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THE RADIATIONS FROM 24.1 HOUR W^{187}

PAUL W. LEVY

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THE RADIATIONS FROM 24.1 HOUR W^{187}

Paul W. Levy*
Oak Ridge National Laboratory
Oak Ridge, Tennessee

A B S T R A C T

The radiations from 24.1 hour W^{187} have been investigated with counter and photographically recording beta-ray spectrometers. The continuous beta-ray spectrum consists of at least two components and there is an indication that a third is also present. The maximum energies and the intensities of these components are: 1.318 Mev, $\geq$ 12 per cent; 0.627 Mev, $\geq$ 65 per cent; $\approx$ 0.38 Mev, $\leq$ 23 per cent. Gamma-rays of 0.133, 0.204, 0.478, 0.615, 0.680 and 0.767 Mev are present. In addition, a photoelectron line is observed that can be attributed either to a gamma-ray of 0.127 and/or 0.061 Mev, or to the Re X-rays accompanying internal conversion electrons.

I. INTRODUCTION

When tungsten is irradiated with neutrons, a radioactive isotope having a half-life of one day and emitting both beta particles and gamma-rays is produced. This activity was discovered by Amaldi et al[1] in 1935 but its radiations had not been studied in detail when the investigation reported here was undertaken. The first accurate determination of the half-life, 23 hours, was reported by McLennan, Grummett, and Reid[2]. Assignment of this emitter to the tungsten isotope of mass 187 was made by Minakawa[3] who,

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in addition, gives 24.0 ± 0.1 hours for the half-life and 1.1 ± 0.1 Mev as the maximum energy of the beta-rays. Minakawa's value for the half-life is in good agreement with the 24.1 ± 0.1 hours reported by Fajans and Sullivan[4]. These authors also claim that 1.40 ± 0.05 Mev is the upper limit of the beta-ray energy and find evidence for a gamma-ray of .87 Mev. Clark[5], who used coincidence absorption techniques, gives 0.90 Mev for the maximum energy of the gamma-rays. He also concluded that there are two components in the beta-ray spectrum and that no gamma-rays accompany the high energy component. Valley[6] investigated the low energy conversion lines associated with this isotope with a spectrograph and found gamma-rays of 0.86, 0.101, and 0.135 Mev. Mandeville[7], by determining the distribution of Compton electrons ejected by the tungsten gammas from an aluminum radiator, concludes that there is only one gamma-ray more energetic than .5 Mev and that its energy is .94 ± .02 Mev.

On the basis of the results quoted above, Sullivan[8] deduced that a gamma-ray of ≈ .6 should be present and succeeded in finding evidence for it with a refined absorption technique. Miller and Curtiss[9], from results obtained with a lens spectrometer, give 0.6 and 1.3 as the maximum energies of the beta-rays and at 0.48 and 0.69 Mev for the energy of the gamma-rays. Interest in this activity was created by the discovery of DeBenedetti and McGowan[10] that it was the parent of a metastable level of .65 μ-sec in Re^{187}. It was at their request that a detailed investigation of the tungsten radiations was undertaken. While this study was in progress, Schwartz and Pool[11] disclosed that a large number of unreported gammas were present. Just recently the work of Peacock and Wilkinson[12] has

appeared. These authors, using a 180° spectrometer, determined the maximum energies of the beta-ray spectra as 0.63 and 1.33 Mev. In addition, they find gamma-rays of 0.21, 0.48, 0.62 and 0.69 Mev.

The results described below were obtained with two beta-ray spectrometers. The first of these employs counter recording, 180° focusing, and has a 10 cm radius of curvature [13]. This spectrometer was used for continuous beta-ray and photoelectron spectra measurements. For the photoelectron measurements an aluminum absorber, thick enough to absorb all of the conversion lines and betra-rays, surrounds the source. A gold radiator, of the proper size to provide good focusing, is cemented to the absorber. With this arrangement one hopes to detect the gamma-rays that are so slightly converted that they may not be detected with the photographic spectrograph.

