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Physics-General

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INFORMATION DIVISION
Radiation Laboratory
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Berkeley, California

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I GENERAL PHYSICS RESEARCH

1. Cloud Chamber Program

Evans Hayward

The Charged Particles Emitted by Carbon When Irradiated by 90 Mev Neutrons

Origin of the Experimental Idea. Secondary charged particles from nuclei bombarded by 90 Mev neutrons were examined in a series of preliminary experiments by Herbert York. He measured the range at various scattering angles from the beam direction, using a telescope of three proportional counters. His preliminary results indicated that if the particles were all protons, the energy distribution in the forward direction showed a broad maximum at about 40-50 Mev, and the angular distribution fell off with angle approximately exponentially with a half width of about 25 degrees. This result was difficult to reconcile with the ideas of a semi-transparent nucleus which seemed to indicate that a forward peak of protons with an energy of about 80 Mev was to be expected. Further, the relatively low energy maximum of the observed protons was difficult to reconcile with the pronounced foward angular peak. It was expected theoretically that large energy loss would be associated with several collisions of the emitted particle in the nucleus and a resulting more nearly isotropic angular distribution.

When these preliminary results of H. York were announced, it occurred to W. M. Powell and the cloud chamber group that data were already available from which a qualitative check of York's observations could be made. Several thousand cloud chamber pictures had previously been taken in which the 90 Mev neutron beam passed through a 16-inch cloud chamber filled with H_2 and water vapor, producing proton recoils in the gas. The beam entered the chamber through a 5 mil aluminum window produing several secondary particles from the aluminum in each picture. Such recoil particles which traversed the chamber were measured for their curvature in the 14,000 gauss magnetic field of the chamber. The analysis of 200 tracks showed the presence of about 40 particles which were of such high $H\rho$ (corresponding to about 140 Mev protons) that comparison with the known neutron energy distribution showed they were very probably not protons. An immediate inference was that these particles were deuterons of about 70 Mev.

This surprising result, together with York's original preliminary work, has led to an experiment designed to identify more certainly the secondary particles from carbon and to study their energy and angular distributions.

Experimental Set-up. A 22-inch Wilson cloud chamber with a magnetic field of 21,700 gauss was used. (Fig. 1) The high magnetic field intensity made possible the more accurate measurement of the radii of curvature of the high energy particles. The neutron beam collimated to 1/2" x 1/2" was passed along a diameter of the chamber through a 1/8" carbon target and through a 3/4" x 7/8" hole in the 1/8" thick glass absorbing plate. A small fraction of the secondary particles from the carbon target struck the glass absorber. The lighted region permitted the measurement of particles which struck the glass absorber along a strip 9" x 1.1". The target and absorber were positioned so that the recoil particles could be definitely identified as coming from the carbon target, and so that an accurate measurement could be made of the curvatures before and after the particles passed through the glass absorber. Estimates of the accuracy of measurement of a single curvature, including errors due to turbulence in the cloud chamber, indicated a probable error of about $\pm$ 3 percent.

The quantities measured were the curvature of the recoil particle before and after entering the absorber, the beam angle β between the beam direction and the horizontal projection of the tangent to the track at its origin, and the vertical and horizontal position of the track on the absorbing plate. From the vertical position on the plate, the dip angle α of the track could be calculated with an accuracy of $\pm$ 2 degrees, which was sufficient for the purposes of the experiment. From the two angles α and β the scattering angle θ could be calculated by

$$\theta = \cos^{-1} \cos \alpha \cos \beta$$

Analysis. A charged particle passing through an absorbing plate loses energy at a rate which depends, for a given initial $H\rho$, on the mass and charge of the particle. However, particles which stop cannot be identified, and if the change in curvature is small, different particles cannot be distinguished. A preliminary experiment with a 1/4 inch glass absorber showed that particles with an $H\rho > 1.48 \times 10^6$ gauss cm were all deuterons and tritons, but low energy particles could not be identified since they stopped in the absorber. Therefore, an absorber (1/8") was used which made possible the identification of the highest energy protons expected and which extended the lower energy limit at which particles could be identified. A plot of the change in curvature in a 21,700 gauss field versus the initial curvature for H^1, H^2, H^3 is given in Fig. 2.

Because of the experimental arrangement, geometrical corrections to the data must be made. The 3/4" wide by 7/8" deep gap in the glass absorber which passed the neutron beam also passed a sizeable fraction of the recoil particles. Geometrical corrections for this were calculated, allowing for the finite neutron beam size and the uncertainty in measurement of the position of the track on the plate. These turned out to be rather large and the uncertainty in the correcting factors was felt to be sizeable. As a check, the data were carefully examined to identify the particles which passed through the hole. The fraction of these which had too high $H\rho$ to be protons were identified as deuterons. The relative number of tritons included by this method of identification is small; less than 15 percent. The remaining particles were then divided into protons and deuterons in the ratio observed for identified particles.

The results of this method of correction were then found to agree, within the statistical error, with the results obtained using the calculated geometrical weighting factors. The former method was used in the final analysis since it was felt that the errors were smaller, particularly for the particles of high $H\rho$ where the corrections turned out to be most important.

An additional correction was made for the finite length of the absorber. The values of angle and curvature were determined experimentally for which the particles missed the plate. The result of this was that for certain angle vs. curvature groups, only part of the tracks were measured. The corresponding corrections apply to groups where the intensity is very low, so that the uncertainty in these corrections does not appreciably affect the data. Data were excluded for which this correction is greater than 100 percent.

The solid angle subtended by the absorbing plate for an angle vs. curvature group depends on the vertical extent of the absorber and the distance along the track to the absorber. The vertical extent of 1.1 inches of the absorber was experimentally determined so that only a few percent of the observed tracks could be lost from the lighted region by scattering in the absorber. The arc length ℓ_s of the tracks was calculated as a function of curvature and angle. The area ΔA subtended on the absorbing

plate for a given angular interval was also calculated as a function of the arc length ℓ_s. The solid angle subtended by an angle vs curvature group is then approximately

$$\Delta \Omega = \frac{\Delta A \cos \overline{\theta}}{\ell_s^2}$$

where $\overline{\theta}$ is the angle at the center of the angular interval. Using these values, the data can be reduced to intensity per unit solid angle. The corrections are less than 20 percent.

The target (1/8" thick) did not affect the energy distributions appreciably except at the lower energy ends. If it is assumed that the variation in intensity vs. range is linear over the energy intervals used, the correction is approximately

$$I'(E') = \frac{E'}{E} I(E)$$

where I(E) is the intensity per unit energy interval observed and E' is the energy ocrresponding to the tracks which started at the center of the absorber. This correction is less than 25 percent for all energy groups and less than 10 percent for energies above 50 Mev.

Results. 386 recoil particles were measured and identified as 202 protons, 162 deuterons, and 22 tritons. Of the deuterons, 57 stopped in the glass absorber and could only be identified as non-protons. However, the number of particles other than deuterons included in this group can be estimated from the data and is probably less than 20 percent. The data was corrected for the geometrical factors discussed above. The protons include energies from 32 to 107 Mev; the deuterons, energies from 25 to 124 Mev; the tritons, energies from 56 to 95 Mev. The angles measured were from 0 to 36 degrees.

The energy and angular distributions of the protons are given in Figs. 3 and 4. There is no energy peak near the 90 Mev of the indicent neutrons. The angular distribution of the higher energy protons (57-107 Mev) is peaked forward, that of the lower energy protons (32-57 Mev) is isotropic within the statistical errors.

The energy and angular distribution of the deuterons are given in Figs. 5 and 6. The deuterons in the forward direction from 0 to 12° show a pronounced high energy peak at about 70 Mev. This is in close agreement with the 72 Mev expected from simple energy consideration and the masses of the carbon and residual boron nuclei. This energy peak disappears at wider angles. The angular distribution of the high energy deuterons (60-120 Mev) is strongly peaked forward with a half-width of less than 15 degrees. The lower energy deuterons (30-60) are still peaked forward but with a considerably greater angular half width.

Auxiliary Experiment. The high energy deuteron peak at about 70 Mev, although apparently statistically significant, was further checked to verify its existence. Other data were available in which a thicker glass absorber was used, making it impossible to distinguish low energy protons and deuterons. In this experiment the tracks showed slight turbulence. However, because of the high $H\rho$ values of the high energy deuterons, it was sufficient to measure curvatures only and obtain an intensity vs curvature distribution. A definite high $H\rho$ peak was again obtained (Fig. 7) confirming the presence of the group of high energy deuterons. The angular distribution of these particles is given in Fig. 8.

Cross-sections. It is possible to estimate the cross section for these phenomena. From other work in the cloud chamber, it was found that in carbon and oxygen stars, 12 ± 3 percent gave particles which would have been included in this analysis. Theoretical and experimental work indicate that the cross-section for star formation is about 1/3 of the total carbon cross-section, and can be taken as .20 ± .05 barns. Using these two results, the cross section for the production of the particles observed in this experiment is

$$\sigma \sim 24 \pm 12 \text{ millibarns.}$$

From this, the following cross-sections can be calculated

	Protons	
0-12°	3.7 ± 1.8 mb	32-107 Mev
13-24°	7.6 ± 3.8 mb	32-107 Mev

	Deuterons	
0-12°	2.9 ± 1.5 mb	25-124 Mev
13-24	4.9 ± 2.2 mb	25-124 Mev

Observation of Mesons.

Immediately following the proton coversion several very rough experiments were performed to find out how we could best use the neutron beam to make cloud chamber observations of mesons. A neutron beam is produced when the 350 Mev circulating proton beam strikes a two-inch copper target. The energy spectrum of the neutrons has not yet been measured, but we assume that the beam contains neutrons up to the full energy of the protons.

Several hundred examples of meson tracks in the cloud chamber have been observed. They have been identified on the basis of their curvatures and ionization in comparison with the protons in the same pictures. The background is very bad. In fact, though six meson tracks have been observed that end in the gas, with one exception the background obscures the end of the track. This one example shows a negative meson being captured by a nucleus, presumably an argon nucleus. Fig. 9.

One example of a π-μ decay has also been observed. A 28 Mev π-meson decays in flight into a 23 Mev μ-meson. The μ-meson has an energy of 3.8 Mev in the center of mass system which is in good agreement with the results of Lattes and Gardner.

Some rather rough measurements have been made of the curvatures of the mesons from a thick target. Fig. 10 shows the energy distribution obtained on the assumption that they are all π-mesons. This distribution is of interest because it gives an idea of the energies of the mesons that are readily available for future experiments.

Cloud Chamber Observations with the Synchrotron.

When the synchrotron began operating, the cloud chamber Helmholtz coils were put in the beam. It was found that the cloud chamber magnet interfered with the operation of the synchrotron to such an extent that it could not be used in the synchrotron building. Some cloud chamber pictures were taken without a magnetic field. These show multiplicative showers due to the incidence of the γ-ray beam on a series of lead plates.

