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CAPTURE GAMMA RAYS

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ORNL Summer Shielding Session

Gale Young, Leader

CAPTURE GAMMA RAYS

E. P. Blizard

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** Explanation on page 3.

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This report is one of a series on shielding and represents part of the work of a summer group working principally at Oak Ridge National Laboratory. Participants are drawn from Nuclear Development Associates (Navy contract), NEPA, Bureau of Ships and Bureau of Aeronautics (Navy Department), AEC, RAND, General Electric, Argonne and Oak Ridge National Laboratory.

These reports are issued through ORNL on Contract No. W-7405, eng. 26.

CAPTURE GAMMA RAYS

E. P. Blizard

The gamma rays accompanying neutron capture have been measured in several ways, but for relatively few elements. With present neutron intensities, such elements as Pb and Bi will be difficult to measure, due to their low thermal neutron cross sections and high self-absorption of capture gamma rays.

Cloud Chamber Technique:

Moak and Dabbs[1] measured capture gamma spectra by observing curvature of positron-electron pairs in a cloud chamber. The gamma source consisted of a small sample near the cloud chamber and in a beam of thermal neutrons from the Oak Ridge Reactor. On reviewing their work, Moak and Dabbs have decided that the thickness of pair radiator is sufficient to produce serious scattering out of the original plane of tracks and consequent loss of pairs observed. Furthermore, even though the straight-through energy absorption in the foil is small, scatterings will increase the self-absorption in the pair radiator, with consequent loss of resolution. The low yield of pairs in their cloud chamber pictures has not been adequately explained to date. If the loss of pairs is random, then the data should represent the spectra. As their data appears to agree with that of other investigators where duplication permits comparison, one would hope that it is all reliable. However, until the loss can be determined, this set of data must remain somewhat in limbo.

Compton Electron Absorption Method:

Kubitschek and Dancoff[2] carried out absorption measurements on the compton electrons produced by gamma rays of capture in a large list of elements. This method requires double differentiation of the observed distribution for determination of photon distribution as a function of energy. For only four elements was the data considered sufficiently reliable to justify reporting a spectrum, and then admittedly only for purposes of showing the major features of the spectrum. In none of this data is line structure evident.

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[1] Moak and Dabbs, ORNL-51, p. 71; ORNL-366, p. 43; Phys. Rev. 75, p. 1770 (1949); and private communication.

[2] Kubitschek and Dancoff, Physics Review 76, p. 531 (1949).

Nuclear Film Techniques:

The deuteron disintegration is often used as a mechanism for detection of gamma rays of energy greater than 2.2 Mev. If deuterium is introduced into nuclear film, the protons leave tracks whose length is a unique function of the photon energy.

B. Hamermesh[3] soaks films in D_2O, whereas Millar, Cameron, and Glicksman of the Canadian NRC Chalk River Laboratory used film which had been loaded by Ilford Ltd. with hexa-deutero diacetin. Millar has investigated both types of loading and believes the latter to be much more uniform. Both investigators used Ilford 100μC2 film and applied a range correction of about 7% for the effect of loading. Millar remarks that his Ilford-furnished range-energy relation is confirmed by alpha tracks from naturally radioactive contaminants.

Pair Spectrometer Technique:

Dr. B. B. Kinsey, also of the Chalk River Laboratory, has measured the capture gamma-rays from a number of light and medium Z elements. To date, he has not published any of this data as he considers it very tentative. This is a preliminary report, and even the raw data should be considered provisional. He places a comparatively large quantity of sample material in an aluminum can of capacity about one pint. This can is then inserted in a 4-inch diameter experimental hole so that it is located well within the carbon reflector of the reactor. Gammas from the reactor are filtered out by a bismuth plug in the hole and nearer to the active lattice. The capture gamma rays from the sample are collimated within the hole by aluminum and filtered by a mixture of boron and paraffin, and outside the beam is again collimated with lead. A well-shielded pair spectrometer with gold radiator then measures the gamma ray energy in terms of its magnetic field, which in turn is calibrated absolutely in terms of the proton flipping frequency. The apparatus is automatic and runs day and night. Sharp peaks are observed for a number of elements and energy is determined to about one part in 500. Self-absorption displaces the peak towards lower energies so that the energy corresponding to a given line is fixed by extrapolating the high energy leg of the peak to background. Most of the data is shown in Figures 2 - 6. The following additional information is available:

(a) Be shows a single energy.

(b) Gold shows a peak at 5.6 Mev and a strong general background.

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[3] B. Hamermesh, ANL-4277, p. 56, and private communication.

(c) Cobalt has been measured.

(d) The aluminum container gives a background peak in all measurements. This is subtracted in the accompanying figures.

(e) Nitrogen shows 5 energies as follows:

10.81 Mev
6.4
5.5
5.3
4.4

The 5.3 and 5.5 pair is the stronger.

(f) Carbon 12 shows a peak at 4.94 Mev.

(g) The mass of the neutron can be determined from this data.

In the attached figures of Kinsey's data, coincidence rate has been plotted, and one should note that the sensitivity of the instrument at various energies has not been applied even for such obvious factors as cross section for pairs production and forwardness of high energy pairs. Kinsey prefers to make internal calibrations, and for this purpose has used the 6.4 and 4.4 pair of lines in the nitrogen spectrum. The 4.4 peak is about 1/6 as high as the 6.4, and this affords a single internal calibration. The method appears to be exceptionally good determination of line structure, but relative intensities will be much more difficult to determine.

Scintillation Counters:

The scintillation counter in conjunction with a pulse-height analyzer might be applied to measuring spectra of gamma rays. Jordan and Francis of Oak Ridge National Laboratory have actually set up such an apparatus but find several limitations to the method. Crystals should be large compared with the range of the most energetic electrons present if the compton distributions are to be resolved into spectra. Crystals presently available are not nearly large enough; furthermore, if larger crystals were used, they would have to be exceptionally clear -- much more so than has been achieved to date -- so that a proportional fraction of the light from scintillation could be recorded by the photo-multiplier.

It is to be hoped that some trick, such as anti-coincidence techniques, might make this method useful in the low-energy end of the spectrum (below 2 Mev.) where the other methods are definitely not applicable.

Comparison of Techniques:

The compton electron absorption method is subject to the usual lack of resolution associated with this type of determination and can be considered superseded by more sensitive methods.

Pair production methods tend to concentrate resolution in the high energy end of the spectrum where the cross sections are higher. The opposite effect is seen in the deuterium techniques. This would indicate perhaps that both should be continued for maximum efficiency. Although the pair threshold is somewhat than that of the deuterium photon process, nevertheless, the practical low energy cutoff is about the same ($\sim 2\frac{1}{2}$ to 3 Mev) for both methods due to the low pair cross section at and near the threshold.

Film data is probably corrected with much more assurance than is the pair spectrometer data. However, it is possible that sufficient cascades such as that in nitrogen will appear and thus enable Kinsey to calibrate his apparatus almost entirely internally. It will nevertheless be reassuring to be able to compare the results of two such different operations.

The film technique appears to be tedious and therefore probably not well-suited to an extensive survey. The line structure of spectra will probably not be easily demonstrated by this technique, but the general shape on the other hand is probably reliable. There appears in film data a small but disturbing set of very long tracks indicating energies considerably in excess of what is accepted for the neutron binding energy. Substraction of background observations has not removed them, and they must go unexplained for the present. The pair spectrometer technique on the other hand is well-adapted to an extensive survey, reveals line structure quite reliably, and seems to be free of anomalous high energy readings.

A typical comparison of the results is seen in Figure 1 for cadmium. Kinsey's data is not included in this figure because of the very large corrections which must be made for the sensitivity of his apparatus as a function of energy. These corrections depend mainly on cross section for pair production, thickness of pair radiator (gold foil), and forwardness of pairs produced at high energies.

