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GOVERNMENT OF INDIA
ATOMIC ENERGY COMMISSION

VAN DE GRAAFF LABORATORY PROGRESS REPORT

Compiled by

T. P. David

Nuclear Physics Division

ATOMIC ENERGY ESTABLISHMENT TROMBAY
BOMBAY, INDIA
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Contents

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INTRODUCTION

The 5.5 MeV Van de Graaff Accelerator has completed its third year of operation. This report covers the period from 1st January 1964 to 31st December 1964 (1).

With the installation of the 3 port switching magnet in January 1964, the experimental facilities have increased significantly. A TMC-400 channel pulse height analyser was received in January 1964. Considerable use is also now being made of the CDC-3600 computer in the Tata Institute of Fundamental Research, Colaba, Bombay also installed in 1964, for subsequent data analysis. The working of the Van de Graaff Accelerator which was on a three shift 5-day week basis from the beginning of the year has lately been switched over to three shift 7-day week operation. All the above factors have contributed to the successful completion of a number of experiments during the period with an increased efficiency in machine utilisation.

The work of the various groups in the Van de Graaff Laboratory during the period is summarised in this report.

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(1) Van de Graaff Laboratory Progress Report, A.S.Divatia, AEET/NP/8

ACCELERATOR

The Accelerator has operated for a total of 4681 hours during this period. A break up of the total time of operation is given below:

1. Total time of operation from 1st January to 31st December 1964	: 4681 hours
2. Time utilized for research experiments	: 3908 hours
3. Utilization efficiency	: 83%
4. Time lost in repairs, maintenance and machine conditioning	: 13.5%
5. Time lost due to malfunction of experimental equipment	: 3.5%

I. Accelerator shut downs and major repairs:

1. The Accelerator was shut down for about three weeks in June when all the Column resistors were renewed with Welwyn high voltage resistors. A good part of this period was, however, utilized for repainting the Accelerator and experimental rooms. A new 3-port switching chamber of section 1" x 2" was also installed in the switching magnet and beam alignment was carried out during this period.

2. A series of breakdowns of different components took place in July forcing a continuous shut down for about 2 weeks. These were: the failure of the thermomechanical leak, failure of the terminal 80 KV insulation bushing and development of sparking across the glass insulator in the differential tube head. A locally fabricated thermomechanical leak was installed,

the terminal bushing was renewed and the differential tube head was reconditioned to ensure good insulation.

3. Other breakdowns that resulted in machine shut down for short periods are listed below:

(i) Renewal of ion source bottle and retuning have been carried out four times during the year including the premature failure of a new ion source in one case.

(ii) Thermomechanical leak used for Helium inlet developed a cold leak and had to be renewed with a new one also fabricated in the laboratory.

(iii) Column and tube sparking started due to failure of four column resistors. These resistors were renewed.

(iv) Belt drive pulley shaft was found knocking due to wear and tear. The shaft ends were slightly turned down in diameter and were provided with metal sleeves fitting snugly in the bearings.

(v) One coil of the switching magnet developed a ground leak. This coil has been isolated as the remaining coils are capable of providing the required ampere turns.

(vi) Differential tube head developed sparking across glass insulation. A new tube head was installed.

(vii) The belt charge limiting resistance developed an open circuit resulting in sparking in the current control unit. A new resistor chain was made and connected up and was found satisfactory.

(viii) One glass section in the Accelerating tube developed an internal crack after a severe tube spark. This section has been electrically shorted out.

II. <u>Modifications and Additions</u>:

1. A good ground connection using a 1" x 1/8" copper strip has been provided in the beam room near the experimental area.

2. The 110 V D.C. supply system for the laboratories has been put into operation.

3. Hewlett Packard frequency counter capable of precision measurement upto 50 MC/S has been received. A high gain wide band preamplifier for using the counter directly with the existing NMR oscillator is under development. A Hewlett Packard wide band high gain preamplifier has also been ordered.

4. The voltage adjust selsyn on the control console has been connected up to all other selsyns through a seven pole six way switch so that this can operate any of these selsyn circuits in case of failure.

5. A 400 channel TMC analyser has been received and is being used for data collection.

6. It is proposed to fabricate ion source bottles for use with the Van de Graaff Accelerator in the laboratory. A prototype has been constructed and is undergoing bench test.

7. A relay operated circuitry for automatic accumulate and print out operation of the multichannel analyser triggered by the current integrator has been designed and added to the current

integrator unit. Also a duplicate standby current integrator incorporating the modifications has been constructed and calibrated.

III. Development Projects:

1. Beam Switching Magnet - T.P.David and U.T. Raheja - A beam switching magnet with a 3-port chamber was installed in January 1964 and has since been in regular operation. This has facilitated the simultaneous set up of three research experiments and the switching over of the beam from one to another as desired.

The magnet was fabricated from forged TATA grade A steel (obtained from the Tata Iron and Steel Company)(Fig. 1). The B-H curve for this steel given by TISCO shows a saturation around 18000 gauss. However, an experiment conducted at the Tata Institute of Fundamental Research on a sample shows a saturation around 12000 gauss.

The magnet has an overall dimension of 42" x 46". The yoke section is 9" x 9" and the circular pole pieces are of 12" diameter tapered at the tips to give 11" diameter pole faces. The pole gap measures 1.040".

Field Requirement:

The flux density requirement is calculated from the equation

$$Bev = \frac{mv^2}{\rho}$$

and in terms of energy

$$B^2 = \frac{2c^2 mE}{e^2} \cdot \frac{1}{\rho^2}$$

Assuming 'l' as length of beam path and θ the deflection angle the radius of bending

$$\rho = \frac{l}{\theta \cos\frac{\theta}{2}}$$

Substituting

$$B^2 = 2\left(\frac{mc^2}{e^2}\right) E \cdot \frac{1}{l^2} \theta^2 \cos^2\frac{\theta}{2}$$

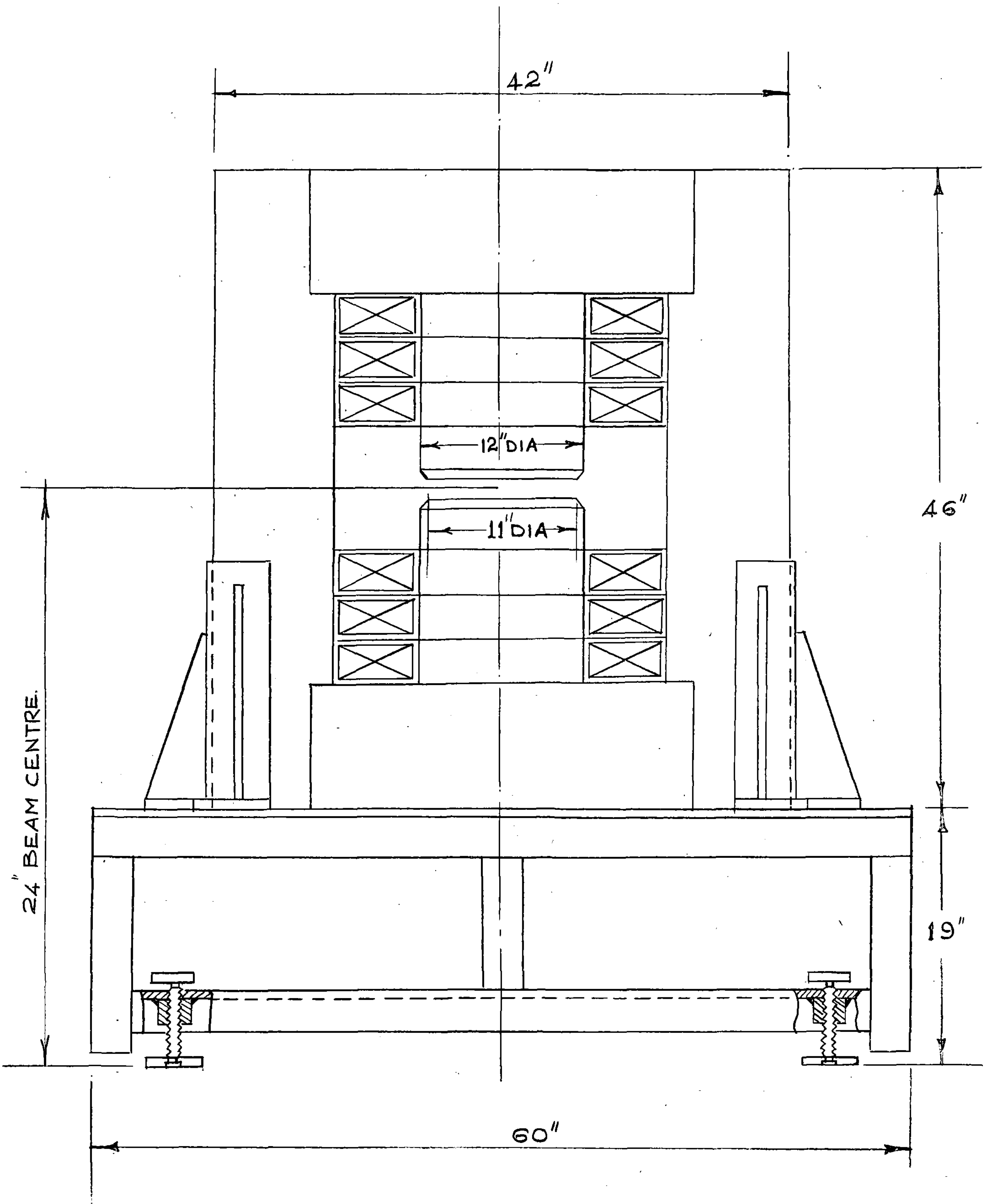
whence

$$B = \frac{c}{e}\sqrt{2mE} \cdot \frac{\theta \cos\frac{\theta}{2}}{l}$$

In the present case, angle of deflection is 30° and the length of the beam path in the magnetic field is about 30 cms. Therefore, the required flux density for 6 MeV protons = 5920 gauss and for 6 MeV He^+, B = 11840 gauss.

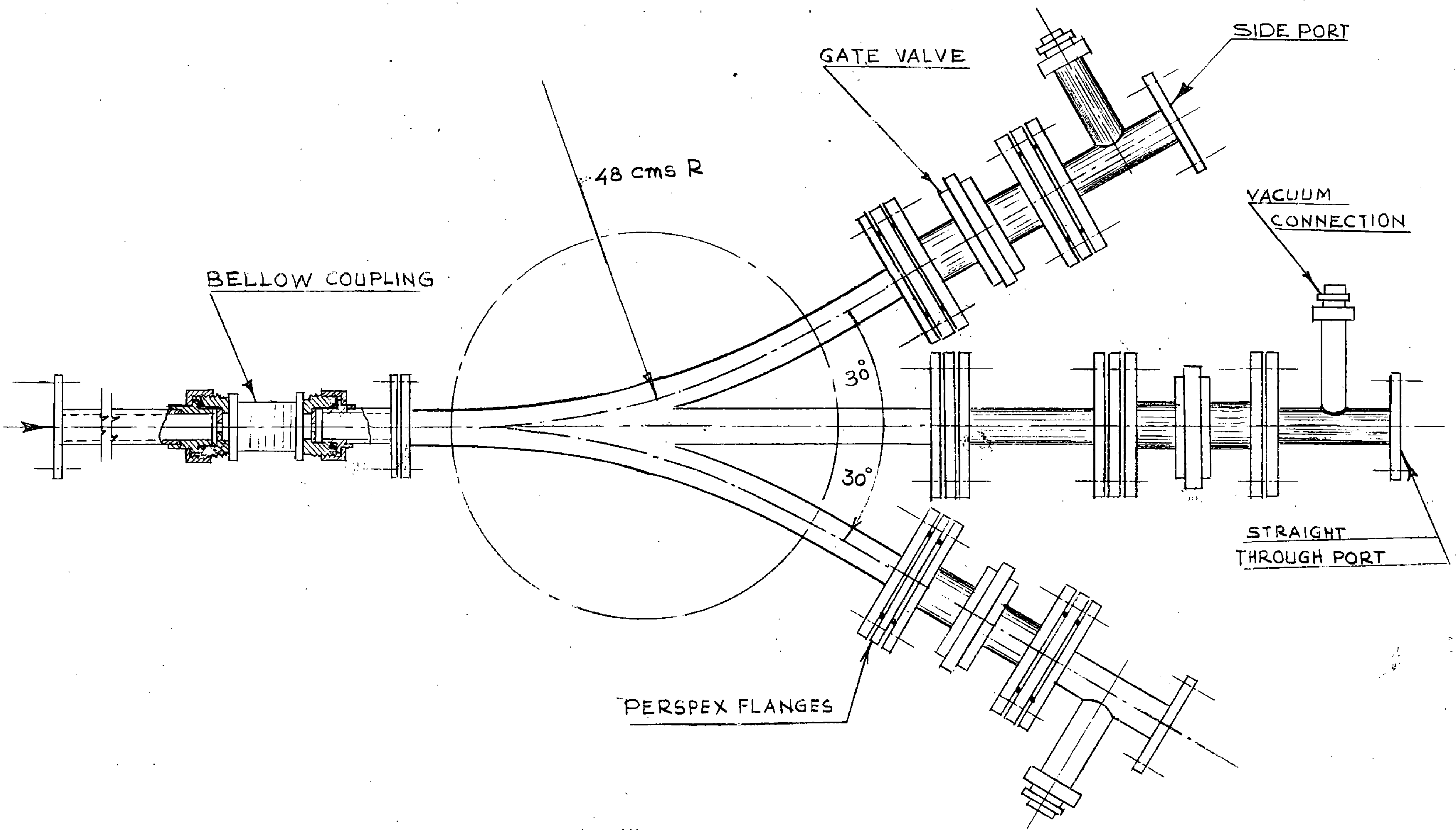
The magnet is fitted with 6 coils connected in series each consisting of 1000 turns wound with 14 SWG DCC copper wire.

The current required for bending 5.5 MeV protons is approximately 1.62 amps and for 5.5 MeV He^+ beam approximately 3.9 amps.



SWITCHING MAGNET

FIG. 1



SWITCHING CHAMBER

FIG - 2

Power Supply:

Magnet current is taken from a variable voltage regulated power supply, using bridge connected silicon rectifiers and a stabilizer circuit. A set of 22 parallel connected 6AS7G series tubes and a current control unit using a standard resistance made from manganin wire in series with magnet coil form the current regulator circuit. Fine and ultra-fine adjustment of current is possible with a 50 KΩ, 15-turn and 200Ω 10-turn helipot used in the current control unit. The drift in the coil current was measured on a Honeywell Brown recording pot. and found to be less than 0.75% over 6 hours of operation.

Switching Chamber:

The switching chamber (Fig. 2) was made of Aluminium tubing with a square cross section measuring 1" x 1" outside and 1/16" wall thickness. It has a straight-through port and two 30° side ports, the side tubes having bent at a radius of approximately 48 cms. Each port is provided with a 1" gate valve fitted with perspex flanges for checking the current pick-up on the 1/2" tantalum collimators inset in the gate valve flanges.

An additional vacuum system has been provided after the switching chamber which can be easily connected to pump any one of the three beam tubes. This system consists of a 2" mercury diffusion pump and a mechanical backing pump with the necessary baffle and liquid nitrogen traps. The switching chamber is connected to the accelerator tube extension through a bellow coupling.

2. Five-port Beam Switching Magnet - T.P.David - A new switching magnet with an overall dimension of 74 cms x 56 cms x 30 cms has been designed. The yoke and the pole pieces are shaped (Fig. 3) to make it compact and minimise the amount of steel.

The magnet coils made from 1" x 1/8" copper strips are designed to carry high current at a very low voltage thereby avoiding high insulation requirement.

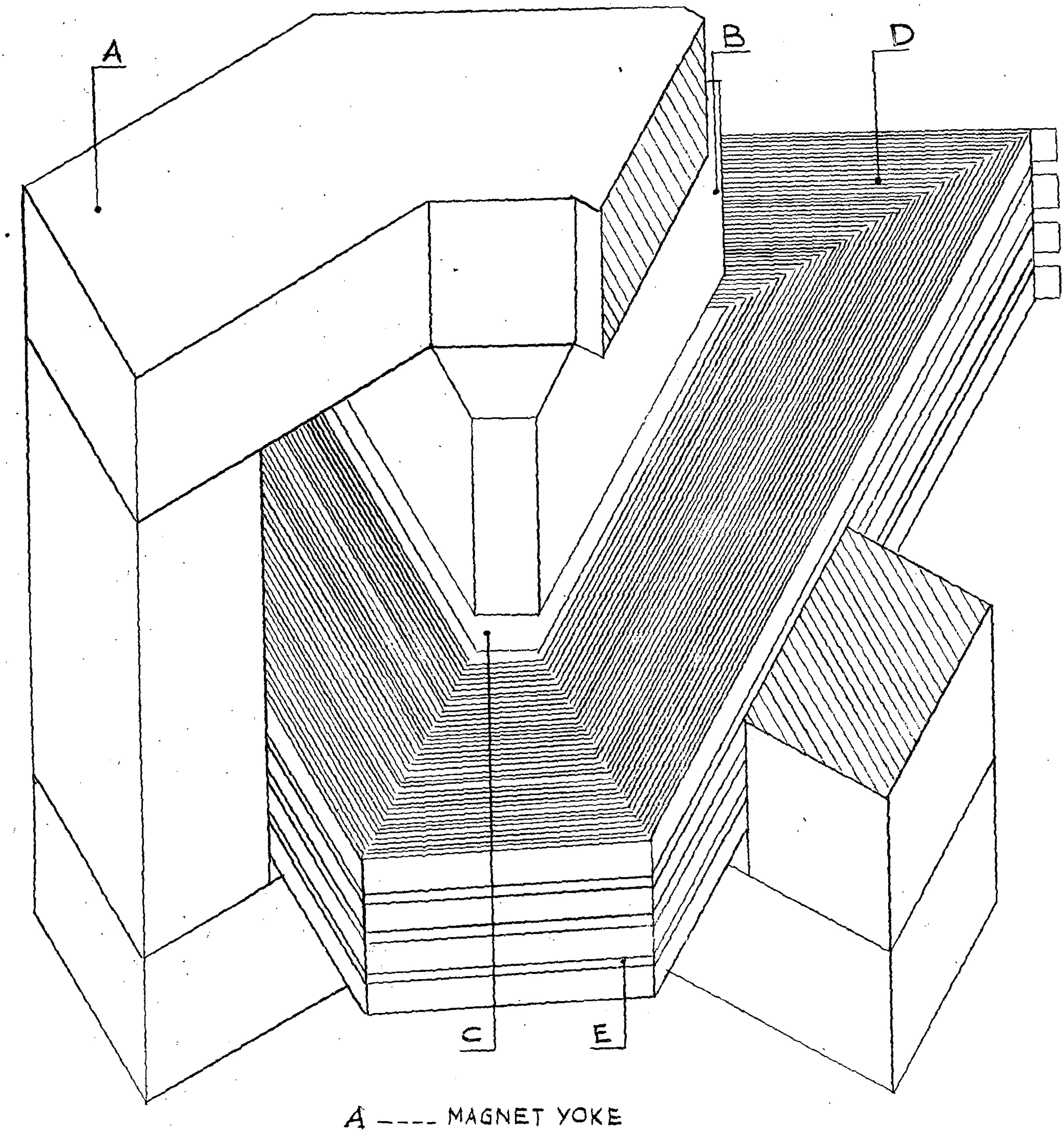
Four 40-turn coils are stacked on each pole piece with alternate layers of cooling chambers. The low voltage 0 - 150 amps current stabilised power supply for the magnet is being built by the CI and S section of the Electronics Division.

