Development and Utilization of Accelerator in BARC

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Abstract. The charged particle accelerators have played a key role in the field of basic sciences. Whether it is physics, chemistry, biology or material science, all of them have gone through radical transformations. All this has been possible because of the accelerators beams which have been used to unfold the secrets of nature. Same is true in case of applied sciences too. In the field of Medicine, the outdated methods of diagnosis are slowly getting replaced by accelerator-produced radioisotopes. The development of accelerators in BARC can be categorized in two ways, i.e., heavy ion accelerators and electron accelerators. The heavy ions accelerators at sufficiently high energies are used in basic science for conducting nuclear research in a variety of new and interesting regimes. The utilization of accelerator for basic sciences is about 70% and rest for industrial usages and application. The electron accelerators have tremendous applications in industries. We have taken up various application programs using these facilities.

1. Introduction

A 5.5 MV Van-de-graaff single ended machine was commissioned in the sixties at BARC. This machine was utilized for various applications. In 1982, the project MEHIA started, where a 14 UD Pelletron Accelerator was purchased from M/s NEC, USA and installed at Tata Institute of Fundamental Research, Colaba, Mumbai. This accelerator was commissioned in 1988 and since then it has been serving as a major facility for heavy ion accelerator based research in India. In 1993, a project to convert 5.5 MV Van-de-Graaff to a 6 MV Folded machine was taken up. The first beam from was accelerated in 2000. The electron accelerators on the other hand, have wide industrial applications. The Electrons Beam Center has been set up at Kharghar, Mumbai, where 0.5 MeV, 3 MeV and 10 MeV electron accelerators are under construction. The 500 KeV electron beam accelerator is operational and being used for cable irradiation etc. The medical cyclotron was set up at Radiation Medicine Centre, Parel, Mumbai for Positron Emission Tomography.

2.Development of Accelerators

2.1 Pelletron Accelerator Facility

The fig 1 shows schematic of this facility. The source for the charge particle is located at the top of the accelerator tower. A cesium sputter ion source generates negative ions, which are initially accelerated to low energies (150-250 KeV) in a short horizontal section. These low energy ions are then bent through 90^0 using an injector magnet into the vertical accelerator column. In the first stage, the acceleration results from electrostatic attraction of negative ions by the positively charged high voltage terminal situated at the center of the column. The high electric potential at the terminal is achieved by a continuous transfer of charge to the terminal by means of two pellet chains. Inside the terminal ion passes through a thin carbon foil or a gas stripper, where they lose electrons and acquire a high positive charge. The optimum charge state of the ion depends upon the energy of incoming ion. Thus, after acceleration through high-energy section ion achieve energy

$$E= V(q+1)$$

Where E is energy of ion in MeV, V is terminal voltage in MV and q is charge state.
The charge particle beam is transported to beam hall, where five beam ports are functional. Various developments to improve the performance of the Pelletron accelerator have been implemented over the last decade. The original corona needles were replaced by large value resistors (1 Giga ohm), which has resulted in remarkable improvement in the voltage stability.

Moreover, machine can be now operated at lower terminal voltages. Various beams accelerated over the years are shown in Fig 2. A superconducting linear accelerator has been indigenously developed to boost energy of the heavy ions emerging from Pelletron. The Linac booster consists of seven modules, each module having four lead-coated copper quarter wave resonators operating at liquid He temperature. This accelerator is designed such that only the particles entering with β=0.07-0.13 will gain energy and total energy gain will be 14 MeV per charge state.

2.2 Folded Tandem Ion Accelerator

The 5.5 MV single ended Van-de-graaff accelerator was converted into a 6 MV folded heavy ion accelerator using NEC accelerating tubes and column. The negative ions are generated by a SNICS source floating at -200 kV deck potential and then bend by 90^0 using a combination of electrostatic deflector (20^0) and injector magnet (70^0). The ion beam in the terminal is bend by a 180^0 magnet after the stripper. The power to magnet and various electronic devices is given by a 5 kVA alternator, operating at 400 Hz, specially designed for this purpose. The alternator rotates at 1500 rpm and driven by a segmented Perspex shaft. The accelerator is operational since 2000 and routinely used for various applications as mentioned above. The accelerator schematic is shown in Fig 6.