The following Table summarizes the spectra measured to date:

TABLE I

Figure Numbers of Spectra

Element	Millar et al	Kinsey	Moak & Dabbs	Hammermesh	Kubitschek & Dancoff
Cd	3	2	1	1	1
Na	4				
Cl	6		7	5	
Fe		9		8	
Ni		10			
Cu		11			
Au					12
Co					13
Ir					14
Mn		15			

For Shielding purposes the general shape of spectra is sufficient so that both film and spectrometer data will be useful. If the present rate of data appearance continues, capture gamma rays will soon be one of the better known sources of penetrating radiation. It should, however, be noted that for none of the measurements to date has there been reported an absolute calibration of the apparatus in the sense that the number of photons in an energy interval per neutron capture is well-known. As long as the whole spectrum, including the low energy end, is not measured, this calibration is of serious importance to shielding.

The data of Kinsey and of Millar, et al, were gathered by F. L. Friedman and myself on a trip to the Chalk River Laboratory of the Canadian National Research Council. I have made liberal use of Friedman's notes on this trip.

It is a pleasure to acknowledge the kindness of Dr. B. B. Kinsey and of Dr. Millar and his collaborators, all at the Chalk River NRC Laboratory, in permitting the preliminary showing of their excellent data.

Dr. B. Hamermesh kindly forwarded his data, with his own evaluation of it for use in this report.

Dr. S. Dancoff kindly loaned slides of his data for reproduction here, and made many helpful suggestions in the writing.

C. D. Moak assisted in evaluating his and Dabbs' results.

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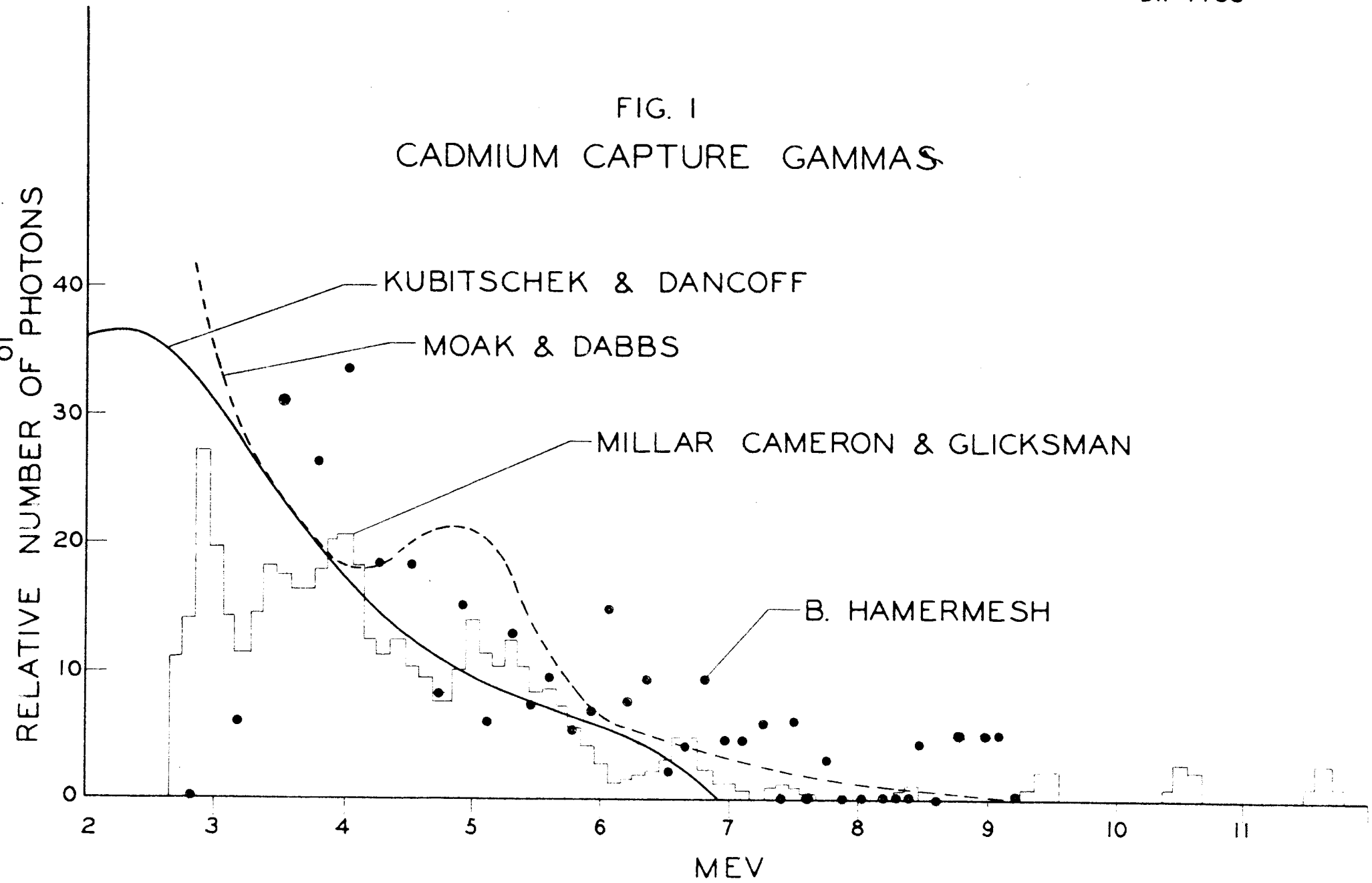
Dr. 7733

