ACCELERATORS AND THEIR IMPACT ON SOCIETY

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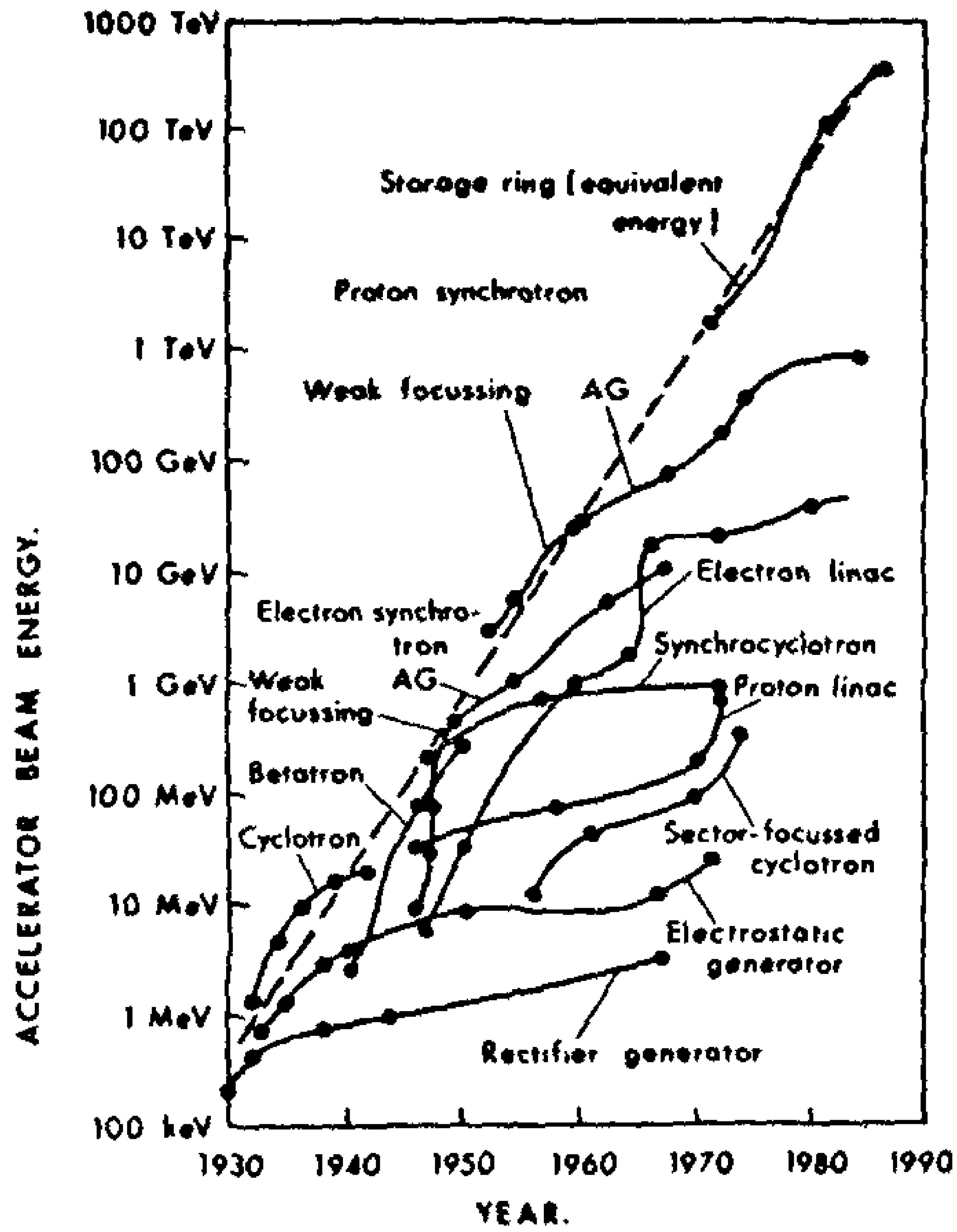
MAN is for ever interacting with his environment, he is curious about it, and he asks many questions. Answers to some questions come easily, whereas answers to others come only after intensive thought and careful experimentation.

