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Classification by authority of CONFIDENTIAL Commission, Per [redacted] (113) By REPORT LIBRARY [redacted] 11-2-17

LA REPORT - 128

August 23, 1944

This document contains 38 pages

ABSOLUTE VALUES OF THE FISSION CROSS SECTIONS OF 25 AND 28 FROM 0.28 TO 2.50 MEV

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Classification changed to UNCLASSIFIED by authority of the U. S. Atomic Energy Commission, Per Jack N. Kalin 4-3-57

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Physics - Fission

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ABSTRACT

Several values of the fission cross section of 25 between 0.35 and 2.5 Mev were measured by comparison with the scattering cross section of hydrogen. For this purpose a double chamber was used, one half of which contained an enriched 25 fission foil, the other half a thin foil of glycerol tristearate. With the same chamber and a depleted 28 foil in place of the glycerol tristearate, the fission cross section of 28 was compared with the fission cross section of 25.

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ABSOLUTE VALUES OF THE FISSION CROSS SECTIONS OF 25 AND 28  
FROM 0.35 TO 2.50 MEV

1. INTRODUCTION

The fission cross section of 25 at high energies has been measured at Wisconsin by Hanson<sup>1)</sup> using a coincidence-proportional-counter method and by Benedict and Hanson<sup>2)</sup> using a manganese-bath method. While there was reason to believe that the relative values of  $\sigma_f(25)$  given by these measurements were fairly accurate, great uncertainty existed as to the absolute scale. This is shown by the disagreement between the two methods which gave, at 1.0 Mev, values of 1.6 and 1.2 barns respectively.

The present experiment was designed to establish more accurately the absolute scale for  $\sigma_f(25)$  as well as to check the dependence of this quantity on energy.

2. EXPERIMENTAL METHOD

The most promising method of attack was that of measuring the fission cross section in terms of the scattering cross section of hydrogen, which is the only cross section accurately known in the region of 400 kv to 5.0 Mev. This cross section has been measured by Williams<sup>3)</sup> and by Bretscher<sup>4)</sup>; their values are in agreement with the curve calculated by Bohm and Richman<sup>5)</sup>. The values

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  - 2) Report CF - 638
  - 3) Report CF - 599
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  - 5) Report UCRL - 320




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given by this latter curve are probably accurate to about 2% in region of 1.0 Mev and to about 5% at the extreme energy ranges mentioned. Since the writing of this report some of the theorists have come to the conclusion that this error may be somewhat higher. In brief, the experiment consisted of measuring the neutron flux in terms of  $\sigma_s(H)$  by counting the hydrogen recoils ejected from a hydrogen radiator placed in the neutron beam and then finding  $\sigma_f(25)$  in terms of  $\sigma_s(H)$  by counting the fission particles from a known amount of 25 when placed in this neutron beam.

Since the energy distribution of the hydrogen recoils is believed to be spherically symmetric in the center-of-mass system, the energy of the recoils will be distributed uniformly from a maximum value equal to the neutron energy in the forward direction to zero at  $90^\circ$  to the incident neutrons. Because of this continuous distribution of recoil energy to zero only a fraction  $\beta$  of the recoils can be counted. In order to determine this fraction  $\beta$ , which depends on the bias energy, it will be necessary to use a recoil chamber for which the pulse-height distribution can be calculated.

Two general types of hydrogen recoil chambers are known. The hydrogen may be present as a gas, occupying the entire chamber, or as a thin layer of hydrogenous material such as paraffin. The hydrogen-filled chamber has the disadvantage of a "wall effect" since the protons originate throughout the entire chamber. This effect can be calculated but it is troublesome. Also in this case one must use ion collection, rather than electron collection. This requires the use of slow amplifiers which do not permit high counting rates and are accompanied by troublesome microphonics unless the parts of the chamber are very rigidly constructed. On the other hand, heavy chamber walls are undesirable on account of possible neutron scattering.

  
  
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A thin-paraffin chamber was constructed by Staub (report forthcoming) for the purpose of studying the energy spectrum of fission neutrons. Staub found that reasonably good agreement between experimental and theoretical bias curves can be obtained. The thin-paraffin chamber permits the use of electron collection and therefore of fast amplifiers. With fast amplifiers high counting rates can be used and troublesome microphonics are not present even though the chamber walls are not massive. For these reasons the thin-paraffin chamber was chosen in preference to the gas chamber.

In the design of a chamber for the present experiment the following features were desirable.

1. Recoil and fission particles should be counted simultaneously.
2. Hydrogen and fission foils should subtend the same solid angle from the target and lie as nearly as possible in the same plane.
3. The amount of scattering material in the chamber should be kept to a minimum.
4. Electron collection should be used.

The first two items are very important because they eliminate the need of monitoring between the two sets of measurements, the need of accurate determination of position, and the need of any correction for different solid angles subtended by the two foils. The third feature is important in order to minimize the uncertainties due to scattering by the walls of the chamber.

In using electron collection it is desirable that the range of the recoils be small compared to the depth of the chamber (perhaps one third or less). For satisfactory electron collection in argon, it is usually necessary to purify the gas in order to prevent electron capture. Circulating the gas over hot

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calcium metal seems to work satisfactorily. Rubber gaskets are objectionable. Neoprene gaskets may be usable, but metal gaskets are definitely to be preferred.

### 3. EXPERIMENTAL ARRANGEMENT

#### (a) Chamber

A cross section of the chamber proper is shown in Fig. 1. The collecting electrode for recoils, the high-potential electrode, and the collecting electrode for fission particles are each fastened to the guard ring by a set of three insulators. These insulators are made of glass rods about  $3/32$ " in diameter. The ends of the glass rods are platinized and then soldered into the hollow heads of small brass screws. The high potential electrode assembly consists of two brass rings with two .002" platinum foils clamped between them. The two foils which carry the fissionable material and the thin layer of hydrogenous material are placed back-to-back so that the two foils are essentially in the same plane. The active layers are one inch in diameter. The paraffin chamber is 1.34 cm deep and the fission chamber has a depth of 0.8 cms. The collecting electrodes are about  $1/64$ " thick and the other parts of the chamber are correspondingly light in weight. The dotted lines show the approximate ranges of 1.0 Mev hydrogen recoils and of fission particles with 7 atmospheres of argon in the chamber.

Fig. 2 shows the chamber mounted at a distance of about 15 inches from a base plate by means of two light-weight brass tubes. Over this assembly is placed a thin-walled (about  $1/64$ " ) brass cap which is sealed to the base by means of a fuse-wire gasket. Connections to the electrodes are made through Kovar-glass seals. The leads to the high-potential electrode and to the collecting

electrode of the fission chamber are carried in through the supporting tubes in order to shield these leads from the lead going to the collecting electrode of the recoil chamber. For purifying the gas, a Ca-filled tube is mounted on one side so that the gas circulates through it when the purifier is heated.

(b) Glycerol tristearate Films

Glycerol tristearate was chosen for the H radiator in preference to paraffin because it has a more definite chemical composition. The films were deposited on .002" platinum by evaporation from a furnace in a vacuum. The platinum foil was heated to redness and then weighed several times on an assay balance before and after deposition of the glycerol tristearate. The weights used were carefully calibrated against Bureau of Standards weights. The weights of the films used should be known to 1%. An analysis of the hydrogen and carbon content of the glycerol tristearate was made by Mr. Potratz's group. It is believed that the error in the hydrogen content of the radiator is 2% or less.

(c) Electronic Circuits

Fig. 3a shows a block diagram of the electronic circuits. The pulses from the fission chamber go through the pre-amplifier and the amplifier into a discriminator and scaler. By a discriminator circuit we mean a circuit which will pass all pulses larger than some specified size and reject all those which are smaller. The bias level can be adjusted to accept any desired pulse height.

The recoil pulse also goes through a pre-amplifier and an amplifier, each of which has a larger gain than necessary for the fission chamber, into a multiple discriminator containing three discriminators of the type previously described. One of these with a scaling unit counts all pulses larger than a



chosen size. The other two discriminators are combined to form a channel, the two feeding into an anticoincidence circuit which will pass a pulse only if the height of the pulse lies between the two levels of the two channel discriminators. This channel can be shifted to any desired level, the width of the channel remaining constant. This we shall call the differential channel. These circuits enable us to count simultaneously fission particles, all recoils above a given bias, and recoils within a given bias interval. The work on the discriminator circuits was done mainly by Froman, Higenbotham, and Rossi<sup>6)</sup>.

The linear pulse amplifiers are semi-fast, having a rise time of 0.5  $\mu$ sec or less and a low frequency time constant of 10  $\mu$ sec. Calibration pulses are fed in through the high voltage from a pulse generator as shown in Fig. 3b after an appropriate amount of attenuation. The size of the pulses, which are obtained by driving a tube to cutoff, can be determined accurately by measuring the potential drop in the cathode resistor in which the pulses are produced. These pulses rise to a full height in a few tenths of a  $\mu$ sec. They are flat topped and therefore comparable in shape to actual ionization pulses.

#### 4. TESTS

##### (a) Calibration Curves

Since an accurate knowledge of the behavior of the amplifier and discriminator is essential in this experiment, calibration curves were taken

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before and after each experimental run. Fig. 4 shows how this is done. First, keeping the pulse height constant, the counting rates in both the integral and differential discriminators are determined for various bias settings and plotted against bias. This is repeated for several pulse heights (two pulse heights in Fig. 4). From these curves the integral bias at half counting rate and the differential bias corresponding to the midpoint of the differential channel are found. These are then plotted against the pulse height.

These curves are necessary for establishing the energy scale in absolute value. The value of the energy corresponding to a given pulse height is obtained by matching the experimental and theoretical differential bias curves.

A comparison of two calibration curves taken at different times is also very informative since a change in slope is indicative of a change in amplifier gain while a change in intercept with the slope remaining constant indicates a change in the discriminators.

#### (b) Behavior of the Chamber

In order to make certain that the chamber was behaving properly, tests were first made with Po  $\alpha$ 's. A thin Po source distributed over a sizable area on a platinum foil was placed on the high-potential electrode. Such an uncollimated source, with electron collecting and zero channel width, (see discussion of electron collection and channel width in section 5) should give a differential bias distribution as indicated by the dotted line in Fig. 5, where the larger pulses are associated with the particles coming out parallel to the platinum foil. The solid line shows the curve obtained with about a three-volt channel width, which agrees, considering the finite width of the channel, with the expected curve except for the slight peak at the higher bias edge. This peak

is probably accounted for by the platinum surface being slightly rough or dirty. If there is no electron capture the bias curve for  $\alpha$  particles should be reproducible over a wide range of collecting potentials. This was not the case with unpurified argon at a pressure of seven atmospheres in the chamber, at least up to 2000 volts. However after heating the calcium metal to  $300^{\circ}\text{C}$  for about two hours, the curves obtained for collecting potentials between 1200 and 2000 volts were practically identical. A repetition of the measurements some 24 hours later gave no indication of an increase in electron capture. In practice the chamber was operated with 2000 volts for pressures up to seven atmospheres of argon, and at 3000 volts for nine atmospheres of xenon.

Since the H radiator was a part of the high-potential electrode there was some question that an accumulation of charge on the paraffin might affect the behavior of the chamber. Tests were made after covering the Po with a layer of glycerol tristearate several times thicker than the actual foils used. The shape of the bias curve agreed roughly with the expected shape and no change was observed when a strong  $\gamma$  source was brought near the chamber.

##### 5. SUMMARY OF THEORETICAL RESULTS

Since for a monoenergetic neutron beam the H recoils are distributed uniformly in energy from a maximum value equal to neutron energy in the forward direction to zero at  $90^{\circ}$ , the shape of the expected differential bias curve is rectangular provided one uses ion collection, an infinitely thin radiator, and zero channel width. The curve marked "ion collection" in Fig. 6 shows this

curve for 1.0 Mev neutrons with 6.7 atmospheres of argon in the chamber.

If electron collection is used the curve will be changed in shape appreciably, as shown in Fig. 6, but the area under this curve will be the same as for ion collection. The reason for the change in pulse distribution can be seen by examining the drawing in the upper part of Fig. 6 which represents an ionization chamber with neutrons coming in from the top. If ion collection is used, the pulse measured is independent of the position of the ion track, provided it is all inside the active volume of the chamber. However, if electron collection is used, in which the effect of the slowly moving positive ions is not recorded, the pulse height depends upon the distance through which the electrons move. For electron collection the pulse height  $p$  is  $p = p_0(x/d)$  where  $p_0$  is the pulse height one would get for ion collection,  $d$  is the depth of the chamber, and  $x$  is the distance from the collecting electrode to the center of gravity of the ion track. While all pulses are reduced somewhat in size by the use of electron collection, the pulses of larger energy are reduced more than those of low energy. The curve marked "finite thickness" in Fig. 6 shows the bias curve for electron collection as affected by increasing the radiator thickness to  $175 \text{ g/cm}^2$  of glycerol tristearate, the thickness still being small compared to the range for 1.0 Mev protons in glycerol tristearate. The difference in abscissa at the peak and at cutoff is due to the loss of energy of the protons in the glycerol tristearate film. The area under this curve is less than that for an infinitely thin radiator since some of the low energy recoils never get out of the radiator.

