Briefings on Nuclear Technology

In India

By

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FOREWORD

Few scientists one knows of, have gone out of their way to educate the public – especially those involved in making policies at the government level – on what nuclear energy is all about and how it is produced. One might begin at the beginning and ask what the basic principles of scientific research are, how they are developed and what the methodology of converting science into technology is. Equally relevantly, how can one sensitise the administration, not to speak of the average citizen, in supporting science and technology. The important issues, these, but who has the time or the desire to explore them? One has, therefore, to be thankful to Dr. P. K. Iyengar, retired Chairman of the Atomic Energy Commission (AEC), for producing this monograph that is as informative as it is educative.

This work is divided into nine chapters. The first one discusses what science really is. The second introduces the reader to nuclear science and technology. The third progressively deals with Indian effort in developing nuclear science and the astounding amount of organisational effort involved. The fourth refers to nuclear testing, a somewhat controversial subject. The fifth addresses itself to the problem of nuclear non-proliferation, yet another controversial subject, but which Dr. Iyengar deals with commendable objectivity. The last three chapters concern administrative reforms that may not command the readers' attention, but for that reason are not necessarily to be considered redundant.

To give one an idea of what the monograph is all about, it would be pertinent to quote some aspects of it, even at random:

- No country can ignore science or an independent growth of technology if it has to sustain the rate of growth as expected by the general public.

- The voluntary moratorium practised by India since 1974 was broken in 1998, probably because the Comprehensive Test Ban Treaty (CTBT) seemed to have a universal acceptance and India would have been pressurized to sign it.

- History shows that India did not work for the bomb, but the infrastructure created at Trombay for the introduction of nuclear power stations in India automatically gave India the capability to make the nuclear weapon, if political decision was forthcoming.

- The manpower generated at Trombay is exceedingly competitive to the rest of the world, and is itself an asset to the nation.

- A country can declare itself a weapon country when it has an arsenal in which all the devices stored are certified as far as their yield is concerned.

- The circumstances in which India tested its first nuclear explosive in 1974 were forced on it by the Indo-Pak war by which Bangladesh became an independent nation and many advanced countries had cast their neutrality to support the military regime of Pakistan.

Dr. Iyengar is understandably appalled at the deliberate efforts made by developed countries for blocking knowledge of nuclear science to India and promulgating restrictions. Such efforts, according to Dr. Iyengar, "are contrary to human dignity, especially for a nation with an ancient history during which no Indian ruler ever invaded a foreign land". But why is India taking an isolationist view on the NPT as well as on safeguards? With understandable feeling writes Dr. Iyengar: "(It) is a direct result of centuries of colonial rule and our subjugation to the dictates of a foreign power ... Fifty years of managing a nuclear programme, while suffering the humiliation of discrimination in the international fora has not weakened this country's scientists from upholding a tradition". And he rightly asks: "An organization in Geneva has sat for the last fifty years as the Disarmament Committee and discussed the problem of nuclear disarmament for several decades and yet we do not see any agreement on the part of the weapons' countries to give up nuclear weapons. Under these circumstances should India tie up its future?" The answer should be obvious. India has its self-respect and self-interest to defend.

It is against this backdrop that Dr. Iyengar is opposed to the 123 Agreement. His reasons are clear and obvious. He says: "The Opposition to the 123 Agreement is not for a lack of faith in the US, with whom we would like to have the best of relationships, especially strategic relationship, but in that process we cannot forsake the rights of the future generations in this country." It is in this connection that the reader should give particular attention to the detailed analysis of the 123 Agreement towards the end of the book, which is a brilliant expose of US intentions. If for nothing else, the sub-chapter should be a must reading for all patriotic Indians. Dr. Iyengar, in summing up all his arguments adds: "These are weighty reasons why the Nuclear Deal is not in the national interest." Rightly put. This monograph spells out the reasons why the Deal should be scrapped. Dr. Iyengar needs to be highly commended for his fearlessness in propounding the case against the Agreement in the face of official submission to US interests. One can only say that he speaks for most self-respecting Indians.

The early chapters dealing with science do not necessarily make easy reading, hard though Dr. Iyengar tries. But, taken as a whole, the monograph calls for attention and deep thought. What is at stake is the future of India in a turbulent world.

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PREFACE

One of the areas of successful development in science and technology in India after independence is the area of atomic energy. Homi Bhabha, a renowned scientist of Nehru's days and the first Chairman of the Atomic Energy Commission had a vision. It was not only to develop reactors for nuclear power and the atom bomb but also to broadly bring India's manpower in science and technology to a level that it will achieve what Nehru called industrial development leading to societal progress. Thus the economic well being of the nation was intertwined with development of indigenous technology. The large size, the creative manpower and the past history, all pointed towards an ability to leapfrog into a new era in as short a time as possible. With Nehru's support, Homi Bhabha developed the basic requirements including manpower, indigenous technology and venturing spirit to innovate and build the most modern facilities in the country. Unfortunately, after Bhabha and Nehru, though the traditions were maintained successfully for several decades, the public at large were disappointed because of the lack of spectacular change on the way of living of the common man. This is accentuated by more people getting under the poverty line with the enormous increase in population.

In the last few decades India has come a long way in being able to build nuclear power stations based on indigenous infrastructure in industries and material resources. It has also led to more manpower being generated with high technical skills which has helped many new ventures like the information technology. General public however, have not understood the difficulties of turning a backward country like India into a technologically advanced country. Steps are very steep and the way to climb was shown by Dr. Bhabha. He discussed this in his famous lecture to the International Council of Scientific Union, in January 1966 and reproduced in the magazine "Science".(1) For the general public a lucid account of how Bhabha performed this miracle is brought out in a book "Bhabha and his Magnificent Obsessions" by G.Venkataraman, a publication that costs very little and printed in India distributed by Orient Longmans.(2) The new approach which Bhabha took is again emphasised by Dr. Balaram, the Director of the Indian Institute of Science, Bangalore in a recent issue of "Current Science".(3)

Present discussions in public on the need for India to join the other advanced nations of the world to contribute to and benefit from the nuclear club is a current issue. It has become necessary to discuss in public fora the need for preserving our sovereign rights in this field. Heated discussions go on in Parliament especially after the Indo-US draft agreement was made public. I have been a student of Homi Bhabha in the early fifties and have worked in the field of atomic energy at Trombay and retired as the Chairman of the Atomic Energy Commission. I have experienced many critical moments in the history of atomic energy which have instilled a sense of loyalty to this country and to our perceptions for growth. In this connection, I felt it necessary to share some of my feelings with those who care to understand the history of the growth of nuclear energy in this country. I have, therefore, attempted to bring out a monograph which might help in elucidating the basic principles of scientific research, the way to grow them, the methodology of converting science into technology and sensitize the administration and the common man into the right approach for supporting science and technology. In a democracy the ultimate decision makers are our elected representatives in parliament who through the cabinet take executive action on many areas including nuclear policies.

In this monograph I have first attempted to summarize from elementary principles in physics, the way that man has been able to use the scientific discoveries into a tangible technology for making electricity from nuclear power or for purposes of defence. To quote Homi Bhabha "the basic methodology for development is the same for both and in his presidential address in 1955, he mentions this in a very direct manner and cautions the advanced nations the need to contain themselves so that the nuclear destruction may not become universal. I quote this below (4).

"The immense concentration of atomic energy has made possible other developments whose immediate results have been less happy, and which have placed a pall of fear over the peoples of the world. I refer, of course, to the development of atomic and hydrogen bombs. The powerful and technically advanced nations have suffered most from this fear. Atomic weapons lie outside the scope of this conference, but we cannot entirely separate the applications to peace from the applications for war. The rise of an atomic power industry in many parts of the world, the development of which is necessitated by the growing demands for power, will put into the hands of many nations quantities of fissile material, from which the making of atomic bombs will be but a relatively easy step. A wide-spread atomic power industry in the world will necessitate an international society in which the major states have agreed to maintain peace."

Ignoring this warning the world has gone ahead with restrictive and discriminatory practices like division of states into nuclear and non-nuclear and international laws which are different for the two groups. Politically, India has refrained from signing this discriminatory law called *Non-proliferation treaty* for the last 40 years, especially with the political background of the nation. Should we change this perception? Is it to our advantage? And what happens to our pronouncements in the past decades of not accepting the discriminatory laws. In various chapters of this monograph, I have tried to build up in an elementary fashion the scientific facts and the scientific reason for keeping ourselves the option for the future. After all we know from history that the capability of nations change with time and if India is poised for economic growth and becoming a major player in the immediate future, then of course it is our duty to safeguard the interests of the future generations. The opposition to the 123-Agreement is not because of lack of faith in the U.S.A., with whom we would like to have the best of relationship especially strategic relationship, but in that process we cannot forsake the rights of the future generations in this country.

I have referred to many articles in this monograph so that those who are interested in particular aspect could lay hands on more detailed arguments in those articles. Nuclear science cannot be condensed in a short monograph especially when it overlaps with policy decisions. It is, therefore, my hope that this article will trigger the reader to go deeper into the subject using the references mentioned therein. This is not meant to be a technical document. This is an attempt to put together salient features of nuclear technology with an emphasis on the history of early years in India. I retired in 1993 and I have not ventured to discuss developments since then. I have used my close association and information I have to be presented to an audience. There may be minor technical lapses which should not make inferences wrong.

(1*) 1966 " SCIENCE"151. p541-548 H.J.Bhabha*

(2) *1994 "Bhabha and his magnificent Obsessions" by G. Venkataraman .University press(Ind)*

(3) *2008 "Current Science" Vol 94, no 4 editorial by P.Balaram*

(4) 1955 Presidential Adress "Conference on the Peaceful Uses of Atomic Energy United Nations by H.J.Bhabha(

WHAT IS SCIENCE

Charles Darwin made an extensive trip in Brazil as a surveyor when it was a British Colony. During this trip he observed many varieties of life in the tropical forests. This made him think of why and what was the necessity for anybody to create such different species. Then it turned out that all are not created at the same time but evolved depending upon the environment and the needs. This led him to the theory of evolution. It was a new way of thinking of creation, which did not find easy acceptance in the powerful lobbies of religion. He influenced the Royal Society in England and showed that science was important for the advance of human civilization. Science tries to explain natural phenomena and puts laws of Nature in precise terms and shows it is universal. The next two hundred years saw more and more people following this line of thinking and discovering new laws. For example, the Newton's Laws of motion, Gravitation, Planetary motions, etc. When formulated they were intended to explain the observations which triggered a parallel thinking which proved it right universally. Thus Newton's Laws of Motion is applicable in any planet or space. Gravitation is universal. It was always an index of civilization that original thinking is a result of development of biological growth since the most evolved brain in Man is most successful in this process than in other forms of life. Even now the scientists are indulging in this parallel thought process. New areas of research in biology explaining all the well known phenomena of hybridization and cross fertilization are now explained by genetic engineering. The communication system in the world is so revolutionized now that anybody can communicate to anybody else in the planet or space instantaneously. All these only indicate that the present state of progress of civilization is necessarily due to science and the creativity of the population in science and technology. What India lost in the 200 years of colonial rule is the freedom to continue to contribute to the original thought that man is capable of evolving. Did not Buddha evolve a universal appreciation of human dignity as the basis for social peace? Did not Mahatma Gandhi evolve a new way for the uplift of the poor villagers? Did not Raman enjoying a trip in the Mediterranean asked himself the question why is the Mediterranean sea so blue which resulted in his discovering the Raman effect which has now found tremendous applications. This clearly shows that no country which aims at a future can ignore science and not encourage people to indulge in scientific activity. Panditji was convinced that the reason for progress in the West and the lag in the East was essentially due to science which produced technology. This argument is beautifully incorporated in the Scientific Policy resolution passed in 1958 by the parliament of India. To quote"…It is an inherent obligation of a great country like India of scholarship and original thinking and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today".

It is interesting to note that this invention of original thought explaining Nature's Laws cannot be ordered by a Government or person but must evolve as a part of human activity. It is only in the University System in the West that encouraged this process. Having found applications in defence during the World War II, the Western Society quickly created national laboratories for individual disciplines for experimentation and evolving of technology. The product of this has now influenced the manufacturing sector which is the basis of economic growth and the domination of the West in the market forces. No country can ignore science or an independent growth of technology if it has to sustain the rate of growth as expected by the population. This problem is more pressing for populous countries like India and China. We cannot ignore even the narrowest field of adventure in science, for one is not sure which will determine the future growth. In our own lifetime we have seen the growth of electronics, rather unknown in early part of last century. However, evolution of transistor replacing vacuum tube, introduction of digital technology, transition from transistors to chips and the efficient communication systems enabled by satellites have all resulted in the mobile telephone and mobile video which was unthinkable in the last century. The productivity in agriculture is a challenge for the future. Can our farmers increase production without support from genetic engineering? Can the control of our diseases by diagnosis and treatment be imagined without the introduction of a whole variety of new instruments? The hospitals no longer look the same as they used to. Medical practice is no longer a narrow field of specialization.

The society at large raises questions as to the necessity for science to be practiced independently in several countries. The answer to this can be seen from the role played by manpower in the evolution of technology. New methods of manufacture and wider use of multi-disciplinary innovations for the societal needs call for competent technical manpower. This requires a frame of mind in decision makers too to plan for the future in terms of technical advance rather than pure economics. This is the difference between governance in advanced countries and the governance in the underdeveloped countries. Over the last fifty years, the country like India has increased its scientific and technical capability enormously, while similar situation does not exist in many countries in spite of the so called euphoria in management courses. New problems in society like the increasing cases of HIV or the bird flu or the river water disputes between the states all require a different perception. India was lucky that in the first few decades of Congress regime there was absolute support to the rate of growth of science. Do we put a stop to it now and be content with the import of Western science, technology to meet the societal needs. Will it help us in our wish to become a super power in the days to come? Can competition among nations be ignored? These are some of the questions which influence the economic progress with the ground realities that we face today.

INTRODUCTION TO NUCLEAR SCIENCE AND TECHNOLOGY

It is only in the early part of last century that man discovered that the things around him are made of atoms and the structure of the atom is similar to that of the solar system with heavy nucleus at the centre with a positive charge and negatively charged electrons hovering around that. Most of the properties that we make use of emanate from this structure and the interaction of electrons with each other. Thus they differ from atoms, molecules, to bulk material. Niels Bohr invented the structure of the atom. The transitions of electrons in the atoms explain the emission and absorption of light with specific colours. The size of the atom is of the order of 10^{-8} cm which is the average distance between atoms in molecules, liquids and solids. Further experiments showed that the heavy part of the atom in which most of the mass is concentrated like that of the Sun in the solar system is only 10^{-12} cm carrying a positive charge varying from 1 to 92 in the periodic table from hydrogen to uranium. This shows that most of the space between the nuclei in the material that we see is in fact empty and the stability is attained by the electrical interaction between the negative and positive charges allowing a whole range of stability and configuration of molecules. This also leads to chemical interactions which we have exploited in manufacturing of all kinds of materials specific to our needs.

A study of the nucleus of the atom and how it is built up with different masses from hydrogen to uranium is complicated and forms the basis of nuclear physics. The charge on the nucleus demands that the hydrogen nucleus which is called the proton must be a constituent but a tally between the charges and the masses is not possible unless additional particles which are uncharged are introduced and interact strongly within the nucleus. It was only in 1931 that the neutron as a component of the nucleus was discovered which had no charge but almost the same mass as the protons and therefore could explain for the mass of the nucleus. The same chemical element in which the neutron part changes in number are known as isotopes. The fact that the nucleus could also be split was demonstrated in 1932 in the small laboratory in Cambridge by Sir John Cockroft and Walton by using arrows of protons energized by the electrical potential in an accelerator. This opened up nuclear reactions.

Earlier in 1905 Soddy, a radio chemist observed the particles and radiation that are emitted in naturally radioactive substances like uranium. Alpha rays are tiny bits of nucleus with a mass 4, beta rays are electrons and gamma rays are electromagnetic radiations like X-rays with high energy. The total energy released in a radioactive decay was so large compared to the chemical energy that one is used to, that he predicted that one day we will discover how to make a nuclear bomb with tremendous energy release. It is interesting to note that all these facts could be understood from close observations of nature. After all we see the sun shining everyday with tremendous release of energy which sustains life on this planet. Civilizations have therefore worshipped the Sun as the God who bestows energy which sustains life on this planet. However, by 1938 it was established that what happens inside the sun is a nuclear process that is copied in the accelerator viz. fusion of elementary nuclei of hydrogen resulting in the release of enormous energy. Today if we go further than the sun, we see all kinds of galactic phenomena in which nuclear energy is produced and it seems to be that the universe is the place where nuclear science dominates. And all that we see on this planet is an evolution that has come about from the scanty radiation that reaches this planet from the Sun. This should make us understand that the life giver is nuclear science and one must not ignore its ramifications for the future.

Subsequent to the discovery of the neutron which by its neutral character was able to be absorbed by other atoms, a whole series of new radioactive substances were produced. In understanding radioactivity one comes across a very curious phenomenon of the decay of the nucleus spontaneously. One can define a half-life as the time it takes for a certain number of particles to decay to half its number. We have now discovered that depending upon the detailed relative stability of the particles interacting inside the nucleus, the half-life of radioactive substances can vary from less than microseconds to millions of years. Obviously in this planet we see only those with long half life, elements like uranium. In the laboratory a whole series of fast decaying nuclei could be produced. The use of this radioactivity varies tremendously from discipline to discipline e.g. we can make luminescent watch dials, trace iodine in the thyroid, use the radiation from cobalt 60 for cancer cure or very strong radiations from californium to make batteries to keep the rhythm of the heart. The industrial applications of such radioactive materials are enormous especially in non-destructive testing. Can one change the half life, if so we could destroy radioactive waste? Though attempts are made no success has resulted yet.

From 1932 to 1939 the ability of the neutron to produce radioactive materials was extensively studied in Europe. However, it was a small laboratory in Germany which discovered that when uranium is irradiated with neutrons it splits and the products are radioactive. This is known as the fission process in which enormous energy is released as the kinetic energy of the two fragments. This discovery was circulated by word of mouth since the war was on. Some of the scientists in Europe saw the tremendous advantage of the fission process in releasing large quantity of energy, two hundred million times of that from a chemical reaction. It became obvious that this release of energy could produce a super-explosion which is now known as the atomic bomb. However, the conditions in the laboratories in Europe were not congenial to carry out further experiments. Since the United States was far away and not directly involved in the war at that time scientists migrated to U.S. with this information and started working on the details of the fission process and its implications. These scientists were mostly immigrant scientists from Europe from Hitlerite anti-Jewish activities and had lost their kith and kin for no fault of theirs. They were afraid that if Germany develops the atom bomb first, Hitler would be unbeatable and therefore, there was an urgency to carry out this work expeditiously. They went to Albert Einstein, the celebrated Nobel Laureate to write to President of the United States about the possibility of an atom bomb and why U.S. Government should take it up on an urgent basis. The President agreed and created the Manhattan Project under the military, specifically for developing all the technologies and to produce the atom bomb as soon as possible. The Manhattan Project was a unique enterprise of the human race. The success of that is seen by the development of a nuclear reactor in 1942 and that of the bomb by 1945. But for the joint effort of those brilliant scientists who migrated to the U.S. and had a common enemy in Hitler, it would not have been so fast.

Let us now discuss some parts of the Manhattan Project to understand how complicated the problem was and how the creativity of scientists solved these problems in a short time. It became a model project for achieving excellence in technology and was almost repeated in the missile and space programmes later. It is also obvious that such crucial projects tend to be shrouded in secrecy for the aim was to acquire new weapons. Later due to the cold war it became a competition between the capitalist societies and the Socialist Soviet Union. Enough has been written on the social aspects of Manhattan Project and its implications for national security and international politics. The history of the atom bomb is well documented in the book by Richard Rhodes (1).

After discovering the fission process the details of this reaction were investigated in the Columbia University. It turned out that energy released was of the order of 200 million electron volts; additionally on an average around 2.5 neutrons were also released with an average energy of 2 million electron volts. This was very important because then even if one neutron is able to cause further fission then a chain reaction could be established just like fire propagates in a burnable stick. It was therefore thought that one should first build a chain reacting system and show that this is feasible. It was Fermi, an Italian scientist who developed many ideas based on his perceptions of neutron interaction with other nuclei. He established his Laboratory in the University of Chicago, showed that if one reduces the energy of the neutron the chance of neutron being absorbed in another uranium atom is enhanced and low atomic mass materials like hydrogen, deuterium and carbon (graphite) could be used to bring down the energy of the neutron by collisions. It was also recognized that of the isotopes of uranium found in Nature, uranium 235 which is present only to an extent of 0.7 per cent is more readily fissionable. It was his idea to build the first graphite reactor which is simply a pile of graphite in which natural uranium rods were inserted and the reactor went critical in December 1942. It was thus proved that in this planet nuclear energy could be produced by burning uranium but required configurations unique to that system. Since the time taken by the neutron to hit another nucleus and propagate the chain reactions is very small, the chain reaction could divulge rapidly and create a pulse of energy as required in the atomic bomb. However, luckily a small fraction of the excess neutrons from fission is emitted after a delay of a fraction of a second thus making it possible to control this divergent reaction. This is where one talks of control rods which enable the reactor to be operated as a constant energy source.

Meanwhile by neutron absorption uranium was also seen to be transformable to heavier element plutonium which is also fissionable. This discovery by Seaborg indicated that uranium 238 captures a neutron and becomes plutonium 239 which is as good as uranium 235 for the fission process. Since natural uranium contains 99.3% uranium 238, the neutrons already generated in a reactor could get absorbed in this and produce plutonium. Thus a byproduct of a reactor could be plutonium 239 which, when chemically separated, could form the basis for a nuclear bomb.

The dynamics of neutron interactions, the mean free path for interactions depending upon the core material like uranium 235 or plutonium 239 were all quickly worked out by the scientists, which was required for the development of the atomic bomb. If uranium 235 could be isolated from natural uranium, then that could form the basis for a uranium bomb of small size. This process of separating the fissionable isotope U-235 from the more abundant U-238 is known as isotope enrichment. By this time many of the scientists from allied nations like France and U.K. joined the Manhattan Project and contributed to the basic ideas of the fission device and isotope separation. Heavy Water which contains only deuterium instead of hydrogen was produced in Norway before the war. A few tons of this material was air lifted critically before Hitler could lay hands on them. Some of the British scientists had migrated to Montreal wherein they started what is known as the tube alloy project. They built a reactor in Chalk River, in Canada in the late forties independent of the Manhattan project in USA. They never attempted to develop an atomic bomb even though they had the capability.

The story of how the Manhattan Team under the direction of Robert Oppenheimer managed to bring in academicians from universities and industries for establishing new processes is well known. Other national centres like Oakridge, Argonne at Chicago and Brookhaven near New York were organized to continue this effort. The size, the number of scientists employed and the money that was spent was tremendously different from any other projects like for example the development of aircraft for defence. The additional factor which made this project succeed was the creativity of the scientists involved. A mechanism of decision making which Oppenheimer introduced was unique. Utmost secrecy was maintained because this was to be used against the enemy Stories connected with the espionage of information to the Soviet Union through scientists working in Manhattan project are all well known. It was also clear that the Soviet scientists had similar ideas and Stalin supported their effort to make the bomb. In June 1945, the first bomb made out of plutonium was detonated at Alamogordo which was witnessed by several scientists from a distance of more than twenty miles. Oppenheimer seems to have quoted the sloka from Bhagwat Gita in which the Lord Vishnu appears in Vishwaroopa with thousand times brighter than the Sun. They were wondering how anybody could write about producing a super sun when there was no evidence that man could achieve it at any time. This device had an explosive power equivalent to that of 15,000 tons of TNT which would have been impossible to make otherwise.

A bomb using uranium was much simpler in construction because of the intrinsic properties of uranium 235. Two pieces of uranium could be brought together to exceed the critical mass in order to establish a chain reaction. In the case of plutonium, spherically symmetric compressive shock waves using chemical explosives in the form of lenses was used to compress a spherical ball of plutonium to a smaller size in order to make it super critical. A neutron source generated at the appropriate time was able to start the chain reaction and a part of the plutonium was fissioned in a short time of milli seconds. The development of the explosive lenses, the purity and complexity of the spherical plutonium core, the neutron initiator and several other components for simultaneous triggering of the lenses were all inventions carried out secretly and tested. This success demonstrated the power of the scientific investigations in solving complicated problems of the future. Very often people quote that we need Manhattan Projects in order to achieve quick success in many areas of human activity. At the time the U.S. dropped the atom bomb on Hiroshima and Nagasaki, they had just enough material for one uranium bomb and one plutonium bomb which they made and dropped on the enemy. If the Japanese had not surrendered probably the war would have continued for some more time.

Hydrogen Bomb

Even at that time scientists had realised that Nature produces nuclear energy in the sun using the fusion reactions bringing together the hydrogen atoms to build up helium and excess energy. It is, therefore, more appropriate if a nuclear bomb also uses hydrogen as the fuel. The properties of isotopes of hydrogen viz. deuterium and tritium had been studied in the laboratories. The easiest fusion reaction takes place between deuterium and tritium and to a limited extent deuterium and deuterium. The initial energy required to cause fusion is smaller for the first reaction even compared to the second. In terms of thermal energy this will work out to several million degrees centigrade. The problem of a hydrogen bomb was therefore the way to heat the gas to million degrees centigrade. The success of the atomic bomb demonstrated that in fact such high temperature was indeed feasible to be created in the fission bomb. It was therefore a challenge to the scientists to discover methods by which a volume of deuterium and tritium could be heated to a high temperature by an atom bomb including compressing it in order to enhance the density. Hans Bethe, the Head of the Theoretical Physics Group at Los Alamos and Edward Teller, another bright scientist had thought about these ideas for several years.

One of the spin offs from the atom bomb was also the large amount of radiation that it creates in a short time. When this radiation is converted into x-rays and impinges on any metal, it causes electrons to be liberated which while flying out give a kick to the metal. This then becomes a device to produce very high pressures and spherical geometry enhances the pressure at the centre by radial convergence. This principle has come to be known as that of Ulam-Teller the people who proposed this for the first time. This is essentially the principle of the hydrogen bomb for details see Winterburg and Rhodes (2,3,4)

A natural extension of these researches demanded a new laboratory with fresh minds to work on. Teller had already fallen off with Oppenheimer who did not want the United States to discover yet another more powerful device like the Hydrogen bomb. In fact the lower cost of making hydrogen bombs will only add to the number one can make, for the raw material which is deuterium is abundantly found and very inexpensive to make. Several tests were carried out in order to design this hydrogen bomb. The first successful test producing energy of 12 megatons of TNT explosive power was achieved in 1952. Meanwhile the Soviet Union also had independently worked on the hydrogen bomb and made successful tests thereafter. Thus the world came to have two independent nations competing with one another in the design and development of nuclear weapons and adding them to their arsenal. The cold war atmosphere and the need to keep oneself more advanced than the opponent allowed unlimited expenditure and effort on the part of these two countries.

There are several variations of the hydrogen bomb which has been tested. The simplest of them is the one in which at the centre of the fission bomb one puts some amount of deuterium and lithium such that by neutron absorption the lithium produces tritium instantaneously which takes part in the fusion reacton. This is known as the booster principle. India detonated a similar device in 1998. It also demonstrated the hydrogen bomb in which a secondary core of lithium, deuterium and tritium were compressed and detonated yielding at least 30 KT.

The military strategists were always looking for various applications of the nuclear devices in war front for e.g. tactical weapons of smaller yields could be useful for an advancing army since the devastation is limited and the army could advance with proper precautions. If the detonation of a hydrogen bomb is largely due to the fusion reaction, then it becomes an extremely powerful source of neutrons which kills biological life rather than damage to buildings and the environment. The name Neutron Bomb was coined and several countries have now experimented with the neutron bombs.

Thus one can see that using the elements of nuclear science that is in the open literature and the capability established in each country, possession of a nuclear device is only a small deviation from basic research and technology development for nuclear power. The raw material and resources required are almost the same and hence the need to curtail the technology from falling in the hands of irresponsible states which are now called as the ‘rogue states’ by the United States.

Non proliferation

The non-proliferation issue has continued to be current in the politics of the United Nations. The advanced countries have not been able to curtail the spread of nuclear technology. Even small nations like Pakistan, North Korea and Libya had acquired these technical capabilities. It is because of these developments that the advanced nations negotiated a comprehensive test ban treaty which could prohibit testing nuclear devices underground. The atmospheric tests had already been banned by a treaty under the United Nations signed by all countries in 1963. It took a long time for the Committee on Disarmament in Geneva to negotiate the Comprehensive Test Ban Treaty. It was necessary to establish methods by which clandestine tests of small yield like one kiloton could be detected. The shockwave that a nuclear test creates, which travels down the mantle of earth like an earthquake, had been used to detect such events. Seismometers, very sensitive to longitudinal waves of the nuclear test and the ability to use the array techniques to locate the epicenter accurately within a few kilometers are the prime method by which the CTBT, if implemented could be monitored. The IAEA even created an organization to establish this monitoring capability. Not satisfied with this step, an additional protocol has been proposed by which those who signed the NPT were also required to declare their nuclear activities in advance and to accept intrusive inspection by the team of inspectors from IAEA as additional measures to ensure that there are no violations. The debate is, therefore, partly political in nature and heavily depends upon the scientific maturity of the participating nations. It is for the first time that the scientific method had entered the field of forensic science to detect clandestine efforts in acquiring nuclear weapons and testing them.

Enormous efforts in scientific manpower, design of new instruments and methods discovering new diplomatic language congenial to international understanding have all gone into these efforts. In fact it has led to non proliferation analysts doing research in all these areas throughout the globe. It has also become a part of the efforts of the political science disciplines in the universities.

Indian position

As far as India is concerned the voluntary moratorium practiced by India since 1974 was broken in 1998 probably because the CTBT seemed to have a universal acceptance and India would be pressurized to sign. The BJP government had got into prolonged discussions with the United States on a strategic relationship. However, after the five successful tests the Government announced that it is now a Nuclear Power, enunciated a nuclear doctrine but was willing to discuss with the United States on joining a fuel materials cut off treaty in the future. The FMCT was again propagated to make the IAEA responsible for keeping an account of the fuel material that are generated in member states signing the FMCT and to make sure that no part of that is made use of to make a nuclear device. This became necessary because there are no international control on the production of U-235 and Plutonium in the world even though the NPT countries were subject to safeguards. The nuclear weapon countries had a huge stock of these materials some of which from disbanded nuclear devices and some as a stock for further development of their arsenal. It was feared that due to lack of tight security, quantities of these material could be laid hands on by terrorists who could then make nuclear devices and threaten to disturb the world order. In the last few years this fear has heightened and therefore the pressure on non proliferation efforts have also considerably increased. Though the US government signed the CTBT, the Congress rejected ratification of CTBT. Thus this treaty has not come into effect.

The only fortunate thing that has happened in the last sixty years is that nobody has used a nuclear weapon in fighting a war other than the United States, whether it is in Asia or Europe, whether it is between two developing countries or very advanced countries. This shows that the human race has realised the immoral use to which a nuclear device can be put to. All right thinking people do agree that in fighting the war for whatever cause, one should not resort to a nuclear weapon. The effect of a nuclear weapon in causing devastation not only to a local region but also spreading the radioactive pollution throughout the globe has been studied and documented. No part of the human race would ever like to see the entire population extinct. This fact has to be seen in the proper way by all nations to ensure that this atomic age does not suffer. It is possible that in future, nuclear disarmament will be accepted by all countries and nuclear weapons will be obliterated. At present nuclear weapons are considered as a deterrent.

Future Developments

While most of the scientific advances made since 1940s are available in the open literature it is a moot question to ask whether there are any other possibilities by which nuclear energy could be produced. The subject of nuclear physics has gone one step deeper into the structure of the nuclear particles like the protons and neutrons. While all evidence shows that the protons are very stable, the neutron is not so stable but decays to a proton and an electron. The composition of both these particles in terms of quarks has been advocated and the experimental evidence shows that it is so. However, it requires an enormous energy to break the proton or the neutron which has been achieved only in very high energy accelerators like that in Fermi Laboratory, U.S.A., and CERN in Geneva. Nobody ventured to predict practical applications of these discoveries but who knows that in future when we understand how to generate the high energy particles more efficiently we will not find many new uses. After all that is the nature of Science.

It has been explained before that the discovery of fission process by neutrons gave the idea of a nuclear explosion caused by using a fissionable material. The trick is to start with a sub critical mass make it critical by either of the two processes (1) bringing together two separate sub critical masses like in the uranium bomb or by compressing and enhancing the density and reducing the size as in the plutonium bomb. In the latter, the super criticality is reached by reducing the surface area such that the neutron leakage is reduced and the chain reaction can proceed exponentially. In both cases the trigger is an external neutron source which could be made to produce the neutrons at the nick of time when the super criticality is at its highest. As it happens in all explosions, the heat and pressure generated inside the super critical material, makes it expand and reach a sub critical stage depending upon the inertia of the system. Thus, the explosive power of a nuclear explosion depends on the time period for which one is able to hold this material together for the exponential growth to reach the maximum and the inertia of the system to disrupt itself due to the high pressure and temperature. In a fission bomb the time period in which the neutron multiplication reaches the maximum is of the order of microseconds and all the energy that is produced is within this period. The production of a shockwave and very high intensity neutrons and gamma rays during this short period is obvious. Of course, there must be enough material in the critical mass for the total yield since fission automatically reduces the availability of fissionable material in the core. Thus even a 10% burn up out of 5 kg of plutonium will produce tens of kilotons of TNT equivalent explosion. This also shows that making a critical system by itself is not making a bomb, e.g. an accident in the laboratory of a reactor could make it super critical. However, it cannot explode like that of a fission bomb. That is why even in the Chernobyl accident the total energy released was limited.

The high temperature and pressure reached in the core of a fission bomb can be estimated. And it clearly showed that the conditions were sufficient to initiate a thermonuclear reaction if the core contained isotopes of hydrogen like deuterium and tritium. The temperature required for the D-T reactions is lower than that of D-D reactions and therefore, by using artificially produced tritium one can induce a fusion reaction at the centre of a fission bomb. This is what is achieved in a boosted fission device. The total energy produced will now be a sum of both the fission energy and the fusion energy and this can be many times that of the fission bomb. The difficulty of course is to put a gaseous D-T mixture in the core. This could be avoided by using lithium deuterate in solid form so that the neutrons produced will convert lithium into tritium and enable the fusion reactions. This is known as the booster principle. Boosted fission devices can be made to yield upto about 100 Kilotons of TNT.

Looking at Nature and the way the sun produces nuclear energy, it is obvious that the Sun does not use a fission device to produce the D-T reaction and how is it able to make this fusion reaction possible? The answer rests on two basic facts. One is that the mass of the sun is so large that the gravitational field automatically confines the core of the sun without allowing it to destroy itself. The second is of course that once the burning is triggered it continues to burn provided the fusion fuel is available. Therefore, a large stock of hydrogen that was created in the early universe enables the sun to live for billions of years. The scientists started wondering whether we can repeat these experiments in the laboratory. That is the search initiated after the U.S. tested its first fusion bomb.

It should be obvious that the physics behind a possible thermonuclear explosion should use the basic facts of nuclear physics and other laws concerning confinement, gravitational fields etc., It was also obvious that the density of the fusioning material should be such that the mean free path for fusion reaction would be minimized and one may have a phenomenon like burning a stick at the end and allowing it to propagate. Many such ideas were discussed and that formed the major issue for scientists at the Los Alamos after 1945. Simple calculations enabled them to guess that a fusion device with minimum amount of fusioning material can produce megatons of explosive power. Therein lays the main difference between the fission bomb and the fusion bomb. One could not stop these ideas being generated and discussed outside of this wartime laboratory. After all, the thinking power of scientists is irrespective of where they work e.g. a book on "The Physical Principles of Thermonuclear Explosive Devices was published in 1981 by a Professor at the University of Nevada which very coherently and using simple mathematics discusses the various possibilities of building a thermo nuclear device. Of course, he has not experimented with these devices but looking at the physical principles used, one can say that his deductions could not be so wrong. This indicates that the physics behind these devices is no longer such a secret. However, experimentation and testing to confirm the yields is expensive and at present restricted to national efforts in Government laboratories. People guess that it might leak into the hands of terrorists who have financial resources and can hire scientific talent and threaten the harmony of the world. This is of course a distinct possibility.

Fusion energy

The demonstration of fusion energy by an explosive device, the hydrogen bomb indicates that it is possible to release this energy if methods could be developed in the laboratory to control the rapid release in the plasma. Several attempts are being tried, the most significant ones being "TOKOMAK'. This is a Russian invention which uses magnetic fields to confine plasma and several other methods to heat the plasma. Successful demonstrations have been made. Lately an international project has been started called "ITER" in France. India too has joined the project with sharing financial needs. In a decade if the attempt succeeds we will have the technology and trained personnel to start building on our own. Another method is to miniature the bomb such that limited energy is produced each time. A large effort is on in USA called "National Ignition facility" located in Lawrence Livermore laboratory. This of course is part of their weapons laboratory. Smaller versions of this are being tried in England and France.