The question pertaining to the ultimate structure of matter is the most basic question. This question has generated many important theories, and stimulated experimentation. The most important tools for experimentation in the last fifty years have been charged particle accelerators, which have been used for studying nuclear reactions and elementary particle interactions. As the knowledge about the fundamental particles has grown, the size, complexity and versatility of accelerators have also grown. The beginning of the accelerator age was made in 1932 by J. D. Cockroft and E. T. S. Walton, using a voltage multiplier circuit, accelerating protons to about 300 keV, and observing a nuclear reaction; the cost of this project was £1000[1]. In fifty years since then, accelerators with a proton energy of 500 GeV have been built, and accelerators with a proton energy of 1000 GeV are just around the corner; the cost of such accelerators runs into hundreds of millions of dollars. Thus the energy available as well as the cost have grown about a million times in fifty years, a phenomenal growth by any standard.

Such a growth is the result of a combination of factors such as motivation for fundamental studies, generation of new ideas in accelerator physics, technological advances and availability of appropriate funding. The growth, in turn, has stimulated further fundamental studies, generation of new ideas, technological advances, and medical, industrial and other applications of accelerators. Panofsky[2] has shown the energy growth of accelerators and storage rings in a diagram reproduced here in figure 1.



Energy growth of accelerators and storage ring.

The overall impact of accelerators on the human society has indeed been very great. In order to fully comprehend this, let us consider the technological, scientific and social aspects of this impact, generated by the accelerators.

TECHNOLOGICAL SPIN-OFF

1. *Generation of technologies*:

When accelerator evolution began about fifty years ago, accelerators were small laboratory apparatus, built and operated by one or two scientists with some help from graduate students and workshop mechanics. Today the technology of accelerators has grown to such an extent that there are large industrial corporations for building accelerators. For example there are the High Voltage Engineering Corporation, U.S.A., for Van de Graaff or electrostatic accelerators, National Electrostatic Corporation, U.S.A., for pelletrons, Cyclotron Corporation, U.S.A., for cyclotrons, Scanditronix, Sweden for various types of accelerators and CSF, France for cyclotrons. Requirements of sophisticated accelerator designs have helped to generate new technologies by providing the necessary motivation backed by adequate funds.

High voltage technology has been highly developed due to the work on Cockroft-Walton accelerators and electrostatic accelerators[3]. The first getter-ion pump[4], for producing ultrahigh vacuum, was built for the University of Wisconsin new electrostatic accelerator, marking a major step in ultrahigh vacuum technology. Magnet technology has developed very rapidly, due to the growth in cyclotrons and synchrotrons. All cyclotrons require accurately built large steady field magnets and all synchrotrons require pulsed magnets, with highly regulated power supplies. Methods for measuring the magnetic fields produced have also been developed. High power radio frequency systems for acceleration have been developed for cyclotrons, synchrotrons and linear accelerators. The Radio Corporation of America has specially developed high power radio frequency oscillator tubes for accelerators, since there is a market for them. Ion source development is a must for the growth of accelerators, and beginning with the simple radio frequency ion source and the PIG ion source, the duo-plasmatron ion source for a variety of ions have been developed. Negative ion production is also important, since negative ions are required for tandem accelerators, ion sources for polarised protons, deuterons and ^{3}He nuclei have been built for electrostatic accelerators as well as for cyclotrons. Electron beam ion source (EBIS) and electron cyclotron resonance (ECR) ion sources, for producing high charge states of heavy ions for the purpose of acceleration, are under different stages of development.

Important concepts in accelerator physics, which have been generated over a period of time, such as strong focussing, storage rings and electron cooling have contributed immensely to the growth of accelerators, and thereby to technological growth.

Sophisticated electronics engineering is required for the power supplies, radio frequency system and the control system. Precision machining and precision alignment require elegant mechanical engineering work. Since the total power requirements are large (~10 MW for a medium sized accelerator), a good electrical engineering study of the power supply system is necessary.

Superconductivity has interacted very strongly with accelerator physics. Superconducting magnets enable production of higher magnetic fields (~50 T and above) and thus help in bending more energetic particles. The National Accelerator Laboratory at Batavia plans to double the proton energy to 1000 GeV, by using superconducting magnets at the same radius[5]. For achieving this, it has to have one of the largest systems in the world for the production of liquid helium. Superconducting coils have been used for bubble chambers. Very recently, in July 1982, a large cyclotron with an enery constant $K=500$ (particle energy $E=K\,Q^2/A$ MeV, where Q is the charge and A the atomic mass number of the particle), using a superconducting magnet has been put into operation at the Michigan State University, East Lansing, USA. Superconducting RF cavities, to reduce power losses, have also been tried out for various accelerators.

2. *Variable Energy Cyclotron at Calcutta*:

At this stage, it is relevant to examine the technological spin-off produced by the construction of the 224 cm Variable Energy Cyclotron at Calcutta, which has been completed and has gone into regular operation in 1981[6,7].

