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FISSION CROSS SECTIONS OF THORIUM 232, URANIUM 233, 235 and 236 AND PLUTONIUM 239 RELATIVE TO URANIUM 238 FOR 14 MEV NEUTRONS

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Chicago Operations Office	47
Columbia University (Dunning)	48
General Electric Company, Richland	49-54
Hanford Operations Office	55
Idaho Operations Office	56-57
Iowa State College	58
Knolls Atomic Power Laboratory	59-62
Naval Radiological Defence Laboratory	63
NEPA Project	64
New York Operations Office	65-66
North American Aviation, Inc.	67
Oak Ridge National Laboratory	68-75
Patent Branch, Washington	76
Technical Information Division, ORE	77-91
USAF - Office of Assistant for Atomic Energy	92
UCLA Medical Research Laboratory (Warren)	93
University of California Radiation Laboratory	94-96
Westinghouse Electric Corporation	97-100

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ABSTRACT

The fission cross sections were measured in a double chamber with thin foils using the 14 Mev neutrons from the D-T reaction. The results are listed below:

for $\sigma_f(28) = 1.13 \pm .03$ barns

$$\frac{\sigma_f(02)}{\sigma_f(28)} = 0.303 \pm 0.006 \qquad \sigma_f(02) = 0.34 \pm 0.01 \text{ barns}$$

$$\frac{\sigma_f(23)}{\sigma_f(28)} = 2.27 \pm 0.05 \qquad \sigma_f(23) = 2.56 \pm .10 \text{ barns}$$

$$\frac{\sigma_f(25)}{\sigma_f(28)} = 1.91 \pm 0.05 \qquad \sigma_f(25) = 2.16 \pm .09 \text{ barns}$$

$$\frac{\sigma_f(26)}{\sigma_f(28)} = 1.6 \pm 1 \qquad \sigma_f(26) = 1.8 \pm 1.1 \text{ barns}$$

$$\frac{\sigma_f(49)}{\sigma_f(28)} = 1.55 \pm .06 \qquad \sigma_f(49) = 1.75 \pm .09 \text{ barns}$$

Absolute measurements of a cross section are in general difficult to do precisely. Determinations of relative cross sections can be done with greater speed and accuracy. Consequently the procedure followed in measuring the cross sections of 02, 23, 25, 26, and 49[1] was to determine them relative to $\sigma_f(28)$, the absolute cross section of which was known[2].

The comparisons were made by placing the foils of fissionable material back-to-back in a double ionization chamber. Fission pulses from the two foils were counted simultaneously, thereby eliminating the necessity of either determining the neutron flux or monitoring it. The chamber was filled with argon or krypton between 35-60 cm. pressure and electron collection was used. The pulses occurring in the two portions of the chamber were fed into separate model 500 amplifying systems and then counted in separate scalers. A ten channel discriminator was connected alternately to the two amplifiers. The pulse-height distributions so obtained were used to set the scaler biases and to monitor these settings continuously. The biases were adjusted such that the number of pulses recorded by the scalers would equal, as closely as possible, the number of pulses due to fissions. In most cases this could be done accurately because the peak due to fissions was well separated from the low energy peak due to α particles and reactions in the argon. The gas pressure was adjusted to an optimum value for each measurement by balancing the gain of a large signal-to-noise ratio at high pressures against the gain in the greater separation of the fission and background

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[1] The isotopes are identified throughout by a code using the combination of the terminal number of the atomic number and the terminal number of the atomic weight, thus thorium 232 is 02 and uranium 235 is 25.

[2] LA-719.

peaks at lower pressures. Fast amplifiers were used to keep the α pile-up at a minimum.

The foils were prepared by John Povelites of Group CMR-4. Platinum foils 1-3/8 inch in diameter and .002 inch thick were coated with about one milligram of active material. The active area was a circle one inch in diameter. Self-absorption corrections were not necessary because what is used is the ratio of such corrections, each of which is very nearly equal to one.

The weight of the material deposited on the foils was determined by weighing. This could be done with an accuracy of better than one percent. However, there are inherent errors in the chemical processing, the magnitude of which cannot be estimated.