Dr Bhabha was excited after the detonation of the first hydrogen bomb in 1952. In his presidential address at the first Geneva conference he made the following prediction. I quote

"The historical period we are just entering in which atomic energy released by the fission process will supply some of the power requirements of the world may well be regarded ***one day as the primitive period of the atomic age***. It is well known that atomic energy can be obtained by a fusion process as in the H-bomb, and there is no basic scientific knowledge in our possession today to show that it is impossible for us to obtain this energy from the fusion process in a controlled manner. The technical problems are formidable, but one should remember that it is not yet fifteen years since atomic energy was released in an atomic pile for the first time by Fermi. I venture to predict that a method will be found for liberating fusion energy in a controlled manner within next two decades. When that happens, the energy problems of the world will truly have been solved for ever for the fuel will be as plentiful as the heavy hydrogen in the oceans." This prediction may still come true

Now about the advances in fusion device. As mentioned before, the simplest way of amplifying the yield of a fission device is to use a mixture of D-T at the core of a fission device and thus make booster. However, since the space available is limited the yield from the fusioning part will be restricted. The next problem is, therefore, whether one can have a separate secondary core consisting of the fusioning material and induce heating and compression by using an efficient fission device. This leads one to the question of how to compress a solid like lithium deutriate effectively in time scales short enough. Secondly, whether this compression will heat that material to a temperature of 100 million degrees to cause fusion reactions. The first choice, obviously, is a spherical core of the fusioning material inside a metal tamper and use x-rays produced by converting the gamma rays from the fission device to cause the electron emission which automatically starts a shockwave compression of the secondary. The technology for converting gamma rays effectively into x-rays and ensuring a uniform compression from all around is a difficult task. Fortunately the time interval for the fission bomb power is of the order of 10^{-8} of a second and since they travel with the velocity of light the pulse does not expand in time when it hits the fusioning core. However, the size of the core, the material of the tamper and the rate at which the material heats up and allows further heating up from the fusion reaction induced are all complicated calculations which are now possible with computers. But in the early years even without a computer scientists were able to generate all the parameters required. Obviously it was necessary to test whether the end results could be achieved. Therefore a whole series of tests were conducted with different designs to optimize the parameters. An account of these efforts is brought out in the book of "Memoirs" by Dr. Edward Teller. (3)

It is useful to compare this with burning a haystack. If somebody wants to burn a huge haystack and one knows the temperature to which the hay should be heated in order for it to catch fire the obvious answer is to heat the whole stack to that of the ignition temperature. However, common sense tells us that a match stick which burns one part of the haystack can trigger a burning process which can then extend throughout the haystack. The energy required to do this is extremely small compared to the total energy one gets out of the burning haystack. Can a similar principle be used in the hydrogen bomb? Obviously one has to work with a pencil like structure for the fusioning material at the tip of the pencil being ignited by the radiation from the fission bomb. The total energy released will now depend upon the burn front traveling throughout the length of the material and the total energy produced will be proportional to the volume that is finally ignited. This would make the hydrogen bomb slender in dimension and capable of being mounted on missiles to be launched in space. This obviously required considerably different design and the fact that even the Chinese had demonstrated several hundred megatons of hydrogen bombs shows that this is indeed feasible and has been accomplished.

The next question obviously is, if it is only necessary to trigger the fusion reaction at one end of the pencil, is it necessary to use a fission device to heat it and compress the tip of the pencil. It is here that further research and development may enable man to achieve this by using other forms of triggering a fusion reaction in a very small volume. The book by Winterberg explains many of these devices and the imagination of this author can be seen by the various suggestions he has made. Of course it is not confirmed or proven by the national laboratories which conduct nuclear tests. However, it does indicate that there are alternative methods of inducing a fusion reaction to make a hydrogen bomb. I quote from a letter written by Hans Bethe to President Clinton in 1996. Hans Bethe was the head of the theoretical group in Los Alamos and successfully steered the theoretical calculations for both the fission bomb and the fusion bomb. He says in this letter that efforts are being made in the national laboratory to produce a fission free thermonuclear explosion and he requested the President to stop all such researches for the simple reason if this is successful a nuclear bomb could be made purely from isotopes of hydrogen which are plentifully available on this planet. Therefore, the question of Non-Proliferation by restraining accessibility to fission material like U-235 and Plutonium will no longer apply. It is also clear from the statement that there are theoretical possibilities of achieving success and when that happens the fusion device will no longer be an expensive and complicated device in the hands of only a few countries. This is the real danger arising from secrecy, unilaterally continuing such experiments in secrecy and testing. It is also obvious that without the freedom to test, one cannot discover these new methods. This is a strong argument for India to maintain its sovereign right for testing new devices in the future.

We started off with fissioning of the uranium and plutonium to yield energy. In the beginning the scientists were worried why Nature has never used these techniques even though fissionable U-235 must have been available in larger quantities in the past for the half-life of uranium is only million years and the earth has existed much longer than that. In 1975, the French scientists discovered in Gabon a country in Africa where uranium mining was going on, traces of fission products which would have come only by a reactor operating there. This could be a Natural reactor using ordinary water collected on this earth and the uranium concentration is ideal like in a light water reactor. Professor Weinberg who was the Director of the Oak Ridge National Laboratory, founding father of the atomic energy remarked “I am happy that the Oklo phenomenon shows that Nature has already demonstrated the nuclear reactor much before the humans discovered.” He was reemphasing the fact that the human effort is simply to rediscover what Nature has already done and one did not expect to discover such evidence. This brings to focus whether it is meaningful at all to talk of secrecy in nuclear research.

Other possibilities

There are yet other possibilities of nuclear energy being created. We still do not know what is the process by which we have, on this planet, the chemical elements from hydrogen to uranium and some of them having different isotopes... The subject is known as nucleo-genesis or the science behind the creation of these elements on this planet. Many theories have been propounded. A classification of the data that is accumulated shows that there could be other nuclei with larger amount of neutrons that could have been formed earlier but decayed in time e.g. if the half life is only a few months and you do not expect to see them on this planet. If the half life is greater than million years like that of uranium then they would be found. One has to search for it. Depending on their abundance various new techniques are necessary. Some of them could even be created using fusion method with accelerators.

We know the electrons in the atoms are responsible for their chemical activity. However until we learned about their arrangement in shells we were not able to predict their relative activity. We now know that closed shell configurations make them inert like helium, argon, krypton etc. The nucleons inside also have these shell structures that would make them more stable than neighbours. Arguments like these predict a region of relatively stable nuclei called superheavy elements. They may have exotic properties like higher number of neutrons per fission, higher cross-sections for fissions etc. The search is on for discovering such superheavy elements.

Physics periodically provides new realities which have escaped notice earlier. All metals conduct electricity, some better than others. However some metals and alloys become superconducting especially at low temperatures making them conduct electricity without resistance. Now superconducting magnets are made to produce high magnetic fields. They are used even in Magnetic resonance imaging in hospitals. Materials which become superconducting at higher temperatures like liquid nitrogen temperature are being discovered. This would make a big change in very exotic applications.

In a similar manner one talks of quantum mechanical tunneling possible to cause fusion between hydrogen ions. This is called cold fusion. For the last 15 years various groups have been experimenting, with success. It is still not well established but efforts are still on to establish reproducibility in a consistent manner. A theoretical understanding is still lacking.

It can therefore be summarized that as Bhabha predicted we are still in the early part of developments in nuclear science. We have already proved that electricity generation from fission is practical, is economical and eco-friendly. It needs consistent efforts to establish the economic advantages of new types of reactors for nuclear power. Use of thorium, in effectively converting it to U233 and burning it for producing nuclear power is still a challenge to the nuclear engineers. A brief account of the problems associated with converting physics ideas to commercial scale operations will be attempted in another chapter.

(1)1986. The making of the Atomic Bomb. Richard Rhodes. Touchstone

(2)1981. The Physical Principles of Thermonuclear Explosions F. Winterberg, Fusion Energy Foundation

(3)2001. Memoirs: A Twentieth-Century Journey in Science and Politics, Edward Teller, Perses Publishing

(4) 1995 The making of the hydrogen bomb Richard Rhodes Touchstone.

INDIAN EFFORT IN NUCLEAR SCIENCE

India gained its independence in August 1947. At that time Homi Bhabha had established the Tata Institute of Fundamental Research in 1945 in Bombay with a small help from the Government of Bombay through the Governor and the Tata Trust. He had worked in Cambridge for his tripos in mechanical sciences followed by Ph.D in theoretical physics. His area of investigations was cosmic rays which bring in nuclear particles from the cosmos. A number of detectors of various types were invented and used to study the Nature of the cosmic rays identifying particles and discover how they interact with other nuclei. He was closely associated with fundamental advances in nuclear science at Cambridge which was then dominated by Lord Rutherford in the Cavendish laboratory. Perhaps the best brains of the world came there to do research; Kapitza from USSR, some French scientists, immigrant Germans and visitors from North America including Canadians. A few Indians too worked there. The creativity of this team is a reflection of what international cooperation can do to advance the frontiers of science. Many Nobel Prizes were won for work carried out at Cambridge. Lord Rutherford, Sir John Cockroft, Chadwick and many others got their Nobel Prizes for new discoveries. It also created many top ranking scientists who led later the atomic energy programme in many countries. Even Oppenheimer spent a year at Cambridge before he went to Germany to take his Ph.D. The Cambridge University has discovered the electrons under Thomson, established the wave nature of the electrons by G.P.Thomson, the nuclear structure by Rutherford, discovered the neutron by Chadwick, built accelerator to study nuclear reactions and the whole lot of development in quantum physics. It is an example of how scientists can make quantum jumps in our understanding of nature and how new generations of students could be trained in the frontiers of science. Remember Srinivasa Ramanujan languishing in the Port Trust at Madras, had no educational qualification was invited to Cambridge to do research in Number Theory and was elected to the Fellow of Royal Society in a short time. That fact shows that the sole purpose of Cambridge was to maintain the leadership in science no matter where the participants came from. Lord Rutherford came from New Zealand; Lawrence Bragg came from Adelaide, Australia and there are visitors from India and other colonies. It was usual for the bright students from all over the world to aspire to join Cambridge, obtain a Degree and contribute to the growth of science. Many times these scientists decide to continue in the West for further progress and because there are no support back at home. Homi Bhabha would have returned to Cambridge but for the intervention of war in 1939. He, therefore, joined the Indian Institute of Science in Bangalore and organized a group conducting experimental and theoretical studies in cosmic rays. In 1945, he moved to Bombay; got support from JRD Tata since he was closely associated with the Tata family and even made use of his Aunty's residence at Kennilworth, Pedder Road to start the Tata Institute of Fundamental Research. He was elected as a Fellow of the Royal Society at a very young age. These qualities had drawn the attention of Pt. Jawaharlal Nehru and he therefore, appointed him as the Chairman of the Atomic Energy Commission formed in 1948. He also decided that here was a young man who could be trusted to grow science in independent India. Even though trained in Western habits, Dr. Bhabha was very deeply involved and attracted by the Indian competence and assured that given the right support, India could also grow Centres like Cambridge quickly. He did realise that assembling together young and creative minds was the most important component for growth. To do this he had to depart from conventional wisdom and practices of the colonial administration and a decaying university system which was meant only to train the Indian mind to support a colonial rule. Technical universities and institutions were very few and there was no point in taking away the few talented teaching staff from these institutions. So at the TIFR he established a Cambridge like centre selecting University graduates after a detailed interview to examine their ability to think. This system of interview by senior faculty members untouched by rules and regulations regarding the class in which he passed his University examination is a unique exercise which was followed for recruitment in the training school of the Atomic Energy Establishment Trombay and was continued to be the mechanism for the last fifty years. A separate chapter to deal with administrative reforms which Homi Bhabha introduced in the Department of Atomic Energy to make it successful in an otherwise decadent bureaucratic system will be dealt with later.

After India's independence Pt. Jawaharlal Nehru decided to build up the scientific infrastructure in the country. He had selected Dr. S.S.Bhatnagar, a Chemist to organize a Council of Scientific and Industrial Research like that in the U.K. and set up infrastructure in all disciplines of science. It is now well known that Dr.

Bhatnagar made a crucial path in organizing a whole series of laboratories starting with the National Physical Laboratory, National Chemical Laboratory, National Metallurgical Laboratory etc., which could provide the backbone and infrastructure for industrial research and economic growth. However, the model chosen was one that existed in UK, which already had a strong infrastructure in industry. The result of this was that CSIR laboratories were not able to bring industry into the main stream and the national effort on industrialization which rested with the Government did not organize research and development either in its own laboratories or interact strongly with CSIR. It imported technology, basic infrastructure for several industries e.g. are the Bharat Heavy Electricals and the Bharat Electronics. There were other areas like steel making, mining which also followed the copying culture.

In the field of atomic energy, Homi Bhabha realised that the infrastructure needed to span a whole lot of disciplines interacting with one another to enable the final product to be made. For example production of heavy water involves chemistry no doubt. But huge chemical engineering exercises had to be undertaken in order to produce large volume of heavy water. Similarly even though we had plenty of rare earths sands which contained uranium and thorium in Kerala an industrial process to separate them and produce nuclear fuel uranium or thorium had to be established in-house. The Indian Rare Earths was one of the very first factories set up by Atomic Energy Department. Homi Bhabha also realised that the feed of manpower to a successful industrial enterprise depends on the ability of the scientist/engineer in basic research and think of fresh moves and methods to attain success. He, therefore, decided that in addition to establishing industrial scale operations they have to be supported by teams of basic researchers in the respective areas. He drew many lessons from the establishments like the Atomic Energy Research Establishment at Harwell in U.K, the larger laboratories in the U.S. of the Manhattan Project etc. They were all supported by visiting teams of scientists from the well developed university system. In India such expertise did not exist and Homi Bhabha had to create them. Therefore, he had to adopt a method departing from the normal methods adopted in the west. The Atomic Energy Establishment Trombay was, therefore, created in 1955 in order to support basic research in relevant areas and establish pilot scale projects which can then lead to industrial production. It is interesting to note that in spite of the meager budget, he had the vision that this establishment had to grow in science, do diverse functions and be the pioneers when nuclear power becomes practical in the world. He selected a large area at Trombay which is several sq. kms in size but most of it covered by hills. The land between the hills and the sea, a narrow strip, was used to build up the buildings for the research laboratories. Many would have questioned his wisdom of acquiring the large area when the efforts were very minimal. Therein lies the confidence of Pt. Nehru in Homi Bhabha. The AEET was initially manned by the Tata Institute of Fundamental Research wherein the physics discipline, especially nuclear physics had grown for a few years. He also borrowed experts in electronics from the Tata Institute of Fundamental Research in order to nucleate instrumentation, especially electronics at Trombay. A small area covered by hills on three sides called the South Site was chosen to start the laboratories. The Indian Rare Earths was asked to set up a thorium factory in that site in order to separate thorium from monazite and obtain very pure rare earths. One of the first efforts of Bhabha was to establish a reactor as quickly as possible in order to encourage research and development in the area of reactors. In collaboration with U.K. he decided to build a swimming pool reactor obtaining the enriched uranium fuel from U.K. but making the Indian scientists and engineers to work out the details and build the control system and the cooling system for this reactor. In fact this reactor which was later named Apsara went critical on August 4, 1956, a few months ahead of a similar reactor which was being built at AERE, Harwell. At the South Site he also established a number of temporary sheds of the industrial type to house production unit in electronics for scientific instruments needed for research as well as practical efforts in mineral prospecting and instrumentation. The growth of the efforts in the south site was marked by the establishment of small units for making nuclear material e.g. uranium metal in pure form was obtained from processing from the uranium contained in the monazite sands, a fabrication facility was establishment to make uranium metal rods for the Canada-India reactor in 1958, canning of uranium with aluminium and making of thorium oxide rods etc. were all achieved in a short time by the Atomic Fuels Division. Dr. Brahm Prakash, a distinguished metallurgist led these efforts. The reactor engineering group designed the control system and looked after the construction of the Apsara Reactor and later to operate it on a three shift basis enabling the use of neutrons for isotope production and basic research. It is interesting to note that the Apsara reactor had a thermal column made out of graphite. While this job could have been contracted out Homi Bhabha decided to establish graphite machining facility in order to get this job done. Perhaps it was at that time graphite moderated reactors were built in advanced countries to produce plutonium. Homi Bhabha perhaps had in mind to go into similar plutonium producing systems for India. However, the offer of a heavy water moderated reactor CIRUS by Canada made it unnecessary for us to build a graphite moderated reactor. It can, therefore, be seen that Homi Bhabha had in mind perhaps priority for being able to produce plutonium as fast as possible and thus the raw material for making the atom bomb. This clearly shows that Homi Bhabha did not venture to have a programme for atomic bomb but was keen to build up the infrastructure for India to be able to make the bomb when needed. I have heard from many discussions from Dr.Ramanna to a specific question whether India should build an atom bomb, Panditji used to tell Bhabha to come and tell him when ready, rather than asking for an early approval.

The greatest impediment to rapid expansion of the AEET was the availability of manpower especially specialists in disciplines wherein India had no laboratory. Disciplines like safety, effects of radiation on health, detailed design of neutronics of reactors, radiochemical activity involving isotopes and plutonium, chemical engineering practices to separate useful and pure nuclear material from irradiated rods, analytical services to test the purity and quality control of the products had to be built up at Trombay. It was then decided to induct 200 scientists and engineers into the establishment every year after a careful selection and initiation into nuclear engineering by a one year course at the Training School in Trombay. He also sent these young scientists wherever possible for gaining experience in foreign laboratories. The close cooperation offered by France, U.S.A., U.K. and Canada enabled a large number of scientists and engineers to be trained in the foreign laboratories. The fact that Homi Bhabha was President of the Geneva Conference on the Peaceful Uses of Atomic Energy enabled him to influence the chiefs of foreign organizations for accepting Indian manpower. The quality of the manpower selected and trained in the AEET School made sure that when sent abroad our scientists and engineers adapted them very quickly and learnt from a wider spectrum of activities in those laboratories. It should be recognized that fastest way of generating manpower in India tuned to the needs of atomic energy were achieved by a successful cooperation agreements with foreign countries.

Homi Bhabha was not only a top ranking scientist but had a great love for ecology as well as architecture of buildings. He encouraged the hills to be forested which were fully under the control of the atomic energy department, established large gardens in the Trombay Establishment, the chief of which was sent abroad to Versailles to get knowledge of the beautiful gardens at Versailles. He spent considerable time in planning the buildings for the laboratories taking into account the interactive nature of the scientific work and the infrastructure needed for generating industrial scale products. Thus five engineering halls devoted to many aspects of pilot plant studies, a modular laboratory 1/3rd of a mile long housing various disciplines from biology to metallurgy, a central complex housing the administrative block of both pure administrators and scientists, a centralized canteen system, centralized air conditioning system were planned by him which make the Trombay establishment a unique laboratory in India quite a departure from the isolated efforts of CSIR and DRDO.

In AEET Homi Bhabha introduced all the administrative reforms as experience showed and became necessary. A democratic system of decision making based on committees in which most of the disciplines were represented and all the leaders of the groups were present was the essential point of departure from conventional administration. All decisions even with respect to budget, scientific plans, deputations abroad, holding of seminars and symposia were all taken by the Trombay Scientific Committee. The Trombay Council which consisted of 5 or 6 Directors was an Advisory Committee to Homi Bhabha and he was Chairman of this Committee. All major decisions of the DAE were taken by this Council. These institutions have grown in size no doubt. However, they still function as the major decision makers of the Department of Atomic Energy. Visitors to this establishment in the early years covered a whole spectrum from Chou en Lai of China, Marshall Tito of Yugoslavia and the Queen of England and several other Heads of States and distinguished scientists from abroad. The Ministry of External Affairs used to earmark Trombay as one of the places to be visited by the Foreign Dignitaries as people remark the whole Trombay Establishment was a different India when compared to the conditions obtained outside.

The establishment of the CIRUS reactor between 1958 and 1960 in collaboration with Canada was another landmark in the history of atomic energy. This reactor operating at 40 MW was the basis for generating many technologies, isotopes and supporting basic research. It also helped to train operating crew for future power stations. It went critical in 1960 but had its problems arising out of the quality of cooling water. Strangely it was due to the bacterial content of the water and it took sometime to identify and purity this system. For the first loading of this reactor with uranium fuel was shared by both India and Canada thus establishing that we could have our own nuclear fuel for such a large facility. Since then it is fuelled only by Indian uranium. The plutonium produced during irradiation is chemically processed in the first chemical reprocessing plant built in Trombay and went into operation in 1965. Thus kilograms of plutonium were available to India even in 1966. Many times a question was asked “when could India detonate a nuclear device”. Homi Bhabha declared in 1966 that we could make the bomb in 18 months. History showed that India did not work for the bomb but the infrastructure created at Trombay for the introduction of nuclear power stations in India automatically gave India the capability to make the nuclear weapon if political decision was forthcoming.

The diversification of research and development in Trombay knew no bounds. Very often new experts with foreign training were used in order to initiate new programmes according to his expertise. There were of course strong emphasis on indigenization and self-reliance, so that anything that is required can be achieved at Trombay. It is therefore, not surprising that the large infrastructure, machining capabilities of material, hot laboratories for dealing with the radioactive sources, the plutonium laboratories for producing plutonium metal and machining it all grew up in Trombay which was generally improving the infrastructure in nuclear technology.

The power sector for producing electricity was of course the ultimate aim. Homi Bhabha decided that he would prefer to buy two light water reactors from USA in order to initiate the nuclear power programme even though it meant borrowing foreign technology. A large part of the operation crew and building parts of the system were still Indian and these two reactors went into operation in 1969-70. They still continue to operate, perhaps the only surviving reactors of that vintage. Many changes and refurbishing were done in order to maintain these two reactors.

It was also realised that in order to expand the programme it is necessary to expand the infrastructure by building dedicated factory type establishments outside of Trombay. A whole complex of facilities and factories were built in Hyderabad which concentrated on electronics and instrumentation under the Electronics Corporation of India Ltd., and the production and fabrication of nuclear fuel using zirconium and uranium oxide at the Nuclear Fuel Complex. The fact that these establishments have grown in size and enabled us to expand the nuclear power industry to fourteen nuclear power reactors at present is due to the vision of Homi Bhabha. Other exotic materials were also produced by Nuclear Fuel Complex. This Unit is being further expanded to take care of the new needs of the atomic energy programme.

Basic research was encouraged in Trombay with the facilities that were indigenously built. One example is in the area of neutron physics where CIRUS was used as the initial facility but a new reactor Dhruva of 100 MWe was commissioned in 1986 entirely through indigenous efforts. A low energy critical system of plutonium called PURNIMA was established in 1972 to deal with the problems associated with fast reactors. Thorium irradiated in CIRUS, DHRUVA and a few of the PHWR power stations were processed to obtain uranium 233 with which a new reactor called Kamini was established at Kalpakkam. At Kalpakkam a 40 MW fast reactor was built in collaboration with France. However, because of their refusal to supply fuel, a new fuel of plutonium carbide was produced in Trombay which proved to be effective in the FBTR. One could therefore see that this huge infrastructure was effectively used in order to minimize the effect of sanctions applied by the Nuclear Suppliers Group after the Pokhran I and Pokhran II tests. Sanctions and controls of nuclear technology from outside have therefore become irrelevant as far as India is concerned. Efforts are on now to build a 500 MWe fast breeder reactor called PFBR at Kalpakkam, which when duplicated will lead to an industrial growth for fast reactors for nuclear power and shifting emphasis from uranium to thorium for the future.

One may ask the question whether any consideration of economics was considered in making this programme. Hans Bethe once said that basic research is expensive. But that is the surest way of making progress in technology. There is no point in industry crying for new technology unless we have an infrastructure which could absorb this new technology effectively and make it economical. It is now clear that the cost of nuclear power stations designed and built by India like the PHWR 560 MWe at Tarapur are cost effective – only half of the international costs per MW and generate further wealth by upgrading industry as well as manpower development. The manpower generated by Trombay is exceedingly competitive to the rest of the world and itself is an asset to the nation. Very senior scientists and engineers have spanned out from this establishment to other centres as well as other organizations to lead the country in frontiers of technology. The growth of space efforts and its establishments is partially due to the initial impetus from Trombay. CSIR and DRDO have also benefited by intense interaction and transfer of staff to those establishments. There has been no dearth of key people to man these various positions and in fact over a period of time there is overcrowding for these posts and a way must be found to make effective use of their talent in new establishments. A rapid expansion of the nuclear power programme will not be affected by lack of manpower. This is in contrast to what is happening in more advanced countries like the U.S.A.

It would be interesting to recall the developments at Trombay which led to Pokhran I nuclear explosion. As mentioned before plutonium became available from 1965. A fast reactor using 22 kg of plutonium went critical in 1972. The metallurgy to produce plutonium metal and fabricate it into the right shape was built in the hot laboratories in the late sixties. The reactor physicists were familiar with codes for calculating the reactivity of such small cores thus enabling good confidence in the physics of an explosive device. Experiments were conducted to make a triggered neutron source using polonium produced from CIRUS reactor by irradiation of bismuth. The design of explosive lenses for simultaneous compression from all sides of the plutonium core was developed in collaboration with the terminal ballistic research laboratory of the DRDO in Chandigarh. Good cooperation existed between Dr. Ramanna, the then Director of BARC and Dr. Nag Chaudhury, the Director General of the DRDO. Dr. Nag Chaudhury looked after the site preparations at Pokhran using an Army engineers regiment to dig a hole of 100 meters deep so that the explosive could be lowered and detonated. The fabrication of the housing for the device was done incognito in the Central Workshop in Trombay. The exercise of detonating a nuclear explosive was thus a small deviation from the normal work carried out by many scientists and engineers at Trombay. This was the reason how the whole project remained a secret and foreigners could not pry on what was going on and how we prepared ourselves for this test. The question was generally asked supposing it did not work according to plan because of the secrecy, the answer lies in the extreme confidence which the scientists had on their design and the laws of physics which govern a nuclear explosion. It is the experience and the confidence that the scientists built up in the laboratory which enabled them to venture into new areas of the unknown. The same thing was repeated in 1998 in detonating a hydrogen bomb. The work was carried out in Trombay with no great fan fare. For a detailed description of Pokhran I, see the autobiography of Dr Ramanna (1)

(1) 1991 "Years of pilgrimage" R. Ramanna Viking (ind)

NUCLEAR TESTING

As explained before, the nuclear material in case of plutonium before exploding due to neutron induced fission, it has to be compressed by shockwaves. That would reduce the diameter of the central core considerably, reduce the area of the spherical surface and increase the density inside the core, of course un-uniformly. This is achieved in the implosion technique by detonating simultaneously several lenses of chemical explosives which will trigger detonation of a spherical charge from all over the surface. The shockwave generated will thus radially penetrate the core and compress it. When we talk about simultaneous detonation, it has to be in the range of a micro second taking into account the velocity of the shockwave in the medium. The rate of rise of criticality is also in the range of micro second range and, therefore, the triggering neutron must appear during the peak of the criticality. The rate of release of power depends upon the super criticality of the core on compression and usually it is of the order of microseconds. When the centre gets hot and vaporizes it tries to push and destroy itself and this time decides the total yield from a nuclear explosion. Various theoretical calculations could be made. However, the uncertainty at which time the first sustaining neutron causes the fission decides the total yield along with other parameters. This is the reason why a testing is required because this is not very much in the control of the designer; secondly the yield can vary depending upon the rate at which the material flies off after detonation. There was a time when such explosions could be conducted in the atmosphere so that one can see, and if necessary, measure certain parameters which will provide the yield. The debris also contains information which could be collated with the yield. After the agreement to ban nuclear explosions in the atmosphere signed by most of the countries in 1964, the only way to test nuclear explosives is underground. Since it is not possible to get access to the site after the explosion, indirect methods are used to evaluate the yield. The most often used method is the seismic method, where the seismic signals generated by the nuclear explosions travel around the globe and can be detected by seismometers. The modern array technique is able to provide the epicenter at which the nuclear explosions took place and indirectly the yield of the nuclear explosion. These array units are now operated in many countries. The weapon countries in particular ensure access to this information from independent countries. A number of tests carried out at Nevada test site have given empirically the relationship between the seismic signals and the yield. However, one has to trust the information provided by the U.S. There is no reason why they should not be providing the right information. The nature of the seismic pulse due to nuclear explosion differs from that of an earthquake by the fact that the nuclear explosion is a single event in a short time whereas an earthquake prevails for much longer time. The longitudinal P-wave signals from a nuclear explosion is always upward, another criterion to distinguish between earthquake and the nuclear explosion. The subject is essentially part of geophysics but the technology has been improved from inputs from the weapon countries. In 1968, in collaboration with the United Kingdom, India established a seismic array centre at Gouribidanur near Bangalore. This has an L-shaped array of seismometers a kilometer from each other; the signals are received at a central station and processed by computers. Soon after establishing this centre, a standard test was made by the Americans exploding a hydrogen bomb in Alaska. We have continued to use this centre for detecting earthquakes as well as nuclear explosions worldwide and we have never missed any significant explosion above a few Kilotons of TNT. Unfortunately the relationship between the yield and the signal strength is non-linear and depends upon the geological conditions in which the array is placed and the geology of the site at which the explosion is done. Therefore, one cannot take these data as exactly correct.

Another method of deciding the yield is to be able to measure the neutron intensity at the core of the explosion. Due to the very high flux multiple absorption of neutrons takes place with very short time isotopes. By measuring the isotope ratios in the debris one can make a calculation of the high flux and thereby indirectly the yield. To do this, one needs to get samples from the core after the explosion, which requires a drilling technology to be able to penetrate the molten core. In the atmospheric explosions since the sample is freely available on the surface the radiochemical method could yield better accuracy. However, in underground explosions one is not sure about the sample, and one has to be careful in assessing the total yield.

Other indirect methods have also been proposed based on the morphology of the cavities generated and the disturbances on the surface created by the explosion.

These are of course indirect and will only ensure that the predictions are roughly correct.

The Pokhran-I explosion conducted on May 18, 1974 was detected by the seismic arrays in England, Australia and Canada which were operating in collaboration with the British Institute for Weapons Research in Aldermaston in U.K. Because of our collaboration they immediately reported to us that they have detected a nuclear explosion in the Pokhran site of magnitude 8 Kilotons of TNT. Our own measurements from Gauribidanur indicated roughly of the order of 10 Kilotons of TNT. As far as the success of the explosion is concerned this difference did not matter much, when 8 Kiloton explosion is truly a fission explosion and the yield is very close to that expected. Further data gathered from radioactive samples picked by drilling did indicate a lower yield. However, it was clear that the sample could have been from the periphery of the explosion and, therefore, will not fully represent the yield. So much for the controversy over the Indian claims of the Pokhran-I Test.

On May 11, 1998, India conducted simultaneously three nuclear explosions underground. One was of very low yield, less than a kiloton and did not matter for the estimation of the yield. The two larger explosions, it was claimed one was of an improved fission bomb and the other was a thermonuclear device. The improved fission bomb could have at a minimum yielded 10 Kilotons. The total yield of these two together was estimated by international arrays to be of the order of 30 Kilotons whereas the Indian estimate was about 43 kilotons. Granting that the Indian estimate is correct the thermonuclear device could have yielded only 43 minus 10 i.e. roughly 33 kilotons. It was reported that the thermonuclear device consisted of a boosted fission bomb to trigger a secondary which was the true thermonuclear device. It is not known what the yield of the boosted fission could be. International experts claim that we can boost the fission trigger upto a factor of 10. Therefore, the total yield of 33 kilotons which includes the boosted fission can only account for a few kilotons for the secondary. A thermonuclear device using the secondary is meant to be detonated when you want the yield to be several hundred kilotons going upto several megatons. The simultaneous triggering of both the devices make the seismic signals overlap and may not get an independent evaluation of the yield of each. Thus an uncertainty in the estimation of the yield of the thermonuclear device was introduced and has been debated in the international circles. If we have to claim full control over the design of a thermonuclear device in the sense that we have established a burn process in the secondary then it is necessary to test a higher yield device so that this uncertainty could be put at rest. It is of course true that India could make boosted thermonuclear devices upto 100 Kilotons or more, even by restricting oneself to the booster principle.

A country can declare itself a weapon country when it has an arsenal in which all the devices stored are certified as for its yield is concerned. In the U.S. at least ten per cent of the weapons in the arsenal have been tested in order to certify to the military the yield of those devices. The design could change from test to test because the mechanism of conducting the x-rays from the primary to the secondary and its effectiveness is not a simple calculation and involves many theoretical assumptions. Therefore, the proof of the pudding is in the eating of it. Unless it is tested the military may not accept certification on the basis of theory alone by the scientists.

It is also known that there is a constant effort to redesign the secondary and make the entire device suitable for being launched in a missile. This is quite different from dropping it from air from an aircraft. The attempts are to reduce the entire weight, to shape it in such a way that it can be mounted on the missile and improve the ruggedness such that it does not collapse when launched in the atmosphere due to the heat generated. Therefore the problem of engineering a device in spite of testing it on the ground is a complicated operation and best done by defence experts. We have fortunately in DRDO the missile scientists who can do this thing.

Our nuclear deterrence philosophy is based on using three types of launches: (1) dropping from the aircraft (2) launching through a rocket from ground and (3) launching the rocket from underwater in a submarine. All these three types of launches have to be tested for its accuracy of guidance and the targeting accuracy. Of course this could be done without the nuclear warhead. And one hopes such data has been collected even though we do not yet have a submarine launcher in our control.

India declaring itself as a nuclear power, therefore, involves many of these factors. It is only prudent that one continuously tests these and upgrades the technology so that it will be foolproof. Declaring a moratorium on testing immediately after the May 1998 test is unfortunate because we cannot test the veracity of the yield and also cannot improve the mechanical design of the device. It is in this connection that one cannot agree on a moratorium of nuclear testing which is now demanded by the 123 Agreement without an accusation that we have violated the 123 agreement. It therefore depends on the politicians to understand and take the technologists into confidence before negotiating a diplomatic agreement which may curtail our freedom of action in the future.

<u>NON PROLIFERATION</u>

The Science behind nuclear energy and nuclear weapons emanate from the researches carried out in small laboratories in Europe. The Manhattan Project was necessary to speed up the development of nuclear weapon and establish large scale facilities for producing raw material for nuclear weapons as well as for nuclear energy. Thus the industrial scale operations were budgeted and managed by a military establishment which enabled them to speed up the process and produce results in a short time. This of course, meant unlimited resources and perhaps unnecessary spending. It, however, demonstrated to the world that nuclear weapons research is expensive, involves a large industrial infrastructure and talented manpower which only large countries like U.S. could afford. Subsequent developments in the Soviet Union, U.K., and France demonstrated that in fact all these processes could be achieved by any dedicated government in smaller countries.

In the fifties, the rapid expansion of the nuclear testing, the development of the hydrogen bomb, the nuclear submarine and the demonstration of nuclear power in the United States made an impact on a world scale. The United Nations recognized the importance of this new technology, overwhelmingly sensitive to power both in terms of military as well as energy production. The demonstration of the destruction at Hiroshima and Nagasaki threw in a new dimension to the politics of nuclear weapons. The United Nations discussed the ways and means of restraining the world, especially powerful countries from following the U.S. However, restraints did not help. The Soviet Union, U.K. and France developed and tested their own atomic bombs followed by China. Detailed negotiations in the U.N. between the U.S. and the Soviet Union could not result in achieving any useful result. With the demonstration of electricity from nuclear reactors by the Soviet Union, U.K. and the U.S.A. proved that nuclear reactors will have a major contribution to energy production in the world. The U.S. declared an Atoms for Peace plans by which it could help weaker nations to acquire nuclear technology for peaceful purposes. Under the auspices of the United Nations a U.N. Conference on

Peaceful Uses of Atomic Energy was organized in 1955. Even though Dr. Oppenheimer was selected to preside over and organize this conference, the political ramifications in the U.S. did not allow this. Instead Homi Bhabha from India was elected to preside and organize the first U.N. Conference in Geneva in September 1955. The proceedings of this conference are historic in the development of human civilization. For the first time nations in the world participated and contributed to open the secrets of nuclear energy to all nations even though certain parts of it were still held in secrecy. The curiosity of the scientific community was triggered and nuclear science became the most modern effort in many universities in the world. Training in nuclear science became most sought after by the intelligent student community. Many universities in the U.S. opened up nuclear engineering departments and consequently scientific research in many aspects of nuclear technology. Large commercial undertakings like General Electric, Westinghouse and Du Pont entered the field with commercial interests to sell nuclear power. The most creative commercial laboratory was of the General Atomics led by DeHoffman who specialized in the new types of research reactors called the Triga which could be easily established in many universities around the globe. This resulted in the proliferation of the uses of nuclear technology in several areas for practical applications.

