ACCELERATOR RESEARCH & DEVELOPMENT ACTIVITIES AT CIAE

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Abstract

Accelerator research and development activities at CIAE were dedicated to basic research in nuclear physics and related sciences in the past. With the economic reform in China, the purposes of the activities are expanded to application of accelerator. Different types of accelerators, such as compact cyclotron, small linac, single cavity machine and so on, are developed for industry or medical applications, including radioisotope production, radiography, electron beam radiation used for cable cross link. Meanwhile some proposals are put forward like BRNBF(Beijing Radioactive Nuclear Beam Facility), an ISOL type radioactive nuclear beam facility consisted of three accelerators, a compact cyclotron which could deliver 70 MeV proton for the production system, then an existed Tandem (2×13 MeV) will be used to accelerate the RIB and a superconducting linac as the booster. A proposal of a display device of accelerator driven reactor system is also suggested.

1 ACCELERATORS DEDICATED TO BASIC RESEARCH IN NUCLEAR PHYSICS AND RELATED SCIENCES

An 80 GW intense electron beam accelerator[1] has been built at CIAE for fundamental researches on pulsed power technology and particle beam inertial confinement fusion. 1 MeV, 80 kA pulse current with duration of 70 ns electron beam is obtained. The spot of the beam diameter on the anode is less than 1.5 mm when cone hollow cathode used.

The accelerator consists of an oil-immersed Marx generator, a Blumleim transmission line filled with deionized water, and a field emission vacuum diode.

The Marx generator consists of 20 0.7μF, 100kV capacitors with 10 gas spark gaps, stores 34 kJ at a charging voltage of 70 kV and has an output capacity of 35 nF and inductance of 12μH. Except the first three gaps triggered by signals from a small Marx generator, the remainders are overvolted by the transient voltages within the generator, and also triggered by the signals derived from the firing of the preceding two stages and coupled by liquid resistors. This improvement greatly reduced the incidence of premature firings. The probability of a prefire of the system before full charge is less than one percent. The Marx generator can be successfully operated at charging voltages less than 50 percent of the mean self-breakdown voltage of individual spark gaps.

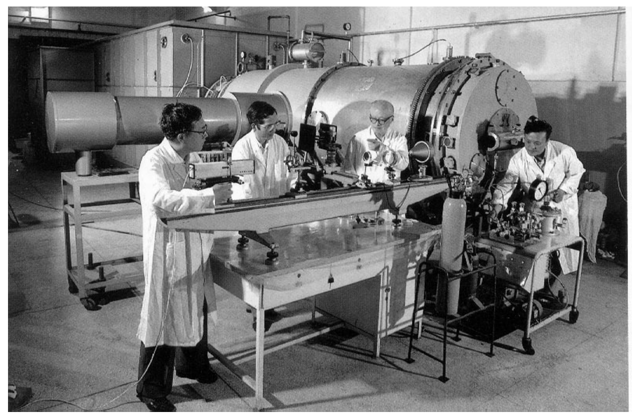

Fig. 1 The experimental apparatus

A high current electron injector for FEL[2] is under construction. It is a far-infrared FEL project with wavelength from 100 to 240μm. The normalized brightness already arrived to 3.4×109 A/(mrad)2 at the beam energy 1.5 MeV. Further acceleration will make the beam up to 4-6 MeV. Then the beam will be transported into an undulator for the final test. Fig 2 shows the layout of the FEL experiment facilities. The electron gun is pulsed at 2.16 MHz to provide a 2.2 ns micropulse with the pulse current 1.9 A at voltage of 75 kV during a macropulse time of 10μs. Finally, it would be pulsed at 108.33 MHz for the FEL application. After 108.33 MHz subharmonic prebuncher the beam gets energy modulation at the gap voltage of about 40 kV. Then a drift distance with focusing coils, the beam is bunched and goes into the 9 cell traveling wave 1300 MHz buncher of 2/3 mode. Whole system is still under construction.

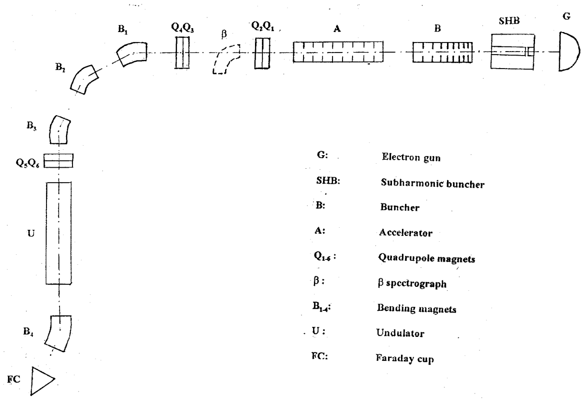

Fig 2 Layout of far-infrared FEL experiment.