The second spectrometer records photographically and is similar to those used by Ellis [14] and Valley and McCreary [15]. This photographic spectrograph possesses the dual advantage, over the photoelectron method, that it will detect lower intensity gamma-rays, even if they are only slightly converted, and is more accurate. Consequently, the values given for the gamma-ray energies are obtained from the conversion electron pictures and the other determinations are regared merely as checks. The error, in both gamma-ray and beta-ray energies, is one precent for values greater than .1 Mev and two per cent for values between .05 and .1 Mev.

All of the sources used were prepared from metallic tungsten that was spectrochemically found to be free from bothersome impurities. For continuous spectrum measurements and conversion electron pictures it is essential to make the source as thin as pos ible and still provide sufficient intensity.

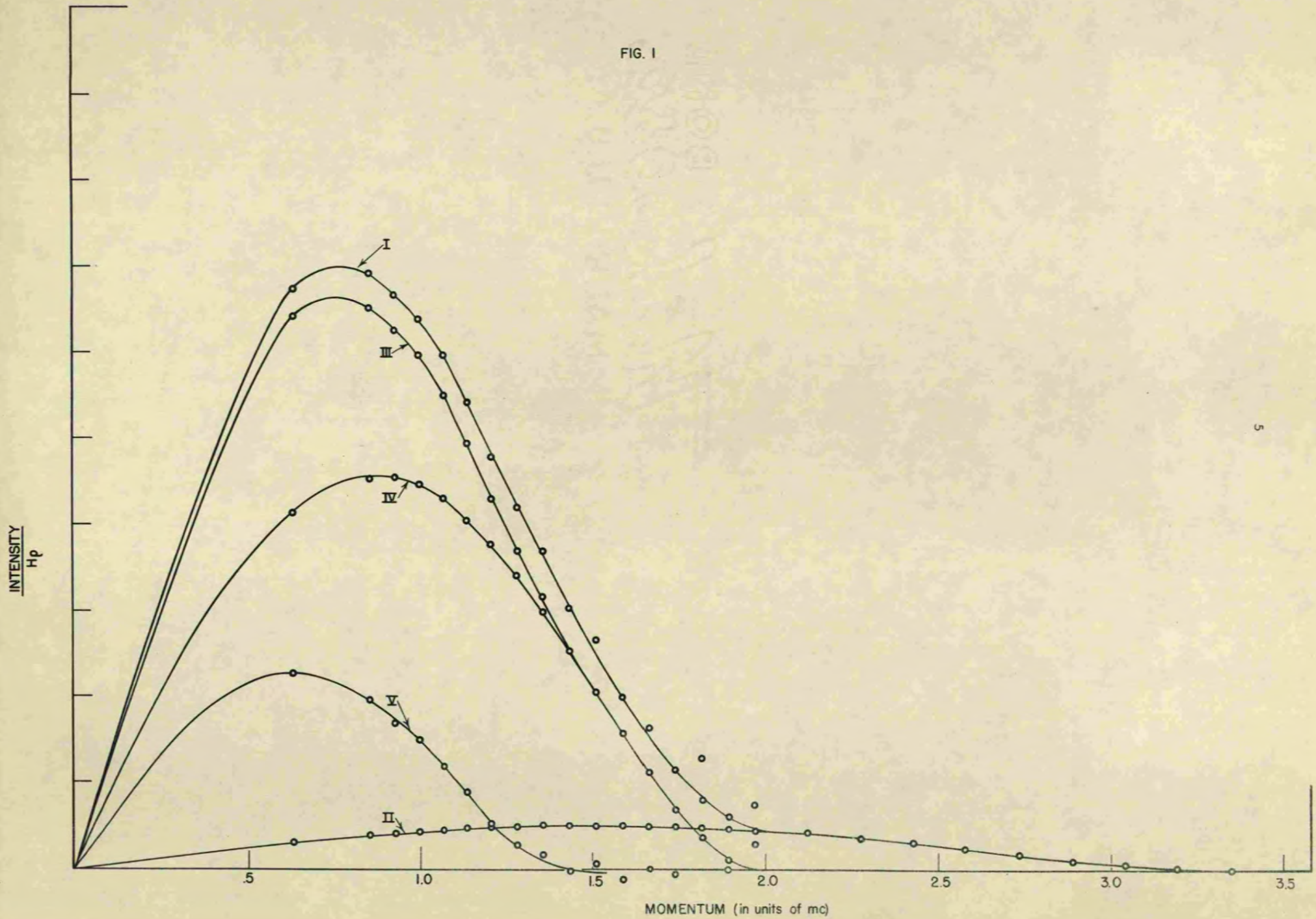
Commercially available tungsten ribbon could not be obtained thin enough to use without reducing its thickness. Attempts to accomplish this by hot and cold rolling, dissolving it in various solvents, etc. were not successful. However, ribbons ≈ 10 mg/cm^2 were eventually made by "electropolishing". Sources were made from these ribbons by irradiation in the laboratory pile. They were mounted on Zapon film $\approx .05$ mg/cm^2 and as such should be free from all scattering from the mounting but it is important to remember that the back scattering from the tungsten itself is not negligible.