With this kind of spreading of technology and information it became obvious that those countries which are after power could indulge in a nuclear weapons programme. It, therefore, alarmed the most advanced countries who wanted to restrict the spread of this technology to peaceful purposes only and not enabling anybody else to go in for nuclear weapons. The sixties saw the development of nuclear technology in China through the assistance of Soviet Union which resulted in a Chinese nuclear test in 1964. It was not known at that time that a broader policy of cooperation followed by the Socialist Countries led by the Soviet Union could result in spread of this new technology. If the North Koreans have exploded a bomb in 2004, the scientists in North Korea were trained in the Soviet Union in their well-known laboratories. India had strong cooperation with France, Canada, U.K. and U.S. by which the Indian programme grew both in manpower as well as in facilities. As it was led by an eminent scientist like Homi Bhabha, he had led India into many aspects which enabled India to make a nuclear weapon. He even declared in 1965 that India could make a nuclear weapon in 18 months. The resources especially the plutonium was already reprocessed at Trombay at the end of 1965.

These developments alerted the nuclear weapon countries to take steps under the aegis of an International Organisation like the International Atomic Energy Agency (IAEA) to bring in controls on the development of non-weapon countries. A non-Proliferation Treaty was drafted and discussed in the international forum for acceptance by all nations. This Treaty was circulated for signature to many countries in the world. According to this Treaty only five nations who had tested nuclear weapon before 1968 were given the right to maintain, develop and build an arsenal of nuclear weapons whereas all other nations who are signatories were classified as non-weapon States and restrained from directly or indirectly developing a nuclear weapon. In return the nuclear weapon countries promised cooperation on the peaceful uses of atomic energy including nuclear power.

Politics in the world at that time was highly polarized led by U.S. on the one side, the Soviet Union on the other side and a host of countries who followed a non-aligned political philosophy like India, Egypt, Yugoslavia, Indonesia and others. The non-aligned countries showed little interest in signing the NPT and resisted losing the sovereign right to develop a new technology which has changed the nature of political security in the world. The larger countries like China and India certainly refused to sign the NPT which was followed by several other larger nations like Argentina, Brazil, South Africa etc., The defeated nations of the Second World War like Japan and Germany had no option because by their Treaties they were prohibited from developing the nuclear weapon even though economically they grew very fast and that resulted in a host of technologies being developed in these countries by which they have acquired the capability to make nuclear weapons.

The terms of the NPT have been discussed in public for a long time and need not be repeated here. The terms of this treaty are reproduced in the appendix. For the first time the classification which infringes on sovereign rights was brought in and was not acceptable to newly independent nations from colonial rule, India was most conspicuous. The successive governments in India refused to accept the NPT for its discriminatory nature. A Gandhian like Morarji Desai who was the Deputy Prime

Minister in the late sixties, though against India developing nuclear weapon was for abstaining from signing the NPT.

After the propagation of the NPT, it became necessary to enforce and supervise safeguards in countries which have agreed to follow the NPT rules. Thus for the first time it became necessary to take in scientific facts, methodology and capabilities into account in framing the rules of safeguards. Inspections have to be arranged such that the rules are not violated. This exercise slowly evolved and became a major activity of the IAEA overtaking the technical purpose of helping developing countries in nuclear technology. The world has lived with this phenomenon for the last forty years. Large resources have wrongly been spent to safeguard the interest of a few countries.

It is now well known that the circumstances in which India tested its first nuclear explosive in 1974 were forced on it. Apart from demonstrating its technical capability, it also focused on the determination of this country to have its own strategic programme for its security. The Pokhran test was precipitated by the Indo-Pakistan war by which Bangla Desh became an independent nation and many advanced countries had cast aside their neutrality to support the military regime of Pakistan. For some time it looked as if democracy is good at home but need not be the foreign policy of a great power.

While discussing the details of the safeguards policy which meant making inroads into the technicalities of generating the resources for making a nuclear weapon several aspects of nuclear technology have come into the open. Few of them are discussed here.

1. Isotope separation: Scientifically each chemical element was shown to have more than one isotope whose nuclei differed in their character and some was more advantageous than others. Thus, uranium has two major isotopes 235 and 238 though chemically the same. U 235 fissions easily with thermal neutrons. Its availability is only 0.7% in natural uranium. Therefore the development of a small sized bomb will depend upon using the U-235 alone and therefore, the need for separating the two. This is

now known as the enrichment process and one of the major technical fall outs from the Manhattan Project is to be able to enrich uranium in 235 to 90% or more The physical processes and the technical details of this enrichment process were kept secret even though the principles are well known, e.g. a magnetic field could deviate a beam of uranium ions into its two components. A centrifuge can concentrate the lighter ones from the heavier ones. A laser could also separate the two types of ions. Initially the difference in the diffusion rate of the molecules of uranium fluoride (UF6) due to the mass difference of 3 in 350 was exploited. Plants have been set up which always use a cascade of similar units to enhance the enrichment. Even today we read reports of clandestine trade in the enrichment process notably by Pakistan under A.Q. Khan's network.

2. Ordinary hydrogen has a mass one. But its isotopes deuterium has mass 2 and tritium has mass 3 but radioactive. This large difference in the mass is due to the addition of a neutron to the simple proton of hydrogen. Its nuclear property, therefore, changes enormously while hydrogen absorbs a neutron it becomes deuterium and after absorption of another neutron it becomes tritium which has short life of a few months. Deuterium is contained in ordinary water to less than 0.7% and since its mass is a factor of two compared to hydrogen , is separated much more easily like what a housewife does between full seeds of rice and broken pieces. Hydrogen quickly forms a molecule and therefore it is necessary to deal with ammonia (NH3), Hydrogen sulphide (H2S) etc. The chemical interaction rates are different for hydrogen and deuterium and this principle can be used for concentrating deuterium. Thus an electrochemical method and other exchange methods have been developed, and tons of heavy water are now produced in India. Sometimes these are just byproducts if additional facilities are built to existing fertilizer plants. Producing heavy water has now been classified as a strategic technology and is subject to IAEA safeguards for those who signed the NPT.

3. If one subjects Uranium 238 to a neutron flux you can convert that into U-239 which by radioactive decay eventually becomes plutonium 239. Thus

any operating reactor in which U-238 exists in the fuel, plutonium 239 is automatically formed. Since plutonium is chemically different from uranium and the fission products, it is possible to chemically separate the plutonium. Of course very sophisticated methods are required since the fission products are radioactive and the plutonium itself is highly radioactive and toxic. The fact that it is a chemical process enables scientists to achieve this by upgrading from small laboratory to reprocessing plants, enabling tons of plutonium to be separated. A quantity of the order of 6 kg of plutonium is sufficient to make a nuclear weapon and much lesser quantity to make a chain reacting system. Even though the highest degree of safeguards has been applied to this technology, it can still be nucleated in any laboratory in any country.

4. For building reactors zirconium alloys are preferred as structural material because of their small neutron absorption. Zirconium is part of the rare earths of the beach sands in many parts of the world. The methods for separating them have been in vogue for a long time. Restrictions on trade in this come under safeguards.

In all these sensitive material production, information and manpower with experience are important and therefore the safeguards also apply in these aspects. For the first time in human history there was a blockage of knowledge being transmitted from one person to the other, one nation to the other or one society to the other. Hindus believe that the greatest gift that you can share with your friends is knowledge and there should be no restriction on transfer of knowledge from one to the other.

One can now see that the so called sanctions being applied to India by the U.S. or the detailed safeguard restrictions promulgated by IAEA are contrary to human dignity especially for a nation with an ancient history and which has propelled Buddhism and other philosophical ideas throughout the globe. It is, therefore, very hurting to the polity in India for the Central Government to accept for the first time new kinds of restraints which affect the sovereign rights.

Many people ask the question “Why is India taking an isolationist view on the NPT as well as on the safeguards”? This situation is a direct result of centuries of colonial rule and our subjugation to the diktats of foreign power. Why did Indira Gandhi refuse to sign the NPT? Why did Morarji Desai refuse to sign the NPT and all the succeeding Governments refused to sign this discriminatory treaty? It is, therefore, not a question of not accepting globalization. It is deeply engrained in our right to speak up when demanded. We cannot forsake our right to be able to do independent research, add to the technologies that we need to develop and the freedom to pursue an independent nuclear policy both for strategic as well as civil uses. Fifty years of managing the nuclear programme while suffering humiliation of discrimination in the international fora has not weakened this country's scientists from upholding a tradition. It is with that objective that the senior retired scientists of the Department of Atomic Energy had appealed to the Parliamentarians detailing the conditions on which the Indo-US nuclear deal could be struck. The ramifications arising out of agreeing for a nuclear deal, accepting the conditions passed as an Act, the Hyde Act in the U.S. have been explained in other fora. It is obvious that there is no unanimity among the political parties to support the 123-Agreement and democracy demands that these objections are listened to by the ruling party. Sometimes, a doubt arises whether India would behave differently if it were a nuclear power before 1968. The moot question is what is our final objective? We have always argued for complete nuclear disarmament. Rajiv Gandhi even made a concession in time for the advanced nations to agree to nuclear disarmament. NPT also spells out that the nuclear weapon countries in good faith will work towards a nuclear disarmament. An organization in Geneva has sat for the last fifty years as the Disarmament Committee and discussed the problem of nuclear disarmament for several decades and yet we do not see any agreement on the part of the weapon countries to give up nuclear weapons Under these circumstances should India tie up its future, that is the moot question that would be asked for a decision? The euphoria arising out of globalization of trade is starting to extinguish slowly. The stock market has become a gambling den often controlled not by the progress of our basic industries but by the profitability of foreign investment in this country. It is quite clear that the foreign investment is attracted by the high interest rates which we are willing to pay at the cost of our poor getting poorer and not by the higher productivity resulting from the capital. Analysis of industry by industry clearly shows that as long as the country is an importer of technology, that particular industry will be controlled by foreign interests. At least in the area of nuclear science and technology we have shown that technology can be grown in this country on the basis of self-reliance and indigenization. We do not require any import of technology. It does not matter if we produce only 560 MWe reactors and not 1000 MWe reactors. We can produce enriched uranium for our own power stations. But we refrain from that since we do not have very large quantities of natural uranium and that is why we have gone in for Pressurized Heavy Water Reactors and Fast Reactors for utilizing thorium. We have the enrichment technology. We have built a nuclear submarine with enriched uranium. We have built the core of the nuclear submarine from the facility that we built in Ratnahalli in Mysore and if necessary we can expand on the enrichment process for future reactors. Natural uranium is found all over the world, richer ores in Australia, Canada, Gabon, Namibia and many other small nations. Why not globalize and freely trade natural uranium because it does not permit making of the bomb in a single step. Why should the world apply safeguards on the materials which are bestowed by Nature? This question was raised during Pandit Nehru's time in the early fifties in Parliament and Panditji replied that we cannot subject what we mine to foreign inspection and control. Is it not what is demanded in the Hyde Act by the President of the U.S. reporting to the Congress how much uranium has been mined and for what purpose? It is therefore, clear that this Indo-US nuclear deal is in the interest of the U.S. and is a back-door push to get us into the NPT regime.

ACCELERATORS

Somebody remarked that nobody today can be ignorant of the existence of electrons, whether it is a housewife or a scientist. The charge on the electron and the proton which are described as negative and positive respectively greatly influence the processes that take place in Nature, from the lightning in the sky to the gas lighter in the kitchen. It is the electric charge that plays the part. In the gas lighter we push a piston which compresses a crystal by which electric charges are separated. Since the pin is attached to one end of this crystal, it magnifies the electric field and sparks so well giving you a luminous spark which heats up the gas resulting in the flame. These processes are so ingrained that we hardly think about it or try to understand the process.

After the discovery of the electricity from Nature in the 18th century, we have been experimenting with static electric charges. Even now if you take your hand close to the TV screen the hair stands showing that the screen is charged which induces a charge on the hair and makes it stand up. The electric field which is the result of the electric charge is established in no time and this is what makes electric current to be conducted from a hydro-electric station to any receiving end several thousand kilometers away. Electro-magnetic radiation that is produced from any motion of the electric charge travels with the velocity of light through space. This is what makes radiation from the Sun reach this planet and give us energy. The radio-station and the TV station and the communication through satellite, all use this electro- magnetic radiation to convey information in varied forms depending upon our ingenuity. We cannot now imagine a world without these facilities even though it did not exist a hundred years ago.

As mentioned earlier, the electric field can ionize an atom and acting on the residual positive charge can accelerate the ion to high energy. This is like a ball falling through gravity where it acquires energy as it travels more and more through the gravitational field. The strength of the gravitational field will decide the energy that the ball will acquire through certain distance. Similarly the electric field will decide on the energy the ion will acquire. Early attempts were to produce static electric potential using electric charges of the order of million volts so that ions could be accelerated to that energy. The first of such attempts were successfully performed by Cockroft in Cambridge in 1932 and accelerated particles to hit other static nuclei and cause nuclear reaction for which he got the Nobel Prize. Since then man has been attempting to build accelerators and accelerate particles to higher and higher energy. The largest accelerator today is called the Tevatron which accelerate particles to the energy of trillion volts that is 10 followed by 12 zeros. When particles reach this energy their interaction can cause disruption of even the very fundamental particles like the proton and the nuclei. A study of this not only adds to our knowledge of what constitutes matter but also tries to answer the fundamental question of what is the building block of matter we are dealing with.

A particle accelerator was an index of advance in nuclear physics in a country or an institution possesses. Therefore, scientists were constantly inventing methods for accelerating particles starting with a static accelerator to synchronous accelerators of trillion electron volts. The discovery of a cyclotron is a major event because in a cyclotron the particle is made to go around in a circle between two D-shaped cavities between which an alternating electric field is generated. Every time the particle crosses this gap it gets accelerated to a limited extent. Since the number of orbits it can make is enormous the particle attains higher and higher energy. Since the radius of the orbit is decided by the magnetic field one can manoevoure for the particles to increase its orbital radius as the energy gets higher. Thus a particle starting at the centre takes a spiral orbit until it attains the required energy before coming out. This is the principle of the cyclotron. However, as the energy increases the effective mass of the particle also increases according to Einstein and therefore, there is a limitation of what a simple cyclotron can do. Building of the cyclotron was an effort of experimental physicists with development of new technology for high magnetic field, high frequency electro-magnetic rays and the coupling of such waves to the system as a whole. The ion source which produces a number of particles that start to run has also been developed to reach very high value.

The scientists of the Manhattan Project who were conducting nuclear physics experiments with meager facilities in the university system got a major encouragement once they succeeded in making the atom bomb. True to their loyalty to basic science many of them migrated to the University Laboratories with huge generous grants from the Government for building bigger and more involved accelerators for the future. Thus several university departments like that of Cornell and Berkeley built the most advanced accelerators in the sixties and seventies. In fact the effort became so large that the emphasis shifted from the university physics department to very dedicated laboratories for accelerator research like the Fermi Lab. in Batavia near Chicago and the Argonne National Laboratory and the Brookhaven National Laboratory. In the Soviet Union a new Centre was created called the International Institute for High Energy Physics at Dubna in which all the countries of the Soviet Block participated, making discoveries which fetched Nobel Prizes. It can therefore be seen that future inventions in nuclear science will depend upon the technical competence established in a country in this field of accelerators.

Homi Bhabha in early fifties agreed to buy the first one million volt accelerator from Philips, Holland to start, because it was easily available commercially and could be set up in a few months. This was installed at the Tata Institute of Fundamental Research in Colaba, and perhaps the first of the accelerators in Asia. Simultaneously the Australians led by a Manhattan Physicist, Titterton established a facility in Canberra. This used to be a show piece for foreign visitors in the early fifties. I started my work with the installation of this accelerator. The fifties was the period when new suggestions and principles for accelerating particles were thrown up. A physicist Mark Oliphant, a colleague of Bhabha in Cambridge who had migrated to Australia used to visit TIFR and advise Bhabha on the progress of accelerators. This in fact delayed Dr. Bhabha's decision to start on a larger project of a Cyclotron in TIFR. A very small cyclotron was built in TIFR so also in the Saha Institute of Nuclear Physics by Dr. B.D.Nag Chaudhury who got components for it from Berkeley where he worked for his Ph.D. The growth of applications of accelerators in several fields like producing new radioisotopes, using the radiation for cancer therapy and for non destructing testing quickly took over and now we have the Linear Accelerators almost in every hospital. Other industrial uses have also multiplied. But the use of accelerators in frontiers of physics has continued to be the most advanced technology in physical sciences. The cost of such facilities was growing fast and after the war the European Nations joined together to build a common facility in Geneva now known as CERN which has built and operated many high energy accelerators for joint research by the world physics community including

India. We have close collaboration with this institution since 1990 and have contributed in kind to construct and participate in the most advanced system in the world.

Just a few years before Homi Bhabha died in an air crash, the future of accelerators in India was discussed. A decision was made to buy an advanced Van-de-Graff accelerator since it was commercially available and to build a cyclotron by ourselves in India. It was decided to put the cyclotron in Kolkata. After his death, close collaboration was established with the Berkeley Laboratories in the U.S. and the Department of Atomic Energy. It was decided to build a machine of 80 MeV similar to that in Berkeley with their help with their drawings. It was decided to locate the same in Kolkata next to the Saha Institute of Nuclear Physics so that the nuclear science initiated at the Saha Institute by Prof. Meghnad Saha will continue to flourish. The responsibility for this project was given to Dr. D.Y.Phadke of TIFR assisted by Shri C.Ambasankaran at Trombay. Emphasis was to develop the techniques and build indigenously all the components so that we get used to the technology for accelerators. This facility went into operation in 1976 and is now upgraded with a superconducting cyclotron which is in the final stages of construction.

Realizing the importance of growing this accelerator technology in the country it was decided to open up a new Centre for Advanced Technology in Indore whose main contribution would be in accelerators and lasers. By this time electron accelerators known as Synchrotrons could not only accelerate electrons to a very high energy but also store them and make them emit radiation which are the tools for research in atomic physics and condensed matter physics known as Synchrotron Radiation Source. The first of this at 400 million electron energy (INDUS I) was completed in 1999 and a one GeV machine known as INDUS II was completed in 2004. This Centre has expanded its activity considerably training manpower on these projects and is poised to take up more challenging tasks in the future. Sub Groups in this area vary from ingenious innovations in ion sources, generation of high power high frequency radiation, radio frequency cavities, superconducting cavities and high magnetic fields and high vacuum which are all major components of any accelerator. The hardware required for this are innovated in CAT, Indore with the support of industries. It also enabled the Centre to contribute to new facilities for other applications. This is a typical area in which technologies grow in the country, finds its applications in the country and thereby feeds the high technology required for other applications.

Application as a neutron source

A major problem identified in the beginning of the nuclear enterprise was the ability to make plutonium from uranium 238 which is a waste if we burn only one per cent of the uranium mined. The conversion of uranium 238 to plutonium 239 depends upon the availability of neutrons and the more intense the source the faster is the rate at which one can make plutonium. Similarly if we use thorium 232 it can make uranium 233 which is also easily fissionable. Considering the scarcity of natural uranium ore in the country, Homi Bhabha suggested that we quickly emphasise and turn to production of plutonium in Fast Breeders and Uranium 233 from thorium. The scientists who dealt with the accelerators have imagined a source of neutrons based on a high current proton accelerator of 5 milli amperes and 1 GeV of energy falling on innocuous lead target, could create neutrons of very large intensity which would then serve as a tool for converting uranium or thorium into plutonium and uranium 233. The technology of high energy accelerators was slow in developing and the technology for acceleration to 1 GeV energy was very involved. Basic research efforts in many countries and the large centres like the Fermi Laboratory and CERN have now brought about a transformation in the concepts. It now looks that a 1 GeV machine for the 5 milli ampere proton current is indeed feasible and the spallation reaction should provide a high neutron flux for this conversion process. A project of this nature has now been suggested in the Department of Atomic Energy known as ADS (Accelerator Driven Source) for quickly getting into thorium conversion. No doubt it is expensive, challenging in technology and needs a special organizational effort like the Manhattan Project to achieve success. The chief of CERN, Carlo Rubbiah has taken up this challenge for Europe and is working towards it. The Americans have built their first spallation neutron source at the Oakridge National Laboratory in order to carry out basic experiments towards production of plutonium. I am sure in course of time with innovations in technology and development of indigenous capability in superconducting magnets, cavities etc. India will be able to contribute and successfully build a neutron source which will augment our efforts to develop fast breeder reactors. Here is the case in which the scientific approach as well as the confidence on self-reliance is more important in decision making than quoting from literature. One of the most difficult areas which the Department of Atomic Energy has successfully overcome is this process of decision making based on intuition and self-reliance, e.g. when we started our reprocessing technology, it was shrouded in secrecy by the advanced nations. It was a very challenging decision for Homi Bhabha to try and develop this technology even at the risk of failure, it was Homi Sethna, a daring engineer who put through developing this technology successfully by 1965 and produced enough quantities of plutonium which could have made a nuclear weapon much before 1968. Now we have built three more of these reprocessing plants and perhaps the most advanced among the developing countries to have established competence in the reprocessing technology which makes this country a target by the weapon countries to cap its capability.

Lasers

In the sixties the idea of making a light source emit light in a unique direction with a definite phase relationship was invented which is now known as the laser. The process of light emission is so controlled that the emitted light takes a unique direction, has electric and magnetic fields overlapping and therefore, becomes a ray of light without any external focusing. Obviously the energy density also goes up because of this concentration in a unique direction. Once we understand this process, it has been possible to make several systems like a gas plasma or solid plasma in a crystal to emit a laser beam. Today we use it as a pointer in a lecture or a small crystal in our CD ROM to read the information stored in the disc. It is also useful in medical field like surgery or coagulation of micro arteries in the eye. This novel technology has wide applications; from bringing down a missile, concentrate energy on a small volume of gas to miniaturize a hydrogen bomb etc. The Department of Atomic Energy started off a laser division in BARC which has now expanded to a very large scale laboratory in CAT at Indore and has expertise in various fields of activity. It has helped the hospitals, the industry as well as basic research in many areas. The manpower generated were turned to the needs of a new technology is another benefit. This could not be done if the management was controlled by economic and financial considerations. The fact that the administration of the Department of Atomic Energy was controlled and managed by scientists themselves made it easier for this organization to grow in this area which could have been done by other organizations for there was no nuclear science involved in it.

Radiation Effects

There are other areas of activity which was initiated by Homi Bhabha in his wisdom as a mature scientist, encompassing the whole of Nature's Laws. Biology is an area in which one would have thought it is distant from nuclear science. However, from the very early years it was clear that nuclear radiation does interact with the biological system and causes chemical changes which have deleterious effect on the organic life. The reason for that is the high density of ionization which the radiation can produce and the effect of this ionization on the chemistry of biological system. After the discovery of the DNA it was obvious that the ionization induced by radiation can cause damage in the components of the DNA which will then control the genetic effects. Thus induction of mutation was demonstrated by radiation. This opens up the question of how much radiation the human system can tolerate without major defects being induced. At the same time the radiation could kill bacteria and thus delay in the rotting of food items like potatoes, onions, spices etc., Therefore in order to properly limit the activities, it was decided to start a group in Biology at BARC with the induction of Botanists, Zoologist, Physicists, Chemists and Bio Chemists including medical professionals. The starting point was of course those who were studying molecular biology and bio chemistry at the molecular level. Since this discipline was not taught in the university systems, much depended upon induction of the right scientists from other disciplines to work together in this area. Over the years, this group has been guided and looked after by Cell Biologists, Entomologists, Bio-chemists, Medical Experts, etc. that we have today an extremely active group who not only carry out basic research in the effect of radiation on biological system but also experiment on areas like mutation breeding, food preservation by radiation and radiation medicine. The new varieties of seeds produced in Trombay like groundnut, urad dal etc., are used by the farmers in a large scale. An irradiation facility for shelf life extension like onions and potatoes has been built at Krushak, near Nashik. Extensive data on the effect of background radiation from the Kerala beach sands on the human population and the occurrence of birth defects have been studied in great detail and has helped in putting a limit to the radiation doses which operators in reactors etc., are allowed.

ATOMIC ENERGY REGULATORY BOARD

As explained earlier, the nuclear reactor produces power by a chain reaction of neutrons inducing fission generating more neutrons which induces further fissions of nuclei etc. However, in order to produce a constant source of power, it is necessary to control the rate of increase of this chain reaction in such a way that the materials do not reach a melting temperature or become dangerously reactive to the environment. This is achieved by what are known as the control rods which are able to control the neutron density inside the reactor by absorbing the neutrons without causing fission. More than one control rod may be utilized depending upon the extent of the reactor and the extent of the variation of neutron density. With high precision engineering, it is now possible to control the motion of these rods inside the core and electronically monitor and give a feedback in order to attain a stable system. Due to commercialization of nuclear power stations, new methods have to be devised to assure that the safety systems are properly implemented and does not lead to repercussions on the public domain. Even though the scientists were able to safely conduct experiments, it was no longer the scientists who were operating the nuclear power stations. Internationally, thanks to the IAEA, the principle of safety even at the time of design and the methodology for approving the design was all worked out such that no untoward accident happens. Yes, there were accidents like the Windscale accident in England, the Three Mile Accident in the U.S. and the Chernobyl Accident in the USSR. These have reinforced the need for the international code of conduct in the reactor safety, the IAEA, doing an excellent job in this field, thanks to the cooperation of the member states.

Early in the history of Trombay, Mr. A. S. Rao, a physicist was designated to look after the health and safety aspects of use of radiation in Trombay. He built up a group of scientists and health physicists in particular who in turn formulated not only laboratory verification but also the methodology to implement the regulatory system in the facilities built at Trombay so that nobody gets radiation above the permitted level. The policing action was entrusted to this group. They no doubt increased in number but did an excellent job of formulating the methodology which could then be adopted in the new facilities that were built for making fuel as well as nuclear power stations. It soon became clear that this regulatory system should have a right to be independent for it has to warn the operators sufficiently in advance so that nothing untoward happens. A regulatory authority was, therefore, created in 1984 with the transfer of well trained scientists and engineers in radiation protection such that a regulatory body could function with an independent check on all activities of the DAE. The healthy growth of this organization in being able to achieve a success without leading to disputes and quarrels goes to the credit of those who took the policy decisions in this matter. The AERB today has its own offices, laboratories, research centres and deals with such matters with the International Atomic Energy Agency without being interfered by other organizations. Development of manpower for such an enterprise is very problematic. They must have the experience of dealing with radiation in their younger years so that they could get the right perception of how quickly and what actions they must take in order to avoid incidents. This training is best given in the existing laboratories of the DAE before they take up the regulatory functions. Thus manpower transfer is a major decision such that the right balance is maintained between law enforcement and the utilities. It is a matter of pride that in spite of the underdeveloped nature of the economy and the usual complaint that people from the developing countries are not used to the western standards, we have proved that we could manage a sensitive technological and novel enterprise by ourselves to international standards. Here again one learns from experience that these regulations have to be India specific because the manpower we use are educated in India and often have their priorities influenced by societal concerns.

ADMINISTRATION REFORMS

India was ruled by the officers of the Indian Civil Service. Many of the candidates who joined the Civil Service were educated in England and some of them were British Nationals opting to enjoy the benefits in the colony. It was not unusual to find Governors, Collectors, Magistrates and other high officials of British origin. The private companies like the East India Company employed Englishmen right from small managers and in the little army they had maintained. The general population in India, therefore, had accepted the superior English speaking officers as their Lords and had subjected themselves to obey and to carry out instructions to strengthen Victoria's rule over this poor country. The Revenue Department was very important for it extracted taxes from the poor farmers whether the crop was successful or not. The administration recruited the best talent available but subject to glorifying British jurisprudence, British Laws and discarding the age old system of Panchayat Raj developed in the country. The industry lagged behind. Raw materials for example cotton were exported to England to make yarn and clothes. Mr. Sathyamoorthy, a Congressman describes the Indian Society very appropriately as follows: He said "sitting in my room I notice that my dhoti comes from England. The sewing thread and needle come from Belgium, the rubber and pencil with which I write comes from Germany, the kerosene lamp I use is from Belgium, the books I read are printed in Oxford and Cambridge." This clearly shows that the whole Railway System which the British introduced was orchestrated for bringing in manufactured products from abroad for the use of the common man in India. Even building materials like cement, steel and architecture of Railway Stations, Palaces and roads, were copies of what was in England. Therefore, there was no doubt that the administrative system was so archaic and inimical to development. Science was in text books and education according to Macaulay was to produce white collared officials of the British Government. Homi Bhabha was trying to introduce science which is the basis for development of technology and that too in the frontier areas of nuclear science which was shrouded in secrecy because of its usefulness in producing the atom bomb. The job of creating healthy administrative system was therefore enormously difficult and he had to fight his way with the Central Government to achieve success.

Let me put down a few of these options. He first abolished Class IV employees sitting in stools outside the offices and carrying files from one table to the other. He abolished long notes on the files starting from the lowest and going from person to person before it reached the Secretary. The notes had to be precise, self contained, and should not be lengthy so that decisions could be taken faster. The scientific administration should be different because it was administering the scientists and growing scientists in particular. He abolished the system of depending on the DGS&D, for supplies, introduced his own system of purchase and stores where things could be done faster and encourage scientists to give up administrative control e.g. signing cheques, making their own pay bills as Gazetted Officers and looking at attendance registers of subordinates. At TIFR he no doubt brought in Mr. Allardice, one of the ICS officers as Deputy Director (Administration) who very faithfully followed instructions of Dr. Bhabha and moved the administration away from the normal methods. The working hours were precise starting early. The professionals enjoyed annual vacations of 70 days a year in order to relax like in University system. The Policy making body was named the common room a term from Cambridge. It consisted of senior scientific leaders who could discuss programmes, initiate new programmes, make invitation to scientist's visits, interview new candidates and even make budget and review programmes. The library was open 24 hours. The laboratories were also open 24 hours. Academic staff that preferred to stay in the hostel was given accommodation and creativity, mutual discussions, lectures, were frequent and productive. In fact the administration was unique that many wondered how exactly he gets away with breaking rules which was made by the Central Government.

With the expansion of the research programmes and the need for engineering and inter-disciplinary teams, he had to plan the Atomic Energy Establishment Trombay, very similar to the Manhattan Project. Engineering research was rather unknown in India and he had to start the practice of test beds, pilot plants and production units in order to build the infrastructure for scientific equipment, technical expertise, and commercial plants for making heavy water, uranium fuel, etc. Material science and metallurgy were given prominence because of the new materials one had to make like Zirconium and Uranium. The metallurgical processes were made to lead to commercial plants like the Nuclear Fuel Complex where time targeted component production was important for reactors.

The recruitment policy was based on interviews for periods as much as one hour so that one can judge the intrinsic ability of the person to think and innovate. The numbers required was large and was slowly expanded from 1955. Temporary buildings were constructed in the South Site of Trombay so that the laboratories could be active very soon. However, permanent buildings were designed and built in the North Site which combined architectural beauty with emphasis on function. Thus, the Modular Laboratories were designed to house all disciplines from metallurgy to biology so that the interactions amongst the scientists could be more productive. Four lecture halls in the Mod. Labs. were constantly used for discussions and seminars.

The AEET being a Government organization funded by the parliamentary grant had to obey the central government rules. He found it most irksome and deceptive and he introduced many reforms to tone up the administration. He chose the right officers from the IAS cadres to help him deal with other departments where necessary. Some of them were disappointed and complained about Homi Bhabha's intrusion into their work. But then it was all planned to make a change for the better. The assessment and promotion of scientific staff was completely revolutionized. In order to attract the best talent, the starting grade of scientists was made equal to that of IAS officers. A confidential reporting system was introduced which very clearly described the work of the candidate, the nature of assessment with more than one assessor so that a proper record is maintained of the growth of a person in his achievements. A periodic review of the confidential reports decided the time for consideration of a person for promotion irrespective of the seniority which usually in government is based on the date of joining. He introduced a fast track scale so that the candidates with outstanding work could move faster and take up leadership positions. At the promotion interviews, outside experts were invited to make the assessment so that no prejudices were tolerated. The system has worked indeed well and produced leaders who could manage the entire programme in spite of its very rapid expansion.

In the promotion of scientists and technical people February and August were considered the date from which they should be promoted based on interviews which were held just before or very soon after those dates. In the central government it is usually the date of joining or taking charge of the post on a particular date that was taken into account for promotion. This was abolished, for promotion did not mean changing the table or chair or moving to another office. It was in recognition on the work he has done in science and technology. There used to be many difficulties from the administrative norms for this but this was put down strongly. Even papers to the Appointments Committee of the Cabinet took effect from the Ist February or 1st August unlike in other Departments.

The Central Government's construction is usually done by the CPWD with all the rules and regulations for floor area, materials for construction etc., Due to the unique nature of nuclear laboratories in terms of air quality, safety etc. Homi Bhabha decided to create our own norms for civil constructions and established a Civil Engineering Group. The result of these efforts can be seen in the high quality of the construction work carried out both at Tata Institute of Fundamental Research and other institutions under the Department of Atomic Energy. No foreign consultants were needed for the radiological laboratories for the scientists themselves prescribed the norms, checked the designs and made sure that the laboratories were well constructed and maintained. Air conditioning was considered a necessity and not a luxury. The reactors are to be housed in specially contained structures with adequate shielding which are made of special materials. Even the canteens and kitchens were well planned such that utmost cleanliness is maintained. Even in the housing sector, special norms were adopted which were functional rather than floor space. Sufficient attention was given to general requirements, like schools, hospitals, playgrounds, roads, shopping etc. which make them attractive and functionally most economical. The colonies at Anushaktinagar and Kalpakkam are very typical of the new way of living. Over fifty years this has proved to be the most cosmopolitan and integrating effect of people coming from all parts of the country. The schools had produced outstanding students with adequate preparations for professional courses. A Homi Bhabha Institute has been started in order to encourage post graduate education in the laboratories of the DAE itself.

From early days, two scientific bodies, the Trombay Scientific Committee and the Trombay Council were formed in order to scientifically programme the role of the DAE as well as take decisions on a variety of subjects including administration. The Trombay Scientific Committee which is equivalent to a Lower House had all the Heads of Divisions represent such that all disciplines were available in the deliberations of this Committee. Policy making was initiated in this committee. Reviews of scientific and technological programmes were conducted by this committee such that inter-disciplinary coordination could be achieved. Members of this Committee had full freedom for travel, for interaction with other bodies and arranging scientific meetings and discussions. This brought in the importance of scientific reasoning in decision making rather than pure administrative control. The institutions which were started later followed the same norms for administrative functioning. They formed their own scientific committees which were primarily responsible for the scientific programme, evaluation, as well as modification when necessary. The responsibility for the planning process rested with these committees.

The Trombay Council consisted of very few major Directors. To start with there were five representing physics, electronics, instrumentation & safety, metallurgy, chemical engineering, reactor engineering, and biology. Directors of these groups were highly respected and they achieved eminence in their own scientific fields. They performed the advisory service to Homi Bhabha on many programmes, and eventually built up huge areas of eminence in their respective fields. To mention a few, Mr. A. S. Rao who headed the electronics built up the safety group at Trombay, expanded the electronics to the Electronics Corporation of India Limited, and even played a major part in formulating the Electronics Commission Report in 1968. Prof. Brahma Prakash specialized in nuclear fuels, starting from ore dressing to fabrication of components for the reactors. The Atomic Fuels Division in Trombay produced uranium fuel for CIRUS in 1959, expanded its activities in Nuclear Fuel Complex in Hyderabad, producing large quantities of zirconium, uranium oxide and fabricated power reactor fuels for the PHWR systems. In Biology starting with Molecular Biology, the studies concentrated on mutation breeding producing new varieties of seeds which revolutionized agriculture, especially groundnuts and rice. Food Irradiation as a technique for increasing the shelf life of the agricultural products like onions and potatoes has now become commercial.

In the engineering field, chemical engineering essentially dominated many activities starting with uranium extraction from Jadugoda ores, rare earths in Kerala, making of heavy water by very exotic processes, reprocessing the spent fuel to extract plutonium were all achieved on commercial scale. The reactor engineering division built many reactors starting with Apsara, CIRUS, Zerlina, Dhruva etc., The expertise developed by these groups was useful to indigenise the PHWR system which was borrowed from Canada to make commercial nuclear power plants of which two are 560 MWe each at Tarapur. One can therefore see that the Department of Atomic Energy had done several things at the same time from training of manpower to indulge on creative thinking, build commercial scale plants on our own with economic returns in mind and look to the future in making full use of the energy content in uranium and thorium. Such coordinated efforts have never happened in any other field in the country where our efforts had been to induct modern plants from abroad.