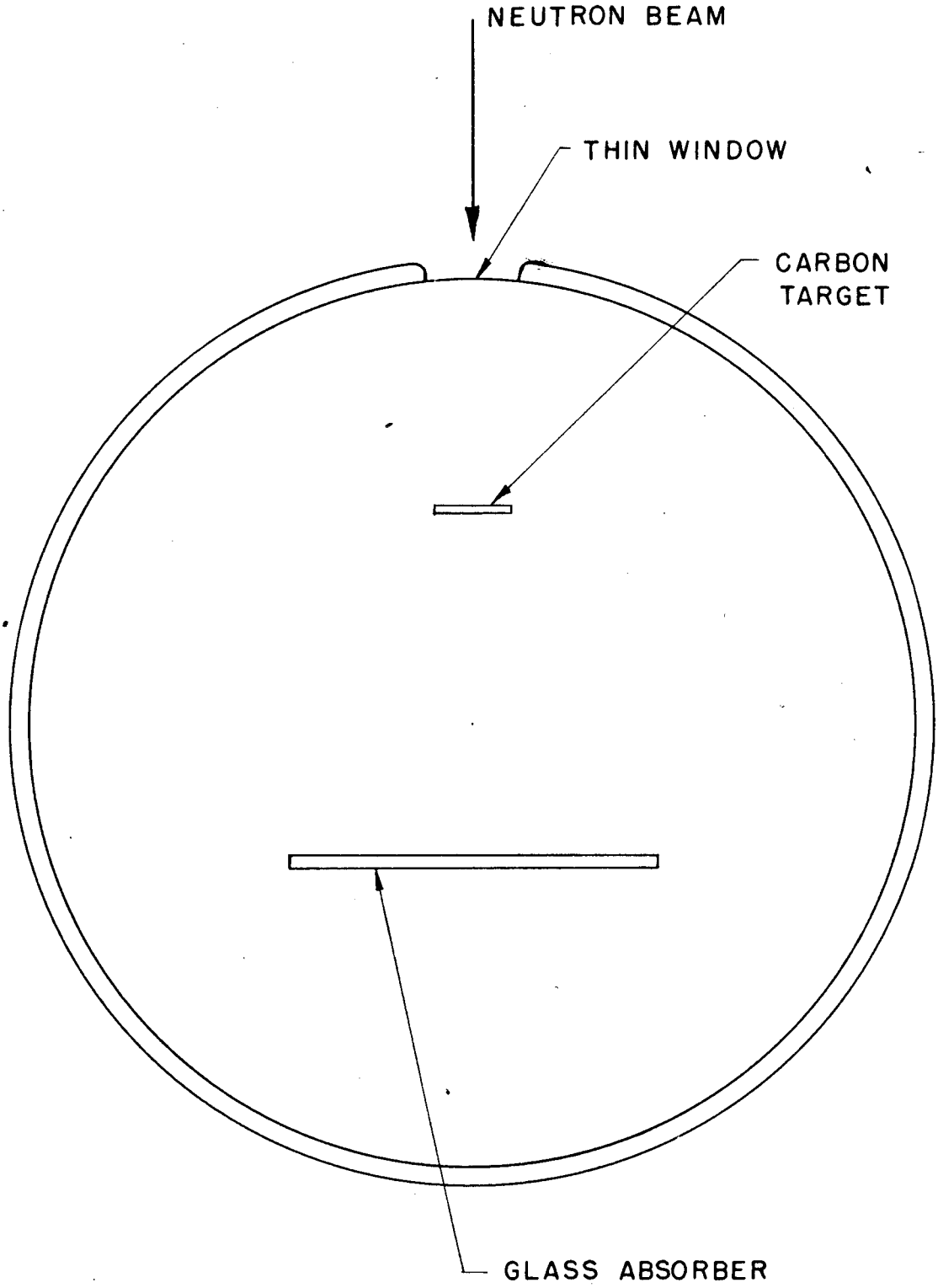


FIG. 1

13102-1

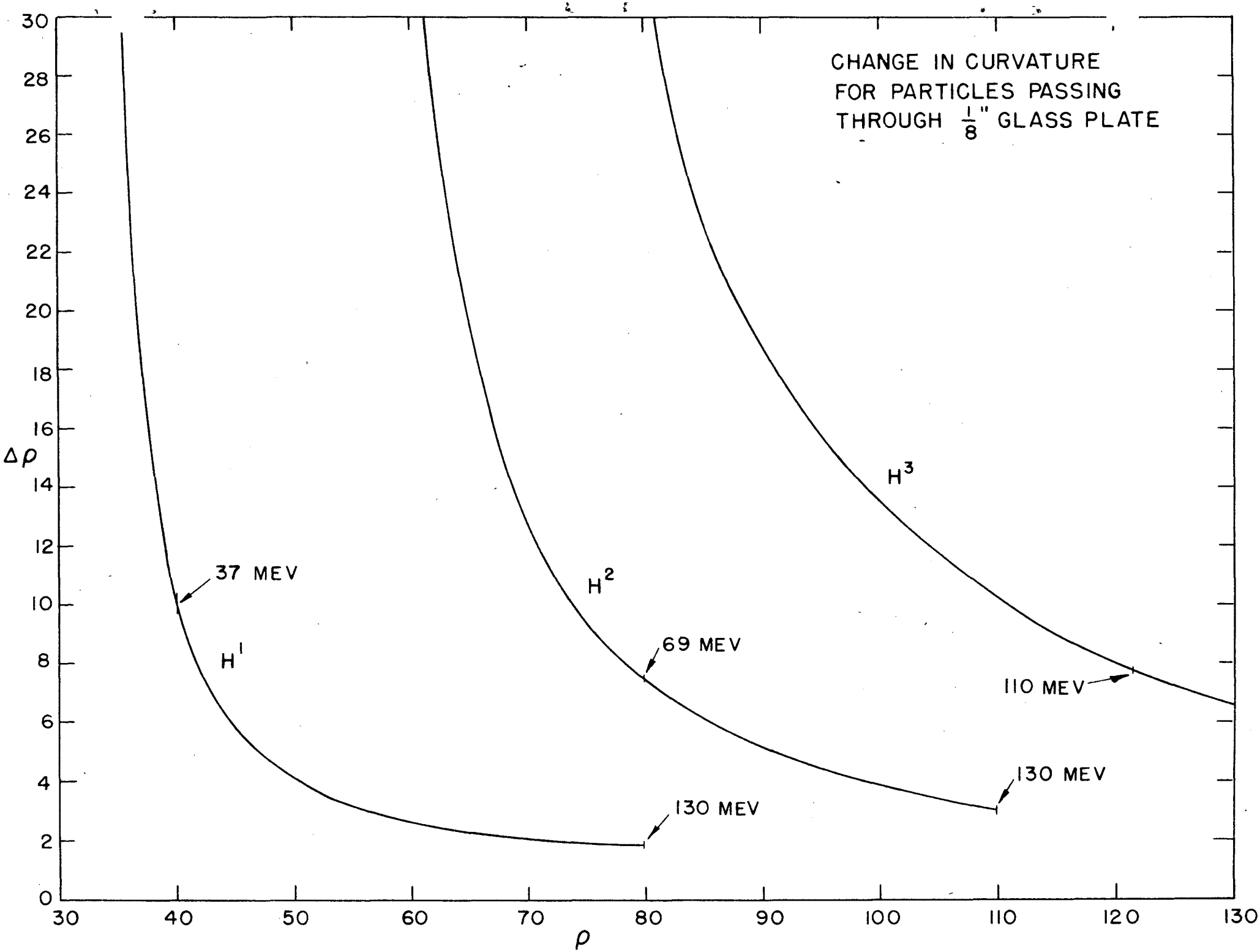

CHANGE IN CURVATURE
FOR PARTICLES PASSING
THROUGH 1/8" GLASS PLATE
H1
H2
H3
37 MEV
69 MEV
110 MEV
130 MEV
130 MEV
Δρ
ρ
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
30
40
50
60
70
80
90
100
110
120
130

FIG. 2

13324-

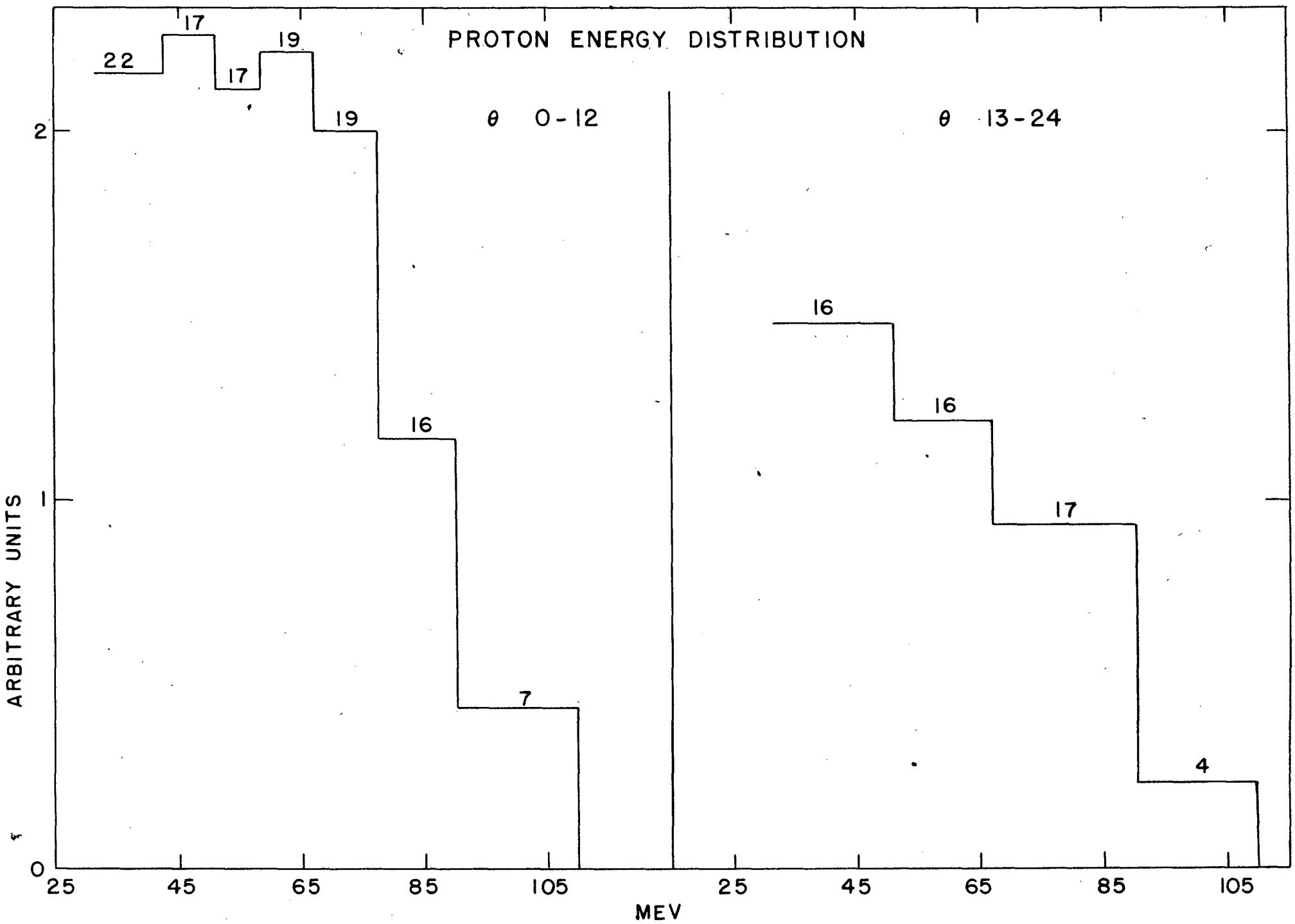

PROTON ENERGY DISTRIBUTION
θ 0-12
θ 13-24
22
17
17
19
19
16
7
16
16
17
4
ARBITRARY UNITS
0
1
2
25
45
65
85
105
25
45
65
85
105
MEV

FIG. 3

13364-1

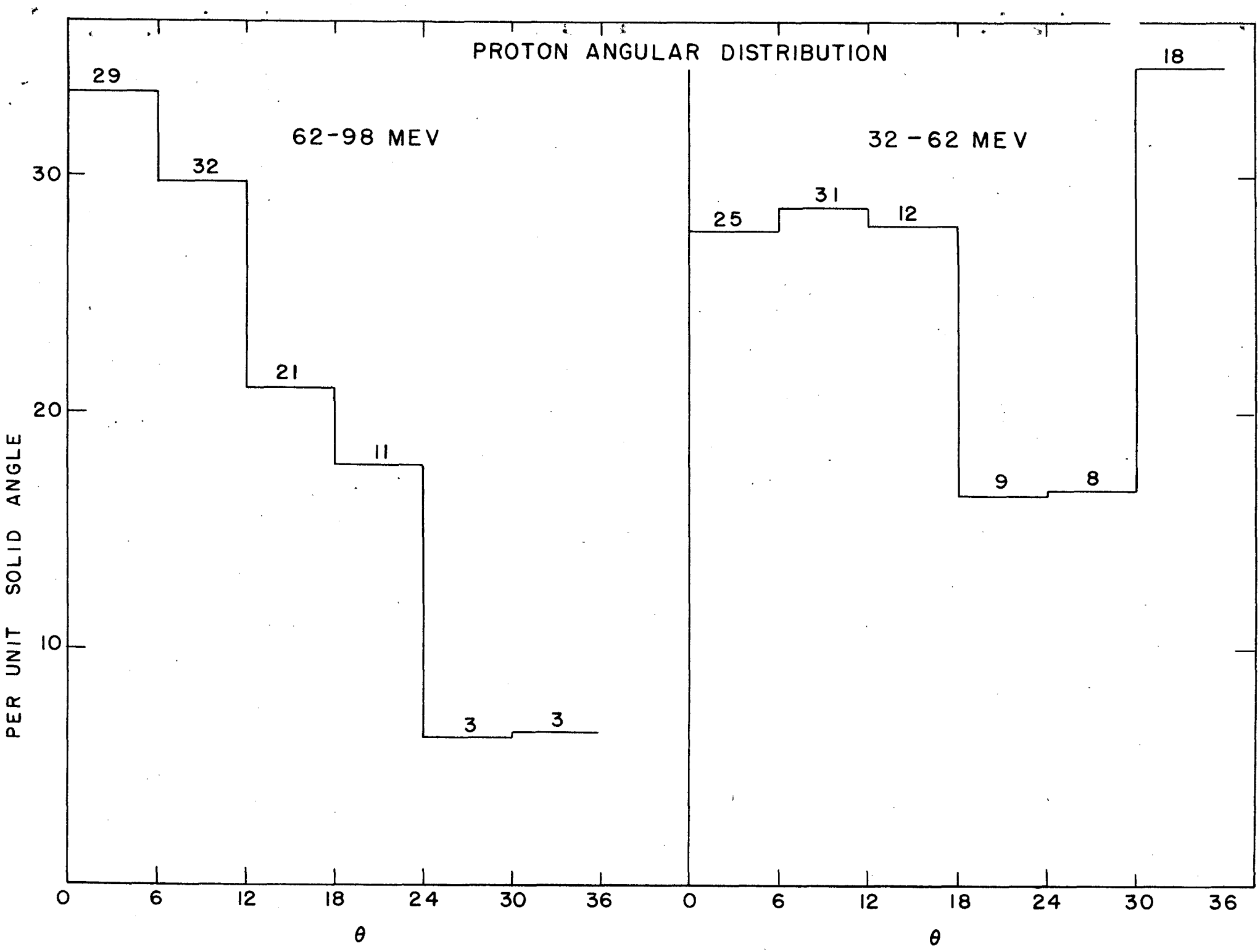

PROTON ANGULAR DISTRIBUTION
62-98 MEV
32 - 62 MEV
PER UNIT SOLID ANGLE
30
20
10
29
32
21
11
3
3
25
31
12
9
8
18
0
6
12
18
24
30
36
θ

