Homi Jehangir Bhabha and the Atomic Energy Programme

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Preamble

Homi Jehangir Bhabha was a man of many parts: a scientist of distinction; the visionary founder of the Tata Institute of Fundamental Research; a lover of art, music and gardens; and the person who single-handedly conceptualized and actualized the atomic energy programme of the country.

This article tries to give a sense of Bhabha's remarkable vision and how he succeeded in transforming the scientific and technological landscape of the country in the short span of two and a half decades.

Homi Bhabha was just seventeen when he left India to study in Cambridge in England. The year was 1927 and the plan was for young Homi to get a degree in Engineering, which would enable him to make a career in industry on his return to India. His father J. H. Bhabha was well-connected to many of the Tata enterprises in the country, so Homi's path seemed well laid out. But rather than maintaining a steady course which would have guaranteed a safe voyage through life, Homi Bhabha changed course and took on a new challenge.

This pattern – a bold decision to chart a new course -- was to be repeated at different junctures of his life. The result was that in 27 short years after his return to India, he successfully spearheaded the effort to bring modern science to India by taking two decisive steps with far-reaching consequences: founding the Tata Institute of Fundamental Research (TIFR), and establishing the Atomic Energy programme in India. These separate, but closely linked, initiatives allowed the country to forge ahead into the nuclear age. He also played an important part in laying the base for India's space programme and the country's involvement with

electronics. How this happened makes a fascinating story, which is brought out in the pages that follow.

Homi Bhabha (right) with his father Jehangir Bhabha, mother Meherbai Bhabha and brother Jamshed Bhabha

Cambridge

While at Cambridge, Bhabha carried on a lively and detailed correspondence with his parents. From his letters, we learn that he immersed himself in the student life at the University, and took part in dramatics, rowing and athletics. But more importantly, he was drawn strongly towards the epoch-making discoveries in experimental and theoretical physics that accompanied the dawn of quantum mechanics in the 1920s and 30s. Bhabha was deeply attracted to these developments and felt strongly that he must be part of the new enterprise, and contribute to it. This is recorded in a memorable passage in a letter to his father.

"I seriously say to you that business or job as an engineer is not the thing for me. It is totally foreign to my nature and radically opposed to my temperament and opinions. Physics is my line. I know I shall do great things here. For each man can do best and excel only in that thing of which he is passionately fond, in which he believes as I do, that he has the ability to do it, that he is born and destined to do it. My success will not depend on what A or B thinks of me. My success will be what I make of my work. Besides, India is not a land where science cannot be carried on."

His father relented, and agreed to finance his son's stay in Cambridge for two more years, provided Homi first completed his Mechanical Tripos in Cambridge with a first class. Bhabha obliged, with firsts in the Mechanical Engineering and in the Mathematics tripos, two years later, although he held the view that "no exam was ever a test of original or creative ability in anybody".

He made the most of his years at Cambridge where he was deeply influenced by Dirac. He was awarded a travel fellowship which allowed him to visit Pauli in Zurich, Fermi in Rome and Kramers in Utrecht. Bhabha was excited by the beauty of the underlying theory of elementary particles, and equally by new experimental studies of cosmic rays which vastly extended the range of available energies. He did his Ph. D. with R. H. Fowler, who incidentally was also the supervisor of the Indian astrophysicist Subrahmanyan Chandrasekhar.

Bhabha's research results from his Cambridge days remain relevant and important to this day. A few highlights follow.

- He was the first to perform the calculation that pertains to the interaction between an electron and a positron when they scatter from each other. Importantly, he included the crucial element of exchange, a quantum effect arising from the indistinguishability of identical particles. It was almost two decades later that these theoretical predictions were verified by experiment. Today, the Bhabha scattering formulae are used routinely to calibrate particle beams at high energy accelerators.
- Bhabha did pioneering work on the physics of cosmic rays, which are comprised of particles moving at very high energies, reaching the earth from outer space. Along with Heitler, Bhabha explained the occurrence showers of particles observed on earth as arising from a cascade of electron-positron pair creation events, as a very high energy cosmic particle passes through the atmosphere.
- A couple of related works, to which he contributed: Bhabha worked on the heavy-particle component of cosmic rays, and was led to invent the word "meson" to describe these particles. There was a debate on the best name for the particle, and Bhabha's proposal won out. Further, he was the first to offer a clear and succinct explanation of why "the time of disintegration (of mesons) is longer when the particle is in motion". The explanation rests on the phenomenon of time dilatation, which is familiar from the special theory of relativity.

Homi Bhabha at Cambridge

Bhabha's achievements in physics at Cambridge earned him a strong international reputation at the time. Both from his own research and by imbibing the stream of new results from others at Cambridge and elsewhere in Europe, Bhabha also discerned the importance of fundamental research as well as its applications. Yet it must be noted that beyond his grounding in physics, it was his earlier training in engineering that was a critical element in his later successes, while planning and executing major projects for the country, after his return to India. Equally important were the friendships he formed in his years at Cambridge, with colleagues like John Cockroft and W. B. Lewis. These stood him in good stead when he embarked on the atomic energy programme in India, many years later.