When the quantity of source material is large (as in the case of 02, 25 28, 49), the actual weights are probably correct to the above accuracy. When the quantity of source material is of the order of milligrams or less (as in the case of the 23, 26), the composition of the source material can be greatly in error. In such cases, the weight of the active material is determined, when possible, by methods other than direct weighing.

The indirect method used to determine the 26 foil weight will be described in the section on 26 measurements. The 23 foil weight given in this paper was determined by direct weighing. It is planned to weigh it by the method used for the 26 foil.

The 14 Mev neutrons were produced on the Z-building Cockcroft-Walton accelerator using the $D(T,n)He^4$ reaction. All observations were made at 90° to the incident beam.

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The design of the chamber and the experimental arrangement are shown in figure 1. A typical pulse-height distribution is shown in figure 2.

$\sigma_f(28)$ The absolute cross sections of 02, 23, 25, 26, 49 were calculated using $\sigma_f(28) = 1.13 \pm .03$ barns.[2]

$\sigma_f(02)$ Fission pulses with energy less than the bias energy, and therefore not counted, were estimated to be one to two percent of the total number of fissions observed for both the 02 and 28. The ratio of these corrections becomes one and the individual corrections are unnecessary. The observed ratios were corrected for the difference (two percent) in the neutron flux at the foils. The results are listed in Table 1.

[redacted]

Table 1

Run	$R_{\frac{02}{28}}$ *(Ratio 02 fissions to 28 fissions corrected for flux difference = $R_{\frac{02}{28}}$)
1	0.330
2	0.330
3	0.335
4	0.333
5	0.328
6	0.323
7	0.324
8	0.342
9	0.338
10	0.344
11	0.332
12	0.318
13	0.340

*The average $R_{\frac{02}{28}}$ = 0.332 probable error 2 percent.

Total 02 counts = 12,534.
Total 28 counts = 37,819.
About 970 02 counts for each run.
m_{02} = Wt. 02 metal = 1.09 milligrams.
m_{28} = Wt. 28 metal = 1.02 milligrams.
Argon pressure 57 cm.

$$\frac{\sigma_f(02)}{\sigma_f(28)} = R_{\frac{02}{28}} \cdot \frac{m_{28}}{m_{02}} \cdot \frac{232}{238}$$

$$= 0.332 \cdot \frac{1.02}{1.09} \cdot \frac{232}{238} = 0.303 \pm .006$$

$$\sigma_f(02) = 1.13 \cdot 0.303 = 0.34 \pm 0.01 \text{ barns}$$

[redacted]

$\sigma_f(25)$ The high 25 cross section for low-energy neutrons necessitated covering the chamber with cadmium to cut out near thermal neutrons. The observed 25 fission rate still had to be corrected for fissions caused by low energy neutrons scattered from the water tanks surrounding the source area. To determine the magnitude of this correction a cadmium covered 25 spiral chamber was used to measure the neutron flux as a function of distance from the source. The flux was then analyzed into two components. One, a function of the inverse square of the distance to the source, was the component of 14 Mev neutrons from the source. The other was an approximately constant component of scattered neutrons with energies below 14 Mev and above the cadmium level. It was also necessary to make a correction in run #1 for the effect of cadmium neutrons. The correction was determined from 25 spiral chamber measurements. The results are in Table 2.

Table 2

Run	Cm. from source	Correction for scattered neutrons	Corrected ratio of 25 fissions to 28 fissions = $R_{\frac{25}{28}}$
1 (no Cd.)	19.04	.965/1.10 = .88	1.91
2 Cd.	19.04	"	1.87
3 "	19.04	"	2.05
4 "	19.04	"	1.99
5 "	19.04	"	2.18
6 "	11.9	.980	1.99
7 "	11.9	"	2.08
8 "	11.9	"	2.06
9 "	11.9	"	1.92
10 "	11.9	"	2.02
11 "	11.9	"	2.04
12 "	9.69	.990	1.98
13 "	9.69	"	2.01
14 "	9.69	"	2.02
15 "	9.69	"	1.95
16 "	9.69	"	2.06
17 "	9.69	"	2.08
18 "	9.69	"	1.97
19 "	9.69	"	2.06
20 "	9.69	"	2.16
21 "	9.69	"	1.92
			Av. = 2.02 probable error 2.6%

Total 25 counts = 20,000.