The aluminium beam switching vacuum chamber is designed to fit in the 2.5 cm magnet pole gap. The chamber has beam ports at 25° and 45° on either side of the straight-through port.

Low carbon TATA 'A' grade steel for the fabrication of the magnet has been ordered and is expected to be delivered shortly.

3. Electromagnetic Quadrupole Focussing Lens - M.Bhatia, N.S. Thampi and T.P. David - A magnetic quadrupole focussing lens system has been designed and constructed. It is at present used for high resolution charged particle experiments. The design is based on a paper by Weidmann (1).

SWITCHING MAGNET



A ---- MAGNET YOKE
B ---- POLE PIECES
C ---- POLE GAP
D ---- MAGNET COILS
E ---- COOLING CHAMBERS

FIG - 3

The system is a combination of two lenses phased 90° for focussing the beam in both X and Y planes since the focussing effect of a lens in one plane is always accompanied by a defocussing effect in the perpendicular plane.

The basic equations used in the calculations are:

$$\frac{1}{F} = \frac{1}{F_1} + \frac{1}{F_2} - \frac{d}{F_1 F_2} = \beta^4 L^2 \left(\frac{2}{3} L + d\right)$$

and $NI = -\frac{\beta^2 a^2}{\mu_0}\sqrt{\frac{mU}{2e}}$

where L is the length of each magnet; d the distance between main focal plane; e and m, the charge and mass of the particle accelerated and U, the accelerating potential.

Semicircular pole tips have been used to facilitate easy machining instead of the ideal hyperbolic tips, with radius R = 1.125a where a is half the lens aperture, a condition that is found to give the best results in practice.

The magnet yoke has been fabricated from mild steel with pole pieces of depth 4.5 cms and length 15 cms. The semi-circular pole tips have a radius of 1.125 cms giving 2 cms gap for the beam tube.

The lens is provided with 2 coils of 1900 turns each of 22 SWG enamelled copper wire and mounted in such a way as to produce equal field distribution in all the pole gaps. Cooling coils have been brazed on to the brass coil formers. The two lenses are mounted on an adjustable table designed with provision for movement of the lenses together and separately both along the direction of the beam and perpendicular to it. The table is also fitted with levelling screws.

The beam tube is fabricated from 2 cm O.D. aluminium tubing with necessary flanges and couplings. Fig. 4 gives a view of the complete assembly. The lenses are fed from independently variable power supplies using silicon rectifiers and bias controlled 6AS7 series tubes.

The system has been installed in the straight port of the switching magnet chamber. It is found to be capable of focussing to a spot 5.5 MeV proton and He^+ beam at a minimum distance of 12" from the second lens with coil current less than 500 mA.

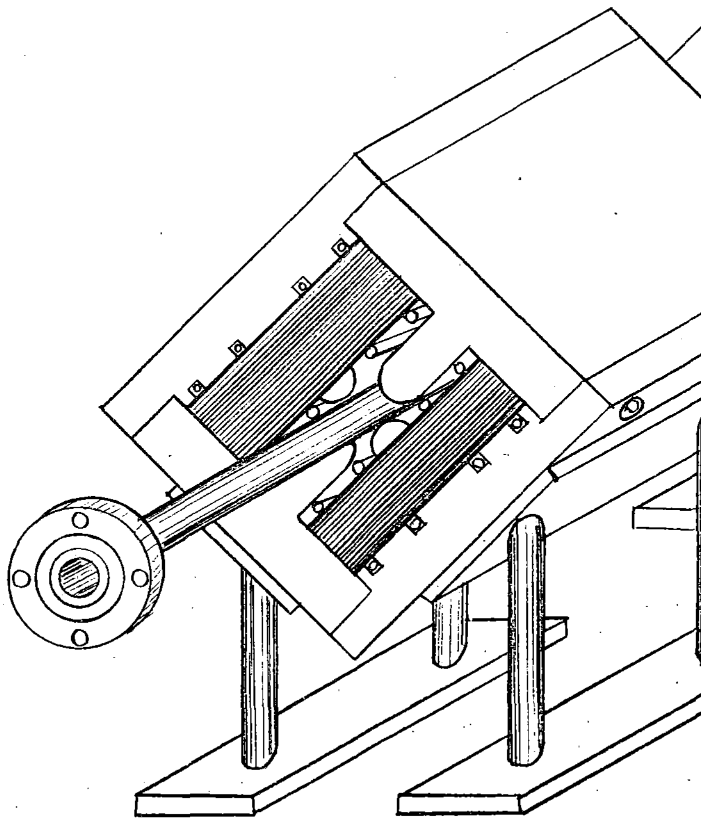
It is proposed to fabricate more similar quadrupole units with aperture 2.54 cms for installation in the side ports of the switching chamber.

Reference

(1) W.Weidmann, Nuclear Instruments & Methods 9 (1960), 347.

4. Thermomechanical leak - N.Sarma and M.G.Betigeri - A thermomechanical leak has been designed and constructed for controlled gas leak into the ion source bottle of the Van de Graaff Accelerator. It consists of a brass cylinder with a hole ending in a narrowed valve seat. A steel ball pressed by an invar rod and tightened by a screw in the cylinder closes the valve seat. A resistance wire wound over the cylinder is used for heating the leak. Differential expansion of brass and invar releases the steel ball against the gas pressure, letting in gas through the thermal leak with a leak rate proportional to the temperature rise in the working range. These are now in regular use with the Van de Graaff Accelerator giving satisfactory performance.

QUADRUPOLE FOCUSSING LENS ASSEMBLY



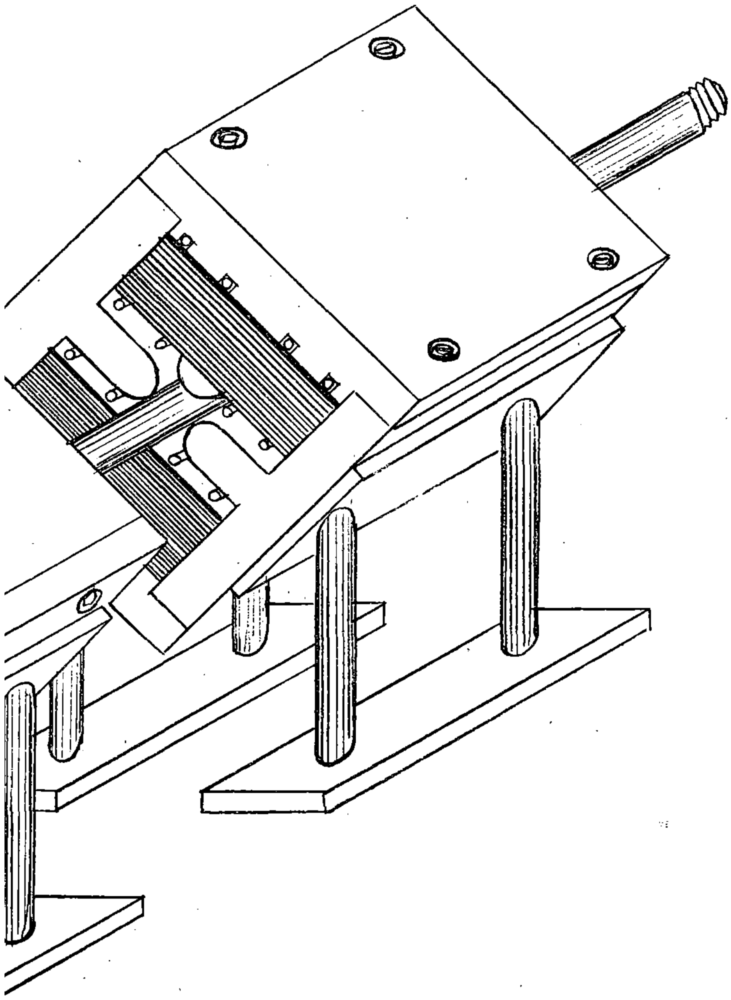


FIG. 4

5. <u>Beam Deflector Assembly</u> - M. Bhatia and G.V.Bhat - A beam deflector assembly for installation in the beam tube extension has been designed and fabricated (Fig. 5). It consists of two sets of deflector rods of radius 3/8" each of length $7\frac{1}{2}$" mounted on a pitch circle of $1\frac{1}{4}$". The whole assembly, enclosed in a 3" O.D. brass tube and fitted with flanges and vacuum tight feed-ins for electrical connections, is approximately $21\frac{1}{2}$" long. Initial tests carried out with the system have been very satisfactory, the deflector being able to shift 5.5 MeV proton beam without distortion by about 6 mm in all directions. Further performance tests are under progress.

6. <u>He^{++} Ion Source for Van de Graaff Accelerator</u> - T.P.David - This work has been started with the objective of obtaining doubly charged ^{4}He and ^{3}He ion beams, thus doubling the energy available for these particles with the Van de Graaff Accelerator.

Helium ions from a high yield ion source bottle are focused by an Einzel lens into a uniform magnetic field produced by a stacked assembly of ceramic magnets. The bending moment of the charged particle beam passing through the magnetic field is neutralised by an electric field applied at right angles to the direction of the magnetic field. This occurs when the electric field potential

$$V = dH\sqrt{\frac{2\phi ne}{m}}$$

Since this potential depends on the charge to mass ratio of the particle, it can be adjusted to separate out doubly charged helium beam which is then projected into the accelerating tube at the high voltage end.

The cross field ion separation chamber incorporating the Einzel lens assembly to be installed on the Accelerating tube head inside the high voltage dome has been designed and constructed. A similar cross fields design has been successfully used at the William Marsh Rice University, Texas.

A laboratory test bench has been built with the high vacuum systems and electronic instrumentation such as the radio frequency oscillator and power supplies. An ORTEC ion source is used to produce the Helium ion beam. The performance of the arrangement is being tested.

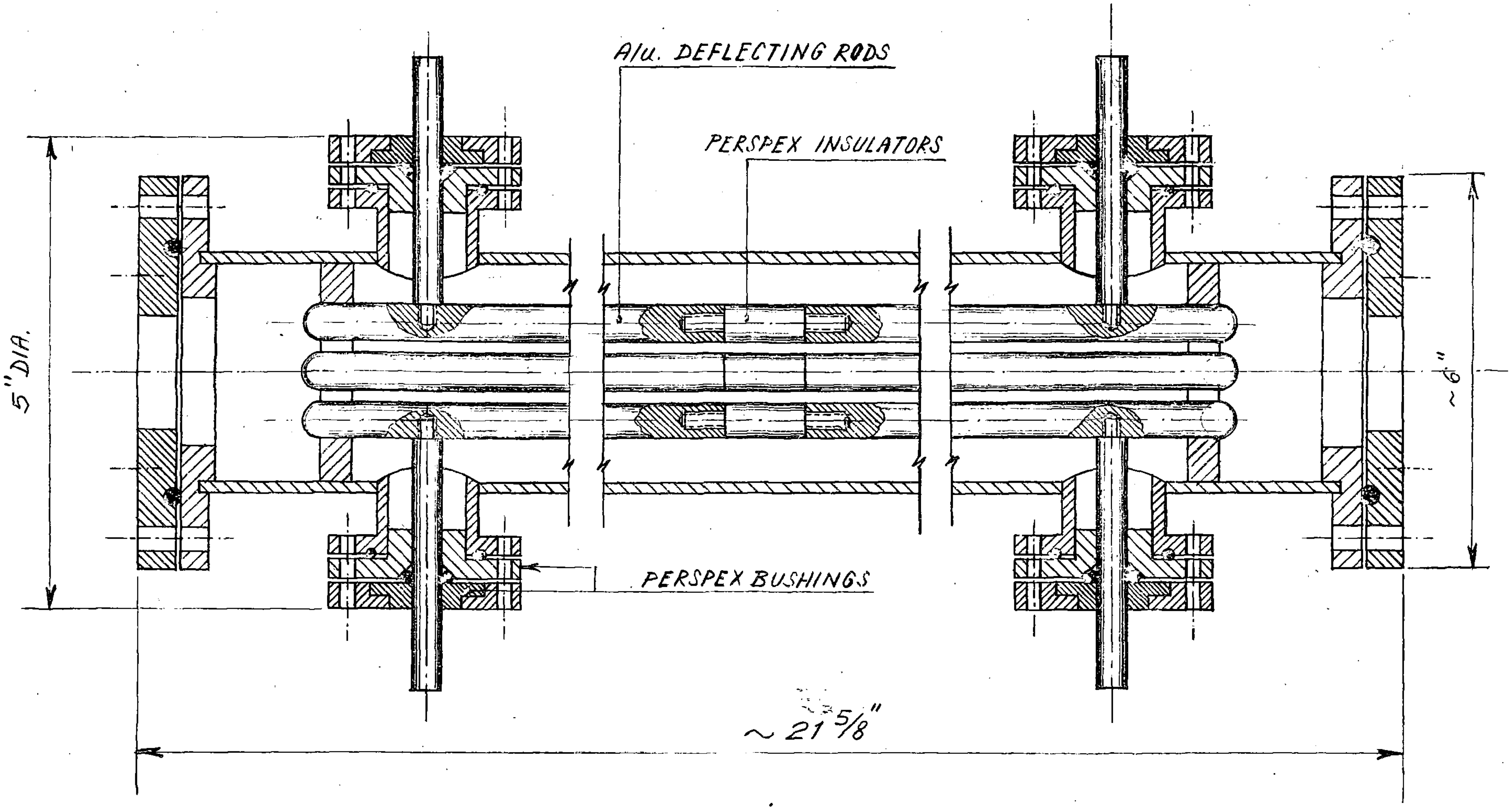


FIG. 5 BEAM DEFLECTOR

RESEARCH EXPERIMENTS

1. A Study of the Levels of ^{44}Ti - M.G.Betigeri and N. Sarma - Nuclei with four particles outside a closed shell such as ^{44}Ti have been of great interest both to experimental and theoretical nuclear physicists. Experimentally these nuclei are easy to investigate since states are well defined at a much higher excitation energies than for other nuclei. Such nuclei in the s - d shell, such as ^{12}C and ^{20}Ne have been well studied. There is however a considerable lack of data on nuclei of the f7/2 shell, i.e. between ^{40}Ca to ^{56}Ni. ^{44}Ti therefore is an extemely interesting nucleus to study. Theoretical calculations have been made on closed shell plus four nuclei using all models postulated so far-the shell model, the alpha particle model, the collective model, even the now fashionable 'pairing force' model. In the pairing force model, calculations reported thus far are only on correlations between two identical particles. One expects that neutron-proton correlation would also be important. Further that four particle correlations must also exist in the nucleus, contributing to the limited success of the alpha particle model. Some calculations on n-p correlations have been carried out.

^{44}Ti was discovered (1) in 1954 and subsequent work has been confined to the measurements on the decay of the nucleus i.e. study of levels in ^{44}Sc. Using the measured half-life of the decay, and assuming the spins of the relevant ^{44}Sc state, the ground state mass difference ^{44}Sc - ^{44}Ti has been estimated as 160 KeV. However doubts regarding the half-life of ^{44}Ti and the level scheme in ^{44}Sc make it difficult to estimate the mass life to any degree of accuracy by this method.

Investigations of the nuclide ^{44}Ti by nuclear reaction methods is not easy because ^{44}Ti is very inaccessible. The only possible reactions that may be used are:

$$^{40}Ca(\alpha, \gamma)^{44}Ti \qquad Q = 5.235$$

$$^{42}Ca(^{3}He, n)^{44}Ti \qquad Q = 5.979$$

$$^{43}Ca(^{3}He, 2n)^{44}Ti \qquad Q = -19.5$$

$$^{46}Ti(p, t)^{44}Ti \qquad Q = -14.12$$

With presently available facilities only the first two are feasible.

Investigations of ^{44}Ti using the reaction $^{40}Ca(\alpha,\alpha)^{40}Ca$ has been made. This method gives the excited states of the nucleus from about 8 MeV to 11 MeV. The second phase of the program would be to study the gamma de-excitation of the nucleus.

Apparatus

The scattering chamber has been described in a published paper (2). Five ORTEC surface barrier detectors of depletion depth 500 and 300 microns were mounted 15 cms away from the target. One detector was used by the accelerator operations crew to monitor the beam on target and so adjust focussing conditions. The signals from the detectors were fed through low noise preamplifier-amplifier systems to the inputs of a TMC 400 channel analyser. It was therefore possible to record spectra from four detectors simultaneously. Correction for dead time of the analyser was made in the usual manner.

The targets used were natural calcium oxide evaporated on to thin self supporting carbon films. It was estimated that the thickness of the carbon was about 40 micrograms/cm^2. It was not found necessary to use separated ^{40}Ca isotope because the solid state detector is able to resolve the elastic scattered peaks from the different calcium isotopes.

The targets were found very stable and could suffer continuous bombardment of more than 1 microampere without rupture.

Results:

Spectra from the detectors printed out by the analyser were plotted. Fig. 6 shows a typical spectrum. The area under the ^{40}Ca peak was then measured. Similar measurements were made at intervals of 10 KeV from 3.5 MeV to 5.5 MeV. After correction for dead time, an excitation function for the elastic scattering of alpha from ^{40}Ca was computed (Fig. 7). The results are still being analysed and the excitation function at three angles should be measured before long.

The resonance behaviour of the excitation curve indicates that analysis of this data must obviously be carried out in terms of compound nucleus theory. The theory of Blatt and Beidenharn (3) has been used for the analysis. However, their final expression is for a single isolated resonance only.