FIG. 4

13328

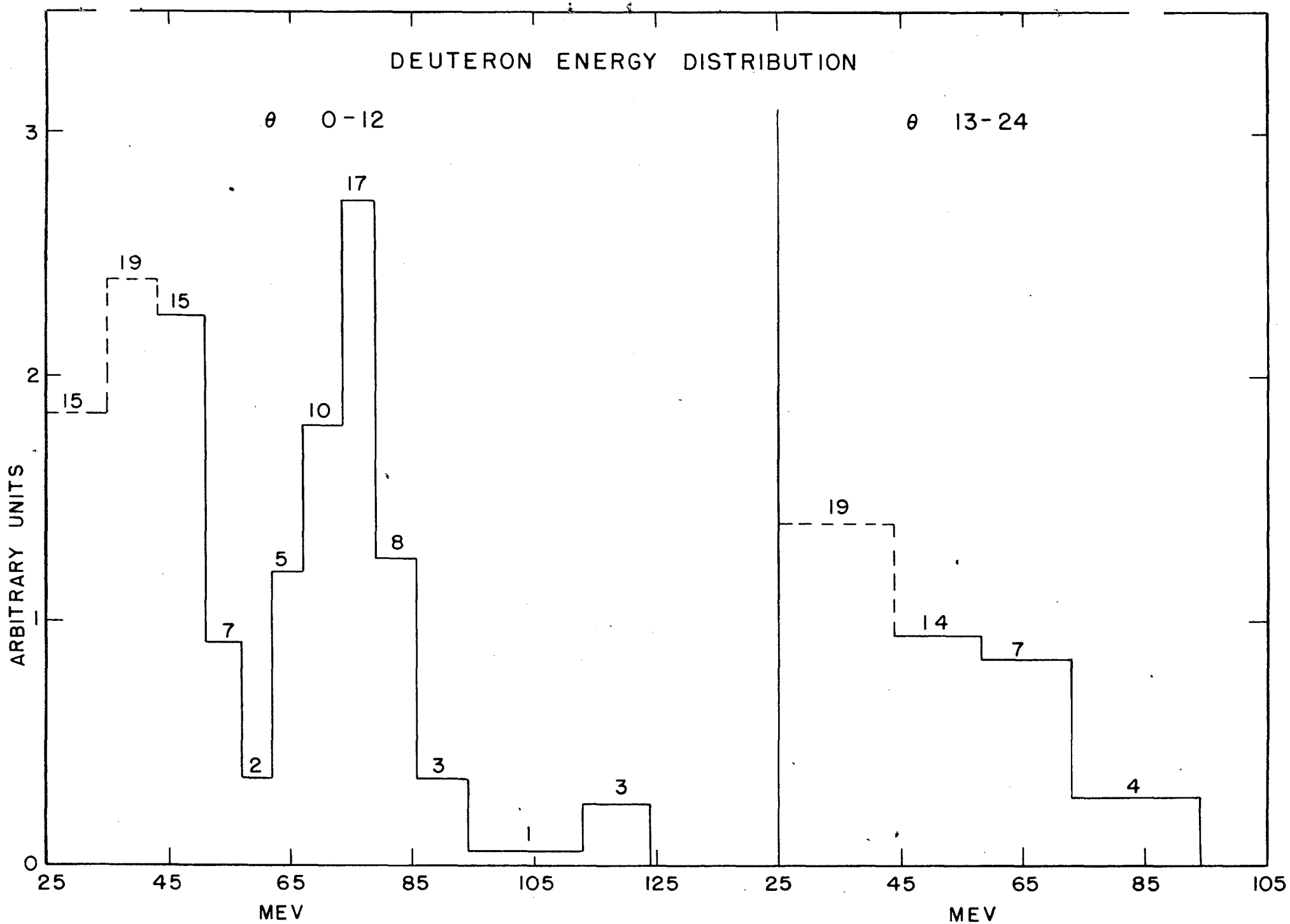

DEUTERON ENERGY DISTRIBUTION
θ 0-12
θ 13-24
ARBITRARY UNITS
0
1
2
3
15
19
15
7
2
5
10
17
8
3
1
3
19
14
7
4
25
45
65
85
105
125
25
45
65
85
105
MEV
MEV

FIG. 5

13326

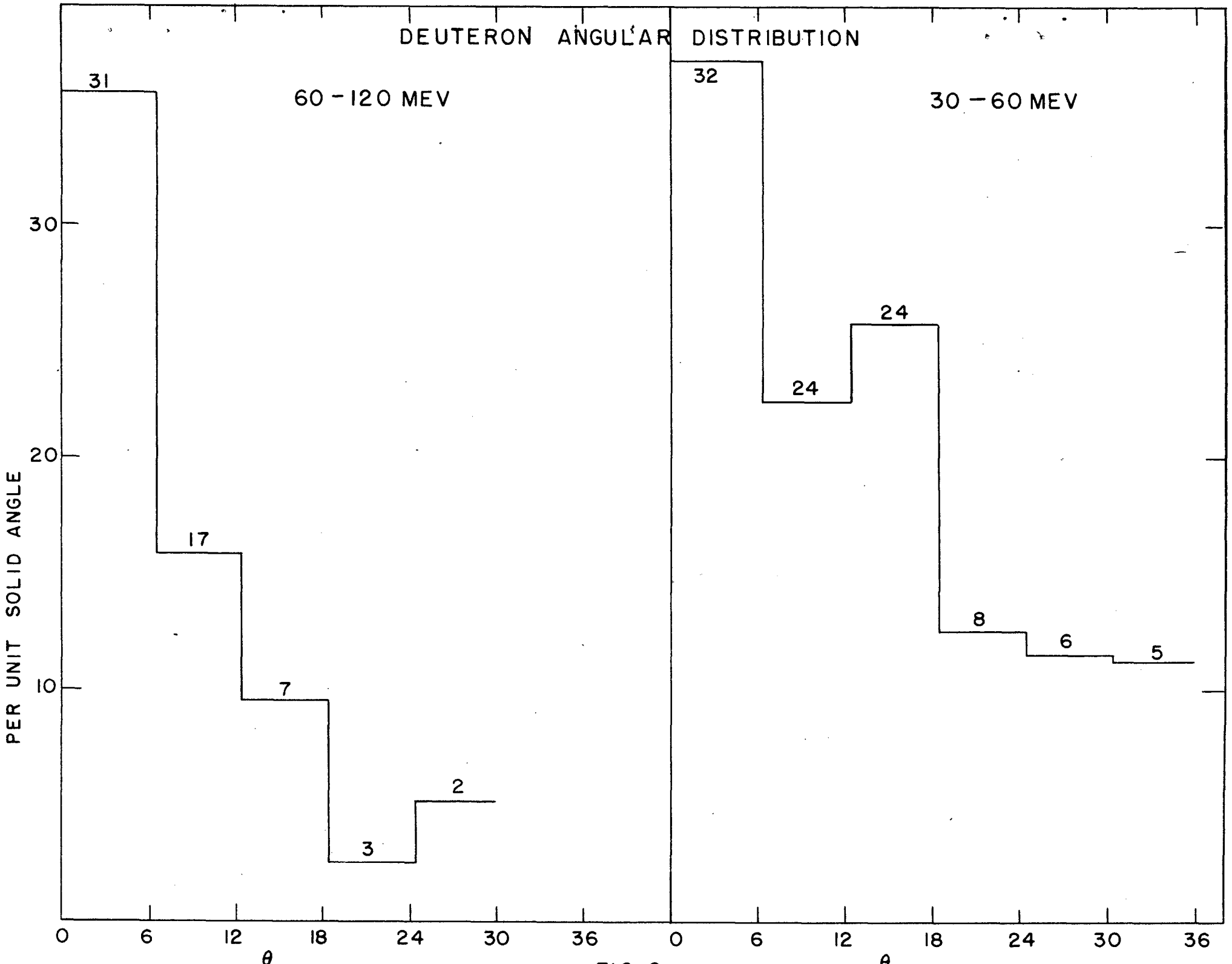

DEUTERON ANGULAR DISTRIBUTION
60 - 120 MEV
30 - 60 MEV
PER UNIT SOLID ANGLE
30
20
10
31
17
7
3
2
32
24
24
8
6
5
0
6
12
18
24
30
36
θ
0
6
12
18
24
30
36
θ

FIG. 6

13327-

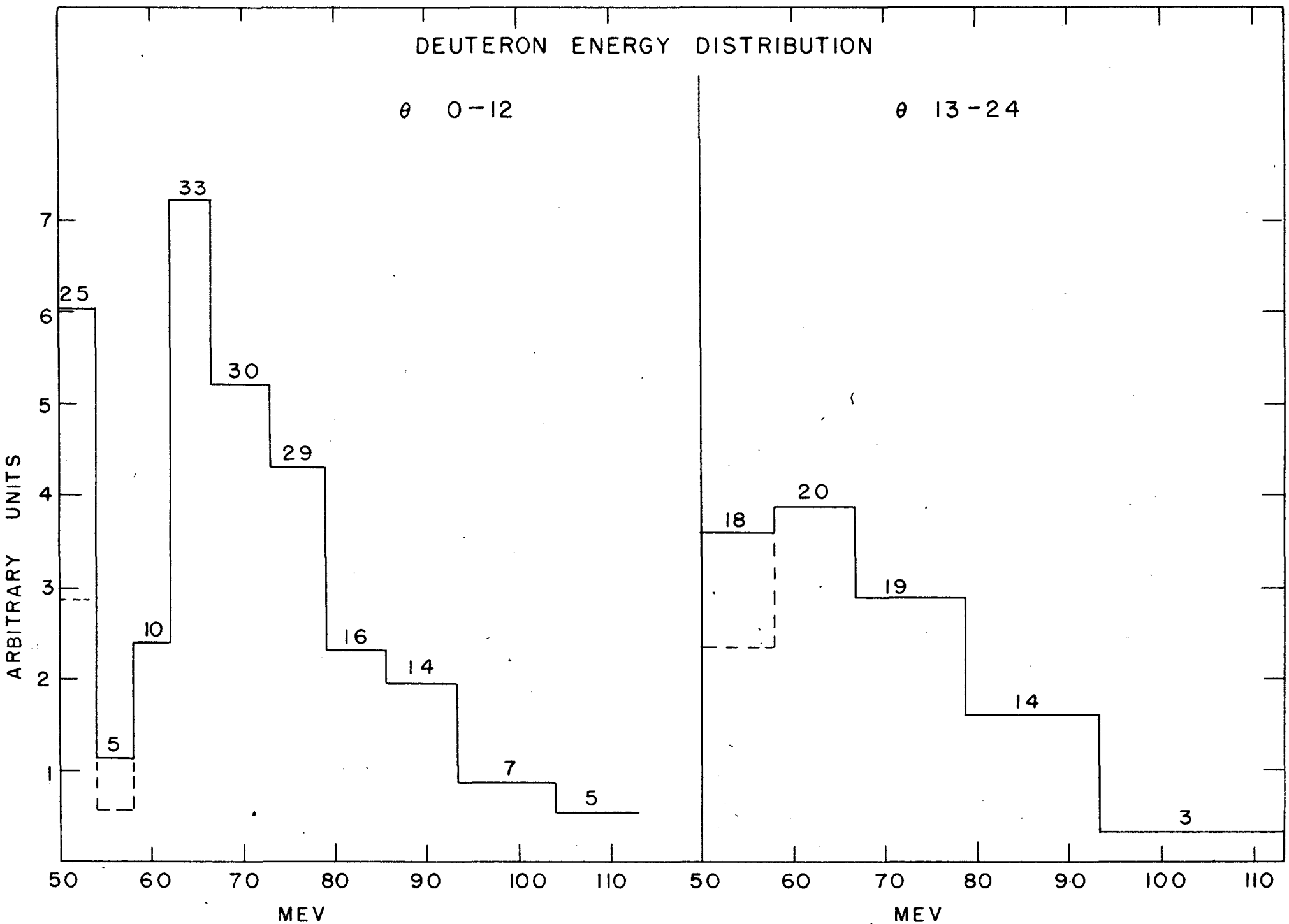

DEUTERON ENERGY DISTRIBUTION
θ 0-12
θ 13-24
ARBITRARY UNITS
1
2
3
4
5
6
7
25
5
10
33
30
29
16
14
7
5
18
20
19
14
3
50
60
70
80
90
100
110
MEV
MEV