FIG. 1

CADMIUM CAPTURE GAMMAS



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TRACING II pps 16-17

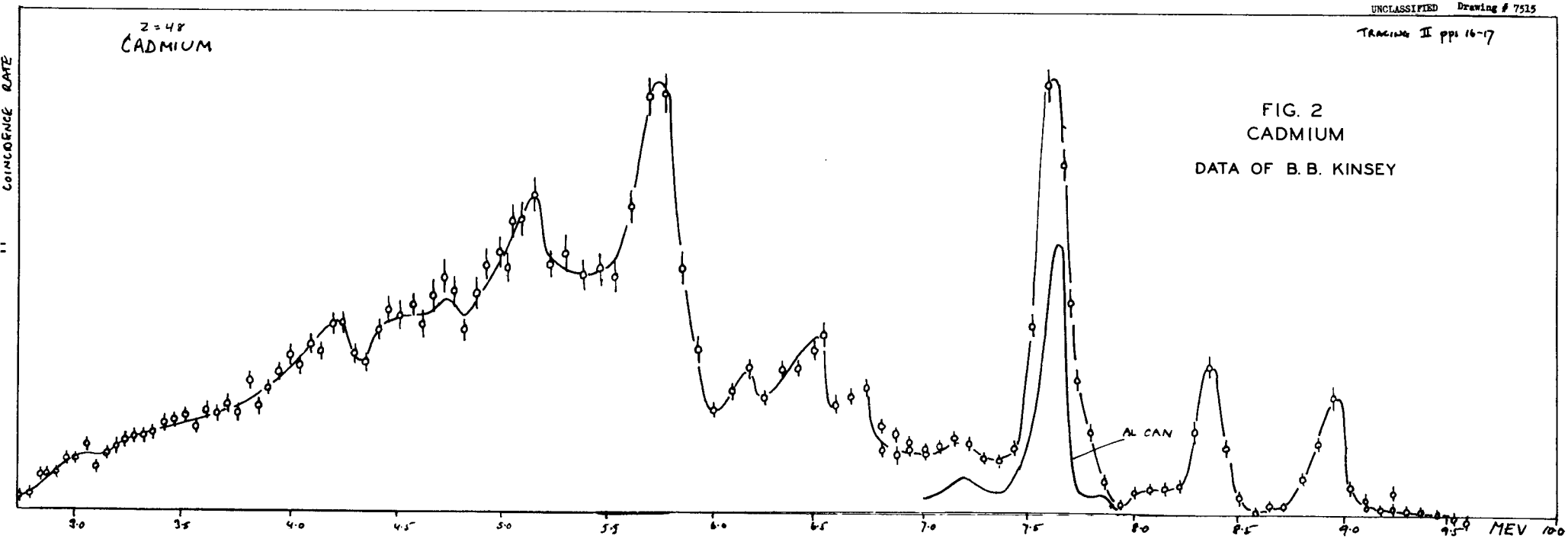
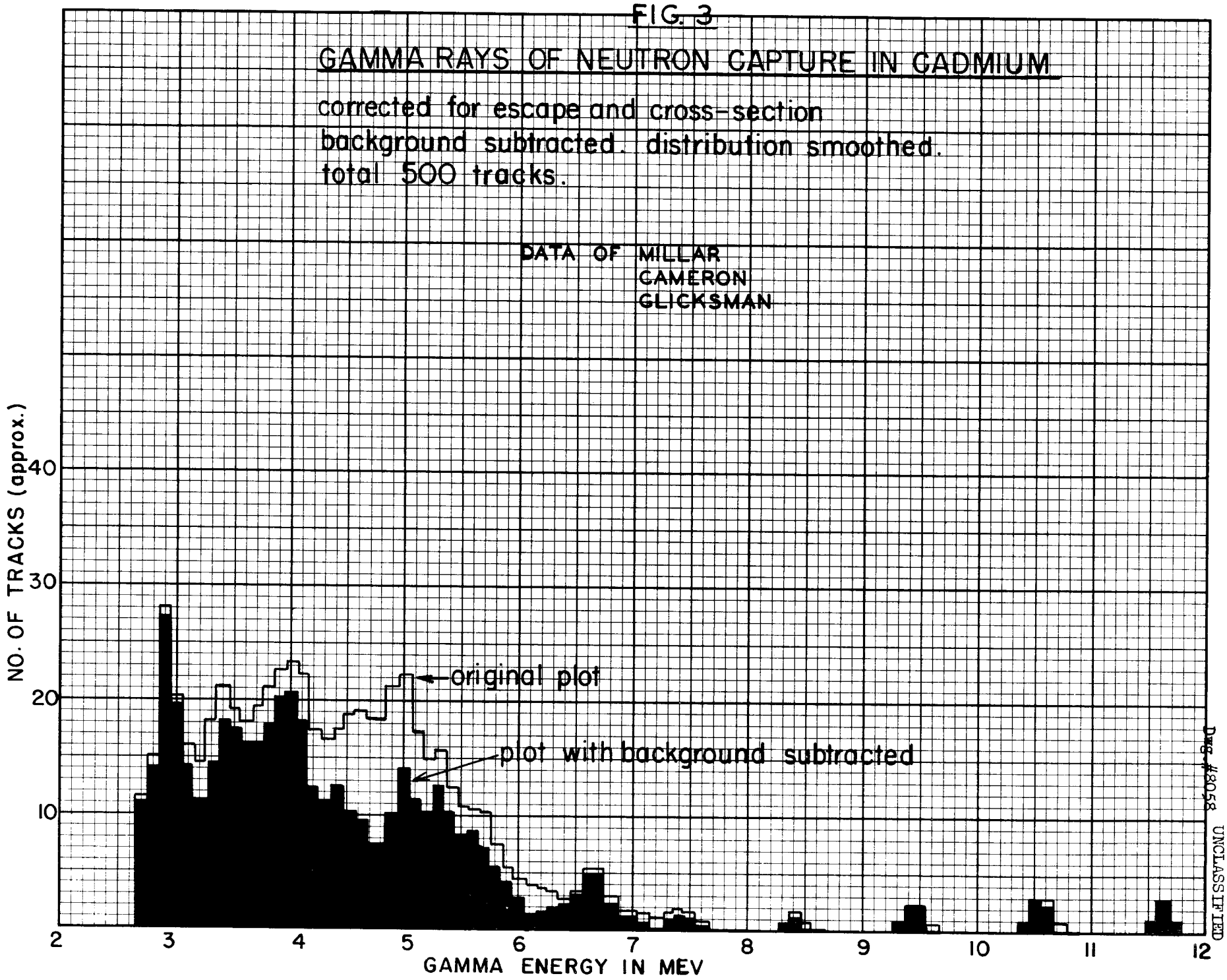


FIG. 2
CADMIUM

DATA OF B. B. KINSEY

FIG. 3



Dwg #8058

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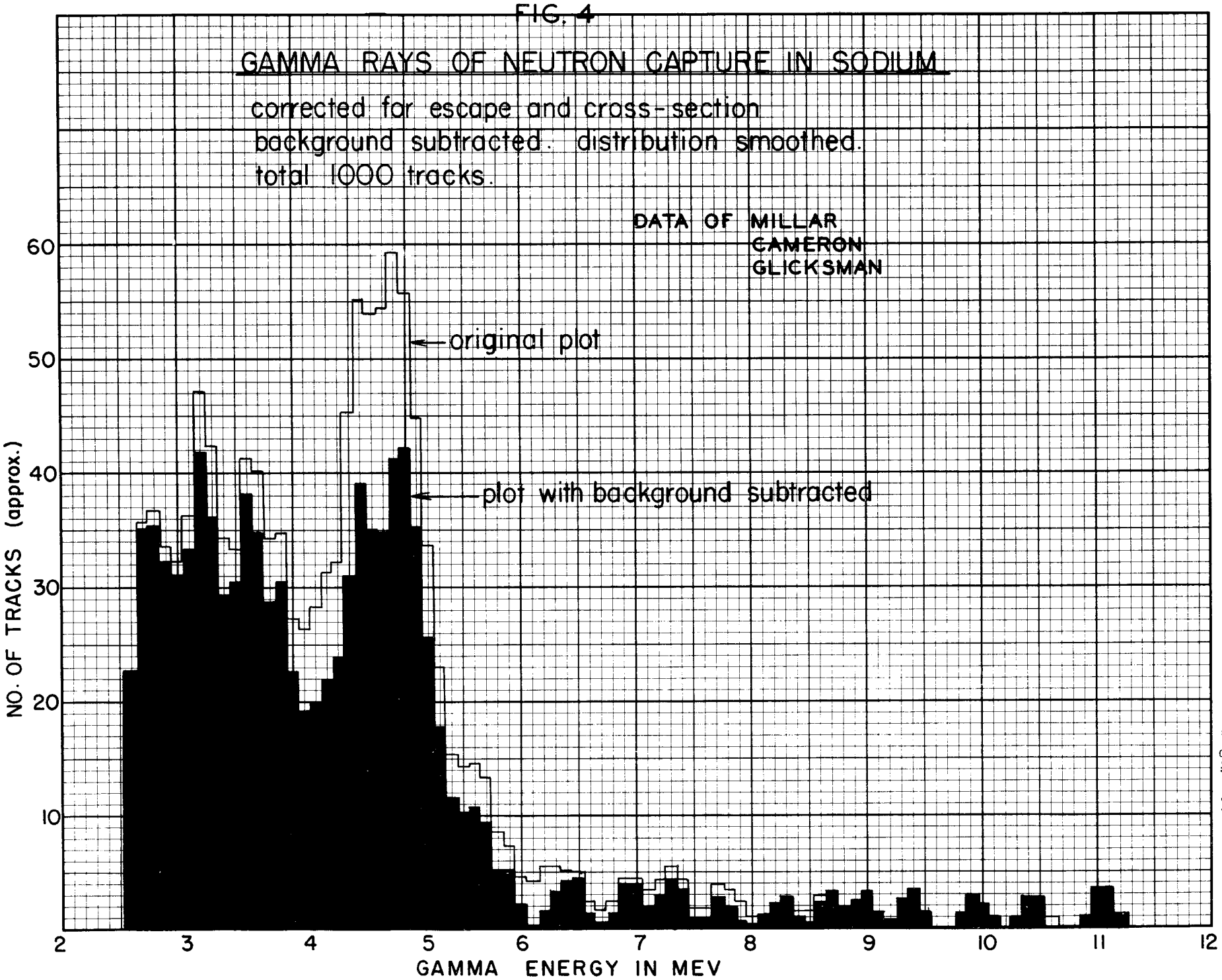
FIG. 4