An existed Tandem (2×13 MeV) imported from States are still operation for low energy nuclear physics experiment. But some spare parts are made in China now.

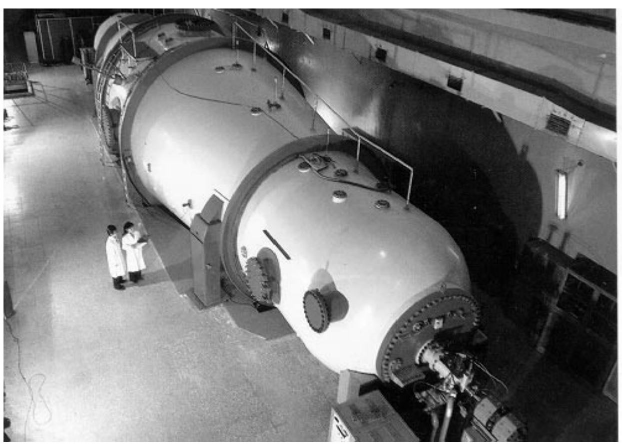

Fig. 3 Tandem (2×13 MeV) accelerator

2 ACCELERATORS FOR MEDICAL AND INDUSTRIAL APPLICATIONS

A 30 MeV compact cyclotron, CYCIAE 30[3] devoted to radioisotope production for imaging and diagnosis medicine was built in CIAE and put into operation in 1995, as shown in Fig. 4.

It was originally designed by IBA, Belgium. Some major modifications of the design had been taken to improve the performance of the machine. This machine is a fixed-field, fixed-frequency isochronous cyclotron accelerating -H Ions beam up to maximum energy of 30 MeV and extracted beam intensity of more than 350μA and low power consumption less than 100 kW. Negative hydrogen ions are produced by an external multicusp ion source located above the cyclotron yoke .The beam from ion source is injected axially and inflected in the median plane by an electrostatic helicoid inflector. It is then accelerated by two 30° Dees electrodes while it is contracted to a fixed magnetic field. The two Dees are located in the magnet valleys, allowing the magnet gap to be very small. The -H ions are continuously accelerated until the beam passes through the carbon foil, the negative ions are stripped off their electrons, become

Fig. 4 The medical use cyclotron CYCIAE 30

positive. Continuously adjustable energy from 15 to 30 MeV is achieved by varying the radial position of the carbon foil.

Partially intercepting foils permit the extraction of two beams at the same time and will direct them to one of the two extraction beam lines.

The extracted beam passes through a 7 meter transport line to a solid target where a pneumatic carrier will ship the isotope products from the station to an unload hot cell for radioisotope distribution.

In original design, the upper and lower yokes consisted of two pieces respectively: a base plate and a base ring. In order to get less magnetic field deformation caused by vacuum, reduce mechanical work and loose the tolerance, the two separate yoke pieces are combined together as one that strengthen the yokes. The field stability and vacuum seal both are improved also.

The magnet mapping results shown the field is quite close to the theoretical isochronous field based on the error of RF shift and first field harmonic. The measurement results are shown in Fig 5 and 6. The maximum RF phase shifts are less than ±10° and first harmonic field is around 5 gauss in the accelerating area. High quality isochronous field keeps the particle accelerated to the extracted energy stably.

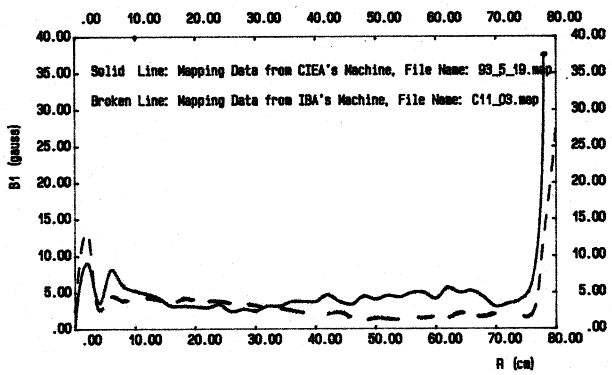

Fig. 5 First harmonic distribution after field shimming

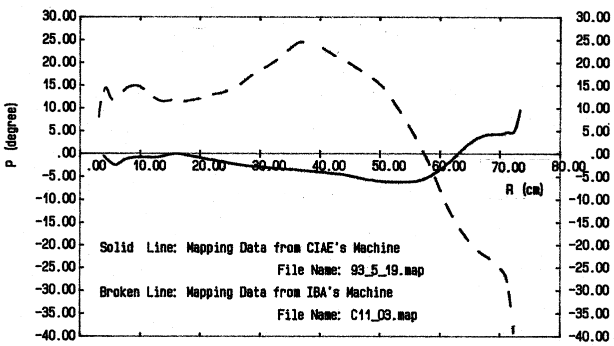

Fig 6 Total phase shift after field shimming

In addition, switching magnets, quadrupoles, steering magnets and corresponding power supplies are fabricated based on our own design. Their quality is same or better than the requested theoretically.

