History and Brief Introduction to R&D Units of DAE

In March 1944, Homi Jehangir Bhabha, the architect of the Indian Atomic Energy programme, and the father of nuclear research in India stated in his prophetic words that,

"***When nuclear energy has been successfully applied for power production in, say, a couple of decades from now, India will not have to look abroad for its experts but will find them ready at hand."***

One has to realize that when Bhabha made this observation it was barely sixteen months after the feasibility of achieving a self-sustaining nuclear chain reaction was established by Enrico Fermi in Chicago, and this fact was a tightly held secret known only to a very limited number of individuals in USA, UK and Canada. Even the discovery of nuclear fission by Otto Hahn and Fritz Strassman was hardly five years old at that time. Very few believed at that time that nuclear fission would provide economically viable electric power before the end of the century. Bhabha had realized that nuclear energy is of utmost importance for the industrial development of India, especially with the limited coal deposits and which also being more or less concentrated in the eastern region, and most of the hydel power being dependant on relatively unreliable and irregular monsoon.

Nuclear research was started with the establishment of the Tata Institute of Fundamental Research (TIFR) in 1945. In April 1948, the Atomic Energy Act was passed and in the same year the Atomic Energy Commission was setup. In 1954, it was decided by AEC to set up the Atomic Energy Establishment at Trombay. During the period 1948-1954 the Atomic Energy Commission functioned within the Ministry of Natural Resources and Scientific Research, in New Delhi.

On August 4, 1954, the Department of Atomic Energy (DAE) was created. The Department was under the direct charge of Prime Minister Pandit Jawaharlal Nehru, and has since then remained under the charge of successive Prime Ministers.

With the creation of the Atomic Energy Establishment, Trombay (AEET), all the scientists working on programmes of direct relevance to the applications of nuclear power such as nuclear reactor design, electronics and materials science were transferred from TIFR along with their research programmes to Trombay, and they became part of AEET. TIFR became an institution truly devoted to fundamental research.

The outstanding achievements of DAE, to a great extent, are due to the excellent planning of activities and the work culture promoted by Bhabha in the early days. This has been nicely reflected in the reminiscences of the scientists who had the privilege of working with Bhabha in the early days. These personal recollections also make it easy for us to understand the vision of Dr. Bhabha and his philosophy in the building of large scientific institutions. Therefore, their personal impressions of Bhabha have been recorded, as narrated to their interviewers, and reproduced these in Annex-I. However, some aspects of Bhabha's magnificent personality, which are generally thought to be instrumental in creating Institutions of eminence in DAE, are briefly mentioned below.

As Prof. Sreekantan tells us, Dr. Bhabha was committed to the thought that the fruits of scientific advances and technological development must serve his fellow citizens. He had great confidence in the abilities of young Indian scientists to achieve the desired objectives. The

philosophy he had followed in the growth and development of DAE was to pick an outstanding man to start a new activity. With the elucidation of DNA structure by Watson & Crick in 1953, a new discipline of Molecular Biology evolved at the interface of Biology, Chemistry and Physics. Dr Bhabha soon realized that a programme in Molecular Biology should be started at TIFR. It has often been said that in 1960s, Homi Bhabha at the suggestion of Leo Szilard decided to invite Obaid Siddiqi to set up such a programme at TIFR. Very soon after Siddiqi and few others joined TIFR, in a short while, a world class Molecular Biology Group got established. According to Prof. Udgaonkar, apart from having an instinct for selecting the right people Bhabha had vision to choose right areas of work. Like he must have foreseen the potential and need of initiating work in several areas, which later got shaped into major programme s of DAE. On one hand, he built a strong school in mathematics and at the same time established a large workshop at TIFR, which not only provided crucial support to experimental work at TIFR but also in building AEET. It is also said that all the scientific decisions were taken after a full discussion and for this reason Faculties / Scientific Councils were established. For any new scientific idea to keep flowing in, he had introduced Wednesday Colloquium at TIFR.

He was convinced that the mode of administration of a scientific institution had to be different from the type of administration in the Government or in an industrial house. He introduced several new features in the administrative pattern of TIFR and DAE and those proved so successful that they were later adopted in other scientific institutions in the country. Bhabha had aristocratic up-bringing and this according to Canadian social scientist named Anderson, led him to plan and succeed in building larger and dynamic institutions.