Here several closely spaced resonances are found, and multilevel theory involving several resonance is required. Using the CDC-3600 to tackle complex numbers it can be written.

$$f_c(\theta) = -Z \operatorname{Cosec}\frac{\theta}{2} \exp\left[2i\left(\theta_0 - \eta \ln \sin\frac{\theta}{2}\right)\right]$$

$$f_{CH}(\theta) = i\lambda\pi^{1/2}\sum_{l'=0}^{\infty}(2l'+1)^{1/2}\left(\exp 2i\sigma_0 - \exp 2i\xi_l\right) Y_{l'}^{0}(\theta,\phi)$$

$$f_R(\theta) = \sum_{\substack{s,s',m_s,m'_s,J,M\\ l,l',\mu'}} i^{l-l'}\pi^{1/2}(2l+\ )^{1/2}(l_s 0 s M_s | l s J M)\,(l' s' \mu' m'_s | l' s' J M)\,\left(\delta_{\alpha\alpha'}\,\delta_{ss'}\,\delta_{ll'} - S^J_{\alpha s l,\alpha' s' l'}\right) Y_{l'}^{\mu'}(\theta,\phi)$$

where

$l\,l'$ = incoming and outgoing orbital angular momentum

$$Z = \frac{Z_A Z_x e^2}{2Mv^2}, \qquad \eta = \frac{Z_A Z_x e^2}{\hbar v}$$

θ_0, σ_l = Coulomb scattering phase shifts

ξ_l = hard sphere scattering phase shifts

There may be several terms for the type $f_R(\theta)$ depending on the number of interfering resonances in the energy range fed into the computer. A search program is being written for the computer where in the selected energy range which contains for example, two resonances, the computer selects two $J\pi$ values out of the range J = 0 to 4 which if used in the dispersion

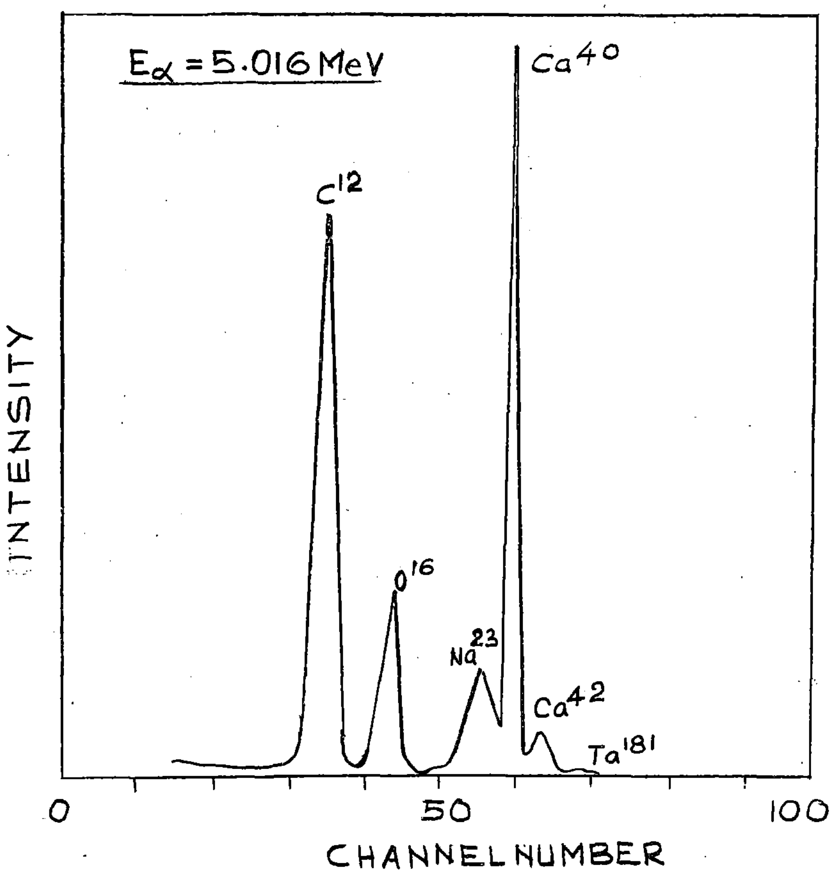
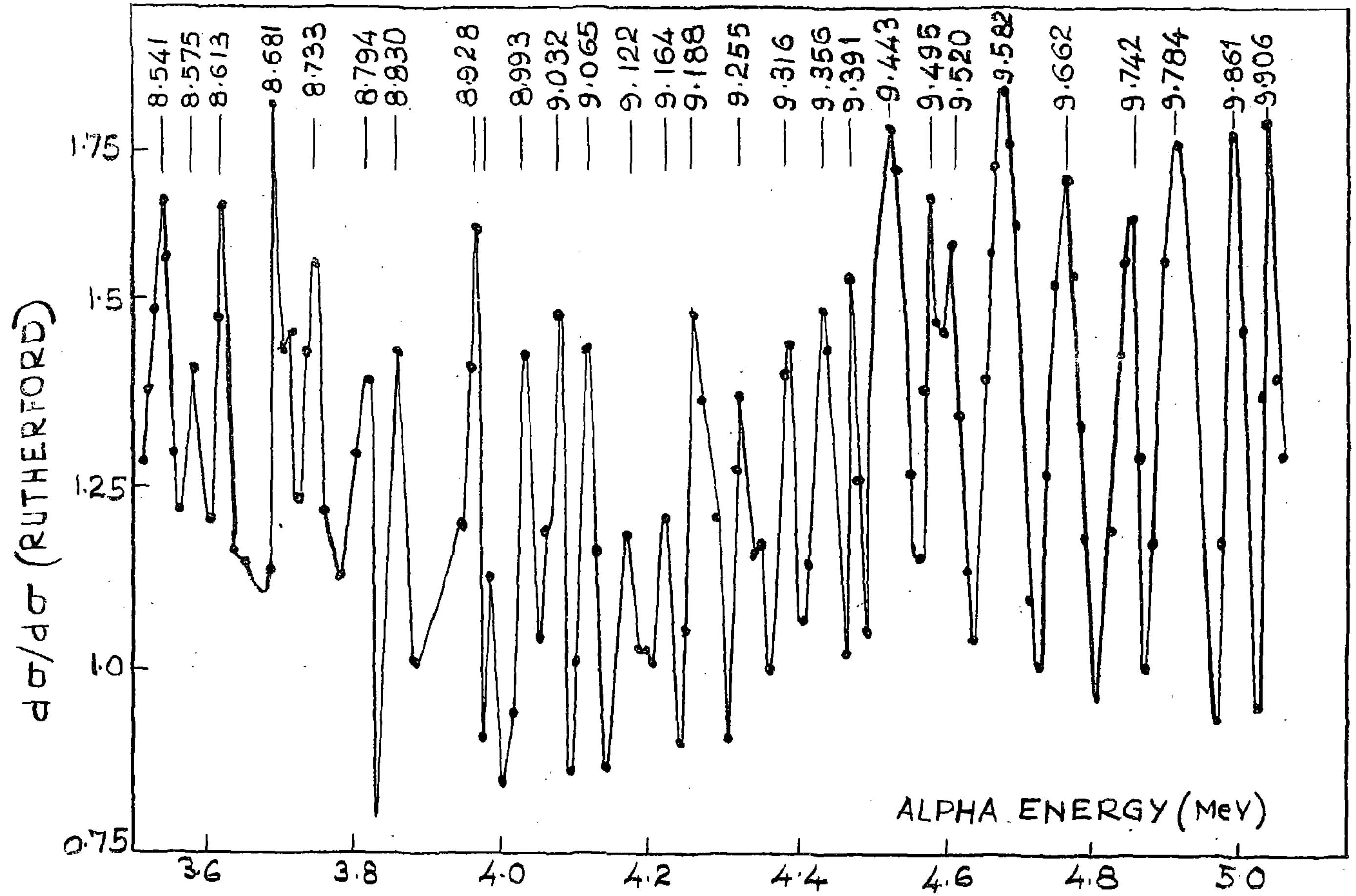


FIG.1 SPECTRUM OF ALPHA PARTICLES SCATTERED FROM TARGET (90°)

FIG-6



EXCITATION FUNCTION $Ca^{40}(\alpha,\alpha')Ca^{40}$ AT θ 90°

FIG - 7

theory give best fit to the results. These two values are printed out along with the best fit curve for comparison. The spin search program is being debugged and the spins and the parities of most of the levels in the compound nucleus ^{44}Ti will be labelled soon. The values of E_0 and Γ for each resonance has to be fed into the computor. This is done at present by direct measurements on the excitation function but it is proposed to write a program for the analysis of an excitation function into a series of Breit-Wigner curves.

References:

(1) R.A.Sharp and R.M.Diamond, Phys. Rev. 93, (1954), 358.

(2) N.Sarma, C.K.Kumar and K.S.Jayaraman, Nuclear Physics, 44, (1963), 205.

(3) J.M.Blatt and L.C.Beidenharn, Rev. Mod. Phys. 24, (1952), 205.

2. A Study of Nuclear Reactions resulting from Proton Bombardment of ^{27}Al - Joseph John, S.S.Kerekatte and M.K.Mehta - Proton bombardment of ^{27}Al with a bombarding energy above 4 MeV would amount to an excitation energy of about 15 MeV in the ^{28}Si nucleus. Generally, it is expected that at energies as high as this, the level density would be so high as to make the statistical model of compound nuclear reactions valid. In such a case excitation curves would exhibit a smooth nature. At the other extreme, if the excitation energy is low enough one would be exciting only one or a few levels at a time, and the excitation

curves would exhibit the familiar phenomenon of resonances. During the last five years, a phenomena called the Ericson fluctuations has been ascertained which is exhibited by excitation curves, taken with high resolution in the so-called 'statistical' region.

The $^{27}Al(p, p'\gamma)$ experiments performed at this laboratory showed 'resonances' in the excitation curves, and the present experiment was undertaken to investigate the nature of these resonances.

Thin self-supporting targets of ^{27}Al were prepared by evaporating aluminium on to glass slides previously coated with NaCl, and by floating the aluminium film off the glass slides in water. The target thickness was measured to be about 5 KeV for 2 MeV protons. This measurement was done by observing the shift in the $^{7}Li(p, n)^{7}Be$ threshold when the protons passed through the aluminium target before hitting the lithium target.

These targets were mounted in a cylindrical chamber designed to take solid state counters. The excitation curves were obtained by using two solid state counters simultaneously the outputs from which were fed into a TMC 400 channel analyser, after suitable amplification. The elastically scattered protons from ^{27}Al, ^{16}O, 8 ^{12}C as well as the α_0, P_1, P_2 and P_3 groups from the reaction $^{27}Al(p, \alpha_0)^{24}Mg$, $^{27}Al(p, p_1)^{27}Al^*$; $^{27}Al(p, p_2)^{27}Al^*$ and $^{27}Al(p, p_3)^{27}Al^*$ respectively, could be easily identified in the resulting particle spectra.

Excitation curves were evaluated for the P_o, α_o and P_3 groups at 90° in the laboratory and the P_o and α_o groups at 150° in the laboratory for a bombarding energy range of 4 to 5.5 MeV. The resulting curves are shown in Fig. 8. The energy step was about 5 KeV. All the curves show a relatively sharp structure. In many cases, a 'resonance' appears in all the channels and at both the angles. There are a number of qualitative criteria which can be applied to determine whether these 'resonances' are real resonance effects and do represent Γ/D which is small ($\Gamma \sim 20 - 50$ KeV, $D \sim 200$ KeV) or they are the fluctuations which Ericson describes.

First, there is the energy correlation between various channels and angles, which should be absent for fluctuations and present for resonances. In the present work the energy correlations do exist for many 'resonances'.

If there are resonance effects, the angular distributions measured on prominent resonances could be analyzed in terms of the (J, π) values of one or more neighbouring levels in the compound nucleus, which could contribute to a single resonance. Although the actual calculations for such an analysis are quite cumbersome, they could be done with a fast digital computer. With this aim in mind, six angular distributions were measured at six prominent resonances marked 'A' in Fig. 8. These angular distributions are shown in Fig. 9. The lack of symmetry about 90°, in general may imply levels of opposite parity, if these are resonances.

A proper fluctuation analysis for the excitation curves and a resonance analysis of the angular distribution have to be done before any definite conclusions can be reached, but qualitatively speaking it is possible that the data represents the 'resonance' region as against the 'fluctuation' region of excitation in the compound nucleus ^{28}Si.

3. <u>Analysis of the Reaction Type (α, d)</u> - B.K.Jain and N.Sarma - The angular distribution of the nuclear reaction of the type (α, d) has been calculated on the plane wave Born approximation theory assuming that both light particle stripping and heavy particle stripping processes occur. The intereference between the two processes has also been taken into account. The angular distribution has been computed for the reaction $^{10}B(\alpha, d)^{12}C$ and the results compared with the available experimental data.

This work is now published in Physical Review, <u>137</u> (1965) 800.

4. <u>Proton-gamma angular correlation in the reaction $^{19}F(\alpha, p\gamma)^{22}Ne$</u>- M.A.Eswaran, N.L. Ragoovansi and P.C. Mitra - Gamma-ray angular correlation experiments play a major role in the study of low-lying states in nuclei. For measurement and analysis of gamma-ray angular correlations for the study of states excited in nuclear reactions, Litherland and Ferguson (1) have developed two procedures which are independent of any assumption regarding reaction mechanisms. Hence these methods are particularly suitable in cases where a number of overlapping levels in compound nucleus are excited or when the direct interaction type of

EXCITATION CURVES FOR $(Al^{27}+p)$ REACTIONS

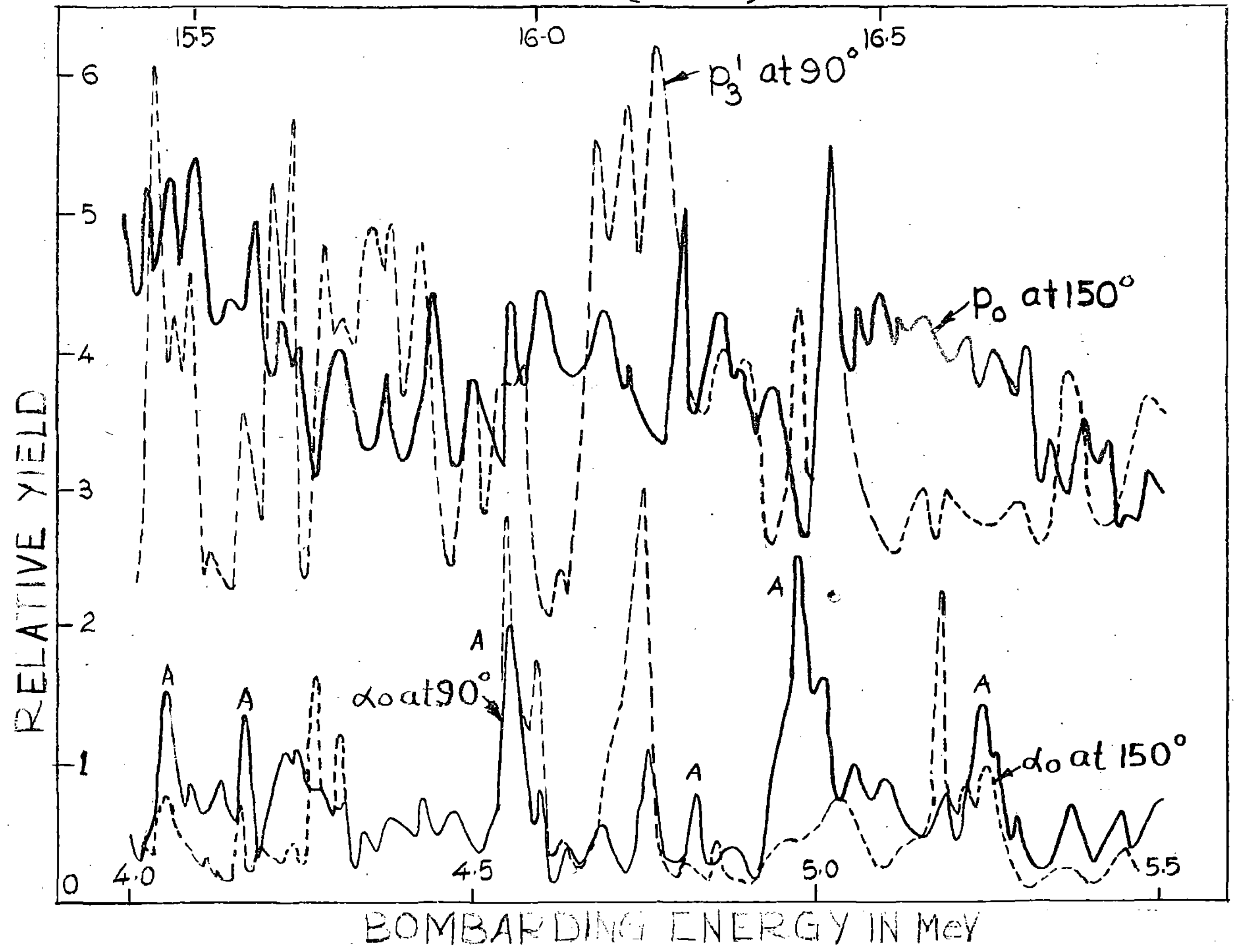
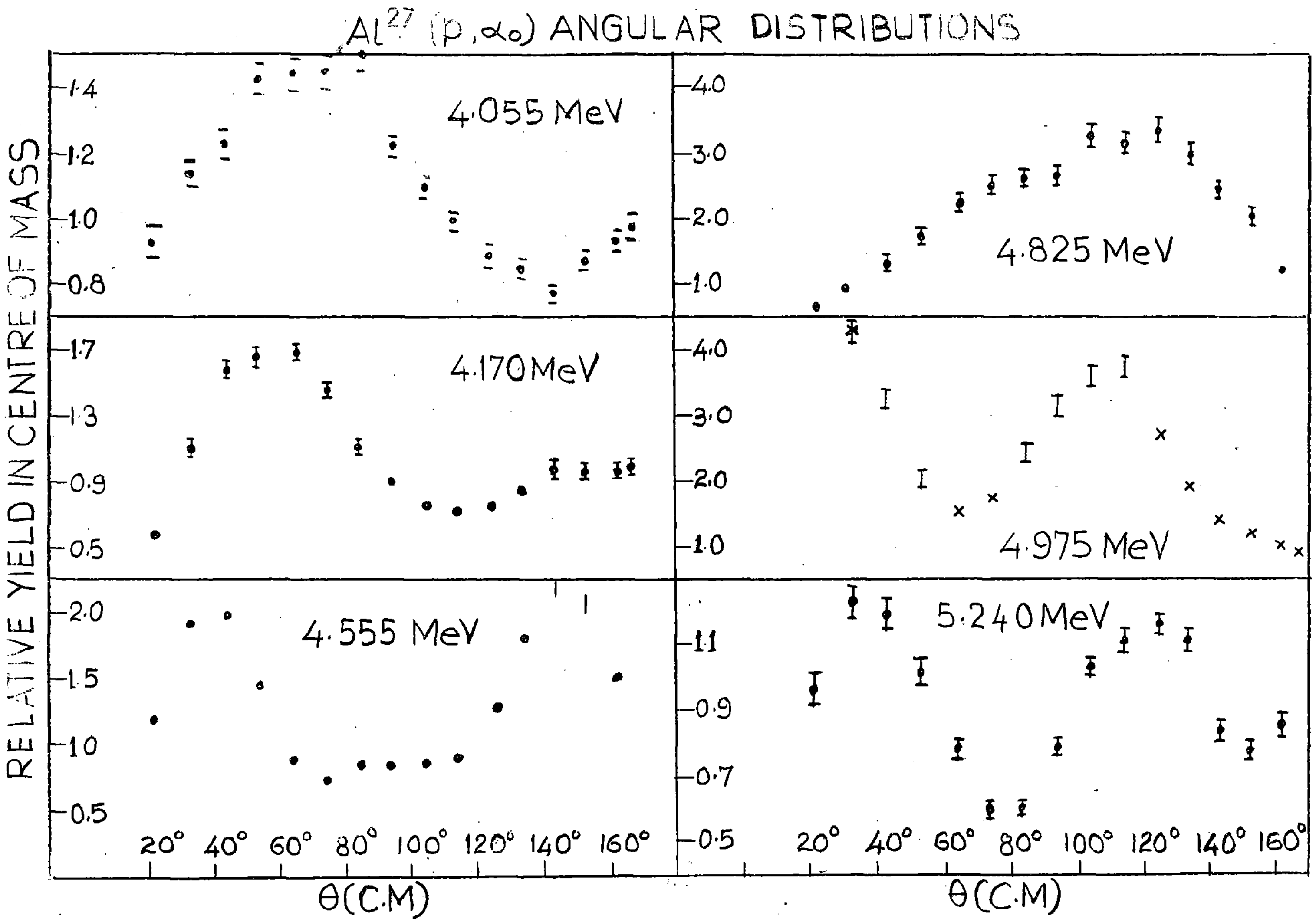