Total 28 counts = 41,000 with about 900 28 fissions per run.

M_{25} = Wt. 25 foil = 1.09 mg. metal.

M_{28} = Wt. 28 foil = 1.02 mg. metal.

m_{25} = fraction of 25 in "25" foil = 0.957.

m_{28} = fraction of 28 in "25" foil = 0.043.

[redacted]

The observed ratio of fissions is given by

$$R_{\frac{25}{28}} = \frac{M_{25}(m_{25}\ \sigma_f(25)/235 + m_{28}\ \sigma_f(28)/238)}{M_{28}\ \sigma_f(28)/238}$$

Then

$$\frac{\sigma_f(25)}{\sigma_f(28} = R_{\frac{25}{28}}\ \frac{M_{28}}{M_{25}}\ \frac{235}{238}\ \frac{1}{m_{25}} - \frac{m_{28}}{m_{25}}\ \frac{235}{238}$$

$$= \frac{2.02}{.957}\ \frac{1.02}{1.09} \cdot \frac{235}{238} - \frac{.043}{.957}\ \frac{235}{238}$$

$$= 1.91 \pm .05 \text{ barns}$$

$$\sigma_f(25) = 1.91 \cdot 1.13 = 2.16 \pm 0.09 \text{ barns}$$

[redacted]

$\sigma_f(23)$ Measurements of the ratio $\frac{\sigma_f(23}{\sigma_f(28)}$ were made with cadmium surrounding the chamber. The contribution to the fission rate made by epi-cadmium neutrons was determined by measuring the 23 fission rate as a function of distance of the chamber from the source. The results are summarized in Table 3. A correction ($<$ 1%) was made for the relative foil positions with respect to the source. Krypton at a pressure of 30 cm. was used in the chamber for the 23, 26, and 49 measurements.

Table 3

Run	$R(\frac{23}{28})$ = ratio of observed 23 fissions to observed 28 fissions corrected for foil position, epi-cadmium neutrons
1	2.35
2	2.31
3	2.36
4	2.41
5	2.28

Av. = 2.35 with probable error of 2 percent

Total 28 counts observed = 35,000.

M_{23} = weight of 23 foil = 1.05 mg. metal.

m_{28} = fraction of 28 in 23 foil = 0.97.

m_{23} = fraction of 23 in 23 foil = 0.03.

M_{28} = weight of 28 foil = 1.017 mg. metal (100% 28).

$$\frac{\sigma_f(23)}{\sigma_f(28)} = \left(\frac{23 \text{ fissions}}{28 \text{ fissions}} \; \frac{M_{28}}{M_{23}} - m_{28}\right) \frac{233}{238} \; \frac{1}{m_{23}} = .98 \; \frac{23 \text{ fissions}}{28 \text{ fissions}} - .03$$

$$= 0.98 \cdot 2.35 - 0.03 = 2.27 \pm .05 \text{ barns}$$

$$\sigma_f(23) = 2.27 \cdot 1.13 = 2.56 \pm 0.10 \text{ barns}$$

$\underline{\sigma_f(26)}$ Two uranium samples enriched in 26 were received from Oak Ridge with data on their isotopic composition.

Foils made from these samples were compared with a standard 25 foil in the thermal neutron flux of the standard pile and in a 500-700 Kev neutron flux. These last neutrons were made in W building with the Van de Graaff accelerator using the $T(p,n)He^3$ reaction.

Both of these measurements and an assay by total α-count indicated a large error in (a) the isotopic analysis; (b) the chemical composition; and/or (c) the total weight of the 26 foils.

A precise mass spectroscopic analysis of the 26 was then made at the Argonne National Laboratory by Mark Inghram. This analysis (which was different from the original O.R. analysis) combined with the data already acquired showed that the material deposited on the foils was not pure uranium.

The 26 cross section at 14 Mev was obtained by the following procedure:

(a) The amount of 25 on the 26 foil was determined by comparing its thermal fission rate in the standard pile with that of the 25 foil (this assumes that only 25 undergoes fission at thermal energies).

