UNCLASSIFIED

[redacted]

CLASSIFICATION CANCELLED
For The Atomic Energy Commisson
by the Declassification Officer
per Gilbert K. Campbell /BE

PUBLICLY RELEASABLE
Per Mark M. Jones FSS-16 Date: 3-13-96
By JDeB., CIC-14 Date: 4-2-96

LA-660

Series A

[redacted] c.3

27 February 1948

This document contains 18 pages.

THE (γ,n) CROSS SECTION OF BORON

Report Written By:

R. L. Walker

~~ment contains restricted data wi~~
~~omic Energy Act of the~~
~~meaning~~
~~information the Espionage~~
~~United States with its trans-~~
~~Act, 50 U.S.C.~~
~~velation of its co~~
~~missi an unauthorized person is pro~~
~~may result in severe criminal penalty~~

UNCLASSIFIED

[redacted]

UNCLASSIFIED

ACKNOWLEDGEMENTS

I am indebted to Mr. Glen Barbaras and Dr. W. P. Jesse for making the boron layers; to Mr. Leonard Treiman and Prof. Don Martin for making the polonium sources; and to Prof. H. H. Barschall for suggesting the experiment and interest in its progress.

[redacted]

UNCLASSIFIED

[redacted]

Abstract

The cross section for the $B^{10,11}(\alpha,n)N^{13,14}$ reactions was measured as a function of the alpha particle energy up to an energy of 5.3 Mev.

Resonances were observed at alpha particle energies of 1.8, 2.5, 4.2, 4.9 Mev. Poor resolution may explain why other resonances found by Maurer and by Fünfer were not observed.

[redacted]

The (α ,n) Cross Section of Boron

INTRODUCTION

Neutrons are produced when alpha particles strike boron, by the two reactions:

$$B^{11} + \alpha = N^{14} + n \qquad Q \approx + .28 \text{ Mev.}$$

$$B^{10} + \alpha = N^{13} + n \qquad Q \approx + 1.2 \text{ Mev.}$$

Reasons are given by Bonner and Mott-Smith[1] and by Maurer[2] for believing that only a small fraction of the neutrons from boron (of the order of one tenth) arise from B^{10}. Thus the principal neutron yield from boron due to alpha particle bombardment is probably due to the first reaction above.

Maurer[2] and Fünfer[3] have studied the $B^{10,11}(\alpha,n)N^{13,14}$ reactions at different alpha particle energies for the purposes of locating resonances, determining upper limits for their widths and determining the level spacing of the intermediate nucleus for the first reaction, N^{15}.

In the present work a measurement of the cross-section for the $B^{10,11}(\alpha,n)N^{13,14}$ reactions was made by determining the number of neutrons emitted from a thin boron target upon which are incident a known number of alpha particles of variable energy.

---

1. T. W. Bonner and L. M. Mott-Smith: Phys. Rev. 46, 258, 1934
2. W. Maurer: ZS. f. Phys. 107, 721, 1937
3. E. Fünfer: Ann der Phys. 35, 147, 1939

EXPERIMENTAL ARRANGEMENT

The conventional arrangement shown in Fig. 1 was used as a means of controlling the energy of the alpha-particles striking the boron target. Alpha particles from polonium coated on the small central sphere, 5 mm in diameter, lose a part of their energy in nitrogen gas before striking the thin boron target coated on the inside of two hemispherical iron spinnings, 7.5 cm in diameter. By changing the pressure of nitrogen in the chamber one can control the energy of the alpha particles when they reach the boron.

The assembly shown in Fig. 1 was placed in a graphite column containing a sensitive BF_3 proportional counter, in order that the number of neutrons emitted by the boron might be measured as a function of the nitrogen pressure in the chamber. The neutron measurement will be described later.

Data on the polonium sources and the boron targets used are collected in Tables I and II. The polonium sources were made by Mr. Leonard Treiman of Dr. Martin's group at Los Alamos. The sources were placed in the nitrogen atmosphere of the chamber immediately after the polonium was deposited in order to avoid oxidation, and all the data were taken within one or two days thereafter. The sources were then returned to Mr. Treiman, who measured their strengths by a calorimeter method.