2.3 Electron Accelerators

Electrons up to energy of 0.5 MeV and 10 kW are being used for coatings, adhesives and paints on thin films, tapes, wooden panels etc. These curing processes enhance the mechanical and thermal properties of the products. Similarly, heat shrink materials use electron beams in the range of 0.5 MeV to 2MeV. To improve upon the lubrication property, Teflon is treated with beams of about 2 MeV and 10 kW. Diamonds with exotic colours are produced by using beams of 4-6 MeV and a power of 10 kW. Green strength of the rubber is enhanced by exposing it to electron beams of 2 MeV and 30 kW. Beams up to 10 MeV and 10 kW are used for cross-linking of cables/wires, food preservation, medical sterilization, etc. The cross linking improves the tensile strength and fire resistance properties of the cables. A 7 MeV electron accelerator for free radical research in Chemistry has been working for last several years. A 400 keV, high current accelerator is being used as 14 MeV neutron generator.

2.4 New Project

A positive ion injector consisting of an ECR Ion Source followed by a Radio Frequency Quadrupole and Superconducting Niobium Cavities will be developed for further enhancing the available beam species and energies. The proposed injector facility will enable the study of reactions above the Coulomb barrier even for very heavy system like U+U.

3. Accelerator Applications

The utilization of accelerators at BARC for research in basic science and application have grown significantly. The highlights of basic research program at Pelletron Accelerator Facility is that there are more than 300 publications in refereed journals including 12 PRLs and 48 Ph.D. theses.

3.1 High current proton irradiation facility

A suitable arrangement (as shown in Fig 3) has been made above analyzing magnet at Pelletron Accelerator facility for irradiation with proton beam from 4 MeV to 26 MeV up to μA current. This setup will be used for production of neutrons and for radiopharmaceutical applications. Thin layer activation technique for study of wear and tear of machine parts has been standardized using the reaction $^{56}Fe(p,n)^{60}Co$. Proton beam at 16 MeV from Pelletron Accelerator was used for the production of ^{56}Co into a stack of stainless steel foils to generate the calibration curve. This facility has been used for preparation of radiotracers.

One of the important prerequisites for successful operation of a nuclear material handling facility is the effective radiation protection of its workers and the environment. Adequate radiation protection measures are followed at various stages of nuclear fuel cycle operations. With increased utilization of plutonium as a nuclear fuel in the nuclear energy program, the accurate monitoring of plutonium inhalation by radiation workers and the environmental materials has become very important. The most ideal tracer isotope is ^{236}Pu. It has a convenient half-life of 2.85 Years and alpha particle energies (5.73, 5.76 MeV) are well separated from those of reactor grade plutonium isotopes. The most promising reaction for the production of ^{236} Pu is by proton irradiation by ^{237} Np.

3.2 Track-etched membrane production

The technology of production of track-etched membranes (TEMs) using accelerated heavy ions has been well established. A beam scanner magnet, vacuum chamber, power supply and rolling mechanism have been developed indigenously. The membranes produced from this facility using variety of heavy ion beams (Ni, Cl, Ag etc) are used in medical science, analytical science and micro-filtration. An SEM photograph of track-etched membrane produced from this facility is shown in Fig 4. Efforts are underway to produce large size Track-etched membranes.

3.3 Accelerator Mass Spectroscopy

Accelerator Mass Spectroscopy (AMS) overcame the fundamental limitations of conventional mass spectrometers to be able to measure isotope ratios as low as 10^{-15} on samples smaller than a milligram in about one hour. So it has become the technique of choice in recent years. Feasibility study to detect ^{3}He in He and ^{14}C in Carbon samples have been carried out. Our focus is on ^{36}Cl dating. We have built a multi anode gas detector for detection of ^{36}Cl in the presence of ^{36}S. At BARC, it is proposed to pursue program AMS program related to ^{26}Al, ^{36}Cl and ^{129}I.

3.4 Material Science

High current proton irradiation in SS at elevated temperature is also being carried out for surface modifications. Hydrogen depth profiling in Zirconium material has been carried out using elastic recoil detection technique using heavy ions.