When the question of a cyclotron in India was discussed, Dr. H. J. Bhabha, then Chairman of AEC, made a policy decision that the cyclotron should be built and not purchased, in order to stimulate technological growth and to increase the interaction between scientific institutions and industries.

The 262 tonne cyclotron magnet was fabricated at the Heavy Engineering Corporation, Ranchi, which was the only place in the country to do the entire job. The steel for the magnet had to be specially cast, with a carbon content ≲0.1% and other elements also properly controlled, for ensuring suitable magnetic properties. The HEC had never cast steel with such stringent specifications earlier. However, they took up the challenge, and after some experimentation, they were able to produce the steel with carbon content ≲0.1% and the required magnetic properties. Since then, we have approached them many times for steel for the smaller magnets, such as the analysing magnet, switching magnet and magnetic spectrometer, and every time a satisfactory quality of steel has been made available. The technology of making magnet quality steel is thus available on a routine basis. This magnet was also machined at the HEC. Precision machining was necessary and the magnet gap had to be uniform within 125 microns over a pole piece diameter of 224 cm. Although HEC is capable of giving these accuracies, they had not been required to do such precision jobs earlier. At our instance they tried, and they succeeded beyond expectations. For achieving this, our engineers and scientists worked in close collaboration with the engineers of HEC.

The magnet main coils, required to carry 2800 A current were to be wound from copper conductors with a central hole for water cooling, insulation being ensured by using special insulating tapes. The trim and valley coils were to be epoxy potted. These jobs were done by the Bharat Heavy Electrical Limited., Bhopal. Precision was important, and many new technologies, pertaining to the use of insulating tapes and epoxy potting, had to be developed in close collaboration with the BHEL, Bhopal.

There are many power supplies required for the cyclotron the main magnet power supply is a high current, low voltage (2800 A, 150 V) power supply with a current stability of 1 in 10^4. The deflector power suppy is high voltage, low current (120 kV, 5 mA) power supply, and the radio frequency oscillator power supply is high voltage, high current (20 kV, 20 A) power supply. Such supplies were not available through commercial firms, and the entire fabrication work was undertaken by the VECC, BARC. This technology is now available at VECC, and as a spin-off a number of x-ray diffraction power supplies (60 kV, 10 mA) have been built for use in BARC.

The radio frequency system of the cyclotron has a resonator tank, with a volume of about 27,000 litres, which has to be evacuated to a presure of $\sim 1 \times 10^{-6}$ torr. This resonator tank had to be welded from steel plates, the weld quality requirement being stringent. The Garden Reach Shipbuilders and Engineers, Calcutta fabricated this tank. The work required continuous interaction between VECC engineers and scientists and GRSE engineers.

The large volume of the resonator tank and the dee tank of the cyclotron (~30,000 litres), which has to be pumped down to a pressure of 1×10^{-6} torr, requires two 89 cm diameter diffusion pumps, each with an unbaffled pumping speed of 42,000 litres/sec. These pumps were specially fabricated by the Technical Physics Division, BARC, these being the largest pumps made in India till then. Later, the know-how for making diffusion pumps was transferred to the Indo-Burma Petroleum Co. Such large size pumps have now been made for evacuation of space simulation chambers, for testing satellite components. Cryopanels have been installed in the dee chamber, to give additional pumping speed by cryopumping and this experience has also been useful in our space programme. Thus the spin-off of vacuum technology required for the cyclotron, has already been utilized in other spheres.

Since the charged particle beam extracted from the cyclotron has to be transported over long paths (~100 metres) in vacuum, an elaborate beam transport system is necessary for obtaining high transport efficiency. Various components of the beam transport system *viz.*, quadrupole magnets, bending magnets, switching magnets and analyzing magnet have been contracted out to various industries, thereby ensuring their involvement in this venture.

There are a number of other developments, such as development of fast electronics for data processing, development of semiconductor detectors for charged particles, preparation of targets, development of computer software and setting up of radio-chemical and isotope production facilities.

It is thus evident that the original motive of generating science-industry interaction through the variable energy cyclotron project has been amply served, and we have moved considerably forward in the field of accelerator technology. A foundation has been laid, and we are now well equipped in many ways to build higher energy accelerators in the 1980's whenever it is decided to build such an accelerator. This effort, if undertaken, is sure to generate further newer technologies, such as ultrahigh vacuum technology, pulsed magnet technology and superconducting magnet technology.