All of the above curves in Fig. 6 are for zero channel width. The curve marked "channel correction" shows the effect of using a 100 kv channel

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which is about that usually used in practice. The main effect of the channel width is to change the slope of the high-energy part of the graph. The last curve is the one which should be compared with an experimental bias curve which is obtained by plotting the counting rate of the differential discriminator against the average bias as determined by the calibration curves.

The details of the calculations of these theoretical curves, as well as several curves not included in this report, are given by Hirschfelder and Magee<sup>7)</sup>. In order to calculate the bias curves, a knowledge of the range vs. energy relation for protons in argon and xenon is necessary and considerable effort was spent (see report LA 129) in finding the most reliable relationship. Staub (report forthcoming) computed a range-energy relation for protons in glycerol tristearate and his results were confirmed by Hirschfelder and Magee. Previously, Richman had calculated a bias curve for 1.0 Mev using somewhat different range-energy relations for the protons. It is interesting to note that the final values for the cross section, calculated on the basis of the two curves, differed by only 1%. This shows that the results of our experiment are not very sensitive to the range-energy relations.

When the integral bias is set at any known value it is necessary to know what fraction  $\beta$  of all the recoils will produce pulses large enough to be counted. This quantity  $\beta$  plotted as a function of pulse height gives the so-called integral bias curve. Theoretically this curve can be calculated by integrating the differential bias curve from the energy under consideration to the energy of the primary neutrons. Experimentally it is obtained by plotting the counting rate in the integral dis-

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7) LA Report 129

discriminator against bias energy. Fig. 7 gives the integral bias curve for 1.0 Mev calculated by Hirschfelder and Magee<sup>7)</sup>, who also calculated other bias curves.

## 6. EXPERIMENTAL DATA

All data except those at 2.5 Mev were taken with the high voltage generator in building W using the  $(Li,p)$  reaction as a neutron source. In most cases the target thickness was of the order of 20 kv but was about 40 kv for part of the 1.6 Mev data. The chamber covered with a Cd foil 0.08 cm thick was placed in front of the target. In most cases the distance from the target to the foils was approximately 8 cm.

The data at 2.5 Mev was taken in building Z using the d-d source. The chamber was at the same distance from the target as in the W runs and was at an angle of  $90^\circ$  with the incident deuteron beam. With the integral bias set a little above the background, simultaneous counts of hydrogen recoils and fissions were taken. At the same time, counts were taken with the differential channel at various bias settings to give the pulse-height distribution of the recoils. Figs. 8 to 17, inclusive, give the experimental bias curves fitted to the theoretical curves to which a channel correction was applied. The shape and width of the channel was determined experimentally by artificial pulses. The shape is approximately a trapezoid as indicated in the graphs. The deviation from a rectangle is, of course, due to noises. It may be pointed out that the channel correction is very insensitive to the shape of the channel used.

The abscissae of the experimental and theoretical curves were matched at

the high energy end near the point of steepest descent where the influence of the channel correction is a minimum. The ordinates were matched a little below the peak of the curves. We wish to emphasize again that an accurate determination of the differential bias curves is important for the following reasons:

1. The cutoff of these curves determines the energy scale quite accurately.
2. The agreement with theoretical curves gives assurance that the calculated values of  $\beta$  are correct. Examinations of Figs. 8 to 17 show that this agreement is generally quite good, except perhaps in two of the runs at 1.0 Mev (Figs. 13 and 14) which seem to show a hump just below 0.5 Mev. We are not able to explain this anomaly which seems to be outside of statistical errors and which was not observed, or at least was much less pronounced, in other runs. No such hump was observed at other energies.

In addition to statistical errors, the following possible sources of error must be considered.

1. Background counts in the recoil chamber which are not due to the H recoils from the radiator.
2. Neutrons which are detected by the fission chamber but are not detected by the recoil chamber, or at least not with the same efficiency as for the forward neutrons.
  - a. Neutrons scattered by the walls of the chamber.
  - b. Neutrons scattered by surrounding objects.
  - c. Neutrons of low energy ranging down to the cadmium cutoff.

The agreement between experimental and theoretical bias curves shows that these effects cannot be very large. In order to check further upon these possibilities of error and to determine the corrections, if any, the following experiments were carried out.

- A. Measurements were taken at 8 cm from the target with and without the cadmium shield. Without cadmium the fission counts were about 10% higher than with cadmium, indicating that 10% of the fissions without the cadmium

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shield were produced by thermal neutrons. These were presumably due to scattering by the surrounding objects, mainly the walls and floor of the room. One should expect that only a small fraction of these scattered neutrons are above the cadmium cutoff.

- B. The ratio  $N_H/N_T$  was measured as a function of the distance from the target. If all of the neutrons originate at the target, obviously this ratio should be constant. However, if some of the neutrons reaching the chamber are scattered by surrounding objects, then this ratio should decrease with distance. This is so because of the directional character of the recoil chamber and because of the degradation which accompanies scattering. On the assumption that the scattered neutrons are distributed uniformly in space, experimental results indicate that the fission background due to these neutrons is less than  $\frac{1}{2}\%$  at W and about  $2\%$  at Z, when the chamber is Cd covered.
- C. Runs were taken with the chamber in the inverted position in which the foils are perpendicular to the neutron beam with the glycerol tristearate film facing the target. Runs were also taken in both the normal and the inverted positions with a blank platinum foil in place of the H radiator. In most cases the background count with the blank was of the order of  $2\%$  of the main effect although it was somewhat larger at the higher energies. The radiator in the inverted position usually gave a few more counts than the blank foil in the same position, again of the order of 1 - 2 % of the main effect, indicating perhaps a small amount of back scattering by the walls of the chamber.

As a net correction for 1 and 2 (a) the quantity

$$\left[ \left( \frac{N_H}{N_F} \right)_{\text{radiator}} - \left( \frac{N_H}{N_F} \right)_{\text{blank}} \right]_{\text{normal position}} + \left[ \left( \frac{N_H}{N_F} \right)_{\text{radiator}} - \left( \frac{N_H}{N_F} \right)_{\text{blank}} \right]_{\text{inverted position}}$$

was used as determined in experiment C. This correction was usually less than 1% and never larger than 2%. The correction for 2 (b) and 2 (c) was found from experiment B and was usually less than 1/2% as already mentioned.

TABLE 1

## Fission Cross Sections of 25

Run No.	$E_0$ Mev	Thickness of H radiator $\mu/\text{cm}^2$	Gas Pressure atmospheres	Bias Energy Mev	Standard Statistical error Fission Ct. %	$\sigma_f(25)$ barns	
1	.54	67	3.0 argon	.16	2.4	1.67	1.67
2	.46	67	3.0 "	.12	2.5	1.49	1.50
3		67	3.0 "	.19	1.5	1.50	
4	.57	173	6.7 "	.19	1.5	1.37	
5		173	6.7 "	.20	1.5	1.37	
6		173	3.0 "	.19	1.5	1.39	1.38
7		67	3.0 "	.11	1.0	1.40	
8	.97	166	6.7 "	.28	2.0	1.33	
9		166	6.7 "	.28	2.2	1.35	1.33
10		173	6.7 "	.27	1.0	1.33	
11		173	6.7 "	.29	2.0	1.32	
12	1.6	173	6.7 "	.70	1.0	1.30	
13		173	9.5 "	.69	1.2	1.30	1.30
14		173	9.5 "	.69	1.0	1.30	
15	2.5	173	9.0 Xenon	.74	3.0	1.37	1.34
16		173	9.0 "	.78	3.0	1.30	
		173	9.0 "	.64	3.0	1.35	



7. RESULTS

Table 1 gives the results of all the measurements. Essentially there are three variables, the gas pressure, the radiator thickness, and the bias point. No deliberate attempt was made to vary the bias point, the bias being set just high enough to be sure that the background count would not affect our results. This background was mainly due to piling up of argon recoils at W and to  $\gamma$  rays at Z. It is interesting to note that there is no noticeable difference in the values for  $\sigma_f(25)$  found with different radiators and gas pressures.

In computing the results the following expression can be written:

$$\frac{n_{25} \sigma_f(25)}{n_H \sigma_s(H)} = \frac{N_F'}{N_H'}$$

where  $n_{25}$  and  $n_H$  represent the number of atoms of 25 and H present and  $N_F'$  and  $N_H'$  are the total numbers of fissions and recoils. This can be rearranged as follows:

$$\sigma_f(25) = \sigma_s(H) \frac{m_H}{m_{25}} \frac{235}{1} \frac{(\alpha N_F)}{(N_H/\beta)}$$

where  $m_H$  and  $m_{25}$  are the masses of H and 25 and  $N_F$  and  $N_H$  are the numbers of fissions and recoils which are counted.  $\beta$  has already been discussed.  $\alpha$  is a correction to the fission count.

In estimating the error in the value for  $\sigma_f(25)$ , the error in each of the above quantities should be considered. The errors in two of these quantities  $\sigma_s(H)$  and  $m_{25}$  are not inherent in our measurements. As mentioned before,  $\sigma_s(H)$  is probably accurate to 2% at 1.0 Mev but may be in error by 4 or 5% at



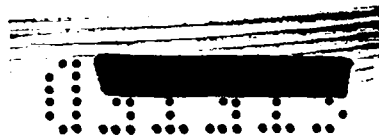
the extreme energies. The 25 foil was made by Corporal Miller. The 25 content was carefully determined by Chamberlain by fission counting against the standard E 10 foils. He gave the value  $0.561 \pm .008$  mgm of 25. This foil was about 77% 25. We checked this result by counting fissions from the 25 foil and from another E 10 foil, in a slow n atmosphere, this foil also having been carefully measured by Chamberlain. It may be noted that an error in  $m_{25}$  would effect the absolute value of  $\sigma_f(25)$  but not the shape of the  $\sigma_f(25)$  vs E curve.

Considering the quantities whose errors are inherent in our measurements,  $m_H$  is probably accurate to 2%. This is checked by the fact that we used three foils with no apparent difference in results.  $\alpha$  was determined by measuring the slope of the fission plateau and by considering the absorption measurements by Wiegand and Segre<sup>8)</sup>, and was found to be  $2 \pm 1\%$ . The error in  $N_p$  is statistical and varies from 1 to 3%. The  $N_H$  counts are high enough for the statistical error to be negligible, but an uncertainty of about 1% may exist because of background corrections. The error in  $\beta$  is estimated to be 2% in most cases but it may be 4% for highest and lowest energies. A check of the accuracy in the evaluation of  $\beta$  can be found in the consistency of the results obtained with different radiator thicknesses and gas pressures. We estimate the over-all error for  $\sigma_f(25)$  to be about 5% at 0.57 and 1.0 Mev and to be somewhat larger at higher and lower energies. The curve  $\sigma_f(25)$  vs E is remarkably flat from 2.5 Mev down to 0.57 Mev, below which it begins to rise rather rapidly.

Since starting this experiment some other values of  $\sigma_f(25)$  have been

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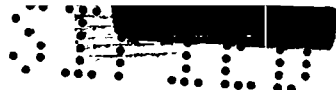
obtained both here and in England. Fig. 13 shows all of the recent values with approximate errors. The two values found by the Z group depend upon measuring the neutron flux in terms of the fission count from a thick U foil of normal concentration. This U foil had been standardized with the d - d source at Chicago in terms of a Ra - Be source by means of a manganese bath (for details see a forthcoming report by Agnew, Jorgensen and Koontz). In Bretscher's measurement<sup>9)</sup> the flux was determined in terms of a total ionization current. The measurements of Chadwick - Kinsey depended upon a three-counter method for the determination of the flux. The solid line shows the results for low energies which were found by John Williams' group by means of their "long counter". These data have been normalized to our value of  $\sigma_f(25) \approx 1.33$  barns at 1.0 Mev.