FIG. 7

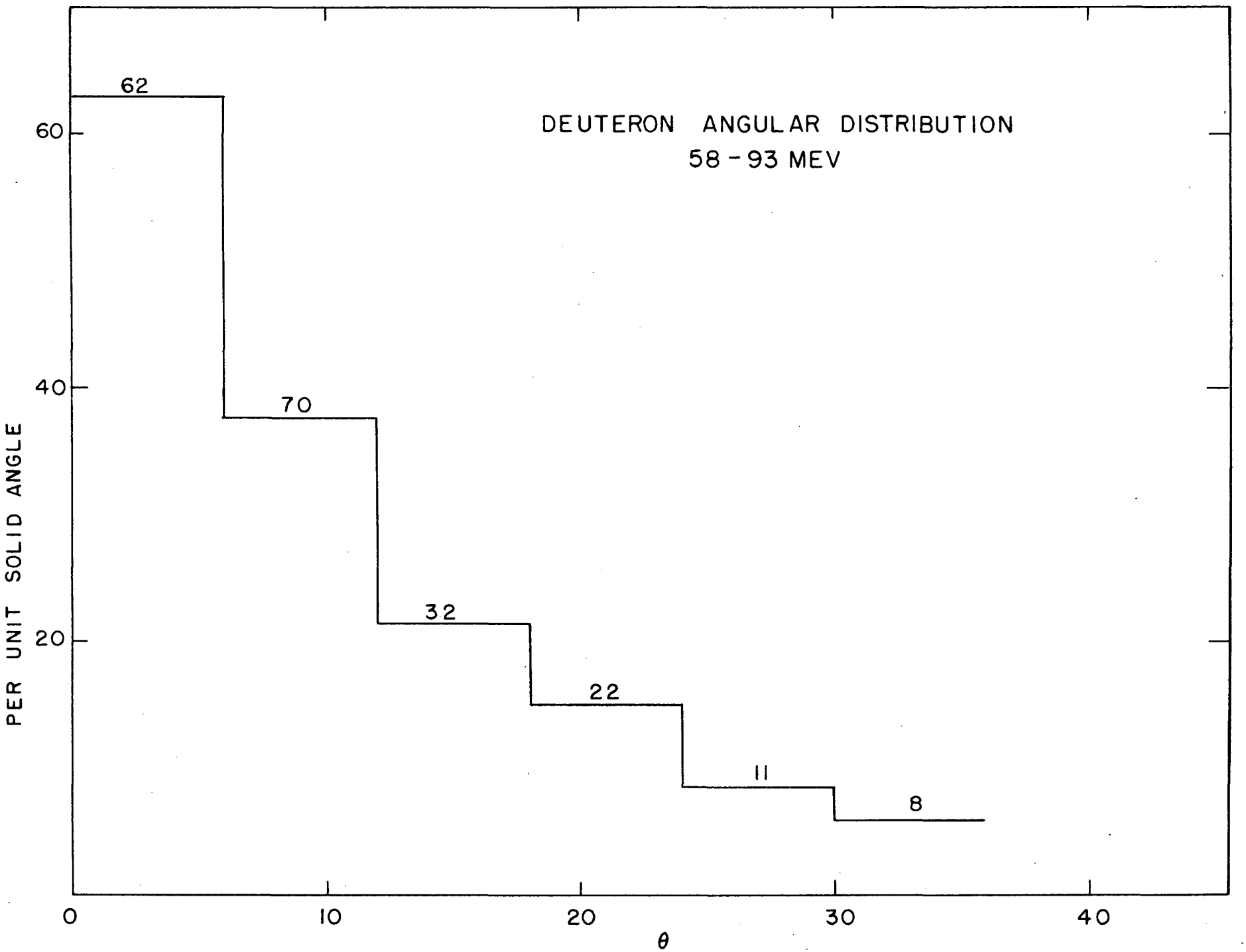

DEUTERON ANGULAR DISTRIBUTION
58 - 93 MEV
PER UNIT SOLID ANGLE
60
40
20
0
10
20
30
40
θ
62
70
32
22
11
8

FIG. 8

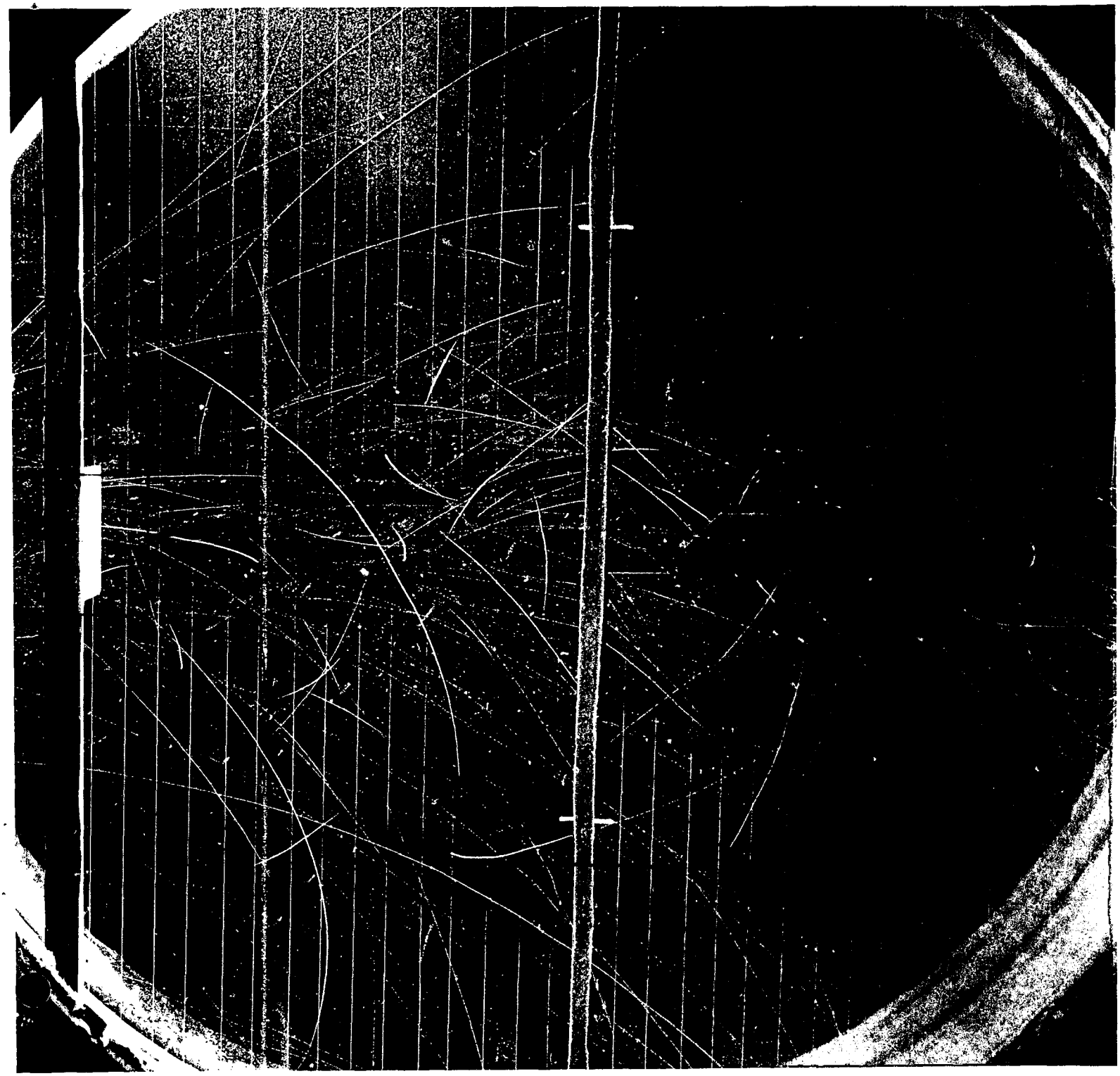


FIG. 9

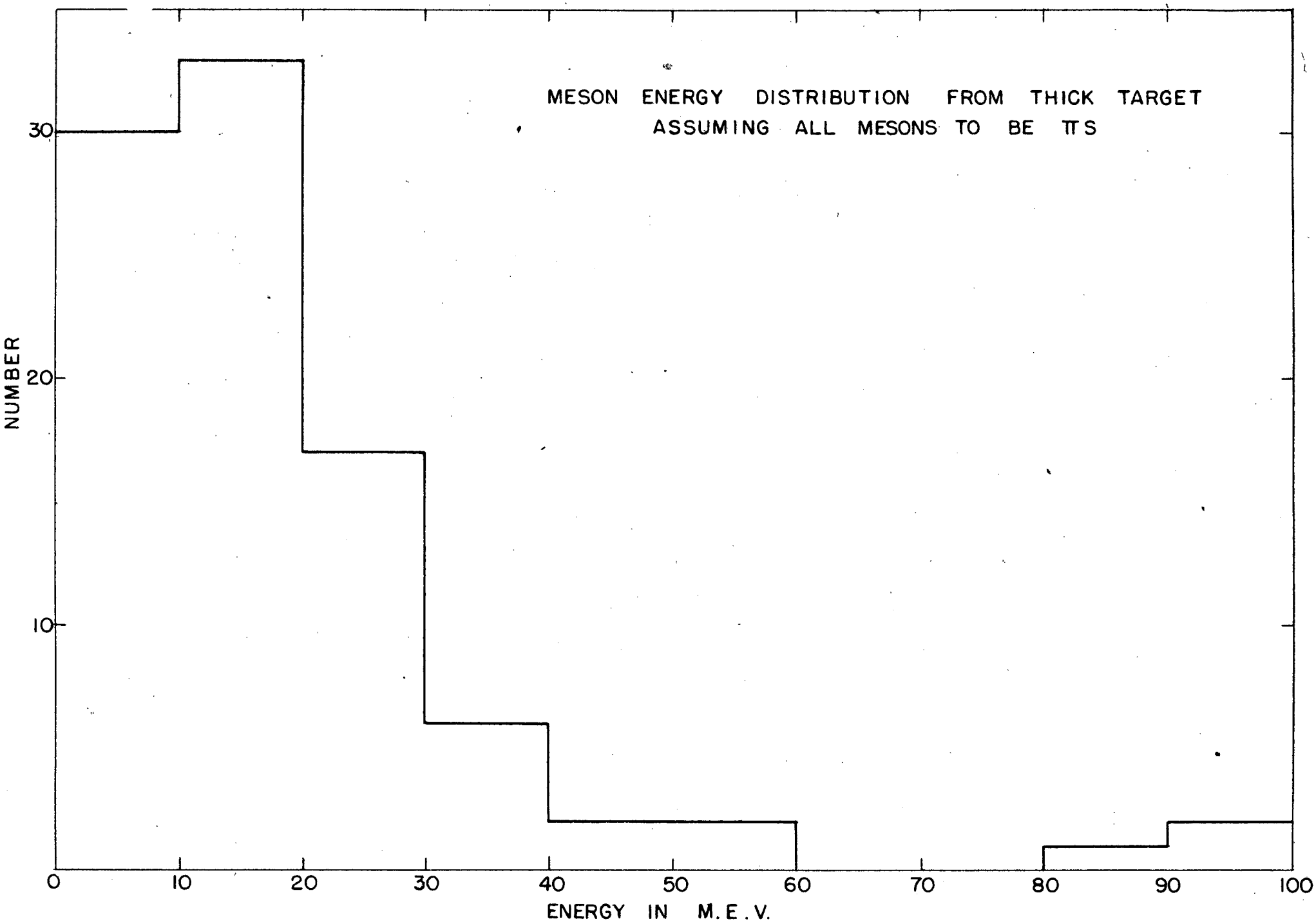


FIG. 10

13422-1

2. Film Program

Stanley B. Jones, R. S. White

Meson Excitation Function.

A study has been made of the excitation function for negative mesons produced in the 184-inch Berkeley cyclotron. The mesons are formed by a beam of alpha particles striking a 1/16 inch carbon target. Ilford C.2 plates of emulsion thickness 50 microns were used as detectors. The position of the plates is such that about 50 percent of the mesons they intercept are of 2-5 Mev, and the rest are of higher energy.

We obtained various bombarding beam energies by varying the distance of the target and plate holder from the center of the magnet. The numbers of mesons counted are shown in Table I. Column 1 gives the energy of the bombarding alpha-particles; column 2, the numbers of mesons actually counted; and column 3, the numbers of mesons relative to the number at 380 Mev, corrected for beam currents, emulsion thickness, and area scanned.

Table I

Number of Mesons as a Function of Alpha-Particle Energy

Beam Energy (Mev)	Number of Mesons	Corrected Relative Yield
380	339	100 percent
342	164	33 percent
304	38	7.4 percent
266	7	0.7 percent

Meson Energy Distribution.

The energy distribution of negative π mesons has been measured by exposing plates at various distances from the target. Experimental conditions were similar to those described in connection with the excitation function measurement except that for this measurement only star-forming mesons were counted. The quantity desired is $\frac{\Delta N}{\Delta E}$ as a function of energy for one selected angular range. The data presented are for the angular range 0°-30°, where angles are measured from the beam direction.

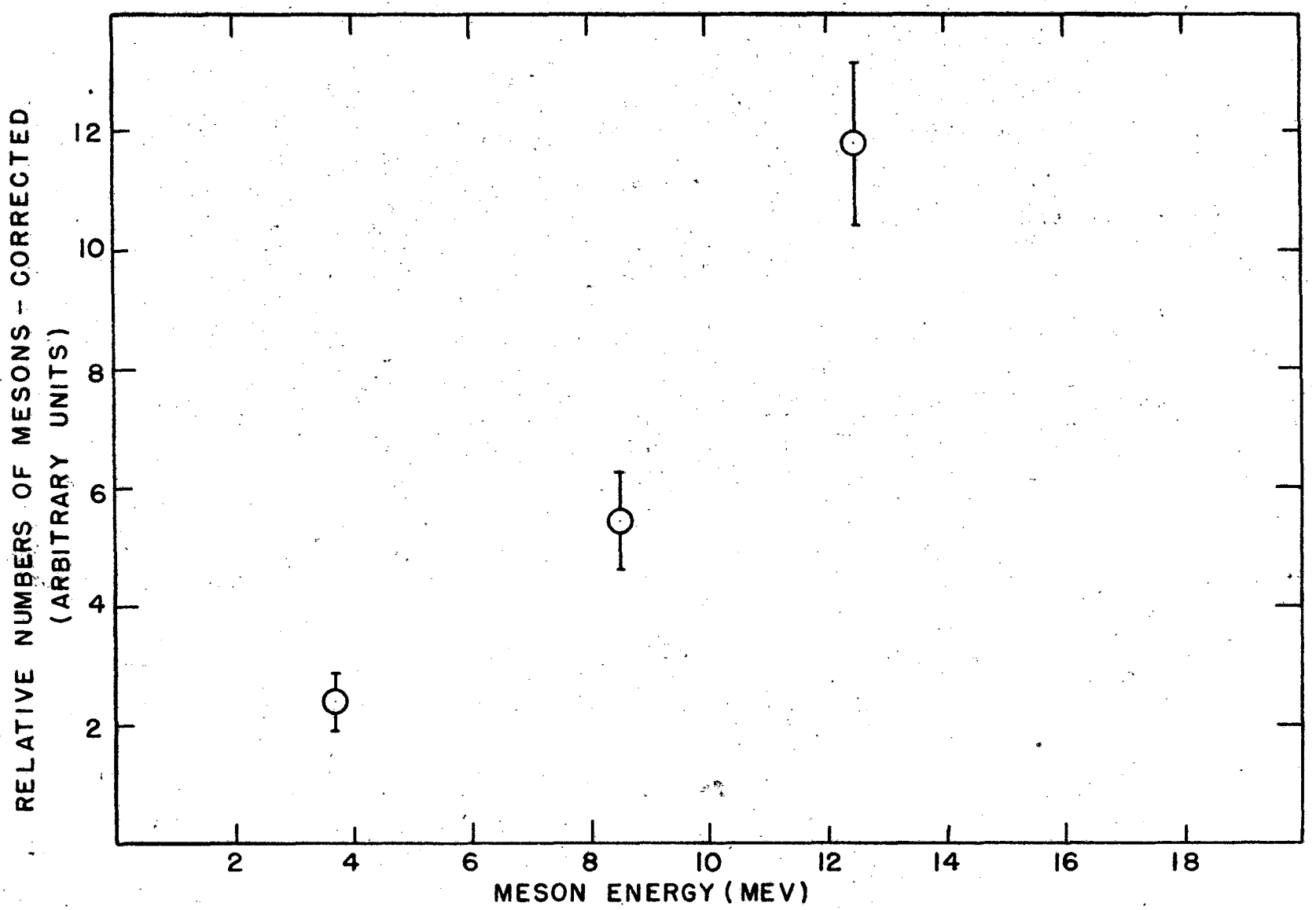
Four sets of photographic plates were exposed simultaneously. Their positions with respect to the target are shown in Table II. Also shown in this table are numbers of mesons actually counted. These numbers do not necessarily correspond to the same plate areas. The energy of the alpha-particle beam was 380 Mev.

Table II

Numbers of Mesons Counted in Plates Exposed in Various Positions

Position Number	Approximate Distance from Target	Number of Mesons Counted
1	1-4 inches	23
2	4-7 inches	169
3	7-10 inches	226
4	10-13 inches	261

In order to find the numbers of mesons in the various energy ranges, a graphical analysis was made which showed the meson energies and trajectory angles corresponding to various points on the plates. The graphical solution made use of the detailed variation of the magnetic field in the plane of the beam, and a correction was made for vertical focussing. A correction was also made for relative emulsion thickness. Fig. 1 shows corrected values of $\frac{\Delta N}{\Delta E}$ for plates in positions 2, 3 and 4. The angular range included is 0°-30°.