In the new area like atomic energy, foreign assistance and training was essential to nucleate a core group of scientists. This was achieved thanks to the policy on international cooperation which was launched with the atoms for peace policy of the United States. Homi Bhabha played a major part in formulating such international programmes which resulted in the setting up of the International Atomic Energy Agency in Vienna in 1958. The Agency as a body of the United Nations has taken up the challenge of propagating use of nuclear energy for peaceful purposes. The number of member countries has increased to 187, a few of them highly developed while a majority on the category of underdeveloped. India has always played a major role in helping the Agency to initiate programmes in the developing world. It has lent expertise to many countries and hosted a large number of scientists to work in India and acquire expertise in a large number of disciplines. Today India is recognized as a developed country in the nuclear field by the IAEA.

In dealing with international relations unfortunately India has had to keep in mind its own requirements as a free and independent nation and safeguard itself against proliferation of nuclear weapons in its neighbourhood. This obviously is inconsistent with the non-proliferation objectives of the five major nuclear powers which acquired the status by chance in history. In 1974, Smt. Indira Gandhi took the major decision to demonstrate to the world India's capability to make a nuclear device which can function as a nuclear weapon. It is interesting that in human civilization, ability to make deadly weapons and acquiring economic prosperity had gone side by side and had a decisive role in the power politics. In order to safeguard India's interest in the near and distant future it has been the policy of the national government not to give in under pressure our choice of becoming a nuclear weapon country. History will note that how in spite of Gandhiji's basic pitching for peace and non-violence, strength of character and ability to transform itself to the needs of the nation is preserved.

It is generally understood that investigations in science is "after truth" but scientists also realise that truth can be subjective for example a body on top of a table is at rest. However, if the table itself is moving as earth rotates the body is no longer at rest when observed from empty space. Similarly many laws in science are subject to certain conditions. It is in distinguishing between philosophical thought and practical demonstration that we come across many conflicts which generally is interpreted as untrue and therefore, science is not absolutely true. However, the scientific principles enunciated in the past whether right or wrong have had an influence in general in our way of life, our faiths and in practical applications to help in technology. The surest example is that of Charles Darwin who by observing nature in its manifest forms brought out the principle of evolution. It can be contradicted since nobody has been able to experiment and prove whether it is right or wrong. For example man is evolved from apes can be questioned but at the same time has some reason to believe so. It is only lately that after the discovery of the DNA and the gene that there is more rational demonstration of heredity, evolution and mutation. The greatest scientists of the last century Albert Einstein and Niels Bohr proposed changes in the very fundamental laws of the physical world. Einstein proposed relativity which is at that time unimaginable. Similarly Niels Bohr proposed the quantum theory which again contradicted known laws of physics at that time. And each did not trust the truth of the theory proposed by the other. However, what resulted from those theories is for all of us to see and it has influenced our understanding of nature's laws. It is therefore, important to realise that in doing science one is not merely interpreting, like in jurisprudence. There is an intuitive character in science which makes tremendous changes in the growth of science. In order to encourage more people to indulge in such a creative activity science administrators have to realise that science cannot be ordered but an environment has to be created such that such creative people could multiply and bring out new ideas which may look crazy at that time. We can quote examples from almost every discipline.

This realization of character of science is what prompted Homi Bhabha to make a science policy consistent with the needed progress of the country. He enunciated his experiences and the need for planning science in the developing countries in an outstanding lecture he presented to the international committee on science in January 1966. This was promptly published in the magazine "Science" soon after. It is therefore, relevant to ask the question how do we ensure that science is given its due place in a progressive society. The need varies from developing countries to developed countries and therefore, the science policy should be tailored to the national needs and not copied from somewhere.

In the last fifty years we have seen tremendous changes in the technologies which affect our way of life, e.g. the communication system, transport systems, the health care systems, agriculture, etc. have changed enormously with the introduction of new gadgets, devices and methodologies. To ignore and stick to ancient traditions is to acknowledge failure. This is where even the political system has to change coping with advances in technology. One example of this is the present emphasis on globalization; Globalisation of trade, industry and therefore, the way of life. This may look contradicting the principles of self-reliance which was propagated by Pt. Nehru and Homi Bhabha in the beginning of our independence. In order to adjust oneself, one has to have a deep understanding of the role of science in producing economically useful result for the progress of the nation. This also depends upon the economic level of the human activity in the country, the educational opportunities, the varied accomplishments of different sections of the society etc., It is, therefore, not correct to adapt free market economy as they call it as the criterion for progress. Let me give a few examples. The Railway system was introduced two centuries ago. The speed of the train was decided more by the effective motive power of the engine and the frictional losses on the rails. The French industry improved these to attain speeds of the order of 200 to 500 km/hour. However, using superconducting magnetic fields experiments were performed to elevate the whole train by magnetic levitation which cuts down the frictional laws and enables very high speeds for trains. It was experimentally demonstrated in short spans of a few kilometers. However, commercializing this has had problems. If the trains are made faster, by this magnetic levitation, the aircraft industry which serves the people will suffer. In fact, that industry almost saw to it that the levitated trains never become a reality. Similarly storing energy in a rotating disc in a centrifuge was modified to provide electric power to a car which would enable the automobile to travel 200 kilometers without any fuel. The centrifuges could then be charged again to high speed. This innovation avoids pollution, dependence on costly oil resources and would suit narrow roads and conditions in India. The establishment which invented this device went to the automobile industry to sell the idea. However, they were rebuked because the infrastructure for the internal combustion engine is so deep rooted that the industry did not want anything new to replace it. These are two examples of how technology can be decelerated by industrialists who are insensitive to the basic advantages of new science.

The solution to many of the vexing problems of our society like that of energy source can be solved by innovation. In nuclear energy, the amount of material required to produce a quantity of energy is million times smaller than that of fossil fuel. The resources on the planet, for example uranium, thorium and other heavy metals, are enough to sustain life on this planet for many centuries. However, the willingness to introduce in large measure nuclear reactors producing electricity is very much inhibited by international policies on non-proliferation. It is true that the same fissile material could be used to make a weapon; but is it not so with respect to dynamite and still we have prospered using dynamite both for peaceful purposes and for making weapons. International restraints cannot stop progress if a nation is determined to do so based on the economics and resources of that country.

Some ground rules

In administering science and in planning for progress it is necessary to build up the capability of scientists on par with international institutions. It is advantageous for the scientists to spend time in other advanced laboratories so that they imbibe the habit of research, find solutions and make it practical. One of the disadvantages in India is that 200 years of colonial rule has prevented growth of creative talent in our university system except for a few who could not be stopped like C. V. Raman. Homi Bhabha wanted to expand this horizon and make it possible for more people to become creative and all the science policies in administration therefore would have a need for assessment which is away from the bookish method. A creative scientist may not produce a quantum of work expected because his abilities are concentrated on inventing unknown phenomena for which there is no limit on time or rate of production. It requires, therefore, freedom for scientists to work if they are to establish and prosper creative talent. It is no wonder that well conducted groups have won Nobel Prizes like for example University of Cambridge while others have lagged behind. In the last fifty years, international schools and institutions have been created such that the best talent from anywhere in the world could join together in their efforts at scientific investigations and discoveries. In order to participate in them, the routine rules which govern civil service had to be amended drastically, e.g. an attendance register where the presence of a scientists has to be recorded had to be abolished so that the scientist is free to spend more or less time depending upon what areas he was working. Often likeminded scientists would like to work together in an area of research so that the interaction is strong and fruitful. That requires a rule by which absence on leave is encouraged, to the extent needed. The University system in the west has a sabbatical rule which enables scientists to join other groups and work for a year or more on problems of common interest and get a feedback into their own laboratory. Homi Bhabha saw this as an absolute need and encouraged scientists to avail of sabbatical leave, maybe once in five years for a year or more for such interaction. This is a departure from the normal rules of the civil service. In Trombay, extraordinary leave used to be granted for scientists and engineers to work in foreign laboratories for two years at a time so that they are exposed to newer techniques, more creative environment and ability to search for the unknown in an effective way. No doubt, this has paid dividends in the last fifty years. The more advanced laboratories now acknowledge that India has a pool of scientific talent which can compete on an equal footing with the rest of the world. It is not only in pure research but also in the application of new technology in industry as well as in other social requirements. The information technology is another example in which a variety of expertise from computing to accounting has enabled Indians to earn on an equal footing with the rest of the world; perhaps staying at home which is now called 'outsourcing' the work to Indians in India. The idea of extraordinary leave in a liberal manner is pioneered by TIFR and in other establishments of the Department of Atomic Energy.

SCIENCE ADMINISTRATION

Science as a part of national policy came into prominence after the industrial revolution and particularly after World War II. The advanced nations saw the benefit of science in creating technology which resulted in increasing the industrial production and thus the economy of a nation. It also improved the basic requirements like in agriculture and health including forecasting of the future. Administering such a complicated subject was, therefore, a new phenomenon in governance. The political system was slow in acquiring the required expertise to administer and grow science in a country. We have, for example, an approach in the socialist countries like the Soviet Union but entirely different approach in the western democracies. It was more difficult under the Indian conditions mainly because growing of science in the past two centuries was not considered a requirement by the colonial power. After independence Pandit Jawaharlal Nehru had the responsibility to grow indigenous science to catch up with the advances made in the west. During the first three decades it meant growing new institutions encouraging science in the universities and organizing a scientific career as a part of the general service in the country. Due to the lack of infrastructure which itself is very ill-defined., the approaches made by the central government varied from discipline to discipline often copying the British traditions, sometimes copying the academic traditions in the universities in the west and the need for services like the department of meteorology, earth sciences etc.,

In the field of atomic energy, Homi Bhabha took the leadership and took the initiative of building up the various components for a structure which will take this country faster in this area. Most of the decisions came out of his perceptions and vision. However, he also made it a practice to consult his colleagues and make them participate in the planning process. Thus there was great emphasis on the basic science side starting with the TIFR and expanding areas of its activities from cosmology to molecular biology. He often recruited talented scientists from abroad in order to lay the foundations and grow groups around them. Many of them succeeded in building up an indigenous capability. However, there were also scientists who returned to the west finding it harder to do basic research in this country. The usual complaint was one of lack of infrastructure. They forgot the fact that the building up the infrastructure is part of education and research and unless that was emphasised in the academic community, you cannot expect industries to provide these infrastructure e.g., Homi Bhabha set up fairly large machine shop in TIFR. Once taking Mr. J.R.D. Tata around, I remember his remark "why you have built such a big machine shop for doing basic research. It seems to be even bigger than that of Air India". Homi Bhabha replied "to serve with the Air India aircraft, you simply have to have the equipment imported and replace them as they get worn out, but here in this workshop, we make instruments that will go down two hundred feet under water or fly in a balloon in the upper atmosphere in addition to all kinds of instrumentation for nuclear research". This was a departure from what was obtained in the university system where the physics department perhaps never had the machine shop and the students did not get the experience of building equipment except for glass blowing and some equipment out of glass. Even that was because glass blowing was required to make laboratory chemistry work possible.

Talking of infrastructure, in the last 5 decades the expenditure on the infrastructure in the Department of Atomic Energy would probably equal to that in equipment and facilities for research. From the training of tradesmen to machinists and electronic technicians people will have to be trained on the job. This often required redundancy and recruitment of the best candidates for their intellectual capability rather than previous experience. The lesson we learnt was that provided one is sure of intellectual capability, the best way to train on a particular area is to give him the facilities and make him do for himself in spite of failures. Vikram Sarabhai used to say on new projects that we must experiment even at the risk of failure. This is against the principles of administration in the government. From civil engineering to material science and high quality electronics, the manpower trained and generated was enormous and became the backbone for the successful programme of indigenization of nuclear technology.

Basic Science

In the university system, the performance of basic science was judged by the number of papers published in journals. The scope of these papers was often limited by the equipment the scientists had or was able to lay hands on. In the Department of Atomic Energy the basic scientist started innovating experimental equipment and techniques so that they could compete with the rest of the world in those specific areas. Two examples are the emulsion techniques used for studying the cosmic rays and the balloon flights developed in TIFR for detecting the cosmic rays in the upper atmosphere and relay it to the ground. In nuclear science from detectors to analytical instruments, instrumentation was developed indigenously. To encourage this kind of creativity the evaluation system has to be different from that of pure academic institutions. That was established in the DAE family. Frequent promotions and appreciation of good work done in the interval of five years kept the scientists on their toes with a pride that their work is being watched and the remuneration will follow according to their performance. In this process, very high standards of monitoring and evaluation were maintained with the result there was no single case of appeal to a court of law by any scientist in the last fifty years.

In basic science, facilities to earn an extra degree like Ph. D. degree are essential to stimulate creativity. This was achieved by the university system recognizing the centres in DAE for candidates to be presented for Ph. D. degree. Now of course, the DAE itself has a deemed university status in the Homi Bhabha Nuclear Institute which covers entire field of science and engineering.

If science is international the scientists themselves must be given opportunities to work in international centres and gain the spirit of creativity comparable to that of those institutions. This was encouraged to a large extent by cooperative research programmes and deputing our scientists to the foreign centres where research is on, on frontiers of science. This has been developed to such an extent that today, most of the large efforts in the frontiers of science like big accelerators take on Indian participants to work on the construction and use of such facilities. This is required in order to allow growth of the centres to take on giant science projects like for example, the accelerators being built in VECC in Kolkata, and Raja Ramanna Centre for Advanced Technology, Indore. These two institutions collaborate very effectively with the CERN and large laboratories in U.S.

Is it feasible to maintain the scientific temper and the scientific acumen throughout the career of a scientist? Very often, a good scientist is also a good teacher and he enjoys teaching so that the excitement of his research he could share with the younger generation. Thus, it is meaningful to combine scientific research in the big centres in DAE collaborating with the teaching institutions like the universities, a separate collaborative project is the DAE-Inter University Consortium, operating from Indore but having young students using the facilities in Trombay and Raja Ramanna Centre for Advanced Technology, VECC, etc., After certain period of research, scientists also require a prestige and a position in policy making bodies so that they could share their experience and give guidance to new generation. Unfortunately in this country due to the traditional separation of careers, this interaction is very weak. One hardly finds scientists taking up professorial chairs or vice versa. In the engineering field, this is even worse. Practical engineers from projects do not find academic teaching even in IITs to their liking. And herein lies the difficulty of transferring technology from the research laboratory to the industrial sector. Partly the industrialists think that it is easier to import technology from foreign countries rather than innovate it within the country. This is the sad part of our industrial development.

In the engineering fields the attempts to scale up the pilot plants to industrial scale operations have been the most difficult and complicated affair in the management, e.g. specifying a pressure vessel on paper is quite different from fabricating a pressure vessel, testing and installing it in an industrial plant. The reprocessing plants for example are typically a chemical engineering effort, but involve several kilometers of stainless steel tubes conveying the solutions from one process to the other. Making all the welds leak proof, subjecting it to remote operation, monitoring their performance, involve not only mechanical engineering and chemical engineering but also detectors and control systems of a very advanced nature. This experience could be gained only at sites and by our own efforts. This is the reason why many plants have taken longer time to commission and operate efficiently. The administration of such venture is again very unique which requires careful encouragement to the staff and appreciation of their talent. Here again, the usual government rules should not apply for promotions and decision on wages commensurate with their experience. It is only in the Department of Atomic Energy that technicians could eventually draw the same salaries of the Joint Secretaries in case they made outstanding contributions.

In the field of engineering, it is not desirable that the teacher is directly inducted after his graduation with a degree. This field optimally combines practical experience, the innovative spirit and the ability to convey technical information and offer solutions to new problems. Even at the very highest levels like in the IITs we seem to think that the professors should have Ph. D. degree from abroad and teaching experience. That by itself does not encourage creativity and when new fields of engineering activities develop for example computer engineering, we hardly find sufficiently experienced people for these jobs. That is why the Indian I.T. industry is more oriented to software rather than hardware. We practically do not manufacture any of the hardware components for computers and are dependent squarely on imports. Take the aircraft industry. Since we do not have an emphasis on indigenous manufacturing in the last fifty years no competitive aircraft industry has taken roots in this country. All the students who took to aeronautic engineering are dismayed and often result in taking up jobs which require only mechanical engineering.

An outcome of the revolution in technology is the need for careful planning and spending of resources from the government which is often the responsibility of the planning commission. Usually the tendency to appoint a committee of experts presided over by a bureaucrat who makes a recommendation on the basis of their knowledge, like for example sharing of river water. Because these new ideas have not originated from working level, these reports go through a metamorphosis which ultimately resorts to unfulfilled results. Even in education, we have had expert committees in the last five decades. These reports are very good on paper because they are mostly borrowed from ideas from abroad, but we have never been able to make a quantum jump in making it succeed in this country. A typical example of course is constituting the Knowledge Commission whose report makes suggestions from primary education to high technology areas. To implement any of these recommendations, different ministries have to be involved and this results in improper coordination. I remember a committee on Ganges constituted by Prime Minister Rajiv Gandhi and the discussions of this Committee have always been in trying to solve the disputes between the Chief Secretaries of the States through which the Ganges flows rather than making concrete accomplishments on ensuring the purity of the Ganges water.

As the total expenditure of the central govt. increases and the promise of raising it further, it becomes necessary that the governance of science and technology in the country gets a new look. In this effort some of the lessons learnt in the Department of Atomic Energy could be most useful. Homi Bhabha often quoted that the success of a new project depends on whether you have the right man in the top with a vision to see the project through and not advertise and look for a man who would be interested in that job. He often quoted the objectives of the various institutes in Germany where the pride of place is given to the founder and after all in science it is the vision of a few individuals that finally produce the right results and infrastructure.

CONCLUSION

As a scientist, I wish to end this monograph after recording my thoughts after crystal gazing. It is very difficult to convince others what science can deliver and in what time. Discoveries happen by accident, but the rate of discoveries has enormously increased because of the large number of scientists researching on each topic now compared to a hundred years ago. Therefore, one should expect new breakthroughs. There are two kinds of breakthroughs. One which explains a new law of Nature with experimental verification which might or might not prove to be important in the near future. For example the field of particle physics. But there are other discoveries which are oriented to make technology adaptable to a variety of applications. To give an example is the field of electronics. As mentioned earlier a hundred years ago we had vacuum tubes, radios, radars and TV to some extent. But then the ability to put satellites into orbits, development of semi conductor technology to produce microwaves more efficiently, the technique of signal processing which enabled weak signals to be detected, and the micro-chips changed the scene. A digital technique to convert analog signals into sharp pulses in a digitized form and the ability to transfer from digital information to analog information have all enabled us to use these novel techniques in communications. It has reduced the time gap for communication and made it inexpensive. If you look at the history of physics, you do not find these discoveries were tailored to make such results but the discoveries enabled such applications to be meaningful. The entertainment electronics at home consumes very little power and is very sophisticated with high resolution colour pictures making a vast difference in the last fifty years. Carl Sagan in one of his articles compares the astrologers of ancient civilization to the modern scientists. He says that the modern scientists do almost the same thing as the astrologers who were very often wrong in their predictions and used lame excuses to explain away their wrong predictions. But the prediction of the modern scientists is based on experimental facts, statistical analysis with even a quantitative probability approach so that it becomes more dependable. Take for example the prediction of the climate change. Nobody believes that it is an astrological prediction. But the data which the scientists have collected and interpreted clearly indicates that it is likely to happen and we already see this happening even this year. Therefore Carl Sagan summarizes by saying science helps to advance civilization and it is better to rely on scientific predictions rather than dogmas.

In the case of nuclear science as was explained in the beginning, we are not at the end of the road. We can see in nature copious energy is produced in the sun and stars by a process we call fusion. Homi Bhabha predicted some fifty years ago in his Presidential Address that scientists will eventually discover methods by which controlled fusion can be established on this planet, and when that happens the raw materials would be the heavy hydrogen in the sea water and there should be no dearth for that. You may ask the question what has happened to his prediction. Even in 1952 Edward Teller and others in US demonstrated how they can produce energy from a can of liquid heavy water. Explosive power of 12 megaton of TNT was achieved in the Mike thermonuclear explosion. Is it not a large amount of power coming from the fusion of deuterium. However, the methodology used to burn this heavy hydrogen in the heavy water was to use a fission bomb which produces high temperature, extremely large amount of gamma rays and x-rays and some clever scientific principles in order to compress and heat the heavy water. Can it be done without using a fission bomb which requires plutonium or Uranium-235? This question has been under investigation for a long time. It is still on. For finding an answer one has to do large scale experiments for example at Livermore National Laboratory they are building a national ignition facility which uses 192 lasers with the beams coming in all directions on to a small pellet containing the deuterium and tritium gas to compress it and make it explode. It does happen. By repetitively doing this one should be able to get a constant source of energy. This national ignition facility is being duplicated in slightly different ways in England at the Rutherford Appleton Laboratories. France and Japan are also engaged in similar experiments. The crucial question in this is “Do you require the laser beam to evaporate electrons from the surface of the tiny pellet and cause a compressive shockwave to trigger the fusion reaction? Can it be done by other means? High power lasers were discovered a few years ago. But now using the electrons from the accelerator you can produce x-ray beams of much higher intensity which are more energetic and therefore, cause electron evaporation and shockwave much more easily. For this purpose one must work on building x-ray free electron lasers which is a subject of current activity in many advanced laboratories. Perhaps, Germany will have such of a facility in the near future. It is difficult for a scientist to predict that he can produce fusion by this method in a short time. But then we have seen how advanced technology has helped to make the so called impossible things happen in our own life time.

The classical understanding of nuclear physics was based on electrical attraction and repulsion between the nucleus and the incoming particle. If both are positive then the incoming particle is repelled like shooting a proton on to a nucleus embedded in a solid material. This repulsion is described in terms of a potential well and one can calculate the energy needed to overcome this repulsion to make the reaction possible. That is what is done by accelerating particles in high energy accelerators and then hitting the nucleus which then shares the incoming energy among the particles inside leading to fissions. Will anything else influence this repulsion? Now people have come out with the idea that the configuration of the electrons of the solid material could indeed influence this potential barrier and make the incoming particle get through this barrier and cause fusion. This is now known as LENR (Low Energy Nuclear Reaction) which was originally called the cold fusion when it was discovered in 1989. A lot of experiments are being done through out the globe in this area at present, the production of tritium, a radioactive element and other isotopes of nuclei have been identified as a result of this process. The beauty of this method is that it does not require external energy. Even if it does so, it requires very little. When we understand deeply the mechanism for this process, one may think of configurations in which these reactions could be seen in plenty and thereby see energy being produced by this process. This is yet another area of crystal gazing.

We still do not understand whether you can influence the half life of radioisotopes except by transforming the nucleus by absorbing a neutron into another element which is more stable. This requires a large amount of neutrons. If they could be produced at economic cost, then this method can solve the problem of burning the radioactive wastes from nuclear power stations efficiently. That leads us to the question of what is the cheapest method of producing neutrons. During the war time, scientists at Los Alamos suggested that the nuclear explosion produces tremendous amount of neutrons and if they could be utilized then we could produce large amount of plutonium. They even went to the extent of suggesting that one should drill a whole in the Arctic Ice – may be 100 meters deep explode a nuclear device surrounded by uranium or thorium and when this produces large quantities of plutonium or U-233, then it could be pumped out and processed. It is a far fetched idea no doubt. But this can be done on the surface of the moon since there is no population. The human race could use the surface of the moon as a factory to produce energy source like plutonium. In fact many suggestions have been made to do manufacturing on the surface of the moon since the gravitational force is smaller and the air pressure does not exist. One could now see how lateral thinking in science can lead to quantum jumps in the methods useful to the human civilization. Reaching the moon and coming back safely has been demonstrated.

It is in biology that you see innumerable variations of this lateral thinking. After all Charles Darwin was triggered from the complex species that have evolved over a period of millions of years on this planet. This evolution is now being speeded up by artificial means which is known as mutation breeding. Some of the solutions to our food problem could indeed come from such lateral thinking and new experimentations e.g. one need not despair non availability of petroleum on this earth if we can have very inexpensive biological material like crop residues to be turned to ethanol. Many new factories which can produce large quantity of ethanol for transportation purposes are being set up in the advanced countries.

It is interesting to stimulate young minds into thinking of science by giving some simple examples. You can see the fire fly producing the white light without it becoming hot. How does it do it? That will immediately tell the child that light is not always connected with temperature. It is only because we started off with burning carbon to produce light for our purposes or the incandescent bulbs to produce light. By a simple chemical reaction, the fire fly produces white light which is enough for its purpose and not for lighting a city. Collapse of small bubbles also produces light. This is known as sono luminescence. Light emitting diodes will soon replace other gadgets which produce light but inefficient. The chlorophyll was evolved by nature to convert carbon dioxide and water vapour in the atmosphere to a hydro carbon with the help of sun's rays. Perhaps the best use of solar energy so far demonstrated is by Nature which uses the chlorophyll. A similar molecule could as well increase the capability to convert solar energy and what this molecule should be can be subjected to scientific investigations. Very often we hear that there is so much of excess of energy from the Sun that it is meaningless to go for nuclear power. It is true provided we have efficient system to convert solar energy into a form like electricity to which we are getting used to. The suggestion is that we should put satellites with large solar panels which will absorb sunlight and produce electricity efficiently and transmit it to the earth so that we can draw upon that source. Just like we use satellite for communication it might become possible one day.

I am giving these examples to reinforce my objective viz. that it is only through science that you can develop technology for human welfare and it is only through that we can sustain the present rate of growth and the needs of human civilization. There is always a danger of complete annihilations by a hydrogen bomb, but that of course depends upon the wisdom of the people. It is, therefore, necessary that people in general are exposed to scientific curiosity and a process of decision making developed which should be based on rational thinking in a scientific way. This is what Nehru called ‘inculcating scientific temper among Indians’.

REMINESCENCES

One of the spin-offs of indulging in pure scientific research is the ability that one develops to communicate and precisely transfer information to an audience or others who should know about it. The glory of teachers and professors in the academic field enhances if they are able to convey information in precise and deeply motivating manner to the students. Great scientists like C. V. Raman could explain very intricate scientific facts in simple language to an audience. This is habit forming which is guided by frequent lectures, seminars and briefings which a scientist makes in his career. Many scientists agree that their ability to give good lectures and impressive talks grows with experience and with advance planning and the need to convince the public especially the bureaucrats they are dealing with. I am particularly referring to my experiences in the Trombay Establishment over several decades. In the beginning I used to be amazed at the clarity of thought and statements by Homi Bhabha and Dr. Ramanna in their lectures, talks to foreign dignitaries and summaries in special meetings. Many times I was introduced to look after dignitaries to the atomic energy establishments which always start with a briefing with a model of the Trombay site in an auditorium. Depending upon the visitor whether they are scientists, politician or an administrator the emphasis on various aspects had to be tailored to suit the visitor. Sometimes analogies have to be invented to make the visitor understand what one is talking about. Take for example, the uranium atom automatically releases energy and decays to another atom. This process has a half life of million years. Naturally the question can be asked why does one atom decay now and another under the same environment decides to decay million years later. It is a hard question to answer but it definitely leads to the fact that all the particles that constitute the nucleus are continuously interacting like molecules in a gas which hits the wall for the container continuously. It so happens that sometimes this random motion can concentrate energy' in one part which can then secede and come out of the nucleus. This is called radioactivity. It is best demonstrated by blowing a soap bubble and observing very keenly how the distortions of the soap bubbles can result in the breaking into two. When this is explained to a lay man he understands radioactivity better than merely saying that nature willed it so. In a similar manner, one can explain many aspects of practical applications of nuclear energy and the technology underlying nuclear power, nuclear weapon and the varied applications. It is, therefore, important for any organization to develop people who can do this effectively and they become automatically team leaders with clear concepts of what is important and what is not. This is yet another difference between routine bureaucracy and science administration.

It will be useful to recall some of the occasions in which I have had personal experience in dealing with people in high places like foreign scientists, high administrators, Governors, Presidents, Prime Ministers etc., To recall an incident of 1957, thirty of us were assigned to Chalk River in Canada to undergo training with their reactor NRX. The Canadians agreed to take in such large numbers at one time and that too from India. Pt. Jawaharlal Nehru visited Ottawa in October 1957. The High Commissioner invited us to go to Ottawa and meet the Prime Minister. The Office of the High Commissioner was only a big house and the thirty of us sat on the ground with Prime Minister Nehru sitting on a chair at the centre. He addressed us for half an hour emphasizing and reminding us that we are there not only to gain knowledge to operate the reactor but to serve as leaders later when we return to India. This talk from Panditji really dealt with his dream of building up India's capability and the way he conveyed this to us enthused us to be with the Department of Atomic Energy and contribute to its success. I am not surprised that at the end of one's career after fifty years, one is able to say that a large percentage of this thirty people remained with the Department of Atomic Energy and handled very senior positions in various capacities.

Panditji was accessible to Homi Bhabha and whenever he got an opportunity, he visited Bombay and the Trombay establishment. He never hesitated to inaugurate new facilities or play hospitality on international conferences. He visited Jaipur where an international conference on cosmic rays was organized by Homi Bhabha. He spent three hours talking to the visiting foreign scientists and having tea with them. This enabled him to assess how much India has progressed and how the others look upon India as a possible academic resource in the future. Homi Bhabha requested Panditji to host Prof. Niels Bohr, the father of atomic physics and a Nobel Laureate from Denmark, when he came to this conference. Panditji readily accepted and invited him to stay at his residence. This is the extent to which Panditji could be influenced by Homi Bhabha. Every senior scientist, Chairmen of the Atomic Energy

Commission etc., who visited Trombay had always had a short visit to the Prime Minister. This tradition has continued. It is well known that Pandit Nehru never missed to address the Indian Science Congress held every January excepting for one or two. That was an occasion when he opened his heart and requested scientists to help him for the development of the country. I remember once in Delhi he criticized the working of the Planning Commission which he said he himself created but today he was ashamed that the same office routine of brown papers going from the bottom to the top continued in the Planning Commission.

Mrs. Indira Gandhi during her regime followed the same method in treating scientists whether it was Vikram Sarabhai, Satish Dhawan, MGK Menon, Homi Sethna or Raja Ramanna. They were consultants and their advice carried weight in her decisions. She did not sign the file if the decision was important unless she personally talked to the scientists concerned. I remember one conversation in Trombay between Ramanna and Mrs. Gandhi when she was visiting Trombay on October 8, 1984. The discussion was about buying Russian Reactors. Dr. Ramanna argued that we should not accept certain conditions like dealing with the irradiated fuel for its life time. We also discussed the economics of importing such nuclear power stations vis-à-vis spending more money on the energy projects in rupees in India. After listening to us she remarked "why is it that my ambassadors when they come to see me always described how wonderful their host countries are and why we should take that country's help." She remarked that it seems to have become the habit of the ambassadors. India Today of April 21, 2008 carries the following remarks of Indira Gandhi: "A nation's strength ultimately consists in what it can do on its own, and not in what it can borrow from others." How many politicians care for such remarks today?

There are several occasions in which scientific management cannot agree with rules of civil service which are generally coined for routine administration. One example is the applicability of reservations which are necessitated by political pressure. Mr. V.P. Singh was strongly in favour of the Mandal Commission Report and wanted that the Government should implement those recommendations in all appointments. However, in the Department of Atomic Energy, we had special exemptions from applying reservations to scientific posts, the selection to the training school wherein highly qualified graduates are selected after a difficult interview. We select only 200 after interviewing some 2000. During that period the administration put up a file to me saying that we have got to change the rules and give a percentage of reservation according to the Mandal Commission Report. When it came to me I held it up. But the IAS administrators were insistent that this is a Government order and cannot be broken. I took the file personally to Mr. V. P. Singh, who was then the Prime Minister explained to him the reason why we have to insist on quality because we were dealing with reactors and which involves safety problems of special kind. Even the records of operational procedures had to be maintained in English language so that there is no misinterpretation. After my briefing, the Prime Minister agreed that the DAE could continue to be exempt to apply this reservation for its scientific staff. This clearly shows that the appeal to rational thinking will be cared for in spite of political necessities.

Not all Prime Ministers had the same feelings for science programmes, scientific institutions and scientific management. The CSIR had undertaken a special project in a backward area known as Karim Nagar. Unfortunately it was an utter failure and it was in Narasimha Rao's constituency. This had coloured his feeling for science and even though he respected the continuity of growing science under the Congress regime, his heart was not in it. The Saha Institute of Nuclear Physics at that time wanted to celebrate the centenary of Meghnad Saha who was the founder, a very accomplished scientist of India and even helped the Congress party by being a Member of the National Planning even before independence under Pt. Nehru. Shri Narasimha Rao asked me whether he should attend this inaugural function. I explained the importance of not only his attending the celebrations but he will also do something to commemorate the centenary. Unfortunately however, he deputed Mr. K. R. Narayanan who was then the Vice President of India to the inaugural function. Of course, Mr. K. R. Narayanan himself was very close to science, having been the Minister for Science and Technology. But the fact remains that for Mr. Rao this was not a priority item.

Of all the Prime Ministers, Rajiv Gandhi was a Prime Minister who was always willing to listen to the technical discussions with scientists explaining new areas of research and ever ready to undertake special visits to laboratories. It was most gratifying to be able to get appointments with him at short notice if the matter is urgent. I remember once I was asked to brief him on the Chernobyl Accident which had occurred in April 1986. When I asked for an appointment he was already planning to visit Bombay for the centenary of the Congress party. I suggested that I travel with them and he could spare a few minutes. He readily agreed and he spared half an hour during the flight for me to explain the circumstances in which the Chernobyl accident took place and its implications. When new areas of research like High Temperature Superconductivity, the Supercollider Accelerator for elementary particle research and the Cold Fusion were current, he was ready to listen and make special allocations in order to speed up research in these areas. He was ever keen to listen to our preparedness in the defence area especially with missiles and nuclear weapons.

We have all the semblance of supporting research areas by Parliament especially the by establishing Parliamentary Advisory Committees. The Prime Minister always chaired this Committee on Science and Technology and it was interesting to watch what the questions were and how the Prime Minister handled it even though the Secretaries and the Scientists were available on hand for any elucidation. Sometimes some trivial subjects used to be discussed. I remember one case in which one of the members of parliament said that "look the Department of Atomic Energy does not buy books in Hindi to the percentage as required". The Department had to answer by saying that there are not enough Hindi books on science subjects and therefore, the usual criteria should not apply. I remember Rajiv Gandhi cutting short the discussion by saying "Do you want us to teach engineering in Gurumukhi?" That ended the discussion.

APPENDIX A

MILESTONES OF THE DEPARTMENT OF ATOMIC ENERGY

1. 29 July 1949: Rare Minerals Survey Unit brought under Atomic Energy Commission and named as 'Raw Materials Division' (RMD), with Headquarters at New Delhi. In 1958, this unit becomes Atomic Minerals Division (AMD), and later in 1974, shifts to Hyderabad. It is renamed as Atomic Minerals Directorate for Exploration and Research (AMD) on July 29, 1998.

2. 18 August 1950 : Indian Rare Earths Limited (IRE), owned by the Government of India and Government of Travancore-Cochin is set up for recovering minerals, processing of rare earth compounds and Thorium-Uranium concentrates. In 1963, IRE becomes a full-fledged government undertaking under DAE.

3. 24 December 1952: Rare Earths Plant of IRE at Alwaye, Kerala is dedicated to the nation by Pandit Jawaharlal Nehru.

4. 03 August 1954 : Department of Atomic Energy is created.

5. 04 August 1956: The first research reactor in Asia attains criticality at Trombay, Mumbai.

6. 30 January 1957: Atomic Energy Establishment, Trombay (AEET) is inaugurated by Pandit Jawaharlal Nehru. The reactor is named APSARA.

7. 19 August 1957: AEET Training School starts functioning.

8. 30 January 1959: Uranium Metal Plant at Trombay produces Uranium.

9. 19 February 1960: First lot of 10 fuel elements for CIRUS reactor is fabricated at Trombay.

10. 10 July 1960: CIRUS – the 40 MWt research reactor attains criticality.

11. 14 January 1961: Research Reactor ZERLINA attains criticality.

12. 22 January 1965 : Plutonium Plant is inaugurated by Prime Minister Lal Bahadur Shastri, at Trombay.

13. 22 January 1966 : H.J.Bhabha dies in air crash

14. 22 January 1967 : AEET is named as Bhabha Atomic Research Centre (BARC)

15. 11 April 1967 : Electronics Corporation of India Limited (ECIL) is set up at Hyderabad for producing electronics systems, instruments and components.

16. 01 June 1967 : Power Projects Engineering Division (PPED), Mumbai is formed.

17. 04 October 1967: Uranium Corporation of India Limited (UCIL) is established with headquarters at Jaduguda.

18. May 1968 : Uranium Mill at Jaduguda, with a capacity of 1000 TPD, commences commercial production of Magnesium diuranate (yellow cake). Jaduguda Mine Shaft is commissioned in November 1968.

19. 31 December 1968: Nuclear Fuel Complex is set up at Hyderabad, Andhra Pradesh.

20. 12 March 1969: Reactor Research Centre (RRC) starts at Kalpakkam, Tamil Nadu. The Centre is fully established in 1971. It is named as Indira Gandhi Centre for Atomic Research (IGCAR) on December 18, 1985 by Prime Minister Rajiv Gandhi.