ACCELERATORS AND FUNDAMENTAL RESEARCH

Since fundamental research is the primary motive of accelerator programmes, it is important to consider the contributions of accelerators to fundamental research. We shall consider only a few examples here, without attempting to examine the total contribution, which is very large and comprehensive.

1. *$^{7}Li\ (p,\alpha)\ ^{4}He$ reaction*:

J. D. Cockroft and E. T. S. Walton at the Cavendish Laboratory Cambridge, observed in 1932 the first nuclear reaction, $^{7}Li(p,\alpha)^{4}He$, by bombarding ^{7}Li with protons accelerated to about 300 keV, using a Cockroft-Walton accelerator.

2. *Lawrence Cyclotron*:

E. O. Lawrence at the Radiation Laboratory, Berkeley, built the first cyclotron in 1932 and accelerated protons to about 1 MeV energy, then the highest energy, for the study of nuclear reactions.

3. *Measurement of $^{7}Li(p, n)^{7}Be$ threshold:*

The first absolute and precise measurement of the threshold for neutron production in the ^{7}Li $(p,n)^{7}Be$ reaction (Threshold energy $E_{Th} = 1.882$ MeV) was done using the 4.5 MeV University of Wisconsin electrostatic accelerator, where the proton energy could be accurately varied in small steps.

4. *Nucleon-nucleon forces*:

Using an electrostatic accelerator, with precise definition as well as variation of energy, nucleon-nucleon forces have been investigated by studying *p-p* scattering at low energies, at the University of Wisconsin.

5. *Charge-exchange reactions*

When energetic charged particles pass through materials, charge exchange reactions take place, yielding different charge states of the incident particle and causing energy loss. This phenomenon was investigated in the keV energy range extensively by S. K. Allison at the University of Chicago in the early fifties, using a low energy Cockroft-Walton accelerator, called the kevatron. A study of charge exchange reactions for heavy ions was done somewhat later at the Yale University, using a heavy ion linear accelerator.

6. *Energy levels of nuclei*:

The Cockroft-Walton accelerator, electrostatic accelerator and cyclotron have been vital tools in acquiring the immense mass of data concerning energy levels of nuclei, and their various properties, such as decay channel, life-time, spin and parity.

7. *Optical model of the nucleus*:

One of the most successful models, the optical model, which uses a complex potential, evolved for explaining a series of measurements of fast neutron cross sections done by H. H. Barschall and collaborators at the University of Wisconsin, using monoenergetic neutrons produced by the 4.5 MeV electrostatic accelerator.

8. *Coulomb excitation*:

Excitation of a nucleus by the Coulomb interaction between the projectile and the target nucleus in a nuclear reaction and its subsequent de-excitation yields information about the deformation and quadrupole moment of the nucleus, leading to the study of collective motion of the nucleons in the nucleus. Gamma rays from Coulomb excited nuclei, produced by protons accelerated in electrostatic accelerators were first observed at the Niels Bohr Institute, Copenhagen and Oak Ridge National Laboratory, Oak Ridge, in the fiftees.

9. *Beam foil spectroscopy*:

When accelerated ion beams pass through thin foils, various charge states are produced and radiative electron capture takes place. The radiations emitted yield valuable spectroscopic information about hyperfine structure, Lamb shift, etc.

10. *Channeling experiments*:

An energetic ion has been found to have a larger range along the low index plane of a crystal, than a plane normal to it. This phenomenon, called channelling, can be used for measuring nuclear life-times.

11. *Production of transuranic elements*:

Cyclotrons at Berkely and Dubna have been extensively used for the production of transuranic elements.

12. *Heavy ion reactions*:

Collisions between heavy ions at high energies yield important information about the complex behaviour of heavy ions. Considerable work on heavy ion interactions has already been carried out with cyclotrons such as the 88 inch Berkeley Cyclotron, and with the Darmstaadt heavy ion linac, giving energies of 10 MeV/nucleon.

13. *High energy interactions*:

Research in high energy interactions has received a tremendous boost on account of high energy accelerators, and extremely valuable information of a fundamental nature has been obtained. The discoveries of anti-proton by Bevatron in the fifties, the structure of the nucleons and the J/Ψ resonance by the Stanford Electron Linear Accelerator and the M.I.T. electron accelerator in the sixties and seventies are specific examples. Today large research programmes in high energy interactions are being carried out at the National Accelerator Laboratory[8], Batavia, CERN[9], Geneva, JINR[10], Dubna, SLAC[11], Stanford, DESY[12], Hamburg, and other similar laboratories[13].