Dwg. #8059

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FIGURE 5

NEUTRON CAPTURE γ – RAY SPECTRUM

OF CHLORINE

DATA OF B. HAMERMESH

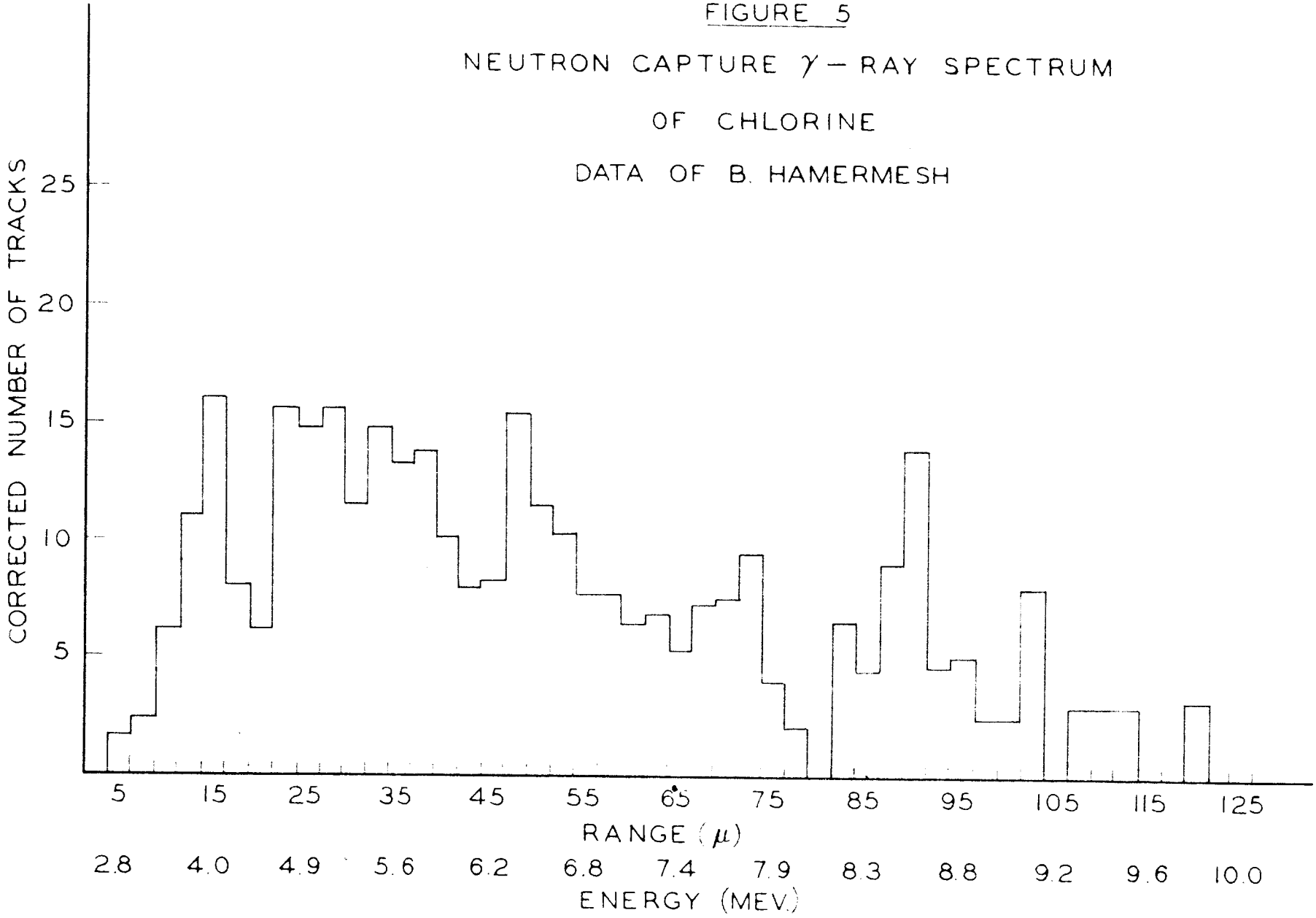
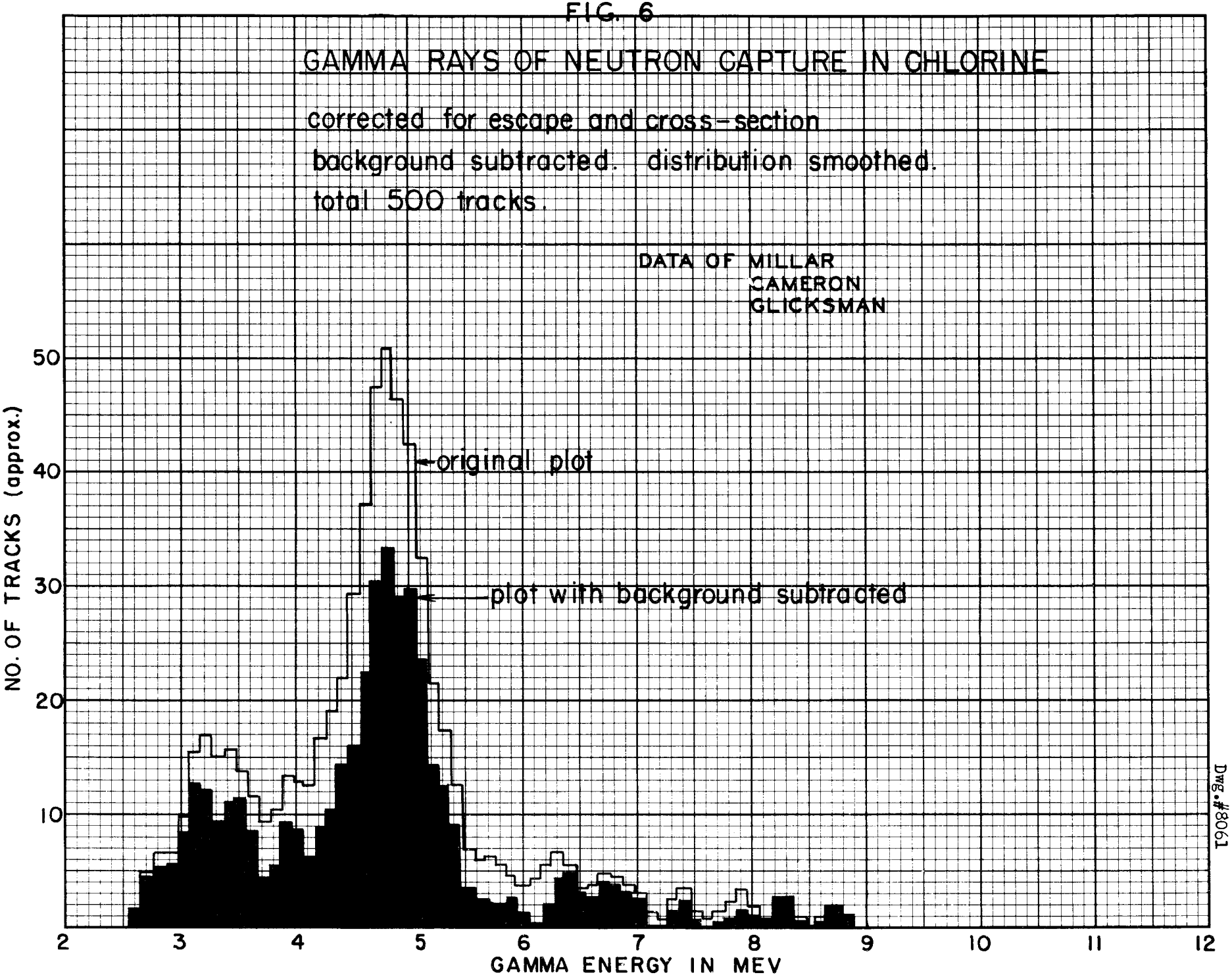


