OPERATION AND UTILIZATION OF THE VARIABLE ENERGY CYCLOTRON AT CALCUTTA

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Abstract. - The 224 cm Variable Energy Cyclotron at Calcutta has started operation for utilization. Initial experiments, using 30 MeV alphas, include, irradiation of copper to study production of ^{67}Ga for medical use, charge distribution of fission fragments from alpha induced fission of ^{232}Th and alpha scattering from Carbon and gold. After the initial operation of the cyclotron in 1978, a programme was undertaken to install a 2 MVA captive diesel generator power plant, to ensure reliable operation for utilization, since the grid power has been erratic. Simultaneously, a new dee, with improved design was fabricated and installed. Under stable operating conditions, an external beam current of 4 microamperes and a beam current on experimental target of 1.5 microamperes, have been obtained. Plans for utilization by various institutions in India and development of various research facilities are underway.

1. Introduction. - An internal beam of 50 MeV alphas and external beam of 30 MeV alphas from the Variable Energy Cyclotron at Calcutta has been reported earlier[1]. Since then, four 500 kVA diesel generators have been installed for having uninterrupted reliable power of 2 MVA; various systems have been streamlined; three beam transport lines have been made ready; work on other beam transport lines have advanced considerably; beam optimization and beam development have been carried out and preliminary experiments by various users have started. A view of the cyclotron vault is shown in Figure 1.

2. Radio Frequency System. - The dee structure used at the initial stages of commiss-

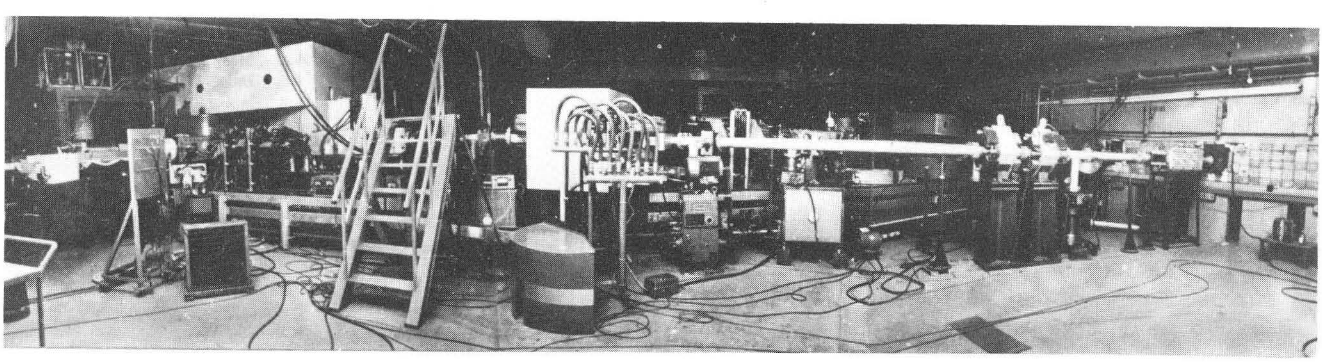

Fig. 1 : A view of the cyclotron vault

ioning the cyclotron was not found satisfactory because of two reasons. The copper tubes carrying the water to cool the dee body were brazed on the surface. This led to occasional water leaks. Also the structure was too delicate and could not be preshaped so as to bring it to the median plane symmetrically during assembly. Hence a new dee, where water is circulated in grooves in the dee, to achieve more efficient cooling, and lesser probability of leaks, was fabricated and installed. Figure 2 illustrates the changes made in the dee. This dee also enabled appropriate shaping of the dee edge to compensate for the deflection resulting from cantilever support of the dee.