FIG. 8



Al27 (p, α0) ANGULAR DISTRIBUTIONS
RELATIVE YIELD IN CENTRE OF MASS
4.055 MeV
4.825 MeV
4.170 MeV
4.975 MeV
4.555 MeV
5.240 MeV
θ(C.M)
θ(C.M)

FIG. 9

behaviour is dominant. The first procedure involves triple correlation measurement of two cascade gamma rays from the decay of the states in the residual nucleus. In the second procedure, the outgoing particles in a nuclear reaction feeding a particular state in the residual nucleus are detected at zero or 180° to the beam in a small counter and the angular correlation of the subsequent gamma ray from the decay of the state is measured. In this case, the magnetic substates which can be populated in the state of the residual nucleus, is limited by the spins of the target incident and outgoing particles and the analysis involves only the magnetic substate population parameters and the multipolarity of the gamma radiation and the spins of the states involved in the residual nucleus.

With a view to study low-lying states in light nuclei excited in nuclear reactions by using the second method described above, an apparatus has been set up containing the following three major parts:

1) A target chamber, with provision for mounting semiconductor charged particle detectors, solid targets and suitable tantalum apertures for collimating the incoming charged particle beam. The angular position of the detectors can be varied in the reaction plane. Introduction and removal of absorbers in the path of the detected particles, without breaking the vacuum are also facilitated.

2) A gamma ray angular distribution table which enables a 4 in. x 5 in. NaI(Tl) gamma detector with associated lead shielding to be rotated in the horizontal plane about a vertical axis passing through the beam spot on the target in the target chamber.

3) An electronic fast-slow coincidence system with resolving time of 200 nanoseconds suitable for detecting the charged particles and gamma rays in coincidence with provision to record the random coincidence and true plus random coincidence spectra simultaneously in different parts of the memory of the TMC 400 Channel Analyser. This is achieved by the use of two identical fast-slow coincidence circuits.

Using the above apparatus, proton-gamma angular correlation measurements were made on the reaction $^{19}F(\alpha, p\gamma)^{22}Ne$. Fluorine target was prepared by evaporating calcium fluoride approximately $400\,\mu\gamma/cm^2$) on 0.0005 in thick Nickel foil. 5.3 MeV He^+ beam from the Van de Graaff Accelerator was well collimated by two 1.5 mm diameter tantalum apertures 25 cm. apart, the aperture nearer to the target being at a distance of 7 cm from it. The beam is stopped in the target backing and the protons from the reaction $^{19}F(\alpha, p\gamma)^{22}Ne$ are detected at zero degree to the beam in an ORTEC surface barrier detector of 3050 Ohm. cm. resistivity operated at 150 volts bias. This proton detector was at a distance of 40 mm from the target and was subtending a half angle of 5° at the target. The front face of the NaI(Tl) gamma detector was at a distance of 16 cm from the target.

Gamma-ray spectrum, detected in coincidence with selected proton group from the particle detector was recorded in the first quarter of the 400 channel analyser, the random coincidence spectrum being recorded simultaneously in the second quarter. Such spectra were recorded for various values of θ, the gamma counter angles with respect to the incident beam. The counts in the selected proton group served as the monitor. These observations were recorded for the range of θ value 0° to 100° in steps of 10° by selecting in the gate of the coincidence system, the p_1 proton group feeding the first excited state of ^{22}Ne. Similar observations were also recorded in the range of 0° to 90° in steps of 10° by selecting in the gate, the p_2 proton group feeding the second excited state in ^{22}Ne.

These p_1 gamma and p_2 gamma angular correlation observation recorded with the proton counter at zero degree are presently being analysed with the analysis procedure developed by Litherland and Ferguson (1) which is independent of any assumption regarding reaction mechanism as mentioned earlier.

Reference

(1) A.E.Litherland and A.J.Ferguson, Can. J. Phys. 39 (1961), 788.

5. A Distorted Wave Born Approximation Calculation for (^3He,p) Reactions - B.K.Jain and N. Sarma - A theoretical expression for the differential cross section of the (^3He, p) reaction has been developed for a direct interaction two-nucleon transfer process. Distorted wave Born approximation theory has been used with a

Gaussian form for the direct interaction potential. The calculations have been programmed for the CDC 3600 computer and the results compared with available experimental data on the $^{40}Ca(^{3}He, p)^{42}Sc$ reaction.

6. Study of Elastic Scattering of Alpha Particles from ^{6}Li and ^{24}Mg - D.K. Sathe, M.K.Mehta and S.S.Kerekatte - Preliminary excitation curves have been obtained for the $^{6}Li(\alpha, \alpha)^{6}Li$ reaction at two angles using solid state detectors. A few charged particle spectra of the reaction products where natural magnesium targets are bombarded with α-particles have been obtained.

7. Study of Reaction Mechanism in $^{37}Cl(p, n)^{37}Ar$ - K.V.K.Iyengar, S.K. Gupta, B.Lal and E.Kondaiah - The (n, γ) angular correlation measurements on the first excited state of ^{37}Ar in $^{37}Cl(p, n')^{37}Ar$ reaction reported in AEET/NP/8 (1964) were continued. Measurement of the (n, γ) angular correlation was performed at E_p = 4.3 MeV. The correlation shows slight deviation from both isotropy and symmetry around 90° in the centre of mass system (Fig. 10). The deviation is felt to be either due to contribution from direct interaction processes or non-fulfilment of the continuous assumption for the compound nucleus formed.

The yield of the 1.42 MeV gamma ray in the above reaction was measured in the proton energy region 3.2 to 4.8 MeV and shows two broad maxima at E_p = 3.7 and 4.3 MeV (Fig. 11). The excitation curve for 1.42 MeV gamma is similar to the excitation curve (n-γ) ANGULAR CORRELATION IN $Cl^{37}(p,n\gamma)\,Ar^{37*}_{1.42\ MeV}$

AT E_p = 4.3 MeV AND θ_γ = 0

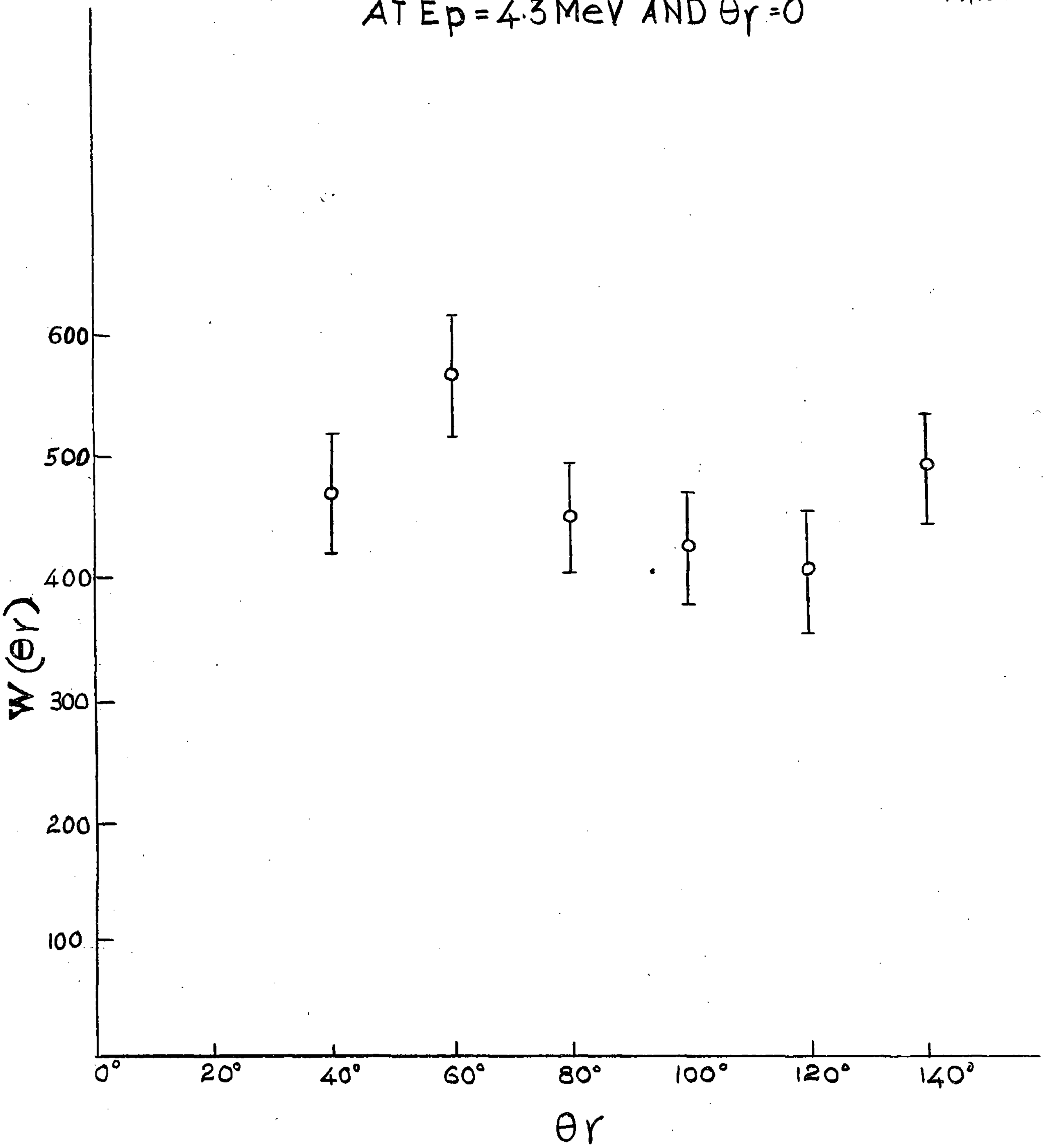


FIG-10

1.42 MeV GAMMA RAY YIELD IN $Cl^{37}(p\,n)Ar^{37}$ REACTION AS A FUNCTION OF PROTON ENERGY

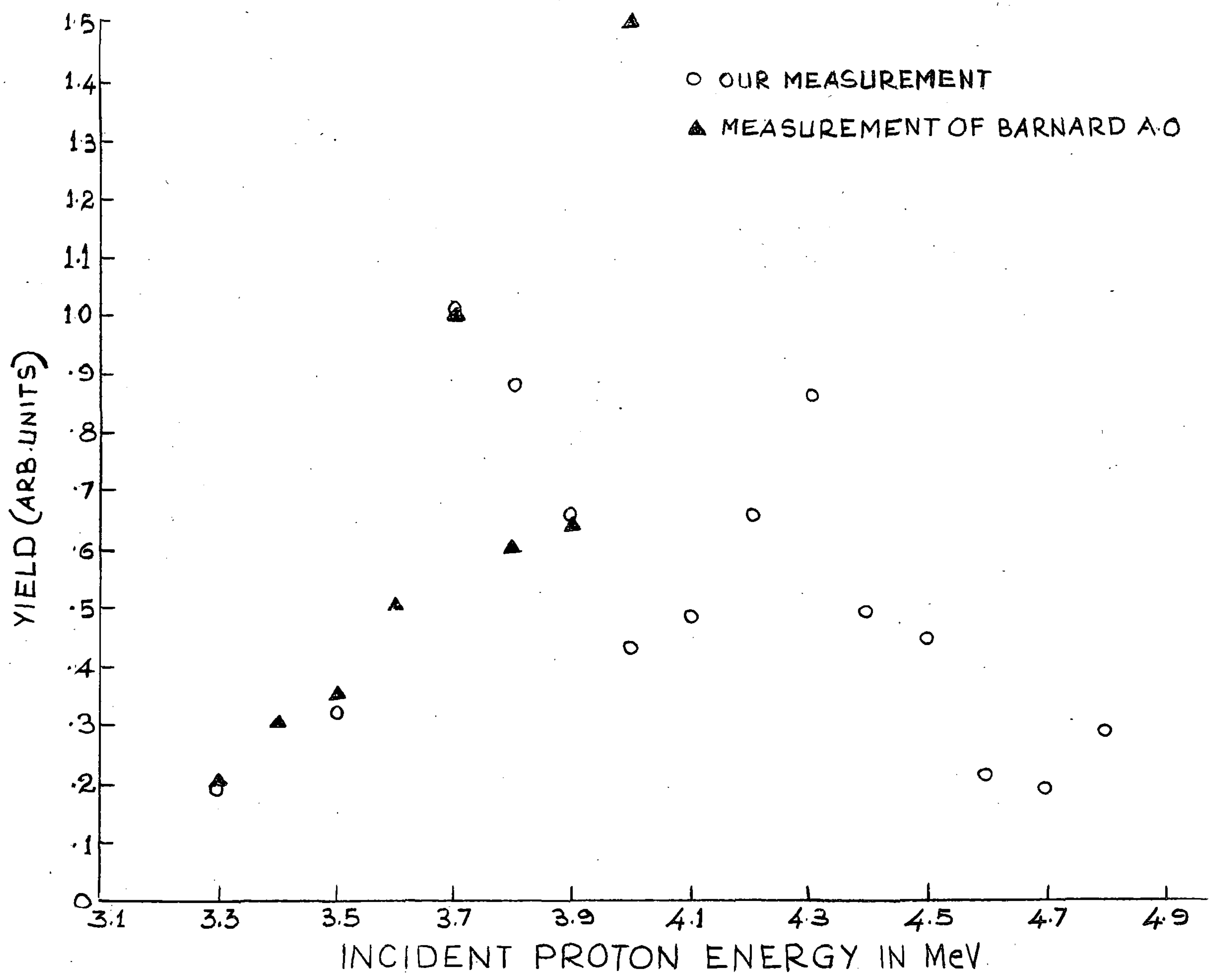


FIG-11

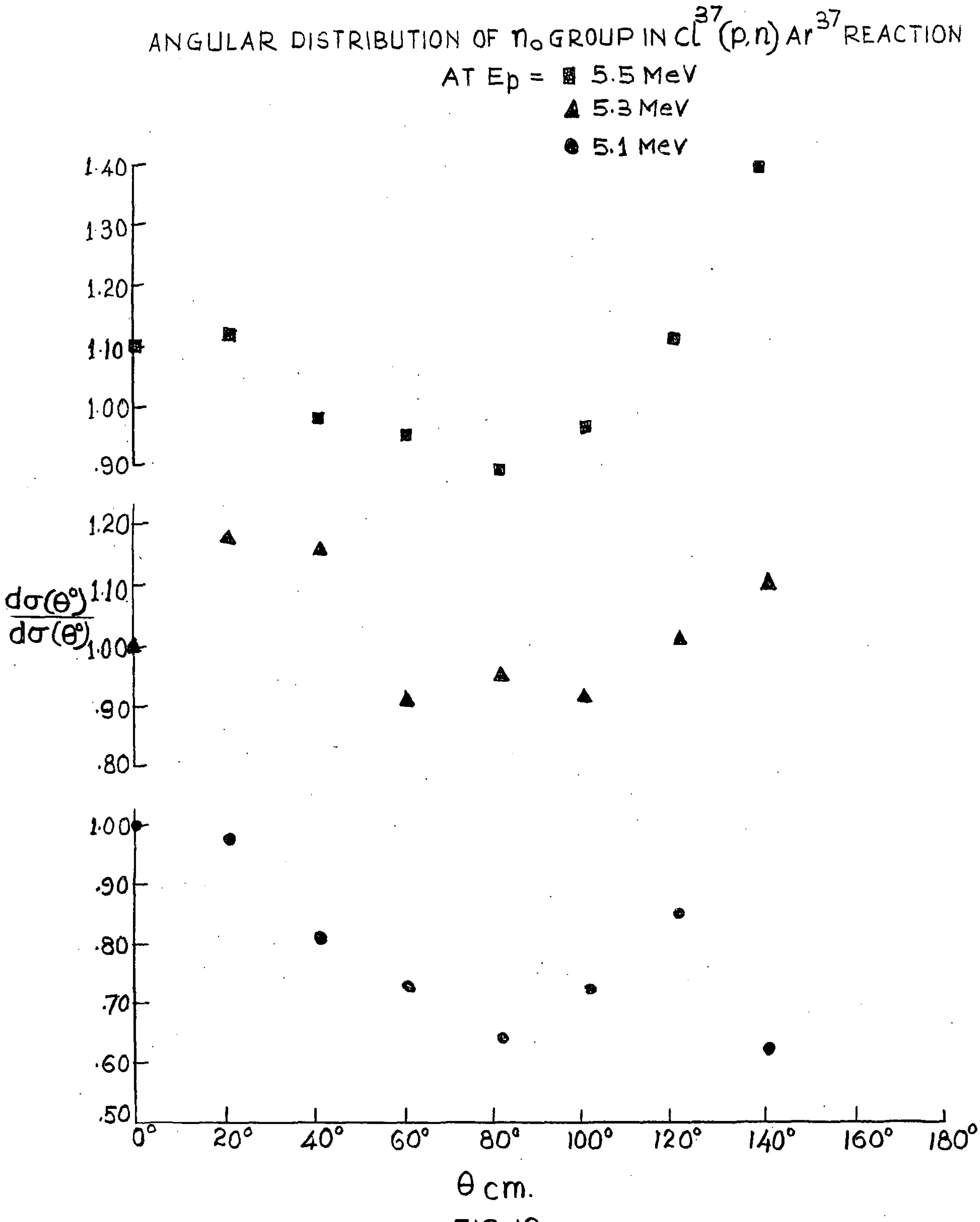

ANGULAR DISTRIBUTION OF n_0 GROUP IN $Cl^{37}(p,n)Ar^{37}$ REACTION
AT Ep = 5.5 MeV
5.3 MeV
5.1 MeV
$\frac{d\sigma(\theta^\circ)}{d\sigma(\theta^\circ)}$
1.40
1.30
1.20
1.10
1.00
.90
1.20
1.10
1.00
.90
.80
1.00
.90
.80
.70
.60
.50
0°
20°
40°
60°
80°
100°
120°
140°
160°
180°
θ cm.

