Bhabha, Builder of India’s nuclear programme

In 1947, when India became independent, science and technology were things that belonged to another world. India was largely underdeveloped and rural, the little technology that one could see was imported and one had to go abroad for higher education. That India has risen to a nation with a vigorous nuclear power programme and research institutes that rival the best in the world is testimony to the rare ability and vision, substantially of one man.

Homi Jehangir Bhabha combined the skills of a first rate scientist with the capacity to dream and then translate dreams to reality. In 19 short years, 1947 to 1966, Bhabha established the Tata Institute of Fundamental Research, in Mumbai, the research center at Trombay, now known as the Bhabha Atomic Research Centre (BARC), the Centre for Advanced Research in Chennai the Centre for Advanced Technology at Indore. And he laid the solid foundation of the gamut of activities within the nuclear programme, from prospecting for nuclear ores to feeding electricity from fully operational nuclear power plants to the national grid.

H J Bhabha was born in 1909 in a Parsi family of great culture and learning. He was brought up in Mumbai and educated in the European tradition, in the arts and in music, as well as in the sciences, in which Bhabha displayed early interest. By the time he was sixteen, he had studied the Special Theory of Relativity, then barely familiar even to the well educated. After school he continued at the Elphinstone College and then the Royal Institute of Science, both of which were in Mumbai. At eighteen, Bhabha left for England and joined Gonville and Caius College at Cambridge. Bhabha took his Tripos, first in Mechanical Engineering, in deference to his father’s wish and then in Mathematics, in 1932, to fulfill his own dreams.

For the next seven years, while he completed his Ph.D, Bhabha had a series of fellowships. These enabled him to work with the leading physicists of the time, including Wolfgang Pauli and Enrico Fermi, and at the best institutes, like the Bohr Institute at Copenhagen.

In 1939, Bhabha returned to India for a short break, but World War II broke out just before he could go back to England. In England, many scientists joined the war effort and basic research was not the priority. Bhabha decided to stay in India and accepted a readership at the Indian Institute of Science, at Bangalore. With the help of a small grant from a Tata Trust, Bhabha set up a unit to work on Cosmic Rays.

Bhabha had got interested in Cosmic Rays while at Cambridge and he ploughed into the field with enthusiasm. Cosmic Rays were a mysterious radiation that seemed to come from outer space. They interacted strongly with the and the upper atmosphere and hardly any of the rays reached the earth's surface. It was later discovered that cosmic rays were largely protons, or the positively charged particles in the nuclei of atoms, probably produced by stars and in supernova explosions. These particles interacted with atoms in the atmosphere and gave rise to 'secondaries' that consisted of a variety of elementary particles.

Cosmic Ray particles are detected by using the principle that a charged particle streaking through a gas would knock electrons out of the atoms of the gas and create charged 'ions'. If there were plates that were connected to a powerful battery on either side of the gas, the ions would conduct electricity and cause a pulse of current. Counting the pulses would then be a count of cosmic rays passing through. To count particles coming in a given direction, one could place a series of such detectors in a row along that direction. If all detectors showed a pulse together, that would be a count of a particle that had come through all of them.

Another device for detecting Cosmic Rays was the 'cloud chamber'. This was a container which would show tracks of charged particles, rather like the vapour trails that jet aircraft produce in the sky. The cloud chamber allowed the tracks to be photographed and also revealed results of a collision, when one occurred within the chamber. As the particles were charged, they curved and deflected in magnetic and electric fields. Having such fields enabled identification of the charge on the particles by seeing which way they curved.

Bhabha soon created a formidable research facility at the Indian Institute of Science, using innovation and improvisation where funds or equipment were wanting. But by 1944, he felt the need or a larger facility and he approached the Tata trusts again. As the war appeared to be reaching an end, there was one possibility of returning to England.He however, wrote in a letter to JRD Tata in 1943, that he could continue to stay in the country and see if suitable conditions could be create, of "*doing one duty to one's country and building up schools comparable with those in other lands*."

The Sir Dorab Tata Trust responded to Bhabha's proposal and the TIR was born in Bangalore in 1945. A few months later, the Institute was shifted to Mumbai, working out of a building in downtown Mumbai, the property of an aunt of Bhabha.