FIG. 6



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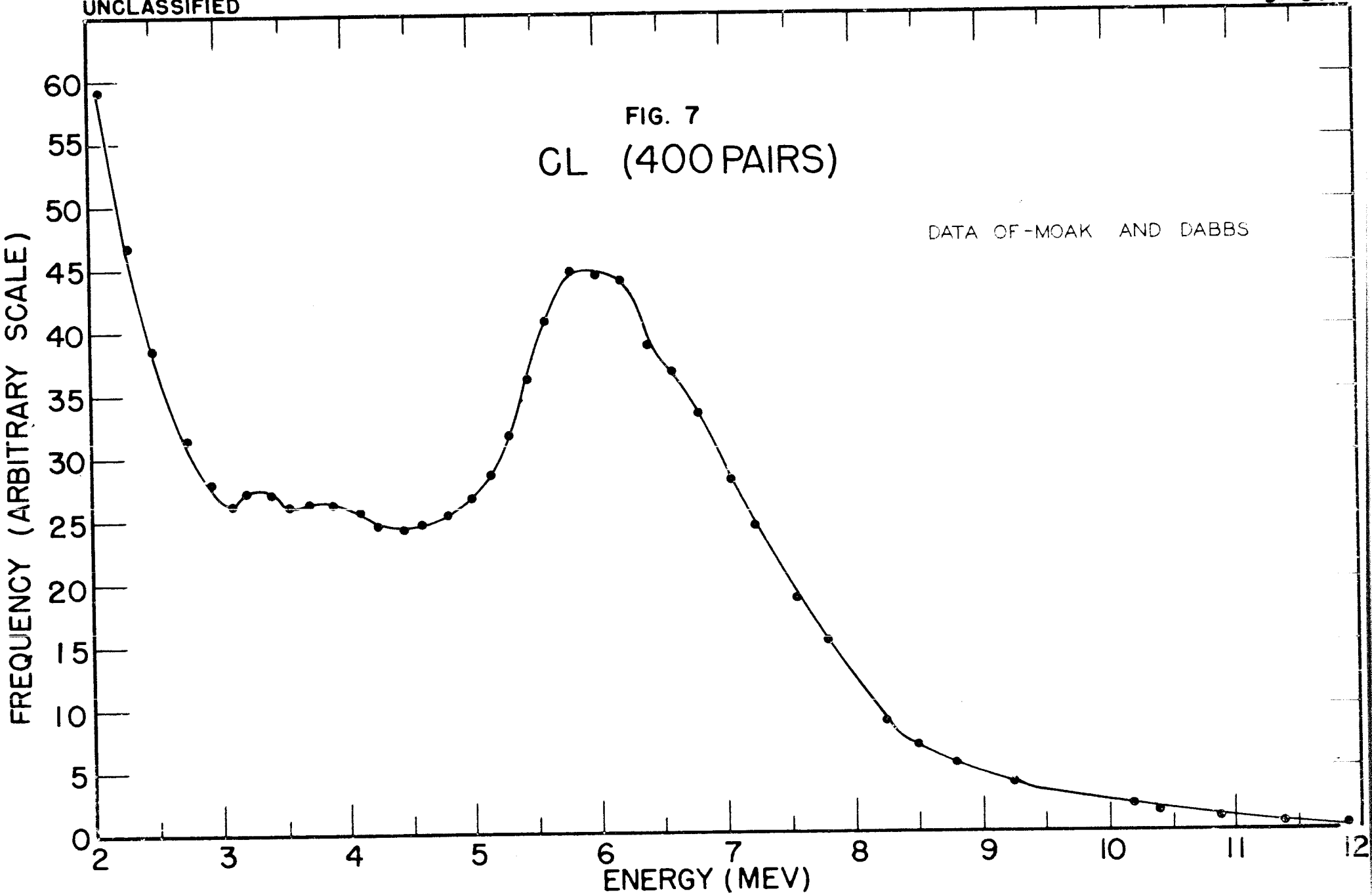


FIG. 7
CL (400 PAIRS)
DATA OF-MOAK AND DABBS
FREQUENCY (ARBITRARY SCALE)
0
5
10
15
20
25
30
35
40
45
50
55
60
2
3
4
5
6
7
8
9
10
11
12
ENERGY (MEV)