This project with most of equipment made in China has been proved fully successful. Satisfied powerful beam current and reliable operation have been achieved since it put into work. Now 7 different isotopes are supplied to many hospitals. Parts of them are exported, like ^{57}Co and so on.

To meet NDT(Non-Desructive Testing) requirements from industry, a 3-4 MeV electron linac capable of producing x-ray beam for radiography have been developed. 4 MeV raphytron consists of 3 major components: x-ray cabinet, modulator, controller. The accelerator assembly, microwave generator, PFN and PT are located in the x-ray cabined. Fig 7 shows the cabinet.

Besides, a 14 Mev electron linac was is used for radiation processing, maily for irradiation of silicon controlled rectifiers (SCR). And irradiation of gemstone to change the colour is another use. A 2 MeV, 20 kW single cavity accelerator is served for cable cross linking. Fig. 8 shows the machine at working.

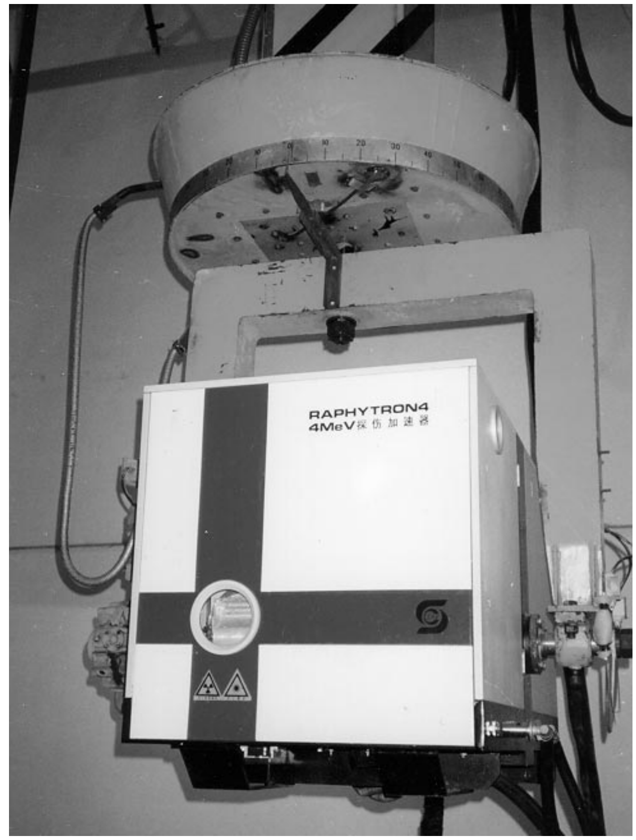

Fig.7 4 MeV raphytron

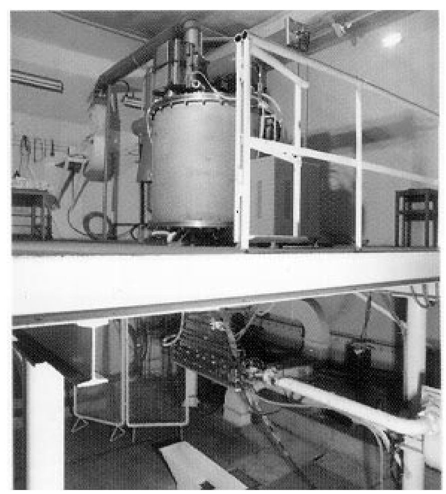

Fig. 8 Single cavity accelerator

3 PROPOSAL OF BEIJING RADIOACTIVE NUCLEAR BEAM FACILITY (BRNBF)

The proposed BRNBF is an ISOL type radioactive nuclear beam facility consisted of three accelerators, a compact cyclotron which could deliver 70 MeV proton for the production system, then an existed Tandem (2×13 MeV) and a superconducting linac will be used as a booster. See Fig. 9

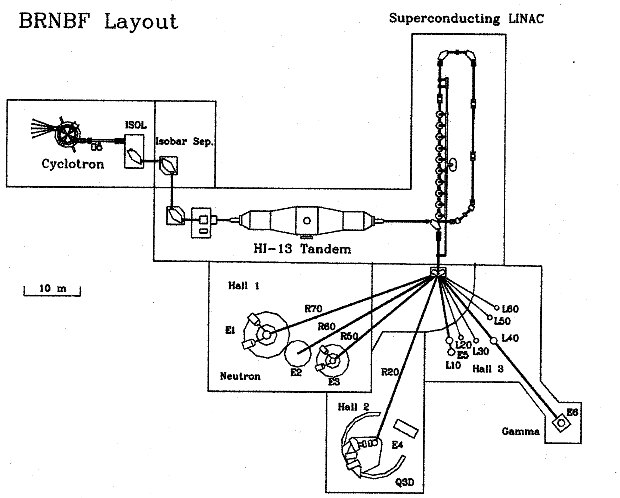

Fig. 9 Layout of Beijing Radioactive Nuclear Beam Facility (BRNBF)