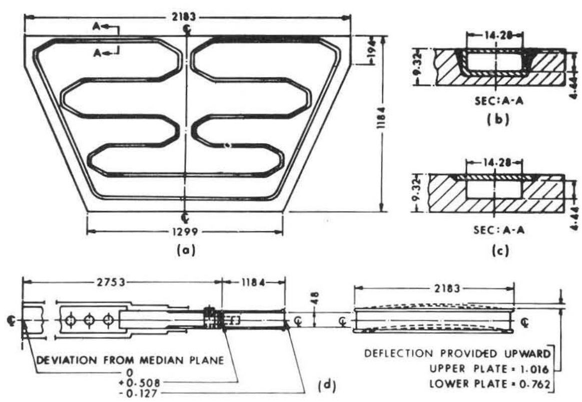

Fig. 2 : Design of new dee with changes

Tests on the radio frequency system with the new dee were carried out and the capacitance of the dee - dee chamber system was measured to be 1800 pF. All the screws on the RF panels were silver plated, and contacts at the joints were improved; this resulted in a Q value of 5000 at 5.5 MHz, after the system was baked with radiofrequency. Operating at a pressure of 5 x 10^{-6} torr in the resonator tank, and frequencies ranging from 5.5 to 13 MHz, a dee voltage of 60 kV was obtained for an oscillator anode voltage swing of 12.5 kV(peak).

In view of the high cost of the RCA - 6949 oscillator tube and difficulty in its procurement, it has been decided to change over to a radio frequency system based on the RCA 4648 tetrode. Work is well under way on this new RF system. Figure 3 shows a schematic diagram of the new rf system. As seen, it is a MOPA system, which is expected to give better frequency stability, of the order of 1 in 10^7.

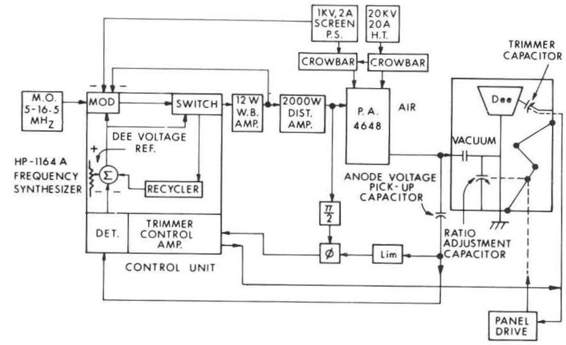

Fig. 3 : RCA 4648 based rf system

3. Beam Extraction System. - The electrostatic deflector requires a field gradient E$\sim$120 kV/cm and VE = 1.5 x 10^4(kV)^2/cm, where V is the voltage applied, for extracting 130 MeV alphas. For proper conditioning of the surfaces, the deflector was baked at a pressure of$\sim$2 x 10^{-5} torr and a magnetic field level of $\sim$10 kG, with the entrance and exit channels, of 72° and 36° respectively, set for a gap of 10 mm. The voltages were applied through epoxy embedded fixed resistances of 20 MΩ for both channels. Most of the sparks observed were at the entrance end of the deflector. Baking was continued till the frequency of sparks reduced to about two in ten minutes. After baking for 24 hours, a field gradient of$\sim$100 kV/cm was achieved on both the channels. After reducing gap to 8 mm, a field gradient of $\sim$112 kV/cm could be sustained. Thus VE = 1.25 x 10^4 (kV)^2/cm was obtained. Results of the baking are shown in Figure 4.

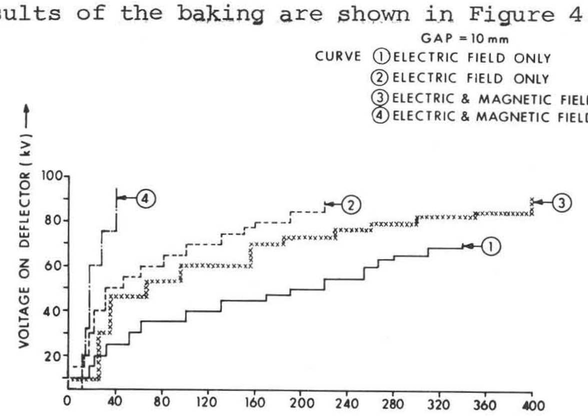

Fig. 4 : Results of deflector baking

4. Beam Transport System. - The beam transport system consists of 3 high intensity, low resolution channels and 6 low intensity, high resolution channels[1]. A 159.5°, $n = 1/2$ analysing magnet provides the analysed, high resolution beam. Figure 5 shows the layout of the beam lines and the analysing magnet in the vault. The high intensity channels are at 0°, 20° and 35° with respect to the beam line emerging from the cyclotron. The