A Larger Purpose

While in the prime of his research career at Cambridge, Bhabha came to Bombay on vacation in 1939. The outbreak of World War II in September 1939 prevented his return to England, and Bhabha moved from Bombay to Bangalore to join the Indian Institute of Science. He was appointed Reader in charge of the Cosmic Ray Research unit, in which capacity he started experimentation with the aid of balloons launched to measure the fluxes of cosmic ray particles and their derivatives, at different heights. At IISc, C. V. Raman thought highly of Bhabha and nominated him for the Fellowship of the Royal Society, London. He was appointed FRS in 1941, and was awarded the 1942 Adams Prize by the University of Cambridge for "The theory of elementary particles and their interactions".

Bhabha with C.V. Raman and others at the Indian Institute of Science in Bangalore

The period 1940-45 was a crucial period in the development of Bhabha's ideas. It was then that he first had inklings of a larger purpose, which saw him transform from a scientific researcher of distinction to a scientific thinker and planner, whose extraordinary vision was to transform the scientific landscape of the country. In the words of B. M. Udgaonkar "he reestablished an identity between himself and his country, and became aware of the role he could play in the development

of India….He discovered his mission in life". In a letter to J. R. D. Tata in 1943, Bhabha wrote: *"The lack of proper conditions and intelligent financial support hampers the development of science in India at the pace the talent in the country would warrant".* He was encouraged to apply to the Tata Trusts, and in an oft-quoted letter he wrote in 1944 to Sir Sorab Saklatvala, Chairman of the Sir Dorabji Tata Trust, Bhabha requested the Tatas to seed a new institute of fundamental research. He says, *"The scheme I am now submitting to you is but an embryo from which I hope to build up in the course of time a school of physics comparable to the best anywhere*". But it is not to be an end in itself, for *"It is absolutely in the interest of India to have a vigorous school of research in fundamental physics, for such a school forms the spearhead of research not only in less advanced branches of physics but also in problems of immediate practical application in industry."* He cites the example of Britain where pure research workers of the standing of Lord Rutherford, W. L. Bragg, R. H. Fowler, Lord Raleigh, James Jeans and A. V. Hill played a crucial role as members of the advisory council of the Department of Scientific and Industrial Research. He adds *"Moreover, when nuclear energy has been successfully applied for production in say a couple of decades from now, India will not have to look abroad for experts but will find them ready at hand. I do not think that anybody acquainted with scientific development in other countries would deny the need in India for such a school as I propose."*

From the very start, Bhabha emphasized the need to strive for and achieve true excellence in an absolute sense. In an address on "Atomic Energy" before the Bombay Branch of the Indian Council of World Affairs in August 1945, he said *"It should no longer be enough for us to say to-day that some scientific or industrial effort in this country is as good or almost as good as that in some other country. We should aim at doing things which are in advance of what has been done elsewhere. Given proper education and facilities for work, the Indian mind is perfectly capable of this, as has indeed been demonstrated by Ramanujan, perhaps the greatest mathematical genius the world has produced in this century."*

The Tata Institute of Fundamental Research

The first step in the realization of Bhabha's vision was enabled by the Sir Dorabji Tata Trust, which accepted his proposal; the Government of Bombay too was a co-founder of the Institute. But even before it had a proper location, the Institute began functioning in June 1945 in a laboratory at IISc in Bangalore. It moved to Bombay in December and occupied a part of "Kenilworth", a spacious bungalow on Peddar Road which belonged to Bhabha's aunt, Ms. Coover Panday. The initial areas of research at the fledgling institute included mathematics, theoretical physics and cosmic ray physics; indeed, by the time TIFR was formally inaugurated in December 1945, eight research papers had been published already, true to Bhabha's dictum that scientists and scientific work matter the most, and must come first; buildings can come up later.

Bhabha's speech at the formal inauguration on December 19, 1945 is a masterly exposition of the state of research in the world for a lay audience, ranging from elementary particle and cosmic ray physics, to the theory of relativity and quantum mechanics. Underlining the fact that scientific knowledge provides the key to control nature and ultimately influence history, he said: *"In the nineteenth century, fundamental research was a curiosity pursued by men with deep interest in nature and looked upon as cranks by the rest. Today we all know of the great importance of fundamental research and the recent release of atomic energy for practical purposes has brought forcibly before the public how new avenues may be opened up by fundamental research, namely the study of nature itself unhampered by preconceived practical*

ends ... As Marx said, "Man's power over nature lies at the root of history", and we have in our own times seen the history of the world shaped by those countries which have made the greatest scientific progress."