(b) The ratio of fission rates was measured at 14 Mev for the same foils.

(c) Assuming the 411 fission rate at 14 Mev to be negligible and using Inghram's isotopic analysis, the ratio of 26 foil fissions to 25 foil fissions at 14 Mev is

$$R_{14} = \frac{M_{26}(m_{25}\ \sigma_f(25) + m_{26}\ \sigma_f(26) + m_{28}\ \sigma_f(28)\ )}{M_{25}(m'_{25}\ \sigma_f(25) + m'_{28}\ \sigma_f(28)\ )}$$

where M_{26} = mass of uranium on 26 foil.

M_{26} = mass of uranium on 25 foil.

m_{25} = fraction of isotope 25 on 26 foil.

m'_{25} = fraction of isotope 25 on 25 foil.

m_{26} = fraction of isotope 26 on 26 foil.

m'_{26} = fraction of isotope 26 on 25 foil = negligible.

From the thermal measurements $M_{26} = \frac{M_{25}\ m'_{25}}{m_{25}}\ R_{th}$ where R_{th} is the ratio of 26 foil fissions to 25 foil fissions in the standard pile.

$$\text{Then } R_{14} = \frac{m'_{25}\ R_{th}}{m_{25}}\ \frac{(m_{25}\ \sigma_f(25) + m_{26}\ \sigma_f(26) + m_{28}\ \sigma_f(28))}{m'_{25}\ \sigma_f(25) + m'_{28}\ \sigma_f(28)}$$

$$\frac{\sigma_f(26)}{\sigma_f(28)} = \frac{m_{25}}{m_{26}}\ \frac{R_{14}}{R_{th}}\left(\frac{m'_{28}\ \sigma_f(25)}{m'_{25}\ \sigma_f(28)}\right) - \frac{m_{25}}{m_{26}}\ \frac{\sigma_f(25)}{\sigma_f(28)} - \frac{m_{28}}{m_{26}}$$

$m'_{25} = 0.957$

$m'_{28} = 0.043$

$m_{25} = 0.735$

$m_{26} = 0.105$

$m_{28} = 0.156$

$R_{14} = 1.07 \quad 0.05$

$R_{th} = 0.89 \quad 0.05$

$$\frac{\sigma_f(25)}{\sigma_f(28)} = 1.91 \pm 0.05 \text{ barns}$$

[redacted]

$\frac{\sigma_f(26)}{\sigma_f(28)} = 1.6 \pm 1.0$ $\sigma_f(26) = 1.9 \pm 1.1$ barns

The large error is due mainly to the low 26 concentration in the 26 foil.

$\underline{\sigma_f(49)}$ α background in the 49 sample made the separation of the fission peak and the α peak less certain than in the previous cases. The manner in which the fission curve should be extrapolated to zero was less certain and the correction for uncounted fissions greater. This correction was two percent with an error of ± 2 percent. Table 4 lists the corrected data.

Table 4

Run	R = Ratio of 49 fissions to 25 fissions	
1	1.59	
2	1.79	
3	1.75	
4	1.59	
5	1.75	
6	1.76	
7	1.74	
8	1.72	
9	1.78	
10	1.75	
11	1.70	
12	1.74	total of 14,000 28 counts
Av.	1.72	probable error 2-1/2%

M_{49} = 1.002 mg. metal $\begin{cases} 98.03\% & 49 \\ .97\% & 4\text{-}10 \end{cases}$

M_{28} = 0.888 mg. metal

$$\frac{\sigma_f(49)}{\sigma_f(28)} = \frac{R}{m_{49}} \quad \frac{M_{28}}{M_{49}} \quad \frac{239}{238} - \frac{m_{410}}{m_{49}} \quad \frac{\sigma_f(410)}{\sigma_f(28)} \quad \frac{239}{240}$$

$$= \frac{1.72}{.990} \cdot \frac{.888}{1.002} \quad \frac{239}{238} - \frac{.01}{.99} \quad \frac{239}{240} \quad \frac{\sigma_f(410)}{1.13}$$

$= 1.55 \ (1 - .006\ \sigma_f(410)) = 1.55 \pm 0.06$ assuming $\sigma_f(410)$ to be small.