14. *Meson interactions*:

With higher energies and grater proton intensities available, intense beams of pions can be obtained, and sub-nuclear structure can be studied using this new and different probe. Meson factories, such as the TRIUMF[14] at Manitoba, LAMPF[15] at Los Alamos and the SIN[16] at Zurich have opened up vast areas for investigation. Kaon factories, for providing a still newer probe, are also being designed.

15. *Accelerators and Nobel Prizes*:

In order to get a global view of the contributions of accelerators to fundamental research, we may consider the Nobel Prize winning researches during the last fifty years[17].

As shown in Table 1A, seven Nobel Prizes were awarded for accelerator-based research. Table 1B shows that three Nobel Prize were awarded for theoretical work based on accelerator produced results.

INTER-DISCIPLINARY SCIENTIFIC APPLICATIONS:

1. *Nuclear Data for reactors*:

The most important application of nuclear energy is the generation of power through

TABLE I

Nobel Prizes

A. For accelerator based research

No.	Year	Scientist	Research
1	1939	E. O Lawrence	Invention and development of the cyclotron and results obtained with it, especially with regard to artificial radio-active elements
2.	1951	J. D Cockroft and E.T.S. Walton	Transmutation of atomic nuclei by artificially accelerated particles
3.	1959	E. G. Segre and O. Chamberlain	Discovery of anti-protons
4.	1960	D. A. Glaser	Invention of the Bubble chamber
5.	1961	R. Hofstadter	Studies of electron scattering in nuclei and discoveries concerning the structure of the nucleons
6.	1968	L. Alvarez	Contributions to elementary particle physics
7.	1976	B. Richter and S. C. C. Ting	Discovery of the J Ψ resonance

B. For theoretical work based on accelerator produced results

No.	Year	Scientist	Research
1.	1963	M G. Mayer and J. H. D. Jensen	Nuclear shell structures
2.	1967	H. Bethe	Theory of nuclear reactions, especially discoveries concerning the energy production in stars
3.	1969	M. Gell-Mann	Classification of elementary particles and their interactions

nuclear power reactors. Design of nuclear power reactors requires a very precise knowledge of neutron cross-sections for a large number of elements used in reactors. This data has been obtained. (and is being obtained) primarily through accelerator-based research. Large collective efforts towards stimulating nuclear data measurements and compilations are under way for a number of years, through national, regional or International Nuclear Data Committees. The need for nuclear data originally arose in connection with weapons research, during the second World War. When the Manhattan Project for the first atomic bomb was under way at Los Alamos, the need for nuclear data was so great and urgent, that the 4.5 MeV electrostatic accelerator at the University of Wisconsin was dismantled and shipped to Los Alamos, where it was installed for the measurements. After the completion of the project, the accelerator was brought back to the University of Wisconsin and reinstalled.

2. *Nuclear data for fusion*:

Fusion reactors hold great promise for the long range future, since the basic raw material, deuterium is plentiful in nature. Design studies require precise information on charged particle reaction cross-sections. National, regional and international efforts have already started for stimulating nuclear data measurements for fusion.

3. *Nuclear cross-sections for astro-physics*:

Stellar bodies are great laboratories where charged particle reactions are taking place at a furious rate, generating immense quantities of energy. A precise knowledge of these cross sections particularly in the keV energy range is necessary for arriving at the appropriate theoretical picture of energy generation in stars. Such cross-section measurements have been extensively carried out at the California Institute of Technology.

4. *Multidisciplinary studies with an electron storage ring synchrotron*:

An electron storage ring synchrotron gives intense synchrotron radiation which is highly collimated, and also polarised, the energy spectum depending on the energy of the electrons. This radiation, after suitable monochromatization, provides an excellent photon source, which has wide applications in spectroscopy, solid state physics, surface studies, and many other fields.

SOCIOLOGICAL FALL OUT

1. *Medical*:

The biggest impact in terms of human welfare, produced by the accelerators relates to their medical applications. Electron linear accelerators have already become powerful tools for cancer therapy, and tomography studies, and more and more cancer hospitals in the country are feeling the need for such facilities. Cyclotrons have been used for fast neutron therapy, and meson factories have been used for meson therapy; however, the usage is not yet extensive. Cyclotrons have been extensively used for producing proton-rich isotopes used for medical diagnosis. For example^{67} Ga which can be produced by the ^{65}Cu $(\alpha, 2n)^{67}$Ga reaction in a cyclotron with α energies of about 30 MeV, is of great use in diagnosing soft tissue tumors; and ^{123}I, proudced by a cyclotron, is used for diagnosis of thyroid gland disorder.