In a few years, both the faculty and student population increased, and in 1948 the Institute began a move to more spacious quarters in the Old Yacht Club which is located close to the Gateway of India in Bombay. As the years progressed, the quality and diversity of research grew and the Institute needed more space once more. Bhabha identified a beautiful site to locate the new Institute, close to the southern tip of Bombay, overlooking the Arabian Sea. The foundation stone was laid in 1954 by Prime Minister Jawaharlal Nehru. It took eight years to design and make the new buildings, and it was in 1962 that they were inaugurated by the Prime Minister. The pace of research grew strongly in the intervening years, and by the time of inauguration, the new buildings already housed many laboratories that were practically complete. As Bhabha noted in his speech at the inauguration, *"The building is only a shell to make possible the work inside it. It is by the quality and volume of its scientific work that an institute like this must be judged, by the extent to which it has helped to explore and push back the frontiers of knowledge.*

Prime Minister Jawaharlal Nehru laying the foundation stone of the buildings of the Tata Institute of Fundamental Research at Colaba, Bombay (1954).

The scientific work in the institute began with mathematics, theoretical physics and experimental work in high energy physics and cosmic ray physics. A cloud chamber, made already in the days at IISc, was brought to Bombay, and two larger chambers were designed and made soon thereafter, with the idea of installing them at high altitudes, to track cosmic rays. As the years passed, research activities were initiated in nuclear physics, condensed matter physics and computer science. The first full-scale electronic digital computer to be designed and built in India, the TIFR Automatic Calculator or TIFRAC, was commissioned in 1960.

The setting up of these programmes illustrates two important components of Bhabha's thinking and way of going about things. First, he felt it was critically important to take up research in modern experimental areas, not only to strike a balance with theoretical activities, but

also to generate confidence in the design, fabrication and use of sophisticated equipment. This was crucial as TIFR was to go on to seed the atomic energy programme of the country, as envisaged by Bhabha. The other point, equally important, is to note is how he went about it. The Bhabha formula is simple to state: Identify a talented individual who is capable of leading the effort, and give him or her complete freedom, with full backing. Of course, it is not so easy in practice, as such individuals are rare, and it is not always easy to identify and attract them. Bhabha's special gift lay precisely in this direction --- he was able to recruit and retain such people, to inspire them and get the best from them, and build lasting programmes around them.

Perhaps this is best illustrated by two later hires he made, which have had considerable impact. In the last lecture he gave a couple of days before his tragic death, to the International Council of Scientific Unions (ICSU), he recalled: *"It may be of interest to give two more examples of building projects and development around people. As early as June 1944, Sir A. V. Hill had written to me that biophysics is a neglected subject in India and that it should be taken up under the wing of the Institute. While I agreed with his suggestions, I did not think it would be wise to embark along these lines till someone was found mature enough to be able to work on his own and build up a group. When however in 1962 my attention was drawn by the late Dr. Leo Szilard to a very promising Indian molecular biologist, it was decided to start work in microbiology which has since then been growing very satisfactorily."* The young molecular biologist in question was Obaid Siddiqi, who went on to build a vibrant group at TIFR which encompassed several branches of modern biology, and later headed TIFR's National Centre for Biological Sciences (NCBS-TIFR), Bangalore. The other instance of a new programme built around people was the radio astronomy programme of TIFR, which was started when four young

Bhabha speaking at the inauguration of the buildings of the Tata Institute of Fundamental Research at Colaba, Bombay. On the dais are Prime Minister Jawaharlal Nehru, Chief Minister of Maharashtra Y.B. Chavan, Governor Sri Prakash and J.R.D. Tata (1962).

Indian radio astronomers proposed to return to India to establish radio astronomy in India. Bhabha recognized the worth of their proposal, and supported it. As he recounted, in his address to ICSU: *"A project has been developed for a large cylindrical radio telescope for studying quasars and other radio sources and locating them accurately by lunar occultation. The telescope, which will have four to five times the collecting area of Jodrell Bank will be designed and built entirely by Indian scientists and engineers..."* This radio telescope, located in Ooty, was built by Govind Swarup, who went on to build the Giant Metrewave Radio Telescope (GMRT) and head TIFR's National Centre for Radio Astrophysics (NCRA-TIFR).

Bhabha knew that building an institution and nurturing it in its many aspects was a process that required patience and care. He likened it to growing a tree. In his Presidential Address to the National Institute of Sciences of India (now INSA), Bhabha said: *"A scientific institution be it a laboratory or an academy has to be grown with great care, like a tree. Its growth in terms of quality and achievement can only be accelerated to a very limited extent. This is a field in which a large number of mediocre or second rate workers cannot make up for a few outstanding ones, and a few outstanding ones always take 10 to 15 years to grow."*

Niels Bohr with Homi Bhabha, J.R.D.Tata and Jamshed Bhabha during the International Colloquium on Function Theory (1960)

Besides establishing vigorous research programmes at TIFR, Bhabha was keenly aware of the importance of exposing students and young scientists to developments at the frontiers of research. To this end, he developed a twin strategy: first, he sent youngsters from TIFR to the best universities in the West, to imbibe knowledge, witness research in the making, and above all, develop the confidence to excel in research themselves. The second leg of the strategy was to invite leading scientists from other countries to visit the Institute and give extended lecture courses. These lecturers, who included P. A.M. Dirac, W. Heitler, B. R. Mottelson, L. Schwartz and C. L. Siegel spent extensive time at TIFR and interacted with students both in and out of the classroom. Beyond this, TIFR hosted important international meetings and symposia in physics and mathematics. These too gave younger scientists an unparalleled opportunity to get to know internationally established scientists, and equally important, for the international visitors to get to know our young scientists.