ENERGY DISTRIBUTION OF NEGATIVE π MESONS
(VERTICAL LINES SHOW STANDARD STATISTICAL DEVIATION)

FIG. 1

13494-1

3. High Energy γ Rays from the Cyclotron Target

B. J. Moyer and H. F. York

The photon character of the radiation under study in these experiments is indicated by measurements of attenuation in Pb and Al. Results were:

	30 Mev		78 Mev	
	Pb	Al	Pb	Al
Measured (barns)	27	-	31	0.98
$\sigma_{pp} + \sigma_{compt.}$ from Heitler	29	-	35	1.05

Removal of the Ta radiator foil causes the coincidence counts to disappear, as does also absorber placed in either the positron or negatron trajectories.

Experimental evaluations have been made for the corrections due to scattering in the radiator and in the counter windows.

When the target (2" Be) is bombarded with 175 Mev protons (instead of 350 Mev), the photon yield is decreased by two orders of magnitude and the energy distribution is similar to that obtained with 180 Mev deuterons. This yield and distribution is consistent with a bremsstrahlung origin.

With 350 Mev protons, after corrections have been applied for scattering of the pair particles as mentioned above, the energy distribution demonstrates a maximum intensity at about 70 Mev when the target is viewed from 180° with respect to the proton beam. This maximum position is shifted upward in energy to above 100 Mev when the target is viewed with a 0° direction. Such a shift is not incompatible with a Doppler shift for photons originating in a proton-nucleon encounter.

The yield of photons integrated over the energy range of observation (30-105 Mev) is about 10^9 per second for a 1/2 μa proton beam on a 2" Be target. This assumes spherical symmetry in their emission. The integrated cross section for their production is:

$$\int_{30}^{105} \sigma\ (E)\ dE = 7 \times 10^{-28}\ cm^2 Mev$$

per Be nucleus. This is more than an order of magnitude greater than the estimated bremsstrahlung yield integrated over the same energies.

Experiments are being devised to determine whether these photons are emitted singly, or in pairs as they would be if due to the decay of a neutral meson.

4. 90 Mev Neutron Differential Scattering Cross Sections

A. Bratenahl, R. Hildebrand, C. Leith, B. J. Moyer

Although the proton conversion program on the 184 inch cyclotron temporarily interrupted experimental work on this program in November, analysis of the data taken to date was continued and a comparison made with the new semi-transparent model of the nucleus (sphere with index of refraction and mean free path deduced from total cross section data) very recently worked out by Fernbach, Taylor and Serber of the Theoretical Group. The differential scattering cross section per unit, solid angle deduced for this semi-transparent model for Pb, Cu and Al is in considerably better agreement with the measured differential cross section than that deduced from an opaque sphere model. However, the forward scattering is some 10 percent higher and the half width somewhat narrower than that predicted by the theory. Integrals of these differential scattering cross sections are in reasonable agreement with data out to largest angles determined about 30°

	Experiment	Theory
Pb	2.67 ± .13	2.43
Cu	1.22 ± .07	1.37
Al	.65 ± .05	.71

These scattering cross sections should be increased by about 10 percent due to elastic scattering into angles greater than 30° as estimated from the behaviour of the theoretical functions.

5. Theoretical Physics

Robert Serber

On a model which takes into account collisions between nucleons in the nucleus and itself gives higher momenta than the Fermi-Thomas model, it is possible to explain the deuteron production under neutron bombardment in terms of the picking up of a proton by the passing neutron.

Approximation methods have been developed for scattering calculations which can be used, for example, for n-p scattering below 30 Mev or for p-p scattering at high or low energy. A paper on this subject has been sent to the Physical Review. The 90 Mev n-p scattering calculations have been completed, and a paper is being written on the results. The p-p scattering calculations await the experimental results. In the meantime relativistic effects are being investigated. The total scattering cross section measurements have been explained in terms of a mean free path of 5×10^{-13} cm for 110 Mev neutrons in the nucleus (a value deduced from the n-p scattering cross section) and a nuclear radius $R = 1.4A^{1/3} \times 10^{-13}$ cm. An explanation of the scattering cross sections of 90 Mev neutrons has been completed. A theory that fits the data can be obtained by assuming a neutron potential energy in the nucleus of 30 Mev and a mean free path in nuclear matter between 3 and 5×10^{-13} cm. A paper on this subject has also been sent to the Physical Review.

The meson production by 350 Mev protons is being calculated. Estimates are also being made of the x-ray production of mesons.

The x-ray production to be expected from high energy protons due to nuclear encounters has been determined. Both ordinary bremsstrahlung and the radiation due to the magnetic moments was taken into account. The bremsstrahlung due to the proton and neutron magnetic moments has been estimated and is thought to be the origin of x-rays which have been observed. The expected radiation is an order of magnitude smaller than that found by Moyer and York.

Various bevatron problems are being investigated such as the requirements for bevatron injection and the effects of resonances in the dynamics of particles in the bevatron.

A paper on the operation of the cyclotron has been completed.

7. Proton-Proton Scattering

B. Cork, C. Richman, L. Johnston, F. Fillmore and W. Panofsky

The main work of the linear accelerator has been on the problem of proton-proton scattering, both with counters and with photographic plates. The statistical errors of the counting technique are now less than 1 percent and the checks on absolute cross section from day to day agree within 2 percent. Most of the effort now is consumed in detection and elimination of systematic errors. The Theoretical Group is working on an explanation of the shape of the scattering curve, but so far there are no definite results. The general shape of the curve is quite different from that which had been predicted from work at lower energies, and it is highly probable that some new and interesting information will come from an interpretation of the results. The photographic method and the counter method agree within the statistical errors of the experiment at the larger scattering angles, but they are outside the statistical fluctuations at the smallest angle of about 15° in the laboratory system. However, only two reliable runs on the photographic method are involved in this discrepancy.

8. Inelastic Scattering

E. Martinelli, A. Silverman and C. Levinthal

The energy spectrum of inelastically scattered protons from carbon, from $0 \rightarrow 32$ Mev, has been obtained. The levels reported previously, with a 16.3 Mev bombardment energy, and a group which seems to correspond to deuterons going to the ground state of C^{11} appear. The extreme low energy end of the spectrum is not resolved into levels and seems to increase more rapidly towards low energy than any statistical theory would predict.

Several good exposures have now been obtained for aluminum, gold, and indium. It is hoped that some correlation with statistical theory will be possible in the heavier elements.

9. Short Half-Life Investigations

L. Alvarez

The work on N^{12} has been completed and the paper sent to the Physical Review. N^{12} has a half life of 12.5 milliseconds, and an upper limit for the positrons of 16.6 Mev. It is produced in a proton-neutron reaction on C^{12}. It is the shortest lived beta radioactivity known, and has the highest energy electronic radiation.

The neutron half-life experiment is progressing, and preliminary results should be available in a few months. The equipment has been altered so that the detector is now an anthracene crystal, instead of a proportional counter. All parts of the equipment have been tested individually.

10. Beryllium^7

C. Turner

The branching ratio of Be^7 is being measured by a new technique. The problem is to determine the number of Be^7's giving neutrinos to the ground state of Li^7 relative to the number going via the 480 KV level in Li^7. Since the gamma rays have energies almost equal to those of annihilation quanta, the gamma ray strength of a Be^7 sample is compared with that of a C^{11} sample in identical geometry. The C^{11} and Be^7 samples are made by bombardment with protons from the Van de Graaff generator at energies just above the proton-neutron threshold. Relative numbers of active atoms are measured by a manganese bath technique so that no aboslute numbers must be determined. The overall determination should be good to better than 5 percent error in the branching ratio. Preliminary runs have been made with the apparatus, and the final results should be available in a month or so.

11. Electron Multiplier

D. Cone

An electron multiplier using the thin beryllium foils originally prepared for the linear accelerator is under construction. The multiplier action involves the transmission of the electrons, rather than their "reflection". The great advantages of this new technique are twofold: (1) The multiplier will operate in a strong magnetic field, and (2) The time resolution should be very much higher than with a conventional multiplier, since all electrons experience identical fields, and therefore have reproducible velocities in passing through the system.

12. Scattering and other Studies

E. Segrè, E. Kelly, J. Jungerman, M. Weissbluth

Neutron-Proton Scattering.

With the increase in energy of the cyclotron it has become necessary to modify the technique of this experiment. To this effect a 10 channel pulse analyzer of a model used at Los Alamos has been built by C. Wiegand and is being tested at present. It will be used in such a way that one will measure specific ionization and range, or specific ionization and $H\rho$ of scattered particles from which their energy and mass may be obtained. The instrument should be very useful for a number of experiments.

Preliminary runs on n-p scattering have been made with the old technique, for the angular distribution and using crystal counters for the total n-p cross section: At about 275 Mev Leith and Wouters report 0.03 ± 0.005 barns for the total cross section.

Excitation Function of α,2n on Bismuth.

The paper on the excitation functions of Bi with α and d has been sent to the Physical Review.

In the meantime the α excitation curve for the α,2n process has been extended to 380 Mev with the following result:

Mean Alpha Energy in Mev	388	300	220	138	99
Cross Section in Barns	1.2×10^{-4}	2.0×10^{-4}	4.3×10^{-4}	1.3×10^{-3}	3.6×10^{-3}

The cross sections here reported are to be understood as upper limits because they may be due to secondary alphas porduced in stars.

A reexamination of the deuteron bombardment results 3 years after the bombardment showed an irregularity in the excitation curve, visible only after the decay of Po^{210}, which was ascribed to a long life alpha emitter Po^{209} heretofore unknown. This was confirmed by an investigation with the 48 channels pulse analyzer of A.Ghiorso. The α particles of Po^{209} have an energy of 4.9 Mev. An estimated decay constant for α emission corresponds to a half life of about 250 years.

Ionization Chamber for use in Fission Studies.

In order to study further fission cross sections and the fission process at high energy it is desirable to have an ionization chamber which can count fission pulses while a beam of charged particles passes through the chamber even if the beam is modulated as the cyclotron beam is.

At C. Wiegand's suggestion a differential chamber has been built which eliminates a major portion of the pulse produced by the deuteron beam. A brief survey of the background pulses was made with no fissionable material in the chamber for several deuteron energies. This showed that it should be possible to measure a fission excitation function in the high energy deuteron beam.

On the basis of these results a differential ionization chamber was designed that could select six different samples by remote control. In addition provision was made for Frisch grids, also in a differential arrangment, with the hope that fission pulse heights could be determined when the fissions were produced by a charged particle beam.

Experiments are in progress with this chamber using the 60 inch cyclotron. A measurement of fission excitation functions produced by both α-particles and deuterons is being attempted with uranium and thorium targets.

Lead Bombardments.

Chemically pure lead of normal isotopic constitution was bombarded with α-particles of 22 and 33 Mev. A proportional counter containing methane at one atmosphere was used to detect the presence of any activities emitting heavily ionizing particles, almost certainly α-particles. Activities having the half-lives of 0.6 sec., 27 sec., 450 sec were found. An absorber equivalent to about 10 cm of air was sufficient to absorb all radiations. An estimate of the relative cross-sections at the higher energy gives

$$\sigma_{0.6_s} : \sigma_{27_s} : \sigma_{450_s} = 100 : 2.5 : 0.15$$

The energy, chemical identification, and excitation function of these substances as well as formation by cross bombardments are under investigation. The interpretation of these activities is not yet clear. The most natural seems to be that they are due to isomers of known Po isotopes, but this meets with some difficulties.

II ACCELERATOR OPERATION AND DEVELOPMENT

1. 184-inch Cyclotron

James Vale

Proton Conversion Unit.

The majority of the time during this period was devoted to the installation, testing and preliminary operation of the new unit for the acceleration of protons to an energy of 350 Mev. These items were accomplished on schedule and successful operation was under way during the last month.

Some of the major steps for the installation of the unit are shown in sequence in the following photographs:

Fig. 1. The roof blocks and one corner of the concrete shielding, partically disassembled.

Fig. 2. The extra section of track in place, preparatory to rolling back the old unit on its truck.

Fig. 3. The old unit rolled back.

Fig. 4. Lifting the proton conversion unit, to be placed on the track near the 184 inch cyclotron tank.

Fig. 5. New unit in place.

Fig. 6. The proton conversion unit in place and the concrete shielding partially back in place.

Fig. 7. One thickness of wall blocks and roof blocks of the concrete shielding essentially in place.

A proton beam of 300 Mev was first obtained on December 22, 1948 and the full energy protons of 350 Mev were obtained shortly thereafter by means of the reconnection of the lower magnet coils.

Many jobs that could not be done previously because of the operation of the cyclotron were completed during this period.

Dummy Dee.

A new dummy dee system shown in Figs. 8, 9 and 10 was installed during this time to replace the old temporary one that had been in use since the 184-inch cyclotron was first put in operation. In addition to having more rigidity and smoother surfaces, thus lessening the effects of electrical discharges in operation, the new lower dummy dee has a section that can be removed by sliding it out of one of the tank ports. This minimizes exposure of personnel to radioactivity if it ever becomes necessary to remove it from the tank after it has become active.

It was found necessary to dispense with this sliding section on the upper dummy dee in order to install a reentrant tube used previously as a "proton" tube but which is now planned for use as a "meson" tube.

Upper Pole Piece Oil Band.

The pole pieces of the 184-inch cyclotron magnet are made up of slabs of steel bolted together. During the early stages of operation of the machine, an oil leak developed which allowed the magnet cooling oil from the upper tank to seep into the vacuum system through the cracks between these slabs. Since this seepage of magnet oil into the vacuum system was undesirable, it was decided to seal up these openings by means of a welded steel band of one-quarter inch thickness all around the upper pole piece. Fig. 10 shows this band after its installation. The lower pole piece was left as it was. The performance of the vacuum system after the proton conversion unit was put into operation indicates that the oil band has essentially stopped the oil seepage.

Roof Block Support on Magnet.

The roof blocks of the concrete shielding are supported on one end by the concrete wall blocks and on the other end by a ledge welded to the magnet. (See Fig.1) This ledge was designed to support one layer of roof blocks. When a second layer of blocks became necessary, this ledge had to be strengthened. This strengthening was accomplished by means of "I" beams across the top of the magnet and large steel bolts going from these beams down to the ledge. See Figs. 5, 6, and 7. This job was started sometime ago, but was completed during this shutdown.