The boron layers were coated on the iron hemispheres by Mr. Glenn Barbaras and Dr. W. P. Jesse at the Metallurgical Laboratory of the University of Chicago. In the process used, both sides of the hemispheres were coated. Since only the total amount deposited could be found by weighing, the weight of boron on the inside surface, as shown in Table II, involves an estimate that 55% of the total weight was on the inside.

[redacted]

[redacted]

TABLE I

Po source	Strength when made (curies)	Thickness (curies/cm^2)	Thickness (cm air equivalent)*
1	1.55	1.96	0.11
3	0.48	0.61	0.033

*Using 4.2 for the atomic stopping power of polonium relative to air for alpha particles of energy near 5 Mev.

TABLE II

Boron Layer	Total weight of boron on inside surface	Thickness mg/cm^2	Equivalent air thickness*
"Thicker Boron"	.056 gm	0.31	0.33 cm air
"Thinner Boron"	.031	0.18	0.18

*Using 0.94 for the atomic stopping power of boron relative to air.

ALPHA PARTICLE ENERGY. RESOLUTION.

The alpha particle energy corresponding to a given pressure of nitrogen in the chamber was found from the range-energy relation given by Holloway and Livingston[4], assuming the atomic stopping power of nitrogen relative to air to be 0.99.

---

[4] M. G. Holloway and M. S. Livingston: Phys. Rev. 54, 18, 1938

[redacted]

[redacted]

The resolution was limited by the spread in the energies of the alpha particles resulting from the finite thickness of the boron target, the thickness of the polonium source, the straggling of the energy loss, and the differences in the geometrical path lengths through the nitrogen gas. In Table III are listed estimates of the loss of resolution due to these causes. The effect of the source thickness was calculated assuming the polonium layer to be pure and of uniform thickness. The energy spread listed is such that, under the assumed conditions, about 90% of the alpha particles emitted have energies differing from the maximum energy by less than the amount listed.

NEUTRON MEASUREMENT

The chamber containing the Po source and boron target was placed on the axis of a large graphite column (approx. 5 x 5 x 9 feet) with a sensitive BF_3 proportional counter about 58 cm away from the chamber, also on the axis of the column. With this separation between the neutron source and slow neutron detector, the counting rate is relatively insensitive to the primary energy of the neutrons emitted by the source, being approximately proportional to the number of neutrons emitted per second. Assuming this proportionality to be exact, the neutron measurement is easily made absolute by observing the counting rate of the BF_3 counter when the polonium alpha particle source is replaced by a Ra + Be neutron source of known strength. In this way, the number of neutrons emitted from the boron under alpha particle bombardment was measured as a function of the pressure of nitrogen in the chamber. Data are shown in Fig. 2 for three combinations of Po source and boron target, corresponding to different energy resolutions. The probable error in the absolute calibration of the Ra + Be source used as a standard was about 5 per-cent.

[redacted]

TABLE III RESOLUTION

Alpha particle energy	Energy spread due to source thickness		Straggling of energy loss	Energy loss in boron target		Energy spread due to the difference in path lengths
	Po source #1	Po source #3	Mev.	Thicker boron	Thinner boron	
1 Mev.	0.5 Mev	0.13 Mev	0.11	0.72 Mev	0.41 Mev	0.32 Mev
2	"	"		0.60 "	0.34 "	0.24 "
3	"	"		0.46 "	0.26 "	0.14 "
4	"	"		0.40 "	0.22 "	0.07 "
5	"	"	0.03	0.32 "	0.18 "	0.01 "

Background of neutrons from impurities in the Po source, from the nitrogen gas, or from the iron hemispheres upon which the boron was deposited, was measured by replacing the boron coated hemispheres with uncoated iron ones. Background from possible polonium contamination on the boron target was measured by removing the Po source, and counting the neutrons still present. These measurements include, of course, the background of the counter when no source is present in the graphite column. The background due to all causes was small as may be seen from Fig. 2.