Bhabha showing Epstein's bust of Einstein at TIFR to M. C. Chagla, Minister of Education. On the extreme left is M. G. K. Menon.

As envisaged at the time of founding the Institute and under Bhabha's guidance, TIFR provided all possible help, in terms of training scientists and building capacity, to assist in the founding of the atomic energy programme of the country, a step of major importance in the history of independent India. We now turn to an account of this phase.

The Atomic Energy Programme

Already in the 1940s, Bhabha envisaged that the country would need nuclear power to fill the gap between demand and supply of power based on traditional sources. Thus in his letter of 1944 to the Sir Dorabji Tata Trust where he proposed the foundation of an institute of fundamental research, he wrote: *"Moreover, when nuclear energy has been successfully applied for production in say a couple of decades from now, India will not have to look abroad for experts but will find them ready at hand"*. It is remarkable that he was thinking in this direction a year before the Hiroshima and Nagasaki explosions showed the world the raw power of nuclear energy unleashed for destructive purposes.

Bhabha advocated the development of peaceful uses of atomic energy as a priority area for the new India, post-independence. Looking to the future, he argued that with rapid industrialization, the power demand would rise steadily and conventional sources of energy in the country would not suffice to ensure an adequate standard of living for our population. Nuclear power would thus be called upon to make a greater relative contribution, so it would be necessary to develop industrial experience in the field, and to acquire the necessary skills. Further, in order to utilize India's abundant and cheap resources of thorium, it would also be necessary to have substantial quantities of fissile plutonium available, so that enriched fuel power stations, with lower capital cost, could also be utilized without the need to import fuel.

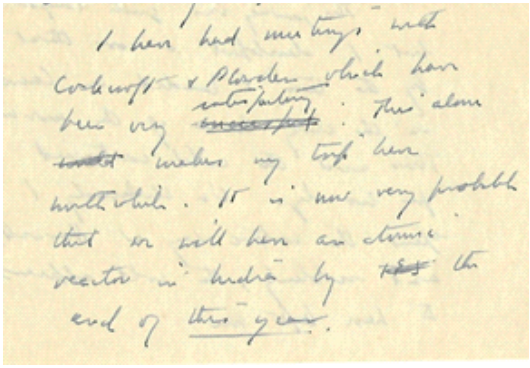
In order to guarantee safe passage of such a large enterprise, Bhabha pro-actively took a series of crucial legislative and administrative steps to channelize the effort and make it effective. In a crisp "Note on the organization of atomic research in India" addressed to the Prime Minister in April 1948, Bhabha made a case for administrative and other measures that should be taken to develop this branch of science. At Bhabha's urging, the Indian Atomic Energy Act was framed in 1948 to give the Government powers to carry out surveys for atomic minerals, to work on them on an industrial scale, to conduct research on the scientific and technical problems connected with atomic energy and to develop personnel to do such work. To carry out these tasks, the Government created a Commission chaired by Bhabha. Initially, the Atomic Energy Commission (AEC) had three members (Bhabha, S. S. Bhatnagar and K. S. Krishnan) and its work was carried out at TIFR. A major decision, namely to build an Atomic Energy Establishment at Trombay (AEET), was taken in January 1954. Further, using the powers under the 1948 act, the Department of Atomic Energy (DAE) was created in 1954, charged with the development of nuclear energy for peaceful purposes. The Department was in the direct charge of the Prime Minister, and Bhabha was appointed Secretary of the Department. A resolution by Bhabha in the Lok Sabha in 1958 defined the powers and responsibilities of the AEC, vesting the full executive and financial powers of the government with the Commission. New legislation in 1962 amended the Atomic Energy Act to empower the Government to also provide control over radiation hazards and public safety, with the central government using the DAE as the instrument to accomplish these objectives. The DAE continued to operate under Bhabha as its Secretary, and ex-officio Chair of the AEC. These steps, taken in the formative years of the atomic energy programme, were vital for its success. Each step was carefully planned and executed, and the resulting structure was finally robust enough to handle the needs of the programme.

Parenthetically, it is noted that the AEET was re-named the Bhabha Atomic Research Centre (BARC) by Prime Minister Indira Gandhi in 1966, after Bhabha passed away. It is as BARC that the establishment is well known today.