2. *Industrial*:

Electron accelerators have been used for food sterilization, polymerization of wood and changing properties of plastics. Cyclotrons and electrostatic accelerators have been used for determining trace impurities in materials by activation analysis, *e.g.* carbon content in steel can be determined; and flourine content in tea leaves can be determined by observing proton capture reactions in ^{12}C and ^{19}F respectively.

3. *Educational*:

A small charged particle elecrostatic accelerator with energy in the 0.4-1 MeV range is an ideal tool for teaching basic concepts in nuclear physics. Simple experiments can be designed to illustrate concepts such as nuclear reaction, differential and total cross-sections, Q-value, stopping power, behaviour of charged particles in electromagnetic fields, etc. A good post-graduate laboratory in a University, offering nuclear physics as a special subject, should necessarily have a small accelerator.

4. *Management*:

Construction of an accelerator is truly a multi-disciplinary activity. Since the utilization of an accelerator will ultimately involve physicists, chemists and bio-scientists, all of them have to be consulted for planning an accelerator facility. During the design and construction stages, the working staff must include accelerator physicists, electronics and electrical engineers, mechanical engineers, health physicists and civil engineers. Most of this staff are required to keep the accelerator operating. Thus the accelerator provides a focal point around which the scientists and engineers work together, interacting strongly. A medium or large-sized accelerator must operate on a round-the-clock basis, for optimum performance and utilization. This requires appropriate staff, suitable transport arrangements, and houses near the accelerator laboratory for the essential staff. Radiation protection and safety aspects have to be adequately taken into account. The management of an accelerator laboratory therefore requires an approach that is quite different from that required for a general research laboratory or a University Department of Physics.

CONCLUSION:

It is thus seen that accelerators have made a very significant impact on society during the last half a century of their existence[18]. Fundamental research has progressed by leaps and bounds due to research produced with the accelerators, and we have been able to go deeper and deeper in understanding the basic structrue of matter. Technological progress has been phenomenal—entirely new industries have come up, to sustain accelerator construction, and new technologies have received a boost. Accelerators have established themselves as valuable tools for medical treatment and diagnosis, and industrial utilization of accelerators is increasing at a rapid rate. In education, accelerators are very useful for illustrating basic concepts. Accelerator laboratories require different management techniques, since they have to operate continuously, and multidisciplinary work in an accelerator laboratory stimulates cohesive scientific work.

Large accelerators have become very suitable platforms for international collaboration. For example, accelerators at NAL, Batavia, CERN, Geneva and JINR, Dubna, have many international programmes. There is also a proposal for a very big accelerator through world collaboration.

Since the emphasis in general for an accelerator laboratory is on fundamental research, the best of scientific talent tends to collect around an accelerator. An accelerator laboratory therefore serves as a bastion of academic excellence.

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ANNOUNCEMENTS

HARI OM ASHRAM PRERIT CHEMISTRY RESEARCH AWARD

Hari Om Ashram Prerit 'Shri Champrajbhai Shroff Chemistry Research Award', Rs. 5000/, for the year 1980 has been awarded to Prof. J. S. Dave, Department of Chemistry, M. S. University, Baroda.

'JOURNAL OF PHYTOPATHOLOGY' HAMBURG AND BERLIN

Change in the administration of the Indian editor's office of 'Journal of Phytopathology', Hamburg and Berlin: During January 1983, Prof. T. S. Sadasivan, 'Gokulam', 86, M. K. Amman Koil Street, Mylapore, Madras-600 004 (India), has taken over the patronage for the 'Journal of Phytopathology' for India.

All Indian authors are requested to submit their manuscripts for this Journal to Prof. Sadasivan.

INDIAN JOURNAL OF COMPARATIVE ANIMAL PHYSIOLOGY

Indian Journal of Comparative Animal Physiology is released as Biannual Journal under the auspices of Indian Society for Comparative Animal Physiologies. Details can be obtained from Prof. K. S. Swami, Chief Editor, IJCAP, Department of Zoology, S. V. University, Tirupati-517 502.

JAWAHARLAL NEHRU AWARD OF THE ICAR

Dr. D. M. Sawant of All India Co-ordinated Fruits Improvement Project on Citrus, Shrirampur Dist. has been awarded the Jawaharlal Nehru Award of the ICAR for the year 1982 in recognition of his research work on the possible methods of control of citrus die-back in India and studies of the yellow mosaic disease of Bell Pepper.