According to Prof. Sreekantan the statement attributed to the Nobel Laureate, Prof. P.M.S. Blackett that a first rate laboratory is the one in which ordinary scientists can produce outstanding work was proven to be a fact by Bhabha. He succeeded in enthusing those who worked around him with the same spirit of dedication in national endeavour, which motivated him, to maintain highest standards of scientific integrity, and to set the highest standards of quality in all that they did. It is this group of scientists and engineers who acquired confidence in their own abilities as well as that of other fellow Indians while working under his inspiring leadership. These scientists and engineers together with the subsequent generation trained by them who now spread over all the DAE institutions are considered to be Bhabha's most important legacy to our country.

A multi-faceted personality, Bhabha was immensely fond of music and painting. It was the painter in him who must have guided him to develop the two great institutions, TIFR and BARC in a manner that the natural beauty of the respective places was fully preserved and this point has been brought out in Annex-II.

Introduction to R&D Constituent Units

Bhabha Atomic Research Centre (BARC), Mumbai

Although it started in 1954, as the Atomic Energy Establishment, Trombay (AEET) it was formally inaugurated by Pandit Jawaharlal Nehru on January 20, 1957. On January 12, 1967 Prime Minister Indira Gandhi renamed it as Bhabha Atomic Research Centre (BARC). BARC has been a mother institution involved with the development of technologies related to building nuclear reactors, fuel fabrication, reprocessing of the irradiated fuel, production or up-gradation of heavy water. In addition, research in nuclear physics, solid-state physics, reactor physics, high-pressure physics, spectroscopy, lasers, plasma physics, materials science, seismology, accel-

erator physics, chemical and life sciences, radiochemistry, nuclear radiation safety, instrumentation, computers, robotics, etc. is also vigorously pursued. The research leading to applications of the radiation technology for medical diagnostics and therapeutic purposes, producing high yielding and disease-resistant varieties of rice, jute, pulses, groundnuts and mustard or the preservation of agricultural commodities, sterilization of medical products etc. has been pursued from the beginning. BARC has also initiated and sustained research and development activities in all newly emerging areas of nuclear technology and basic sciences which are of national importance, and has served as the cradle of all DAE's programmes.

The first experimental nuclear reactor Apsara was indigenously built and commissioned in 1956. Subsequently, five more reactors namely CIRUS (40 MWt), ZERLINA, Purnima, Kamini and Dhruva (100 MWt) reactors were built for specific research programmes. As and when the activities in specialized areas grew to a critical size they were shifted out of Trombay for further growth and this led to the creation of new centres and organizations. The research centres thus created include Indira Gandhi Centre for Atomic Research (IGCAR) at Kalpakkam, Variable Energy Cyclotron Centre (VECC) at Kolkata and Centre for Advanced Technology (CAT) at Indore. Many other organizations, that include public sector undertakings and industrial units, also grew out of the R&D at BARC.

Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam

IGCAR was set up in 1971 with the main objective of conducting broad based multidisciplinary programme of scientific research and advanced engineering, directed towards the development of sodium cooled Fast Breeder Reactor (FBR) technology, in India. This is part of the second stage of the Indian Nuclear Power Programme, aimed at efficient utilization of the plutonium produced in pressurized heavy water reactors (PHWR's) and providing means to meet the large scale demands of electrical energy in the country. For meeting these objectives, a modest beginning was made through the construction of a sodium cooled Fast Breeder Test Reactor (FBTR), with a nominal designed thermal power of 40 MW. The reactor attained its first criticality on October 18, 1985 and has been in operation at a power level of 10.5 MWt with a small core. It is the first of its kind in the world to use Plutonium-Uranium mixed carbide as a driver fuel. The fuel developed for FBTR has performed exceedingly well with a burn up of more than 100,000 megawatt days/ tonne without any fuel failure.