The growth of the atomic energy programme, and more generally the scientific enterprise in the country, owed much to the consonance of Bhabha's vision with that of India's first Prime Minister, Jawaharlal Nehru. His firm support was vital in helping to translate Bhabha's vision into action and reality. In January 1955, Bhabha made a trip to Britain where he met Sir Edwin Plowden, Chairman of the Atomic Energy Authority and Sir John Cockroft (his colleague from Cambridge days, and then director of the Atomic Energy Establishment at Harwell) to explore the possibility of Britain supplying enriched fuel elements to India. In a letter to his mother Meherbai and his brother Jamshed, Bhabha wrote that his meeting was *"very satisfactory. This alone makes my trip worthwhile. It is now very probable that we will have an atomic reactor in India by the end of the year."*

Bhabha with E.C. Allardice, Controller of the AEET (1955)

The decision to build a light water reactor was taken in April 1955, and the design and experimental facilities were decided in August. It took about a year to complete its construction. Other than the fuel rods, which were supplied by Britain, all components were made indigenously. Assembly commenced in 1955, and most physicists associated with the project, who were earlier housed in Colaba, now moved to Trombay. On reaching the milestone of the reactor becoming functional, Bhabha presented his mother with a one rupee note, on which he wrote "Apsara first reached criticality, 4 August 1956".



Bhabha's letter to his mother Meherbai Bhabha and brother Jamshed Bhabha (1955)

Note presented by Homi Bhabha to his mother Meherbai Bhabha (1956)

The reactor Apsara at AEET was formally inaugurated by the Prime Minister Jawaharlal Nehru (1957).

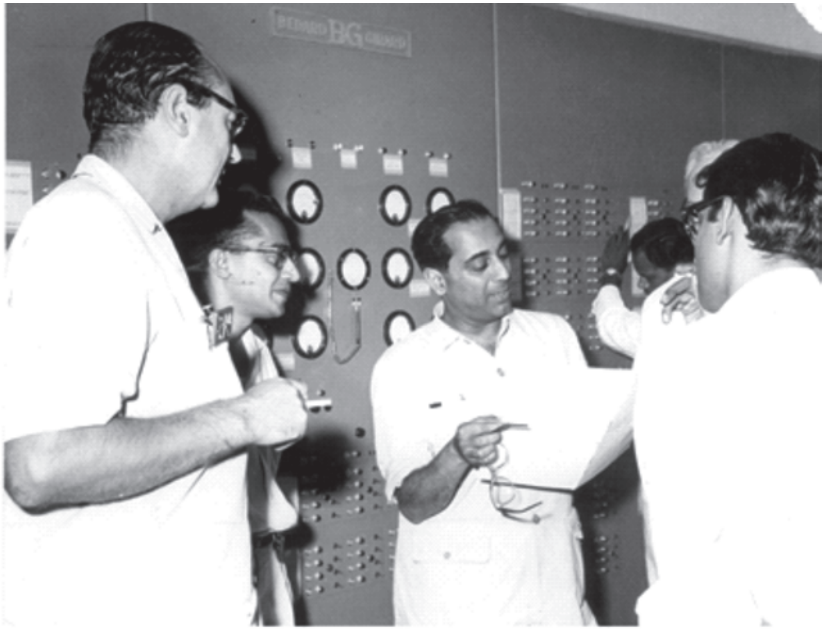
At the inauguration of the AEET and swimming pool reactor in January 1957, the Prime Minister dedicated the facility to the nation. In his speech, Bhabha noted that *"A plentiful supply of energy is the first requirement of modern civilization"* and argued for the economic feasibility of atomic power. At the same time, he emphasized that atomic energy would have many other uses: *"The aim of the Department of Atomic Energy is to develop atomic energy as a source for electric power, and to promote its use in agriculture, biology, industry and medicine. On the industrial side we intend to produce all the materials required for a full atomic power*

Bhabha with Norman Hilberry, Director, Argonne National Laboratory, R. Ramanna and P.K. Iyengar (1957)

programme." Commenting on innovative makeshift arrangements that had to be made in the absence of buildings, he said: *"We did not wait for the new buildings to come up to start the research activities of the Establishment. The Physics and Engineering Divisions were located in TIFR at the Yacht Club, and in war-time hutments on its new site at Colaba. A warehouse at another part of Bombay was converted for housing the Chemistry Division, while the Biological and Medical Divisions were set up at the Indian Cancer Research Centre…Many parts of the control system were made in our sister organization, TIFR, while the grid plate of the reactor was made in the Naval Dockyard".* Other steps taken were also outlined, including the establishment of a plant to treat monazite sands on the west coast. Bhabha also discussed the next project to be taken up, namely the design of a powerful high flux reactor for engineering research.

