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THE DISINTEGRATION CROSS SECTION OF NITROGEN FOR FAST NEUTRONS

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ABSTRACT

The cross sections of the N(n,p)C and N(n,α)B reactions were measured for neutrons of from 0.2 to 1.7 Mev energy. Strong resonances were observed for neutron energies of 0.55, 0.70, and 1.45 Mev. The Q values of the two reactions were also obtained.

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THE DISINTEGRATION CROSS SECTION OF NITROGEN FOR FAST NEUTRONS

1. INTRODUCTION

Measurements on the cross section for the disintegration of nitrogen by fast neutrons appeared of interest mainly for estimates of the range of neutrons from the nuclear explosion in air. For the same purpose, measurements of the scattering of fast neutrons by nitrogen were planned. An interpretation of scattering data requires also a knowledge of the disintegration cross section. Another reason for wanting to know the disintegration cross section of nitrogen was a proposal by Feld to use the N(n,p) reaction for measuring the distribution in energy of the fission neutrons.

Many investigations of the disintegration of nitrogen by neutrons have been carried out in the past. The following reactions have been observed for neutrons of several Mev energy:

$$\text{(I)} \quad n + {}_7N^{14} \rightarrow {}_6C^{14} + p + Q_I$$

$$\text{(II)} \quad n + {}_7N^{14} \rightarrow {}_5B^{11} + \alpha + Q_{II}$$

Baldinger and Huber[1] measured the disintegration cross section of these reactions for 2.8 Mev neutrons and found for reaction I a cross section of 0.04 barns and, for reaction II, 0.16 barns. These authors give $Q_I = +0.55 \pm 0.03$ Mev and $Q_{II} = -0.43 \pm 0.1$ Mev. E. Wilhelmy[2] claimed the discovery of several resonances in the disintegration of nitrogen, but the experimental evidence presented has been subject to doubt. Several other authors have subsequently reported similar resonances, most recently Zagor and Valente[3] investigated these resonances in some

1) E. Baldinger and P. Huber, Helv. Phys. Acta 12, 330 (1939).

2) E. Wilhelmy, Zeits. f. Physik 107, 769 (1937).

3) H. I. Zagor and F. A. Valente, Phys. Rev. 67, 133 (1945). This paper contains also a good survey of the work done previously.

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more detail. These authors also made an attempt to find out which reaction is responsible for the resonances and attributed all resonances to reaction II. None of the authors except Baldinger and Huber[1] obtain any estimate of cross section. The evidence presented for the existence of resonances does not appear convincing, in particular the resonance energies found differ according to the various authors (cf. Table V of reference (3)).

In the present work an attempt was made to obtain a rough estimate of the disintegration cross sections of nitrogen as a function of neutron energy in the region of the fission spectrum.

2. APPARATUS

The nitrogen disintegrations were observed in a cylindrical ionization chamber with well defined active volume. The chamber was designed and constructed by Koontz[4]. The chamber was filled with spectroscopically pure nitrogen to a pressure of 4.52 atmospheres. The active volume of the chamber was 2.54 cm in diameter and 10 cm long. 860 volts obtained from batteries were applied between the central wire and the cylinder. The pulses were amplified by a semi-fast amplifier designed by Sands and fed into a pulse analyzer designed by Higinbotham. The pulse analyzer allows one to count all the pulses above a certain bias (integral count) and simultaneously the pulses the height of which lies between two biases (differential count). The differential channel could be moved to any position without changing its width. The overall response could be measured by artificial pulses fed into the high-voltage supply of the chamber. By this procedure the linearity of the amplifier and the width of the differential channel and its position with respect to the integral channel could be determined.

4) P. G. Koontz, forthcoming LA report on the scattering of fast neutrons by helium.

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The neutron flux was monitored by means of a high-sensitivity spiral chamber constructed by Bright. This chamber effectively contained about 19.0 mg of 25 and 15.6 mg of 28 for the amplifier biases used.

The Li(p,n) reaction served as a neutron source. The Li target was about 30 Kev thick. The nitrogen chamber and the monitor chamber were placed on opposite sides at an angle of 30° with respect to the proton beam.

The operation of the chamber was tested by placing it in a flux of slow neutrons obtained by slowing down the neutrons from a 500 mg Ra-Be source in paraffin. For slow neutrons only the N(n,p) reaction takes place. The differential bias curve obtained for slow neutrons is shown in Fig. 1. It shows a reasonably sharp peak. In order to determine the effect of gamma rays the Ra-Be source was replaced by a 500-mg Ra source. The pulse size distribution due to gamma rays is shown by the dashed curve in Fig. 1. It indicates that very few pulses as large as those due to the nitrogen disintegrations are reproduced by gamma rays.