Dee Side Shields.

In the old unit, the dee side shields were bolted to the top and bottom pole piece copper liners. Their function was to enclose the dee and thus complete the grounded portion of the transmission line of which the dee is a part. Since the mouth of the dee is larger than its throat, the dee could not be removed from the tank without first removing these side shields. A design has been worked out previous to the proton conversion to eliminate this difficulty and was installed on the proton unit. In this scheme, the side shields are carried by the main face plate and thus both the dee and the dee side shields are removed together. Electrical contact to the upper and lower pole piece liners is made through a series of flexible phosphor-bronze fingers mounted on the shields. See Fig. 4.

Magnet Coil Terminal Box.

A new terminal box was installed on the lower magnet coil tank. This eliminated the junction box, on the bottom of the coil tank, which presented a fire hazard because of the presence of cooling oil in the terminal box. This oil entered the terminal box by means of seepage past the various gaskets used to seal the micarta plate through which the electrical connections entered the coil tank. In addition to eliminating this fire hazard, the connections to the various sections of the lower coil are now far more accessible.

Magnet Coil Tank Drain Lines.

Consistent with the policy of eliminating fire hazards, a fast oil draining system was installed. The upper and lower coil tanks are now connected through

appropriate valves to a ten thousand gallon oil resorvoir located on the side of the hill below the cyclotron building. In case of an emergency, the oil can be drained from the coil tanks in about five minutes.

Permanent Steel Platforms.

Advantage was taken of the shut down time for the proton conversion to complete the installation of the steel platforms. These replaced the temporary sections supported by wooden cribbing. The steel platforms will support loads up to thirty tons on each section and will thus facilitate experiments involving heavy deflecting magnets and the 30 ton concrete "igloo" which is normally on the platform.

Water Regulators.

A water regulator was installed in the pump room to take care of the cooling for the mechanical pumps. This facilitates turning pumps on and off by keeping the water pressure constant when the water lines are turned on or off and thus not disturbing the pumps that may be running.

An additional regulator was also installed on the east yoke of the magnet to protect the deflector pulse transformers from excessive pressure and to stabilize the flow through the probe, thus minimizing trouble with the probe water flow switch interlock.

Dee and Rotor Support Capacitors.

The bottom supporting rods, for the rotor and dee, are terminated electrically by an inductance and a capacitor. The capacitors pass about 150-200 amperes at the dee frequency. Various types of commercial capacitors were tried, with no success because of their large inherent losses. A capacitor was developed that so far shows promise of giving very little trouble. The construction is very simple, consisting of two plates of copper separated by a mica sheet and bonded together with Apiezon W wax to eliminate air bubbles and thus to get rid of corona which ultimately destroys the capacitor. This assembly is clamped between two water cooled plates to keep the wax cool and thus to prevent it from flowing out of the capacitor.