II. THE BETA-RAY SPECTRUM

To determine the number of components and maximum energies of the beta-ray spectra the momentum distribution was studied with the 180° counter recording spectrometer. All parts of the spectrum were found to decay with the same half-life and consequently the amount of 78 day W^{185} activity present is negligible. To ascertain the effect of source thickness on this distribution, runs were made with two different sources. One of these was ≈ 10 mg/cm^2 and the other ≈ 30 mg/cm^2. The momentum distribution from the thinnest source and its subsequent decomposition are shown in Fig. 1. A Kurie analysis of the data from both sources is shown in Fig. 2 where the open circles refer to the thinner source and the solid circles to the thicker one. The fact that there is no apparent difference in the Kurie plots obtained with the two sources indicates that the back scattering is the same in the two cases. However, this does not necessarily mean that the back scattering has been eliminated.

From the Kurie plot it is apparent that there are at least two components in the beta-ray spectrum. The end point of the highest energy component is 1.318 ± 0.013 Mev. Above 0.63 Mev the Kurie plot is linear and

FIG. I


I
III
IV
V
II
INTENSITY / Hρ
.5
1.0
1.5
2.0
2.5
3.0
3.5
MOMENTUM (in units of mc)

we assumed that it could be linearly extrapolated over the region where the other component is superimposed on it. Using this assumption, the 1.318 Mev component was subtracted off. The result is Curve II of Fig. 2 from which the end point of the second spectrum, 0.627 ± 0.010, is obtained. Since this curve is not linear it is feasible to consider that it represents two spectra. Proceeding on the assumption that the 0.63 spectrum also has a linear Kurie plot, it was subtracted from Curve II. In this way Curve III is obtained which indicates that the end point of the possible third component is ≈ 0.38 Mev.

The two high energy spectra have been shown to exist both by Clark and by Peacock and Wilkinson. Since it was necessary to use thick sources, the entire third component could be due to back scattering. Also, it is conceivable that the second spectrum could deviate so markedly from having the shape of an "allowed type" spectrum that Curve II represents its true shape. However, as we will discuss below, considerations pertinent to constructing a decay scheme lend support to the existence of this low energy component.