The use of slow neutron measurements in a graphite column to obtain the approximate ratio of the strengths of two neutron sources, even though their energies may be different, is based upon an analysis which may be briefly outlined as follows.

According to elementary age theory of the slowing down process[5], if a source of neutrons of a single energy is placed in an infinitely large block of graphite, the spatial distribution of neutrons just reaching thermal

---

[5] See, for example, E. Fermi, Neutron Physics (Los Alamos Lecture Notes)
R. E. Marshak: Rev. Mod. Phys. 19, 185, 1947

[redacted]

energies, or the density of nascent thermal neutrons, q, is a Gaussian,

$$q = \frac{Q}{\pi^{\frac{3}{2}} r_0^3} e^{-\frac{r^2}{r_0^2}}$$

where Q is the number of neutrons emitted per second by the source.

The parameter of the Gaussian is $r_0 = 2\sqrt{\tau}$ where τ is the neutron age. The age τ is closely related to the primary energy of the neutrons, and becomes larger as the primary energy increases. Age theory is, of course, only an approximation, and the distribution of nascent thermal neutrons, q, is not a perfect Gaussian. However, for the present application, the exact form of the distribution q is not important, but only the amount of "spreading out" of the neutrons from the source during the slowing down process. In practice, a measured distribution, q, can usually be represented satisfactorily by a sum of two or three Gaussian terms having different parameters, r_0.

If the graphite block in which the neutrons are slowed down is not infinite in size, the distribution of nascent thermal neutrons must satisfy boundary conditions that the neutron density vanish at the sides of the block. The Age Theory result for a source on the axis of a graphite column of large height and square cross section of side a is:[6]

$$q = \frac{4Q}{a^2 r_0 \sqrt{\pi}} e^{-\frac{Z^2}{r_0^2}} \sum_{\substack{n,m=1 \\ \text{odd integers}}}^{\infty} e^{-(n^2+m^2)\frac{\pi^2 r_0^2}{4a^2}} \cos\frac{n\pi x}{a} \cos\frac{n\pi y}{a}$$

The origin of coordinates is at the position of the source, and the Z-axis coincides with the axis of the column.

---

[6] E. Fermi: Neutron Physics (Los Alamos Lecture Notes)

[redacted]

[redacted]

The above distribution is characterized by the same parameter, $r_o = 2\sqrt{\tau}$, which appears in the simple Gaussian distribution for an infinite medium, and which serves as a measure of the amount of "spreading out" of the neutrons from the source during their slowing down.

The function q gives the distribution of neutrons just reaching thermal energies, and thus represents the source of thermal neutrons in the graphite block. It may thus be inserted as the source function in the thermal neutron diffusion equation, and this diffusion equation solved with the boundary conditions that the neutron density vanish at the sides of the block.

In this way one may calculate the flux, nv, of thermal neutrons at any point in the graphite, as a function of the parameter r_o in the source function q. In Fig. 3 are shown the results of such a calculation for four different distances from the source on the axis of the graphite column used in the present experiment.

By choosing a distance from the source for which the curve is as flat as possible over a large range in r_o, one may assume that the density of thermal neutrons at this position will be approximately proportional to the total source strength, Q, and will be insensitive to the primary energy of the neutrons.

For the distance between source and detector, $z = 58$ cm, used in this experiment, the thermal flux curve is seen to be flat within about ten per cent for parameters $r_o \leqq 45$ cm. Unfortunately it is not possible to say that this corresponds to a definite primary energy of the neutrons. According to the Age Theory approximation, $r_o \simeq 42$ cm for neutrons of 4 Mev. primary energy, in graphite, and increases only slowly with further increase in primary energy. However, if the actual distribution arising

[redacted]

[redacted]

from a source of 4 Mev. neutrons were expressed as a sum of two or three Gaussian terms, one of them would probably have a parameter, r_o, considerably larger than 42 cm. This means that the value of the strength of a neutron source of energy 4 Mev., or greater, would probably be too low if measured by comparing the thermal neutron flux from this source at a distance $z = 58$ cm with the flux at the same position due to a standard source of lower energy.