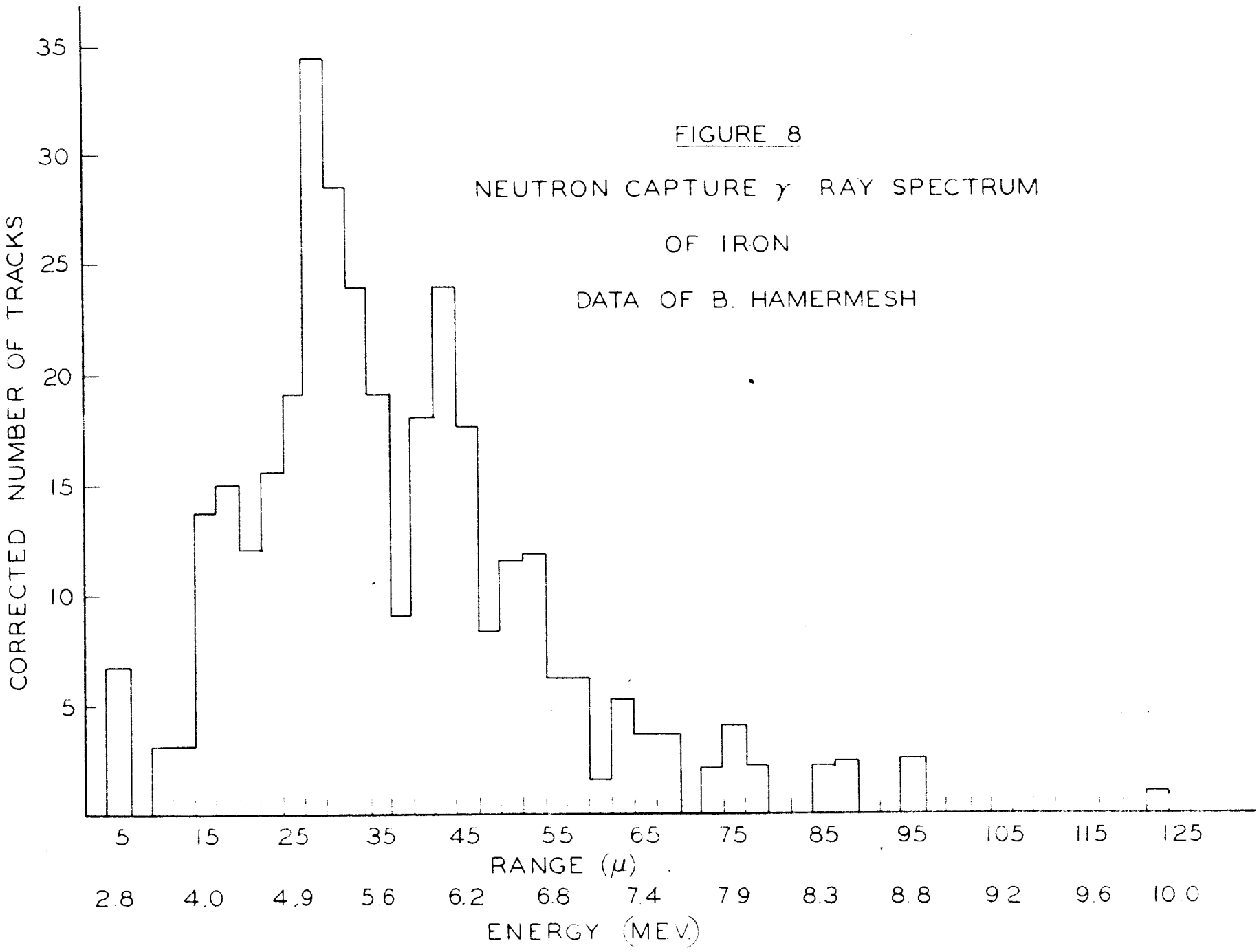


FIGURE 8

NEUTRON CAPTURE γ RAY SPECTRUM

OF IRON

DATA OF B. HAMERMESH

UNCLASSIFIED Drawing # 7517

Training II, pps 34-35

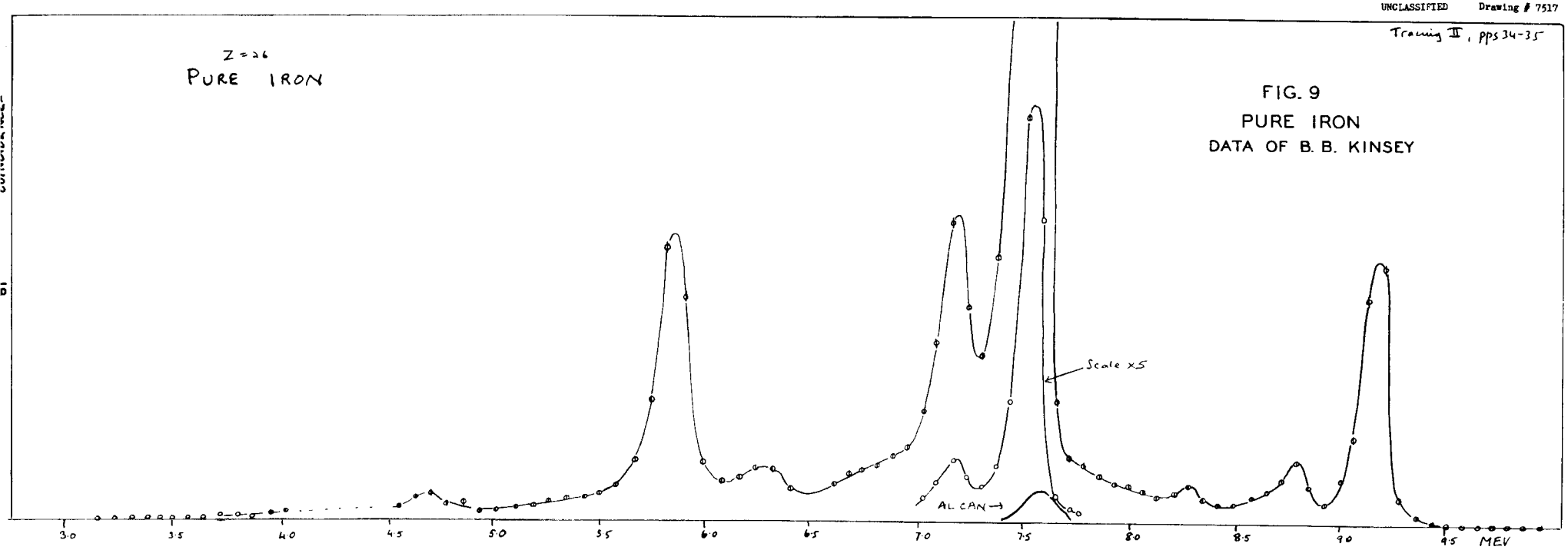


FIG. 9
PURE IRON
DATA OF B. B. KINSEY

UNCLASSIFIED Drawing # 7530

