit may be around Rs. 6,000 –7,000 crore, so an industrial scale ADS proejct will easily cost Rs. 4,000 to 5,000 crore. Who will take up this type of project ? A typical project would require at least a few hundred professionals. Can an ADS be built by engineers, who come out from our engineering colleges today or even from the DAE training school ? The answer is no, because they do not know what the accelerators are and are not knowledgeable about the problems of high current accelerators. They do not know how to manage super conducting systems. We have physics graduates coming out of science colleges. Can they build the system? Again the answer is no, because while they understand how these work, at least some of them do, they cannot engineer these systems. These systems are not experimental set ups. They have to work 24 × 7 with 90% capacity, which is a different ball game! That is the technology challenge. You have to do a lot of development but even if you do that, we have to prepare the whole country in terms of education and training for developing such systems.

If we say that we will set up such a thing it may be 10 or 15 years from now, by that time we must have at least three, four or five hundred professionals who can work on such a project. We are going to start from scratch. We need to have very robust strategies and that is what we are trying to do. Under the aegis of the Homi Bhabha National Institute, we want to promote research at the interface of basic research and applied research. We need engineers who understand science and we need scientists who understand engineering. Homi Bhabha was one such person. Professor Govind Swarup is another who comes to my mind. We need hundreds of such people if we want to implement such a program.

There are many other technologies and I will only give a glimpse of things. We are talking about metallic fuel, molten salt cooling, both required for fast reactors and for accelerator driven systems. To give some other examples, high temperature reactors will be necessary for production of hydrogen. We need materials which can run for 30, 40 or 50 years at 1,000 degree Celsius. Do we have these material today? Everyone talks of hydrogen utilization but it is a major technology challenge and if we want to realize that, say 30 years from now, then there is a great need for developing this technology today. The same thing is true about fusion and about many other things. Right now what is happening is that we have a structured program, there are people who are working on individual technology areas and there are people who are working at a system level. At some stage, we will have to integrate them in order to undertake the projects I have mentioned.

I have come to more or less to the end of this talk which is about the synergy of science and energy-technology. I think this community recognizes all that had been done in the past in the country. Much has been achieved. The question now is : Can we translate that into the kind of capability, which I was mentioning? I think if we organize ourselves, my answer would be an emphatic yes. But we need to move forward in a very serious manner because we are talking about very large scale projects in the area of accelerators, super conductivity, cryogenics, radio frequency, microwave, plasma technology and lasers for many applications but particularly for enrichment and other material possessing applications. I think one can visualize that these are the energy technologies of future. So at times I talk about a term called the physics based energy technology. I think, all of you will agree that we have not given enough attention to this. Since I am talking to a community of physicists, I strongly urge that we need to be more proactive about this.

Now let us come back to generalizations. It is clear that we need to have continued persistence on self–reliance because self-reliance provides us immunity from vulnerability and even if vulnerability is not there, self-reliance allows us to sustain our capability to build new innovative technologies. We need to have a new emphasis

on our education and training as I mentioned earlier. DAE has taken some initiatives and to me the most important ones are the recent beginnings of the DAE Mumbai University Center for Basic Sciences and the starting of NISER at Bhubaneswar. These are places where we will have scientists undergoing an integrated masters program with emphasis on experimental skills. I think you need science graduates to come up to be able to build their own equipment and their own instruments. Many people can do push button research. We need scientists who says, I want to solve a problem important either for advancing human understanding or for making an important contribution to national development and having said that one must be capable of doing every thing that is required and that implies partly a white collar job and partly a blue collar job. We should be in a position to achieve once we determine that this is what we want to do. So we require stronger bridges between basic research and technology development and that is what we are trying to emphasize in HBNI as I mentioned that earlier. BRNS, in fact, has embedded this in its new policy. The new campus of BARC at Vizag will have a twin co-located structure which will permit and will enhance this synergy. We should come out with more co-located institutions.

So with this I thank you again. I wish that on the Technology Day we make a resolve that we will work to secure our technology future, be it for energy or be it for something else. ❐