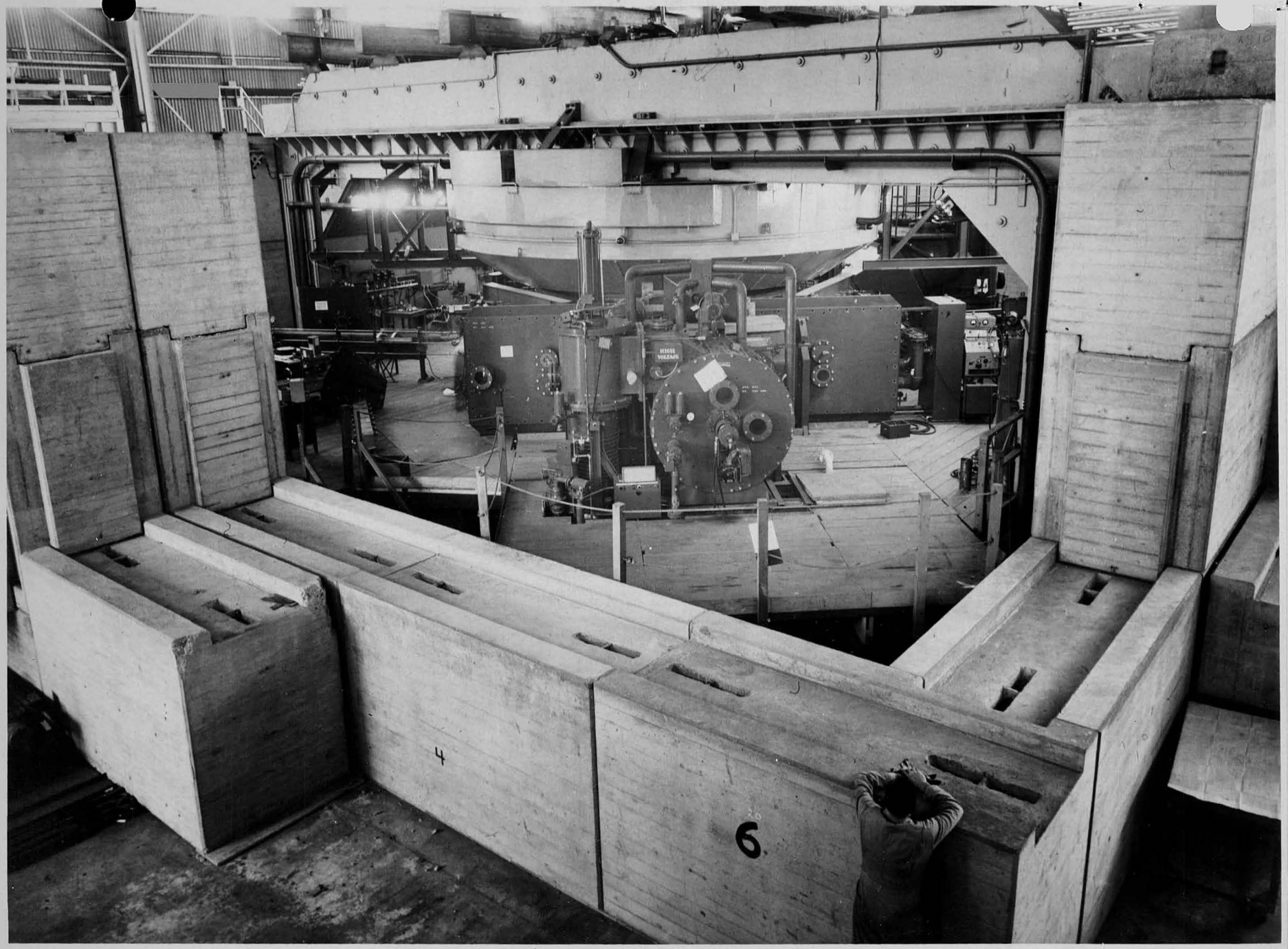


FIG. 1

OZ 379

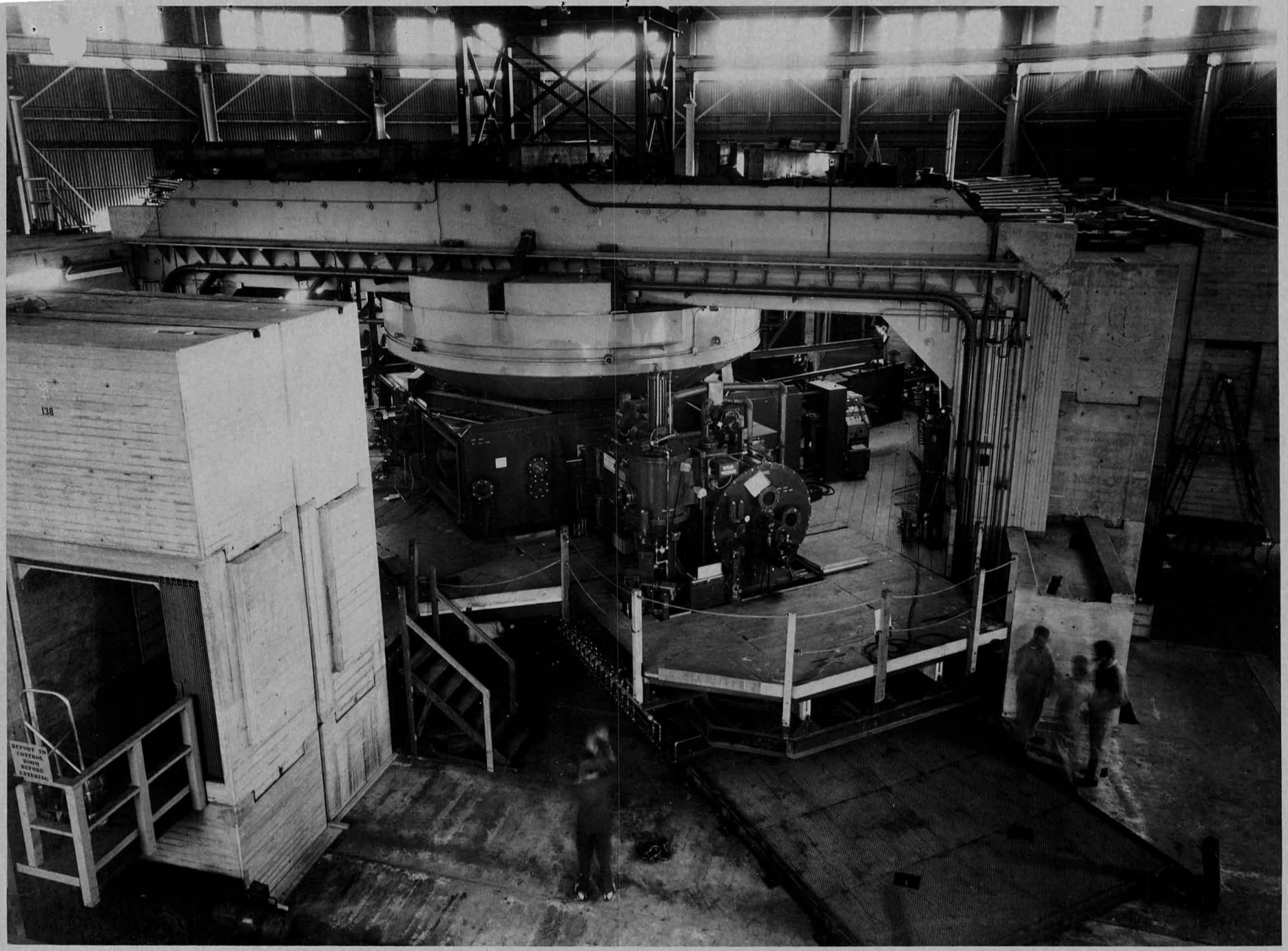


FIG. 2

OZ 376

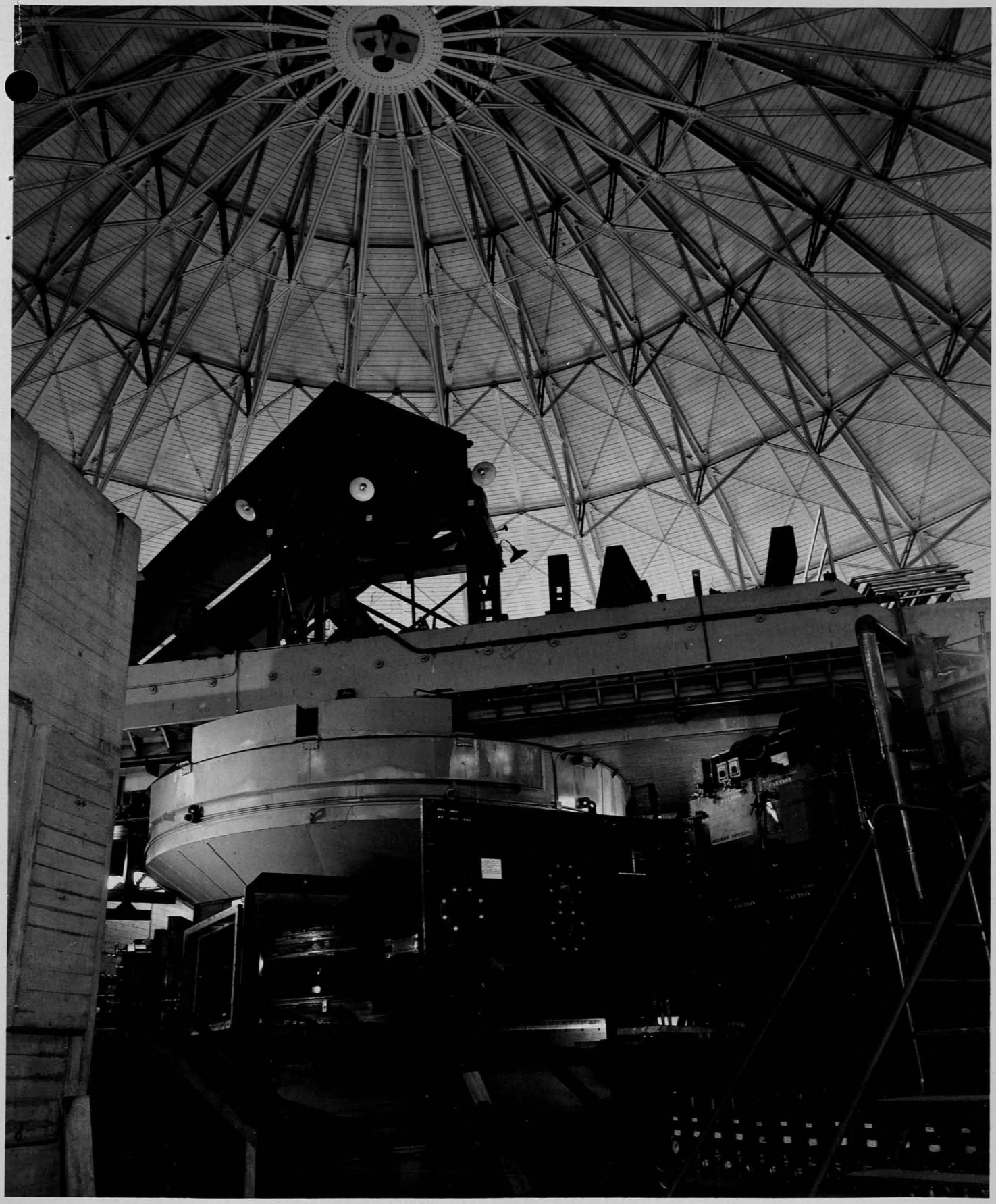


FIG. 3

OZ 378

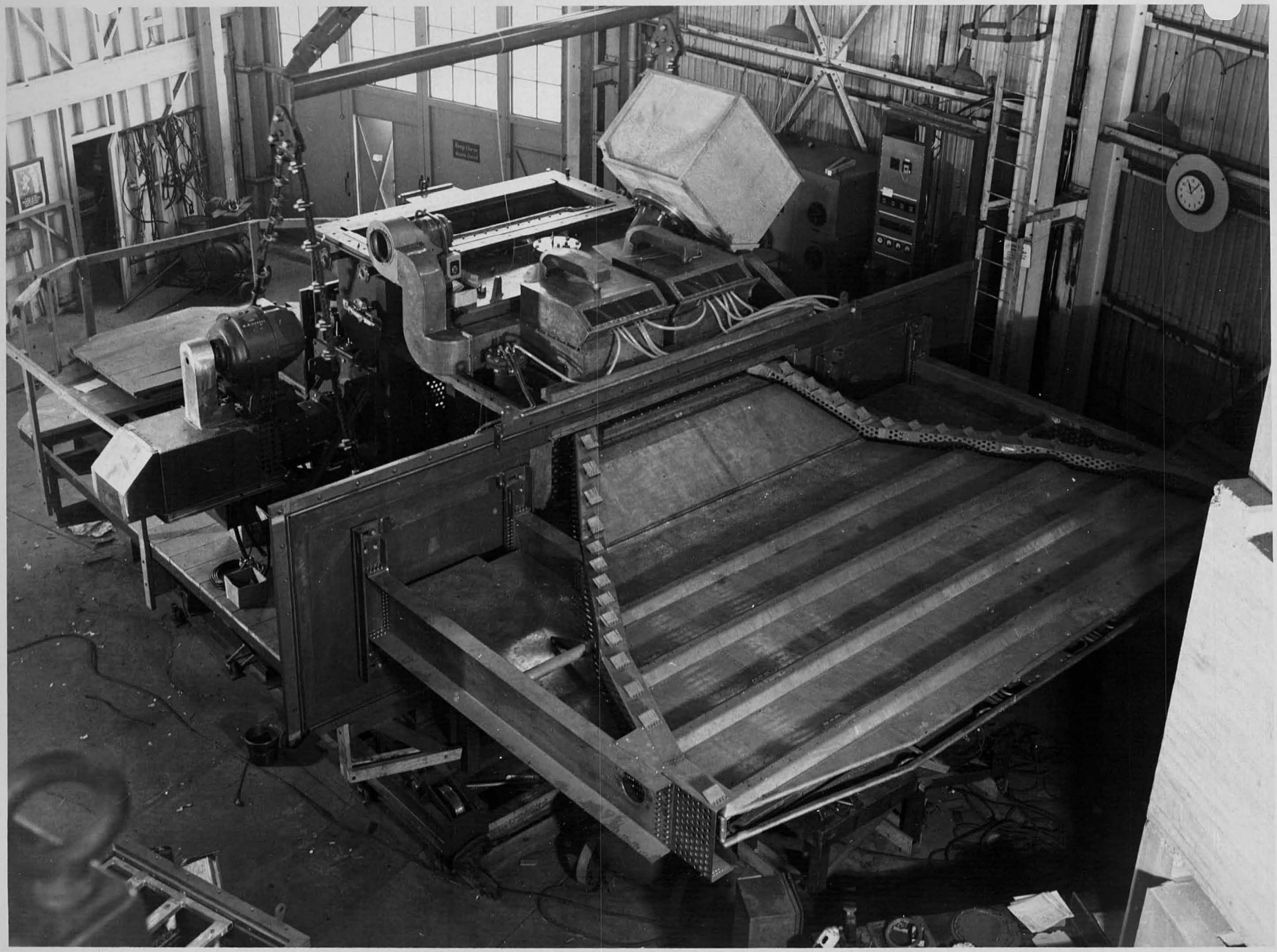


FIG. 4

OZ 375

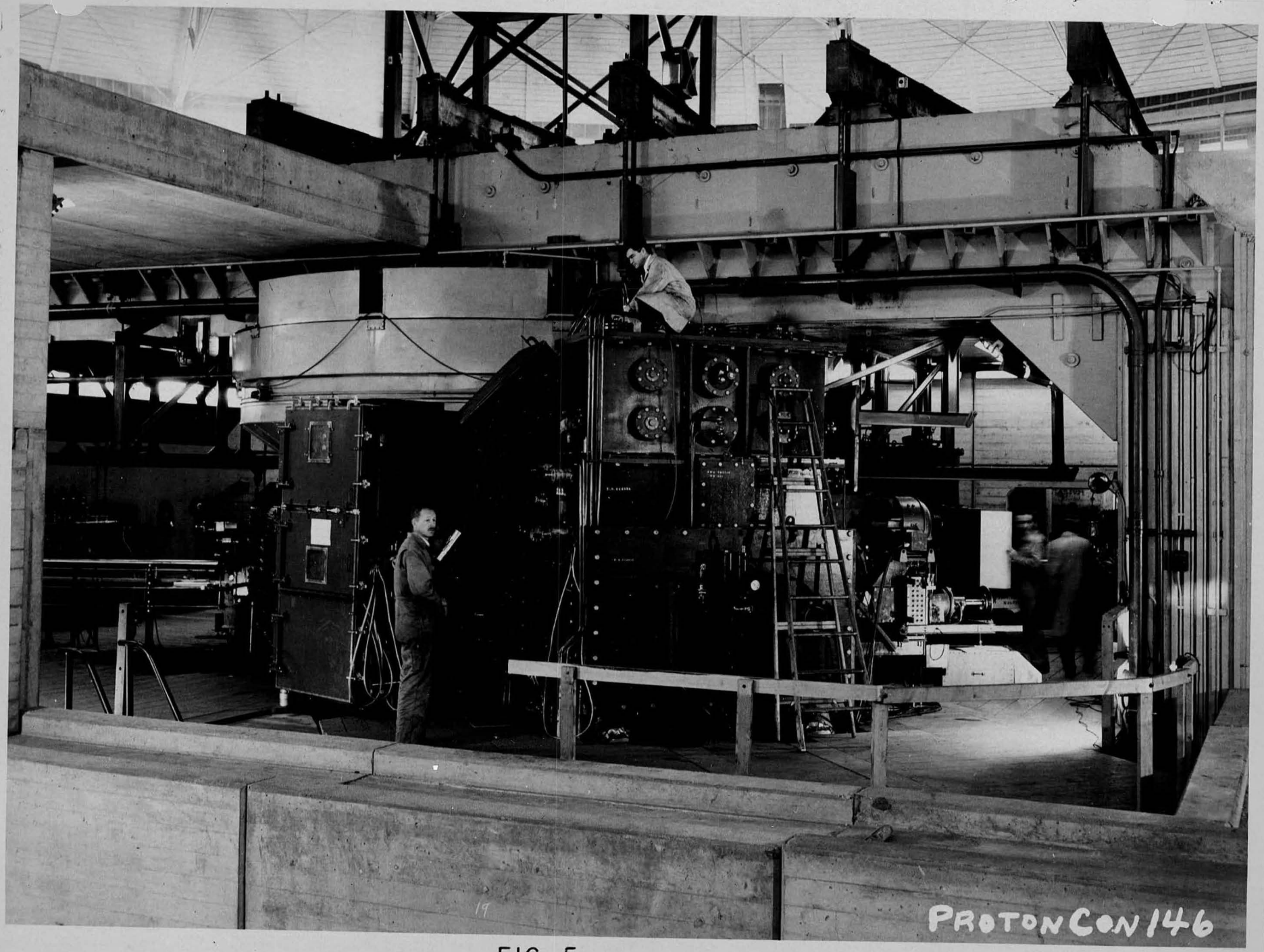


FIG. 5

OZ 380

FIG. 6

OZ 377

FIG. 7

OZ 381

FIG. 8

KODAK SAFETY FILM

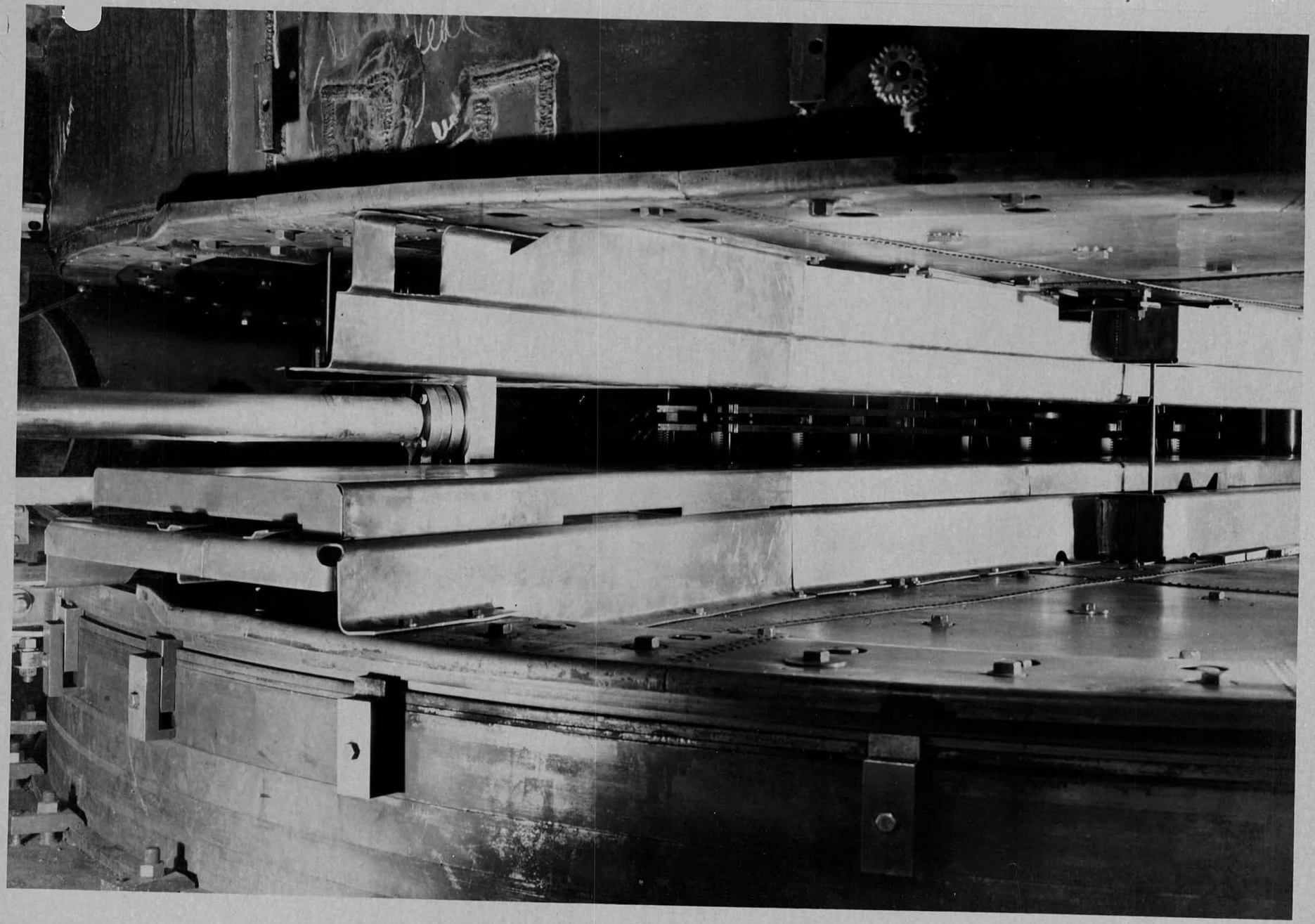


FIG. 9

OZ 373

FIG. 10

OZ 374

2. Bevatron Development

William Brobeck

Since February 1948 the laboratory has been proceeding with the design of a six billion volt synchrotron for the acceleration of protons. This machine has been named the bevatron in reference to its production of energies in the billion electron volt (Bev) range.

The cost of the machine is estimated at nine million dollars which amount has been allocated to the project. The magnet which is in the form of a ring 110 feet in diameter will require approximately 11,000 tons of steel and 25 miles of cable. The exciting power supply will deliver pulses of 100,000 KW peak deriving the energy from two 85 ton flywheels. The site of the machine will be in the valley a few hundred yards north of the present 184 inch cyclotron site. The topography provides natural shielding while at the same time the building is conveniently close to the existing laboratory facilities.

One of the most important and certainly the most difficult decisions to make in design of any synchrotron concerns the size of the aperture to be allowed for the ion beam to pass through the magnet. The cost of the machine is almost proportional to the area provided so that great savings are possible through reducing the aperture. However, if the aperture is made too small the ouput of the machine may be low or even zero. Unfortunately not much help can be obtained from theoretical analysis and the decision must be based largely on the performance of existing machines. In the case of the bevatron the question has been to some extent avoided by designing a magnet whose aperture can be changed with a minimum of expense. As planned at present an opening nominally four feet high by fourteen feet wide is to be used for the first experiments. With this aperture the output will be limited to about 1-1/2 Bev. Much useful physics can be done at this energy, about three times that of the largest cyclotron now under construction, and experience can be gained which will make it possible to go to the final aperture of 1 by 4 feet which is required to obtain six billion volts.

Tests of magnetic models have been going on almost continuously throughout the year to determine the best configuration for the magnet with the various apertures considered.

To be even more certain of the performance of the machine it was decided in July to build a working model to one-quarter scale. This model will be used to verify that the proton beam can be successfully injected into the magnet and stably accelerated. Acceleration will be carried only to six million volts due to limitations on the power available. The magnet for the model is now complete and the vacuum system is being installed. This model is expected to be ready for testing in April or May.

The bevatron will require a separate accelerator of four to ten million volts to accelerate the protons to sufficient energy to enter the big magnet. It is now planned to use a cyclotron for this purpose and a small cyclotron of 1/2 to 1 Mev energy is being built for use with the quarter scale model.

Architects are at work on the building for the full size machine and the site is being cleared preparatory to grading. The magnet power supply is on order from

Westinghouse Electric Co., the steel order has been placed with U. S. Steel Co. and the bids for magnet cable are being considered.