Over the years, the centre has established comprehensive R & D facilities covering the entire spectrum of FBR technologies related to molten sodium as a coolant, reactor engineering, reactor physics, metallurgy and materials, chemistry of fuels, fuel reprocessing, reactor safety, control and instrumentation, computer applications, etc. and has developed a strong base in a variety of disciplines related to this advanced technology. With the experience and expertise gained through the operation of FBTR, the Centre has completed the design of a 500 MWe Prototype Fast Breeder Reactor (PFBR) and embarked on its construction along with the newly created organization BHAVINI. As a part of efforts for closing the fuel cycle, a Fast Reactor Fuel Reprocessing Plant is under construction. A 30 kWt, U-233 fuelled mini reactor (KAMINI) has been built for neutron radiography and neutron activation analysis. Apart from thrust areas related to nuclear technology, radiochemistry, etc. research in topical subjects like quasi crystals, oxide superconductors, nano-structures, clusters, SQUID, exopolymers and experimental simulation of condensed matter using colloids is also being carried out.

Variable Energy Cyclotron Centre (VECC), Kolkata

During sixties, a decision was taken to construct and install a medium energy cyclotron with the possibility to vary the energy of the accelerated particles over a wide range. The proposed machine was of sector focused cyclotron variety enabling acceleration of protons from 6 – 60 MeV, deuterons from 12 – 65 MeV, alpha particles from 25 – 130 MeV and heavy ions up to a maximum energy of 130 Q^2/A MeV. The work started formally in the year 1969 at BARC and it was decided to locate the accelerator in Kolkata. On June 16, 1977 the cyclotron was commissioned when a beam of alpha particles was accelerated for the first time in the machine. It is now a national facility that is open to all research institutions and universities of the country. An Isotope Separator On Line (ISOL) facility has also been added which allows one to study the properties of very short-lived nuclei that are far from the beta stability line. The Centre is currently developing a superconducting cyclotron to provide heavy ion beams for nuclear physics experiments. Also, another on going activity is to develop radioactive ion beam facility for basic research in nuclear physics. The production of radioisotopes for medical diagnostics is yet another activity of the centre. The centre supports all the R&D activities pertaining to instrumentation and computer control systems necessary for the above mentioned activities. A programme on helium exploration and purification is amongst other activities being pursued. The theoretical work to understand quark gluon plasma and related phenomena is also carried out.

Centre for Advanced Technology (CAT), Indore

CAT was established with an aim to expand the activities carried out at BARC, in two frontline areas of science and technology, namely, Lasers and Accelerators. President Giani Zail Singh had laid the foundation stone of the Centre on February 19, 1984. The construction of laboratories and houses began in May 1984. In January 1986, first multi-purpose shed was ready and the first scientific activity at CAT took place with the holding of a “Workshop on Plasma Diagnostics”. In June 1986, the first batch of scientists from BARC, Mumbai, moved to CAT. In February.1987, CAT became an independent unit of DAE. Since then, the centre has rapidly grown into a premier institute for work related to research and development in lasers, accelerators and their applications. CAT has been working on the design and construction of synchrotron radiation sources and their utilization. INDUS-1, a 450 MeV storage ring has already been commissioned in which electrons are injected using a booster synchrotron, which in turn is fed by a 20 MeV microtron. Four beam lines have been made operational for different investigations, while two more are under construction. Currently, work on setting up electron storage ring with beam energy of 2.5 GeV (INDUS-2) is under execution. The development of magnets of various kind, cavities, ultra high vacuum systems, rf power supplies, precision magnet positioning system, computer simulation studies form integral part of this activity. Besides, the development of industrial and medical accelerators and a free electron laser based accelerator is also in progress. The development of lasers of varying specifications and their applications in laser driven inertial confinement fusion or as tool for R&D in basic sciences, material processing, medical diagnostic and surgery, metrology are other major activities of the centre. The development of laser crystals, semiconductor based laser diodes, optical limiters etc. is also being pursued.