### 8. FISSION CROSS SECTION OF 28

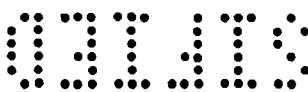
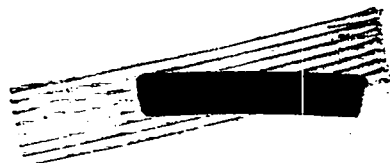
In determining  $\sigma_f(25)$  at energies above the fission threshold for 23 (about 1.0 Mev) a correction must be made for the fissions of the 28 which is present in the foil used. Measurements at Wisconsin gave relative values for  $\sigma_f(28)$  at various energies, but the absolute values were very doubtful. Using the 25 foil and a depleted 23 foil with an R values of 1650 instead of the normal 141, we measured the ratio  $\sigma_f(25)/\sigma_f(28)$  at three energies. We found ratio values 22.6, 3.72 and 2.44 at energies 1.28, 1.57 and 3.0 Mev respectively. Fig. 19 gives the values for the ratio  $\sigma_f(25)/\sigma_f(28)$  found at various energies by several experimenters. With the exception of the Chadwick - Kinsey points, these values lie quite well on a smooth curve.

Fig. 20 shows the values for  $\sigma_f(23)$  itself. The solid line is the

9) BM Report 493.



Wisconsin data fitted to our value at 1.57 Mev. Bretscher's measurements gave a constant cross-section for 28 in the region 2.2 Mev to 4.0 Mev.