The Ra +Be source used as a standard in the present experiment is not a "standard of lower energy", of course, since the spectrum of neutrons from a Ra +Be source extends to quite high energies. However, the distributions of nascent thermal neutrons, q, from various Ra +Be sources have been measured experimentally so that the flux of thermal neutrons may be calculated with fair accuracy. The result for one particular Ra+ Be source at a distance $z = 55.6$ cm is indicated in Fig. 3. Since the flux from this Ra +Be source is seen to be 10 or 15 per cent below that calculated for a source function with small r_o , the value of the boron (α ,n) cross section may be too high at the low energy end by about this amount.

The highest neutron energy which is important in the present measurements in 5.2 Mev. This is the energy of a neutron emitted in the forward direction by a 5.3 Mev. alpha particle striking a B^{11} nucleus, and leaving the residual nucleus, N^{14}, in its ground state. Thus the measured cross section as shown in Fig. 4 may be relatively low at the high energy end.

THE CROSS SECTION

In Fig. 4 is shown the cross section for the $B^{10,11}(\alpha,n)N^{13,14}$ reactions as a function of the alpha particle energy. The energy was taken to be the average energy of alpha particles in the boron layer, taking into account energy losses in the Po source and in the boron layer, as well as

[redacted]

[redacted]

in the nitrogen gas. Because of poor resolution, the cross section shown in Fig. 4 at a given energy is, of course, an average over a small energy interval determined by the resolution width.

The cross section is:

$$\sigma = \frac{I}{NS}$$

where I = number of neutrons emitted per second.
S = number of alpha particles striking the boron per second.
N = thickness of the target in boron atoms/cm^2.

The alpha particle energies corresponding to the four resonances suggested by curve 3 of Fig. 2 are listed in Table IV. For comparison are listed the eight resonances observed by Maurer[2] and those resonances observed by Fünfer[3] with Th C' alpha particles, which lie below 5.3 Mev.

TABLE IV

Energy of the alpha particles at resonance.

Present Paper	Maurer*	Fünfer
1.8 Mev.	1.90 Mev.	
2.5	2.68	2.65 Mev.
	3.15	3.25
	3.59	3.60
4.2	4.26	4.10
	4.55	4.45
4.9	4.85	4.73
	5.02	5.08

*These energies, which differ slightly from those listed by Maurer, were found from Maurer's ranges using the newer range energy relation given by Holloway and Livingston[4].

[redacted]

[redacted]

The fact that fewer resonances were observed in the present experiment than were found by Maurer and by Fünfer may be due to the relatively poor resolution indicated in Table III.

From the cross section, σ, as a function of the alpha particle energy shown in Fig. 4, the total neutron yield from Po alpha particles on a thick boron target has been calculated. The result is, for the thick target yield:

19 neutrons per 10^6 Po alpha particles.

This is in good agreement with the value of 22 neutrons per 10^6 Po alpha particles measured directly by Roberts[7] and 19 neutrons per 10^6 Po alpha particles found by Segre and Wiegand[8].

An estimate of the probable error in the cross section shown in Fig. 4 would be about 20 per cent.

---

[7] J. H. Roberts: Manhattan Project Report CF-864

[8] E. Segre and C. Wiegand: Los Alamos Declassified Report LADC-61

[redacted]

[redacted]

CAPTIONS

Fig. 1. Experimental arrangement of the alpha particle source and the boron target.

Fig. 2. Number of neutrons emitted in the $B^{10,11}(\alpha,n)N^{13,14}$ reactions as a function of the pressure of nitrogen in the chamber.

Fig. 3. Flux of thermal neutrons as a function of the parameter r_o, of the source function. Z is the distance from the source along the axis of the graphite column. The arrow marked "Ra + Be" indicates the value of $\frac{nv}{q}$ calculated from a measured distribution q for one Ra +Be source, at $z = 55.6$ cm.