FIG-12

in the region E_p = 3.2 to 3.9 MeV for neutrons leading to the 1.42 MeV level in ^{37}Ar in the same reaction reported by Barrard et al. These measurements have been extended upto E_p = 4.8 MeV.

The angular distributions of the neutrons to ground state of ^{37}Ar in the same reaction have been measured at proton energies of 5.1, 5.3 and 5.5 MeV. These distributions are neither isotropic nor symmetric around 90° c.m (Fig. 12) and appear to depend upon proton energy in a significant way.

The data are under further analysis.

8. <u>Study of $^{19}F(\alpha, n)^{22}Na$ and $^{13}C(\alpha, n)^{16}O$ Reaction</u> - K.K. Sekharan, S.S.Kerekatte and M.K. Mehta - Measurement of absolute cross section of (α, n) and (p, n) reactions yields valuable information. For example, the properties of the compound nucleus are studied by analysing the energy dependence of these cross sections. To interpret the reaction mechanism it is necessary to know the total reaction cross section and below the Coulomb barrier the (α, n) and (p, n) cross section from a large fraction of the total reaction cross section. Using a 4π counter (1) for absolute reaction cross section measurement has the advantage that the yield curve will be characteristic of the resonance levels in the compound nucleus. The levels in the residual nucleus will not contribute significantly to the resonances in the yield curve. This method was used for studying the $^{19}F(\alpha, n)^{22}Na$ and $^{13}C(\alpha, n)^{16}O$ reactions.

Experiment:

Accelerated alpha particles were obtained from the 5.5 MeV Van de Graaff Accelerator. The targets were made of spectroscopically pure CaF_2 evaporated on a thick tantalum backing. The targets were about 10 KeV thick for 3 MeV alpha particles. The 4π Neutron Counter has been described earlier (AEET/NP/8).

The excitation function of $^{19}F(\alpha, n)^{22}Na$ has been measured from 2.4 to 5.5 MeV and is shown in Fig. 13. Readings were taken in steps of 6 KeV in low energy region and 10 KeV in high energy region. The threshold for this reaction is about 2.36 MeV. The yield of neutrons at threshold is low and hence it was masked by the background neutrons from the carbon contamination on the target. Separate investigations have been made to establish that the background is due to the $^{13}C(\alpha, n)^{16}O$ reaction neutrons. Arrows in Fig. 13 show the position of peaks from this reaction. $^{19}F(\alpha, n)^{22}Na$ reaction has been earlier studied by Williamson et al. (2) upto 3.5 MeV using a modified long counter. There is a general agreement in spacing and peaks in the two data. The fact that different types of counters are used limits the scope for complete similarity in the two sets of curves.

The excitation function of $^{13}C(\alpha, n)^{16}O$ reaction has been measured from 2 to 5.5 MeV using an enriched carbon-13 target on thick tantalum backing. The target was obtained from Atomic Energy Research Establishment, Harwell. The relative

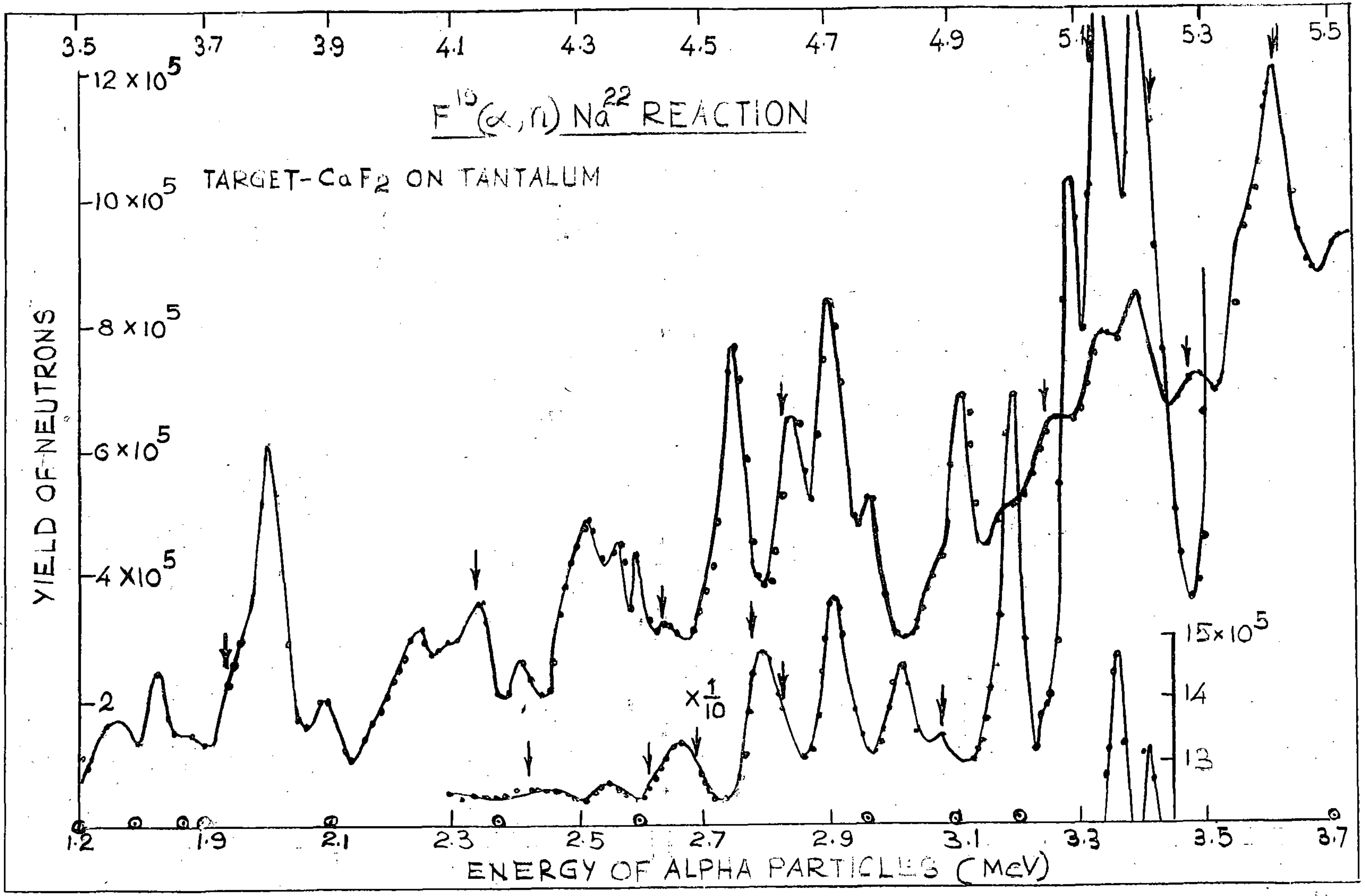
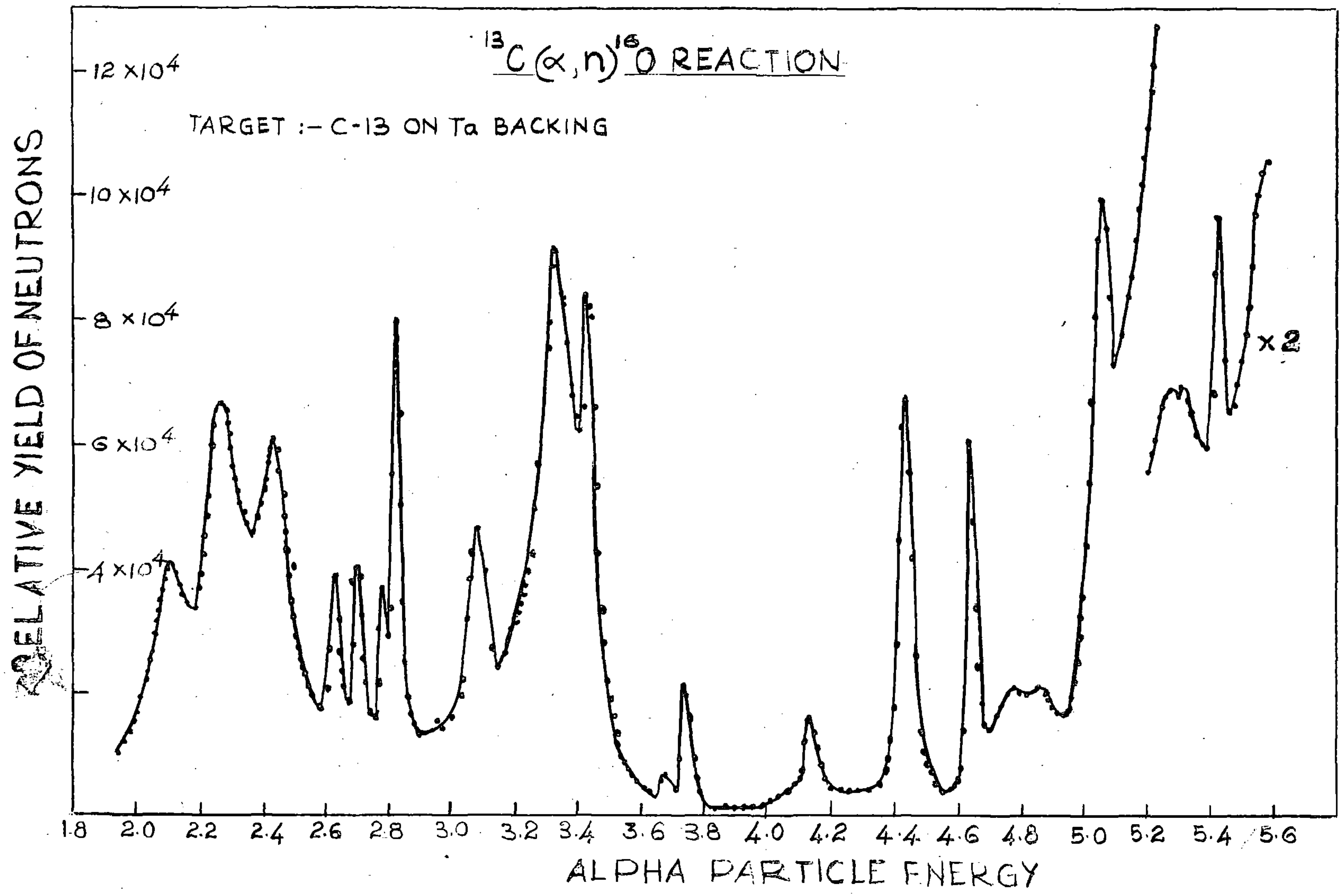

$F^{19}(\alpha, n) Na^{22}$ REACTION
TARGET-CaF_2 ON TANTALUM
YIELD OF NEUTRONS
ENERGY OF ALPHA PARTICLES (MeV)
12 × 10^5
10 × 10^5
8 × 10^5
6 × 10^5
4 × 10^5
2
× 1/10
15 × 10^5
14
13
3.5
3.7
3.9
4.1
4.3
4.5
4.7
4.9
5.1
5.3
5.5
1.2
1.9
2.1
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7

FIG-13



$^{13}C(\alpha,n)^{16}O$ REACTION
TARGET :- C-13 ON Ta BACKING
RELATIVE YIELD OF NEUTRONS
12 x10^4
10 x10^4
8 x10^4
6 x10^4
4 x10^4
x 2
1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2 5.4 5.6
ALPHA PARTICLE ENERGY

FIG -14

yield from the six inner counters is shown in Fig. 14. No correction has been made for the variation of efficiency of counters with neutron energy. The graph shows 19 resonances in this region many of which are well separated. The positions of peaks upto 5 MeV agree within 20 KeV with the earlier measurement by Bonner et al.(3) using a modified long counter at 0° - 10° and 80° - 100°. Two more peaks are observed above 5 MeV. There is a reversal in the relative yield of peaks at 2.27 and 2.43 MeV compared with the data obtained by Bonner. This shows a strong forward peaking in the case of resonance at 2.43 MeV. The increase in the neutron yield above 5 MeV is due to the reaction $^{13}C(\alpha, n)^{16}O^*$ leaving ^{16}O in the first excited state.

Data has just been obtained to determine the absolute cross sections of these two reactions. They are being analysed to correlate with the levels in the compound nuclei ^{23}Na and ^{17}O.

References:

(1) J.B.Marrion et al.,Nuclear Instr. & Methods 8 (1960), 297.

(2) R.M.Williamson et al., Phys. Rev. 117, (1960), 1325.

(3) T.M.Bonner et al., Phys. Rev. 102 (1956), 1348.

9. Long Range Alpha Particle Emission in the Fission of U-235 by 3 MeV Neutrons - V.A. Hattangadi, T. Methasari*, D.M.Nadkarni, R. Ramanna and P.N. Rama Rao - The emission of charged particles of long range has been observed in spontaneous fission as well

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* IAEA Fellow on leave of absence from the Office of the Atomic Energy for Peace, Bangkok, Thailand.

as in fission induced by different projectiles (1). In almost all these cases the charged particles have been identified as alpha particles. This fission process is known as ternary fission. The probability of ternary fission is very low and the reported values of the relative probabilities of binary to ternary fission are not in agreement with each other. An understanding of this ternary fission phenomenon gives information about the scission stage in the fission process. To study the mechanism of emission of the long range alpha particles in fission, investigations have been carried out in the fission of U-235 by 3 MeV neutrons to obtain the energy spectrum and the angular distribution of long range alpha particles with respect to the incident neutron direction. 3 MeV neutrons were used bacause second chance fissions are energetically impossible and do not complicate the angular distribution.

<u>Experimental Arrangement and Method</u>:

The experimental arrangement is shown in Fig. 15. The three solid state detectors were used to detect the long range alpha particles emitted in coincidence with fission fragments. The fission fragments were detected by scintillations produced in Xe gas and were observed by a photomultiplier tube. The detector D_1 was placed close to the target so as to detect all the alpha particles emitted in the backward hemisphere. Two detectors D_2 and D_3 were used to detect the alpha particles emitted at 0° and 90° with respect to incident neutron beam. The alpha particles were detected with an angular resolution

$\pm$ 18°. The Xe gas pressure was about 2/3 atm. which was sufficient to stop the fission fragments and natural alpha particles from reaching D_2 and D_3. The uranium target was made by electroplating U-235 on an Al. backing of thickness 10 Mg/cm^2. The thickness of uranium coating was about 1 Mg/cm^2 over an area of about 2 cm^2. The Al backing was of sufficient thickness to stop fission fragments and natural alpha particles from reaching D_1. 3 MeV neutrons were produced by $T(p, n)^3He$ reaction using the 5.5 MeV Van de Graaff Accelerator. Three charge sensitive pre-amplifier and amplifier systems were used to amplify the pulses from the detectors and were recorded by a 400 channel analyser.

<u>Results and Discussion</u>:

The anisotropy N (0°)/N (90°) was found to be 1.32 $\pm$ 0.12 and is in agreement with that predicted by the statistical theory (2). According to this theory the angular distribution of evaporated particles is given by

$$N(\theta) \sim 1 + \frac{\alpha^2 \bar{I}^2 \bar{l}^2}{2} \cos^2\theta$$

where $\bar{I}^2$ is the average angular momentum of the compound nucleus,

$\bar{l}^2$ is the average angular momentum of evaporated particles,

$\alpha = n^2/2JT$, where J and T are the moment of inertia and temperature of the compound nucleus. $\bar{I}^2$ and $\bar{I}^2$ were calculated using the sharp cut-off approximation and α was calculated using the value of K_0^2 obtained from an analysis of angular distribution of fission fragments (3). The expected anisotropy is of the order of (10 - 25%) depending on the value of r_0 to which parameter this value is very sensitive.