Tata Institute of Fundamental Research (TIFR), Mumbai

TIFR started with a modest beginning at the Kenilworth Building on Peddar Road, Bombay (now Mumbai) in 1945 and later moved to the Royal Yacht Club, Apollo

Bunder until the buildings at the Navy Nagar Campus in South Mumbai were ready in 1962. The Institute is working in various disciplines grouped into three major schools: the School of Mathematics, the School of Natural Sciences and the School of Technology and Computer Science. The Homi Bhabha Centre for Science Education (HBCSE) at Mankhurd, Mumbai; the National Centre for Radio Astronomy at Pune, Maharashtra and The National Centre for Biological Sciences at Bangalore, Karnataka also form a part of TIFR activities.
The School of Mathematics has research interests in areas such as algebra, algebraic geometry, Lie groups, Lie algebras, algebraic groups, representation theory and quantum groups, theory of numbers, combinatorics, differential geometry and topology, real and complex analysis, Ergodic theory, probability theory on groups and mathematical physics. The School of Mathematics in Bangalore is dedicated to the study of applied mathematics where mathematicians work in the fields of differential equations, harmonic analysis, numerical analysis and probability theory etc.

The School of Physics work mainly in the fields of astronomy and astrophysics, chemical physics, computer science, condensed matter physics, high energy physics, nuclear & atomic physics, radio astronomy and theoretical physics. The Department of Biological Sciences is involved in the study of genetic and molecular studies of microbial organisms, organization and regulation of glycolytic pathway in yeast, protein structure-function relationship, molecular biology of cancer, functioning of sensory systems, stress induced changes in brain etc. The National Centre for Biological Sciences (NCBS) is located in Bangalore and in a short period of around two decades, NCBS has earned an outstanding international reputation.

The Institute is also actively involved in the field of educational research with a special emphasis on school level education as well as some aspects of public health. The Institute has several field stations and research facilities in different parts of the country. A Giant Meterwave Radio Telescope, the largest of its kind in the world, is operational at Khodad near Narayangaon, north of Pune and a large equatorially mounted cylindrical radio telescope and a high energy cosmic ray laboratory are operational at Udhagamandalam (Ooty) in Tamil Nadu. High energy cosmic ray and gamma ray laboratories are operated from Pachamarhi in Madhya Pradesh. TIFR runs a National Balloon Facility in Hyderabad which is among the best in the world and has the geographical advantage of being close to the geomagnetic equator. At Gauribidanur, Karnataka, TIFR scientists have built an extremely sensitive balance to study the difference between gravitational and inertial masses. A Heavy Ion Low Energy Accelerator capable of accelerating particles to moderate energies for studying heavy ion atomic interactions and a Nuclear Magnetic Resonance Facility to study complex molecules are also housed in TIFR. The Institute's Dental Section has been actively involved in investigations pertaining to carcinogenic effects of tobacco.

Pioneering work done in the Institute in several areas has resulted in the establishment of new national organizations such as the Society for Applied Microwave Electronics Engineering and Research (SAMEER) and the National Centre for Software Technology (NCST).

Saha Institute of Nuclear Physics (SINP), Kolkata

The Institute grew out of the Palit Research Laboratory in Physics of the University of Calcutta.
Professor M. N. Saha had seen immense potential of nuclear science for betterment of the country. In 1940, he reorganized the syllabus of the Post-Graduate Physics to include Nuclear Physics in the Physics curriculum.

Multifarious experiments in Nuclear Physics and instrumentation had started in his laboratory. Soon a small-scale cyclotron was felt necessary for gaining a first-hand knowledge in this virgin field. He decided to have it built at the University College of Science campus in Rajabazar at 92 Upper Circular Road (now known as Acharya Prafulla Chandra Road). For this purpose, a new building was planned. With the laying of the Foundation Stone for the building by Dr Syamaprasad Mookerjee, the Institute of Nuclear Physics was founded in the year 1949. It became fully functional on 11 January 1950 when the building was formally inaugurated by Madame Irene Joliot-Curie. In 1956, the Institute was renamed as Saha Institute of Nuclear Physics. The Institute shifted to its present location in late eighties and became an aided institution of DAE in 1992.