21. 01 May 1969: Heavy Water Projects is constituted at Mumbai. This later becomes Heavy Water Board.

22. 02 October 1969: Tarapur Atomic Power Station starts commercial operation. Prime Minister Smt. Indira Gandhi dedicates it to the Nation.

23. 06 September 1970: Uranium-233 is separated from irradiated thorium.

24. 03 February 1972: DAE Safety Review Committee is formed.

25. 18 May 1972: Research Reactor PURNIMA-I ATTAINS CRITICALITY.

26. 30 November 1972: Unit-1 of Rajasthan Atomic Power Station at Rawatbhatta near Kota, Rajasthan, begins commercial operation. Unit II goes commercial on November 1, 1980.

27. 18 May 1974: Peaceful Underground Nuclear Experiment is conducted at Pokhran, Rajasthan.

28. 16 June 1977: Variable Energy Cyclotron becomes operational at Kolkata.

29. 18 November 1977: Plutonium-Uranium Mixed Oxide (MoX) fuel is fabricated at Trombay.

30. 19 November 1982: Power Reactor Fuel Reprocessing Plant at Tarapur is commissioned.

31. 15 November 1983: Atomic Energy Regulatory Board (AERB) in Mumbai is constituted.

32. 1984: Sandstone-type uranium deposit at Domiasiat, Meghalaya is identified.

33. 27 January 1984: Madras Atomic Power Station-Unit I at Kalpakkam starts commercial operation. Unit II goes commercial on March 21, 1986.

34. 19 February 1984 : Centre for Advanced Technology (CAT) at Indore (Madhya Pradesh) is inaugurated by the President of India

35. 03 March 1984: Plutonium-Uranium mixed Carbide Fuel for Fast Breeder Test Reactor (FBTR) is fabricated at Trombay.

36. 10 May 1984: Research Reactor PURNIMA-ii, A Uranium-233 fuelled homogeneous reactor, attains criticality.

37. 05 March 1985: Waste Immobilisation Plant (WIP) at Tarapur is commissioned.

38. 08 August 1985: Research Reactor DHRUVA (100 MWt) attains criticality.

39. 18 October 1985: FBTR at IGCAR attains criticality.

40. October 1986: Bhatin Mine is commissioned by UCIL and the ore is transported to Jaduguda Mill for processing.

41. 17 September 1987: Nuclear Power Corporation of India Limited (NPCIL) is formed by converting the erstwhile Nuclear Power Board.

42. 30 December 1988: 12 MV Pelletron Accelerator is inaugurated in Mumbai.

43. 1989: Board of Radiation and Isotope Technology (BRIT) is constituted.

44. 12 March 1989: Narora Atomic Power Station Unit I attains criticality. Its Unit II attains criticality on October 24, 1991.

45. 09 November 1990: Research Reactor PURNIMA-III, a Uranium-233 fuelled reactor, attains criticality.

46. 03 September 1992: Kakrapar Atomic Power Station, Unit I attains criticality. Its Unit II attains criticality on January 08, 1995.

47. 1995: Research Irradiator Gamma Chamber 5000 is launched by BRIT.

48. 1996: 30 KWt Kamini Reactor attains criticality. The reactor is taken to full power in September 1997.

49. 31 March 1997: Rajasthan Atomic Power Station Unit-1 is re-commissioned.

50. December 1997: Jaduguda Mill is expanded to treat 2090 tonnes ore per day.

51. 11 & 13 May 1998: Five underground nuclear tests are conducted at Pokhran Range, Rajasthan.

52. 27 May 1998: Rajasthan Atomic Power Station Unit-2 is re-commissioned after enmasse replacement of coolant channels.

53. 10 August 1998: Ammonium diuranate (ADU) production commences at Rare Earths Division of IRE at Alwaye, Kerala.

54. 22 April 1999: 450 MeV Synchrotron Radiation Source, Indus-1 achieves electron beam current of 113-milli-ampere superceding the design value of 100 milli-amperes.

55. July 1999: Solid Storage and Surveillance Facility (S3F) is commenced at Tarapur.

56. 24 September 1999: Unit-2 of Kaiga Atomic Power attains criticality. It is synchronized to the grid on December 02, 1999.

57. 24 December 1999: Unit 3 of Rajasthan Atomic Power Station attains criticality. It is synchronized to the grid on March 10, 2000, and becomes commercial on June 2, 2000.

58. 21 April 2000: Folded Tandem Ion Accelerator (FOTIA) at Trombay delivers first beam on target.

59. 26 September 2000: Unit-1 of Kaiga Atomic Power Station attains criticality. It synchronises to the grid on October 12, 2000.

60. 03 November 2000: Unit-4 of Rajasthan Atomic Power Station attains criticality. The unit becomes commercial on December 23, 2000.

61. 2001 : FBTR fuel reaches burn up of 1,00,000 MWd/T

62. 18 March 2001: Units 3 & 4 of Rajasthan Atomic Power Stations dedicated to the nation by Shri Atal Bihari Vajpayee, the Prime Minister of India.

63. 12 February 2002: India signs the contract with the Russian Federation for the Nuclear Power Station at Kudankulam, Tamil Nadu.

64. 31 October 2002: Waste Immobilisation Plant and Uranium-Thorium Separation Plant and the Radiation Processing Plant Krushak at Lasalgaon, District Nashik, Maharashtra are dedicated to the Nation.

65. November 2002: UCIL's Turamdih Mine is inaugurated.

66. 2003: The demo facility Load Mini Cell (LMC) for reprocessing of FBTR carbide fuel on lab. Scale, is commissioned at IGCAR.

67. 06 March 2005: India's first 540 MWe Nuclear Power Reactor Tarapur Unit 4 attains criticality.

APPENDIX B

Significance of the milestones

Perhaps India was the first country in Asia to have processed nuclear fuel uranium from its own source and done the fabrication of fuel, the first step for any country to have an indigenous nuclear programme.

In 1955 at the First Geneva Conference, the United States brought out various versions of research reactors using enriched uranium, known as Swimming Pool reactors. The U.K. which already had enriched uranium fabricated fuel elements with an alloy of uranium and aluminum. Thanks to Homi Bhabha's friendship with Sir John Cockroft, they agreed to spare the fuel elements for the Swimming Pool Reactor, if India chose to build for itself. Homi Bhabha assembled a team of physicists and engineers consisting of Mr. A.S.Rao, Dr. R.Ramanna and N.B. Prasad to design the Swimming Pool Reactor and build it for ourselves simultaneously with that of the U.K. This reactor went critical on 4^{th} August 1956 becoming the first research reactor in Asia outside the Soviet Union. It is a moment of great joy, for India could then get into a programme on use of this reactor for research and development of technology in nuclear engineering, for example producing isotopes and processing them for a variety of uses. In January 1957, the Atomic Energy Establishment Trombay was inaugurated by Pt. Jawaharlal Nehru. Looking at the bluish glow of water in the swimming pool from the reactor, Prof. K.S.Krishnan, a Member of the Atomic Energy Commission and a distinguished physicist suggested the name "APSARA". It was immediately accepted by Panditji and he named this reactor 'APSARA".

It was obvious at that time that a variety of scientific research could be started at Trombay involving physics, chemistry, engineering and biology. To grow the manpower fast enough, it became necessary to recruit appropriate graduates from the university system and induct them into the multi-disciplinary area of nuclear research. Homi Bhabha thought that inducting something like 200 trainees into the training school every year would allow rapid growth of manpower tuned to our needs. He also predicted that out of this, at least a few would become outstanding leaders and would lead the future programme in India successfully. After 50 years, we can now confidently say that the training school was the most unique experiment by which appropriate scientists could be trained for the programme. Dr. Ramanna, the Head of the Physics Group at that time took the trouble in organizing the training school in terms of the syllabus, choosing of lecturers and evaluating the performance of the trainees. Because of the strict selection principles by a personal interview, there were hardly any failures at the end of the year. They were all directly inducted as scientists in the appropriate grade in TIFR, AEET and in other organizations under the Department of Atomic Energy. This training school is similar to the military schools, establishing a tradition.

After the Geneva conference in 1955, Canada offered to build a research reactor in India, based on their experience of the reactor NRX. This used heavy water as moderator, uranium metal as fuel and would function upto 40 MW with light water coolant and produce neutron flux in the range of 10^{13} neutrons per sq. centimeter which was considered a decent flux for isotope production, basic research and for engineering test loops. It also became clear that training operators and participating in the construction of reactor would enhance the technical capability of Indian engineers to design and build power stations using natural uranium and heavy water as moderator. This was the period in which the computers were not available and many theoretical predictions in the behaviour of the reactor had to be experimented with. For this purpose a zero energy reactor {critical facility} was necessary and the reactor ZERLINA was built in the course of two years and went into operation in 1961. The name stands for Zero Energy Reactor for Lattice Investigations of Nuclear Assemblies. After conducting several experiments it was shut down

This was a period in which the demand for electronic instruments to monitor radiation, to build electronic control units and large scale production of survey meters in order to survey the country for radioactivity were all needed, These instruments were not commercially available. So Homi Bhabha decided that to supplement and assure a constant source of instruments, it was necessary to have a large base in electronics and instrumentation and make it available to other users. It was strange that a fundamental research centre like TIFR organized a production unit for electronics equipment under Mr. A.S.Rao in the early fifties. This was later transferred to the South Site, Trombay. The scientist in charge for that unit was Mr. Vadali Rama Rao who was the most important person because he supplied all the equipment needed and the scientists were generally obliged to him for this help. Later on in 1967, this unit was expanded into Electronics Corporation of India Limited and relocated at Hyderabad. The instrumentation work in the country got a great support, thanks to this venture. ECIL made TV sets in the seventies and was in great demand. The circuits were designed and built at Hyderabad. Mr. A.S.Rao who became the Managing Director of this Corporation is well known for his proficiency in electronics and instrumentation. He was one of the pillars of the Department of Atomic Energy. Later he piloted a committee called Electronics Committee which planned for the expansion of electronics in the country and resulted in the formation of the Department of Electronics in New Delhi.

Chemical Engineering was indeed very important. From treating the monazite sands to make nuclear fuel and fabricating it into fuel elements was an immediate need. This was achieved in Trombay on a small scale in a pilot plant and allowed research and development leading to larger commercial unit. Dr. Brahm Prakash an able metallurgist took up the development and fabrication of fuel elements, separation of zirconium from rare earth sands making zirconium metal, alloying them and making them into good quality tubes for the power programme. These were done first in what was then called the Atomic Fuels Division in Trombay and later expanded to the Nuclear Fuel Complex, Hyderabad. Dr. Brahm Prakash was ably supported in this venture by well known metallurgists like N.K. Rao, H.C.Katiyar, C.V. Sundaram and K.Balaramamoorthy among others. At no time in the history of atomic energy have we felt lack of ability in metallurgy thanks to the leadership of Dr. Brahm Prakash. In 1972, he moved to the Department of Space as Director of the Vikram Sarabhai Space Centre in Trivandrum and contributed significantly to the rocket programme which ultimately resulted in the missile programme.

The Chemical Engineering Group was looked after by a very energetic engineer Mr. Homi N.Sethna who initially looked after plants in Kerala and moved to Bombay when the rare earth plant was built in Trombay. The separation of plutonium from the irradiated fuel in the CIRUS reactor required a chemical separation plant which was entirely different from that of any commercial operations in chemical engineering. First of all, the irradiated uranium fuel is radioactive, contained a toxic element like plutonium and therefore all chemical processes and physical processes had to be done remotely. The solvent extraction process was a chemical technique for separating plutonium from the other elements. A plant of this type was approved in 1958 without any project report for one was not sure of the details at that time. . But here again Homi Bhabha wanted to establish India's capability to acquire plutonium, a strategic material on its own. By 1964, project Pheonix was completed in Trombay and was inaugurated by Prime Minister Lal Bahadur Shastri. The irradiated fuels from CIRUS reactor were charged into this facility and plutonium was extracted. That was a significant milestone in the history of the Department of Atomic Energy. There is no doubt that the quantity of plutonium – roughly 5 Kgs. – needed for making a bomb was indeed available before 1968 and if India had chosen, it could have detonated a device by that time. In fact Homi Bhabha declared in 1965 that we could do this in 18 months' time. Mr N. Srinivasan worked with Mr Sethna and became an expert in Reprocessing technology

Simultaneously uranium was discovered in Jaduguda in Bihar and it was decided to exploit that mine for the extraction of uranium. Mining operations followed by processing of ores and extracting uranium was started in Jaduguda and provided yellow cake for the power programme since 1968. They supplied the Nuclear Fuel Complex at Hyderabad for further processing of this uranium to uranium dioxide and fabricating the fuel elements for the PHWR type of reactors.

Equally important component for the power programme was heavy water. It can be separated from the ordinary water by several methods. One was through electrolysis. Others were based on exchange processes involving hydrogen sulphide H2S and another involving ammonia. Projects for separating the heavy hydrogen from ammonia were built in conjunction with the fertilizer plants at Baroda and Tuticorin which produced ammonia in large quantities. They started successfully operating in Baroda, Tuticorin and later at Thal. Research work was also started at Kota based on H2S process. This was rather an independent process and took some time to mature and produce satisfactory operation. This was expanded and a new plant at Manuguru in Andhra Pradesh with a larger capacity was commissioned. By now, the DAE has built up a surplus stock of heavy water which is now traded with other countries like Korea. Heavy water is a proscribed material under the safeguards for non-NPT countries. India has the capability to build any number of new heavy water plants and produce heavy water at an economic price.

The use of the research reactor CIRUS was intense both in basic research and production of isotopes and then to process them for use in hospitals and for other industrial uses. The Isotope Division under Dr V. K. Iya a pioneer in isotope chemistry expanded his activities by building facilities with remote operating capabilities in-house. Later on it graduated to a Board of Research in Isotope Technology (BRIT) which not only makes isotopes for other uses but also for uses like the irradiators for food preservation, treatment of sludge ,and Cobalt-60 irradiators for cancer therapy. This again is a long story of how indigenous capability was built up from the scratch.

The power programme started off as an independent administrative unit in 1967 naming it as the Power Projects Engineering Division (PPED). DAE was already collaborating with the General Electric of the United States and ordered two boiling light water reactors which are now known as the Tarapur Atomic Power Station (TAPS) of 200 MWe each. This was of course a turn-key project but wherever possible, Indian manufacturers were involved. The erection of the equipment was mostly supervised by the Indian engineers. TAPS started commercial operation in October 1969; it was inaugurated and dedicated to the nation by Mrs. Indira Gandhi. Since then the power programme has expanded first with an agreement with Canada to build 200 MWe Pressurized Heavy Water Reactors (PHWR) in Kota which was started in 1965 along with their own first reactor at Douglas Point. Many engineers from PPED were deputed to Canada who not only gained experience but also helped in supervising the construction of the Canadian power stations.

At Trombay, thorium utilization was an important subject. Thorium oxide blankets were made and irradiated in the CIRUS reactor and after a few years was chemically processed to extract U-233. The first samples of U-233 were produced in 1970. By that time several kilograms of plutonium had been separated. When Trombay decided to enter into the Fast Reactor field , cooperation was established with the most advanced country in fast reactors viz. France, Homi Bhabha had signed an agreements with France to build a 40 MW Fast Breeder Test Reactor (FBTR) and the location was selected at Kalpakkam in Tamil Nadu. It was realized that simultaneously there has to be research and development on a large scale to be able to manufacture materials for the Fast Breeder Reactors as well as the general engineering support. The Kalpakkam Centre started work in 1971 and the Fast Breeder Test Reactor was completed in 1984. It was renamed as the Indira Gandhi Centre for Atomic Research by Prime Minister Rajiv Gandhi in December 1985. Today it has graduated to design and build a 500 MWe Prototype Fast Breeder Reactor (PFBR). It has also established reprocessing plants to extract Uranium-233 on a larger scale and to reprocess the exotic fast reactor fuel, plutonium-uranium carbide.

An experimental fast reactor was built in Trombay called PURNIMA, a plutonium reactor for neutronic investigations of multiplying assemblies. This was a very useful gadget and when designing this, various new concepts were incorporated for example the core is held in position by an electro magnet and any safety signal will allow the core to be dropped and thus reach sub criticality. Of course this was in addition to control rods. The design of this reactor, a small core of about twenty centimeters in diameter and 22 kg of plutonium in the form of oxide canned in stainless steel tubes was designed in such a way that one could carry out experiments leading towards a pulsed fast reactor in which there will be reactivity changes by a movable reflector. The same core was used with U-233 when it became available and helped to design an entirely U-233 based reactor KAMINI which went into operation in Kalpakkam. This is a unique reactor of this kind in the world entirely based on U-233 and housed inside a hot cell laboratory. This was meant to be used as radiograph facility for examining irradiated fuel of FBTR.

In the evolution of the fast reactor fuel, it was decided that Trombay will make Plutonium-Uranium mixed Carbide fuel for FBTR as the help from France was terminated in 1974. This decision and the subsequent accomplishments over the years were highly appreciated by the Fast Reactor community in other parts of the world. The FBTR fuel has now seen irradiation of 100,000 MWd/T which is a unique achievement.

Among other achievements mentioned in the milestones are the PNE conducted at Pokhran in 1974 and the improved variety of nuclear weapons in 1998. In the second series of explosions, an H-Bomb was also tested which enables the country to launch on a nuclear weapons programme.

Meanwhile the Nuclear Power Corporation of India Limited became a large commercial enterprise in 1987 and they built and operated many power reactors now contributing 3000 MW of electricity to the national grid. The reactors built by the NPCIL use entirely indigenous resources, designed and built to very high safety standards which are overseen by the Atomic Energy Regulatory Board (AERB). Their safety records are extremely good. They also designed and developed 560 MWe PHWR reactors. Construction was started in the 1990s and now two of these 560 MWe reactors are functioning in Tarapur as Tarapur 3 & 4. Further developments to upgrade this to 800 or 1000 MWe are also in progress.

The power programme does not shun international collaboration. While India does not wish to build on its own, Light Water Power Reactors since it uses enriched uranium, it has collaborated and are building two 1000 MWe reactors at Kudankulam the first of which should go into operation at the end of this year.

Historically, Dr. Vikram Sarabhai who was Chairman between 1966 and 1971 wanted to have our own enrichment plants so that we could easily adapt the currently used technique of LWR for nuclear power. An effort was started in the early seventies at Trombay to make the centrifuge which could produce low grade enriched uranium for light water reactors. The pilot plant for this was tested in Trombay but a commercial plant using several thousands of centrifuges were set up at Ratnahallli in Mysore and is operating well. India still believes that it cannot afford to waste uranium by going through the process of enrichment and using them in light water reactors. In this process, one can only burn 1% of uranium without reprocessing and in the case of heavy water pressurized reactors by successive reprocessing one can go much higher. Secondly the plutonium that comes out of reprocessed PHWR fuel is necessary for building fast breeder reactors. This process of going from natural uranium to use of thorium in the FBTR is known as closing the fuel cycle. It is significant that India has all the capabilities and special systems which will enable us to achieve this entirely by ourselves in the future.

APPENDIX C

TREATY ON THE NON-PROLIFERATION OF NUCLEAR WEAPONS

The States concluding this Treaty, hereinafter referred to as the “Parties to the Treaty”,

Considering the devastation that would be visited upon all mankind by a nuclear war and the consequent need to make every effort to avert the danger of such a war and to take measures to safeguard the security of peoples,

Believing that the proliferation of nuclear weapons would seriously enhance the danger of nuclear war, In conformity with resolutions of the United Nations General Assembly calling for the conclusion of an agreement on the prevention of wider dissemination of nuclear weapons,

Undertaking to co-operate in facilitating the application of International Atomic Energy Agency safeguards on peaceful nuclear activities, Expressing their support for research, development and other efforts to further the application, within the framework of the International Atomic Energy Agency safeguards system, of the principle of safeguarding effectively the flow of source and special fissionable materials by use of instruments and other techniques at certain strategic points,

Affirming the principle that the benefits of peaceful applications of nuclear technology, including any technological by-products which may be derived by nuclear-weapon States from the development of nuclear explosive devices, should be available for peaceful purposes to all Parties to the Treaty, whether nuclear-weapon or non-nuclear-weapon States, Convinced that, in furtherance of this principle, all Parties to the Treaty are entitled to participate in the fullest possible exchange of scientific information for, and to contribute alone or in co-operation with other States to, the further development of the applications of atomic energy for peaceful purposes,

Declaring their intention to achieve at the earliest possible date the cessation of the nuclear arms race and to undertake effective measures in the direction of nuclear disarmament,

Urging the co-operation of all States in the attainment of this objective,

Recalling the determination expressed by the Parties to the 1963 Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water in its Preamble to seek to achieve the discontinuance of all test explosions of nuclear weapons for all time and to continue negotiations to this end,

Desiring to further the easing of international tension and the strengthening of trust between States in order to facilitate the cessation of the manufacture of nuclear weapons, the liquidation of all their existing stockpiles, and the elimination from national arsenals of nuclear weapons and the means of their delivery pursuant to a Treaty on general and complete disarmament under strict and effective international control,

Recalling that, in accordance with the Charter of the United Nations, States must refrain in their international relations from the threat or use of force against the territorial integrity or political independence of any State, or in any other manner inconsistent with the Purposes of the United Nations, and that the establishment and maintenance of international peace and security are to be promoted with the least diversion for armaments of the world's human and economic resources,

Have agreed as follows:

ARTICLE I

Each nuclear-weapon State Party to the Treaty undertakes not to transfer to any recipient whatsoever nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices directly, or indirectly; and not in any way to assist, encourage, or induce any non-nuclear-weapon State to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices, or control over such weapons or explosive devices.

ARTICLE II

Each non-nuclear-weapon State Party to the Treaty undertakes not to receive the transfer from any transferor whatsoever of nuclear weapons or other nuclear explosive devices or of control over such weapons or explosive devices directly, or indirectly; not to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices; and not to seek or receive any assistance in the manufacture of nuclear weapons or other nuclear explosive devices.

ARTICLE III

1. Each Non-nuclear-weapon State Party to the Treaty undertakes to accept safeguards, as set forth in an agreement to be negotiated and concluded with the International Atomic Energy Agency in accordance with the Statute of the International Atomic Energy Agency and the Agency's safeguards system, for the exclusive purpose of verification of the fulfillment of its obligations assumed under this Treaty with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices. Procedures for the safeguards required by this Article shall be followed with respect to source or special fissionable material whether it is being produced, processed or used in any principal nuclear facility or is outside any such facility. The safeguards required by this Article shall be applied on all source or special fissionable material in all peaceful nuclear activities within the territory of such State, under its jurisdiction, or carried out under its control anywhere.
2. Each State Party to the Treaty undertakes not to provide: *(a)* source or special fissionable material, or *(b)* equipment or material especially designed or prepared for the processing, use or production of special fissionable material, to any non-nuclear-weapon State for peaceful purposes, unless the source or special fissionable material shall be subject to the safeguards required by this Article.
3. The safeguards required by this Article shall be implemented in a manner designed to comply with Article IV of this Treaty, and to avoid hampering the economic or technological development of the Parties or international co-operation in the field of peaceful nuclear activities, including the international exchange of nuclear material and equipment for the processing, use or production of nuclear material for peaceful purposes in accordance with the provisions of this Article and the principle of safeguarding set forth in the Preamble of the Treaty.
4. Non-nuclear-weapon States Party to the Treaty shall conclude agreements with the International Atomic Energy Agency to meet the requirements of this Article either individually or together with other States in accordance with the Statute of the International Atomic Energy Agency. Negotiation of such agreements shall commence within 180 days from the original entry into force of this Treaty. For States depositing their instruments of ratification or accession after the 180-day period, negotiation of such agreements shall commence not later than the date of such deposit. Such agreements shall enter into force not later than eighteen months after the date of initiation of negotiations.

ARTICLE IV

1. Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination and in conformity with Articles I and II of this Treaty.

2. All the Parties to the Treaty undertake to facilitate, and have the right to participate in. the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy. Parties to the Treaty in a position to do so shall also cooperate in contributing alone or together with other States or international organizations to the further development of the applications of nuclear energy for peaceful purposes, especially in the territories of non-nuclear-weapon States Party to the Treaty, with due consideration for the needs of the developing areas of the world.

ARTICLE V

Each Party to the Treaty undertakes to take appropriate measures to ensure that, in accordance with this Treaty, under appropriate international observation and through appropriate international procedures, potential benefits from any peaceful applications of nuclear explosions will be made available to non-nuclear-weapon States Party to the Treaty on a non-discriminatory basis and that the charge to such Parties for the explosive devices used will be as low as possible and exclude any charge for research and development. Non-nuclear weapon States Party to the Treaty shall be able to obtain such benefits, pursuant to a special international agreement or agreements, through an appropriate international body with adequate representation of non-nuclear-weapon States. Negotiations on this subject shall commence as soon as possible after the Treaty enters into force. Non-nuclear-weapon States Party to the Treaty so desiring may also obtain such benefits pursuant to bilateral agreements.

ARTICLE VI

Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control.

ARTICLE VII

Nothing in this Treaty affects the right of any group of States to conclude regional treaties in order to assure the total absence of nuclear weapons in their respective territories.

ARTICLE VIII

1. Any Party to the Treaty may propose amendments to this Treaty. The text of any proposed amendment shall be submitted to the Depositary Governments which shall circulate it to all Parties to the Treaty. Thereupon, if requested to do so by one-third or more of the Parties to the Treaty, the Depositary Governments shall convene a conference, to which they shall invite all the Parties to the Treaty, to consider such an amendment.

2. Any amendment to this Treaty must be approved by a majority of the votes of all the Parties to the Treaty, including the votes of all nuclear-weapon States Party to the Treaty and all other Parties which, on the date the amendment is circulated, are members of the Board of Governors of the International Atomic Energy Agency. The amendment shall enter into force for each Party that deposits its instrument of ratification of the amendment upon the deposit of such instruments of ratification by a majority of all the Parties, including the instruments of ratification of all nuclear-weapon States Party to the Treaty and all other Parties which, on the date the amendment is circulated, are members of the Board of Governors of the International Atomic Energy Agency. Thereafter, it shall enter into force for any other Party upon the deposit of its instrument of ratification of the amendment.

3. Five years after the entry into force of this Treaty, a conference of Parties to the Treaty shall be held in Geneva, Switzerland, in order to review the operation of this Treaty with a view to assuring that the purposes of the Preamble and the provisions of the Treaty are being realised. At intervals of five years thereafter, a majority of the Parties to the Treaty may

obtain, by submitting a proposal to this effect to the Depositary Governments, the convening of further conferences with the same objective of reviewing the operation of the Treaty.

ARTICLE IX

1. This Treaty shall be open to all States for signature. Any State which does not sign the Treaty before its entry into force in accordance with paragraph 3 of this Article may accede to it at any time.

2. This Treaty shall be subject to ratification by signatory States. Instruments of ratification and instruments of accession shall be deposited with the Governments of the United Kingdom of Great Britain and Northern Ireland, the Union of Soviet Socialist Republics and the United States of America, which are hereby designated the Depositary Governments.

3. This Treaty shall enter into force after its ratification by the States, the Governments of which are designated Depositaries of the Treaty, and forty other States signatory to this Treaty and the deposit of their instruments of ratification. For the purposes of this Treaty, a nuclear weapon State is one which has manufactured and exploded a nuclear weapon or other nuclear explosive device prior to 1 January, 1967.

4. For States whose instruments of ratification or accession are deposited subsequent to the entry into force of this Treaty, it shall enter into force on the date of the deposit of their instruments of ratification or accession.

5. The Depositary Governments shall promptly inform all signatory and acceding States of the date of each signature, the date of deposit of each instrument of ratification or of accession, the date of the entry into force of this Treaty, and the date of receipt of any requests for convening a conference or other notices.

6. This Treaty shall be registered by the Depositary Governments pursuant to Article 102 of the Charter of the United Nations.

ARTICLE X

1. Each Party shall in exercising its national sovereignty have the right to withdraw from the Treaty if it decides that extraordinary events, related to the subject matter of this Treaty, have jeopardized the supreme interests of its country. It shall give notice of such withdrawal to all other Parties to the Treaty and to the United Nations Security Council three months in advance. Such notice shall include a statement of the extraordinary events it regards as having jeopardized its supreme interests.

2. Twenty-five years after the entry into force of the Treaty, a conference shall be convened to decide whether the Treaty shall continue in force indefinitely, or shall be extended for an additional fixed period or periods. This decision shall be taken by a majority of the Parties to the Treaty.

ARTICLE XI

This Treaty, the English, Russian, French, Spanish and Chinese texts of which are equally authentic, shall be deposited in the archives of the Depositary Governments. Duly certified copies of this Treaty shall be transmitted by the Depositary Governments to the Governments of the signatory and acceding States.

IN WITNESS WHEREOF the undersigned, duly authorised, have signed this Treaty.

DONE in triplicate, at the cities of London, Moscow and Washington, the first day of July, one thousand nine hundred and sixty-eight.

APPENDIX D

Writings of Dr. P. K. Iyengar on the Indo-US nuclear deal

(1) Letter to Prime Minister
(23 February 2006)

(2) Deal will destroy nuclear research
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(3) Indo-US 'Unclear' Deal
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(4) India won't accept US nuclear policing
(Asian Age, 9 August 2006)

(5) First Appeal to Parliamentarians
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(6) Controversy over the nuclear deal
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(7) 123 Agreement a gilded cage
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(8) Nuclear power & the nuclear deal
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(9) Weighty reasons not to accept 123
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23 February 2006

Shri Manmohan Singh
Honourable Prime Minister of India.

Dear Mr. Prime Minister,

I seek your kind indulgence for taking some of your valuable time to present, as elder scientist of this country, a few considerations that you might find useful while giving final shape to the Indo U.S Nuclear Agreement.

At the outset, I would like to compliment and congratulate you for adopting an out-of-the box, and statesman-like approach while responding to the American offer, that could conceivably put an honourable end to the "outcaste" status, unjustly imposed on this country by the big powers, when we sought to pursue an independent nuclear policy in the best interests of this Nation.

In this context, a brief recall of the historical perspective would be useful. The first step down the nuclear road was taken by Homi Bhabha as far back as 1944, when the world was not even aware of nuclear energy. Working closely with Nehru, himself a visionary, Bhabha, in the years following Independence, outlined a clear and systematic strategy for sustaining nuclear power generation by steadily moving forward from our limited reserves of uranium to our vast reserves of thorium, via the intermediary stage of plutonium, produced in our first-generation reactors.

The visionaries that they were, Nehru and Bhabha went even further, using the nuclear programme as a vehicle for propelling this country into high-class science and advanced technology, covering many aspects that ranged from particle physics and innumerable applications of atomic energy for peaceful purposes, to space science and technology. As a scientist who received his education in the West, Bhabha understood the importance of cooperation and did not hesitate to enter into bilateral agreements with other countries, if it benefited the country. Such was his eminence that he, more than anyone one else, was asked to chair the historic, First Geneva Conference on the Peaceful Uses of Atomic Energy. That is the great tradition on which our nuclear programme has evolved.

The design and development of nuclear weapons came into the picture only later, when security considerations made that imperative. In the years that followed, many export restrictions were put in place by the Western countries but in spite of it, our scientists and engineers, thousands of them, acquitted themselves most creditably against great odds. As an example, we might mention that the FBTR in Kalpakkam [which has been working since 1985] is the only reactor in the world using an advanced carbide fuel, made using our own plutonium. Similarly, Kalpakkam also boasts of the only reactor in the world fuelled entirely by uranium 233, produced from our own thorium. The technology for the PFBR now under construction has also been developed entirely in India. It is also pertinent to mention in this context, that very recently, BARC scientists have come out with a conceptual design for a thorium breeder reactor, using a plutonium-thorium feed. Thus, while negotiating the details of the proposed Agreement, perhaps, the following considerations could be kept in mind:

1. In the development of the breeder cycle, much R & D would be required. The construction of our first fast power reactor has just commenced, and the mastery and management of the fuel cycle – the most crucial element of a long-term power reactor programme – should not be allowed to be hampered by considerations of safeguards. This is an area where we **simply** will not get any help from the international community and in any case, most countries do not possess vast reserves of thorium as we do. Thus, unlike us, thorium utilization may not be of any interest to them.

2. It is perfectly reasonable to put all the new reactors we get from abroad under safeguards. These would be merely power generation units and not vehicles of R & D. The main thrust of our R & D would thus in no way be handicapped.

3. It might also be prudent to emulate what Homi Bhabha often did namely, enter into **bilateral** rather than omnibus multilateral agreements. Thus, one might seriously consider the revolutionary step of placing these new reactors under special **bilateral** safeguards rather than routine international safeguards.

4. In amplification of point 3 above, two clarifying remarks need to be made. Firstly, the IAEA type safeguards with additional protocol, though applied to all, were, historically devised mainly as a means of preventing so-called "irresponsible" and potentially "rogue" States from acquiring nuclear weapons. Secondly, where matters of great importance are concerned, responsible countries have dealt with each other bilaterally rather than under international umbrella safeguards. When America and USSR/Russia could negotiate on a bilateral basis regarding the reduction of nuclear weapons, it stands to reason that America and India (which is now hailed universally as not only a great democracy but also as a very responsible one and a significant power in its own right), could conceivably enter into a **bilateral** agreement that is to the satisfaction of all.

5. Considering the high regard you personally command in international circles, and the very responsible manner in which our scientists have conducted themselves, both in terms of high transparency of our power reactor and space programmes and in the strict avoidance of either clandestine or proliferation activities, we venture to hope that America could be persuaded to give us the respect and dignity that is our due.

If India's progress could drive the President of America so far as to launch an Advanced Competitiveness Initiative [ACI], (as he declared in his recent State of the Union address), then that says something.

We are confident that under your stewardship, you would, quietly but most emphatically and with dignity, ensure that the morale of our scientific community, the integrity of our R & D programme, and the heritage bequeathed to us by Nehru and Bhabha would be fully protected.

Finally, I trust that the points that I have made, which are born out of our long and direct association with the early days of the Nehru-Bhabha era, would provide you with additional perspective, besides that which those currently in service might have already furnished.

Thanking you for sparing some time for this, and with regards,

Yours sincerely,

P. K. Iyengar

India-US deal will destroy nuclear research

P.K. Iyengar and M. Gupta

(Asian Age, 15 April 2006)

The initial impression of the July 18 Joint Statement as an outline of the nuclear deal Prime Minister Manmohan Singh signed with President George W. Bush was that it may herald a new chapter in India-US scientific cooperation. But the PM's suo moto statement in Parliament of March 7, 2006 and the recent release of the "Separation Plan," disabused the scientific community of any such hope.

Particularly surprising was the Indian government agreeing to put research facilities like the Tata Institute of Fundamental Research (TIFR); Variable Energy Cyclotron Centre (VECC), Saha Institute of Nuclear Physics (SINP), Institute for Plasma Research, Institute of Mathematical Sciences, Institute of Physics, Tata Memorial Centre, Board of Radiation and Isotope Technology, and Harish Chandra Research Institute, which are legitimately safeguards-irrelevant, under International Atomic Energy Agency (IAEA) safeguards. This is especially disturbing since the Prime Minister owned up to the fact that India had surrendered the right to decide for itself which facilities will come under IAEA safeguards.

Moreover, since the Manmohan Singh government has virtually accepted a non-nuclear weapons state status for the country in the Non-Proliferation Treaty regime, negotiating India-specific safeguards and Additional Protocol with the IAEA, will be worrisome. It is well known that the Additional Protocol has evolved in recent years specifically to deal with "rogue states" attempting to acquire sensitive technology clandestinely.
The problem has clearly arisen due to artificially imposed requirements of categorising the various components of the Department of Atomic Energy into "civil" or "military." Thus the Bhabha Atomic Research Centre and the Indira Gandhi Centre for Atomic Research have been rendered strictly "military" to avoid attracting safeguards, when more than 90 per cent of the work carried out in these institutions is "civilian."

It is well known that safeguard inspections by IAEA when applied to non-nuclear states, are extremely intrusive, immensely disruptive, and are often conducted in an atmosphere vitiated by suspicion. Without any substantiated assurances to the contrary, there is little reason to assume that such will not be the case for India. That the "judicious" use of suspicion may serve to irreversibly tilt the balance is best illustrated by the Iranian affair where the right of an NPT signatory to develop technology (in this case, the centrifuge to enrich uranium), is subject to advance approval from the IAEA. The resulting inspection regime, if applied to fundamental research facilities in India, would imply that any or all research may come under scrutiny or have to be first vetted by the large 65 member Board of Governors ruling the intricate IAEA bureaucracy. With India not being a Non-Proliferation Treaty signatory, would the topics "allowed" for scientific investigation not be decided within the framework of rules applicable to non-nuclear weapons countries or, worse, rogue states? What would be the yardstick for deciding what research is "sanctioned"? Would this mean that "civilian" scientists cannot collaborate with their "military" counterparts since separation must be maintained?