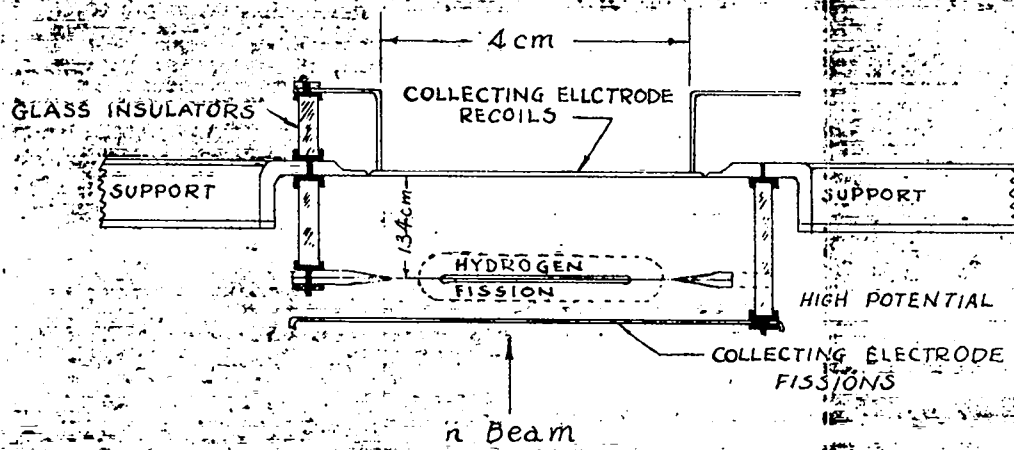


FIGURE 1  
DETAILS OF CHAMBER

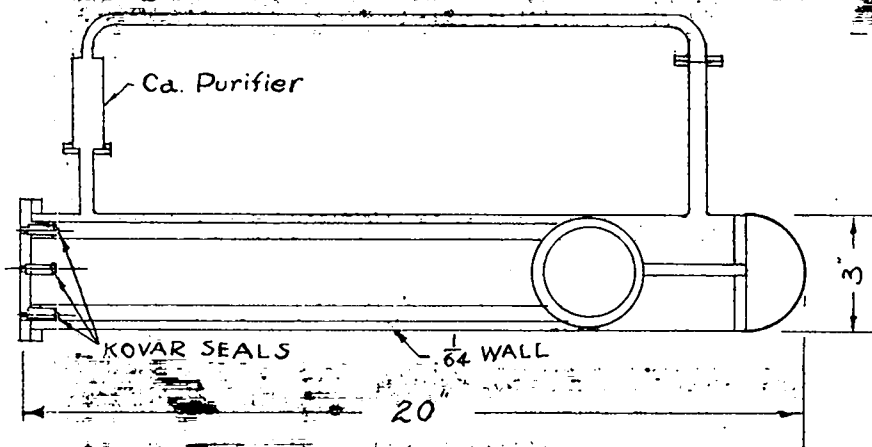


FIGURE 2  
DOUBLE IONIZATION CHAMBER

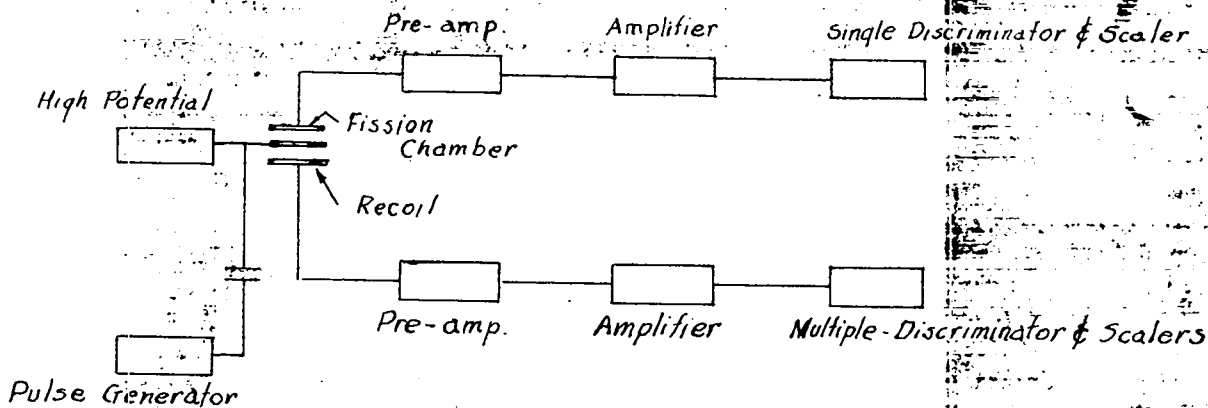


Figure 3a

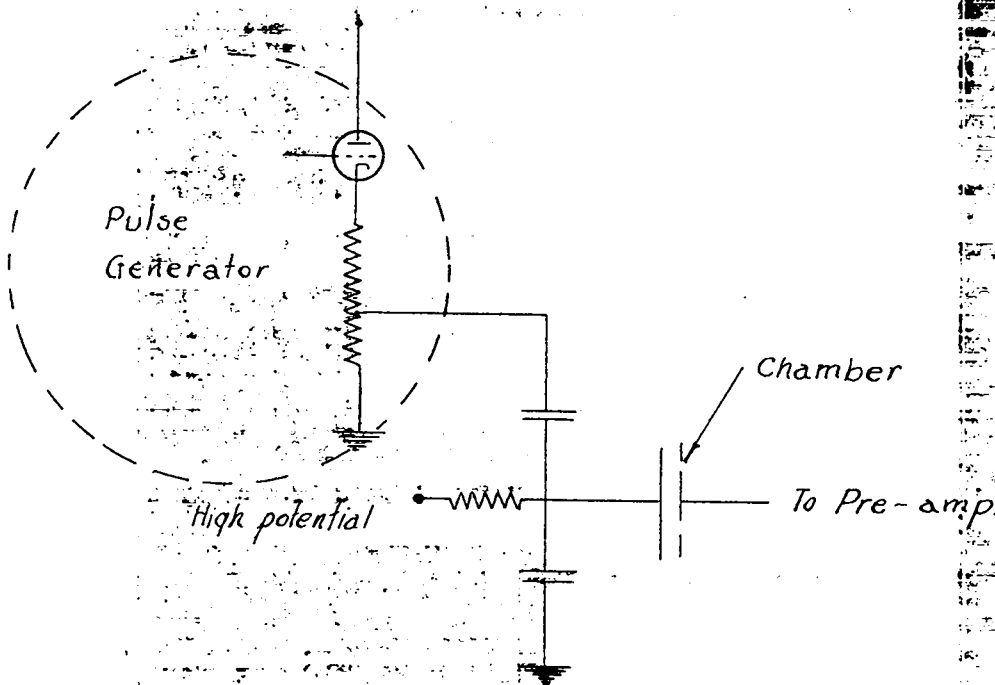


Figure 3b

KEUFEL & ESNER CO. N. Y. NO. 35-114  
Manufactured by receipt of the U.S. Army

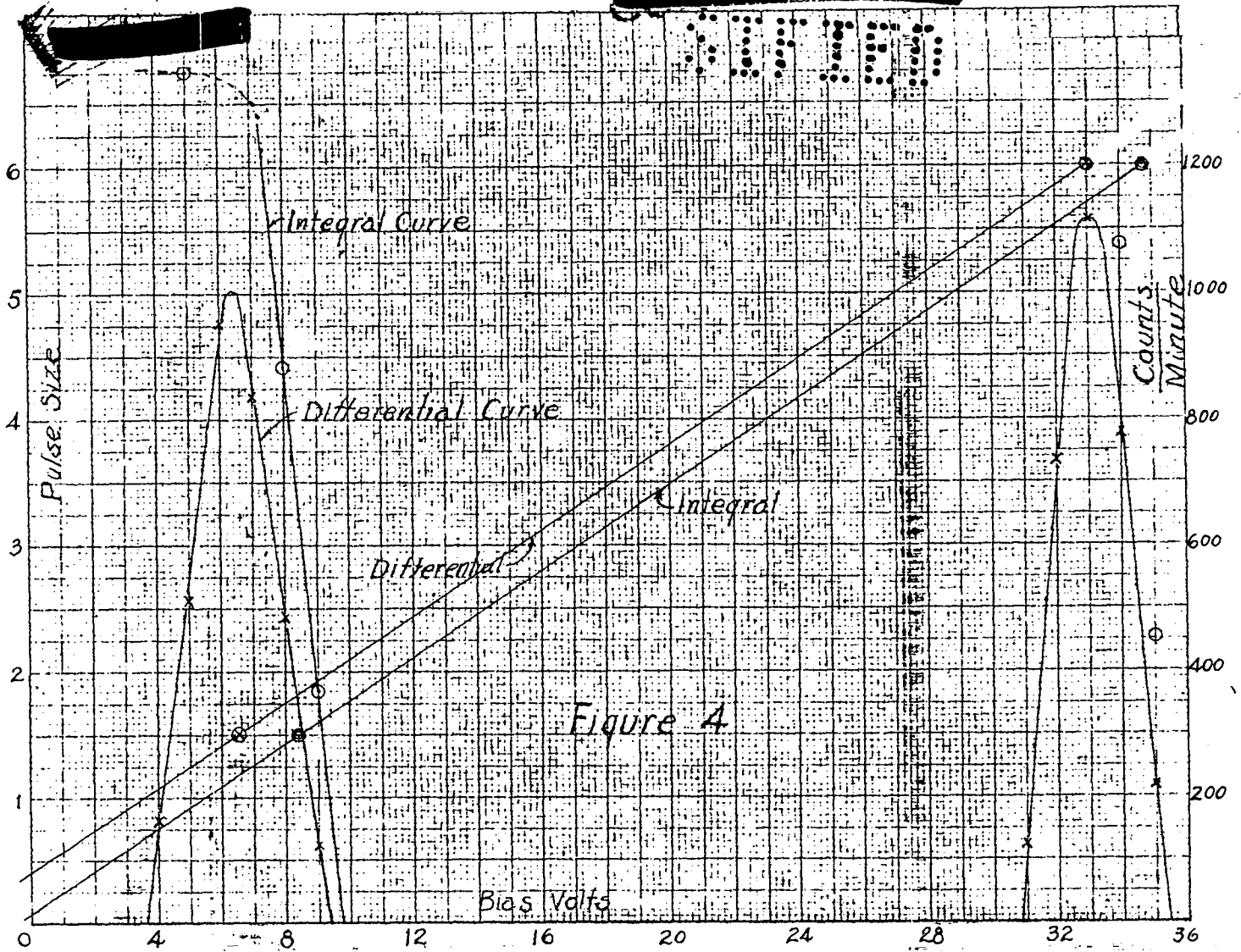


Figure 4

KEUFEL & ESNER CO. N. Y. NO. 35-114  
Manufactured by receipt of the U.S. Army

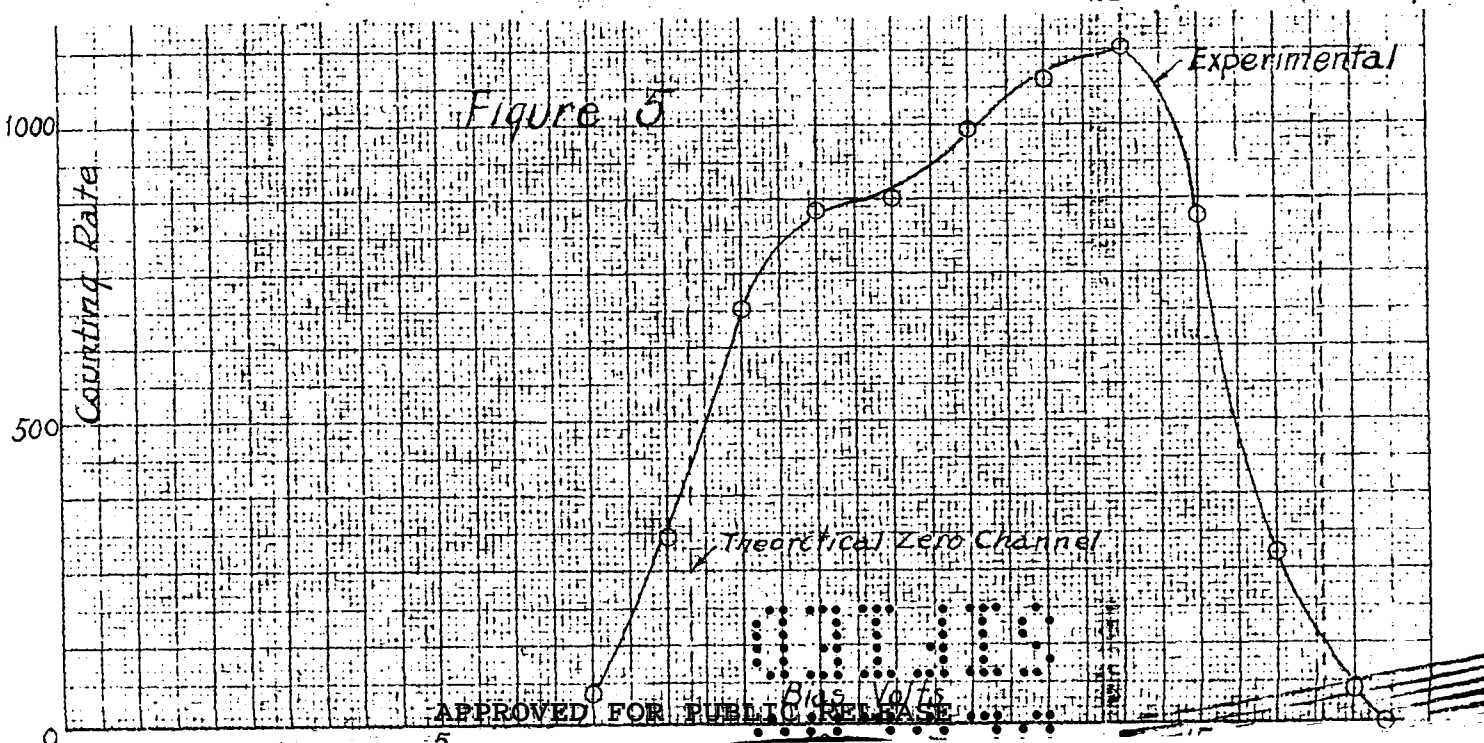
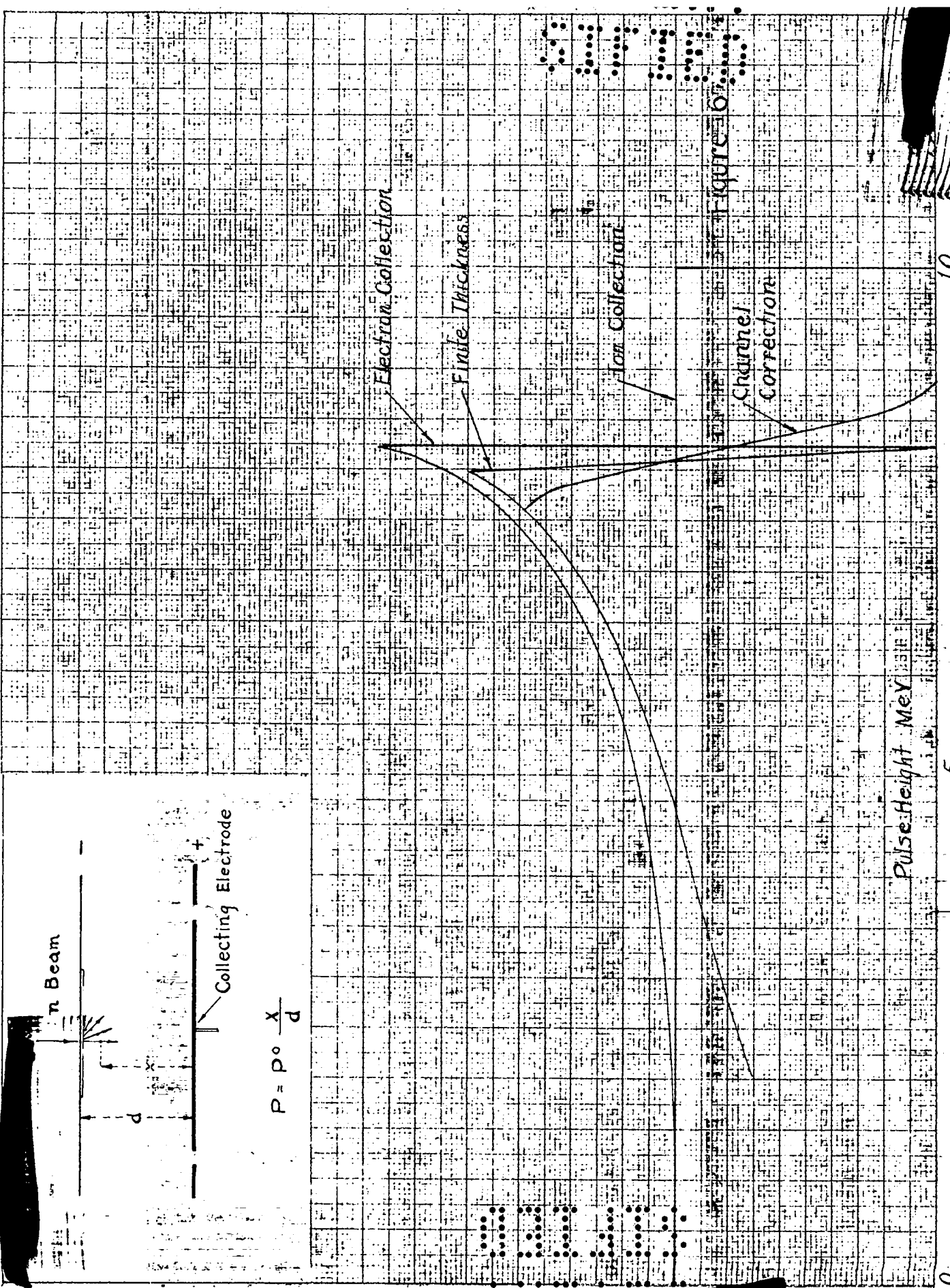
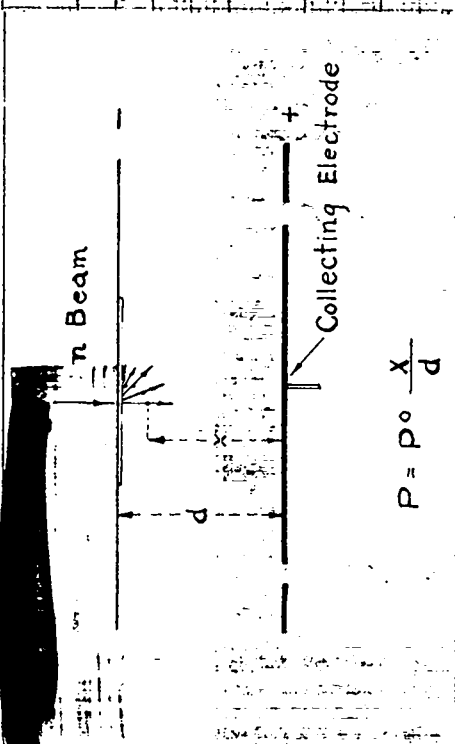
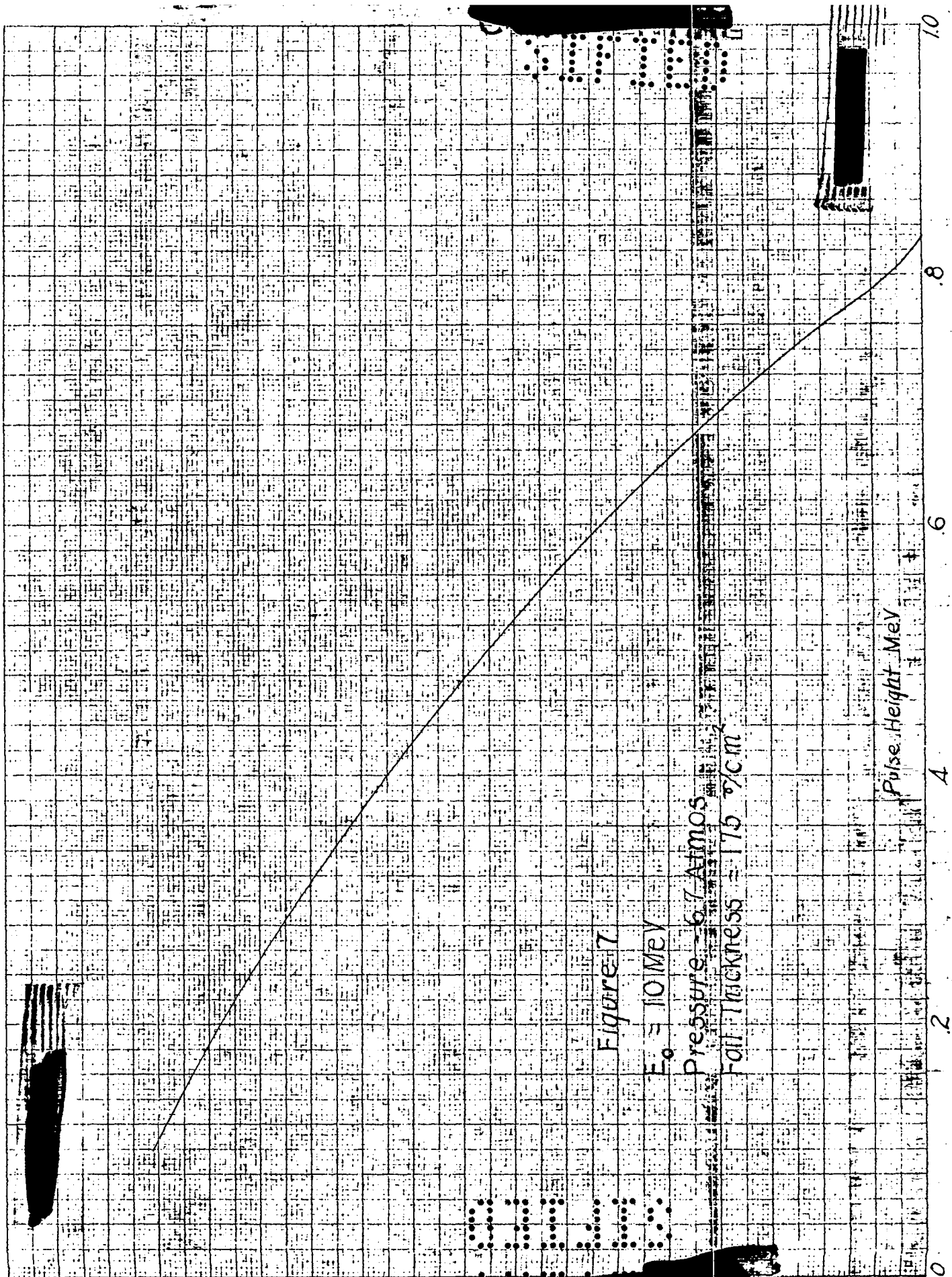