$\sigma_f(49) = 1.55 \cdot 1.13 = 1.75 \pm 0.07$ barns

[redacted]

[redacted]

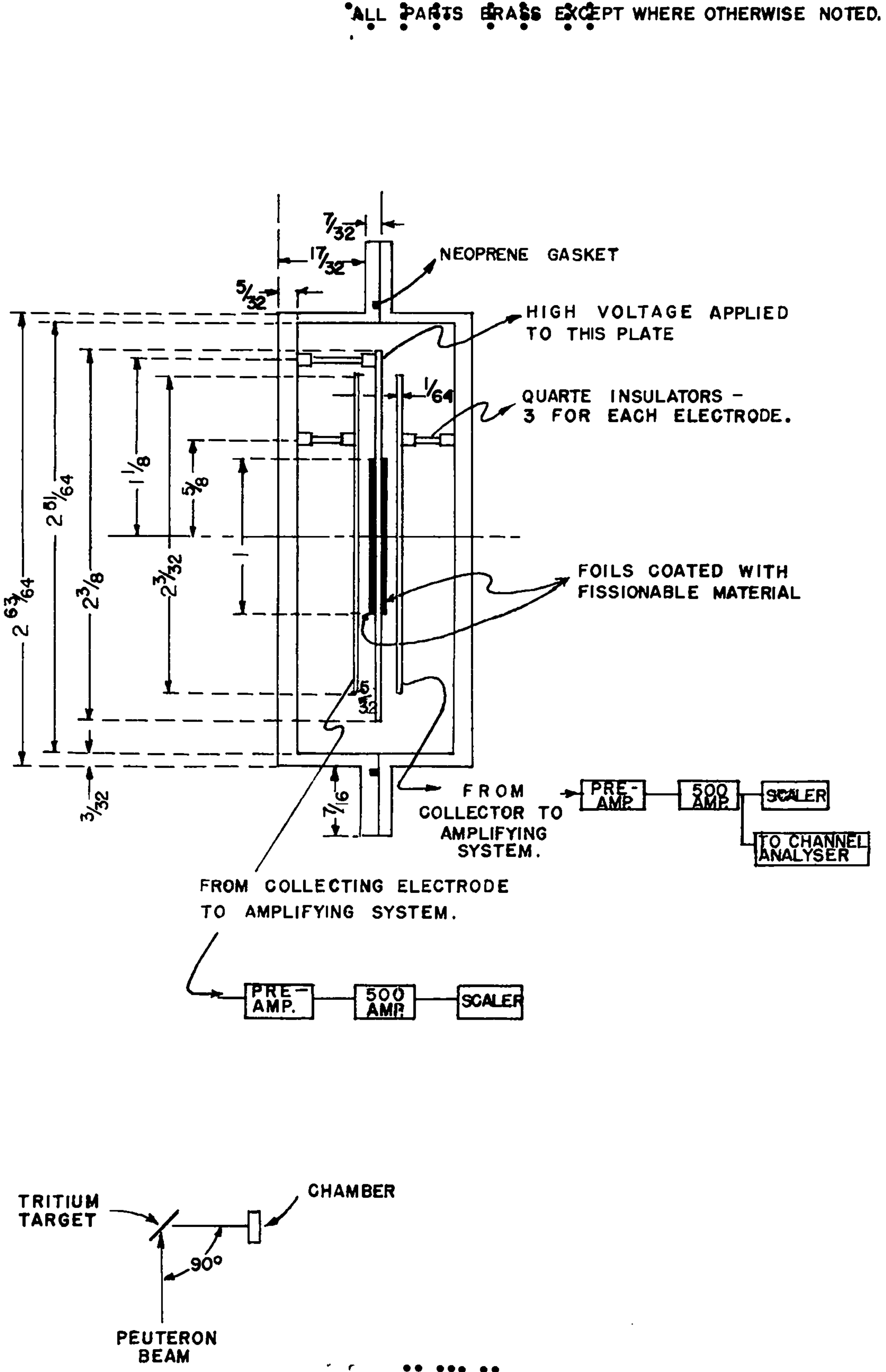