3.5 Radiation Biology

A thin (20 μm) window of Ti has been placed at the end of beam line and proton beam of varying intensities $10^4 - 10^9$ have been taken out in air for radiation biology programme.

The radiation biology set up is shown in Fig 5.

4. Conclusion

A brief account of accelerator development and utilization at BARC has been presented**.** A new program to develop indigenously high current, low energy accelerator as an injector to

Accelerator Driven System (ADS) has been initiated. Over the years the performance of accelerator and its utilization has shown a significant growth.

5. Acknowledgement

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#Tata Instititute of Fundamental Research, Mumbai -400 005 available online in NIM A (in press)

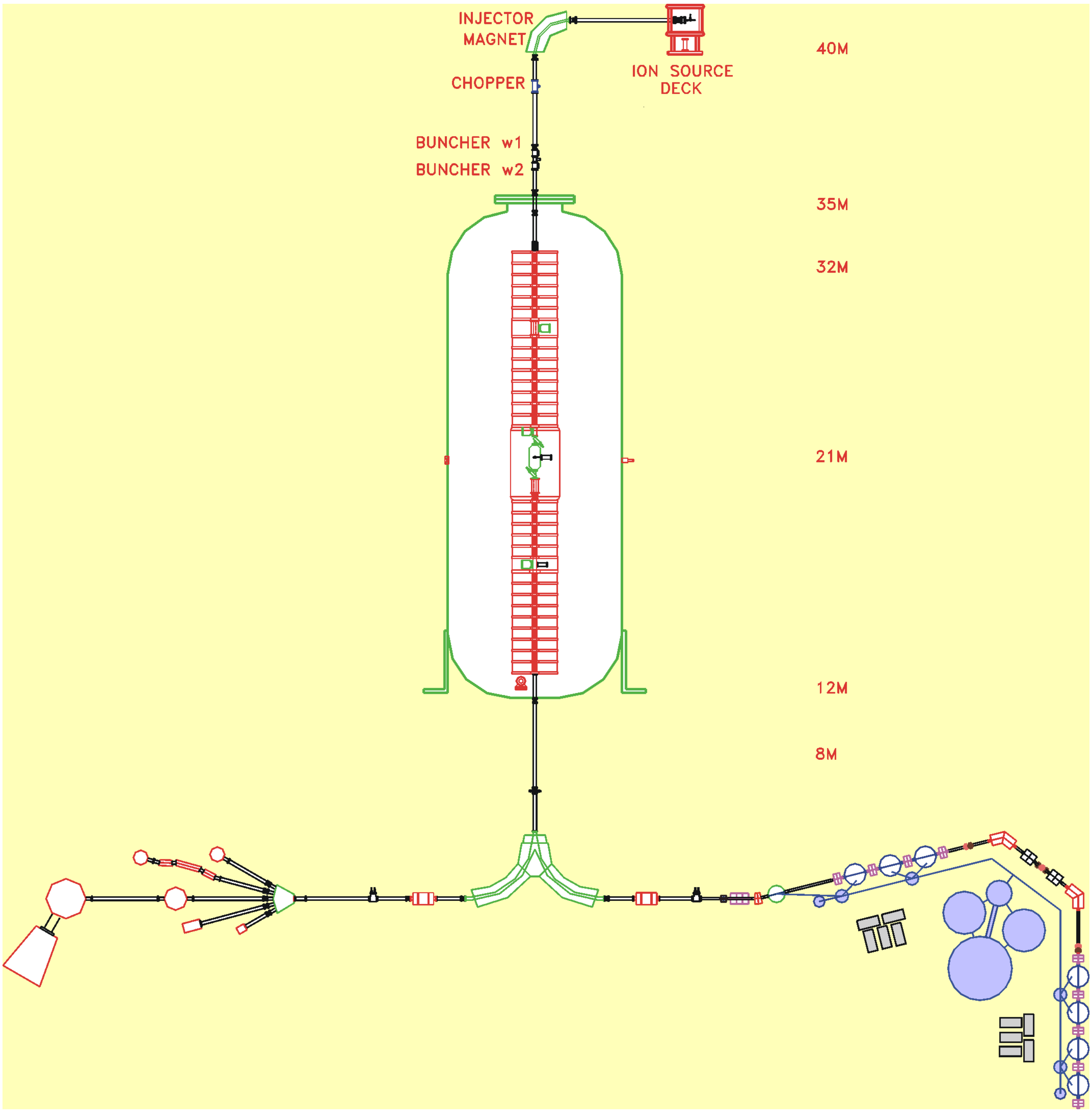

Fig. 1. Schematic of 14 UD Pelletron Accelerator Facility

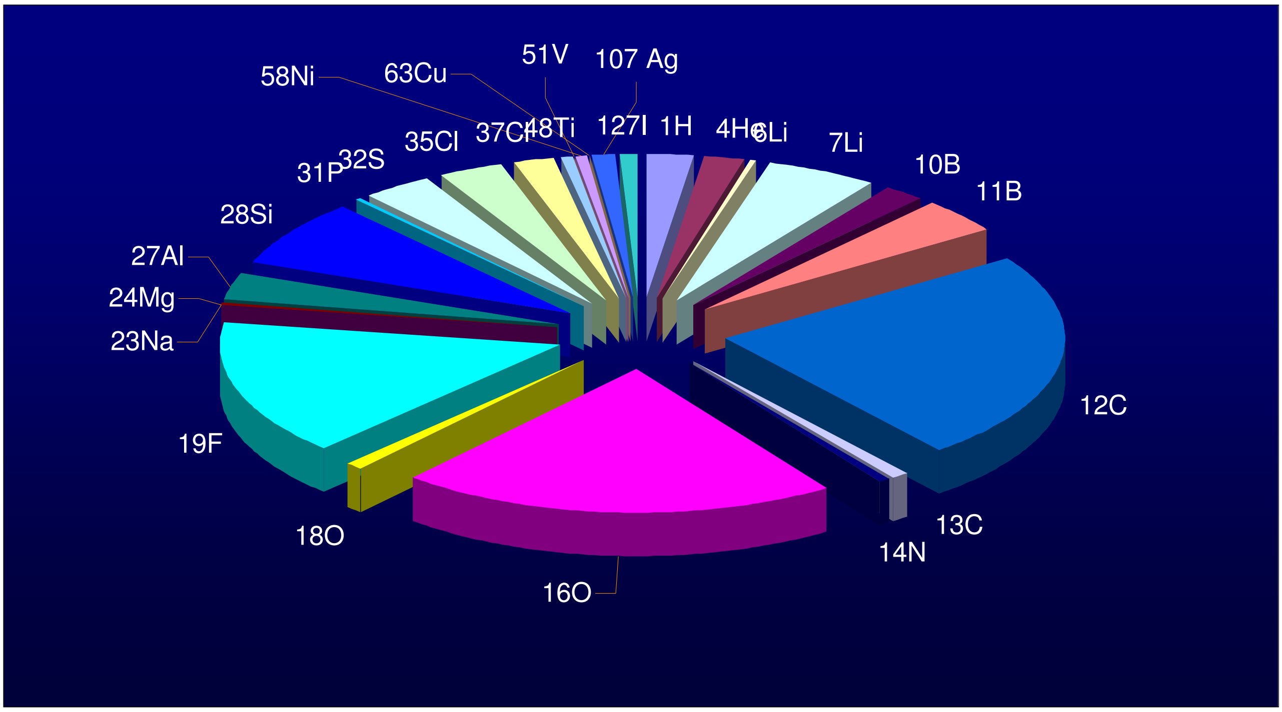

Fig.2. Ion beams accelerated

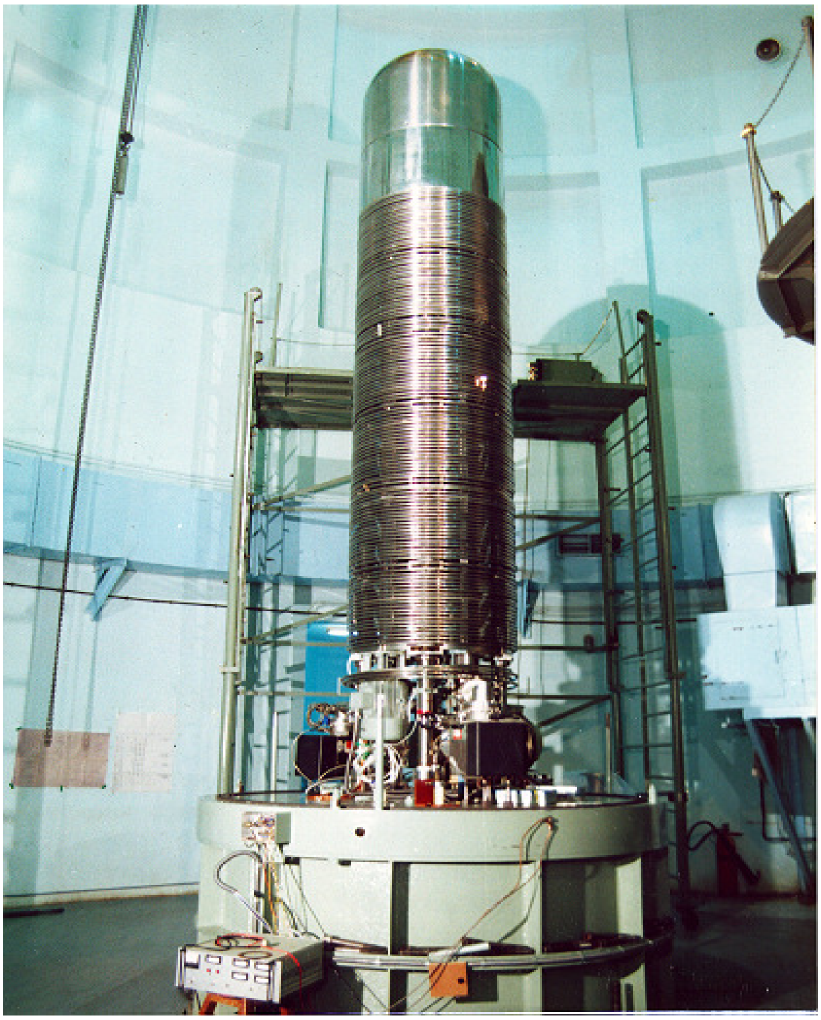

Fig3. Folded Tandem Ion Accelerator

Fig. 4 Proton Irradiation set up

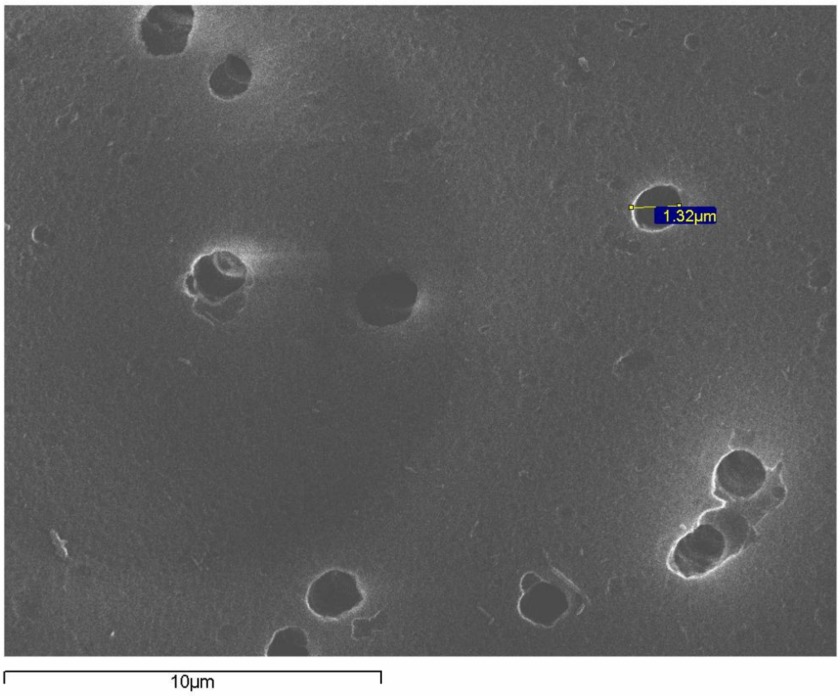

Fig. 5 SEM photograph of Track-Membrane

Fig 6 Radiation set up for biological experiments.