The energy spectrum of the alpha particles has been corrected for loss in Al and is shown in Fig. 16 together with that in the case of thermal neutron fission of U-235 (4). The spectrum of particles evaporated from a nucleus is given by

$$N(E_\alpha)\, dE_\alpha \sim \text{Const.}\, E_\alpha \sigma_c(E_\alpha)\, \omega(E^* - E_\alpha)\, dE$$

where $\sigma_c(E)$ is the cross section for the inverse reaction, E* is the excitation energy of the compound nucleus, and $\omega(E^* - E_\alpha)$ is the level density of residual nucleus. The nuclear temperature T is given by

$$\frac{1}{T} = \frac{d}{d(E^* - E_\alpha)}\left[\omega(E^* - E)\right]$$

and can be obtained by plotting $\ln\left[N(E)/E\sigma(E_\alpha)\right]$ vs E Using the numerical calculations of σ (E) for a spherical nucleus with r_0 = 1.2 fermis, it was found that the high energy part of the alpha spectra in 3 MeV and thermal neutron fission of U-235 correspond to temperatures of 0.76 $\pm$ 0.04 and 0.66 $\pm$ 0.03 MeV respectively (Fig. 17). The peak of the alpha particle

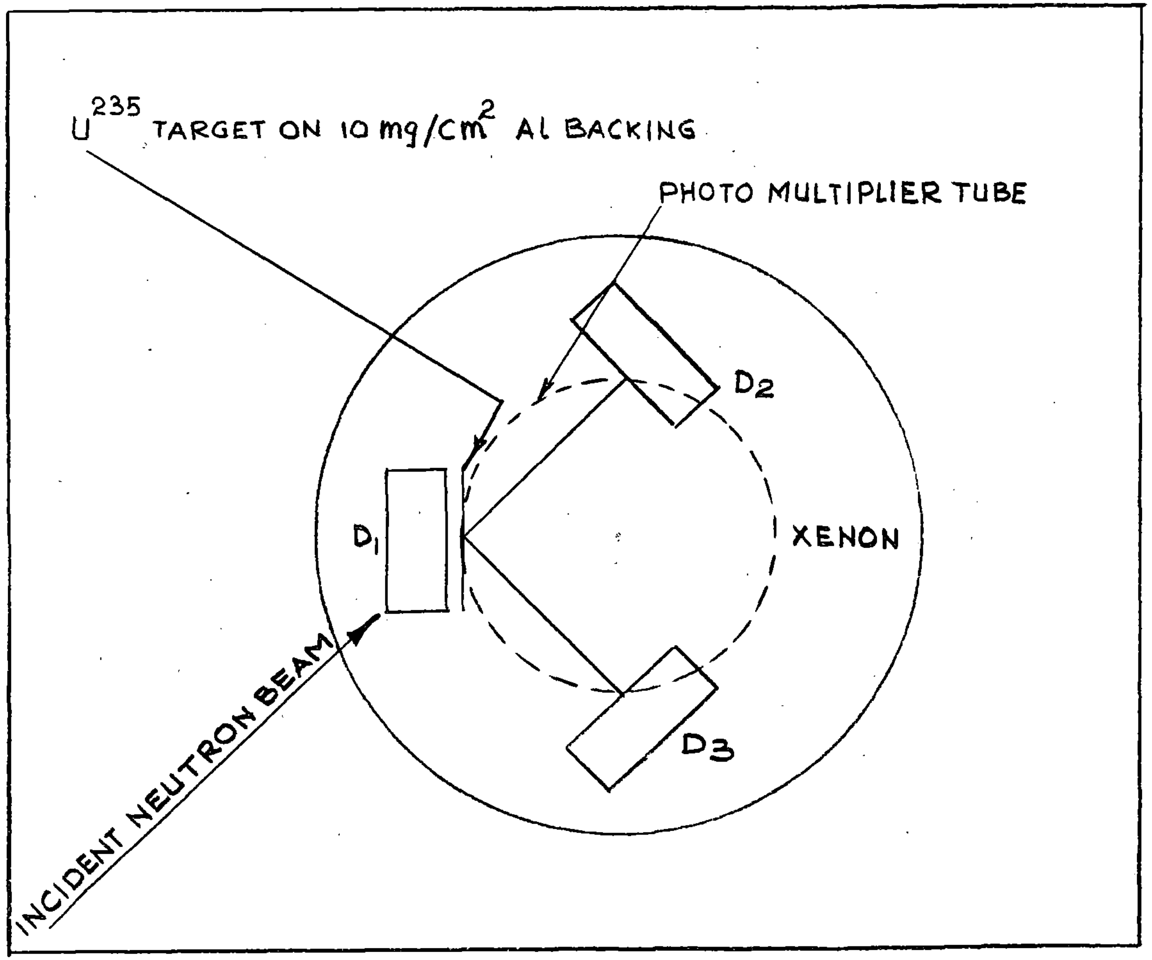
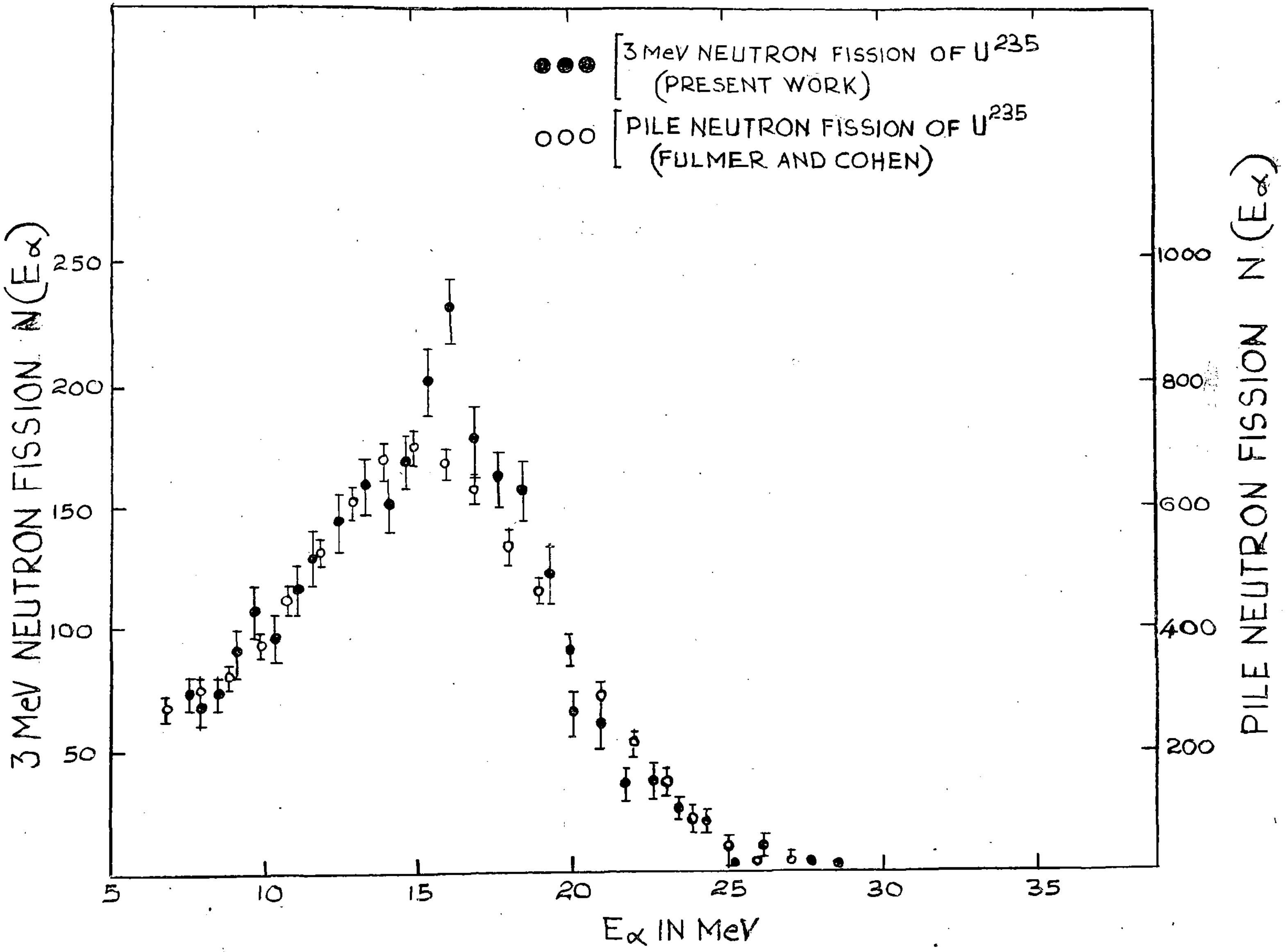
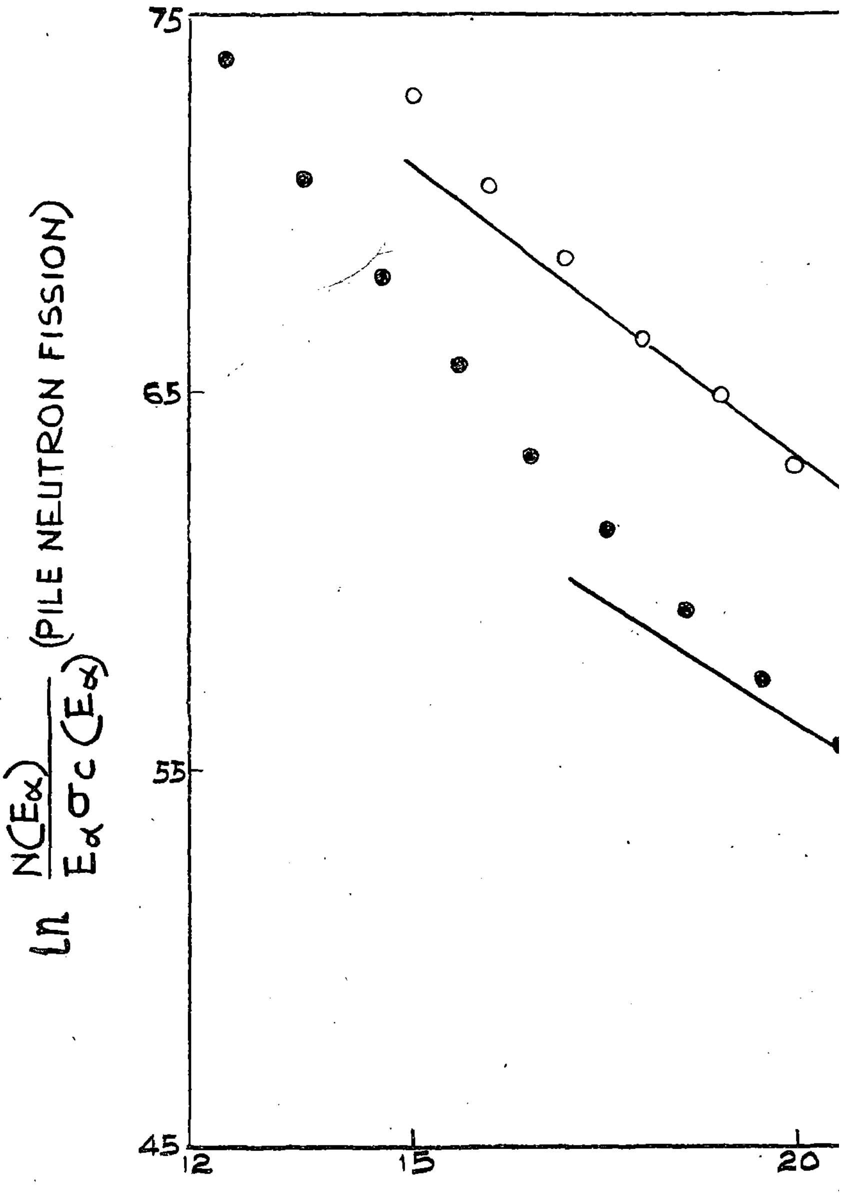

U^{235} TARGET ON 10 mg/cm^2 Al BACKING
PHOTO MULTIPLIER TUBE
D_2
D_1
XENON
D_3
INCIDENT NEUTRON BEAM

FIG. 15


3 MeV NEUTRON FISSION OF U^{235} (PRESENT WORK)
PILE NEUTRON FISSION OF U^{235} (FULMER AND COHEN)
3 MeV NEUTRON FISSION $N(E_\alpha)$
PILE NEUTRON FISSION $N(E_\alpha)$
50
100
150
200
250
200
400
600
800
1000
5
10
15
20
25
30
35
E_α IN MeV
FIG·16



ln $\frac{N(E_\alpha)}{E_\alpha \sigma_c (E_\alpha)}$ (PILE NEUTRON FISSION)
75
65
55
45
12
15
20

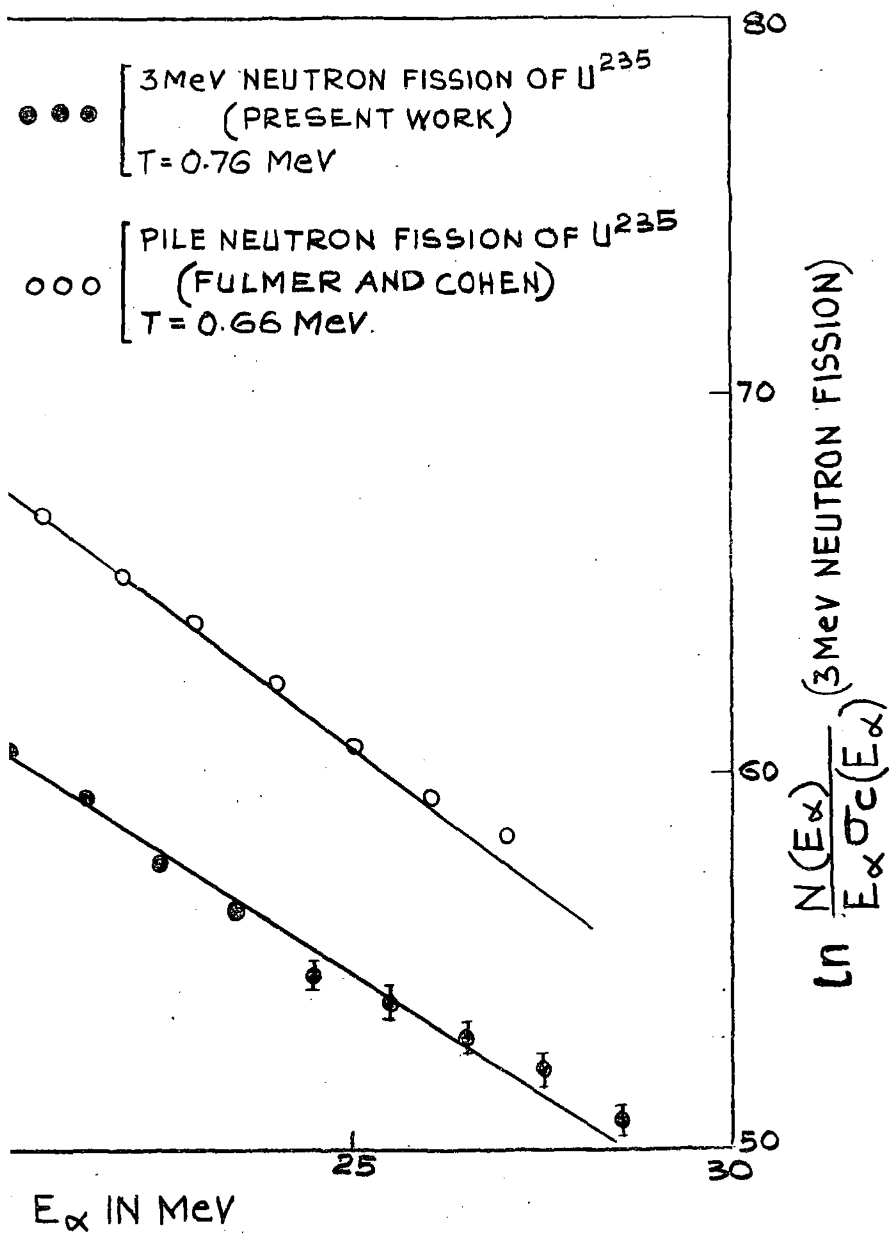

3 MeV NEUTRON FISSION OF U235
(PRESENT WORK)
T = 0.76 MeV
PILE NEUTRON FISSION OF U235
(FULMER AND COHEN)
T = 0.66 MeV.
80
70
60
50
25
30
Eα IN MeV
ln N(Eα) / Eα σc(Eα) (3 MeV NEUTRON FISSION)

FIG-17

spectrum is 3 MeV neutron fission of U-235 was found to be at a slightly higher energy compared to that in thermal fission of U-235 (4) and also the width of the spectrum in the former case was found to be smaller. These differences are probably due to the relative higher temperature in the former case. The relative probability of binary to ternary fission is found to increase with excitation energy of the compound nucleus and is in agreement with the result of previous measurements (5). This increase may be due to competition between the modes of evaporation of alpha particles and neutrons in the fission process.

The results of the present investigation support the hypothesis that the long range alpha particles are evaporated from the compound nucleus prior to scission (6).

References:

(1) N.A.Perifilov et al. Soviet Physics Uspkhi 3 (1961), 542.

(2) T.Ericson and V.Strutinski, Nucl. Phys. 8, (1958), 284.

(3) J.E. Simmons and R.L.Henkel, Phys. Rev. 120 (1960), 198.

(4) C.B.Fulmer and B.L.Cohen, Phys. Rev. 108 (1957), 370.

(5) R.A.Nobles, Phys. Rev. 126,(1962), 1508.

(6) R.Ramanna, K.G.Nair and S.S.Kapoor, Phys. Rev. 129 (1963), 1350.

10. <u>$^{40}Ca(n,\alpha)^{37}A$ Angular Distribution at $E_n = 4.7$ MeV</u> - S.M. Bharati, U.T.Raheja, B.Lal, P.N.Tiwari and E.Kondaiah, Tata Institute of Fundamental Research, Bombay - A gas proportional counter telescope, which has been described earlier (1), was used

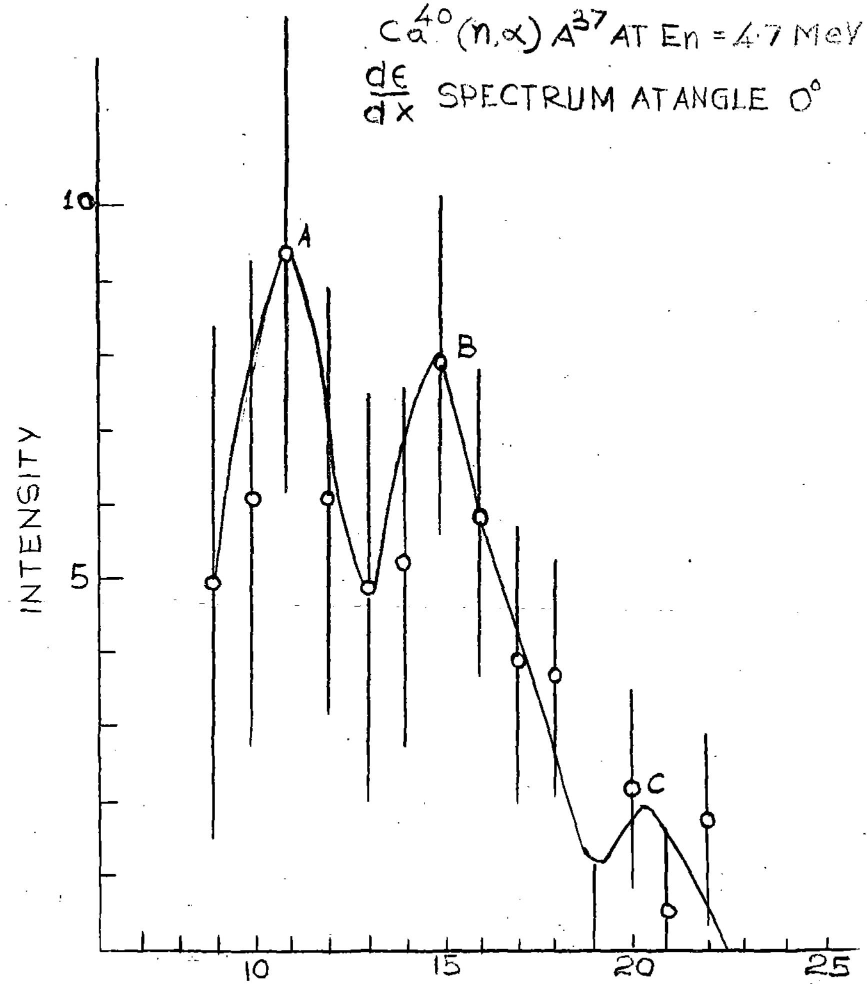
to study the energy and angular distribution of alpha particles arising from Ca(n,α)A reaction at $E_n = 4.7$ MeV. A tritium target bombarded with 5.5 MeV protons in the Van de Graaff Accelerator was used as the source of neutrons.