TRACING II pps 46-47

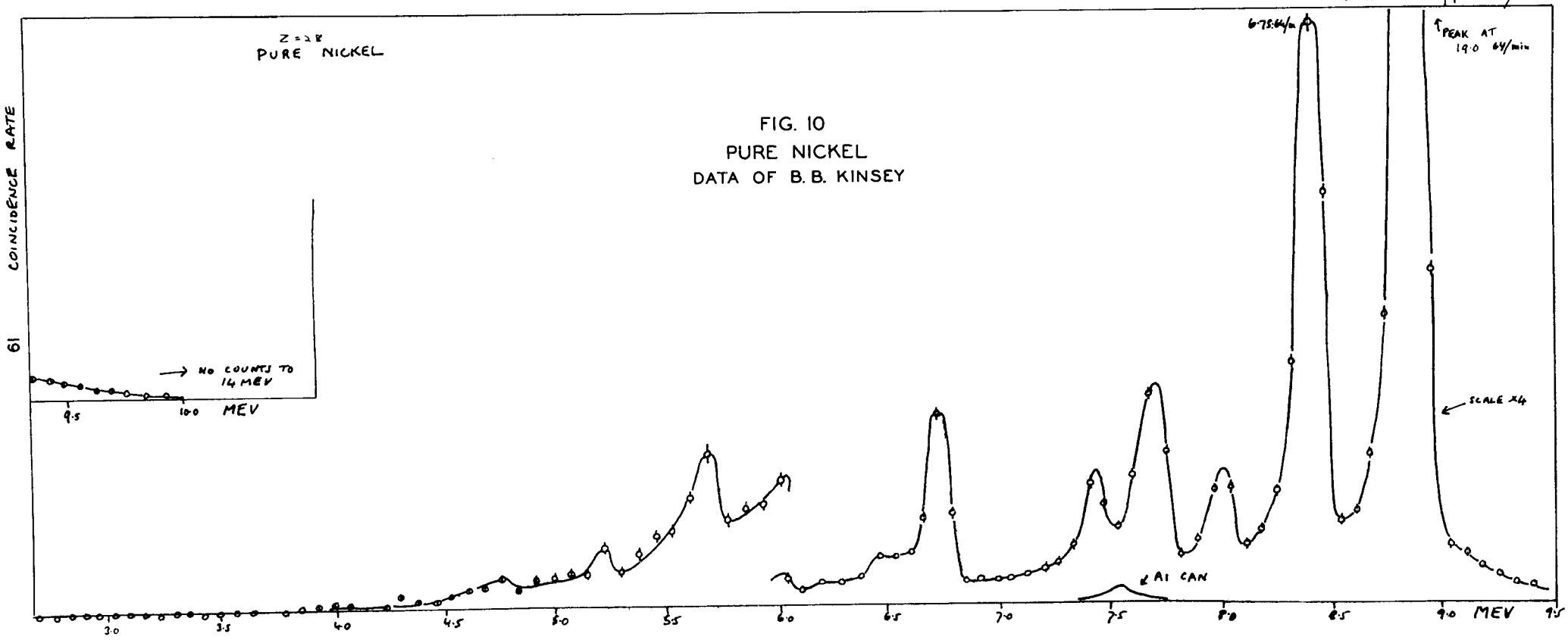


FIG. 10
PURE NICKEL
DATA OF B. B. KINSEY

UNCLASSIFIED Drawing # 7516

TRACING II pp 22-23

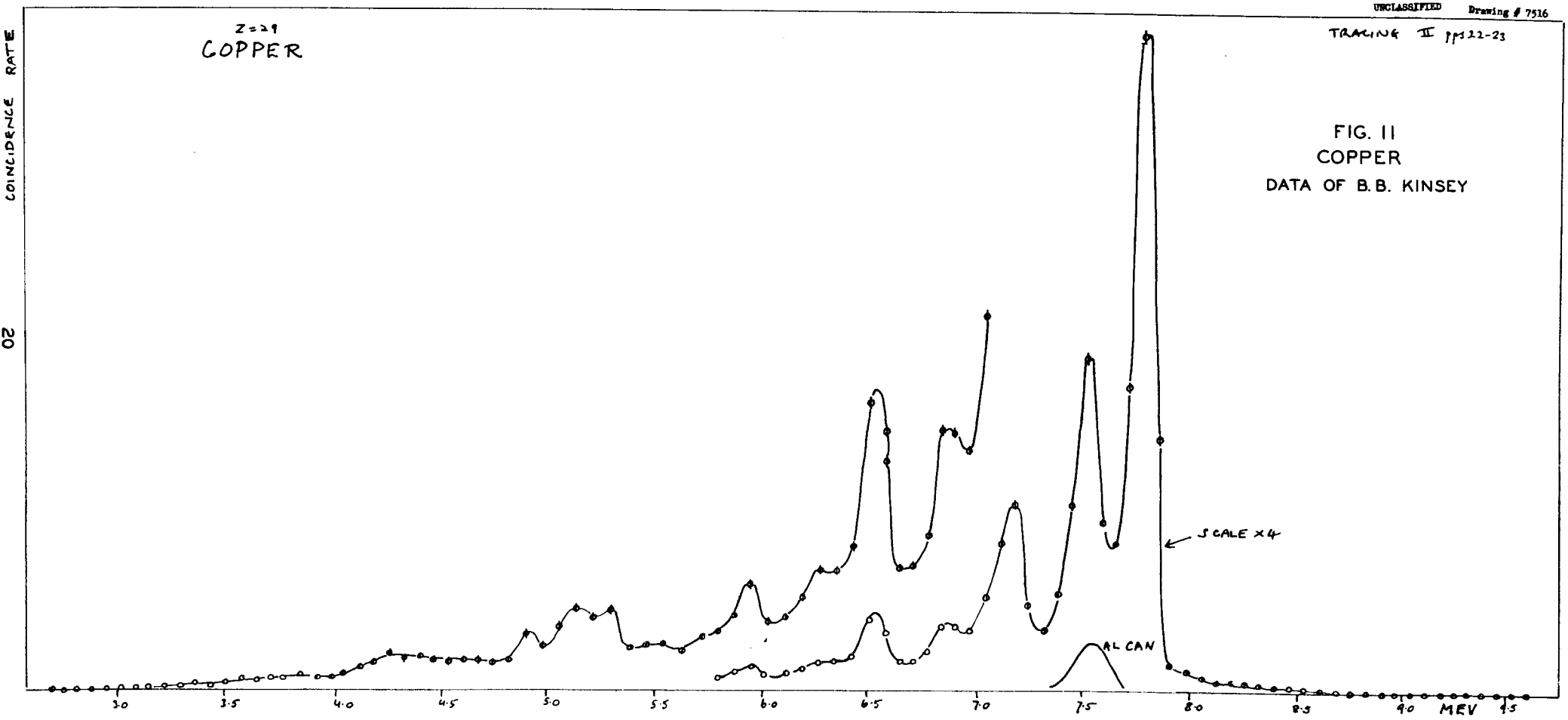
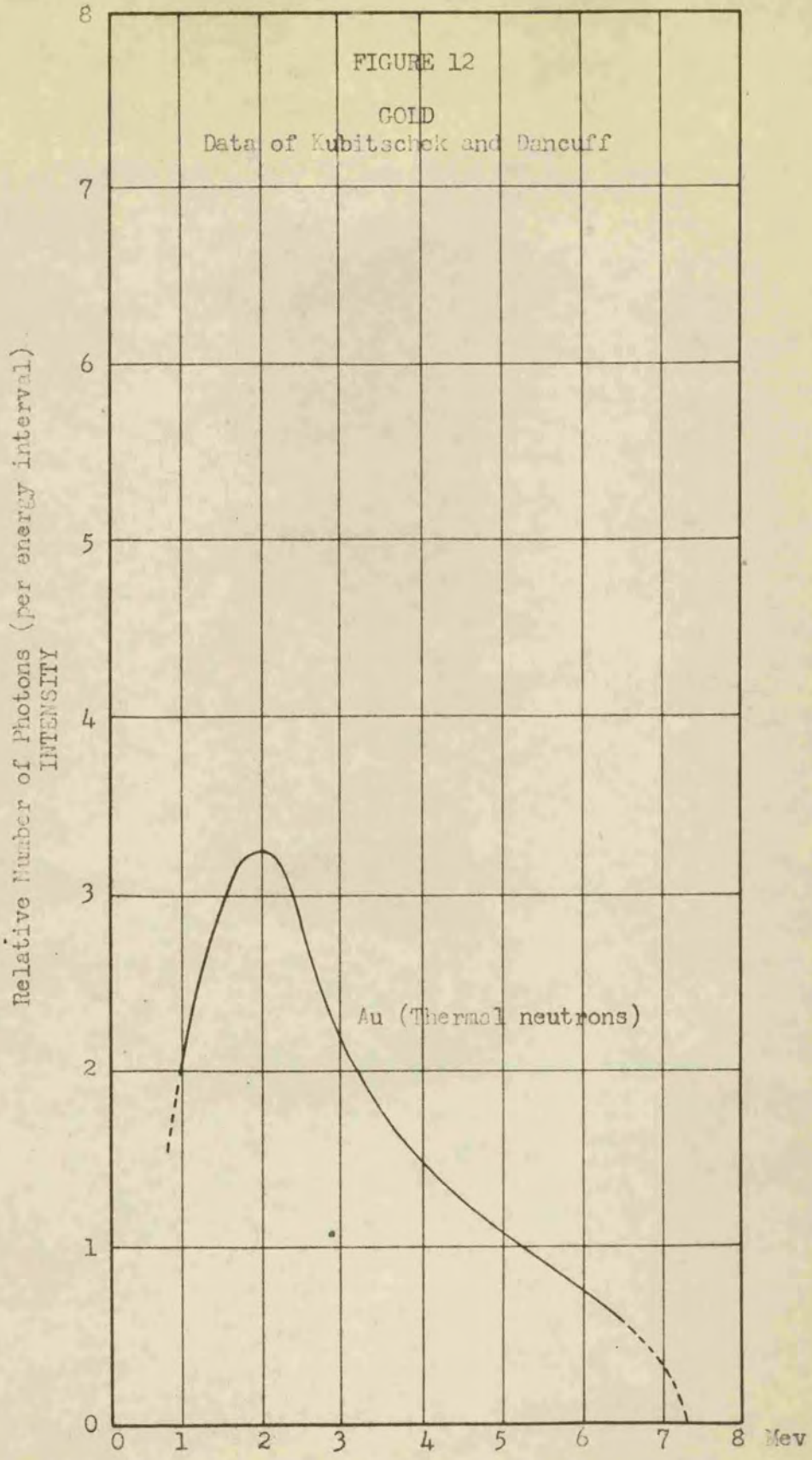
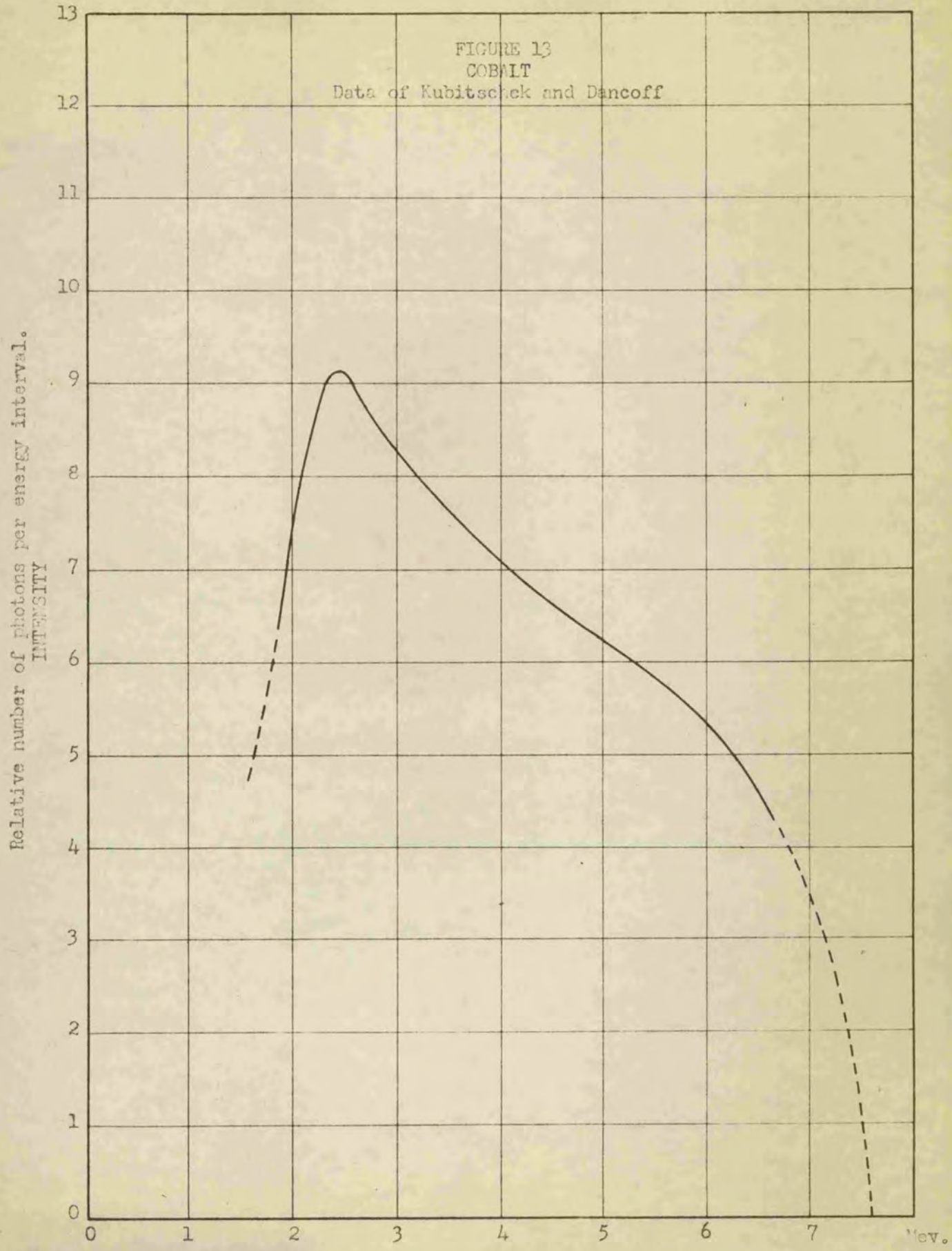