To extend the argument, since such constraints would necessarily have to be focused on indigenous research, criteria could be selective (foreign collaborations with "acceptable" countries may not be scrutinised) and/or restrictive (it may become increasingly difficult for India to choose its research collaborators if they happen to belong to the "wrong" country). In such an environment, there will be little scope for pursuing India's tried and proven self-reliance policy in the future since all indigenous work would invite invasive scrutiny. It has been mentioned that in the event of a national crisis, perhaps none of the trained workforce, equipment or any technology fall-out from such research will be available for military work since India has accepted "in perpetuity" safeguards on all civilian facilities and purportedly given up its sovereign right to cite national security reasons for withdrawal — a privilege enjoyed by all technologically advanced nations.
Such an artificial "segregation" would create multiple problems of its own. There is adequate proof that the DAE's applied programmes have drawn heavily from human resources developed in these institutions. In the absence of sensible and responsible negotiations, if inspections include "pursuit" in principle as they may in the case of nuclear fuel, associated universities, grant funding institutions such as the Department of Science and Technology and other organisations like the Council of Scientific and Industrial Research, etc., will be forced to submit to humiliating and intrusive supervision. Gone will be the days of unfettered technology development via collaborative research with, say, a private biotechnology company. An international "licence-permit raj" on Indian scientific creativity will be here to stay and the army of IAEA inspectors will invade all related public and private sector entities, sometimes even without prior intimation. At the very least it would guarantee that scientists and engineers would be endlessly tied up in bureaucratic red-tape so as to satisfy an infinite number of queries so that very little constructive work is actually achieved.

It is far from true that the entities on the list are "merely" academic institutions when one realises that BARC in its entirety was born from TIFR which was the first institute of its kind in the nation devoted to the physical sciences and mathematics. Recall that Homi Bhabha's vision was to build up indigenous capability through promoting manpower generation in the basic sciences. He wrote in 1944 to J.R.D. Tata that the Tata Institute should be created in order to produce the experts for nuclear energy in India when it becomes feasible. With the firm grounding that such training inculcates, professionals can adapt themselves with alacrity to the requirements of creating technology and its spin-offs.

Indeed, this has been the way all technological innovations have happened throughout the world. To enable this in India the DAE created autonomous institutions like SINP, VECC and others to create and sustain a strong and wide base of specialisations providing an unshakeable foundation for a healthy technological future. Such institutions have also enabled us to initiate new research, such as in the fusion programme. It helped India gain entrance to the International Thermonuclear Experimental Reactor project, and register successes in computing technologies, and space and nanoparticle research and a whole gamut of laser based scientific research to name a few areas.

Regardless of the exact nature of the safeguards, the scientific community in India is extremely upset and alarmed that the autonomy of these institutions may now be severely eroded and their research programmes subjected to the worst external interference. Having been put to great inconvenience of the kind related here. NPT signatory Brazil, for example, has finally been forced to object to IAEA inspections on projects funded by the Brazilian atomic energy agency in the university sector. But as a non-NPT state, the Indian government may not have retained an escape route in its haste to please Washington. In advanced nuclear countries such as the United States, premier institutions and universities funded by its atomic energy commission would consider it inconceivable to give up their autonomy, which is jealously preserved to enable new and innovative research in the frontiers of science to take seed, grow and flourish.

There can be no artificial constraints on the dissemination of scientific thought and the world has reaped the benefits of a free system, as has India. To put centres of excellence under safeguards of whatever type, would be to serve a body blow to the future of indigenous Indian science. Since scientific and technological strength has brought us to where we are today, this is obviously too high a price to pay. The negative ramifications of such a drastic step would be hard to envisage in their entirety.

On the whole, it is clear that inserting these facilities into the already complex problem of separating the DAE's civilian and military programmes as required by the nuclear deal is a fatal mistake. If it has happened as a result of bureaucratic oversight, this must be corrected. Scientists must come forward with their concerns and initiate a constructive dialogue with the Prime Minister's Office and the ministry of external affairs to prevent such an outcome. The government of India needs to be far more transparent and to consult with a range of retired and serving scientists from the science establishment before actively assisting in the demise of basic research in this country.

Dr. P.K. Iyengar retired as Chairman, Atomic Energy Commission. Dr. M. Gupta is a physicist at the Manipal Academy of Higher Education, Manipal, Karnataka.

The Indo-US 'Unclear' Deal

The Science behind the bomb

Nuclear fission, a process in which a nucleus splits releasing 200 million electron volts of energy, was discovered in 1939. This is in contrast to chemical reactions, which typically release only a few eV of energy. In order to cause fission, the nucleus has to be excited, just like you have to heat coal for it to burn. The particle called the neutron can do this effectively, but different nuclei have different thresholds for the neutron energy needed to cause fission. It was discovered that U^{235}, an isotope that occurs in natural uranium to the extent of 0.7%, gets easily fissioned by very low energy neutrons. The process also releases, on the average, 2.5 neutrons per fission. This allows a chain reaction to be established. This is the basis for the production of nuclear energy from a reactor, as well as a nuclear bomb. In 1942 the first chain reaction was established with natural uranium as the fuel. The size of this reactor was very large. However, to make an explosive device, a bomb, of reasonable size, you need to concentrate U^{235}. A minimum of around 15 kg of U^{235} is required for an explosive device. The process of separating and concentrating U^{235} is known as enrichment. This process is based on different principles such as electromagnetic separation, different rates of diffusion through a barrier, or through centrifuge action in a cascade of centrifuges. There are other methods, like laser isotope separation, and perhaps many more processes yet to be invented.

In a nuclear reactor the fuel contains some proportion of U^{238}, which cannot be fissioned. This U^{238} gets converted to Pu^{239} by adding one neutron. As a rule of thumb, the efficiency of production of plutonium for every fission that occurs in a reactor, can vary from 0.5 in a light-water reactor, to 0.8 in a heavy-water reactor, to nearly 1.5 in a fast-breeder reactor. One Megawatt-day of energy is produced by burning 1 gm of U^{235} in a reactor. Thus, a 200 MWe power station, which produces 600 MW of thermal power, will burn 600 gm of U^{235} per day, and produce 300-500 gm of plutonium per day. In one year, a 200 MWe power station will produce 90–150 kg of plutonium. Depending upon how long you leave the uranium fuel in the reactor, all this plutonium could be used for making nuclear weapons. Hence the connection between nuclear power and nuclear weapons. It may also be noted that the minimum mass required to make a nuclear weapon out of Plutonium is around only 5 kg, corresponding to a 10 kilotonne bomb.

The science behind nuclear explosives has been with us for such a long time, that it is now no longer a secret, and any determined nation can make a bomb with the help of a few bright scientists and the required materials.

A brief history of the bomb

The history of attempts to restrain new nations from acquiring the capability to produce nuclear weapons goes back to the late 1940s and the early 1950s, after the use of nuclear weapons on Hiroshima and Nagasaki in 1945. The Americans felt that the science and the technology were so complicated, that other nations would not be able to achieve a breakthrough. However, the Soviet Union, UK, France and China successively detonated nuclear devices. This frightened the Americans. While on the one hand the US government propounded the Atoms for Peace plan in the mid-50s, they also were worried that the capability would spread. The IAEA, a multi-national

UN body, was formed in 1958, in order to propagate the peaceful uses of Atomic Energy, and also in a multi-national way, control the spread of nuclear technology for making explosives. A test ban for atmospheric nuclear explosions was the first attempt at stopping the spread of nuclear weapons. India, under Nehru, was one of the first signatories to this treaty.

However, when the Chinese entered the field with their first explosion, it became obvious that even a developing country, struggling for improving its conditions of living, could think of national security through nuclear weapons. The five nuclear nations therefore formulated the NPT, which recognised these five as Nuclear Weapon States, and all the rest as Non-weapon States – thus introducing discrimination for the first time.

India had produced its own plutonium by 1965, and Homi Bhabha announced that if necessary India could detonate a nuclear device in 18 months time. Unfortunately, Homi Bhabha died in an air crash in 1966, Pandit Nehru, a visionary statesman, had died in 1964, and this nation had severe economic problems. The Government of the time tried to get an umbrella protection from the advanced countries, but failed.

The NPT came into being in 1968, with a blatant, discriminatory motive. It required non-weapon states to abstain from attempting to make nuclear weapons. In return they were promised help in nuclear technology for peaceful purposes. The NPT recognised the right of nuclear weapon states to retain their arsenal, which grew in number due to the Cold War. India decided not to sign the NPT, and upheld its sovereign right to acquire nuclear weapons when the need arose. Even a strong Gandhian like Morarjee Desai, who was Deputy PM at that time, was against signing the NPT, even though he was not in favour of India acquiring nuclear weapons.

Pokhran-I

The 1960s saw a few wars: one with China and a couple with Pakistan. During this time the US continued to support the unelected military regime in Pakistan. At the end of the decade the political turmoil in Pakistan led to revolt and the formation of Bangladesh, in which India was forced to get involved. During that war it looked as if America and China would help Pakistan, and the US Navy moved into the Bay of Bengal. This really frightened the Indian government, and Mrs. Gandhi took the decision to ask us to prepare for a nuclear explosion through entirely indigenous efforts. This resulted in the first Pokhran test of 1974. That was the time when the US and the Soviet Union were experimenting with nuclear devices for applications in earth-moving operations on a large scale. Therefore, India named the Pokhran-I test as a Peaceful Nuclear Experiment. It is also true that the device was not engineered to be used as a deliverable weapon, but had to be physically assembled at a depth of 100 m, manually. Pokhran-I resulted in sanctions being applied by all the Western countries, denying to honour obligations made under international agreements, under which the Tarapur reactor was purchased from the US. The Canadians, the French, and the US walked out of the obligations under the bilateral agreements between India and these countries.

The Congress government at that time was willing to accept the challenges that the sanctions threw up. The Indian scientists and engineers struggled to complete and push forward the programmes that had been started with foreign collaborations. The heavy-water reactors in Rajasthan, the fast reactor at Kalpakkam, and the many heavy-water plants at various stages of construction, were all affected. Yet these were successfully completed, and have been operating for a long time now.

The tightening of the NPT regime started when India exploded the nuclear device, and countries like South Africa, Brazil and Argentina had developed their own capabilities for nuclear explosives. It became obvious that no nation could be stopped from pursuing research and development, and innovate technology, for becoming a nuclear power. In order to bring in all nations under the NPT, inducements and punishments were tried. Some of the threshold states were brought into the NPT in this manner. The NSG came into existence, denying technology for peaceful applications, unless nations signed the NPT. Progress in the development of new types of nuclear reactors was curtailed, and this led to the stagnation of nuclear technology for a couple of decades.

Pokhran-II

India resisted all threats and inducements and held to its position to keep the sovereign right of a nuclear option to itself. Meanwhile Pakistan clandestinely acquired the technology for making enriched uranium, and was ready to make the nuclear explosive by the end of the 1980s. The US shied away from putting any restrictions on Pakistan, because of their strategic help in the Afghan war. When it became obvious that Pakistan had indeed assembled a nuclear device and was ready to test, the Government of India decided to carry out a series of test explosions in May 1998, which were soon followed by nuclear tests by Pakistan. India declared itself a Nuclear Weapon country, voluntarily applied a moratorium on further testing, promised a no-first-use philosophy, and enunciated a Minimum Credible Deterrent policy. This resulted in a renewed application of sanctions by the US and other NSG countries, which we took in our stride.

Soon the US recognised the strategic importance of India, for peace and stability in South-East Asia. The NDA Government cooperated by engaging in a series of long negotiations in this strategic partnership. Meanwhile, in the international arena, the CTBT was promulgated and the majority of nations who were party to the NPT accepted and ratified the treaty. It is strange that the US Congress however went against the recommendation of the US Administration and did not ratify the CTBT. The Review Committee of the NPT decided to extend the NPT in perpetuity, which finally left only three nations outside the NPT net – India, Pakistan and Israel.

The Indo-US deal

It is to the credit of the Bush Administration that the agreement for a strategic partnership, including the agreement on cooperation on civil nuclear power was signed on 18 July 2005. This agreement was well drafted, sugar-coated, and suggested the opening of a new chapter in Indo-US relations. The main points with respect to nuclear policy were the following:

(a) The US recognises that India is a *de facto* nuclear weapon country, and does not object to India having a nuclear doctrine and an arsenal;
(b) The US and its allies in the NSG will cooperate with India in the area of civil nuclear energy, through commercial channels, and participation in international efforts;
(c) India will, on its part, modify its aversion to the NPT, and will, like other Nuclear Weapon States, join and help the non-proliferation regime by putting its civil nuclear facilities – to be chosen by itself – under IAEA safeguards.

Everybody, including the nuclear scientists thought that this was a break-through, and would help in expanding the nuclear energy programme, which has its effects on restraining green-house gases, energy security, etc. However, a major obstacle for the US was its own Atomic Energy Act of 1954, which prohibits that country from cooperating with any other nation which has not agreed to full-scope safeguards under the IAEA as a non-weapon state. We have all seen the attempts by the Bush Administration to get an exemption for the Indian case, through their Congress.

The progress in this respect is dramatised in the last few months. The details of negotiations between the US and India have come through testimonies in the US Congress, as well as statements on policy by the US Administration. These have been the only source of information for the general public in India. There has been no transparency in what way India will define its obligations and benefits, which was at one time defined as equivalent to that of an advanced nation like the USA. Matters have moved so quickly, especially during and after the visit of President Bush to India. This has resulted in the following:

(1) A separation plan of entities in the Department of Atomic Energy, into civil and military, supposed to come into force over the next few years. India will offer the civil facilities for IAEA safeguards progressively.
(2) The promise that the decision as to which entities will be under the civilian category and which under the military category, will be entirely a decision of the Indian government.
(3) The Indian government will have the option of augmenting its resources for the strategic part, to be decided by itself.
(4) There will be American influence on the NSG to exempt India from the restrictions presently placed on it.
(5) The US will also help to negotiate with the IAEA an India-specific safeguard agreement. This will be different from the agreement applicable to non-weapon states.

Obviously, this is a very involved and complex issue for the Government of India to negotiate simultaneously with the US, the NSG countries, and the IAEA. The US Congress has expressed their desire to see the agreements with the IAEA and the NSG countries, before agreeing to amend their law.

Problems with the deal

The separation plan as announced earlier, and amended later, has been placed in Parliament. This has raised many questions. The Indian nuclear programme, through the vision of Homi Bhabha, was built with an emphasis on nuclear power production through indigenous technology and resources, with a future expanded programme to be based on thorium, which is very abundantly found in India. The strategic programme was more recent and does not constitute a well-defined set of laboratories, group of scientists, or infrastructure, which could be logically identified and separated.

For the first time, the Chairman, Atomic Energy Commission, made the pronouncement that the US is changing its goal posts, which is a clear indication of the pressure applied in the negotiations between India and the US. The fact that the US was dictating terms as to what facilities must become civilian, and therefore subject to IAEA safeguards, has come from non-proliferation Ayatollahs in the US, like Spector, and Congressional members. Thus, an innocuous reactor like Apsara, which has been in operation for almost 50 years, built entirely indigenously, is being offered to be shifted from BARC in order not to attract safeguards inspection into BARC. It has been declared, in legal terms, that India did not violate any legal agreements with Canada on the utilization of the CIRUS reactor. However, now CIRUS is to be shutdown in the next few years – after it has just recently been rejuvenated.

Around 65% of the nuclear power stations in operation or under construction will be placed under safeguards, irrespective of whether there has been any contribution from abroad or not. All future nuclear power stations, including fast-breeder reactors producing power, will be put under IAEA inspection. The nature of the safeguard agreement with the IAEA is not clear. For example, one is not sure if R&D will be exempt from control and inspection from the IAEA. This will infringe on the sovereign right of the country to be innovative in technology development. In short, even in the civilian power sector, substantial R&D is necessary to establish and consolidate new processes and improve efficiencies, and this cannot be done with the IAEA constantly looking over the shoulders of our scientists and engineers. For example Brazil has developed a new and more efficient centrifuge process, and is having trouble asserting its intellectual property rights in the face of mandated IAEA inspections.

India has also agreed to negotiate an additional protocol with the IAEA, whose terms and conditions are not defined. This additional protocol, invented in the mid-90s on suspicions of the production of WMD by certain states, is highly intrusive and infringes on the right of a nation to independently pursue R&D in nuclear science and technology. Can and should India subject its scientists to intrusive inspections and questions by an outside body, when vital interests are involved? For example, the choice of the form of fuel for the fast-breeder programme, reprocessing technology involved in the thorium breeding, and the parallel programme of thorium utilization in heavy-water reactors, are all areas of vital interest to this country. There may also be various other methods, simpler and more cost effective, in the area of enrichment and new nuclear systems for energy production.

India has agreed to go along and accept the Fissile Material Cut-off Treaty (FMCT) at a multi-national level, with verification by an external agency. While India has a need for fissile material for its strategic programme, its stock of such material is nowhere near the stocks that are in the possession of the Nuclear Weapon countries. It is thus a dangerous commitment, inconsistent with our declared policy of a minimum credible deterrent for strategic purposes.

The benefits of the Indo-US deal are highlighted as a panacea for the expansion of nuclear power in our energy sector, offering energy security for the future. This essentially means buying of nuclear power stations, buying of fuel for the reactors, and such other items. Enriched fuel for the power sector may be available under the agreement, but every gram of that should be proven as necessary for utilisation in the power sector. It is not clear whether India will have the option of accelerating its own, well-established, nuclear power programme based on the PHWR. There is no estimate of the economics of imported nuclear power stations, nor a comparison with other sources, such as oil, coal, etc., which will also be augmented by India.

The testimonies before the Congress, the additions to the Bush proposal, which have been recommended by the Congressional committees, have all come as a shock to those who follow the intricacies of the nuclear deal. It is now obvious that in spite of the exemptions to be approved by Congress, the President of the US will have to certify every year, in detail, that he is satisfied with the behaviour and programmes of India in the nuclear field, especially with respect to the augmentation of the nuclear arsenal. He has to certify that no benefit is derived by the Indian strategic programme from the external assistance derived through this deal. This is a very dangerous proposition, for in such a complicated interaction it is very difficult to provide clear evidence to justify such a certification. Therefore any such certification will be highly subjective and can result in disagreements in the future.

Implications of the deal

Enough has been written in the media of the political implications of the strategic partnership. India's active cooperation in diverse areas in implementing the non-proliferation regime as seen by the US, may be counter-productive. The mention of Iran is itself extraordinary in an agreement that is only between India and the US. Similarly, there could be objections on the very invasive verifications to be carried out in implementing a stricter non-proliferation regime in the world. This needs very careful analysis, and I am not going to attempt to do this here.

One gets the feeling that these additions to the agreement of 18 July 2005, will, in effect have the following fall-outs: (a) cap our strategic programme for a credible minimum deterrent; (b) information on almost all activities on nuclear science & technology, related to basic research or technical development, will be available to the US; (c) India will essentially forgo its sovereign right to develop modern science and cutting-edge technology in areas of nuclear science, strategic devices like nuclear explosives and missiles, and innovations that can have implications on the use of thorium, and in space technology, etc.

As a scientist I feel that the non-proliferation agenda of the US, trying to restrain acquisition of even simple technologies, like that of enrichment, is bound to fail. If one looks at the growth of electronics and the innovations that have been brought about by a deeper understanding of semiconductor physics and innovations in making devices, including computers, imaging devices, etc., it is clear that the sovereign right to be able to develop science and technology is important and necessary for any country. Surrendering these basic rights is dangerous and we will be doing injustice to future generations in India.

It is in this context that one raises the question whether the government should enter into such a complicated and long-term agreement with so little debate and consideration. Debate among informed citizens, called for by our PM, is a pre-condition for any government to enter into such an important deal. From the modifications suggested by the US Congress and Senate committees, it is clear that the intention of the US government is to tighten safeguards, impose intrusive inspections, and to bind this country in perpetuity to the NPT, CTBT and FMCT, to which we have always been opposed. One has to admit that these strategic implications of the 'civilian' nuclear deal cannot be completely discussed in open fora. However, at present there seems to be no mechanism for evolving a consensus on such crucial strategic issues. I trust that the Parliament will enact laws to establish a mechanism by which informed decisions and consensus could be arrived at in a discreet way, without compromising national interests.

I hope articles such as this will trigger further discussion and participation from scientists, policy makers, and the academic community, who are not under pressure to work out a diplomatic agreement, to come together and analyse threadbare the implications of such a deal, and at the same time trigger a more careful and informed analysis by the government of the strategic aspects. We should recall the 'tryst with destiny' that Pandit Nehru proclaimed at the dawn of our independence. The time has come to revive this call and act accordingly.

P. K. Iyengar

(Dr. Iyengar is former Director, Bhabha Atomic Research Centre, former Chairman, Atomic Energy Commission, and was a key figure in Pokhran-I)

(Lecture at FINS, June 2006)

India won't accept U.S. nuclear-policing

Dr P.K. Iyengar

The Indo-US nuclear deal has gone through a metamorphosis in the hands of the Committees in the American Senate. The July 18, 2005 agreement recognises that India, though not a signatory to the Non-Proliferation Treaty, has over the years behaved with great responsibility when it comes to non-proliferation. Our record is perhaps better than some of the weapons countries that have signed the NPT. In light of this fact, the statement seeks to give India a status roughly equal to that of the recognised nuclear weapon states, and to bring it into the mainstream of the nuclear community. However, the tone of the Senate discussions and of the amendments proposed by them, suggests that India still needs to be "policed" by the United States, to the extent that the US President has to give a yearly "character certificate" to keep the nuclear deal alive. These aspects have been elaborated in these columns. This is clearly contrary to the spirit and words of the July 18 agreement, and absolutely unacceptable to any sovereign nation — a fact that even the Indian government now concedes.

I wish to emphasise here the deleterious impact this "modified" nuclear deal will have on our nuclear power programme. To understand why the nuclear deal is not something that is essential for Indian nuclear power programme, we must understand the broad contours of the programme.

India has vast resources of thorium, not uranium, and we therefore have a well-thought-out, three-stage nuclear programme, that is based on exploiting this resource. It must be borne in mind this is based on the present understanding of physical laws in nuclear physics. This could change if new discoveries are made. In the first stage, we have chosen to build heavy-water reactors that use natural uranium. It was the Canadian scientists who proved the virtues of heavy-water nuclear reactors for energy production and the efficient conversion of the unburnt 238U to plutonium. It is these characteristics that have attracted us. South Korea, China and other countries have since gone for heavy-water reactors, for electricity production. Some countries like the US, France, Germany and Russia, however, have gone for light water reactors which use low enriched uranium as fuel and hence are more compact. They would like to sell to us. This requires the development of enrichment technology, primarily through centrifuges, which is an unnecessary additional step. If a country develops this technology to be able to produce its own fuel, it has the option to extend this technology to produce weapon usable 90% enriched uranium. Conversely, if the country decides not to develop enrichment technology, then it remains forever dependent on the nuclear powers for fuel for its light-water reactors.

The second stage of our nuclear programme envisages building fast-breeder reactors that generate more fuel than they burn. They use plutonium reprocessed from the heavy-water reactors, and thorium available on the beaches of Kerala together as fuel. This is a new technology, and we have spent decades mastering it. We have now started building the first 500 MWe Prototype Fast-Breeder Reactor (PFBR) at Kalpakkam, which is expected to be ready in 2010. Since we have the largest resources of thorium, we can ensure energy security for the foreseeable future. The third stage will use Uranium 233 converted from thorium and will give us the freedom to use any type of reactors, thermal or fast, thus freeing us from any type of restrictions from the point of view of resources.

With this background, it can be easily understood that, in terms of relevant nuclear technology, we have little to gain from the nuclear deal. We actually lead the world in fast-breeder technology, and are well on the way to bringing it to commercial fruition. We are not so bothered about technology transfer in fast-breeders, or other areas such as heavy-water production, reprocessing, and enrichment. All we need is to be left alone, so that our scientists and engineers can make further technical advances in these areas. It is especially important to realise that thorium utilisation depends on the reprocessing technology applicable to that fuel cycle, which is being researched upon only in India. The successes that we have achieved at Kalpakkam need to be protected and further strengthened, so that in a decade India will have developed all the necessary technology to usher in copious nuclear electricity through fast-breeders, making use of thorium as the basic fuel. This is of course the third stage of our nuclear programme, as envisaged by Homi Bhabha. We should not be side-tracked by non-scientific propaganda, that this route is not economically attractive, for nobody has so far worked on it consistently.

Until such time as the fast-breeder reactors take over the nuclear landscape, we will depend on the heavy-water reactors. These require natural uranium, which we have not located in large amounts in the country. However, the Department of Atomic Energy estimates that we have sufficient deposits to fuel 10,000 MWe of nuclear power for 30 years. The availability of uranium for our heavy-water reactors can be ensured by our strengthening our exploration and mining operations of uranium deposits within the country. The cost of production may initially be higher than the international cost, but the fact that natural uranium can go into our heavy-water reactors, and its share of the tariff is only a small percentage, should be noted. For doing this, we have all the technology and experience. These reactors are also more efficient than light-water reactors in producing plutonium, which is essential for expanding the fast-breeder reactor systems. We are also exploring the direct use of thorium in heavy-water reactors — another area of research in which we are ahead in the world.

No scientist opposes a strategic relationship with the US on matters like energy security, development, and stability in the South Asian region. What has to be ensured, however, is that our domestic nuclear power programme, which is based on ground realities at home, and our independence of research and development in nuclear technology, for the benefit of future generations, are not bartered away for a few imported reactors with fuel. Technology is a product of science, and very often new, more efficient, technologies are generated by lateral thinking by scientists and engineers. We see this all around, whether in agriculture, computers, new materials, or engineering practices. But lateral thinking and innovation need a large degree of openness and independence, and are fatally hampered if one is under constant observation and supervision. The recommended provisions of the nuclear deal imply precisely that, and it is clear that this will have a deleterious effect on innovation in nuclear science and technology — and perhaps even in basic sciences, given that institutes of basic research, that are under the DAE, will also come under IAEA safeguards.

If we believe that the development of human resources leading to a knowledge-based society can make a quantum jump in prosperity, we should trust the scientists and take their advice seriously without putting unnecessary brakes on research and development. Their proven competence is recognised internationally. The Congress Party, especially the Prime Ministers, from Pandit Jawaharlal Nehru onwards, have always believed and trusted the ability of scientists. There is no reason why there should be a rethinking on the issue of future prospects of nuclear energy in this country. Import of technology is not the answer, for we have developed sufficiently in this area and proven that we can, very competitively, enhance our capacity.

Dr P.K. Iyengar retired as Chairman, Atomic Energy Commission

(Asian Age, 9 August 2006)

Appeal to Parliamentarians on the Indo-US Nuclear Deal

While the nation and Parliament discuss the Indo-US nuclear deal from various angles, we feel it is our responsibility to place before the nation our well-considered views on the impact of this deal on the future of Indian nuclear science & technology, and its effects on the energy security of the nation. We have all worked in the field of atomic energy from the very early years after India's independence. From very small beginnings, we have now reached a stage where we are in possession of all the technologies needed for the production of electricity from indigenous nuclear minerals, and have successfully applied these technologies in diverse sectors from health, agriculture and industry to national and energy security. All this has been possible with the support of the people represented in the government through Parliament, and the outstanding statesmen who have guided and supported our plans. We therefore feel it is our obligation to make public our perceptions for the effective and continued nurturing and utilization of this technology in the country.

Science is universal. Knowledge can be created in any part of the world, and technology comes with experimentation and the willingness to take risks. We have followed all these paths to reach the present stage of development. We are amongst the most advanced countries in the technology of fast-breeder reactors, which is crucial to the future of our energy security. Along the way we have derived benefits from international collaboration. At the same time, we have also shared some of our abilities in this field with the world. Indian scientists have been ambassadors, with knowledge and creativity as their tools. It is of prime importance to uphold these cherished traditions.

It is significant that the most advanced country in nuclear science and technology has come forward to accept us into the international nuclear community, by the historic document signed by our Prime Minister with President Bush on 18th July, 2005. The basic principles for cooperation were well laid out in this bilateral understanding and the Prime Minister has appraised our Parliament of this. No doubt it needs the concurrence of the other nations comprising the Nuclear Suppliers Group, and of the International Atomic Energy Agency. Based on this agreement, the US lawmakers and the administration are in the process of re-framing their laws, which could change the nature of relations between the two countries. This is a most welcome initiative of the UPA government, and is a continuation of the process essentially begun during the previous NDA government. Thus, there is no question of any political partisanship on this matter.

However, the lawmakers of the US Congress have modified, both in letter and spirit, the implementation of such an agreement. At this juncture, among other aspects, it is essential that we insist on the following four central themes:

(a) India should continue to be able to hold on to her nuclear option as a strategic requirement in the real world that we live in, and in the ever-changing complexity of the international political system. This means that we cannot accede to any restraint in perpetuity on our freedom of action. We have not done this for the last forty years after the Non-Proliferation Treaty came into being, and there is no reason why we should succumb to this now. Universal nuclear disarmament must be our ultimate aim, and until we see the light at the end of the tunnel on this important issue, we cannot accept any agreement in perpetuity.

(b) After 1974, when the major powers discontinued cooperation with us, we have built up our capability in many sensitive technological areas, which need not and should not now be subjected to external control. Safeguards are understandable where external assistance for nuclear materials or technologies are involved. We have agreed to this before, and we can continue to agree to this in the future too, but strictly restricted to those facilities and materials imported from external

sources.
(c) We find that the Indo-US deal, in the form approved by the US House of Representatives, infringes on our independence for carrying out indigenous research and development (R&D) in nuclear science & technology. Our R&D should not be hampered by external supervision or control, or by the need to satisfy any international body. Research and technology development are the sovereign rights of any nation. This is especially true when they concern strategic national defence and energy self-sufficiency.
(d) While the sequence of actions to implement the cooperation could be left for discussion between the two governments, the basic principles on which such actions will rest is the right of Parliament and the people to decide. The Prime Minister has already taken up with President Bush the issue of the new clauses recommended by the US House of Representatives. If the US Congress, in its wisdom, passes the bill in its present form, the 'product' will become unacceptable to India, and, diplomatically, it will be very difficult to change it later. Hence it is important for our Parliament to work out, and insist on, the ground rules for the nuclear deal, at this stage itself.

We therefore request you, the Parliamentarians, to discuss this deal and arrive at a unanimous decision, recognizing the fundamental facts of India's indigenous nuclear science & technology achievements to date, the efforts made to overcome the unfair restrictions placed on us and the imaginative policies and planning enunciated and followed in the years after Independence. The nation, at this critical juncture, depends on its representatives in Parliament to ensure that decisions taken today do not inhibit our future ability to develop and pursue nuclear technologies for the benefit of the nation.

14 August 2006

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Controversy over the nuclear deal

P.K. Iyengar

AT THE time it was struck, the July 2005 India-U.S. nuclear agreement appeared historic. The compromises by both sides looked acceptable then. The U.S. seemed to agree to recognise India as a nuclear weapons country, and to not interfere with its nuclear doctrine, strategic programme, or further development of its nuclear arsenal, which includes design, development, and testing of new nuclear weapons. Secondly, the U.S. recognised the need for more nuclear power in India, and was willing to do commerce in civil nuclear power, and encourage the Nuclear Suppliers Group to do the same, subject only to the condition that such reactors and their fuel would be under IAEA safeguards specific to India. In March 2006, the U.S. gave assurances that in order to avoid situations like Tarapur, where fuel was denied to us after the 1974 Pokhran test, they would guarantee fuel supplies to these imported reactors for their lifetime, and, if necessary, help us build fuel stockpiles.

The U.S. also agreed that our efforts for nuclear energy based on a three-stage programme could continue unrestricted, with fast breeders and thorium reactors, and that we would have the opportunity to collaborate with the U.S. on their R&D efforts for a new generation of nuclear reactors. The Prime Minister repeated these promises in Parliament many times, and it was said that the only thing we were committing was the continuation of our voluntary moratorium on nuclear testing and a separation plan such that our strategic programme and R&D would not be subject to IAEA inspection. It was claimed that this separation plan would be entirely voluntary.

However, when subsequent changes in the U.S. position made the deal unpalatable for India, the Indian negotiators failed to hold to the Prime Minister's stand. Delivery of fuel was linked to non-testing and fuel supply was no longer guaranteed. Reprocessing, which is essential for our three-stage programme, was specifically disallowed. Instead of participating as an equal in R&D programmes, India would now only be a bystander. All these changes were codified in the Hyde Act — an appropriate name, given the Jekyll and Hyde act that the U.S. government is pulling!

These serious changes alarmed the community of nuclear scientists. A number of us who have led the civilian and strategic nuclear programmes in the past found it necessary to express our grave reservations in writing. This had its effect, with the Prime Minister giving a detailed reply and categorical assurances in Parliament that India would not play a game with "shifting goalposts." However, our statement also received criticism from some quarters, which alleged that this was tantamount to interference in the government's executive rights and responsibilities. This criticism is obviously unjustified because it is not just our right but also our responsibility, as people with the relevant technical expertise, to provide appropriate advice to the people, Parliament, and government of this country.

In this context it is interesting to recall a letter written by Hans Bethe to President Clinton in April 1997, advising him to cease all research, even computer simulations, into a new generation of nuclear weapons:

"As the Director of the Theoretical Division at Los Alamos, I participated at the most senior level in the World War II Manhattan Project that produced the first atomic weapons. Now, at age 90, I am one of the few remaining senior project participants. And I have followed closely, and participated in, the major issues of the nuclear arms race and disarmament during the last half century. I ask to be permitted to express a related opinion. It seems the time has come for our Nation to declare that it is not working, in any way, to develop further weapons of mass destruction of any kind. In particular, this means not financing work looking toward the possibility of new designs for nuclear weapons. And it certainly means not working on new types of nuclear weapons, such as pure-fusion weapons...

"The underlying purpose of a complete cessation of nuclear testing mandated by the Comprehensive Test Ban Treaty is to prevent new nuclear weapons from emerging and this certainly suggests doing everything we can to prevent new categories of nuclear weapons from being discovered. It is in our national and global interest to stand true to this underlying purpose."

In his reply, President Clinton's wrote:

"Thank you for sharing your thoughts on nuclear weapons with me... I am fully committed to securing the ratification, entry into force and effective implementation of the CTBT. By banning all nuclear explosions, the CTBT will constrain the development and qualitative improvement of nuclear weapons and end the development of advanced new types of nuclear weapons. In this way, the Treaty will contribute to the process of nuclear disarmament and the prevention of nuclear proliferation, and it will strengthen international peace and security... I have also directed that the United States maintain the basic capability to resume nuclear test activities prohibited by the CTBT in the unlikely event that the United States should need to withdraw from this treaty..."

Look at the tone of Prof. Bethe's letter. Now imagine the consternation if an Indian scientist were to use such a tone in a letter to the Prime Minister!

The reply from President Clinton is also interesting. He openly states America's willingness to resume nuclear testing should such a situation arise in the future. He also indicated that the national laboratories will maintain an alert group to redesign new weapons of mass destruction, for which new facilities are being approved. We now know that even this exit clause was not considered sufficient, and the U.S. Congress refused to ratify the CTBT. In June 1996, India withdrew from the CTBT Conference because of its discriminatory nature, and because the way to nuclear disarmament is not through imposing such limited agreements on some, while others are carrying out research towards discovering new weapons.

Such research is probably not restricted to the Americans. In June 2006, the Russian Foreign Minister told the Duma the Americans are already experimenting with deep penetrating mini-nukes called `bunker-busters.' This suggests that perhaps even Russia is trying such innovations. In spite of agreeing not to develop anti-missile defence systems in the 1970s, the U.S. unilaterally withdrew from that treaty. The Chinese have even demonstrated recently that they could bring down satellites in orbit.

The supporters of the nuclear deal argue it is essential to augment nuclear power to support our rapid growth, and that this requires the nuclear deal. The first part of the argument is correct. Where they err is in not understanding that the nuclear deal will not achieve this goal, that we will lose more than we gain through the deal. For one, we are getting neither nuclear fuel nor reactors for free or at a low cost but at the prevailing market price, and this is definitely more than the cost of indigenous nuclear power. Secondly, the promise of nuclear technology rings hollow — it comes too late and offers too little. Today we are quite self-sufficient in the technology of heavy-water reactors, and are world leaders in the technology of fast-breeder reactors. These are the technologies we have chosen for our three-stage nuclear programme, with good reason.

The light-water reactors (LWRs) we may buy use only 0.5 per cent of the uranium mined, leaving the rest to be stored if the fuel is not reprocessed and reused, as in the once-through cycle. It is more profitable to reprocess and extract the plutonium from heavy-water reactors and use it as fuel for the fast-breeder reactors, which is the essence of our three-stage programme. They have also been shown to be more economical in terms of capital cost and tariff. Imagine the benefits that would accrue if we succeed in burning up to 10 per cent of the uranium mined as well as the thorium that we use, in a once-through cycle. Efforts are on to achieve this through our own research and development.