Fig. 4. Cross section for the $B^{10,11}(\alpha,n)N^{13,14}$ reactions as a function of the energy of the alpha particle.

[redacted]

[redacted]

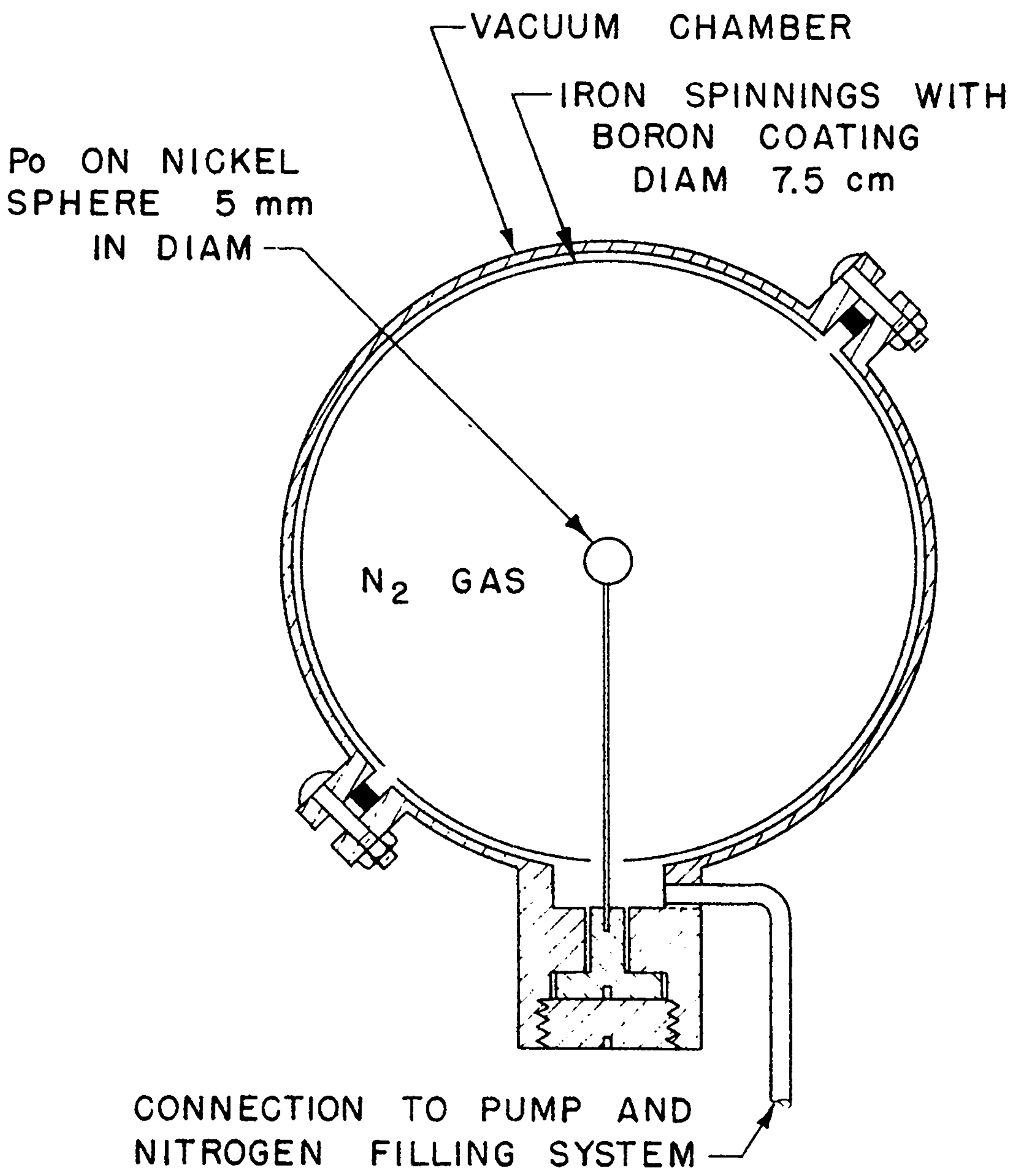
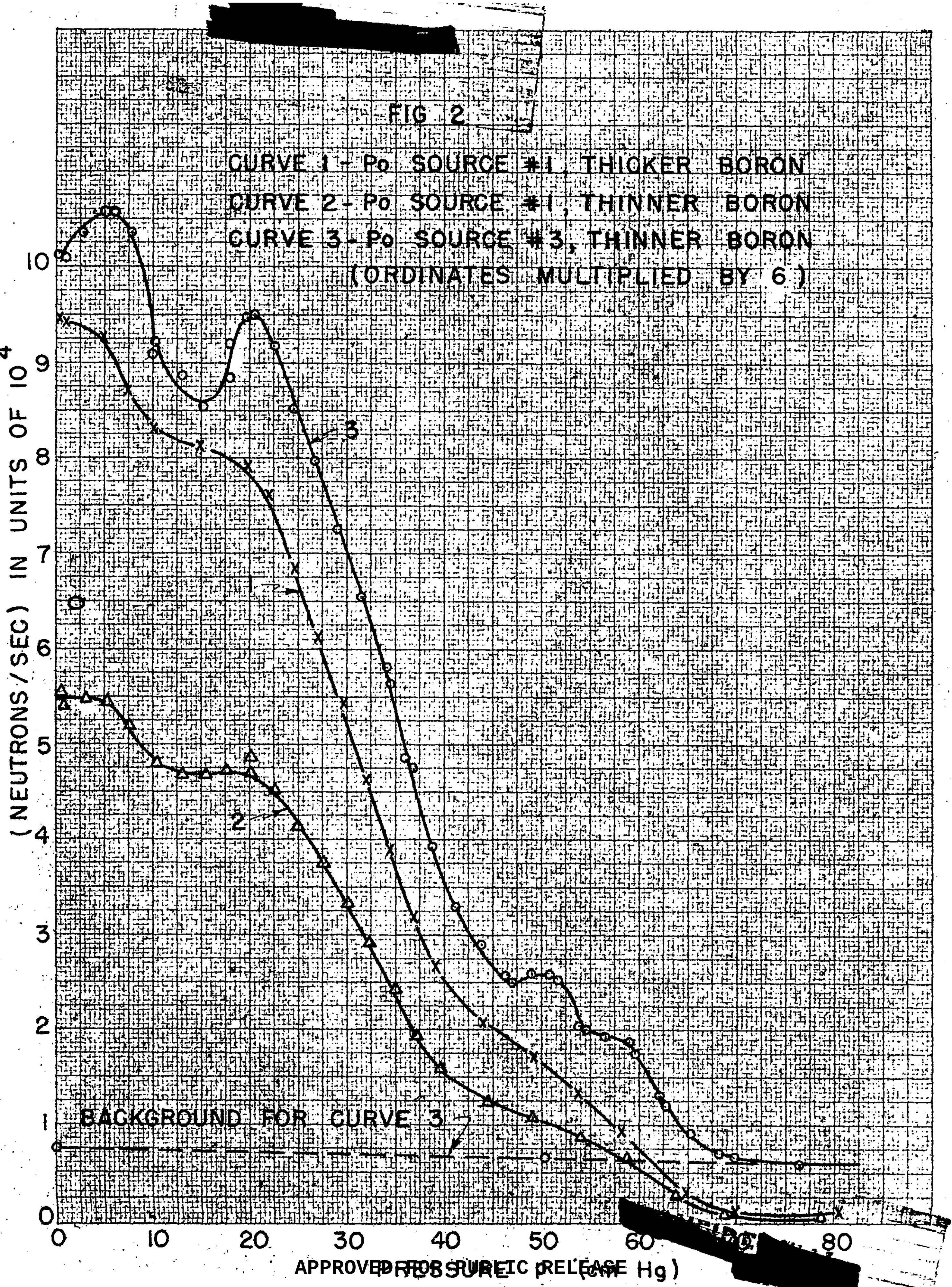