A large variety of systems / instruments required for various activities of the centre have been developed from time to time. The list of important developments include; a cyclotron, a 400 keV Cockcroft-Walton accelerator, a nuclear magnetic resonance spectrometer, nuclear quadrupole resonance system, an electron paramagnetic resonance machine, an electron microscope, etc. In earlier times, experimental plasma physics activities centered around a duoplasma ion source, Penning ionization gauge and developing rf diagnostics using impedence probe. Subsequently, the activities on high temperature plasma have been centered around a Tokamak machine. The theoretical work has been mainly carried out on nuclear structure and reactions, nuclear astrophysics and quark gluon plasma, conformal field theory, string theory and plasma physics. The studies conducted in the more recent times include; the electronic structure of disordered systems, transmission properties of disordered open quantum systems, level spacing distribution studies in 1d systems, surface properties like chemisorption, surface reaction and catalytic activities of transition metals and their alloys, high temperature superconductors, colossal magnetoresistance in magnetic systems, nano-materials, quantum renormalization group systems, the magnetic and superconducting regimes in the phase diagram of Hubbard related models etc. Other activities carried out include radiation chemistry of aqueous solutions of various metal complexes; nucleic acid bases and radiation induced grafting. The institute also sustains research activities in the areas of biophysical sciences and protein crystallography. The activities of the biophysical sciences cover structural biology, biomolecular spectroscopy, macromolecular crystallography, cell biology, molecular genetics membrane biophysics, genetic toxicology and realization biology, genetics and mutation studies of various neurodegenerative diseases. The structural genomics activities involve gene expression and mutation studies, crystallization and structural determination by X-ray crystallography and different spectroscopic techniques to study folding and aggregation of proteins.

Institute for Plasma Research (IPR), Gandhinagar

The roots of Institute for Plasma Research can be traced back to early 1970's when a coherent and interactive programme of theoretical and experimental studies in plasma physics with an orientation towards understanding space plasma phenomena was established at the Physical Research Laboratory, Ahmedabad, Gujarat. The early studies carried out were on simulation of E x B instabilities characteristic of the equatorial electrojet, plasma-neutral gas interaction with relevance to the cometary plasma-solar wind interaction and single particle confinement in non-adiabatic magnetic mirrors. Experiments on non-linear ion acoustic waves and double layers were added later. High power plasma experiments using intense electron beams to form compact toroids and electron rings in toroidal devices started in 1978 reflected a re-orientation to fusion-

relevant experiments.

In 1982, it was decided to initiate studies on magnetically confined high temperature plasma, which resulted in the establishment of the Plasma Physics Programme (PPP) supported by the Department of Science and Technology. Design and engineering activities on India's first tokamak named ADITYA started at the same time. In 1984 the activities moved into an independent campus at Bhat village on the outskirts of Ahmedabad. The Plasma Physics Programme (PPP) evolved into autonomous Institute for Plasma Research under the Department of Science and Technology in 1986. With the commissioning of ADITYA in 1989, full-fledged tokamak experiments started. The programmes in plasma processing and basic and computational plasma research were also taken up.

In 1995, it was decided to build the second generation Superconducting Steady State Tokamak SST-1 capable of 1000 second operation. Around this time, the institute became a constituent unit of the DAE. IPR specializes in the areas of theoretical plasma physics, computer modeling, superconducting magnets and cryogenics, ultra high vacuum, pulsed power covering microwave and rf regimes, computerbased control and data acquisition systems and industrial, environmental or strategic plasma applications. The industrial plasma activities have been reorganized since 1998 under the Facilitation Centre for Industrial Plasma Technologies (FCIPT) for their commercial exploitation.

Harish Chandra Research Institute (HRI), Allahabad

This institute was started as the Mehta Research Institute of Mathematics and Mathematical Physics with the initial support from the B.S. Mehta Trust, Calcutta (now Kolkata) in 1968. The Government of Uttar Pradesh provided about 66 acres of land in Jhunsi, Allahabad. In 1983 it became first a grant-in-aid institution and subsequently a fully aided institute of DAE. The Institute was renamed as Harish Chandra Research Institute (HRI) in the year 2000 after the eminent mathematician, late Prof. Harish Chandra.