Yes, we would be happy to have more reactors if they are economically viable, such as the LWRs we are buying from Russia — without having to sign any nuclear deal from them. But the price we are being asked to pay by the U.S. is too high: no testing, no reprocessing, no guarantees of future fuel supplies. Once we sign the deal we will be at the mercy of the U.S. and the NSG for our energy security. This is hardly a situation a country that sees itself as a future superpower should place itself in. There is another solution to the problem of generating more nuclear power: rapid expansion of the indigenous programme with more capital for more reactors, greater exploitation of our uranium resources, greater urgency to our fast-breeder programme and thorium utilisation.

Scientists ignored

Unfortunately, in India scientists no longer have influence on the nuclear policy of the government. Technical realities and long term programmes based on scientific expertise and the collective wisdom of half a century are dismissed with neither thought nor debate. The vision of a self-reliant nuclear India that Jawaharlal Nehru and Homi Bhabha envisioned, and which Indira Gandhi and Rajiv Gandhi nurtured and sustained, seems now ready to be consigned to the dustbin of history. It is true that there are new pressures and new imperatives in a changing India. But equally, there are no quick fixes. FDI will not turn nuclear power economical, and `outsourcing' nuclear power will not ensure our energy security. It is the creativity of Indian scientists and their work in Indian laboratories alone that can prove beneficial to the future of this country. It seems to me that already great damage has been done to our strategic planning. Nine years after the Pokhran II tests, we haven't evaluated the detailed requirements for a minimum credible deterrent, including delivery systems. Our R&D limps on, while elsewhere a new generation of efficient nuclear weapons and their delivery systems is being actively worked on. Decisions need to be taken, and urgently, for the civilian and strategic nuclear programme, but not without thought, consideration, consultation, and an appreciation of scientific realities. This is a time not for politics but for statesmanship.

(The author is a former Chairman of the Atomic Energy Commission.)

(The Hindu, 31 May 2007)

123 AGREEMENT IS A GILDED CAGE

P.K. Iyengar

For some reason, the text of the 123 Agreement of the India-US "civilian" nuclear deal was kept secret until it was approved by the Union Cabinet. Once the text was made public, the reason became clear. In spite of the best efforts of our negotiators, the United States has succeeded in imposing the Hyde Act on us. The relevant part of the Agreement is Article 2, which states: "The parties shall cooperate in the use of nuclear energy for peaceful purposes, in accordance with the provisions of this agreement.

Each party shall implement this agreement in accordance with the respective applicable treaties, national laws, regulations, and license requirements concerning the use of nuclear energy for peaceful purposes."

The treaties and national laws alluded to above certainly include the NPT and the Hyde Act. Thus, by signing this Agreement we would essentially agree to bind ourselves to the Hyde Act, whose provisions are not acceptable to India as declared by the government of India and the political parties, and not by the scientists alone. This Article can be used by the US government at any time to delay, block, or disapprove collaboration in critical areas dealt with in the l23 Agreement. The consequences are very serious to the future generations of this country, and I therefore have serious objections to this Article. There is a belief in some quarters that the ambiguity in the language of the Agreement will somehow help us circumvent the Hyde Act. Article 2 makes it clear that there will be no ambiguity in the actions of the US if we go against the Hyde Act. Some suggest that our only hope is that the US Congress will refuse to ratify this Agreement, just like they refused to ratify the CTBT in spite of the US administration getting almost the whole world to sign the treaty.

However, since this agreement is a total gain for the US non-proliferation lobby, it may even be agreed to by the US Congress. It is therefore essential that we do not go ahead with this Agreement without further, and explicit, assurances from the US.

We should also be clear about what we can expect to get from the Agreement, if it does go through. The much hyped promise of nuclear technology doesn't translate to much in real terms. Long years of isolation have made us self-sufficient in the technologies needed for our three stage programme, particularly fast breeder technology.

Besides, the American nuclear industry hasn't built nuclear plants in over 20 years. It is more likely that we can help them, rather than that they can help us.

Nor can we be sure that we will get copious and cheap nuclear power. The actual building of nuclear plants will be driven by market forces. It is not clear that such plants will provide cheap nuclear energy, given the high price of uranium in the international market.

Other costs are also likely to be high, and we may well end up with not one but several Dabhols.

The events witnessed in Parliament on August l4 clearly bring out the fact that there is no national consensus on this issue, with almost all non-UPA parties protesting against the government steamrolling Parliament. The fact that on such a crucial issue of national importance, it is possible for the government to take a unilateral decision against the wishes of the majority of the elected representatives in Parliament shows that there is a lacuna in our political system.

Another weakness comes from the whip system practised by the parties which prevents the elected representatives from airing their opinions openly. But the vigorous debate in Parliament is also a healthy sign that Indian democracy is showing its teeth for the first time.

It has been sixty years that India has gained freedom from colonialism and asserted its sovereignty.

Through the Dandi March Mahatma Gandhi showed how the most basic rights of the people were being controlled and suppressed by the colonial government, even for a simple matter like producing salt from seawater using radiation from the sun. In the last 50 years, the Department of Atomic Energy and the scientists in particular, thanks to the founders, have maintained our sovereign right to research and develop technologies for practical applications in the nuclear field.

The country has never subjected itself to external restraints thus not agreeing to sign the NPT, which is almost universally accepted. Through the 123 Agreement the US has presented us with a gilded cage. By signing the Agreement we would voluntarily walk into the cage. Then it only remains for the US Congress to lock the door by the simple act of ratifying the 123 Agreement.

DR P.K. IYENGAR is a former chairman of Atomic Energy Commission

(Asian Age, 17 August 2007)

Nuclear power and the Indo-U.S. nuclear deal

P.K. Iyengar

Preface

The urge to use neutron-induced fission to produce energy (explosive or continuous) was the main purpose of the Manhattan Project, and they succeeded in both. In addition to the atomic bomb, this resulted in priority for compact-core reactors for propulsion in submarines. That was the beginning of light-water reactors using enriched uranium. This technology was turned over to General Electric and Westinghouse who scaled it up to 220 MW and later to 1,000 MW.

The development of the technology for pressure vessels of this large size depends on industrial infrastructure. India still doesn't have that infrastructure. In parallel, countries like France, England, Canada ***and Soviet Union*** developed power stations burning natural uranium which of course produces plutonium as a by-product. The compactness of the light-water reactor eventually took over if the country had enrichment capability due to its defence efforts. Thus, the nuclear weapon countries dominate the scene with light--water reactors.

India chose to follow the Pressurized Heavy Water Reactor (PHWR) route due to the strong collaboration with Canada, who pioneered this reactor. The availability of natural uranium, zirconium, and production facilities for heavy water, in combination with fertilizer plants, gave further advantages to India. From 220 MW reactors it has now built and operated 550 MW reactors. The major advantage of the PHWR is the relative size of the components which could be manufactured locally. Eventually, like in Canada, 1,000 MW PHWRs can also be built.

The development of reactor technology has demonstrated how basic concepts in nuclear science can influence the systems we choose for commercialization. Avoiding enrichment capability, which is expensive, was the main motivation for India to go for this system. Reprocessing is a relatively simpler technique involving chemical engineering. The conversion of 238U to 239Pu is also more efficient in PHWRs. The fast reactor breeds more Pu than it burns. Also, thorium could be used in its blanket to convert it to 233U. Hence, India planned to develop fast-breeder technology and use its vast resources of thorium for deriving fission energy for the future. More modern scientific developments have shown that by an appropriate design of mixed-oxide fuel, one could even burn fertile material in situ, in thermal and ***fast*** reactors.

This paper emphasises the achievements of India in developing a self-reliant fission energy programme for the country. At the same time, the world market for reactors is dominated by the Pressurized Light Water Reactor, essentially arising from the weapon countries. The globalization of nuclear technology was ***inhibited by*** the Non-Proliferation Treaty promulgated in 1968, and the Nuclear Supplier Group's guidelines much later.

Should nuclear power become a more common source of electrical energy in the world, it can't be monitored by a small organization like the IAEA, unless it has enormous ***manpower*** strength and financial resources. Just like we cannot safeguard dual-use technology in steel-making or internal combustion engines, one cannot safeguard against the use and misuse of nuclear technology throughout the world.

Secondly, many practical applications of science are compulsions of local conditions. India, being a vast country, with enormous need for additional electrical power, needs to choose systems which will grow locally without external inputs. While the Indo-U.S. 123 Agreement provides for the import of reactors and the specialized fuel for it, it i***s very*** expensive in the context of the Indian economy. Moreover, because India is not a Non-Proliferation Treaty country, the 123 Agreement has specified unacceptable political conditions, which makes it sensitive from a political angle. This paper describes the technical alternatives.

Introduction

It is clear that nuclear power is essential to the future of the world. This is based on the high cost of oil, the limited resources of fossil fuels on the planet, and the dangerous effect of emissions from fossil fuels on our climate. For a large, fast-growing country like India, nuclear power is doubly important. The Indo-U.S. nuclear deal is supposed to address our growing need for nuclear power. To decide whether or not this particular deal is truly beneficial for the country, we must naturally perform a detailed cost-benefit analysis. Since these are deeply technical matters, this cannot be done by politicians or diplomats alone– it has to involve the scientists.

It is a matter of regret that based on such an analysis one has to reject the Indo-U.S. nuclear deal in its present form, for the simple reason that its benefits are outweighed by its costs in terms of the conditions imposed on our independence of action.

Need for a Deal

Two major types of benefits are advertised: access to the latest technology to strengthen the indigenous programme, and access to uranium and to reactors to augment our power production. Of these, the former is simply incorrect. Our indigenous programme is based on heavy-water reactors, fast-breeder reactors, and thorium utilization. The U.S. programme is based on light-water reactors – and even these have not been built in the U.S. for almost 25 years. In fast-breeder technology we are well advanced. Unlike us, the U.S. and other Western countries have easy access to uranium and few resources of thorium, so they have no interest in thorium utilization. Finally, around 90% of the components in our reactors are indigenous. So what technology import are we talking about? It would be economically more fruitful for us to instead focus on the export of nuclear technology!

The latter, access to uranium and additional power-producing reactors, is also hyped-up. The deal does not involve selling us uranium at subsidized or fixed prices. It only allows us to buy uranium from the market. Similarly, the deal does not guarantee us a single new reactor. It only makes it possible for us to explore the international market, and negotiate to buy reactors at market prices. The price of uranium is presently $85 per pound, up from $20 per pound three years ago. If the demand from India and China goes up, the price can only go up further. Overall, the cost of electricity from imported reactors will definitely be more than the cost from indigenous reactors. In addition, one can expect a host of legal wrangles, including the issue of government guarantees, in importing such expensive and sensitive items. Further, we have to submit to intrusive safeguards, the character of which have changed in the past and will continue to alter in the future. Being a non-weapon country we will be at the receiving end without any option for withdrawal.

The costs of the deal, on the other hand, are substantial. The most important one is that it will seriously impact national security. Further testing is essential for us to develop and maintain a credible nuclear deterrent. That will become impossible, in spite of the repeated assertions that the agreement does not infringe on our sovereign right to conduct nuclear tests. Imagine that the 123 Agreement is indeed ratified and operationalized, and we have imported some 5,000 MW of reactors. If then changed geopolitical circumstances make it desirable, even imperative, for us to conduct nuclear tests, no reasonable Indian government of the future would dare to do so, given the large dependence on power from the imported reactors. In other words, when we sign the 123 Agreement, we will also be signing away our ability to act independently in the strategic sphere. It is sometimes argued that it is not essential to test. This position is contradicted by the actions of the U.S. itself. Even after sixty years of weapons development and over 2,000 tests, after the end of the Cold War and the emergence of a 'unipolar' world, the U.S. wants to start Reliable Replacement Warhead project, to invent new nuclear weapons and to maintain their stockpiles in operating readiness. Further, the Russians announced the other day a new weapon called the 'father' of non-nuclear weapons. Does this presage a return to the 'Cold War' days, and if so, will we not need to be well prepared?

So, if we need more nuclear power, and if the Indo-U.S. nuclear deal is not acceptable, then what are the alternatives? Let me address these alternatives in some detail.

Our reactor options

We have chosen the pressurized heavy-water reactor (PHWR) route to nuclear power. These reactors use natural (i.e. un-enriched) uranium as fuel, and heavy water as moderator. The technology for making the components for such a system, from developing exotic materials like zirconium, to the control electronics, to the turbo-generator, have all been developed in the country. Two 550 MW electrical power stations have been built and are operating at Tarapur, which were recently dedicated to the nation by the Prime Minister. Work is on hand to scale up the design to 700 MW in the new power stations to be built. The economics of nuclear power based on an indigenous industry, has also been proven. The clamour for the import of light-water reactors of 1,000 MW capacity as an additionality, is therefore only like importing high-end cars like the Mercedes. It is not the work-horse for securing nuclear power for the future of the country.

Light-water reactors from the U.S. are not the only option. Recently the head of Atomic Energy Canada Limited has issued a statement (published by the Press Trust of India) which talks of modified Candu reactors which will use MOX fuel involving plutonium and thorium and thus introduce thorium in the fuel cycle earlier than fast breeder reactors – an old concept similar to our Advanced Heavy Water Reactor (AHWR) but utilizing the same hardware of CANDU which will make it most economical. He has also welcomed cooperation in introducing it in India since we have established reprocessing and MOX fuel making facilities long ago some fifteen years. We should grab such opportunities because we have demonstrated successful cooperation with them. It will also free us from the hold of enrichment cartels that can hold us to ransom in the future.

Another direction is to accelerate our fast-breeder programme. Breeder reactors make more fuel than they burn. Theoretical concepts which will allow in situ burning of fertile material like depleted uranium and thorium are also coming up, especially from BARC. Because of the high-temperature sodium that is used as the heat removal agent, they have higher efficiency in converting heat to electricity. The Prototype Fast Breeder Reactor (PFBR) project will establish our capability to be on our own in this area. To speed up large scale commercialization we should invest in one more PFBR as well as on reprocessing plants. Dedicated reprocessing plant with IAEA and U.S. approval under additional protocol can be a non-starter if we go by previous experience. The dedicated reprocessing plant as envisaged in the 123 Agreement will at least take ten years to provide plutonium fuel for our fast reactors. Do we wait for another six yeas or more to reprocess the accumulated fuel from the light water reactors at Tarapur?

Problem of availability of uranium

It is true that there has been a mismatch between our mining and processing of natural uranium and our needs, which has produced a bottleneck in our operating PHWR reactors. This is because of several reasons: the high cost of production due to the low grade of the ore, diversion of uranium for enrichment for strategic purposes, lower burnup in the reactors for operational reasons etc. At one stage one did hope for import of yellow cake from the international market, which was prevented by our dearest friends even though we offered to put them under safeguards. As the Australian PM recently declared, if we sign the 123 Agreement that country will consider supplying uranium to India, for we will then have effectively signed the Non-Proliferation Treaty – something Indian governments have refused to do for years. Should we really panic at this stage? Does this not give us an opportunity to plan better, fuller utilization of the un-burnt fuel in our existing reactors, the Tarapur reactor in particular, and not be content with just burning less than one percent of the uranium that we have mined and utilized? The Canadian approach described earlier is one example of reducing our requirement of fresh natural uranium. The AHWR concept is again a feasible proposition, but has not proceeded fast enough. In any case, for the good of the world, when every uranium atom is fissionable we should try and make it possible rather than wasting most of it as the U.S. has pioneered over the last 35 years. Special scientific committees in the U.S. have advocated reprocessing of commercial fuel and utilization of the fissile material more effectively, but the insistence on the 'black box' non-proliferation regime advocated self-denial in that country. It is only Japan which has very strong interest in reprocessing light-water reactor fuel, to make it a richer energy source for the future.

Uranium ore was not considered a valuable material until the discovery of fission. It had very little practical use as a chemical substance. Therefore, there wasn't much interest in exploration for uranium deposits. It is only now that we find that the uranium is getting to be more important even compared to oil and gas. The resources must be more uniformly spread on the planet than we think it is. Research and development in uranium exploration hasn't received enough attention. Since the discovery of rich ores in Africa, Canada and Australia, and their easy access to the U.S., it prevented commercial interests for exploration. In the Soviet Union, because of its connection with the defence needs, there was no question of costs and therefore exploitation of even low-grade ore has gone on for years. If we prove greater percentage of burn-up of uranium, then the cost consideration may not apply.

What about the availability of uranium in non-Nuclear Suppliers Group countries? There are several areas in Africa and South America that have uranium ore. They are not members of the Nuclear Suppliers Group. Unfortunately, the commercial industries in advanced countries quickly grab control over these sources, and prevent free trade. The question may be asked, whether controlling trade in natural uranium is called for to implement the non-proliferation regime. But, it is they who make the rules.

Barter deals

In our experience, during the early years of our independence, Homi Bhabha complained to Pandit Nehru, that there was an attempt to internationally control even the mines of exotic materials in developing countries. The Atomic Energy Act in India, thanks to his efforts, described in detail the atomic minerals and prescribed that the ownership and control will rest with the government. Once, in Parliament, Panditji even talked of how we cannot agree to international control of mining operations. The export of beach sands was stopped and was taken over by the Department of Atomic Energy. Nobody had a right to export monozyte without approval of the DAE, which bought over that portion of the mineral sands for stockpile. There is a complaint that right now the beach sands are being illegally exported from the southern tip of the country, and there is even a court case in Madurai.

When necessary, Homi Bhabha also resorted to bartering strategic materials in return for equally important equipment. I remember a 6 MeV van de Graff accelerator, a state-of-the-art machine made by High Voltage Corp., then coming into vogue for nuclear research, was imported by bartering mineral sands to the U.S. The beryl ore, which contains beryllium, another strategic material, was bartered with France for sharing the technology of making beryllium oxide, as well as using it as a moderator in a reactor, under joint collaboration with Saclay, France. We have at present capability in nuclear technology, ranging from isotope production, research reactors, use of isotopes in health and industry, heavy water – a very sensitive material for reactors – zirconium and its alloys for components of nuclear reactors, as well as beryllium metal. At a crucial stage like this, when not market forces but international cartels control trade, it is necessary for us to think of bartering this material with non-Nuclear Suppliers Group countries, who are not bound by Nuclear Suppliers Group rules. Don't forget that there is more uranium dissolved in the ocean waters, and when researchers succeed in extracting that from sea-water, there could be no control over the uranium supply. For that, effective research and development is required.

Separation plan

In the July 2005 statement India offered to provide a plan for separating its facilities into civilian and military. The option of putting the civilian facilities under IAEA safeguards, and at what time, was supposed to have been left to India. However, it took seven months, until March 2006, in lengthy discussions with the U.S., to arrive at an agreement coinciding with the visit of President Bush. Since the separation plan is applicable only to weapon states, it was presumed that the U.S. had at last accepted India as possessing nuclear weapons and having a strategic programme. However, the non-proliferation lobby in the U.S. had argued that the separation plan violated the Nuclear Suppliers Group requirement of full-scope safeguards, which means, all facilities should come under IAEA safeguards. The U.S. Congress eventually passed the Hyde Act with the sole aim of restricting the availability of basic material for weaponisation, and putting many restrictions on our reprocessing facilities. This was to make it acceptable to the U.S. Congress, and they in turn brought in the termination clause on the nuclear tests such that India doesn't make further progress in this field. Even though India protested, the U.S. administration could not influence the decision of the Congress. In the 123 Agreement, we see no mention of an agreement with respect to the separation plan, which clearly shows that the U.S. has now left the burden of agreeing to the details of the separation plan to the IAEA, under the India-specific safeguards agreement that is to be negotiated. It was not an easy task for DAE to agree to this separation plan, because the facilities weren't built like that. Now the IAEA can ask for a complete list of nuclear facilities and ask why only certain facilities are put under the civilian list, and question the timing. It can logically put restraints on the use of any of these facilities from one sector to another. When we signed an agreement with Pakistan on not attacking each other's nuclear facilities, we had to declare where and what are the nuclear facilities, which certainly revealed information which was not necessary in the public interest. In the same way the IAEA India-specific agreement may also be injurious to our strategic programme. It is surprising that the separation plan is neither an agreement nor a unilateral declaration by India. The Nuclear Suppliers Group will again have a chance to pick holes in our separation plan. Therefore the claim that the 123 Agreement solves all problems satisfactorily is not necessarily true.

Conclusion

The scientists have no fears about importing light-water reactors along with the fuel, to augment nuclear power sources. We have, for example, started off our nuclear power programme with the Tarapur light-water reactors, imported from the U.S. We have the Kudankulam project which has 1,000 MW reactors built in collaboration with Russia, which is a Nuclear Suppliers Group country and has agreed to supply fuel for its lifetime. Other countries have bought light-water reactors, like Japan, South Korea, China. But what is questionable with the Indo-U.S. deal, is their insistence on conditions extraneous to nuclear power, about which the media have elaborated. Even Supreme Court lawyers and judges have pointed out how amending the national law by the U.S., under the Hyde Act, is not sufficient to give us the freedom to pursue our strategic programme, and continue our three-phase power programme without strings attached. If the US trusts us as a strategic partner, which believes in their non-proliferation regime and will not do anything to support attempts at making WMD in other countries, I don't see why they should not trust that our efforts in enhancing our abilities in reprocessing technology is purely for our fast-reactor programme and thorium utilization. We don't have to fall in line with their thinking on the next generation reactors or what their programme is to enhance nuclear power in their countries. On the other hand, competition in nuclear technology could lead to safer, more economic and cost-effective systems being developed, by India and China, taking into account the much lesser cost for R&D as well as manufacturing of components.

The growth of nuclear power in this country has to be based on expanding our indigenous capability, rather than importing the reactors as well as the fuel for its lifetime. To make a stock for a lifetime of 40 years of a nuclear power station, by investing in the fuel, is certainly not economical, considering the high interest rates obtained in India. It also speaks of a lack of confidence in our own ability to expand the enrichment capability in India, as well as making the MOX fuel, which also can be used in the light-water reactors. We must allow the future generation of scientists and engineers to innovate new systems, so that we demonstrate to the rest of the world that India is capable of leading the world in nuclear technology. The AHWR and the fast-breeders are examples of this type.

Nuclear science will progress, and new options will appear, as long as one is willing to think, experiment and innovate**.** Cold fusion and low energy nuclear reactions focused in this journal are important. The control on the thinking process is the worst thing that can happen to any country. Well established infrastructure can quickly decay if rational progress is not maintained. Even the US will find it difficult to get manpower if a sudden decision is made to climb back onto the nuclear bandwagon. Political decisions cannot create capability overnight. It has to be nurtured and grown in a systematic manner, without entanglements like in the proposed deal. That is where political decision of a type which goes beyond pure finances and economics, are called for. The debate is about not survival but progress. For example, if we hadn't expanded our agricultural production, wouldn't we be importing food at enormous cost, upsetting our economy? If we hadn't built large-scale steel, cement etc. industries, would our industrial capacity and growth-rate have the present status? Mere foreign investment in terms of dollars is not enough to sustain a growth-rate, unless it is backed by productivity in agriculture, industry, and in education. We are reaping the benefits of a high level of education in the software industry, but this has to be backed by a sustained growth in technology. The satellite launching capability demonstrated by the Geo-Synchronous Launch Vehicle is an example of how the future can be secured by a consistent policy which is based on self-reliance.

The scientists' opposition to the nuclear deal is not based on capitalism or socialism, but to allow indigenous growth in capability in nuclear technology, which will assure energy security in the long run. No economist has ever proved that out-sourcing nuclear technology for sustaining power growth in India is feasible or warranted. The sacrifices one has made in the past and that one is willing to make in the future, are testimony to a vision which originated with Nehru and Bhabha, and which was sustained for generations by a political will. One can change perceptions on non-alignment, global trade, etc., but it has to be realistic, taking into account the teeming population, the opportunity for jobs, and building up our capabilities in the industry, defence, and agriculture. A holistic view of progress is what is called for, and perhaps a rededication of what happened in space and atomic energy in the past, is the best way for growth in the future.

(New Energy Times, November 2007)

There are weighty reasons not to accept the 123 Agreement

Dr P.K. Iyengar

(Former chairman of Atomic Energy Commission)

The US is making strenuous efforts to get India to sign the Indo-US nuclear deal, essentially by threatening that it is 'now or never'. This is in contradiction to the statements made by US Ambassador that a new US administration may be willing to renegotiate the deal within a year of taking over. But this begs the question whether the deal is desirable or not. Obviously, it is desirable from the American perspective because it will, in essence, prevent any further nuclear tests, cap our strategic programme, and bring us into the Non-Proliferation Treaty (NPT) through the back door. But is it in our national interest? The lack of scientific debate in the media has led the Indian people to believe that we need the nuclear deal, and they are in broad support. But the reality is that this deal, in the present form, is just another way of getting India to accept that it is not a nuclear power. To understand this, we must go back to the beginning of the deal.

Joint Statement

After several years of negotiations by the NDA Government and later by the UPA Government, the Prime Minister of India and the President of the United States of America signed an agreement on the strategic relationship between the two countries on July 18, 2005. That agreement devoted three paragraphs to cooperation in civil nuclear energy. Specifically, it said that "as a responsible state with advanced nuclear technology, India should acquire the same benefits and advantages as other such states". President Bush promised that he would "also seek agreement from Congress to adjust US laws and policies, and the United States will work with friends and allies to adjust international regimes to enable full civil nuclear energy cooperation and trade with India …." In return India agreed to separate its civilian and military nuclear facilities and programmes in a phased manner, to place most of the civilian facilities under IAEA safeguards, to sign an Additional Protocol with the IAEA, to continue its unilateral moratorium on testing, and to work with the US on concluding at a multilateral level the Fissile Material Cut-off Treaty (FMCT).

I, and many like-minded people, welcomed this Joint Statement. Though there was some concern about the statement regarding the FMCT, the statements about 'adjusting' US laws and international regimes suggested that this agreement would bring us to the nuclear table as a de facto nuclear power, in recognition of the realities of the day. It would also allow us to augment our indigenous nuclear power programme with imported reactors, such as the Russian VVER reactor already under construction at Kudankulam. Most importantly, it seemed to recognise India's impeccable non-proliferation record since 1974, and to protect our strategic programme. The Prime Minister, in his suo-motu statement in Parliament of July 29, 2005 emphasised that "… we have ensured the principle of non-discrimination. I would like to make it very clear that our commitments would be conditional upon, and reciprocal to, the US fulfilling its side of this understanding." He added, "should we not be satisfied that our interests are fully secured, we shall not feel pressed to move ahead in a pre-determined manner." And finally, "our autonomy of decision-making will not be circumscribed in any manner."

The Separation Plan

The problems with the nuclear deal commenced with the very next step—the Separation Plan. This document clearly spells out the guiding principles behind our approach to separation: "Consistent with India's national security and R&D requirements as well as not prejudicial to the three-stage nuclear programme in India"; "must be cost effective in its implementation"; and "must be acceptable to Parliament and public opinion." However, the separation plan was only submitted for information to the Parliament by the UPA Government, not for approval.

The Plan also clearly states that: “a facility will be excluded from the civilian list if it is located in a larger hub of strategic significance.” However, in spite of the APSARA and CIRUS reactors being located within BARC, which is our largest ‘strategic hub’, CIRUS is to be closed down, and the fuel core of APSARA will be moved outside BARC and put under safeguards in 2010. Compromises like this weaken the legitimacy of the Separation Plan, and lead naturally to suspicions that on other matters too we may succumb to external pressure. For example, the two ongoing fast-breeder reactors (PFBR and FBTR) have rightly been kept out of safeguards, since the fast breeder programme is in an R&D stage. However, before the fast-breeder technology becomes mature, much more R&D will be required to evolve the reactor design. For this we will need to have more breeder reactors, and related facilities, outside safeguards - and this will be opposed by US. Will the government of the day have the strength to withstand the pressure? Similarly, we are working on a new Advanced Heavy-Water Reactor (AHWR). Since this is for the power programme, it is likely to be designated as civilian, but since considerable R&D remains to be done, it would not be in the national interest to subject that programme to safeguards.

Finally, the separation plan also spells out that: to further guard against any disruption of fuel supplies, the United States is prepared to take the following additional steps.” These include: (1) The United States is willing to incorporate assurances regarding fuel supply in the bilateral U.S.-India agreement; (2) The United States will join India in seeking to negotiate with the IAEA an India-specific fuel supply agreement. We now know that the US has reneged on both points. The bilateral 123 Agreement contains only vague reassurances and no concrete assurances, and India is negotiating with the IAEA alone, not jointly with the US. If the US has already, before the deal is done, turned its back on us, it augurs ill for the future of the relationship.

The Hyde Act

After this, the US produced a document and submitted it to their Congress for amendment of their Atomic Energy Act. This was deeply debated in the US with testimonies from several experts in that country. Going through all these statements, the Indian public was worried that the US Congress may prescribe conditions not intended in the July 2005 agreement. By November 2005 the US passed the Hyde Act for Indo-US Cooperation in Civil Nuclear Energy.

The Hyde Act states very clearly that: (1) nothing in this title constitutes authority for any action in violation of an obligation of the United States under the NPT; and (2) a determination and any waiver under section 104 shall cease to be effective if the President determines that India has detonated a nuclear explosive device. These statements are not from the ‘advisory’ part of the Act, but from the prescriptive part. They make it explicit that the NPT will cast its shadow on the 123 Agreement, and therefore that India will not be treated as an equal of the other nuclear powers, in contradiction with the July 18, 2005 Joint Statement. More dangerously, the moment India tests a nuclear device, the entire deal falls through. In essence the Hyde Act, in one stroke, also terminates the development of India’s strategic programme. For many of us the Hyde Act made it decisively clear that the US had no intention of treating India as a de facto nuclear power, as the July 18, 2005 Joint Statement seemed to indicate. It became clear that this was only another way of getting us to agree to IAEA safeguards as a non-weapons country, which every Indian government has resisted since Pokhran I in 1974.

Many in and outside the government have argued that the Hyde Act is not binding on India, and therefore we need not worry about its provisions. This reasoning is clearly flawed. That the Hyde Act will constrain the actions of the US government has been made very clear by virtually every major US government official. The Indo-US nuclear deal is between two partners—India and the US. If the Hyde Act constrains the actions of one of the partners, how can it fail to have an effect on the other? Specifically, if the deal is made operational and we become dependent on imported nuclear plants and fuel, will it be possible for any responsible Indian government of the future to conduct a nuclear test and lose those plants, whatever the geopolitical realities and demands of the day? We should be very clear in our minds that, in the real world, the Indo-US nuclear deal will strike deeply at our strategic programme. All talk of retaining our 'sovereign right to test' is just theoretical rhetoric.

The 123 Agreement

After a series of negotiations the Government of India announced that it has initialled a 123 Agreement, without publishing the details. This created political protests and later, after the Cabinet had approved the draft agreement, it was made public. The text of the agreement confirmed our fears. The 123 Agreement very clearly states that: "each Party shall implement this Agreement in accordance with its respective applicable treaties, national laws, regulations, and license requirements concerning the use of nuclear energy for peaceful purposes." This means that the actions under the 123 Agreement are circumscribed by national laws such as the Hyde Act. By agreeing to the present draft of the 123 Agreement, India has agreed to accept all the provisions of the Hyde Act.

Further, the 123 Agreement also states that "… India will place its civilian nuclear facilities under India-specific safeguards in perpetuity and negotiate an appropriate safeguards agreement to this end with the IAEA." (Emphasis added.) This is a seriously objectionable clause, especially when the 123 Agreement itself is valid only for forty years (after which it can, by mutual consent, be extended for ten years at a time). It is completely unacceptable to place our nuclear facilities under safeguards in perpetuity. This also shows that the 123 Agreement does not treat India as an equal of the US, contrary to the word and spirit of the July 18, 2005 declaration.

The 123 Agreement seems to allow India the right to reprocess irradiated uranium, and carry out several processes towards a closed fuel-cycle, though the details as enumerated are not well thought-out. However, such a reprocessing facility will be under IAEA safeguards. Since India has so far kept the reprocessing technology out of the scrutiny of others, opening it up to the US and an international body like the IAEA will not be in the national interest, and will not help non-proliferation.

Naturally the political upheaval against this agreement was intense. There were debates in public fora, in the Committees of the political parties as well as amongst some concerned scientists. However, the offer of foreign investment in billions of dollars for nuclear power stations on a turn-key basis and assurances of supply of nuclear fuel, possible approval by the nuclear suppliers' group to the 123 Agreement which might result in cooperation being extended by other nations, the need for nuclear energy security, have all played a part in swinging the public into favouring the 123 Agreement. Since the stability of the government depends on the support of the left parties in Parliament, which is coordinated by a special committee, the Government had to concede that they would discuss the 123 Agreement with the left parties alone. Those negotiations were continued for months without the leftists conceding their basic objections to the 123 Agreement.

IAEA negotiations

The 123 Agreement clearly states that: The United States will join India in seeking to negotiate with the IAEA an India-specific fuel supply agreement. However, the US did not honour this commitment (which was also contained in the Separation Plan), and India approached the IAEA on its own. The negotiations with IAEA completed six rounds of talks and then it was announced that the text of the agreement was almost final. However, this text has not been made public. There have also been contradicting statements that the agreement is not final. The story goes around that the US has asked India to make IAEA responsible for ensuring fuel supply when for any reason the Agreement is violated by an Indian nuclear test. It isn't clear when, if at all, the agreement will be finalised and made available for scrutiny to Parliament and to the people of

India.

End-game

The entire Indo-US nuclear deal started grandly, with the July 18, 2005 Joint Statement announcing that "as a responsible state with advanced nuclear technology, India should acquire the same benefits and advantages as other such states". This had all the connotations of India being admitted to the nuclear club as a card-carrying member, in recognition of both, our achievements and our responsible behaviour. In the three years since then, the arguments in favour of the deal have become weaker. Today the proponents of the deal have two much narrower arguments to make. The first is technical: we are short of uranium and we need the deal to keep our reactors operational. The second is political: this is the best deal we can get, so let us grab it before it disappears. More recently a third has been added: if we don't conclude the deal we will 'lose face'.

Let me take first the uranium problem. For years we have claimed that we have enough uranium ore to support 10,000 MW of nuclear power for 30 years. We have not used up even major part of it, then why this sudden cry? Further, there has been no discussion regarding the economics of importing uranium or the legal issues (related to providing guarantees). The 123 Agreement does not guarantee free or cheap uranium to India. It only formalises the intent of the US government to allow trade in nuclear material and technology, which is presently forbidden. The actual sale of uranium will still be a commercial transaction, governed by market price of uranium, and by commercial terms and conditions, and will be subject to perpetual safeguards. The price of uranium has gone up four-fold in the last three years—from $20 to $85 a pound—and the price will shoot up even more with increasing demand. Therefore, the 123 Agreement is not a panacea for our uranium problems. A cheaper and faster solution would be to spend the money on uranium prospecting, and simultaneously to look towards non-NSG countries for importing uranium.

The second argument is that we should clinch the deal now; otherwise a new US administration may not offer a similar deal. This flies in the face of statements from the US Ambassador that a new administration may be able to negotiate a deal within a year of taking over. In the time-scales of nuclear power, this is not a very long time. In fact, the longer we wait, the stronger the country becomes economically, the better the deal we can negotiate.

Finally, 'losing face' is an argument that may apply to individuals and human emotions. It is scarcely an adequate basis for conducting the foreign policy of a large nation.

Conclusion

It is clear, from the texts of the various acts and agreements, which I have quoted above, that:
(1) the 123 Agreement will be circumscribed by the provisions of the Hyde Act;
(2) if India conducts a nuclear test, the 123 Agreement will be abrogated and we will have to return all nuclear material;
(3) consequently the nuclear deal, via the provisions of the Hyde Act, does, for all practical purposes, severely constrain our strategic programme;
(4) the 123 Agreement does not secure our national interests, does not give us a status equal to the US, and is therefore in direct contradiction with the July 18, 2005, Joint Statement and the assurances given by the Prime Minister to Parliament on July 29, 2005;
(5) The US has already, by not joining us in approaching the IAEA, not fulfilled its reciprocal obligations, again contradiction to the assurance given in Parliament;
(6) Given that the purchase of uranium and nuclear technology will be governed by market forces, and safeguarded in perpetuity, it has not been demonstrated that the nuclear deal will be cost-effective in its implementation.

These are weighty reasons why the nuclear deal is not in the national interest. This is perhaps why a majority of Parliamentarians are also opposed to the nuclear deal. Winston Churchill has defined democracy as "the rule of the majority with the willing consent of the minority". Here is a case in which a government in a minority wants to rule without the willing consent of the majority! It would be a matter of regret for the nation if the democratic process is not allowed to play its role in coming to a conclusion on a very important and strategic area of activity. In many countries in the world this could be a subject for a referendum, but we have never experimented with this method.

One is reminded of the call given by Pandit Nehru at the dawn of Independence, on our "Tryst with Destiny". The right to decide our own destiny is what we gained. However, in the last sixty years, we seem to have described destinies on paper but never implemented them effectively. Education for children, emancipation of women, abolition of distinctions have all continued without a firm decision at any time. All the good work done by this Government will be obliterated by a single mistake which affects the future generations.