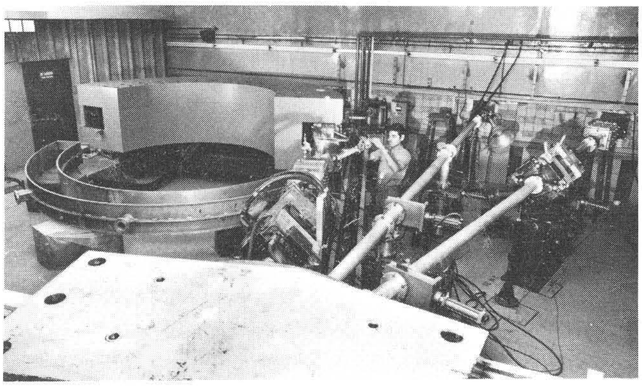

Fig. 5 : Beam transport lines and the analysing magnet in the vault.

positions of the beam transport line elements such as the switching magnets and the quadrupole magnets, have been computed by the ion optics code TRANSPORT. Faraday cups, beam viewers, beam profile monitors and collimator slits have been installed at

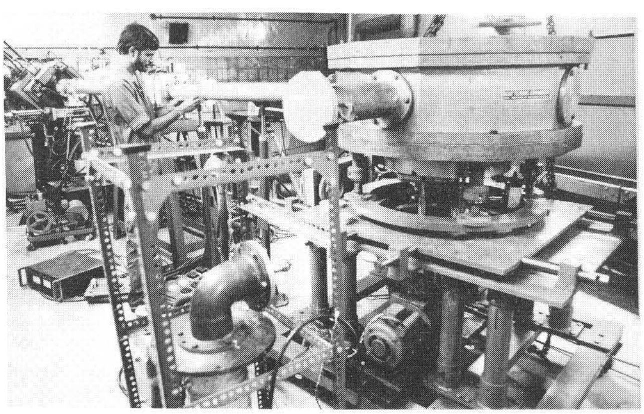

Fig. 6 : Beam transport line at 0° in the experimental area.

appropriate places. Pumping modules located at intervals provide a pressure of $\sim 2 \times 10^{-5}$ torr in the line. The three high intensity beam lines have been aligned optically to an accuracy of 25 µm and 1 sec. of arc. The beam has been transmitted on to the target in the experimental areas in the 0° and 20° high intensity lines. Figures 6 and 7 show the beam lines in the two experimental areas.

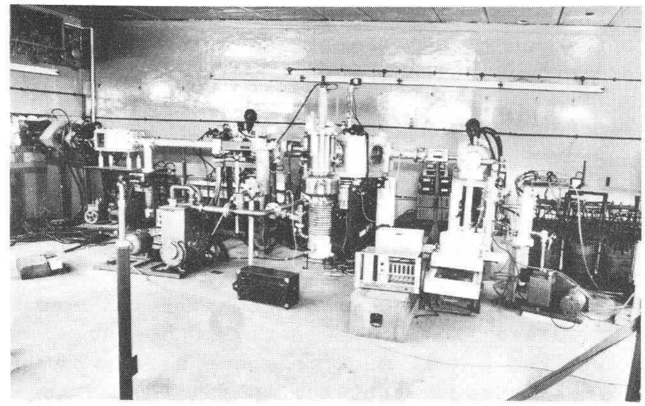

Fig. 7 : Beam transport line at 20° in the experimental area.