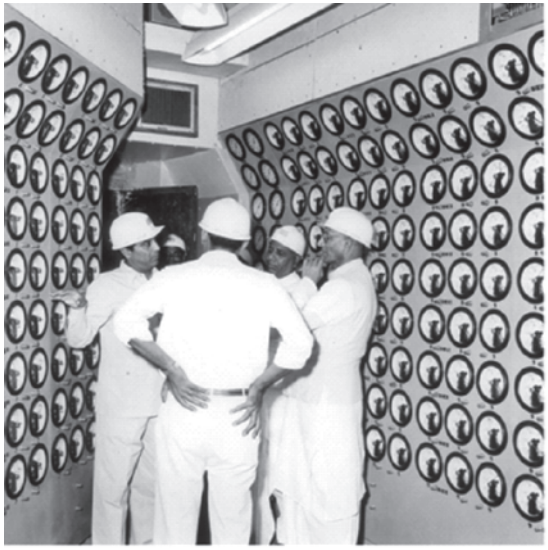
Working on APSARA had raised considerably the levels of know-how and confidence of the engineers and physicists involved with the project. Bhabha turned his attention next to the design of a heavy-water based reactor, which would have the advantage of using natural uranium as the fuel, removing the dependence on other countries for the import of enriched fuel elements. The first plant to manufacture heavy water was set up at Nangal close to the Bhakra dam, and demonstrated that the country had the capability of producing this crucial component.

In order to move to this next phase, it was deemed necessary to partner with a country where such reactors were already in operation. Canada already had functioning heavy-water reactors, as part of its atomic energy programme, which was led by W. B. Lewis, Bhabha's friend ever since they met in Cambridge in 1927. In early 1955, the Canadian government offered to set up a reactor of the NRX type (in use at Chalk River, Canada) at Trombay. Subsequently Bhabha met Lewis in the 1955 Geneva conference on the peaceful uses of nuclear energy, and a Canada-India tie-up was agreed on. The Canada-India Reactor (CIR) project entailed sending a team of Indian engineers to the site in Canada while construction of the facility proceeded at a pace in Trombay. The Indian-made fuel elements performed very well and CIRUS became operational in 1960.



Bhabha with reactor engineers at Trombay (1960)

In January 1961, several important new facilities were inaugurated at Trombay by the Prime Minister, including the CIR. In his speech, Bhabha made the point that *"The environment of Bombay is very different from Chalk River... and several problems had to be considered.*" He added: *"That the reactor has not yet reached its full power is due to a number of very interesting teething troubles, from which valuable experience is being gained."* Eventually, many improvements were made on the system over the next two years in response to unanticipated difficulties like the growth of algae in the primary system, corrosion and rupturing of the rods. Describing this later in a letter to the Prime Minister in January 1962, Bhabha wrote: *"...all problems connected with its operation have been overcome by our staff. In overcoming these difficulties, the staff of the Reactor Operations Division were helped in an important way by the staff of other Divisions, as for example the Analytical Chemistry, Radiochemistry, Metallurgy and Biology Divisions. Unless the work of the Establishment covered all the other fields, we would not have been able to overcome the difficulties on our own. The scientific staff of the Establishment, and especially that of the Reactor Operations Division, have put up a very creditable performance."*



Bhabha with Morarji Desai at Trombay (1960)

A crucial feature of the heavy-water reactor was the efficient production of plutonium, important as a key element of the three-stage programme enunciated by Bhabha, and adopted by the DAE. The full programme was well summarized by Bhabha: *"The total reserves of thorium in India amount to 500,000 tons in the readily extractable form, while the total known reserves of uranium are less than a tenth of this. The aim of long-range atomic power programme in India must therefore be to base the nuclear power generation as soon as possible on thorium rather than uranium. The first generation of atomic power stations based on natural uranium can only be used to start up an atomic power programme.... The plutonium produced by the first generation power stations can be used in a second generation of power stations designed to produce electric power and convert thorium to U^{233}... or depleted uranium into plutonium with breeding gain ... The second generation of power stations may be regarded as an intermediate step for the breeder power stations of the third generation all of which would produce more U^{233} than they burn in the course of producing power."*

Inauguration of the Plutonium Plant by Prime Minister Lal Bahadur Shastri (1965)

Bhabha knew that the key resource for the success of the atomic energy programme was the right people. At the inauguration of AEET in 1957, he outlined his plan: *"To ensure a steady supply of trained scientific and technical personnel, we are starting a training programme in June this year, in which 250 young graduates and engineers will be recruited annually from the universities and given supplementary training for a year to fit them for work in our atomic energy programme."* This was the start of the BARC Training School which, over the years, has imparted unique skills to thousands of graduates, and has been indispensable in producing the core manpower required for the multifarious activities of the DAE. An important point about this mode of training was noted by Bhabha in his final address to ICSU in January 1966: *"... this method of building up our staff does not drain away senior persons from the universities, but on the contrary gives training, employment and opportunities to young graduates passing out of the universities."*