For the measurement with fast neutrons, the nitrogen-filled chamber and the monitor chamber were covered with cadmium sheet 1/32" thick. In view of the fact that the monitor chamber did not have a good plateau its counting rate was checked before each run in a paraffin geometry using a Ra-Be source. The chamber had previously been calibrated in comparison with its counting rate in the same paraffin geometry.

3. RESULTS

It was originally planned to take measurements at only three neutron energies, but it became evident that the counting rate varied very rapidly with neutron energy so that it was necessary to change the neutron energy in small steps. At 14 values of energy, differential bias curves were taken. Three typical differ-

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ential bias curves are shown in Fig. 2. The counts at different neutron energies are normalized to the same number of monitor counts. At all other energies only integral counts were taken. At neutron energies below 1 Mev a well defined peak due to the disintegration protons appears (see curve for 750 Kev). At 1 Mev the range of the disintegration protons is approximately equal to the radius of the chamber. Because of this fact, the peak due to the protons becomes broader above 1 Mev. At 1.3 Mev a second peak due to the disintegration α-particles appears clearly above the γ-rays and nitrogen recoils.

The peak due to α-particles appears in Fig. 2 for the differential bias curves taken at 1.5 and 1.68 Mev. At the highest energy the wall effect for the protons becomes so important that the peak is not well resolved.

It should be mentioned that no direct evidence was obtained which proves that the peak of lower energy is due to α-particles and not to protons which might leave the C^{14} nucleus in an excited state. But since Baldinger and Huber[1)] found that at 2.8 Mev the (n,α) reaction is four times as probable as the (n,p) reaction one would expect to find evidence of the (n,α) reaction at 1.5 Mev. As will be shown later the energy of the observed particles agrees well with the assumption that they are α-particles.

The differential bias curves obtained enable one to determine the integral bias setting to count the protons and α-particles. At each neutron energy, all pulses counted above one bias were assumed to be due to protons, all pulses above a lower bias were assumed to be due to α-particles and protons. The choice of these biases was subject to considerable uncertainty, and the lack of definition of the peaks is the principal cause of error in the results.

The counting rate of the nitrogen chamber was compared with that of the monitor chamber. Using the known values of 25 and 28 fission cross sections as a

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function of energy, the cross section for the disintegration processes were computed. A summary of the results obtained on two different days are shown in Fig. 3. The (n,p) reaction shown resonances at 550, 700, and 1450 Kev. In the neighborhood of these resonances the counting rates fluctuated presumably because of small fluctuations in the neutron energy. The true width of the resonances may be narrower than measured, since the measured width corresponds to what one would expect due to the thickness of the Li target. On the basis of the same argument, the true height of the resonances may also be larger than measured. The (n,α) cross section was measured at only four neutron energies. The values are indicated by circles in Fig. 3. There is a definite indication (see also Fig. 2) that the (n,α) process shows a resonance at the same energy as the (n,p) reaction. This is to be expected, since both processes result from the disintegration of the same compound nucleus.

Errors in the measurements of the cross sections are due to the following facts:

1) Lack of definition of the peaks, principally because of wall effects,

2) Uncertainty in the calibration of the monitor chamber (a better calibration may be carried out in the future),

3) Lack of resolution of the resonances because of the energy spread of the neutrons,

4) Large size of the detectors compared to the distances from the neutron source.

It is difficult to estimate the error caused by these factors. It is not unreasonable to assume that values of the cross sections may be in error by 25%.

In Fig. 4 the positions of the peaks due to the two reactions are plotted as functions of neutron energy. The line through the pulse sizes of the (n,p) reaction intersects the axis of abscissae at -710 Kev. If one draws a line parallel to that for the (n,p) reaction through the (n,α) points the intersection occurs at

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260 Kev. In Table I the present results are compared with those computed from the isotopic masses given in the Project Handbook[5] and those obtained by other authors.

TABLE I

	Q(n,p) (Kev)	Q(n,α) (Kev)
Chicago Handbook[5]	605	-280
Bonner and Brubaker[6]	620	-300
Baldinger and Huber[1]	550	-430
Present measurements	710	-260

The values of Q obtained in the present measurements depend entirely on the energy calibration of the long electrostatic generator. The reasonable agreement with other measurements is evidence for the proper assignment of the observed peaks to the two reactions.