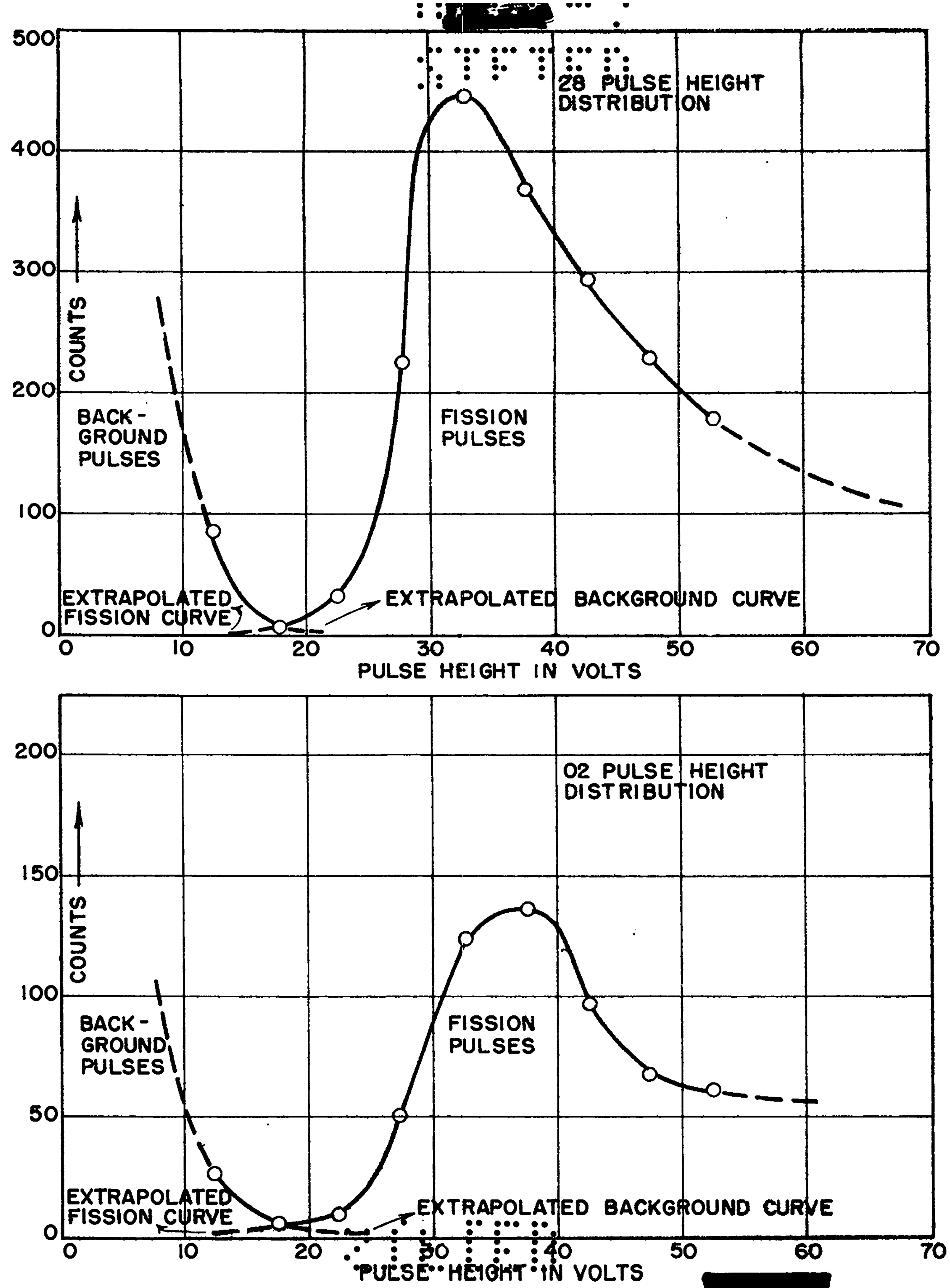


FIG. 1

[redacted]

[redacted]



[redacted]

FIGURE 2