Talented persons gravitated to TIFR and Bhabha soon had a formidable team at work. By 1949, the premises grew cramped and they moved to a picturesque building near the Gateway of India. The work involved research in Cosmic Rays and mathematics. International conferences were held and the world's leading scientists were regular visitors. As the problem of space cropped up again, in 1962 the institute moved to its present location, at the southern tip of the Mumbai island.

The Institute is now a vigorous center of committed research in a variety of frontier areas in physics and mathematics. It has facilities for experimental work, including those in the hill resort of Pachmarhi, in Madhya Pradesh and in the gold mines at Kolar, in Karnataka. A sizeable branch is at Bangalore, dedicated to research in the biological sciences.

The tradition of order, organization, commitment and dedication that Bhabha inculcated into TIFR, during the time he guided its affairs, has survived. Today, the institute, is a model for other to emulate. The work done is of the highest order and its colloquia and seminars attract the best in the world.

A great development of the times when Bhabha started work in India, was the possibility of immense energy from the splitting of atomic nuclei. Einstein had already formulated his celebrated equation, $E=mc^2$ (where E is the energy, m is the mass and c is the speed of light), or the equivalence of mass and energy and discoveries had been made about the nuclei of atoms.

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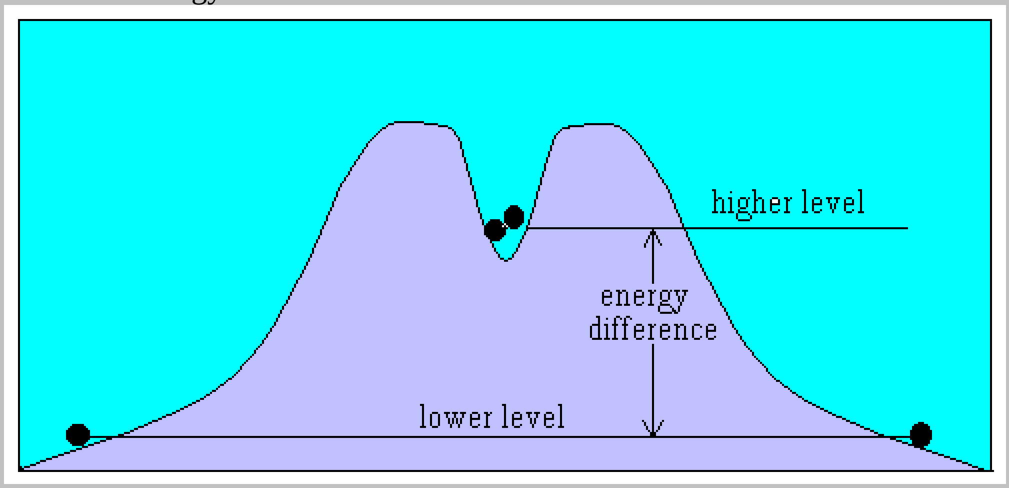
The nuclei of atoms consist of positively charged *protons* and about the same number of electrically neutral particles called *neutrons*. The act of holding together a number of such particles takes energy and it is found that the total mass of such a nucleus is a tiny bit *less* than the total of the mass of each of the constituents – the difference being the mass which is equivalent to the *binding energy*. In some heavier nuclei, it is found that the nucleus could be more economically packed as two smaller nuclei, economical, that is, in the use of binding energy. If the nucleus could be split into these smaller parts, the saving in binding energy would be released. And this energy could be used to set off an explosion, or to drive a turbine in a power plant!

It is like having a pair of golf balls in a golf hole at the top of a mound. The golf balls together are in a higher energy state than when separate, on the fairway. If the balls were pushed out of the hole, using a little energy, they would roll down the slope and release a good deal more energy!



Uranium, which is about the heaviest of natural elements, has two forms of its nucleus. Both forms have 92 protons, but while one form has 143 neutrons, the other has 146 neutrons. As it is the protons that decide the chemical properties of an element, both forms are uranium. But the different numbers of neutrons make for slightly different ‘packaging economies’. These forms are called U_{235} and U_{238}, the subscripts being the total number of particles in the nucleus, and are central to the design of nuclear reactors.