If one wants to compare the observed resonances with those previously reported one has to add the Q value to the neutron energy since in earlier work a continuous neutron spectrum was used and only the energy of the products was measured. Using the Q values from the present measurements this yields 1.26, 1.41, and 2.16 Mev for the (n,p) reaction, and 1.19 Mev for the (n,α) reaction. According to Table V of reference 3, resonances have previously been reported at the following energies: 0.60, 0.75, 0.90, 1.05, 1.25, 1.31, 1.33, 1.40, 1.42, 1.60, 1.64, 1.75, 1.94, 2.00, 2.04, 2.05, 2.15, 2.16, 2.25 Mev and at higher energies. Since these values form almost a continuum within the accuracy of the measurements, it is difficult to say which values found in the present work might correspond to those observed previously.

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5) CL-697, III A, 2.1.

6) Bonner and Brubaker, Phys. Rev., 49, 778 (1936) and 50, 781 (1936).

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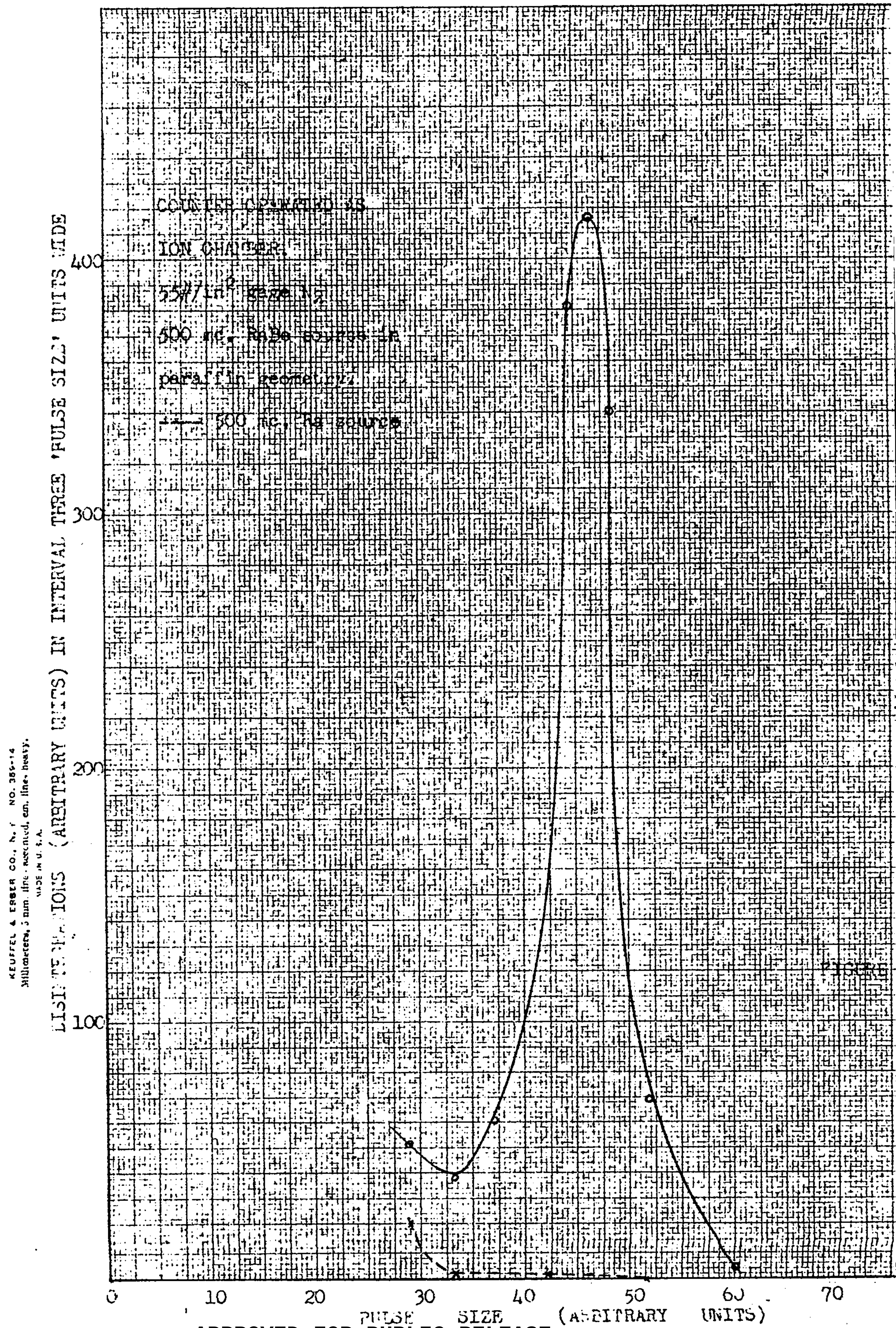