5. Cyclotron operation. - Preparations for cyclotron operation could begin in earnest only after the availibility of reliable uninterrupted power of 2 MVA was available from the diesel generators at the VEC site in July 1980. The limitation of 2 MVA on power restricted the operation to 50 - 60 MeV alpha energies. Further, the cyclotron operation was restricted to two cyclotron runs, each of 24 hours, per week, on account of the high cost of operating the diesel generators, the diesel consumption rate being 0.2 litres per KVA - hour. Various stages in cyclotron operation, indicating periods for testing of systems, beam trials, beam development and preliminary experiments are shown in Table 1.

Table 1

STAGES IN CYCLOTRON OPERATION

1. Individual testing of cyclotron systems	:	July - Nov.,1980
2. Initial beam trials with 30 MeV alphas	:	December, 1980
3. Beam development and preliminary experiments with 30 MeV alphas	:	Jan. - July,1981
4. Beam development with 30, 50 and 60 MeV alphas and 26 MeV He^+ ions.	:	August, 1981

During the nine months of operation, there was one major breakdown, when the Ag - plated Be-Cu spring, through which the rf current flows from the moving panels to ground, got overheated and melted at a few points. The spring has been partially replaced, and until it is fully replaced the dee voltage is restricted to about about 35 kV. On two occasions, water leaks have developed in the cooling coils of the rf panels. These were detected and confirmed quickly, by using a quadrupole mass analyser installed on the resonator tank, and repaired in-situ. Other minor breakdowns include, damage to the puller due to overshooting of the limit and accidental decoupling of LCW lines, resulting in water sprays over components. The ion source life varied from 25 hours to 110 hours, mostly limited by filament to anode short, produced by sputtered tantalum metal. A summary of the cyclotron operation is given in Table 2.

Table 2

CYCLOTRON OPERATION FROM JANUARY TO AUGUST, 1981

1. Total time scheduled for cyclotron operation (50 runs, 24 hours each) : 1200 hrs.

2. Debugging and testing of sub-systems, ion source filament change, start up and shut down time : 750 hrs.

3. Cyclotron operation time (vault and pit door closed, ion source and rf on) : 450 hrs.

   a. Beam development : 250 hrs.

   b. Experiments including beam tuning, ion optics and beam on target : 200 hrs.

For 30 MeV alphas, an internal beam current of about 15 μA, an external beam of 4 microamperes, and a beam current on an experimental target of 1.5 microamperes have been obtained. External beams of 50 and 60 MeV alphas have also been obtained. 26 MeV He^{+} ions, corresponding to K = 104, have also been accelerated. Details of beam development have been given in another paper at this Conference[2]. The beam profile, monitored by a wire scanner, showing the beam spot to be 3 - 4 mm diameter in the experimental area, is shown in Figure 8. The beam energy spread, as measured directly by a Si(Li) detector, and also by elastic scattering of alphas from carbon and gold is ~300 keV at 30 MeV. A typical spectrum of alphas elastically scattered from gold is shown in Figure 9.

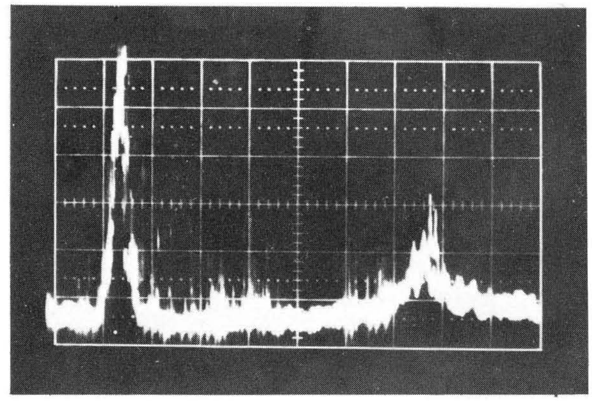

Fig. 8 : Beam profile monitered by by a wire scanner.