FIG. 11
COPPER
DATA OF B.B. KINSEY

Drawing #7545



Drawing #7547



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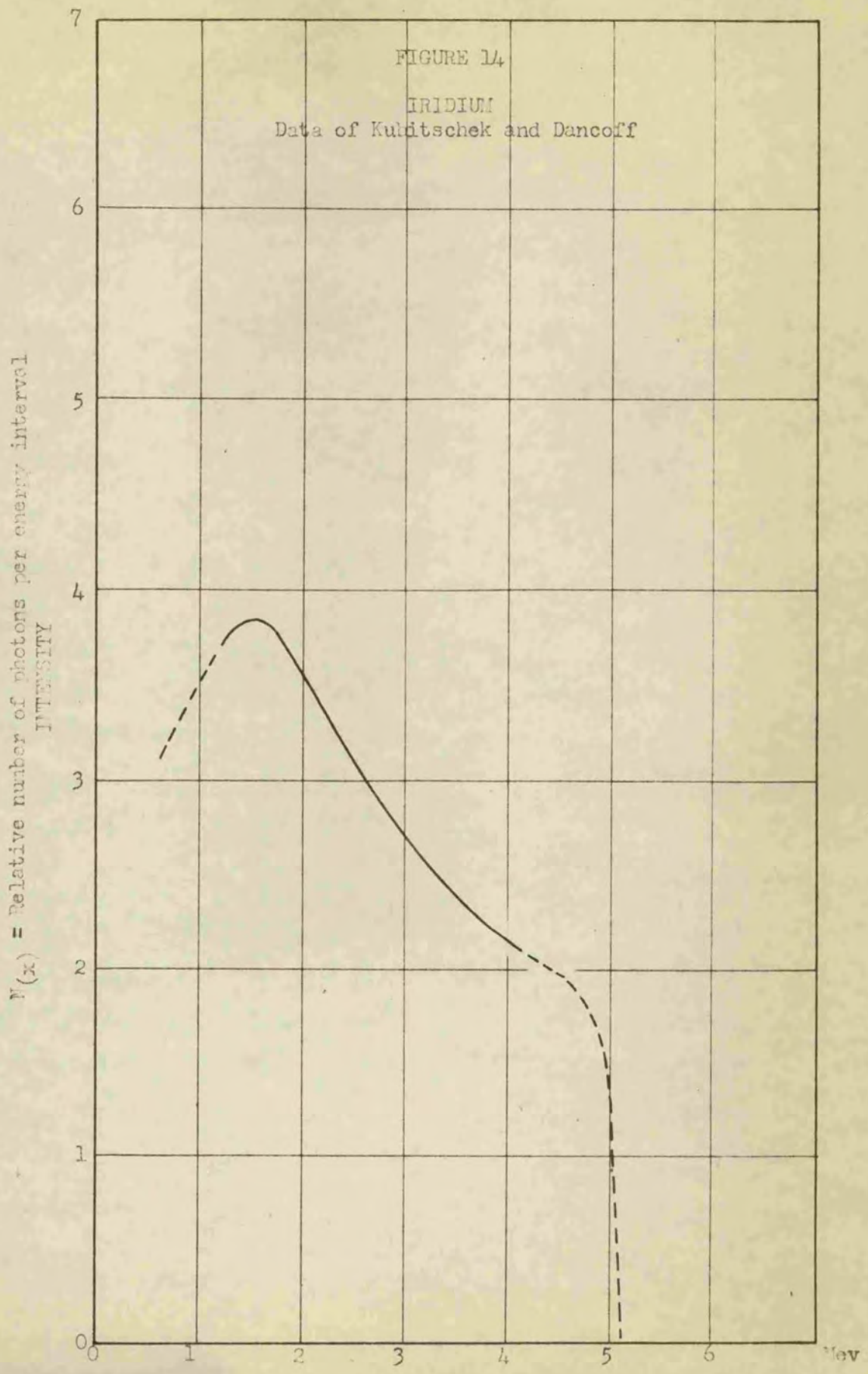

UNCLASSIFIED Drawing # 7518

TRACING II pp. 40-41.

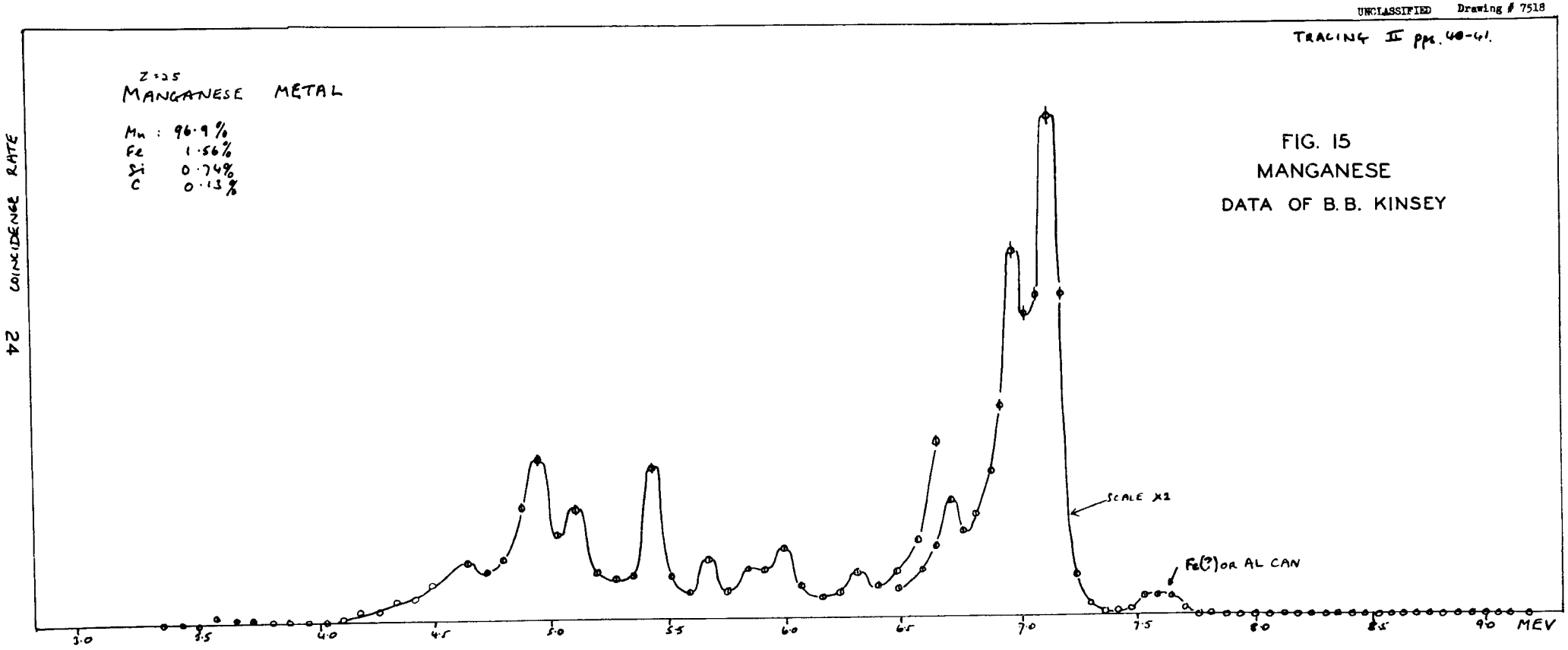

FIG. 15
MANGANESE
DATA OF B. B. KINSEY