COUNTER OPERATED AS
ION CHAMBER.
55#/in² gage N_2
500 mc. RaBe source in
paraffin geometry.
500 mc. Ra source
400
300
200
100
0
10
20
30
40
50
60
70
PULSE SIZE (ARBITRARY UNITS)
DISINTEGRATIONS (ARBITRARY UNITS) IN INTERVAL THREE 'PULSE SIZE' UNITS WIDE
KEUFFEL & ESSER CO., N.Y. NO. 359-14
Millimeters, 5 mm. lines accented, cm. lines heavy.
MADE IN U.S.A.

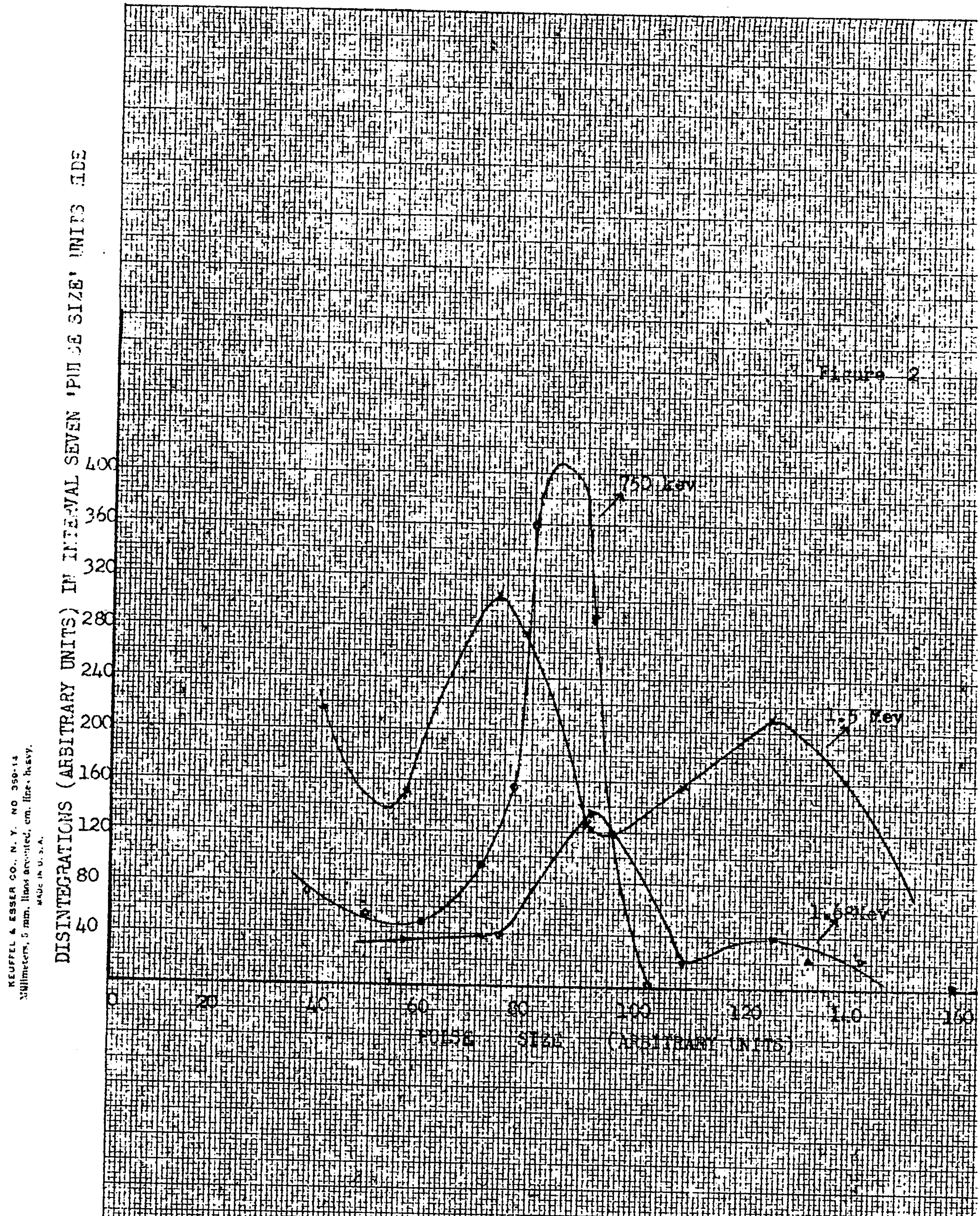
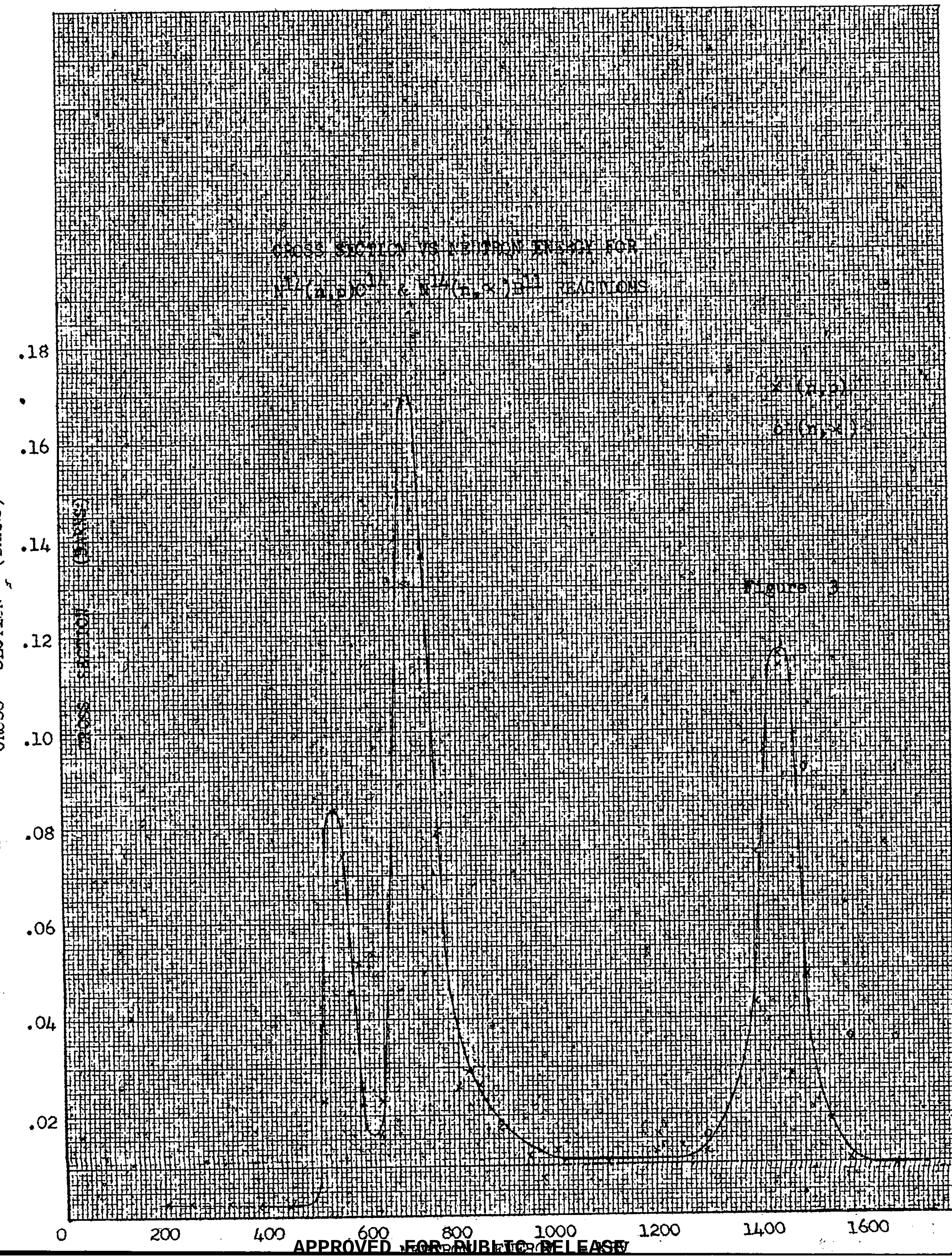
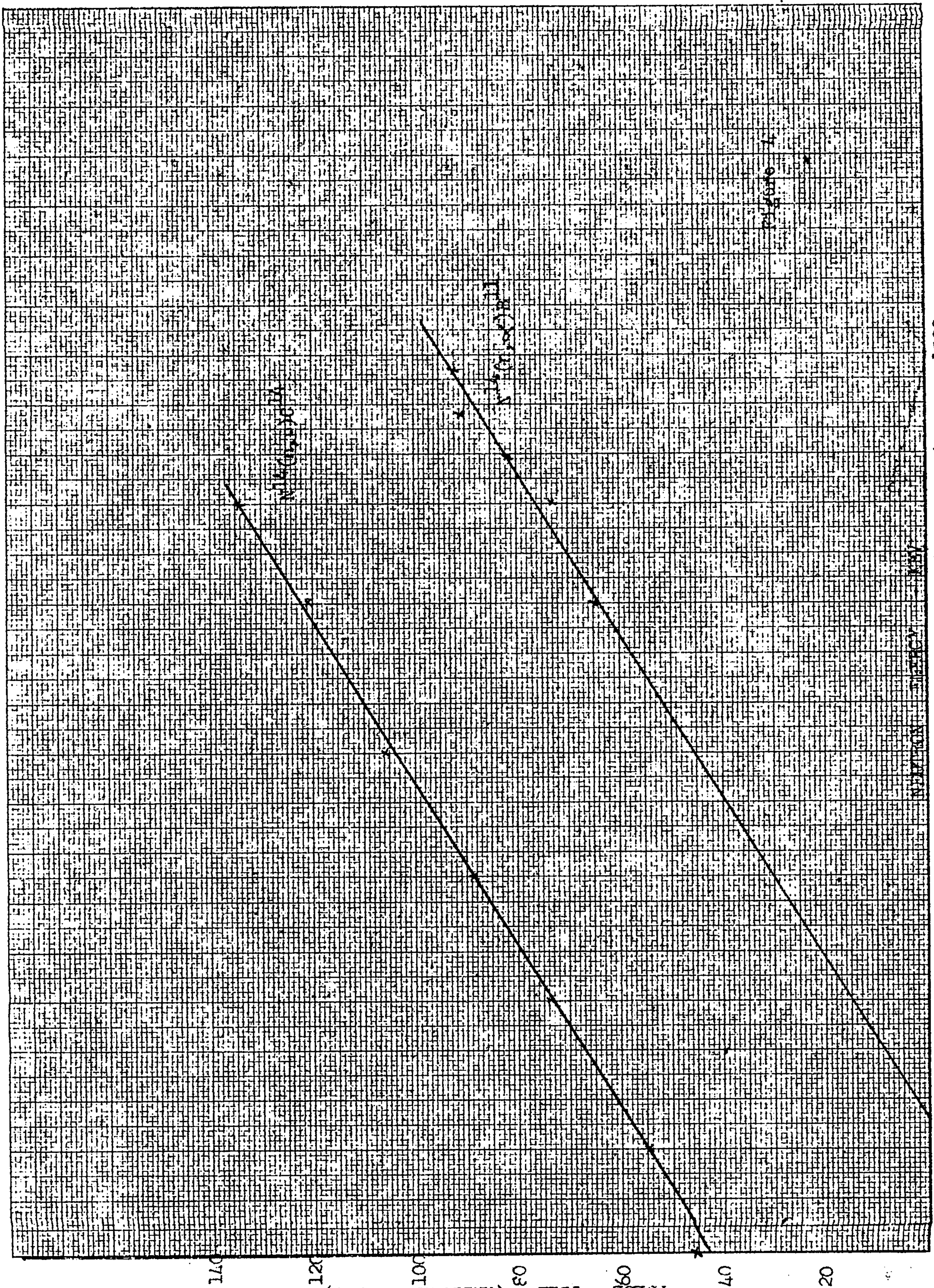

DISINTEGRATIONS (ARBITRARY UNITS) IN INTERVAL SEVEN 'PULSE SIZE' UNITS WIDE
400
360
320
280
240
200
160
120
80
40
0
20
40
60
80
100
120
140
160
PULSE SIZE (ARBITRARY UNITS)
750 kev
1.5 Mev
KEUFFEL & ESSER CO., N. Y. NO 359-14
Millimeters, 5 mm. lines accented, cm. lines heavy.
MADE IN U. S. A.

Figure 2



CROSS SECTION VS NEUTRON ENERGY FOR
$N^{14}(n,p)C^{14}$ & $N^{14}(n,\alpha)B^{11}$ REACTIONS
x (n,p)
o (n,α)
CROSS SECTION (BARNS)
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
200
400
600
800
1000
1200
1400
1600

Figure 3



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