FIG I

[redacted]

[redacted]

FIG 2



[redacted]

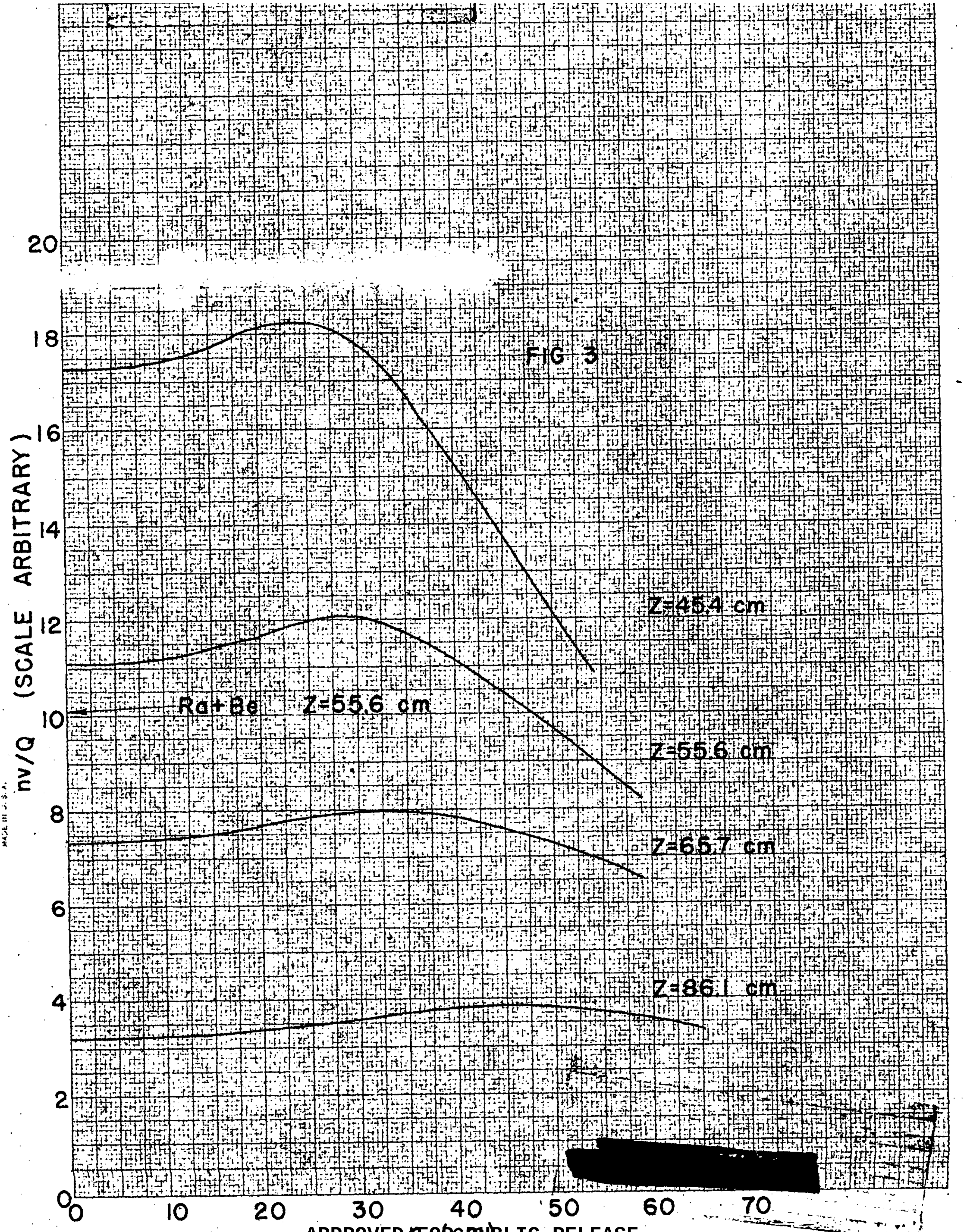