In his speech during the inauguration on the new facilities at Trombay, Bhabha made a couple of other important points. He was acutely aware that the health of workers in and close to nuclear establishments needed to be well protected, and made the point: "*As atomic energy grows in the country and its uses become more widespread, the need to safeguard the health of the scientific workers and the general public will increase. An efficient health physics service is, therefore, essential, and this is provided by the Health Physics Division."* Separately, broaching the question of sharing our knowledge and expertise in setting up reactors with others, Bhabha had this to say: *"With the facilities we have built up here, to which the CIR is a major addition, Trombay has become an important centre for atomic energy work in the world. In the spirit of*

cooperation which has built the CIR, we would be happy to share the scientific knowledge and technical know-how we have acquired with other countries, who wish to use atomic energy for peaceful purposes and for the good of their peoples. We would be particularly happy if advantage were taken of these facilities by the countries of Asia, for we are convinced that eventually atomic energy is bound to make an important contribution to their industrial development and welfare. It is our firm resolve to use atomic energy only for peaceful purposes and for the good of the people of India and the world as a whole."

Opening of the International Conference on Peaceful Uses of Atomic Energy Left to right: Swiss president Max Petitpierre, U.N. Secretary General Dag Hammarskjold, Homi Bhabha, President of the Conference, and Walter G. Whitman from the U. S., Conference Secretary General (Geneva, 1955)

As a key figure in the atomic energy landscape worldwide, Bhabha was held in great esteem by his counterparts from other countries, for his contributions to physics and to scientific policy and planning, and for his general erudition. Little wonder then, that at the first international conference on "Peaceful Uses of Atomic Energy" held in Geneva in 1955, Bhabha was unanimously elected President of the Conference. His inaugural address makes for wonderful reading, putting, as it does, atomic energy in a historical perspective. Arguing that "each epoch marks a change in the energy pattern of society", he traces successive stages of development --- energy from muscle power in olden times was supplanted by chemical energy, leading ultimately to the industrial revolution. Given that resources for chemical energy are rapidly dwindling, Bhabha argues for *"the absolute necessity for finding a new source of energy, if the light of our civilization is not to be extinguished because we have burnt our fuel reserves."* He adds *"For the full industrialization of the underdeveloped countries, for the continuation of our civilization and its further development, atomic energy is not merely an aid, it is a necessity. The acquisition by man of the knowledge of how to release and use atomic energy must be recognized as the third epoch of human history."*

Of course, Bhabha was fully cognizant of the potential of atomic energy for wide-scale destruction. He urged the USA and USSR to jointly maintain peace and stop proliferation of

nuclear weapons in the next ten to fifteen years. He concludes *"If this is not achieved in this period, the situation may well go outside their control, and the world become a much more unstable place"*. He continued to espouse these views on non-proliferation at various fora. At the Pugwash conference held at Udaipur in January 1964, he drew attention to *"proliferation dynamic inherent in the situation, which made it imperative that urgent action be taken within the framework of the United Nations"* and then added *"It would, therefore, appear to be in the interest of everyone to see that substantial progress towards general disarmament is made as soon as possible."*

Space and Electronics

Bhabha contributed in an important way to India's space programme in its early days. In late 1961, when the Government wanted to start the programme, the responsibility was allocated to the DAE. Presciently, Bhabha remarked that space research is likely to yield *"results of great practical interest and importance in the near future, and we would be falling behind the advanced countries in technology if we were not to look ahead and prepare ourselves to take advantage of these new developments also…If we do not do so now, we will have to depend later on buying know-how from other countries at much greater cost…"* He went on to add: *"In space research we are today at the stage where we were in atomic energy work over ten years ago…in the DAE we have (today) the largest scientific research organization in the country. I therefore expect that within a few years our present modest beginnings will grow appreciably and Indian scientists will be making important contributions in the field of space research…"*

Bhabha with Cecil Powell, Patrick Blackett and Vikram Sarabhai

Bhabha was instrumental in setting up the Indian National Committee for Space Research under the chairmanship of Vikram Sarabhai. Further, the Thumba Equatorial Rocket Launching Station was set up, and plans for an Indian Space Science and Technology Centre were put in place.

Bhabha's engagement with electronics had its origin in the atomic energy programme. In his address to the second conference on Nuclear Electronics in 1965, Bhabha stated that *"in any*

developing country which does not already have an organized electronics industry, a self-reliant atomic energy programme will necessitate not only the indigenous development of nuclear electronic instruments, but also organized work on other aspects of nuclear electronics and computers, process instruments and control systems". With this background and first-hand knowledge of what could be accomplished in the country, the AEC recommended to Government that an electronics committee be set up to survey the needs of the country in electronics and to recommend measures for planned development to achieve self-reliance in the shortest possible time and in the most economical manner. The Electronics Committee was formed in 1963 under the chairmanship of Bhabha. He remarked: *"Our country came to realize rather belatedly in 1963 that electronics is not just something for the entertainment industry but one of the most vital and essential branches of modern technology"*. The Committee's report was finalized towards the end of 1965, but was presented to the Prime Minister only in February 1966, after Bhabha's death.