Both forms of uranium are found to split, or ‘fission’ either naturally or on being struck by a stray neutron. The natural fission is very slow, but in both cases, there is release of huge energy. The energy released by fission of one gram of uranium, for instance, is about 6 million times the heat of burning a gram of coal, more like burning a tonne of coal! But it is the specific way that U_{235} breaks up, when struck by a neutron, that makes possible the nuclear ‘chain reaction’.

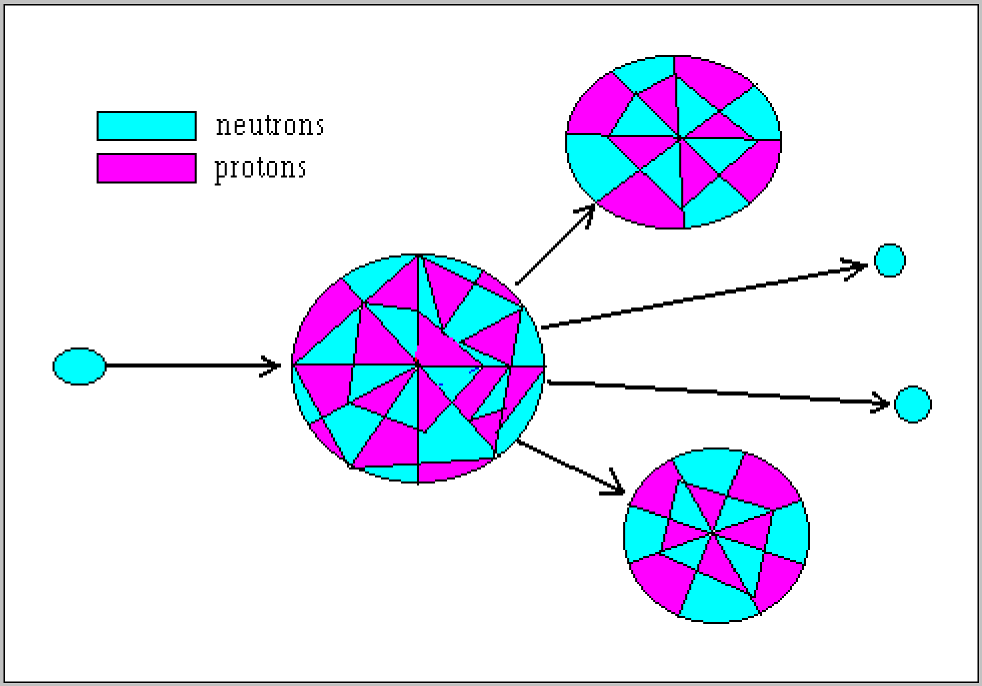
The way U_{235} breaks up can be shown like this:

$$U_{235} + n \rightarrow Sr_{94} + Xe_{139} + 3n \quad \text{[Strontium and Xenon]}$$

Or

$$U_{235} + n \rightarrow Br_{87} + La_{147} + 2n \quad \text{[Bromine and Lanthanum]}$$

In both the reactions, the products are the ‘daughter’ nuclei, plus three or two, left over neutrons. That a reaction induced by a neutron results in neutrons again has an important consequence. If just one nucleus in a mass of uranium were struck by a chance neutron, this would produce more neutrons, which, in their turn, would induce more fissions, and so on! In a fraction of a second, all the nuclei would fission.



There is, of course, a threshold quantity of uranium, so that the ‘daughter’ neutrons do not get wasted and the chain is kept going. In pure or natural uranium, which has only 0.6% of U_{235}, this quantity is about 90 kg, but even much smaller quantities get unbearably hot and give off radiation.

Apart from this ominous scope for destruction by plunging quantities of fissile material together, Enrico Fermi had also discovered the possibility of a *controlled* fission reaction, which could be used to generate power. In this method, portions of the fuel are not allowed to come close enough for a runaway reaction, but are kept separated by shields of lead or graphite, which absorb neutrons and slow things down. The result is only generation of heat, which could be siphoned off by a circulating coolant and used for driving turbines.

Bhabha saw at once the promise of atomic power to fuel the development of free India. It was audacious, to think that a country without enough to eat and barely able to produce cement and steel for basic civil construction should dream of harnessing newborn technology as a short cut to industry and growth. But Bhabha was a visionary and his comprehension of science and its relation with life went beyond the academic.