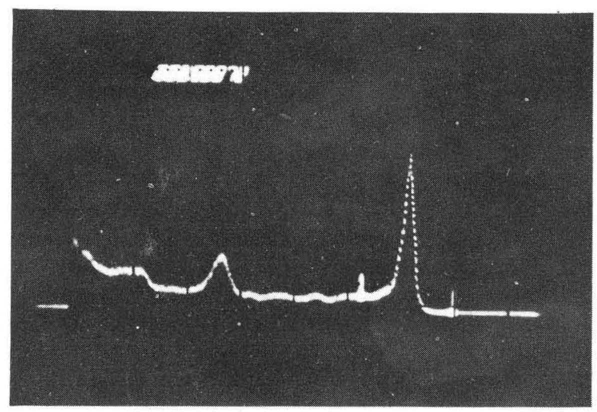

Fig. 9 : A spectrum of alpha's elastically scattered from gold.

6. Utilization. - Some experiments were done by various users in order to test out their equipment and obtain preliminary data for detailed planning. A summary outlining these experiments is given in Table 3.

Programmes for utilization of VEC proposed include studies in nuclear physics, radiation damage and radio-chemistry and production of isotopes for medical use. Target, detector and electronics facilities are available. The 915 mm scattering chamber, connected to the 20° high intensity channel, is ready for use. A radio-chemistry labotory has been set up. Progress has been made on the second switching magnet and the QSD magnetic spectrometer. An IRIS-80 computer has been installed and it is being utilized.

User groups from the Tata Institute of Fundamental Research, Bombay, Saha Institute of Nuclear Physics, Calcutta and Bhabha Atomic Research Centre, Bombay, have installed equipment for various experiments.

Table 3

EXPERIMENTS WITH VEC
USING 30 MEV ALPHAS

1. Charge distribution of fission fragments from alpha induced fission of ^{232}Th.
2. Standardisation of method of preparation of ^{67}Ga for medical use by $^{65}Cu(\alpha,2n)^{67}Ga$ reaction.
3. Alpha induced activity in K-monel.
4. Excitation function of $^{19}F(\alpha,n)^{22}Na$ reaction by stacked foil method.
5. Scattering of alphas from Si.
6. Cross section measurement for $^{162}Dy(\alpha,3n)^{163}Er$ reaction.
7. Elastic and inelastic scattering of alphas from C and Au.
8. Fission isomers from $^{235}U(\alpha,2n)^{237}Pu$ reaction and fission fragment angular distributions.
9. Conversion electron spectra using solenoidal spectrometer from $^{208}Pb(\alpha,2n)^{210}Po$ and $^{209}Bi(\alpha,3n)^{210}At$ reactions.
10. Search for $^{63,65}Cu(\alpha,{}^{7}Be)^{60,62}Co$ by activation analysis.
11. Surface topography of Mo foil.
12. Three body break up in $^{2}H(\alpha,\alpha p)n$ reaction.

Universities all over India have worked out plans for VEC utilization.

7. Acknowledgements. - We are deeply grateful to R. Ramanna for his continued encouragement and to C. Ambasankaran for his active guidance at all stages of the work. We thank B.D. Nagchaudhuri, the late D.Y. Phadke and D.N. Kundu for taking personal interest in the Project. We acknowledge the active participation at various stages, of V.M. Gad, S.R. Gowariker, V.G. Khandekar, C. Viswanadham, the late D.N. Basumallick, C. Halder, the late S. Mukherjee, G. Muthukrishnan, C. B.S. Rao, A.P. Thatte, A. Banerji, M.L. Barde, R.K. Bhandari, N.C. Bhattacharya, S. Das, S. Dasgupta, S. Kotiah, R. Mukherjee, K.B. Nambiar, S. Saha, S.M. Sahakundu, M.M. Sathe, K.V. Venkataramu, Y.P. Viyogi, A. Guha, S.T. Bhavsar, R.K. Goel, R.C. Gupta, C. Mallik, S. Bhattacharya and all other VEC Project staff.

References.

1. VEC STAFF - PRESENTED BY A.S. DIVATIA IEEE Tran. Nucl. Sci., Vol. NS-26, No.2, (April 1979) 1882.

2. A. JAIN, R.C. SETHI AND A.S. DIVATIA Proc. IXth Int. Conf. on Cyclotrons and their Applications, Caen, France, September, 1981 (to be published).