Figure 5







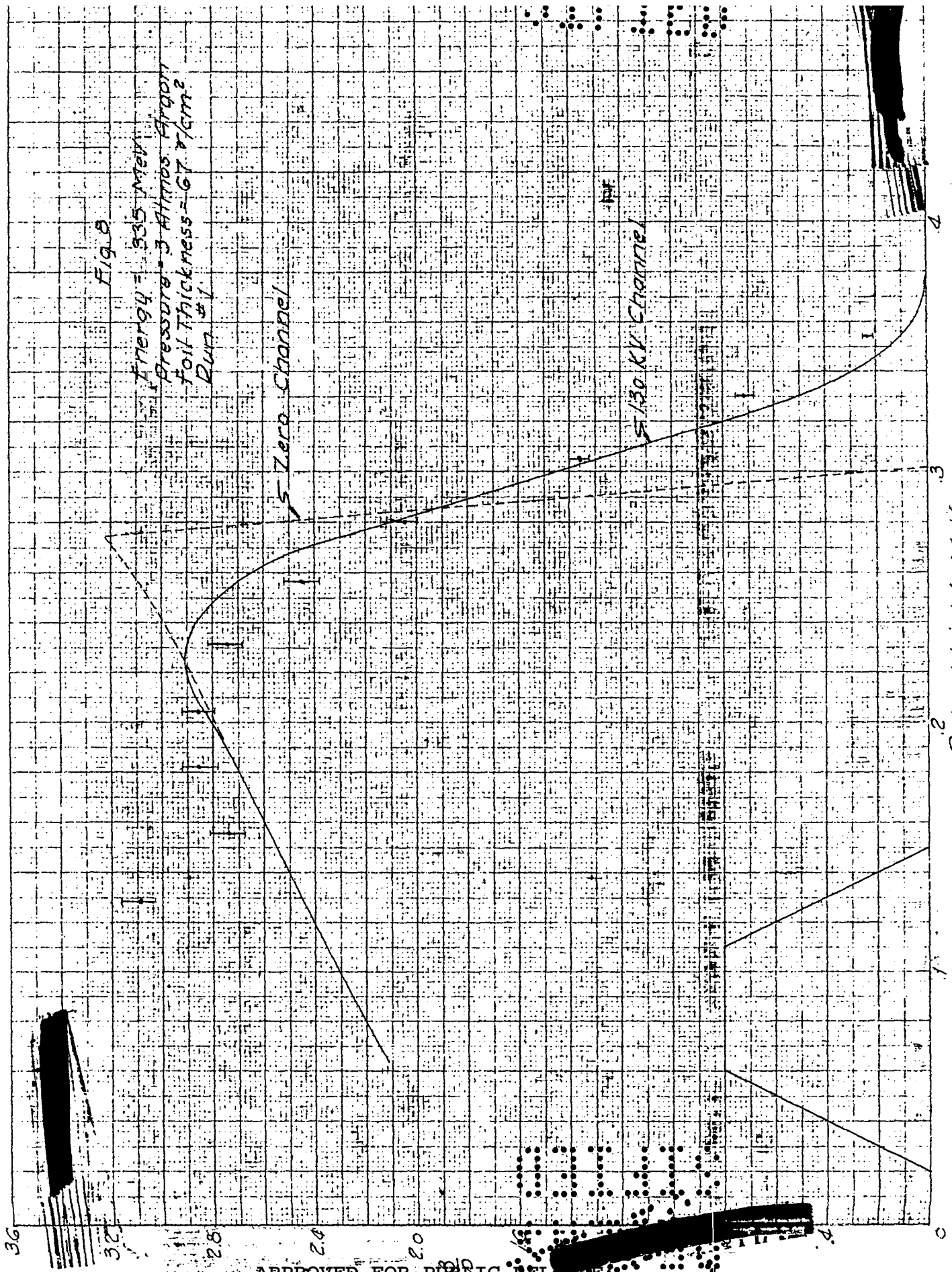


Fig 9

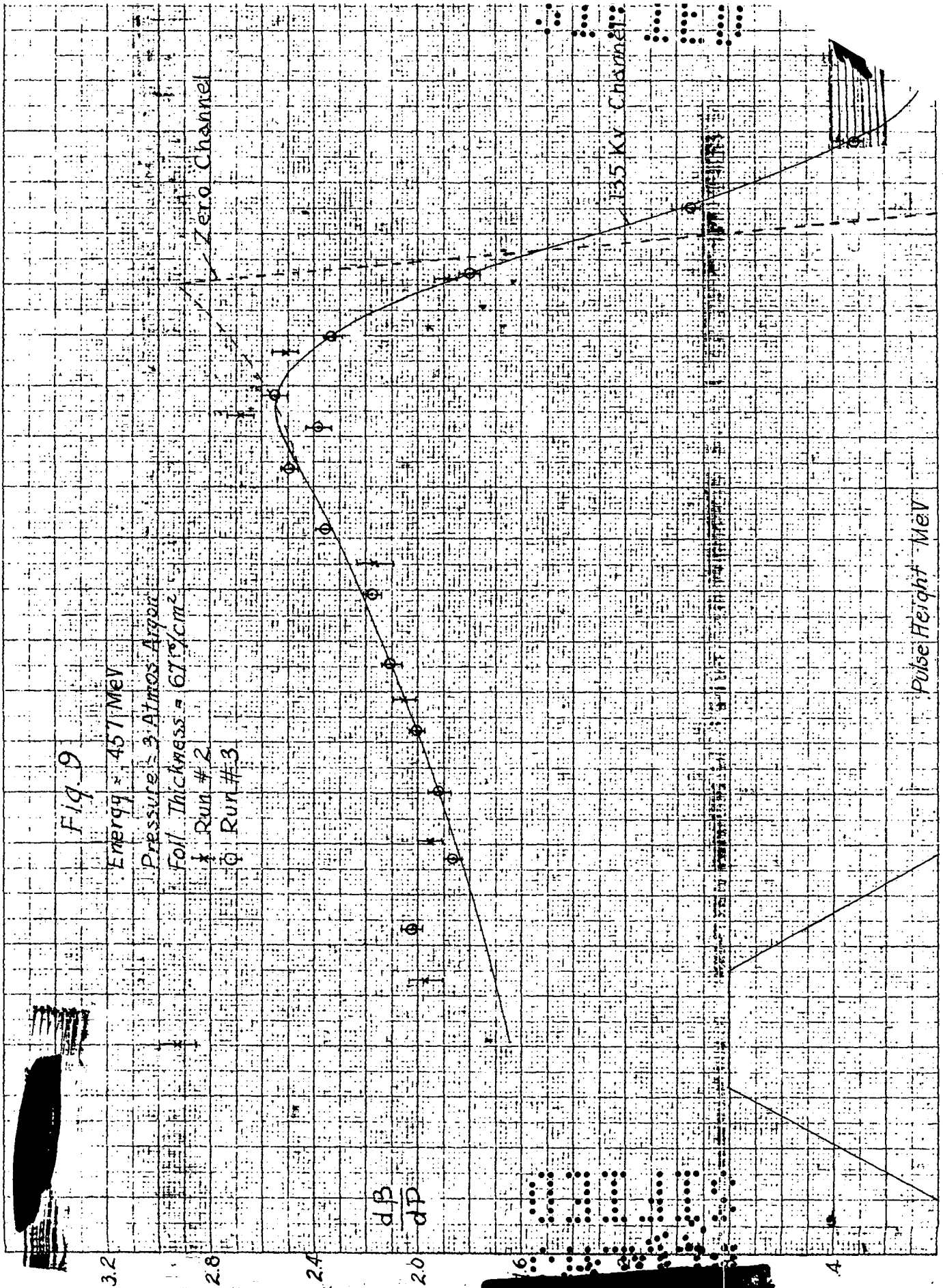
Energy = 457 MeV

Pressure = 3 Atmos Argon

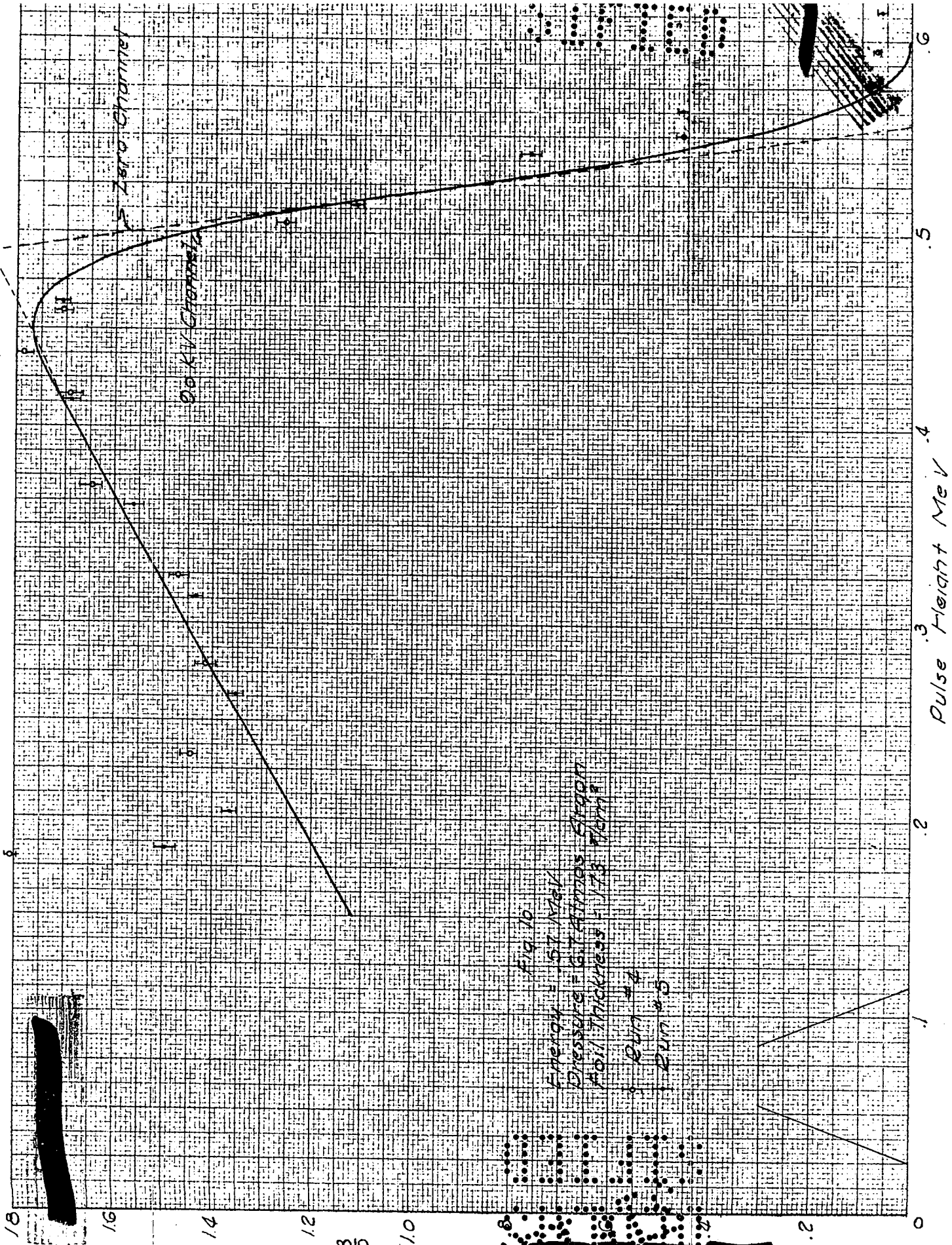
Foil Thickness = 67% cm<sup>2</sup>

Run #2

Run #3

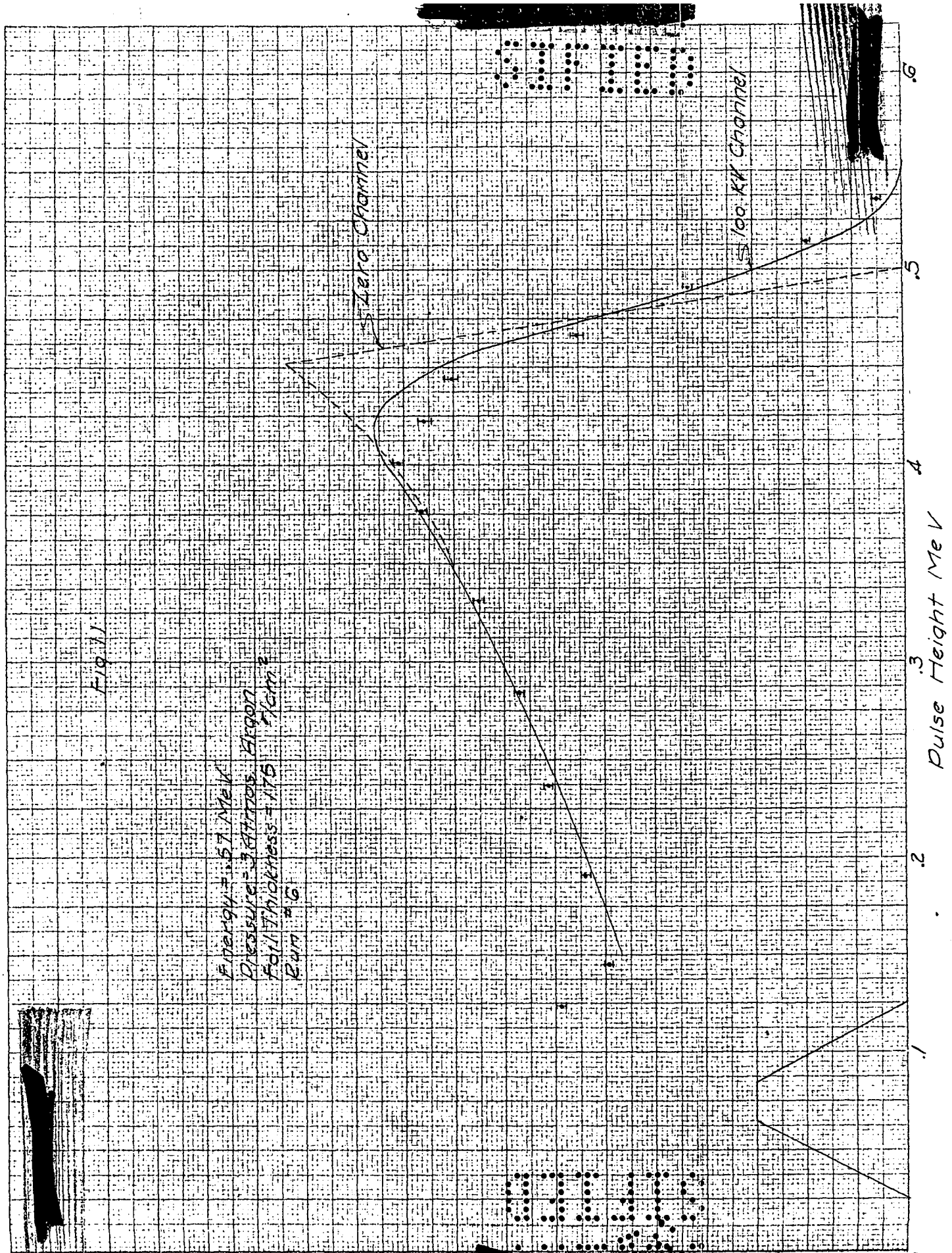


KEUFFEL & ESSER CO., N. Y. NO. 759-14  
Millimeter, 5 mm. lines inverted, cm. lines heavy  
© 1954 U. S. A.