This was the year 1947. The war was just over, independence was at hand and a regular government was yet to be formed. Bhabha did not think it proper to wait. He convinced Pt Nehru, then leader of the interim government, that despite all the political and economic priorities of a country newly free, development of atomic energy capability could not afford to be delayed. In the months that followed formal independence and even during the turmoil of partition, Bhabha was able to set up an independent Government agency, the Atomic Energy Commission, to take on the first needs of prospecting for nuclear energy ores and funding basic research. And soon, the development of a full-fledged programme was put in the hands a specially empowered Department of Atomic Energy, with Bhabha at its head.

The purification of nuclear materials was still a close military secret and the technology of controlling nuclear reactions for power generation had made hardly any headway. It was in 1953 that Bhabha's team had made its first gram of uranium. The power needs of countries run into thousands of millions of watts and a nuclear programme would have to think of plants that would use tonnes of fuel, with precise controls and meticulous safety, as every nuclear plant had the potential to transform itself into monster of horrendous destruction.

Basic research that was being carried out in TIFR was soon shifted to a dedicated facility, the Atomic Energy Establishment (AEE), now known as the Bhabha Atomic Research Centre, then just outside Mumbai. The AEE soon grew into a powerhouse of research and development, with its well planned laboratories and programmes to train scientists and engineers at the best facilities in the world. There was also the Training School, which recruited fresh graduates and honed them into the experts that the phenomenal growth in activities would demand.

As India had scarce resources of uranium, Bhabha tailored India's nuclear energy programme to make the best of what there was. The thrust was hence on using natural uranium, which had only 0.6% of U_{235}, the fissile kind, in place of 'enriched uranium, with better a proportion of U_{235}. The economics of this strategy was that by suitable methods, the natural ore could fuel an initial nuclear energy programme, so long as the supply of ore lasted. This would save the time and expense of creating an ore enrichment plant. A bye-product of fission in natural uranium, was plutonium, which got generated by the U_{238} present in the fuel. Plutoniun is also capable of nuclear chain reaction. By the time the U_{235} got used up, there would thus be a stockpile of plutonium for another spell of power generation.

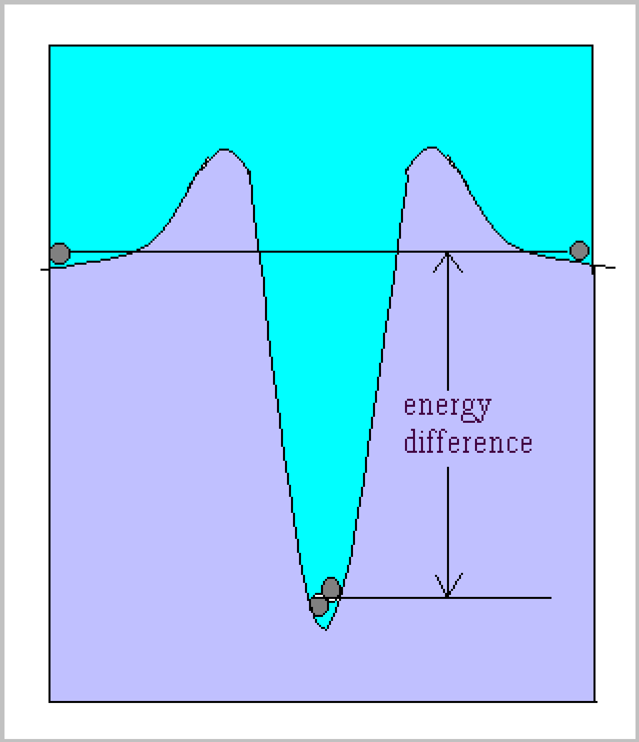
This possibility arises from the fact that the two or more neutrons that emerge from fission of U_{235}, are are too energetic to optimally set off fresh U_{235} fission reactions. They could be more effective if slowed down a bit. The reactor is thus designed to be filled with a *moderator*, a material that the neutrons can hit, en route to striking U_{235} nuclei. The best moderato is *heavy water*, a form of water where the nuclei of the hydrogen atoms are heavier than normal hydrogen nuclei. In natural uranium, in fact, Heavy water also acts as the coolant and serves to carry away the heat generated in the reactor to be used to generate power in turbines.