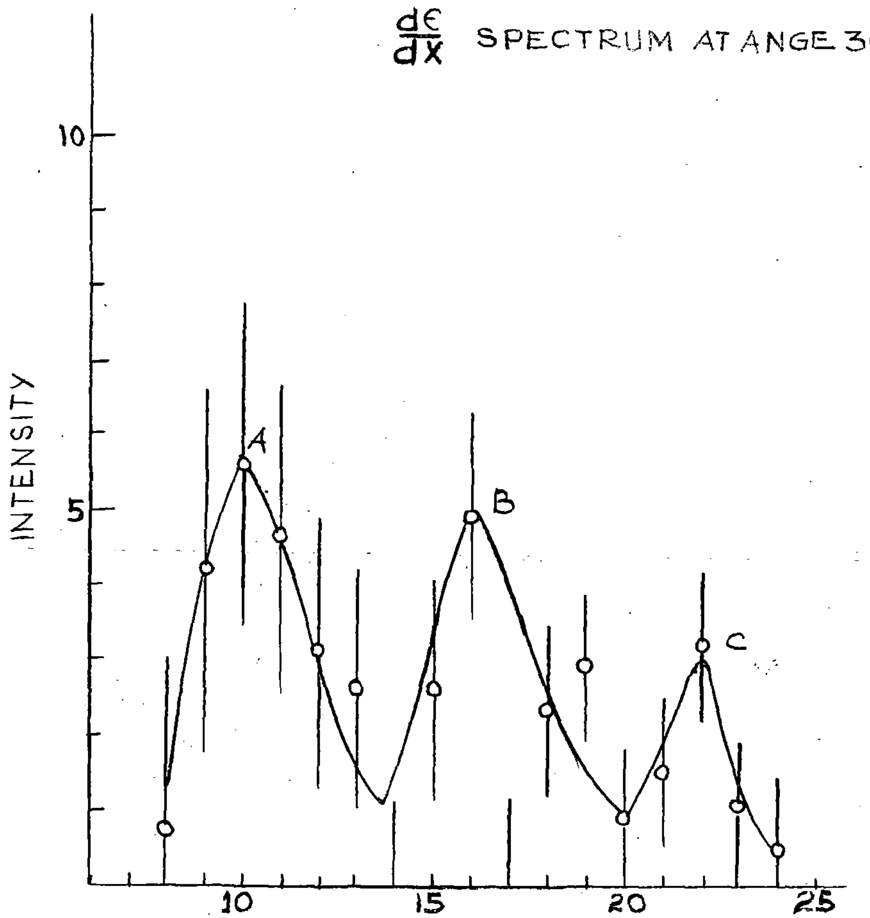
The dE/dX spectrum of alphas from the counter nearer the source, gated by the coincidence pulse derived from both the counters was observed on a TMC 400 Channel Analyser. An ^{241}Am course was used for testing and calibrating the telescope. The energies of alpha particles giving rise to the observed pulse heights could be assessed by means of standard range energy curves.

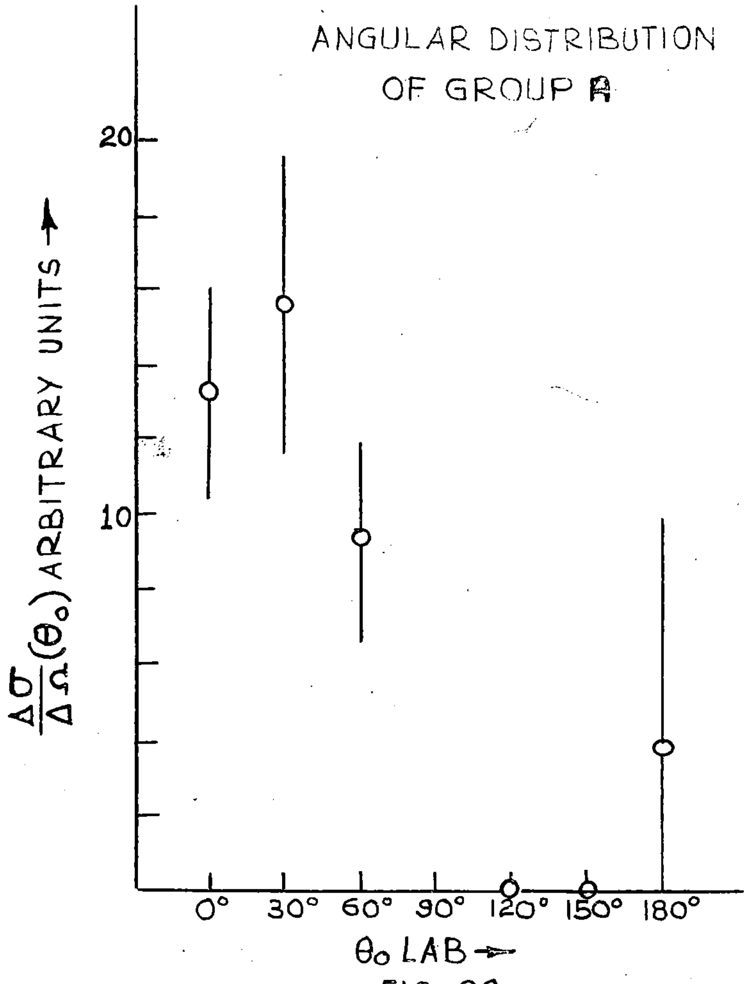
dE/dX pulse height spectra (energy distributions) were obtained at angles 0, 30, 60, 120, 150 and 180. Figs. 18 and 19 show two typical dE/dX spectra. Table I will serve to predict the levels of ^{37}A corresponding to the three groups A, B and C.

From the tabular column, it is easily seen that group A comprises of good state alphas, group B consists of alphas leading to first and second excited levels, while group C includes alphas leading to third, fourth and fifth levels of ^{37}A. These levels could not be resolved due to the limited resolution introduced by the target thickness and the counter.

Figs. 20 and 21 give the angular distributions of groups A and B respectively. The total angular distribution of all the three groups is given in Fig. 22.


$Ca^{40}(n,\alpha)A^{37}$ AT En = 4·7 MeV
$\frac{d\epsilon}{dx}$ SPECTRUM AT ANGLE 0°
INTENSITY
10
5
A
B
C
10
15
20
25
CHANNEL NUMBER
FIG-18


$\frac{d\epsilon}{dx}$ SPECTRUM AT ANGE 30°
INTENSITY
10
5
A
B
C
10
15
20
25
CHANNEL NUMBER
FIG-19.


ANGULAR DISTRIBUTION
OF GROUP A
20
10
$\frac{\Delta\sigma}{\Delta\Omega}(\theta_0)$ ARBITRARY UNITS →
0°
30°
60°
90°
120°
150°
180°
θ_0 LAB →
FIG-20

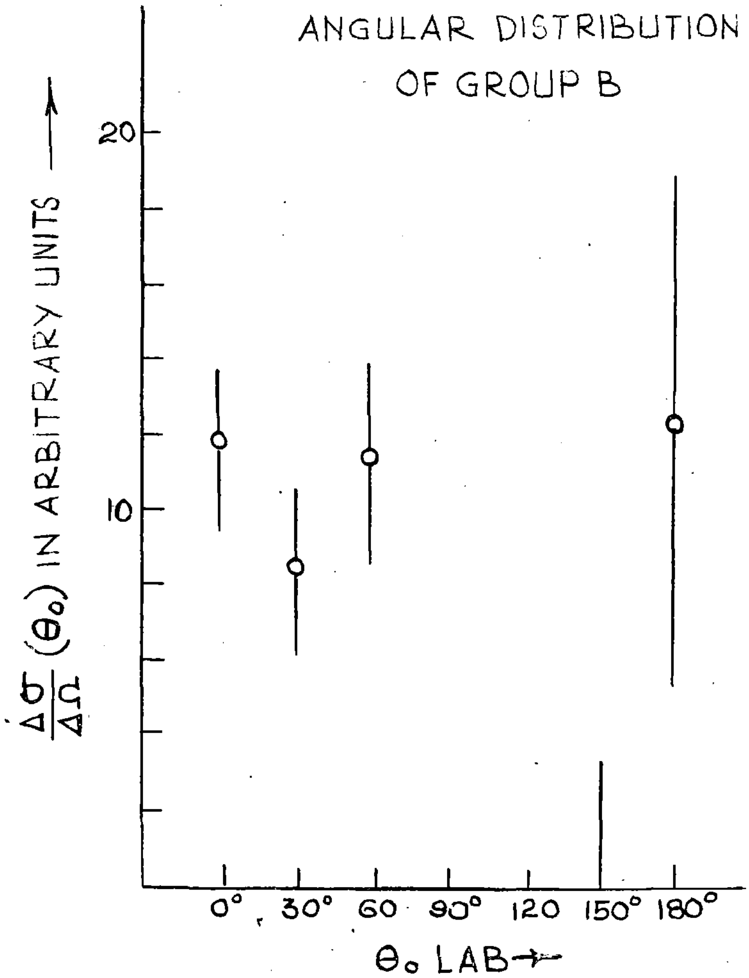

ANGULAR DISTRIBUTION
OF GROUP B
20
10
$\frac{\Delta\sigma}{\Delta\Omega}(\theta_0)$ IN ARBITRARY UNITS
0°
30°
60
90°
120
150°
180°
θ_0 LAB

FIG-21

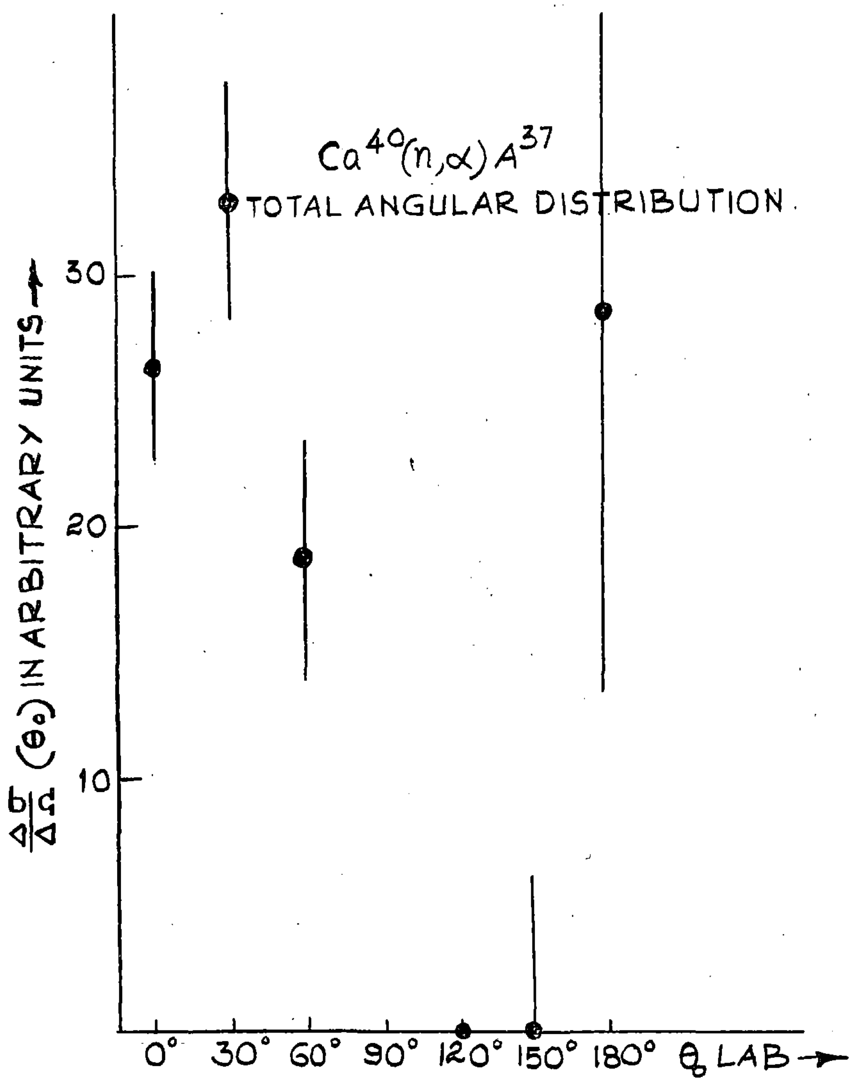

$Ca^{40}(n,\alpha)A^{37}$
TOTAL ANGULAR DISTRIBUTION
$\frac{\Delta\sigma}{\Delta\Omega}(\theta_0)$ IN ARBITRARY UNITS
30
20
10
0° 30° 60° 90° 120° 150° 180° θ_0 LAB

FIG-22

Angle	Levels of A^{37}	Calculated (From Q value) E leading to level in Col.II	E Observed (Group)
0°	0	5.6 ± 0.6	6.25
	1	4.32 ± 0.48)	4.95
	2	4.16 ± 0.46)	
	3	3.58 ± 0.40	
	4	3.43 ± 0.38	3.5
	5	3.32 ± 0.36	
30°	0	5.53 ± 0.64	6.25
	1	4.25 ± 0.47)	4.5
	2	4.08 ± 0.45)	
	3	3.5 ± 0.39)	
	4	3.37 ± 0.37)	3.0
	5	3.25 ± 0.36)	
60°	0	5.36 ± 0.6	5.5
	1	4.09 ± 0.45)	4.14
	2	3.91 ± 0.44)	
	3	3.39 ± 0.37)	
	4	3.20 ± 0.35)	3.4
	5	3.08 ± 0.34)	
180°	0	4.7 ± 0.52	4.13 (Peak Position) A
	1	3.42 ± 0.38)	3.4 (Peak Position) B
	2	3.25 ± 0.36)	
	3	2.67 ± 0.30)	
	4	2.43 ± 0.28)	2.5 (Peak Position) C
	5	2.41 ± 0.27)	

Further work is in progress in order to improve the statistics and to get data at some more angles so that theoretical curves could be fitted, for drawing conclusions regarding the mode of reactions.

Reference:

(1) U.T. Raheja and E.Kondaiah
Proc.DAE Nucl. Phy.Symp. Bombay 255 (1963)

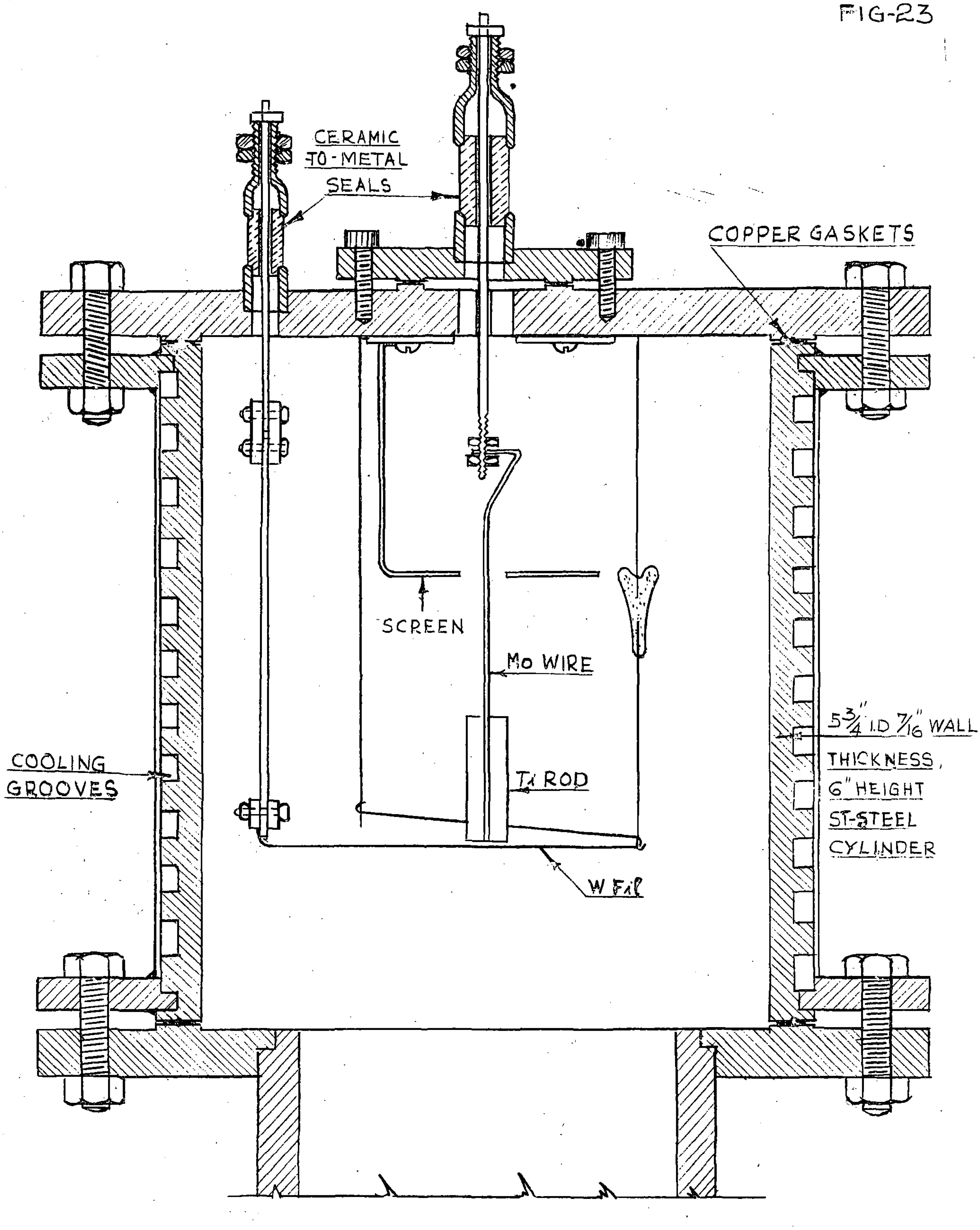
INSTRUMENTATION

1. Multiple Coincidence System - N.L. Ragoovansi, P.C. Mitra and M.A. Eswaran - For use in the charged particle gamma ray coincidence experiments, an electronic multiple coincidence system has been built which is capable of extending the utility of the TMC 400 Channel Pulse Height Analyser to that of two parameter analyser by making use of the Gatti type 20 channel analyser. With the use of this system four coincidence spectra can be recorded simultaneously effecting considerable reduction of accelerator running time necessary for an experiment. An additional feature incorporated in this system enables random coincidence spectrum to be recorded simultaneously with the genuine coincidence spectrum, thereby increasing the reliability of the data.