NEUFF, J. ESSER CO., N. Y. NO. 33, 174  
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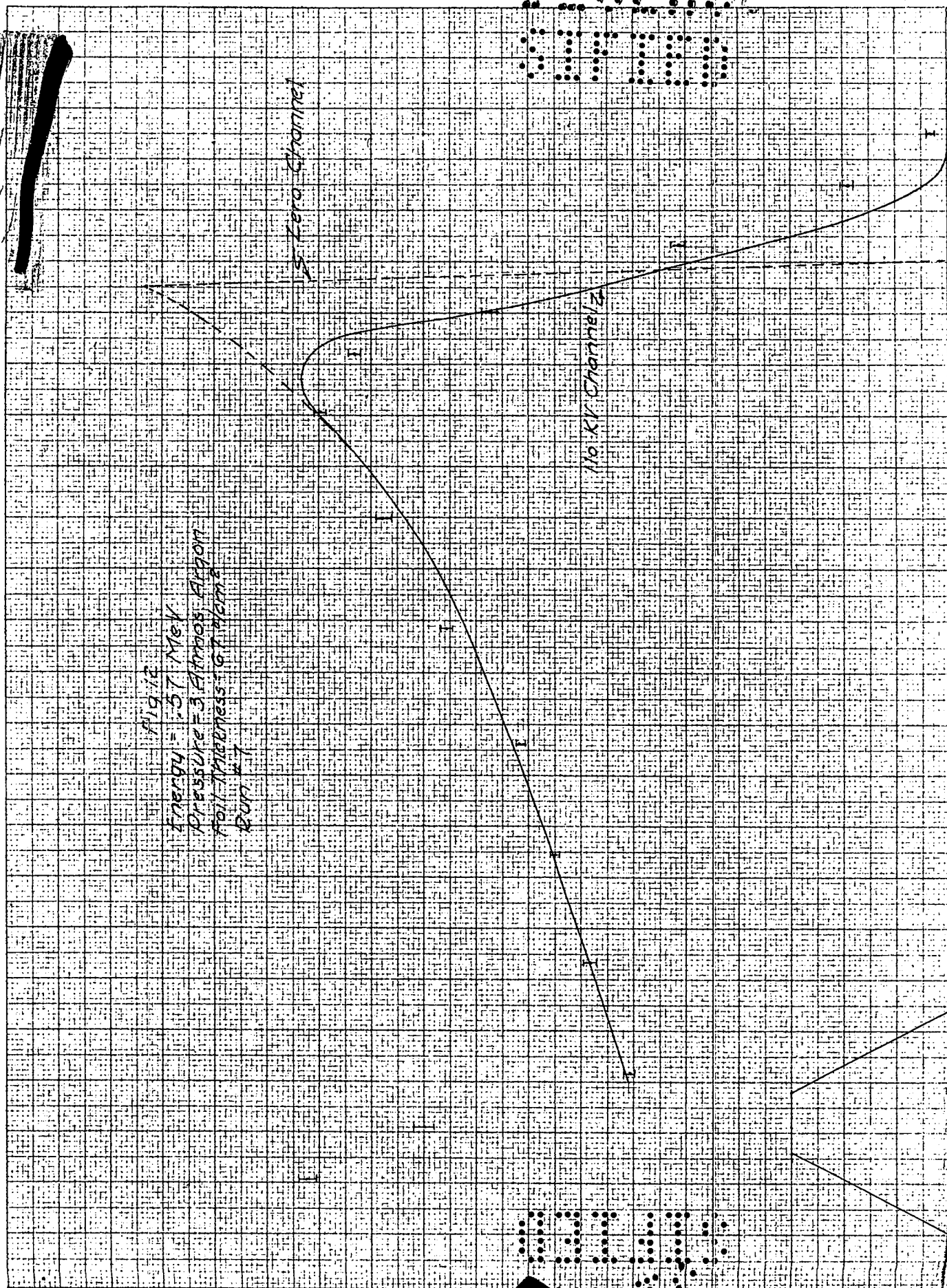


FIGURE  
 ENERGY = 57 MeV  
 PRESSURE = 3 Atmospheres  
 FOLIUM THICKNESS = 0.1 mils  
 BURN 47

15 KV Channel

10 KV Channel

3.2

2.8

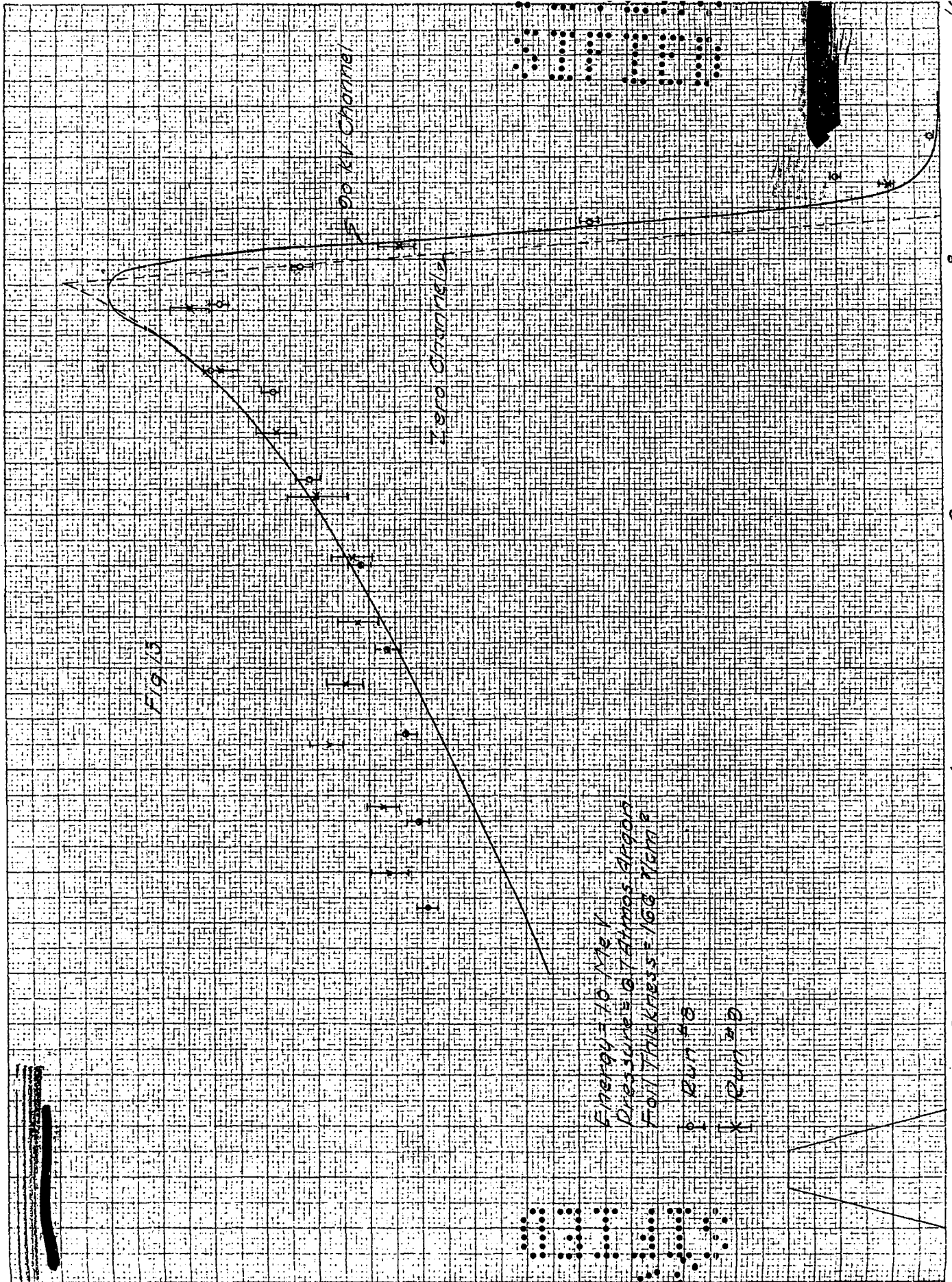
2.4

2.0

1.6

Oilso Height Mel 4

KUFFEL & ESSER CO. N. Y. NO. 753-14  
Manufacturers of high precision electronic equipment  
400 W. 11th St. N. Y. C.





KEUFFEL & ESSER CO., N. Y. NO. 350-14  
Millimeter, 5 mm lines vertical, cm, 1/16" - heavy  
5, 10, 15

Figure 14

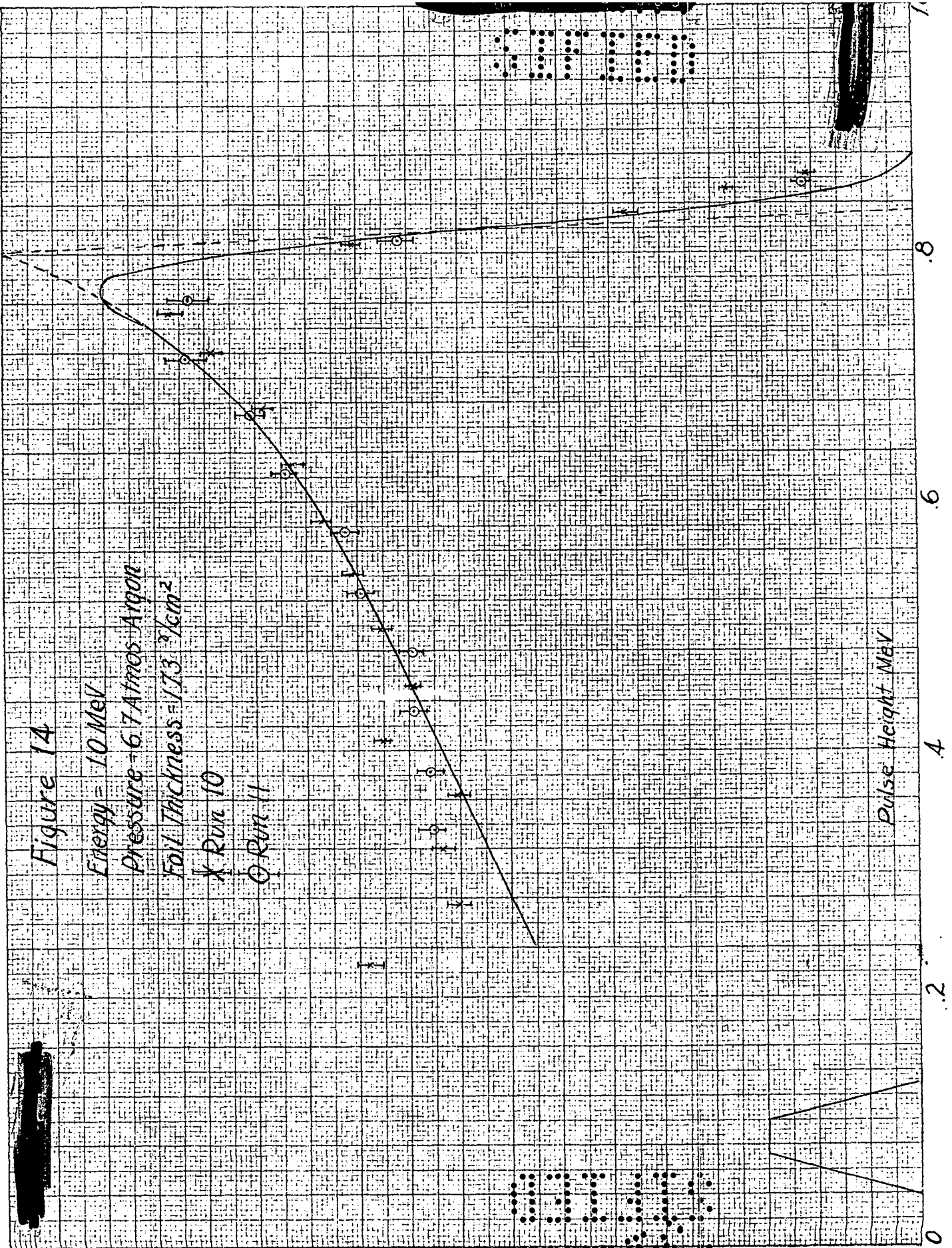
Energy = 10 MeV

Pressure = 6.7 Atmos Argon

Foil Thickness =  $113 \frac{3}{4} \text{ cm}^2$

X Run 10

O Run 11





KUFFEL & ESSER CO. N. Y. 90, 354-14  
Multiplex, 5 mm, line spacing, all 100 lines  
KUFFEL & ESSER