Music, Art and Gardens

Throughout his life, Bhabha was passionate about music and the arts. In a letter to his brother Jamshed written during his student days at Cambridge, he describes a concert he had just attended (a performance of Beethoven's Ninth Symphony): *"Never before have I been so moved. The performance was by no means faultless, but all the faults are forgotten in the greatness of the work. I was drawn out of myself and raised to sublime heights, and my mind hardly got back to earth till a long time after the end ..."*. Jamshed later noted that "In his last fifteen years …he would find relief from tension and fresh stimulus in listening to music at night. There was hardly a single free evening at home when he would not be listening to music after dinner and before taking up his mathematical work till late at night". He added: "For Homi Bhabha, the arts were not just a form of recreation or pleasant relaxation; they were among the most serious pursuits of life and he attached just as much importance to them as to his work in mathematics and physics. For him, the arts were, in his own words, 'what made life worth living'."

Bhabha was a good artist himself, and his paintings and sketches of various subjects provided a creative outlet. He was also immensely appreciative of good art, and strongly encouraged young artists in the 1950s. Members of the Bombay Progressive Artists' Group, which included F. N. Souza, K. H. Ara, M. F. Husain, Tyeb Mehta and S. H. Raza, benefited from his abiding interest and patronage. Today, many of their paintings adorn the corridors of TIFR, which has one of the finest collections of art in the city.

A sketch of young M. F. Husain by Homi Bhabha

Bhabha had a love for trees and gardens. The art critic Rudi von Leyden, who was a friend, visited him at home, and noticed: "…there stood, near his desk, an enormous drawing board with huge printed plans, pinned to it. It appeared they were the first layouts for the afforestation schemes and suggested gardens at Trombay…He spent many hours at night poring over these plans, trying to visualize in his mind's eye the setting of this new city, which he had founded and built nestling below the tree-grown flanks of the Trombay Hill and within a vast arrangement of gardens. The planning, design and the style of these gardens fascinated him…"

A Tragic Loss

On his way to Vienna to attend a meeting of the Scientific Advisory Committee of the International Atomic Energy Agency, Homi Bhabha died on board an Air India Boeing which crashed on Mont Blanc in the Alps on January 24, 1966.

The world lost a great physicist and advocate of the peaceful uses of atomic energy. India lost a dedicated visionary and patriot, in the best sense of the word, who worked relentlessly towards bringing the advances of science and technology to bear on the development of the country.

A condolence meeting held at TIFR on January 25, 1966 passed the following resolution:

"The hearts of all present are too full to find expression that would be truly fitting or appropriate for this most gifted son of India, whose splendid vision and imagination were ever at the service of his country, whose unsurpassed energy and enthusiasm were a driving force that spurred men to give their best, and whose humane and gentle thoughts were for his family and others nearest to him and yet moved out to larger and ever widening circles of all who needed his care, attention and regard."

At a condolence meeting held at the Atomic Energy Establishment, Trombay on the same day, Vikram Sarabhai read out a condolence resolution, from which an excerpt is quoted below:

"The meeting places on record its deep sense of inconsolable grief at the sudden and tragic passing away of Homi Jehangir Bhabha, one of the greatest scientists and engineers of the country, and the most versatile genius India has produced.

The death of a great man does more than put an end to a scientific career. It destroys an accumulation and synthesis of knowledge, skill, judgement and experience that cannot be transmitted and preserved in its entirety because it is incommunicable. To all of Homi Bhabha's associates and colleagues these were the best part of what by devotion, industry, enthusiasm and intelligence of the highest order he had made of himself in almost every field of human endeavor – the arts, sciences and humanities – an achievement even greater than his contributions to atomic energy, and never to be replaced. His contributions to research will perpetuate his scientific memory. But as a unique personality who sparked the development and advancement of atomic energy, and as one, who more than any single individual in this country, at any time in its history, recognized the importance of science in its manifold aspects for the progress of civilization and as one who ardently advocated the cause of scientific progress in developing countries, Homi Bhabha was one of the great experiences in the life of the country and in this sense he will never die unless science itself ceases to exist."

"I know clearly what I want out of life. Life and my emotions are the only things I am conscious of. I love the consciousness of life and I want as much of it as I can get. But the span of one's life is limited. What comes after death no one knows. Nor do I care. Since, there, I cannot increase the content of life by increasing its duration, I will increase it by increasing its intensity. Art, music, poetry and everything else that I do have this one purpose- increasing the intensity of my consciousness of life."
Homi Bhabha in a Letter to Jessie Maver, 1934

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I have drawn extensively on material from the following books:

- "Bhabha and his Magnificent Obsessions" by G. Venkataraman, Universities Press (1994)
- "Homi Jehangir Bhabha on Indian Science and the Atomic Energy Programme: A Selection", Tata Institute of Fundamental Research (2009)
- "The Visionary and the Vision", based on the TIFR Permanent Exhibition

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