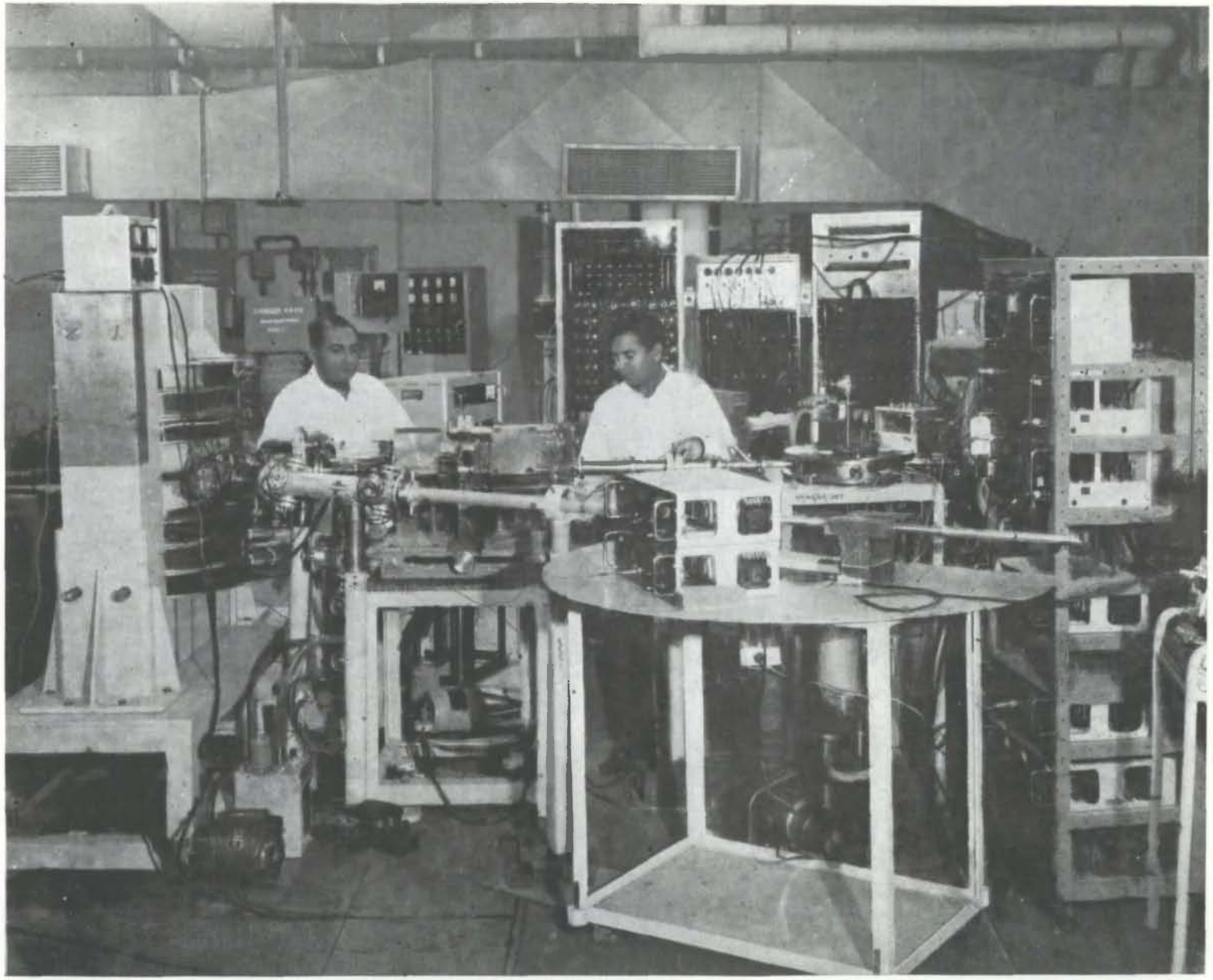
2. Ion Pumps - K.B.Nambiar and A.S.Divatia - A getter ion pump in which titanium is evaporated by electron bombardment has been built and incorporated in a metal system. A stainless steel pump chamber, 5¾" I.D., 7/16" wall thickness and 7" high forms the pump body. The chamber can be baked and then efficiently cooled by circulating water through grooves cut on its outer walls. The pump assembly is shown in Fig. 23.

Commercially available titanium in the form of a rod 1/4" diameter and about an inch in length is mounted axially with respect to the pump chamber. A loop of tungsten wire, 10 mils thick, surrounding the titanium anode forms the pump

FIG-23



GETTER ION PUMP ASSEMBLY



Instrumentation in the experimental area in the Beam Room filament. Initial pumping down is carried out by means of an oil diffusion pump connected through a liquid nitrogen trap. An average current of $\sim$4 amperes is fed to the filament at 20 volts and the anode voltage is gradually taken to $\sim$1.3 KV with respect to the filament. The pump chamber is baked simultaneously and when titanium starts sublimating, the system under test is isolated by closing a baffle valve.

The lowest pressure achieved by the pump is $\sim 2 \times 10^{-7}$mm of Hg. Pumping speeds for various gases have been measured by using the constant pressure method. The speed is comparable to that of a mercury diffusion pump.

The pattern of chemisorption of different gases in the system is being studied by analysing spectrochemically a sample of the titanium film recovered from the inner walls of the pump chamber.

Another type of pump, viz. sputter-ion pump in which titanium is sputtered in a Phillips discharge assembly has been built and its performance studied. The pump body consists of a stainless steel chamber, 4" I.D. and 6" high. Titanium sheets 2" x 2" in area and 1/32" thick are mounted on stainless steel supports screwed on to the top and bottom flanges and they form the pump cathodes. The anode assembly consists of two concentric cylinders of copper, providing large surface area for the gettering of gas molecules. A solenoid provides the necessary magnetic field for the pump.

The ultimate vacuum achieved by the pump is $\sim 8 \times 10^{-6}$ mm of Hg. The pump current vs pressure shows good linearity in the range 2×10^{-4} mm of Hg to 2×10^{-5} mm of Hg.

3. Development of a Polarised ^{3}He-ion Source - M.N.Viswesvariah and N. Sarma - An arrangement is being set up for the study of nuclear polarisation in ^{3}He gas employing the optical pumping technique. The gas is contained in a pyrex bulb of 5 cm diameter at a pressure of 0.7 mm of Hg. The bulb stays at the centre of a helmoholtz coil, with 400 turns per coil. Light from a ^{4}He lamp containing helium gas at 4 mm pressure is excited by an 80 MC/S rf-oscillator of about 100 watts power. Under operating conditions, helium diffuses into walls and the pressure drops significantly in small lamps after a few hours of operation. For this reason all lamps are built with a chamber at ends to act as reservoirs.

Light from the lamps should be circularly polarised. The polarising equipment consists of a linear polariser and a quarterwave plate.

Spectroscopically pure ^{4}He gas has been used. The pumping light is monitored by a lead sulphide detector SV61 Mullard which has a good infrared sensitivity. The optical signal at 1.08 μ converted into equivalent electrical signal by the phototube is handled further by a simple electronic circuitry consisting of a signal comparator, a difference amplifier and a Honeywell recorder. In the study of polarisation, change in absorption from a polarised state to an unpolarised state is observed by destroying, the polarisation using an r.f. magnetic field available from an r.f. coil fed from an r.f. generator (Sanwa type) supply upto 30 MC/s. The r.f. power is increased using 6L6 power amplifier of the cathode follower type giving r.f.power at 10 V output.

The building of the equipment necessary to study the polarisation produced in pyrex bulb is nearly complete except for the polarising equipment. A stabilised current unit as supply for the helmoholtz coils is under construction. Auxiliary equipment for photo detection consisting of phototransistors and amplifiers have been completed.

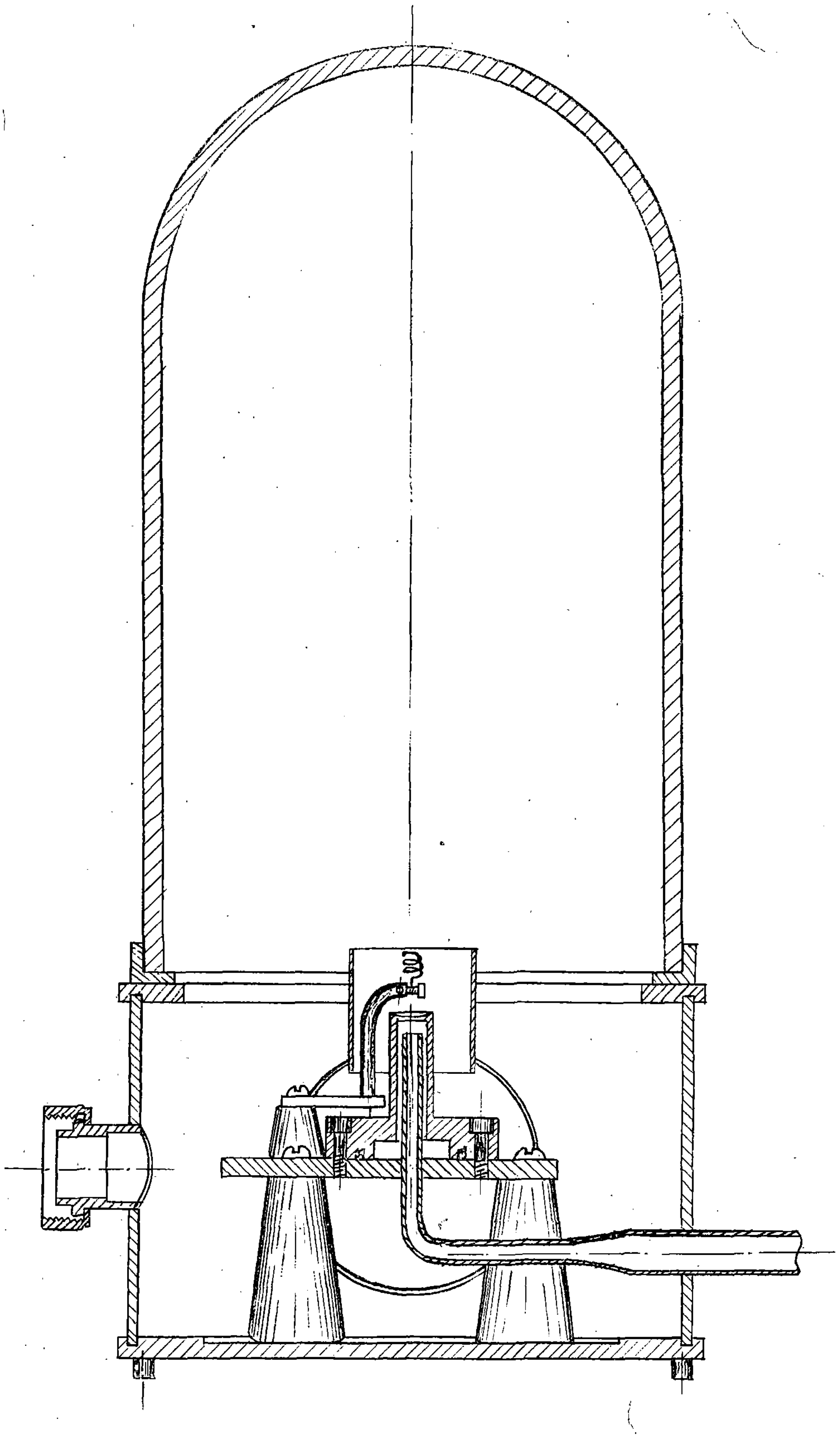
4. Electron Bombardement Apparatus for Preparation of Targets - M.G.Betigeri, K.M.L. Jha and N. Sarma - Various techniques for evaporation of target materials for the use in experiments have been developed. One of the oldest methods is the resistance heating method. A boat prepared out of some material of very high melting point is put across two electrodes. The material to be evaporated is put in the boat and under vacuum of the order of 1×10^{-4} mm of Hg, high current is passed, thereby heating the boat. The limitation of such a method is the boat itself. In the case of materials like Boron, Calcium, the temperature required is so high that the tantalum boat gives way. Another disadvantage is that the current variation is not too fine, thereby increasing the temperature of the boat suddenly.

Another technique used is the electron bombardment technique, in which the heating is done by the electrons bombarding the material to be evaporated. An apparatus incorporating this principle has been developed (Fig. 24). A heated tungsten filament acts as a source of electrons. These are accelerated by a - 2 KV supply on the filament itself. The guiding of electrons and a sort of focussing effect is rendered by a tantalum skirt, kept at a relatively negative voltage compared to the filament. A water cooled copper rod in the centre with a section of the upper face of the rod cut at 2° angle, serves as anode and is at ground potential. The whole assembly is mounted on a vacuum system. An ultimate vacuum of 6×10^{-6} mm of Hg has been reached on this system.

The supply to the filament is given through a 6.3 volts transformer coupled to a variable autotransformer. The - 2 KV supply is obtained from a special power supply. A block diagram is shown in Fig. 25.

The slow but sure evaporation by this apparatus ensures very good uniformity of the target material evaporated.

5. <u>Electromagnetic Isotope Separator</u> - K.K. Damodaran, S.R. Gowarikar, R.Suryanarayan, V.N. Jayaraman and F.R.Bhathena - The machine went in operation (1) in the month of February 1964. For the first few months, the machine was run mainly to study separation of Neon, Argon and Krypton isotopes. It was found that good separation takes place for Neon and Argon. The



ELECTRON BOMBARDMENT APPARATUS

FIG-24

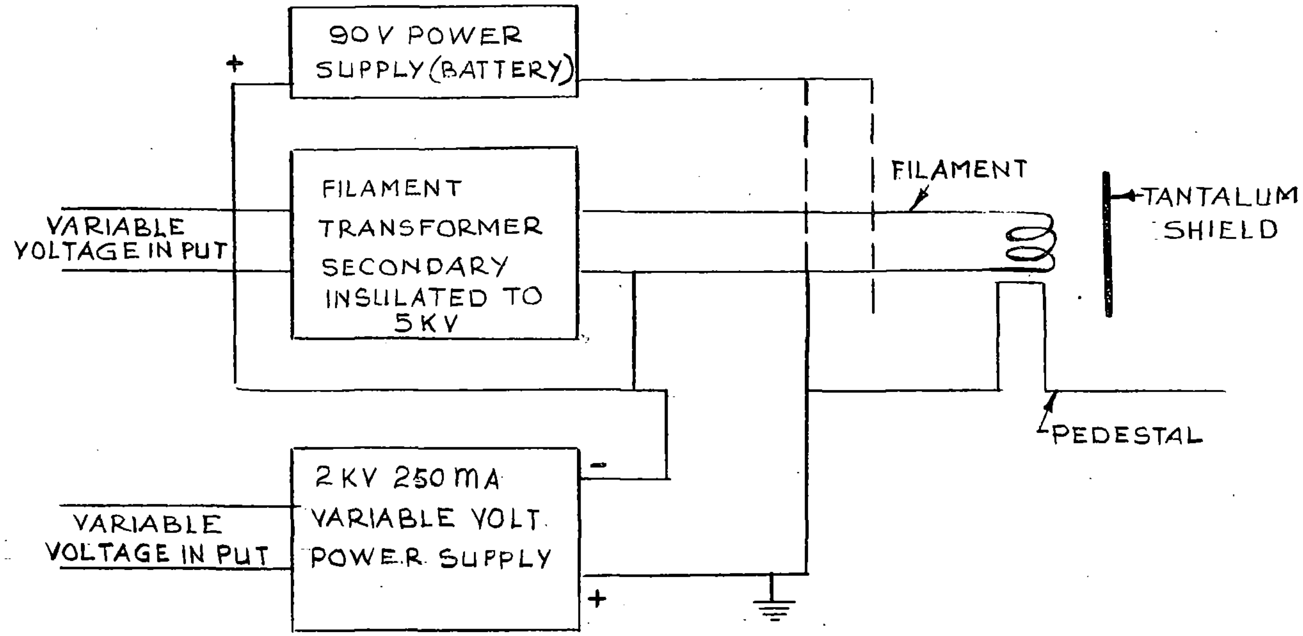

90 V POWER SUPPLY (BATTERY)
+
FILAMENT TRANSFORMER SECONDARY INSULATED TO 5 KV
VARIABLE VOLTAGE IN PUT
FILAMENT
TANTALUM SHIELD
PEDESTAL
2 KV 250 mA VARIABLE VOLT POWER SUPPLY
-
+
VARIABLE VOLTAGE IN PUT

FIG-25

separated isotopes were collected on Aluminium foils, but it was not possible to assess the enrichment and the quantity collected. During the latter half of the year, separation of Zinc isotopes was tried by vapourising zinc granules in the ion source chamber. Recently a gold foil with ^{24}Mg deposition on it was prepared.

<u>Reference:</u>

(1) Van de Graaff Laboratory Progress Report, A.S. Divatia, AEET/NP/8

6. <u>Twenty Channel Pulse Height Analyser</u> - Joseph John, P.C. Mitra and S.G. Shukla - A twenty channel Gatti type pulse height analyser has been built and tested. This has been used for experiments with the Van de Graaff Accelerator.

7. <u>A Counter for Fast Neutron Dosimetry</u> - K.B.S.Murthy, G. Muthukrishnan and C.M. Sunta - A fast neutron counter has been developed (1) such that its energy response varies inversely as the current values of maximum permissible flux of fast neutrons of energies upto 14 MeV.

<u>Reference:</u>

(1) K.B.S.Murthy, G.Muthukrishnan and C.M.Sunta AEET/HP/D-1 (1964)

LIBRARY

The Physics and Mathematics Section of the A.E.E.T. Library is located in the Van de Graaff Laboratory. The library has been re-organised during the year and a few shelves added to accommodate a number of volumes received. The library provides facility for inter-library loans.

Books and Periodicals - The library has a collection of 2104 books including 360 received during this period and 1362 bound volumes of periodicals.

About 40 journals are regularly sent to the Scientific Information Officer, Atomic Energy Establishment Trombay for abstracting.

Indian Nuclear Data Group - All INDSWG and I.A.E.A. publications are catalogued and kept in the library. A list of these are sent to various laboratories and Scientific institutions from time to time. These publications can be borrowed through the Van de Graaff Library.

Catalogue - A catalogue of periodicals held in Van de Graaff Library, has been compiled which is a valuable reference manual.

Photo copies - A dark room facility with an enlarger is now available in the building. The gadget for making photo copies is under fabrication. It will be possible to supply photo copies when this work is completed.