Another moderator, already present in the natural uranium fuel is the U_{238}. High-energy neutrons get slowed down when the bump off U_{238} nuclei, just like with heavy water. This useful function apart, when a nucleus of U_{238} absorbs a neutron, the product is a nucleus with 238+1=239 particles. This is an unstable form of uranium, which spontaneously breaks down into the element, plutonium. Plutonium, like U_{235}, also undergoes fission, with production of neutrons that could sustain a chain reaction. When the U_{235} is gone, then, we could continue with a plutonium reactor!

If one stuffed leftover U_{238} into this plutonium reactor, one would get still more plutonium. This kind of reactor could now become a *breeder*, a reactor that produces more fuel than it consumes!

This was the first step in economising and making the best of the uranium reserves in the country. There is yet another step. This depends upon thorium, Th_{232}, of which, happily, India has ample reserves. When thorium is exposed to neutrons, in a plutonium reactor, it gets transformed into U_{233}, again a fissile material. Phase III of India's atomic energy plan was to generate U_{233} by exposing thorium to neutrons. This phase would last a long time, because of abundant thorium discovered on the Kerala coast.

As early as 1955, at an international conference on atomic energy at Geneva, Bhabha had recognized atomic power as being the practical, long-term answer to the world's energy needs. At the conference, Bhabha had spoken of the next development in nuclear power, nuclear *FUSION*, as being the real holy grail. While nuclear *fission* is getting power out of the splitting of heavy nuclei into more economical smaller units, nuclear *fusion* looks to the *merging* of light nuclei into more complex nuclei, a process that releases even more energy! Specifically, the nuclei of heavy hydrogen, which consist of a proton and a neutron, are forced close together. When they re close enough, nuclear forces which attract each other take over and the nuclei merge, into a nucleus of helium, two protons and two neutrons.



As in the case of fission, in fusion too, energy has first to be supplied to overcome a barrier before energy can be tapped when the system crashes down to a low-energy condition. But in the case of fusion, a truly formidable energy input that is required. The only way it has been done is in the hudrogen bomb, where a normal, fission bomb is used to start off the fusion r\eaction. But, in 1955, Bhabha spoke of the prospects of the process being controlled and harnessed. With the huge quantity of heavy hydrogen, in the oceans, mastering fusion would put to an end any concerns about energy!

It was with this confidence and optimism that Bhabha had approached setting up India's atomic energy plan. With the large, master plan of going from heavy water reactors to breeders and then using the thorium cycle in place, Bhabha set about its unfolding in practice. Innumerable details had to be developed, mastered and implemented. A professional prospecting body had to be set up to locate where nuclear ores could be mined. The metals had to be extracted and the content of the useful isotopes improved. The fuel material then had to be shaped and packed, for the tortuous conditions in the reactor.

Reactor design was an uncharted territory, esoteric in theory and exacting in practice. High temperatures and pressures apart, there was the need to contain radiation, as well as to provide for safety, in case of mishap. Even the civil structures that housed the facilities had to be specially designed and the plants had to be located far from towns and cities. And then the methods had to be devised to dispose of spent fuel.

With uncanny judgment, system and method, Bhabha led and inspired his team to plan and build the wide spectrum of interlocking systems, quite unlike anything in the ‘developing world’. But in 1966, when he was on his way to Vienna for a meeting, he met an untimely and tragic end when the plane he was on crashed into the Alps.

The nation was plunged into despair and the setback seemed impossible to repair. But the ultimate testimony to the organization that Bhabha had created was that it rolled on, when he died, almost without a break after his death. In a country where it is customary to stop work to mourn the passing of great men, the Department of Atomic energy worked resolutely the days following Bhabha’s death. Bhabha’s grand plan had marked out a clear path and the department followed it with energy and dedication. India is now self-sufficient in most components of nuclear power. Her heavy water technology, largely indigenous, has captured export markets. Her research establishments are second to few in the world and her back-bone of manpower is formidable.

Nuclear power is now an important and growing part of the power plan of the country, thanks to the grand vision and untiring effort of one man.