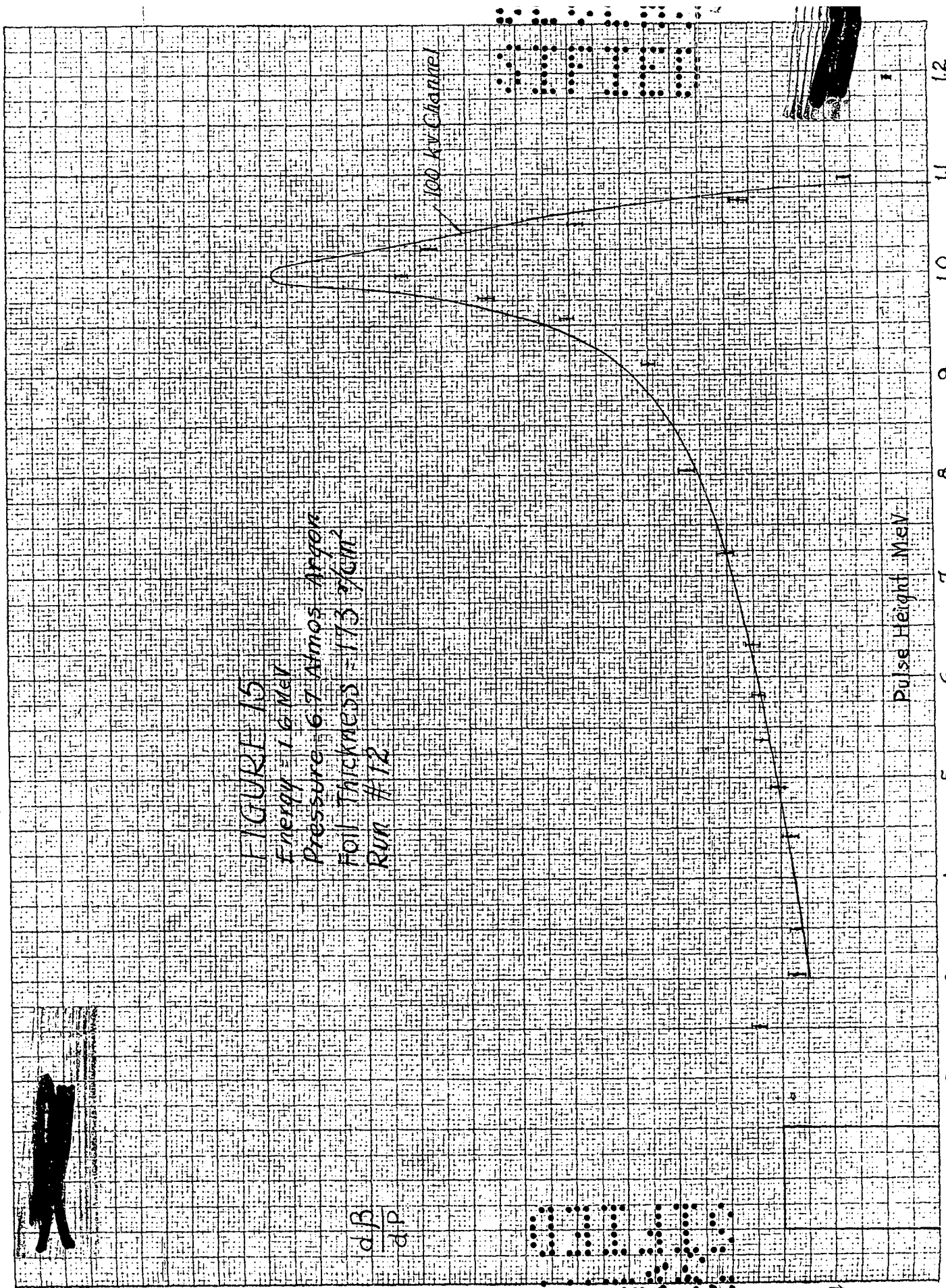


FIGURE 15

Energy 1.6 MeV  
Pressure 6.7 Atmos Argon  
Foil Thickness 173  $\mu$ GM  
Run #12

KUUFFEL & ESSER CO., N. Y. NO. 75-113  
Manufacturers of high precision instruments, etc., New York, N. Y.

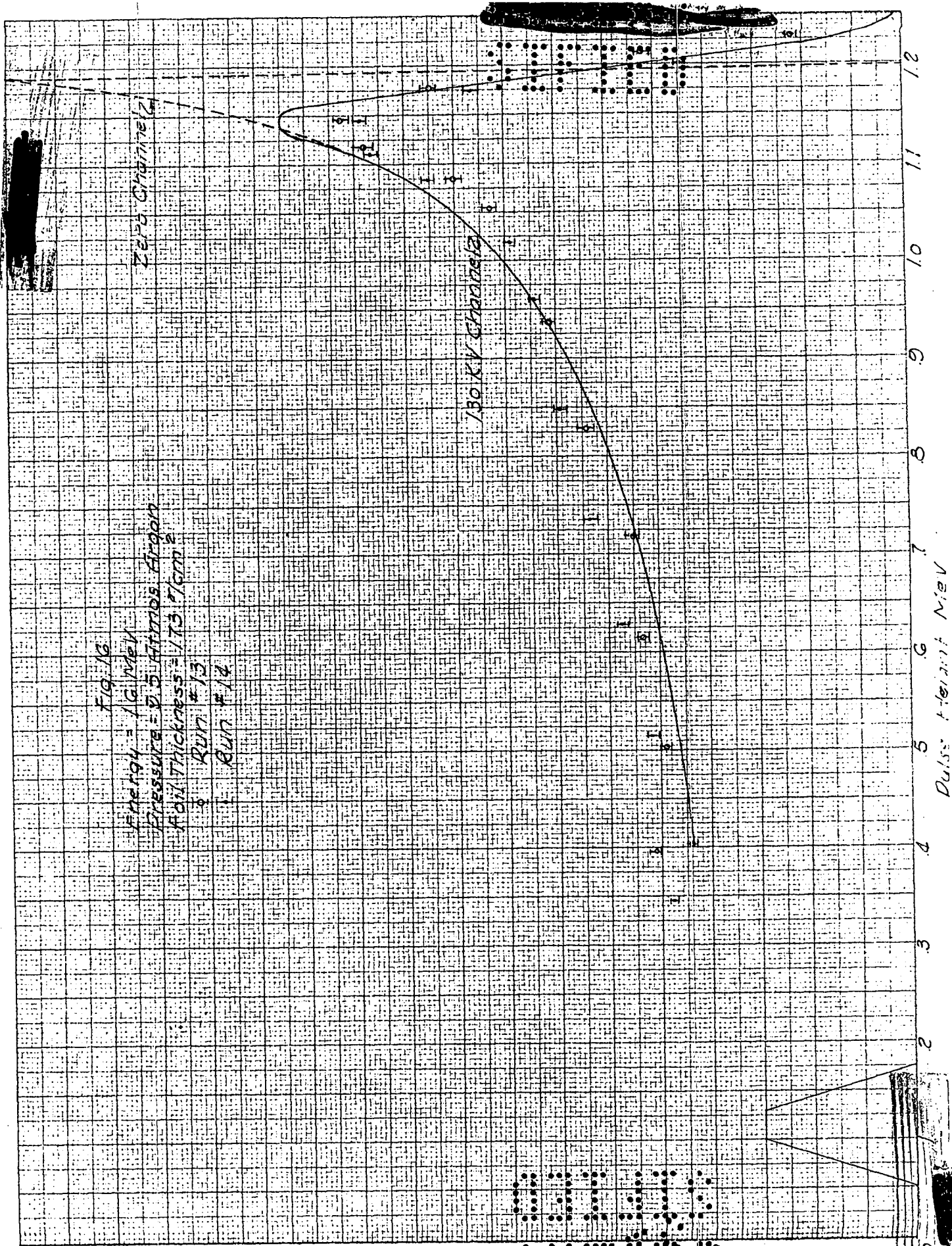
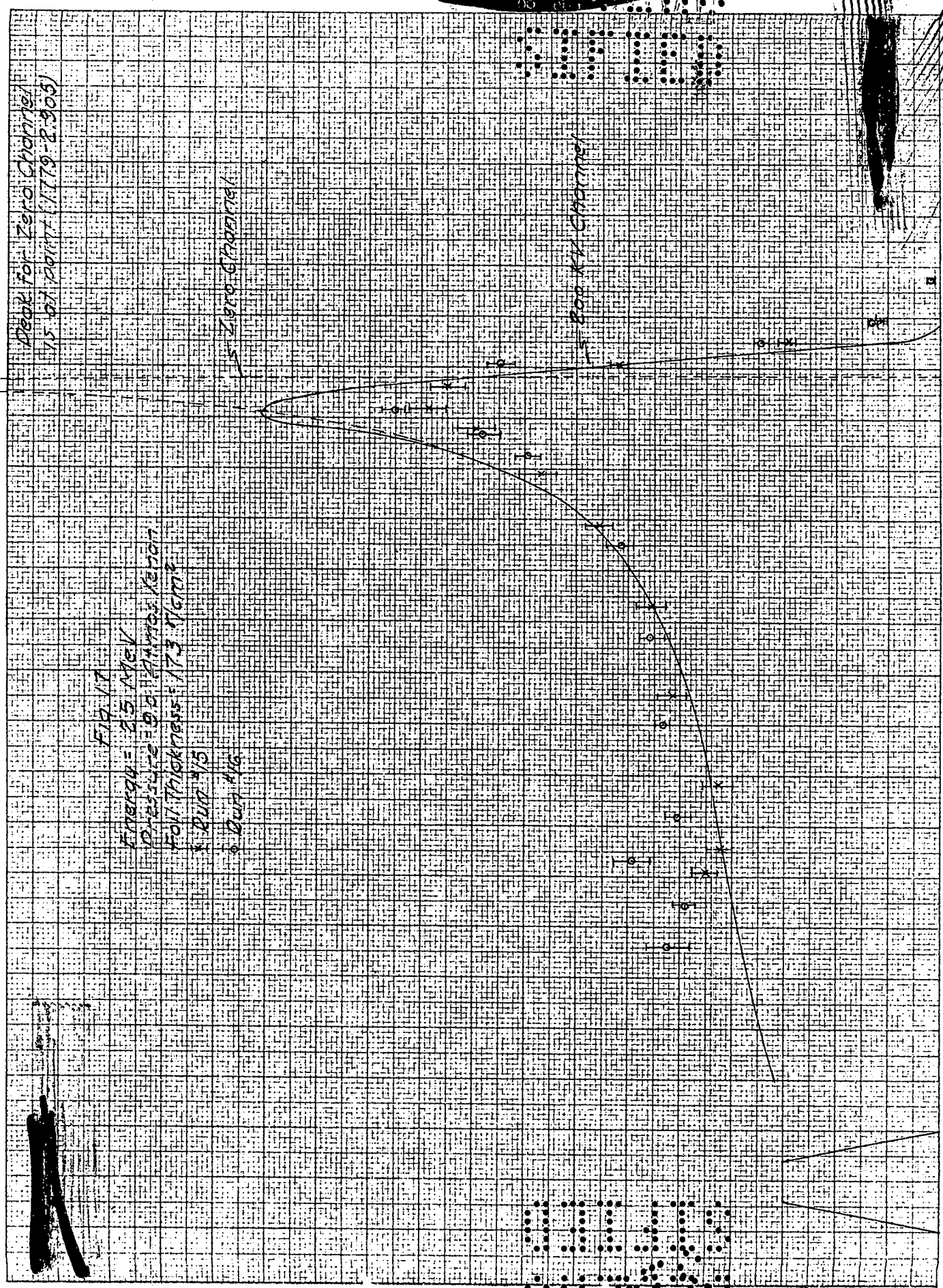


FIG. 13  
 Energy = 1 G.M.P.V.  
 Pressure = 0.5 Atmos. Argon  
 Film Thickness = 1.75 μgm.  
 Run #13  
 Run #14

KEUFFEL & ESSER CO., N. Y. NO. 359-14  
Millimeters, 8 mm, lines accurate .01 mm, lines heavy  
30-21 IN U.S.A.