At present approximately 25 percent of the laboratory shops and engineering groups are engaged in the bevatron project. Only five members of the scientific staff are engaged full time on this project but all of the principle scientists take an active interest and provide advice and criticism.

3. Linear Accelerator and Van de Graaff

Luis W. Alvarez

Performance and Development in the Accelerator.

With the replacement of the electrical generator in the 4 million volt shell of the Van de Graaff machine, operation has become very much more reliable than before. The new generator has no brushes and this eliminates the main source of trouble which had been found previously. The Van de Graaff column had to be taken down and cleaned in early December because of a vacuum failure, at which time the automatic shutoffs failed to work. In the month after the replacement of the column, the Van de Graaff operated for over 90 percent of the time as figured on a four-hour shift basis. This is the most reliable operation we have had. From the 15th of January to the 15th of February, the operation was better than it had ever been before the replacement of the generator, but not up to the 90 percent figure.

The new ion source has been completed and is undergoing bench tests prior to the installation on about the first of March. The whole machine will be shut down for several weeks during which time a number of changes will be made. In addition to the ion source installation, the radio frequency buncher cavity will be installed and the capacity of the pulsed line will be increased to the point where the duty cycle can be quadrupled.

The new Eimac tube oscillator is almost ready for r.f. tests, and if successful, two such oscillators employing a total of four tubes will replace all the 25 Baker oscillators now in use on the machine.

A number of tests are being made to see what can be done about reducing the x-ray background in the linear accelerator. The best indications at the present are that if the radii of curvature of the rounded edges of the drift tubes are increased, the x-ray background will go down by an order of magnitude. It has been shown possible to cut the x-ray production by a large factor by placing a di-electric sheet halfway across the gap so that the energies of the electrons producing x-rays are reduced by a factor of two. This makes the shielding problem very much easier, but much more has to be done along this line if it is to become a practical method of eliminating the x-rays.

Ion Source Develpment.

The Philips ionization gauge-type source has produced pulsed proton currents of 2 milliamperes, and up to 4 milliamperes flash performance. A model suitable for installation in the Van de Graaff has been completed by the shops and is now undergoing bench tests. If there are no troubles, this unit will be installed in place of the present source in the Van de Graaff. This P.I.G. source has a good ratio of H^+ to H_2^+ ions in its beam, which should permit greater proton current for a given total beam current. It also has an un-ionized gas flow rate smaller than the old type source by at least a factor of 20, which should simplify the pumping problem at the source end of the accelerating tube.

4. 60-inch Cyclotron

G. B. Rossi and K. Jenkins

Operations Summary for 1948.

There were 8784.0 hours available from January 1, 1948 to January 1, 1949. Of this time, 220.7 hours are considered as unavoidable outage time as follows:

Total time		8784.0 hrs.
Holiday shutdown	92.4 hrs	
Power conservation	128.3 hrs	
	220.7 hrs	-220.7 hrs
	Balance	8563.3 hrs

The dispersement of the actual available operating time (8563.3 hrs.) was made as follows:

I. Deuteron Bombardments		
a. External targets	@2649.8 hrs	
b. Probe targets	@2.3 hrs	
	2652.1 hrs	2652.1 hrs
II. Alpha bombardments		1939.5 hrs
III. Proton bombardments		1324.8 hrs
	Total Bombardments	5916.4 hrs
IV. Cyclotron Experimental Time		512.5 hrs
	Total Operations	6428.9 hrs
V. Outage time		
a. Dee stem breakdown repair	@370.0 hrs	
b. Operation difficulties	@1764.4 hrs	
	2134.4 hrs	2134.4 hrs
	Total Time	8563.3 hrs

Bombardments utilized 69 percent of the available time. These bombardments were performed for members of the University of California Radiation Laboratory, as well as A. E. C. groups outside the campus and were performed in the interest of basic physical research, the production of radio-isotopes for biological research and the production of hitherto unknown radio-isotopes.

Bombardments for members of the Radiation Laboratory Research Groups headed by Dr. G. T. Seaborg, Dr. E. Segrè, Dr. Carl Helmholz, Dr. E. McMillan, Dr. L. Alvarez, Dr. J. G. Hamilton and Dr. J. H. Lawrence were performed. The results of this work have been published in articles appearing in the various scientific publications.

The time spent in improving existing operating conditions, developing new operational methods and components, and gathering data for future design changes was 6 percent of the total available time. The results of some of this work has been presented in earlier editions of this report.

The breakdown of Operation Difficulties indicates that the most time-consuming troubles were as follows:

1.	Filament changes	2.8 percent
2.	Bake in	2.75 percent
3.	Adjustments	2.75 percent
4.	Mechanical maintenance	2.6 percent
5.	Replacements	2.6 percent

While operating with protons or deuterons, arc filaments usually last for 15-25 hours. Under exceptional conditions, 50-70 hours have been recorded.

During operations with alpha particles, with filaments identical to those used with deuterons or protons, the average life is from 5-8 hours. This life time is rarely any greater, but is sometimes less (from 2-3 hours) because of air or water contamination in the gas supply. This contamination is usually due to leaks that develop in the water-cooled blocks in which the filament is mounted, and in the filament holder.

Efforts that have been made to eliminate air contamination of the gas supply has already been reported. In addition, a new design for a filament holder is under test and should eliminate our present difficulties.

A certain percentage of the bake in time remains a problem of all vacuum systems. Since the normal precautions to minimize this period have been taken, a study of pumping speeds and preheating by the use of steam or hot water is under consideration. At the present time, the heat due to r.f. losses in the system is relied upon for the bake in.

It has been found difficult to obtain readily a representative alpha beam after prolonged periods of deuteron or proton operation. It follows that the necessity of changing particles repeatedly to meet bombardment demands has increased the time necessary for adjustments. However, during the periods when operation was confined to one particle (i.e., deuterons or protons) the adjustment period was negligible and usually consisted only of filament positioning. An effort, therefore, is being made to change particles at regular intervals to make more time available for productive operation.

The replacement time is consumed almost exclusively in replacing ion cones. An accompanying photograph (Fig. 1) shows the condition of some cones upon removal from the tank. This erosion is evident only on the hooded type of source and results from bombardment by off-center ions of about one-half the energy of the normal beam.

A water-cooled source has been placed in successful operation that has completely eliminated this condition but must be developed further to minimize ion erosion of the ejection orifice. This ion erosion hampered the efficiency of the cones on the first models after approximately one month of operation, during which alphas, deuterons and protons were accelerated.

The small amount of time indicated under "Probes" arises from the fact that they are considered as secondary runs made while the instrument is operating with an external target. Consequently, only time spent in inserting and removing the probe is considered. Time spent in handling external targets is usually small and is reported along with bombardment times.

Attempts to Pulse Oscillator.

Attemps were made to pulse the main oscillator to a high power to see if the beam would increase with an increase in beam power. No conclusions were reached as it was not possible with our present equipment to pulse the oscillator to a sufficiently high power.

The procedure of pulsing was to grid modulate the oscillator. The pulse width was chosen as 500 microseconds, which is approximately 5 times the logarithmic decriment for a tank Q of 3000. Meters were placed in the circuit to measure instantaneous grid and plate voltages and currents. The plate power supply has a constant current network such that the oscillator could be tuned with a low plate voltage and high plate current (14 KV, 7 amps.). No drop in cyclotron efficiency was noted by the change in oscillator plate current-voltage ratio. The grid voltage was increased until the plate voltage rose to 18 KV. The pulser shorted out this additional grid voltage for 500 microseconds at a pulse rate of 60 cycles per second. Two syncroscopes were used, one to show the beam current and the second to show the dee voltage.

The results were not satisfactory. The internal impedance of the main oscillator power supply was too high. When additional capacitance was placed on the supply, the stored energy was enough to do damage to the oscillator tube when it sparked. The experiment did show that it is possible to pulse the oscillator. The most interesting thing was the dependence of cyclotron resonance of a function of oscillator power. The two beams come out at slightly different magnetic fields.

An explanation of why this type of pulsing was not successful is shown in Figs. 2 and 3.

When the current is increased during the pulse, the voltage drops rapidly when the drain is above the supply capacities. Hence, the r.f. voltage rises slowly, the power output of the supply is greatly reduced by the time the r.f. builds up.

In order to pulse the oscillator successfully, it will be necessary to apply a pulse that has sufficient energy to hold the power at a high level during the pulse, while at the same time to have a low total stored energy. Such a system could be a pulse line which gives up its energy during the pulse but delivers it at a constant rate.

FIG. 1

OZ 382

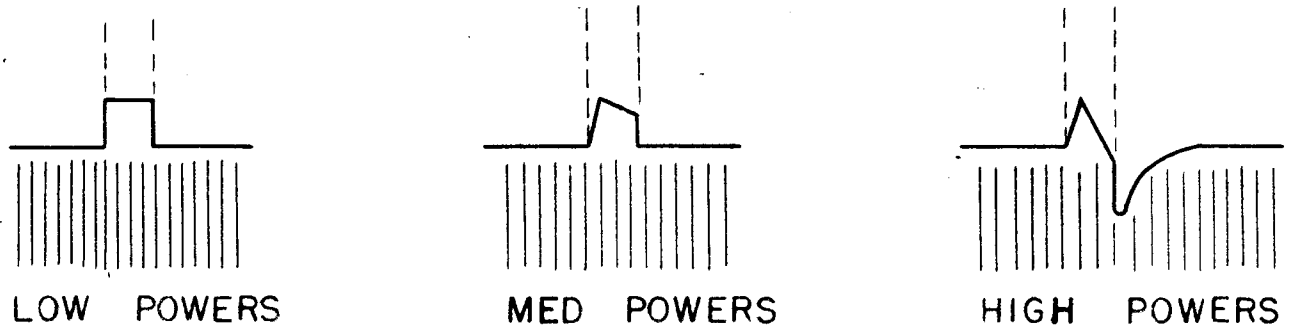


FIG. 2

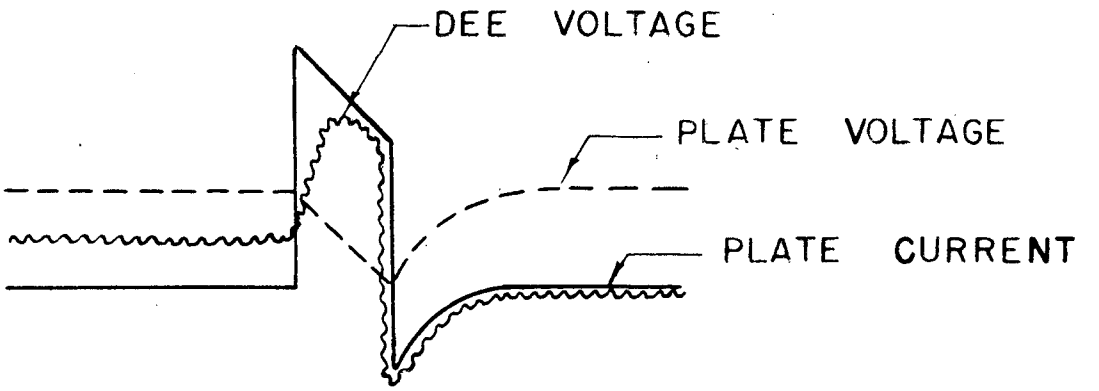


FIG. 3

13495-1

5. Synchrotron

Marvin Martin

During the past quarter the magnet was re-assembled with the quartz donut in place, and a betatron beam was observed on November 23rd by reducing the magnet excitation to 1-1/4 percent of its rated value. After having observed a betatron beam, it was soon possible to increase the magnet excitation and maintain the beam by adjusting currents in compensating loops above and below the orbit. When the beam was observed at full excitation the magnet was disassembled and the r.f. cavity and oscillator installed.

The first synchrotron beam was observed on December 14th using a short r.f. pulse which permitted the beam to collapse into the anthracene detector shortly after the end of the betatron period. Additional adjustment permitted increasing the length of the r.f. pulse until radiation could be detected by ionization chambers outside the machine. The magnet excitation was then gradually increased to full value, making the necessary adjustments to maintain the beam, until an energy of 300 Mev was reached. Continued adjustment of the magnetic field shape, injector, and r.f. timing has made it possible to obtain an intensity of about 100 mr per hour at 300 Mev as measured in a cubical ionization chamber having a linear dimension of 8 inches, covered by a 1/4" lead sheet, and located in the beam at a distance of about 12 feet from the target.

An investigation has been made of the space inside the donut required for the beam, using probes which could be moved during operation and which were capable of restricting the aperture both vertically and horizontally. From these tests, it appears that substantially all of the beam lies in a cross-sectional area having a 1 inch vertical dimension and a 3 inch horizontal dimension. The donut has internal dimensions of 2-1/2" x 5-1/2".

No good explanation is yet available for the inability of the beam to fill the donut. There is some possibility that inhomogeneities in the magnetic field near the surface of the donut may result in the loss of any electrons which follow orbits bringing them into close proximity to the surface. These inhomogeneities might be caused either by eddy currents in the conducting surface of the donut or may be those inhomogeneities noted near the pole faces during magnetic measurements.

Considerable effort is being devoted to attempts to increase the intensity of the synchrotron. One of the most promising methods appears to be reducing the jitter in the timing of the injector pulse. It is not known whether this jitter is caused by actual changes in the time of the firing of the injector or by changes in the most desirable firing time, since the present monitoring instruments do not permit differentiating between these two effects. It is noted, however, that occasionally several large pulses will occur in succession which result in increasing the output by a factor of 3 or 4 and that the optimum timing for obtaining this succession of pulses most frequently is not constant.

Some work has also been done on shaping the injector pulse in such a manner as to make the injector voltage rise with time at a rate which corresponds to the rate of change of the magnetic field in order to give an increased period of injection.

This technique is believed to improve the output although the tests are not yet complete. The best performance of the pulse shaping equipment cannot be obtained until timing jitter is eliminated.

Some work has also been done on shaping the radiofrequency envelope during the period immediately following the turning on of the oscillator. It was thought that such shaping might improve the catching of the betatron beam into a synchronous orbit. To date, however, no very beneficial effects have been noticed from this experiment.

During all synchrotron runs since it was possible to obtain full energy, nuclear plates have been located in and near the beam in an attempt to observe mesons produced by the x-ray beam. Numerous mesons have been observed in these plates and quantitative experiments are now being started.

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