Radioactive nuclear beam (RNB) arise a great enthusiasm among the scientific community since they allow to achieve experiments frontier of nuclear physics and related sciences. Proposals for RNB facilities have been put forward in many countries, that are in various stages of completion.

In order to promote the fundamental and applied research of nuclear physics in this foremost frontier, CIAE has proposed the Beijing Radioactive Nuclear Beam Facility (BRNBF), which is an extension of the existing HI-13 tandem accelerator. The proposed BRNBF is an ISOL type radioactive nuclear beam facility. A high intensity -H cyclotron will be adopted for the production of radioactive nuclei, which will then be isotopically separated by an on-line mass separator and then injected into the pre-existing HI-13 tandem accelerator. A superconducting heavy ion linear accelerator (LINAC) will be used for post-acceleration. Thus, high intensity and high energy resolution RNBs of A up to 140 can be obtained with energies above the Coulomb barrier.

Investigation has shown that the BRNBF is technologically feasible in China. The BRNBF will be an advanced and competitive facility on the world in the first decade of next century. It will be a major tool for searching for new nuclides and studying the nuclear structure physics, nuclear astro-physics, nuclear reaction mechanisms, atomic physics, material science, life science as well as other applications of nuclear physics. The BRNBF will be a facility belonging to a national laboratory accessible for users in China as well as from foreign countries. The BRNBF could be built in a five-year construction period, following a three-year detailed facility design at a cost of $20M.

A new proton cyclotron will provide 70MeV, 200μA proton beam, which will be used to bombard thick targets for producing radioactive nuclei, that will then be positively charged by an ion source and then isotopically separated by an on-line mass separator. The selected isotopes will become negatively charged ions by passing through an ion exchange canal and then injected into the pre-existing HI-13 tandem accelerator. A superconducting heavy ion linear accelerator with energy increase of 17MeV/charge will be used for post-acceleration. This device is calculated to be able to deliver radioactive nuclei of 10^9-10^{11} ions/sec. Both radioactive nuclei and stable nuclei in the energy range from 14.5 MeV/A (^{12}C) to 4.9 MeV/A (^{133}Cs) can be obtained with high resolution and variable energies.

4 PROPOSED PLAN ON ACCELERATOR DRIVEN RADIOACTIVE CLEAN NUCLEAR POWER SYSTEM

An important factor for economy development in China is next century will face energy source problem. In order to promote the study of this new technical option to practical phase, CIAE with a partner Institute of High Energy Physics have jointly submitted a proposal.

The multi-facet of the scientific goals of this facility may describe as: high current medium energy accelerator development, nuclear-data measurement, material test, different sub-critical blanket conception and transumution conception verification, technical problem related spallation target and the coupling between external neutron source with blanket.

The verification facility will be constructed in two phases. In the first phase, the R & D of key components of low energy part of the Linac and neutronic study with a zero power assembly driven by D-T neutron source are planned. In the second phase, a Linac with Ep=150 MeV, Ip=3 mA is used to drive a changeable core structure light water moderated Sub-critical reactor.

By 2020, using the experience which we will gained on the verification facility, it is hopefully that a full-scale demonstration experimental facility consisting of a proton Linac with Ep≥1 GeV, Ip≥10 mA and a 1000 MWt sub-critical reactor may be expected to realize.

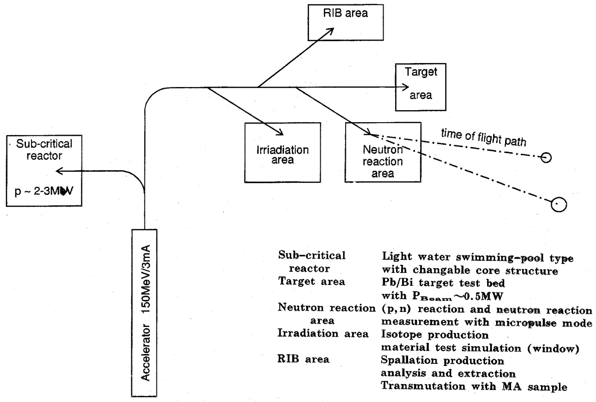

Fig. 10 Conceptual layout of verification facility for AD-RCNPS

5 ACKNOWLEDGMENT

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