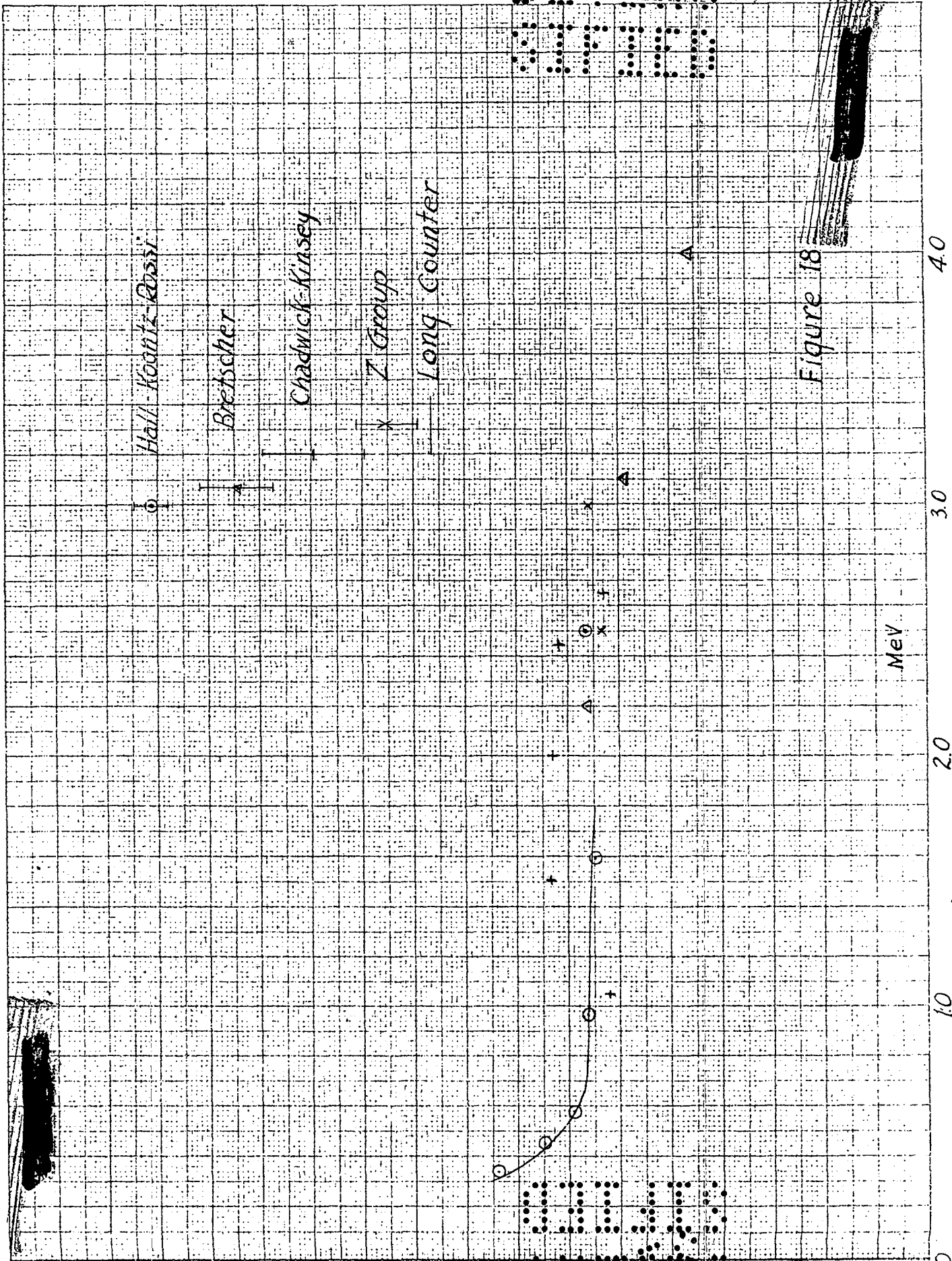


Figure 18

NUFELS & ESSER CO., 11 NO. 17014  
Alhambra, Calif. Has. Instruments, em. line. Army  
1954

KODAK SAFETY FILM  
Manufactured by Eastman Kodak Company

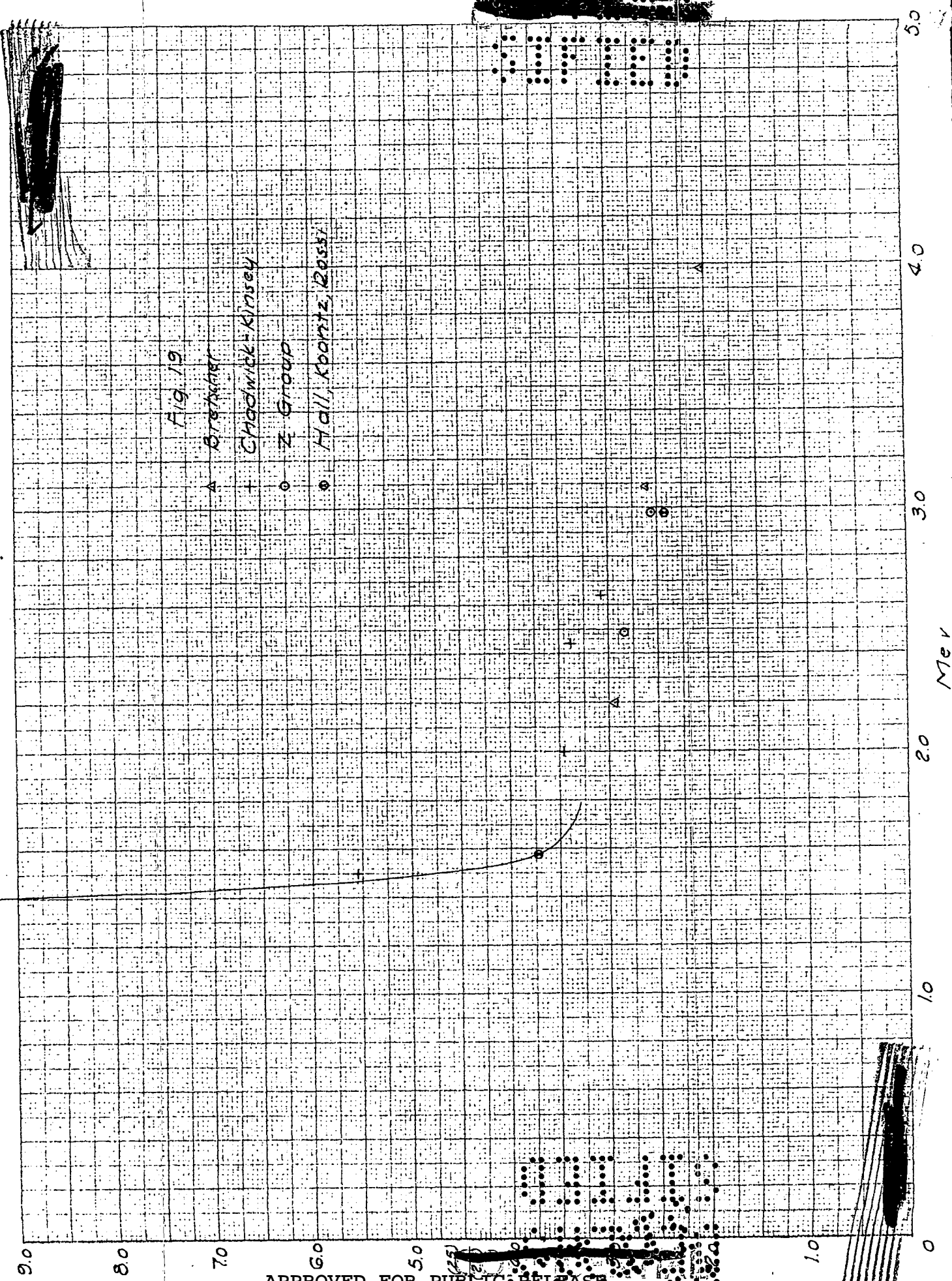
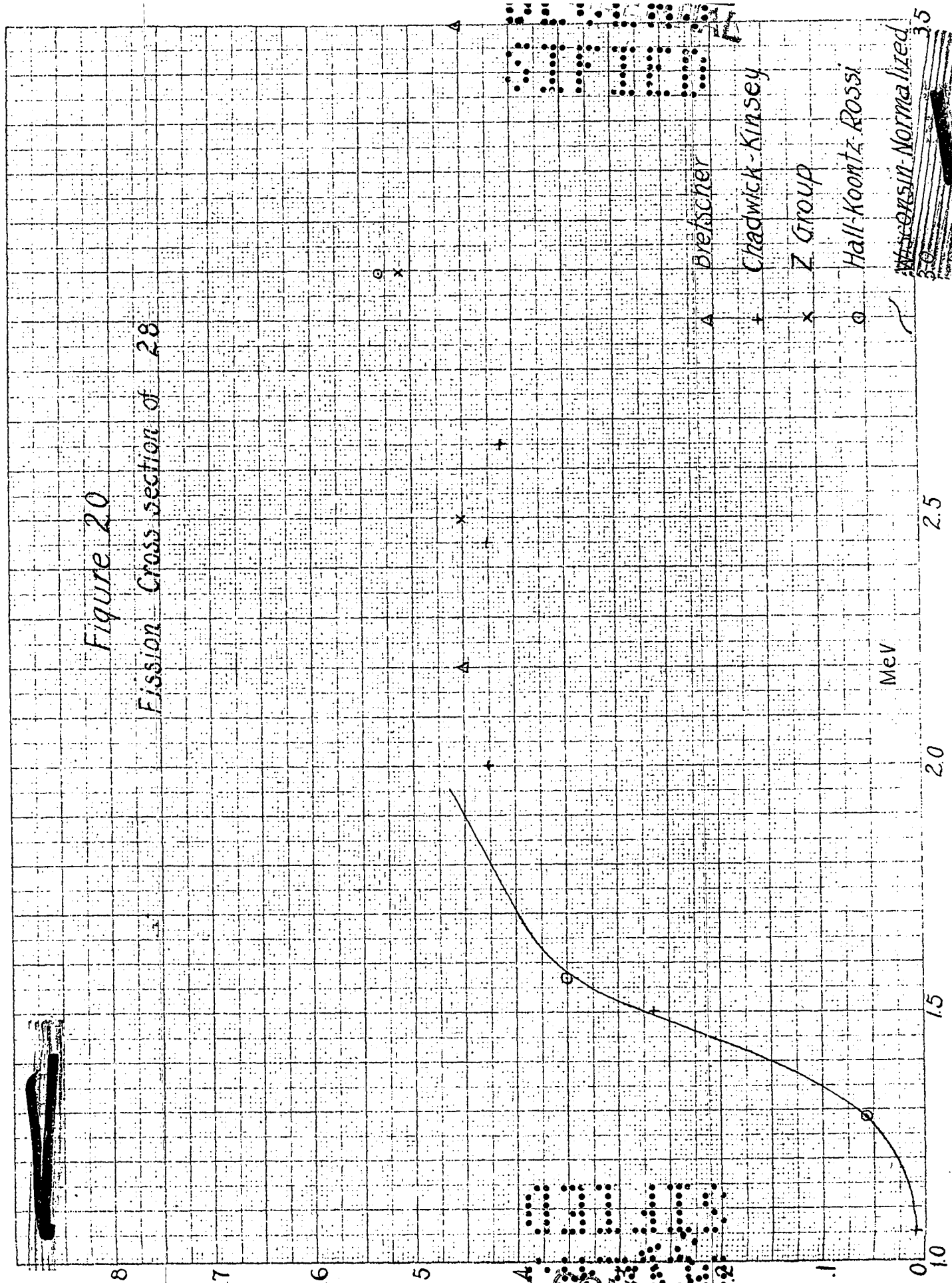


Figure 20  
Fission Cross section of <sup>238</sup>U



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