The Institute is devoted to fundamental research in various fields of mathematics and theoretical physics. In the recent past, the Institute has embarked on some major projects. A new Beowulf Cluster is installed to do high performance numerical simulations for astrophysics, condensed matter physics, and lattice gauge theories. The studies on disordered and correlated electron systems have been carried out. These involve coupled electron, phonon, and spin degrees of freedom, in the presence of a disordered background. The materials that can be modeled include the manganites, f-electron magnets and a wide variety of magnetic semi conductors (of potential importance in spintronics). The numerical method involves Monte Carlo, and exact diagonalisation for the fermion degrees of freedom. Accessing large sizes involves computational effort {O}{N^3), and the cluster has been a vital resource in studies on Anderson-Mott transition, and disordered double exchange magnets. The high energy physics theory is another research area to which the institute is devoted. More recently, work on cryptography and computational number theory was initiated.

Institute of Physics (IOP), Bhubaneswar

The Government of Orissa established the Institute of Physics in 1974 and on March 25, 1985 it became a DAE aided autonomous research institute. The institute is involved in research on the broad areas of condensed matter, high energy and nuclear physics. The institute has a 3MV pelletron accelerator along with beamlines for Rutherford backscattering (RBS), Proton induced x-ray emission (PIXE), Accelerator Mass Spectrometry

(AMS), microbeam and ion implantation for experimental work. The experimental research focuses on condensed matter physics, material characterization, surfaces and interfaces, ion induced effects on the surfaces, bulk materials and on nano-islands grown on substrates, photoluminescence and quantum tunneling. Theoretical research activities being carried out include string theory, high energy phenomenology, condensed matter physics, statistical physics, quantum computing, mathematics, nuclear spectroscopy and structure, astrophysics, biophysics etc. The institute is also participating in STAR and ALICE international collaborations. In the area of human resource development, the institute is contributing quite significantly by conducting Predoctoral courses and Doctoral programmes in different branches of physics.

Institute of Mathematical Sciences (IMSc), Chennai

The Institute of Mathematical Sciences, founded by Alladi Ramakrishnan in 1962, is a national institution for fundamental research in frontier disciplines of the mathematical sciences. It became an aided institute of DAE in 1995. At present, IMSc has about 45 faculty members working in the areas of mathematics, theoretical computer science and theoretical physics. The Institute trains graduate students through active research programmes, which culminate in the award of the PhD degree. The institute supports post-doctoral research through fellowships and has a Visiting Scientists Scheme. The theoretical computer science activity of the institute is being pursued in the areas of concurrency, logic, algorithms, complexity theory and automata theory. The mathematicians are working in the areas of algebra, algebraic geometry, number theory, partial differential equations, subfactors, representation theory and topology. The physics related activities pursued are in wide areas of condensed matter theory, high energy physics, mathematical physics, non-linear dynamics, charge particle beams, quantum optics and quantum information theory.

Tata Memorial Centre (TMC), Mumbai

Tata Memorial Centre is dedicated to the medical applications of radiations in public domain. Radiodiagnosis, radiation oncology, external beam therapy, brachytherapy and medical physics are the important research activities of the centre. Since early days of radon plant, the radiotherapy and radiodiagnosis have grown to today's state-of-the-art modern facilities. Technical advances such as Stereotactic Radiosurgery (SRS), Stereotactic Radiotherapy (SRT), Intensity Modulated Radiotherapy (IMRT) with Computer Networking and virtual simulation have been made in the area of radiation therapy. The infrastructure available for external beam therapy includes; three linear accelerators with 6 to 15 MV photon energy and multiple electron energies from 6 to 20 MeV (Clinac-2100C, Clinac 2100C/D, Clinac 6EX), four Telecobalt units (Theratron-780, Theratron-780C, Alcyon, and Elite 80) with one conventional simulator (Ximatron) & a CT simulator (Somatom-Emotion) with virtual simulation (Coherence Dosimetrist) and a fully equipped mould room. Brachytherapy forms an integral part of many treatment protocols in radiotherapy. Various brachytherapy procedures are judiciously practiced with after-loading systems, both remote and manual, in a wide range of clinical situations. Interstitial brachytherapy using Iridium-192 was introduced for the first time in the country. Medical Physics is equipped with sophisticated modern equipment such as radiation field analyzer (Blue Phantom), ionization chambers & brachytherapy dosimetry systems with electrometers, TLD dosimeter, film dosimetry system, etc. for accurate and precise dose computation and treatment delivery.