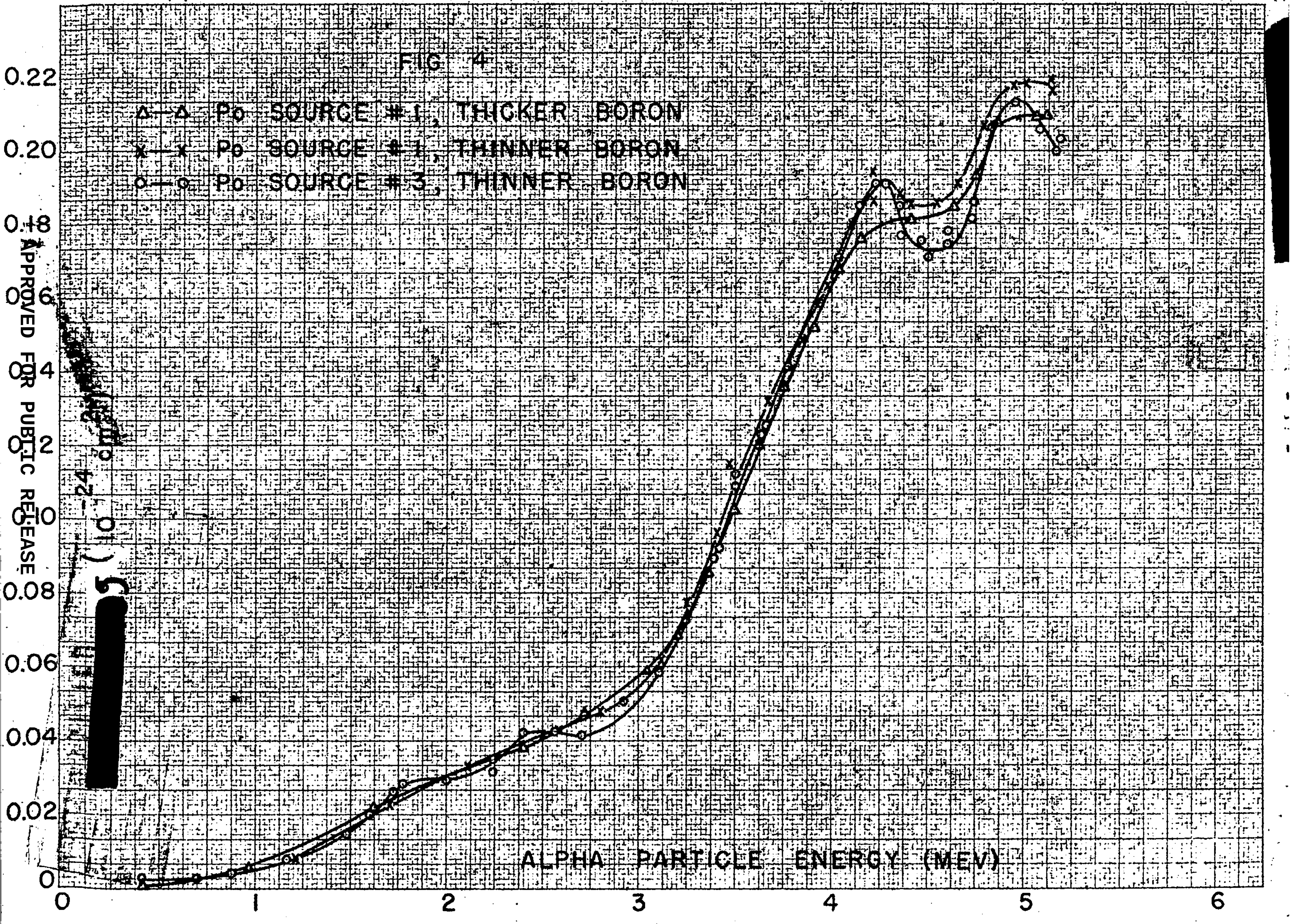


FIG 3

[redacted]

FIG 4



[redacted]

[redacted]

[redacted]