It is also a matter of regret that the Government has not considered the advice of senior scientists who appealed to the Parliamentarians in August 2006, to look to the future of nuclear policy in an objective manner and not accept the conditions extraneous to the cooperation in civil nuclear power. It is also regrettable that this country which has grown on its own for the last sixty years still seeks expert advice from outside and does not care for its own accomplished experts. It is not only in the nuclear field such problems exist but also in other fields like in agriculture, health, education and economic policies. Recently, India Today quotes former Prime Minister Indira Gandhi as follows: "A nation's strength ultimately consists in what can it do on its own, and not in what it can borrow from others." Let us remember her words, and act by them.

(Organiser, 8 June 2008)

Deccan Herald Interview

Political and bureaucratic circles are elated with the latest approval of the Indo-US deal by the US House of Representatives that turned down some damaging amendments. Seen as a kind of coup against the India baiters as well as the non-proliferation lobby, the deal now has to be approved by the Senate before being signed into a law by the president. But there has been one section whose voice has been muted in this debate. That of the country's scientists. Wary of the deal from the beginning with respect to what it would mean to research and development, this section has now expressed some reservation even with the assurance from the PM that the deal will not be diluted from the agreement of 18 July 2005.

But there are still aspects not sufficiently discussed and recognised. Calling for debate among informed citizens as a precondition to enter such deals in future, these experts have been seeking a mechanism to evolve consensus on such crucial strategic issues. Speaking to Deccan Herald in an exclusive interview was Dr P K Iyengar, one of the country's top nuclear scientists. Having served as director of BARC, and later as chairman of Atomic Energy Commission, Dr Iyengar was also a key figure in Pokhran I blast.

From a scientist's point of view what is wrong with the deal?

It is the loss of sovereignty over research and development. If water is to be purified the US may use reverse osmosis or steam condensation but that is not applicable to our village economy. We need to apply local conditions. So also in the nuclear programme, we have large Thorium reserves and we will go for a reactor that uses it. But this deal restrains even that. Every gram of uranium mined, from where it was taken, how much is used for weapons, etc has to be specified to the IAEA. That is unpalatable to me and to many others. This is very similar to the situation in early 1950s, when, as part of the Baruch Plan, it was recommended that all sources of uranium should be under international inspection. At that time Jawaharlal Nehru strongly objected to this proposal, on the grounds that we would lose our sovereignty. It is happening again.

Today the US is working on a new generation of nuclear weapons in the tonne range and not kilotonne. These won't destroy cities but can be more target-specific. They are looking at making energy unidirectional. For such research, we need independence, not someone breathing down our necks!

In the past we have proved our abilities when technical sanctions were imposed and we had to get the reactors and plants going. We successfully commissioned heavy-water plants and we now even export heavy water. It is only in the space and atomic energy departments that we have shown that technology can be developed in the country. We need to take some risks and if out of 10 launches two fail, that is ok and we can learn from it.

When I was director of BARC, when the French walked out on supply of enriched Uranium, we decided to go for a Plutonium Uranium carbide fuel for the FBTR. The French ridiculed the idea and said that it would catch fire if we heat plutonium and carbon together. So we decided we would use double containment with inert gases. It was the first time in the world that a carbide fuel was used in a fast reactor. This fuel has seen 100,000 MW days per tonne of irradiation so far. We have since reprocessed the fuel, and all is well with this reactor. So R&D needs both ability and willingness to take risks. We have it but the government does not recognise this. It prefers to import fuel and technology for nuclear power!

In fact we have enough Uranium reserves in the North-East and in Nalgonda district in AP. In the latter, a tiger sanctuary was the bone of contention. All we need is a few acres of land to drill a hole and no tiger need be disturbed for this. Also there is uranium dissolved in the sea water. We can separate it at a cost.

Why then is the government so keen on imports?

What I suggest here may be more costly than what can be imported. However the cost of Uranium has recently gone up 300%. Even now we can buy only if the uranium is subject to safeguards in perpetuity.

What is the problem with separation of civilian and military facilities?

This is a problem for us because we did not grow that way. Today at BARC we have 90% of the scientists and engineers working on civilian uses of nuclear energy while a few work on military uses. Now the plan is to designate BARC, Kalpakkam, etc. as military establishments so they escape safeguards. And in the process a reactor like Apsara (50 years old) has to be shifted out and CIRUS shut down. This is an illogical decision forced on us.

Due to resistance from scientists, the fast breeder reactor that is operating and the one that is under construction have been placed outside safeguards. However, future FBRs will come under inspection!

What about the TIFR and the Variable cyclotron facility, which has been placed under civilian list by the government?

How can a basic science centre and deemed university like TIFR be placed under IAEA inspection? Under the additional protocol, this may imply that the scientists have to send their research proposals to the IAEA in advance for its approval! It is through research in basic science that new ideas develop. For example, in inventing new methods of enrichment, or a new kind of thorium fuel for the fast breeder. If we have to reveal all our ideas to the IAEA in advance, what happens to the concept of intellectual property rights?

Do we need n-energy? What projection can we aim at?

We need power for our developing economy and a reliable supply of energy can come only from nuclear. This is the technology of the future. We need it given our demands from our large population and also because it is a clean energy that can save the planet from pollution and greenhouse gas problems.

The energy availability per person in our country is only 400 kW-hr per year per person, as against 10,000 KWh-hr per year per person in Norway. With the rapid industrialisation ongoing we need to harness at least 2,000 KWh-hr per person per year. By using nuclear energy based on uranium or thorium, we will overcome the difficulties of pollution and emission of green-house gases. With the present plans, we can aim to increase the share of nuclear energy from the present 3% to at least 10% by 2020.

Don't you think renewables like wind, solar and hydel are better options?

Yes we must pursue them provided we research on them and learn to optimise. Solar energy is a great option but again there is the efficiency problem of how to convert the radiation to electricity. In a thermal plant the efficiency of conversion of heat to electricity is around 30%. In a fast breeder reactor using liquid sodium as coolant, the efficiency can exceed 40%. For solar power the efficiency is only around 10%. Windmills are good but do you have wind all round the year? The windmills themselves have to be imported. These are good options for small amounts of power for domestic use, but are not viable for industries, where you need large amounts, hundreds of MW, of power.

There is a belief that the costs and gestation period make nuclear energy not economically viable.

We have decreased the gestation period from 8 to 6 years. It depends on infrastructure in the country for manufacturing components. As more orders are placed, it will improve. It creates job opportunities, unlike in the case of imported reactors, where jobs are created abroad. Also the money is ploughed back into the Indian economy. Another problem was with the privatisation drive of the 90s. Capital costs were high and returns expected in 5 years. It was then realised that government will have to invest in energy sector, especially nuclear energy.

What about the lifetime and safety aspects?

The lifetime is usually around 30 years but can be extended to 50 years. We haven't shut down any nuclear power reactor. As to nuclear safety: our record is as good as, if not better than, any other country. There have been no Three Mile Islands or Chernobyls in India. We are as technologically as advanced as any other nation, especially the US. What they have is huge infrastructure. We need to grow ours. Why do we have only one BHEL? We ought to build many more.

A final word on the deal.

India has always pursued an independent foreign policy and been a spokesman of the developing world. We have learnt that it is best to steer clear of the big powers and not be influenced by their policies. So why now succumb to US pressure and vote against Iran and lose the gas? India has always advocated universal nuclear disarmament: to have a nuclear deterrence capability is due to circumstances forced on us. We don't need to be taught lessons in nuclear non-proliferation from countries that continue to stockpile nuclear weapons.

Way back in 1965, Homi Bhabha, the Chairman of the Atomic Energy Commission at that time, announced that if needed we could make the bomb in 18 months. That announcement was credible because it came from a scientist and the Chairman of the AEC. Today scientists are shut out and the PMO thinks it knows all. That is the difference between then and now.

(Deccan Herald, 13 July 2008)

Appeal to the Members of Parliament On The India-US Civilian Nuclear Co-operation Agreement

1. We were part of a group of senior nuclear scientists who had in the past expressed our grave concerns and objections to India entering into a nuclear co-operation agreement with the US under the aegis of the Hyde Act 2006. We had written earlier to the Parliamentarians on this matter, and the Prime Minister had given us an opportunity to meet with him and discuss our views.
2. At this critical juncture, when the Government is about to rush the safeguards agreement through the IAEA, there is a great deal of disquiet among the scientific community at large in this country. Should the country be entering into such a long term binding arrangement without a detailed and rigorous examination of the IAEA Safeguards? Should a Government, based at best on a wafer thin majority and a divided Parliament, commit the country in this manner? *We, therefore, are strongly of the opinion that the Government should not proceed to seek IAEA Board approval for the current draft safeguards agreement, until its implications are debated more fully within the country, and with a group of experts who were not party to the IAEA negotiations.*
3. The government is enthusiastically pushing the Deal on the basis that it will bring about energy security to India, since it will enable the import of foreign nuclear power reactors. But, analysts have convincingly and quantitatively shown that this additional power will come at a much higher cost per unit of electricity compared to conventional coal or hydro power, which India can generate without any foreign imports.
4. *Once the Deal is in place, it is also clear that India's commercial nuclear interactions with the US, as well as with any other country, will be firmly controlled from Washington via the stipulations of the Hyde Act 2006 enforced through the stranglehold which the US retains on the Nuclear Suppliers Group.* Any argument to the effect that the Deal will be governed only by the bilateral 123 Agreement is untenable, because this Agreement in turn is anchored in US domestic laws, which include the Hyde Act. And, the Hyde Act contains several stipulations which are extraneous to the issue of bilateral nuclear co-operation, including foreign policy behaviour which India needs to adhere to if the Deal is to be kept alive. *The real issue facing India, therefore, is whether or not we want this mythical extra 'energy security ' through this Deal, paying two to three times the unit capital cost of conventional power plants, with the additional burden of subjugating the freedom to pursue a foreign policy and indigenous nuclear R&D program of our own.*
5. The nuclear Deal could also have other serious repercussions, including a potential weakening of India's nuclear deterrent and an inability to protect & promote indigenous R&D efforts in nuclear technology. A combination of the extreme secrecy with which the government has carried forward this deal, the media hype they were able to generate in its favour, the parochial interests of opportunistic individuals & organizations, and the unfortunate ignorance of the issues involved among the general public have put the country on a dangerous path, likely to lead to the detriment of the current & future generations of Indians. Today's urgency to rush to the IAEA Board, in consonance with the American timetable, to get the safeguards agreement approved and thereafter clinch the Deal during the tenures of the current governments in India and the US must, therefore, be replaced with an openness &

introspection that is vital for a serious debate which the situation demands.

6. The central issue about the IAEA safeguards agreement has been the doubt as to how "India-specific" these are. *In particular, since it is distinctly clear from the Hyde Act and the 123 Agreement that no uninterrupted fuel supplies have been guaranteed in these documents for reactors which India will place under safeguards*, the Government had assured that this defect will be corrected in the safeguards agreement. Since the IAEA was all along known to be no fuel-supply guarantor, *it is not surprising that Indian negotiators have failed to obtain any assurance in this regard. All that the IAEA Agreement states in its preambular section is that it notes uninterrupted fuel supply and support for a strategic fuel reserve is the basis of placing Indian facilities in safeguards. It places no obligation on the IAEA other than merely noting this. The corrective measures, indicated in the preambular section, have nothing that anchors them to any section in the operative part of the agreement. Against such unspecified and vague mention of corrective measures, India's obligations are clear and binding. In effect, India has agreed to place its facilities that it will list out in the Annex under perpetual safeguards without any link to an uninterrupted fuel supply.*

7. The Government is asserting that the IAEA safeguards have "provisions for *corrective measures* that India may take to ensure uninterrupted operation of its civilian nuclear reactors in the event of disruption of foreign fuel supplies. Taking this into account, India is placing its civilian nuclear facilities under India-specific safeguards in perpetuity". *The nation would like to know clearly what these "corrective measures" are, before plunging headlong into this Deal. India being merely allowed to withdraw the Indian-built civilian PHWRs from safeguards, and that too after stripping them of all spent & fresh fuel and components of foreign origin, is no corrective step at all because such action does not ensure uninterrupted operation of these civilian nuclear reactors in the event of disruption of foreign fuel supplies.* Even here, Article 32 of the Safeguards Agreement appears to stand in the way of any such withdrawal. *Besides, this relaxation does not apply to the imported power reactors, which will use up the bulk of our investments in nuclear power; these units will perpetually stay under safeguards*, *even after fuel supplies are denied.* The Hyde Act prohibits the US Administration from directly or indirectly (through the IAEA or other countries) assisting India with life-time fuel supplies after suspension of the Deal. Therefore, the Government owes a clarification to the Parliament and the public about how they intend to avoid the consequential huge economic loss from the non-operation of these extremely costly imported reactors, as a result of fuel denial.

8. The 123 Agreement states that the imports under the Deal "shall be subject to safeguards *in perpetuity* in accordance with the India-specific Safeguards Agreement between India and the IAEA and an *Additional Protocol*, when in force". *While the actual draft of the Additional Protocol (AP) applicable to India may have to be negotiated and agreed to at a later date, it is absolutely necessary that a prior agreement between the IAEA and India on the essential features of such an Additional Protocol must be reached simultaneous with the finalization of the safeguards agreement and certainly before signing it.* The most intrusive actions under the IAEA safeguards are always taken on the basis of this protocol, including the "pursuit clause" which permits interference with our non-civilian programs on the basis of unsubstantiated suspicion. *India needs to make it clear what the limits are beyond which we will not entertain any IAEA action or intrusion, and it should be clear that a standard Model Protocol applicable to non-nuclear weapon States will not be acceptable to India. The leverage to debate and get the kind of restricted Additional Protocol we want will be entirely lost once a safeguards agreement alone is first put in place and the installations put under safeguards*. As we understand, the limitations within which India is willing to enter into the Additional Protocol regime was neither discussed by Indian negotiators at the IAEA nor do they appear in the safeguards draft or its attachments. In this context, the Government needs to clarify their thinking on the Additional Protocol, before entering into the safeguards

agreement.

9. Reprocessing the spent-fuel arising from burning fresh imported fuel in our civilian reactors provides us valuable additional plutonium, which in turn can be recycled into future civilian fast breeder reactors (FBRs) or advanced heavy water reactors (AHWRs). Reprocessing, therefore, is at the core of India's plans to build long-term energy security. The government had all along pledged to secure an unqualified right to reprocess spent-fuel and even termed India's right to reprocess “non-negotiable". But, in the 123 Agreement, what has finally been obtained is merely an empty theoretical right to reprocess. The actual permission to reprocess will come after years, when a dedicated state-of-the art reprocessing plant is built anew to treat foreign fuel, along with a host of allied facilities. There will be a large number of safeguards & Additional Protocol issues related to this, and all these hurdles will have to be crossed to reach the beginning of reprocessing. Much of the fundamental basis on which all this will be done has to be discussed and settled now at the outset, while the overall safeguards agreement is being finalized. But, the Government has not done this exercise during the recent set of negotiations with the IAEA, and this deficiency will come to haunt India in future unless it is rectified.

10. Similarly , there are many other key safeguards-related issues of crucial importance which have not been addressed in the current draft . Furthermore, none of the issues included presently has been handled adequately or in an acceptable manner. We therefore appeal to the Members of the Lok Sabha to direct the Government not to proceed further with the current safeguards agreement , and ask the Prime Minister to initiate wide-ranging and structured deliberations on the Indo-US Nuclear Co-operation Agreement , both within Parliament and outside , to develop a broad consensus on this Deal among political parties and the general public , before proceeding any further .

SIGNATORIES:

1. **Dr. P. K. Iyengar**, Former Chairman, Atomic Energy Commission

2. **Dr. A. Gopalakrishnan**, Former Chairman, Atomic Energy Regulatory Board

3. **Dr. A. N. Prasad**, Former Director, Bhabha Atomic Research Center

18 July 2008

Ten misconceptions about the nuclear deal

In spite of the fact that the Indo-US nuclear deal is not in the national interest, many in the country, and in Parliament, support it because of misconceptions about the deal, which need to be clarified.

(1) The nuclear deal is an agreement between India and the US for the US government to supply nuclear fuel and reactors to India.

Contrary to common perception, the nuclear deal or the 123 Agreement is ***not*** a commitment on the part of the US government to provide us with uranium or nuclear reactors. Presently American law prohibits nuclear cooperation with India because we have not signed the Non-Proliferation Treaty (NPT). All the nuclear deal does is to grant a 'waiver' from that law, so that American companies can now pursue nuclear trade with India. However, if India conducts a test at any time, the waiver is revoked.

(2) Imported uranium and nuclear reactors will be cheap and cost-effective.

Even if the nuclear deal is made operational, the actual sale of uranium and nuclear reactors will be governed by market forces – there are no guarantees of cheap or competitive nuclear power. To the contrary, there is every reason to believe that it will be expensive. The cost of uranium in the international market has gone up four-fold in the last few years, and will rise further with further demand. The same is true of the cost of steel and other materials used in a reactor. Manpower costs are much higher in the West. The example of the Dhabol power plant has already shown us that importing power plants from the West is not necessarily a viable option. We would do well to learn from that experience.

(3) The nuclear deal will safeguard our energy security.

It is true that nuclear energy is green energy, and therefore essential for our ***long-term*** energy security. But this does not translate into the nuclear deal ensuring our energy security. Power from the nuclear reactors that we buy will definitely be more expensive than indigenous nuclear power. Further, to keep the reactors running, we will always be dependent on imported uranium, which is controlled by a cartel – the Nuclear Suppliers Group (NSG). Therefore, the nuclear deal, by making us dependent on the cartel, will only compromise our energy security. Only our indigenous nuclear power programme can truly ensure our energy security. And in any case, for the next few decades, nuclear power will not exceed 6% of our total electricity production.

(4) Importing nuclear plants is a quick-fix solution to the present power crisis.

Nuclear technology is sensitive. Even if the nuclear deal goes through, it will take time to buy and setup new reactors. We have examples of the French reactors in China, and the Russian reactors in Kudankulam, India. It will actually take longer to setup foreign reactors compared to indigenous ones. Just the negotiations and legal formalities could take years. It will be at least eight years before we see the first power. So importing reactors is certainly no quick solution. For the short term, we will still have to rely on coal and hydroelectricity.

(5) The nuclear deal does not stop India from further nuclear testing, and therefore does not compromise our national security.

It is very clearly stated in the 123 Agreement it will be subject to national laws, and the Hyde Act is a law of the US. Therefore, the 123 Agreement is certainly circumscribed by the Hyde Act, which very clearly states that if India tests a nuclear device, all further nuclear trade is to stop, and the nuclear materials that have already been sold to us have to be returned. No future Indian government would dare to jeopardise such a huge investment in nuclear power, by testing. So, for all practical purposes the nuclear deal caps our strategic programme – which is precisely what the Americans intend.

(6) We can pass a national law to counteract the Hyde Act, and this will protect our strategic programme.

Just as the Hyde Act is not binding on us, our laws are not binding on the US. We can certainly amend our Atomic Energy Act to enable participation of the private sector in nuclear power. But if we pass a law saying that we will retain the right to test, it will have no influence on the actions of the US. If and when we test, they can simply quote the 123 Agreement and the Hyde Act, and pull out all their nuclear materials, leaving us devastated. The only option here is to renegotiate the 123 Agreement and have the clause inserted there. However, the Americans are unlikely to agree to this, since it goes against their non-proliferation policy.

(7) The nuclear deal and the safeguards agreement give India the status of a nuclear power.

While the 18 July 2005 Joint Statement did indeed talk about India being treated as an equal by the US, neither the 123 Agreement nor the IAEA Safeguards Agreement, have borne out those optimistic statements. In fact, the IAEA safeguards agreement that has been negotiated is closely based on the model agreement that IAEA has for non-nuclear weapon states. The safeguards agreements that the nuclear weapon countries have signed with the IAEA require them to put very few reactors under safeguards, and allow them to take reactors out of safeguards. India, however, will have to place most of its reactors under safeguards for perpetuity. Therefore we are certainly not being treated as a nuclear weapons country.

(8) Without the nuclear deal, we cannot get adequate uranium for our domestic nuclear programme.

The Department of Atomic Energy has always maintained that we have enough indigenous uranium for 10,000 MW of nuclear power for 30 years. We are not yet close to that number. The present mismatch in uranium availability for operating reactors is a consequence of poor planning, and inadequate prospecting and mining. There is talk of importing 40,000 MW of nuclear power, which will cost not less than $100 billion or Rs. 4 lakh crores. If even 10% of this money were spent on uranium mining in existing mines in Andhra Pradesh and Meghalaya, on searching for new uranium deposits, and negotiating with non-NSG countries, there will be enough uranium for a robust indigenous nuclear power programme, until such time as thorium reactors takes over.

(9) The safeguards agreement with the IAEA guarantees fuel supplies even if India conducts a nuclear test.

The safeguards agreement only notes, in the preamble, that India's concurrence to the safeguards is linked to getting fuel supplies. However, the IAEA has no role in this matter, and certainly, no such commitment is given in the safeguards agreement. It also notes that India may take ‘corrective measures’ in the event of a disruption of foreign fuel supplies. It does not specify what these measures will be, it does not provide for any role for the IAEA in this, and it does not bestow legitimacy on any such measures that India may take. It may well be that any such measures that we suggest, such as importing fuel from another country, will be disallowed by the nuclear cartel (the NSG). The only tangible corrective measure is for India to explore and mine more uranium, and to enhance the enrichment capability to provide fuel for those reactors. The latter is subject to uncertainty.

(10) The nuclear deal has no impact on our foreign policy.

The Hyde Act states clearly that it is the policy of the US to secure India’s cooperation on a number of issues involving Iran, including its capability to reprocess nuclear fuel (in spite of the fact that Iran, as an NPT signatory, has the right to enrich uranium for use in light-water reactors). This has nothing to do with the nuclear deal, and can only be related to influencing our foreign policy. Recent statements by Gary Ackerman, Chairman of the US House Foreign Affairs Committee, regarding Indo-Iran gas pipeline, only add fuel to such suspicions.

It can therefore be seen, that the Indo-US nuclear deal is not in the national interest. It presents the very serious danger of capping our strategic programme. That alone is reason enough not to go forward with the deal. Additionally, it does not guarantee the energy security that we are seeking, and, in fact, may only end up making us as vulnerable to the nuclear cartel, as we are today to the oil cartel.

It is easy to see why the US wants this deal so badly. At virtually no cost, since there is no commitment towards fuel supplies, they can cap our strategic programme, bring us into the NPT net, through the back door, as a non-nuclear power, keep a close eye on our nuclear activities, including R&D, through intrusive IAEA inspections, and subjugate us to the wishes of the nuclear cartel. If there were no cartel, we could have easily extended the Kudankulam agreement for more reactors, and avoided the present situation. If these are not reasons enough not to go ahead with the nuclear deal, then there are no reasons that reason can find.

P. K. Iyengar
Chairman (Retd.), Atomic Energy Commission

(Statement released on 22 July 2008, and carried by many newspapers and Websites.)

Reaction to the letter released by House Foreign Affairs Committee

The letter released by the Foreign Affairs Committee of the US House of Representatives has clearly shown that:

(a) if India conducts a nuclear test, America will immediately abrogate the 123 Agreement, and take back all nuclear materials, including fuel, it has supplied;
(b) there are no guarantees of perpetual fuel supply or provisions to stock for lifetime;
(c) there will be no transfer of sensitive nuclear technology such as reprocessing technology;
(d) the US does not consider the 123 Agreement as the only document governing civil nuclear cooperation with India – it's actions will also be dictated by the provisions of the Atomic Energy Act and the Hyde Act (see answer 3).

There is nothing new here (though it is disturbing if this letter was not shared with the Indian government). This is what many of us have been saying for a long time. But now, for the first time, these facts are being confirmed by the American government. Should we take note of it or not? The Indian government continues to bury its head in the sand and insists that the 123 Agreement is the only thing it will look at. It is now made explicitly clear that the US government does not share this view, and nor will the NSG. The intention is, clearly, to cap India's strategic programme, and not allow it to grow or modernize. Any non-proliferation law which will enable them to do that will be applied. Once we sign the agreement we will find that all the implied understandings vanish, and we will be confronted only with the harsh realities of being treated as a non-nuclear power – in direct contradiction with the 18 July 2005 declaration, which the government maintains is the touchstone for the entire nuclear deal.

The government also keeps tiredly reiterating that the 123 Agreement does not prohibit us from conducting a test. But it fails to inform the people that if we conduct a test we will be punished, by the cessation of all nuclear cooperation and the return of fuel. It is very likely that the NSG will also make this a conditionality for their approval. The later this happens, the bigger the financial catastrophe and, even more importantly, the energy catastrophe. Is this punishment acceptable to us? The government does not address this point.

One could ask: why test? Because, it is impossible to maintain a credible nuclear deterrent, without at least some degree of testing beyond the five tests we conducted ten years ago. Why maintain a nuclear deterrent? Our growing geopolitical presence, and the worsening political situation, in our neighbourhood, in Pakistan, between the West and Russia over Georgia, between Israel and Iran, etc., all point to the need to maintain a strong strategic programme. This is why the nuclear powers are in no hurry to move towards complete nuclear disarmament.

Therefore we find ourselves in the following impossible situation. If we go ahead with the nuclear deal, and, by some miracle, we even manage to import nuclear power at competitive prices (but many years from now), we simultaneously destroy our strategic programme as well as put ourselves at the mercy of the nuclear cartel. In return, we will not even get any sensitive nuclear technologies! How can this deal be in the national interest?

The letter reveals other things that we could learn from. Firstly, the level of technical detail of the questions, which the US government has had to answer. They have not been able to get away with vague generalities, as the government has in India. Secondly, the direct questions asked about PM Manmohan Singh's statements in various fora (questions 42-44), and their implications for the 123 Agreement – there is no pretending that statements made within India are irrelevant to the Agreement. Thirdly, the deep questioning of the meaning of terms, such as ‘disruption of fuel supplies’ (question 15) and ‘corrective measures’ (question 25), which again have gone unquestioned in India. All this shows a degree of transparency and responsiveness to the legislative branch of their government, which has been lacking in India.

I hope that our elected representatives take note of the categorical statements made in the letter, as also the depth of technical questioning, and revisit the Indo-US nuclear deal in Parliament. The time to debate these issues need not be constrained by US politics. This is also an appropriate time to ask if the country needs to revisit the ‘checks and balances’ present in our Parliamentary system, to ensure that governments cannot commit the nation to very serious constraints, without a greater degree of debate and consent.

P. K. Iyengar
Chairman (Retd.), Atomic Energy Commission

4 September 2008

APPENDIX E

Homi Jehangir Bhabha: A Personal Tribute

Homi Jehangir Bhabha (1909-1966), was an outstanding scientist, innovator, and organizer of science in this country. In this centenary year, it is a pleasure to recall my association with him, and his influence that led me to devote a lifetime to the field of atomic energy.

I was very young when I joined TIFR in 1952, and therefore not in Bhabha's close circle. But, TIFR was very small then, and we could interact with the Director closely, through his weekly visits to the laboratories, meetings at tea before the weekly colloquium, and in participating at the lectures from distinguished visiting scientists. The atmosphere he created, of high scientific standards and open discussions, evoked an intense desire for doing creative science in competition with the rest of the world.

Homi Bhabha's early education was at Cambridge University in England, where he was exposed to research by outstanding physicists of the world into the structure and properties of Nature. These included not just theoretical investigations, but also some of the highest quality experimental work at the Cavendish Laboratory. All this made a deep impression on Homi Bhabha, and he decided to pursue research in this field, even when he was confined to this country accidentally due to the Second World War.

Homi Bhabha's belief that fundamental research is the stepping stone to success in science and technology is evidenced even by the choice of the name of the institute he created. He believed, and had experienced in his life, that fundamental research is the backbone of creativity. Rational thinking helps in finding solutions to old problems by new methods. One therefore has to constantly emphasise basic science in all disciplines, irrespective of whether the objective is atomic energy or fundamental particles. In his own lifetime, he nucleated two strong groups, one in radio astronomy, and the other in molecular biology, for he understood the relevance of these subjects for the future. Similarly, he was not averse to supporting fundamental research, irrespective of discipline, which is the characteristic of a true scientist.

While his roots were always in pure science, his thoughts also turned to growing science and technology in independent India, especially in the newly emerging area of nuclear physics, which, he saw, could have a fundamental role to play in the development of the country, through nuclear power. He, no doubt, had the credentials to undertake this Herculean task, but it was also the country's great fortune to have in Pandit Jawaharlal Nehru a Prime Minister who strongly believed that it was only through science and technology that one could bring about social and economic change in this country. It is well-known that Nehru and Bhabha shared an excellent rapport, and this helped enormously in growing science and technology in the country, in accordance with Bhabha's vision.

Bhabha was elected President of the First United Nations Conference on the Peaceful Uses of Atomic Energy in 1955. There he predicted the unavoidable result of spread of nuclear technology, in a manner when many nations will have the capability to make nuclear weapons, and warned the advanced nations to restrain themselves at that stage to prevent the proliferation of nuclear weapons. Unfortunately, due to the Cold War these words fell on deaf ears, and a discriminatory treaty like the NPT came into being, and India refrained from being a party to it.

What I remember of the early years at TIFR is the fact that he made experimental science respectable, and very necessary for future growth. He even set up a production unit to make electronic instruments in support of basic research and applications, a step which normally an institute of 'fundamental research' would not have attempted. At the appropriate time he created the Technical Physics Division, the Electronics Division, and Health and Safety groups related to the use of radiation, all in preparation for a robust, self-confident and self-reliant programme in the field of atomic energy. That it has flourished through the expansion of BARC and other centres, is there for all to see and appreciate. When one considers that internationally India is now recognized as an advanced nation in nuclear science and technology, it goes to the credit of Homi Bhabha, and his influence on his successors. In the applications of science, he recognized the importance of instrumentation and went even to the extent of taking over the Cancer Research Centre, in order that medical research on cancer could find its appropriate methodology.

Personally, my closest interaction with him was during a two-week trip to Canada and the US, in 1957, attending an international conference at Columbia University, and visiting national laboratories, including the Bell Telephone Lab. Those two weeks brought me into personal contact with Homi Bhabha as a human being. He was ever friendly, with advice and suggestions to visit the Art Gallery in Chicago or the science museum there. He agreed to visit with me the laboratories of my interest, *i.e.* neutron scattering, and we even bargained a few single crystals from Bell Labs., which was normally denied to others. Such was the respect he commanded that two months after my visit to Bell Labs., I received a packet containing large single crystals of Ge and Si, without interference from any officialdom. At the international conference, where many distinguished scientists from the Manhattan Project participated, I had opportunity of being introduced to them by him. He was quick to recognize merit and leadership qualities, and the fact that he appointed me Head of the Nuclear Physics Division in 1965, at the young age of 34, shows the confidence he reposed in me.

He was quick to respond to official requests, whether with regard to working space, manpower, or financial resources. Disposal of papers was most direct, and avoided any intermediate steps. The way the Trombay Scientific Committee functioned, the decisions taken with him as Chairman, speak eloquently of his democratic and effective management of science and technology. Regarding the management of scientific institutions, his last speech at the ICSU Conference in Bombay, elaborates very clearly on this topic. It is not surprising that after forty years the editor of Current Science had commented on the need to revive the spirit contained in that speech, in the present-day administration of science. Such brilliant ideas, which are based on fact, rational thinking, and innovation, never die.

In spite of being a basic physicist, he was at the same time a distinguished architect, painter, engineer and anything that you can think of for the advance of human civilization. The Department of Atomic Energy, unlike many other organizations abroad, he believed, should be the cradle of modern science and technology in India, and therefore he nucleated, supported and multiplied programmes which are relevant to the development of this country. He had a horse sense of what is important, and how economics alone should not decide on the future programmes. For example, he understood that nuclear metallurgy was essential to the Atomic Energy programme, and all relevant infrastructure, from the prospecting of uranium to processing of exotic metals like zirconium and beryllium was necessary, and so, in spite of the costs, he set up units to achieve this. The fuel for the first of the uranium metal rods for the CIRUS reactor in 1958, was born out of the rare-earth sands in Kerala. In Jadugoda, even though the quality of uranium ore was poor, he ventured to set up the mill and the processing unit, so that India would have its own uranium for the power reactors. He strongly believed that a self-reliant nuclear programme can be based only on indigenous resources, and hence formulated the three-phase programme: natural uranium, plutonium, and then on to thorium. This basic idea was far advanced in comparison with the programmes in other countries: it was because of his strong belief that sustainability and security of energy sources can come only through the natural resources of that country. Compare this to the present push to make ourselves strongly dependent on imported fuel for future reactors! I'm sure that if Bhabha were alive, he would have stopped the Indo-US nuclear deal, with objections based on fundamental issues of policy and philosophy.

In the mid-fifties Dr Bhabha realised that he has to expand research and development in applied areas like chemical engineering, nuclear metallurgy, reprocessing etc., he recognized that the rate of addition to the staff cannot depend on the vagaries of availability of expertise from educational institutions. He also recognized that pilot plant studies are important for developing industrial processes. He therefore embarked on a process of inducting, by careful selection, the best graduates from the educational institutions into a one-year course work followed by hands-on experience in the laboratories. This Training School was started in 1957 and continues even today. It has resulted in creating excellent manpower tuned to the requirements of Atomic Energy. Graduates of the Training School have today reached the senior-most positions in the organization.

Homi Bhabha will also be remembered for the innovations he brought about in science management, successfully modifying the administrative practices of a colonial form of government, in which most of the power rested with the officialdom of the ICS (which was succeeded by the IAS). He used the help of retired ICS officers, like Mr. Allardice, and borrowed officers of the IAS cadre to help him deal with the government, but the final say in all matters was his. They fell in line, took cues from him as to his desire, and amended the rules and regulations to suit his perceptions of scientific management. There are several instances of how he had to overrule suggestions and markings of those from the pure administrative service. Once, a BARC scientist was invited to submit a paper to the proceedings of a conference held under the UN. He put up the proposal through his Head of the Department, to the Trombay Council, which was discussed at a time when Bhabha was not in town. Small-minded arguments were made against the proposal and finally they quoted the service rules to deny him permission. When Bhabha returned and saw the minutes, he was aghast. He reversed the decision and even reprimanded the Trombay Council for taking such an unscientific attitude. He said "the conduct rules of the civil service have nothing to do with publications of scientists, which will rebound to the credit of the institution." This incident illustrates his rational approach to solving administrative problems, and he was never forgiving, even of his close colleagues, if they took an irrational decision.

Many times in my career, when such problems arose, I would ask myself what Bhabha would have done under the circumstances. One of the toughest situations was in 1990, when Mr. V. P. Singh, the Prime Minister, decided to implement the Mandal Commission recommendations. The DAE had always enjoyed exemption from reservations in its recruitment and promotion policies, with a view to supporting merit and excellence, and to make sure that our personnel would have the highest standards in issues relating to the safety of nuclear operations. However, the government order demanded that all Departments implement the recommendations of the Mandal Commission. The administrators of the Department put up a note to me, as Chairman, that we should also instruct the various units to implement the same. However, I decided that I would take up the matter with the PM himself, in person. I started off by saying that I am asking for a waiver to which he may have strong reservations, and explained that, in the interests of what we have built-up in BARC, and to preserve the highest standards, it is necessary to get a waiver from the implementation of the Mandal Commission recommendations. After 20 minutes of discussion, he agreed, and signed the file exempting the Department. If I had not drawn moral strength from the principles of Bhabha, I would not have attempted to do this. There are many such examples I could quote.

Homi Bhabha was also aware of the social needs, consistent with an enlightened lifestyle in a modern society. Keeping the scientists happy through support for academic work alone is not sufficient to retain, encourage and preserve a growing number of experts in the country. So, from the very beginning, he emphasised the importance of appropriate housing, educational facilities, transport facilities, etc., along with amenities like gardens, playgrounds, shopping complexes, etc. The planning of the Anushaktinagar complex, the Kalpakkam complex, and the housing units of several organizations under DAE, is a reflection of how sensitive he was to respecting human dignity, providing the best opportunity, not only for academic work, but also for the family. The Contributory Health Service (CHS) scheme is another area where the Dept. is unique, and over a period of time, even after retirement, the scientists and officers enjoy the privilege of the most modern medical facilities. This is where Homi Bhabha made a big change in planning for scientific development. Because he strongly believed it is not enough to create islands of prosperity, but these must be sustained and allowed to grow. The housing colonies in the DAE enjoy an educational system which has created a future generation of scientific manpower which is invaluable to a society. A new creation, the Homi Bhabha Centre for Science Education, is another example of how the basic scientists could expand their creative talent to areas of social concern. This part of the social responsibility was unique in Homi Bhabha, and in this respect he was not only a scientific administrator, but also a social reformer and a diplomat.

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