III. THE GAMMA-RAY MEASUREMENTS

A summary of the data obtained from conversion electron pictures of this 24.1 hour tungsten activity is contained in Table I. Typical examples of these pictures, covering the entire energy range over which the lines were found, are shown in Fig. 3. The energies of the conversion lines tabulated are a weighted average of the values obtained from one, two or three different pictures. The gamma-ray energies contained in the column "Best value of gamma-ray energies" were averaged in the same way, after adding the appropriate binding energy to the energy of the lines. In one of the continuous

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FIG. 2

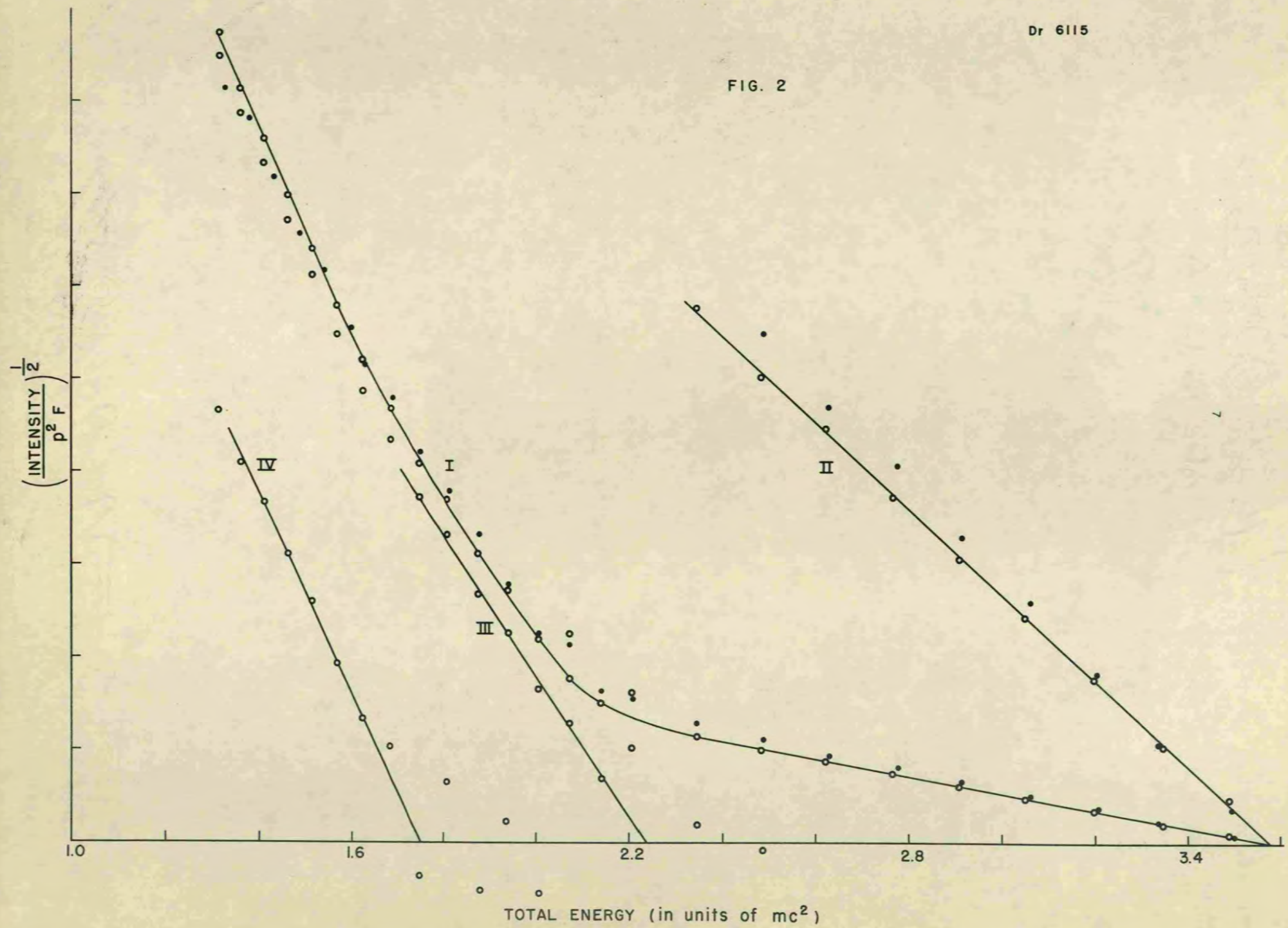
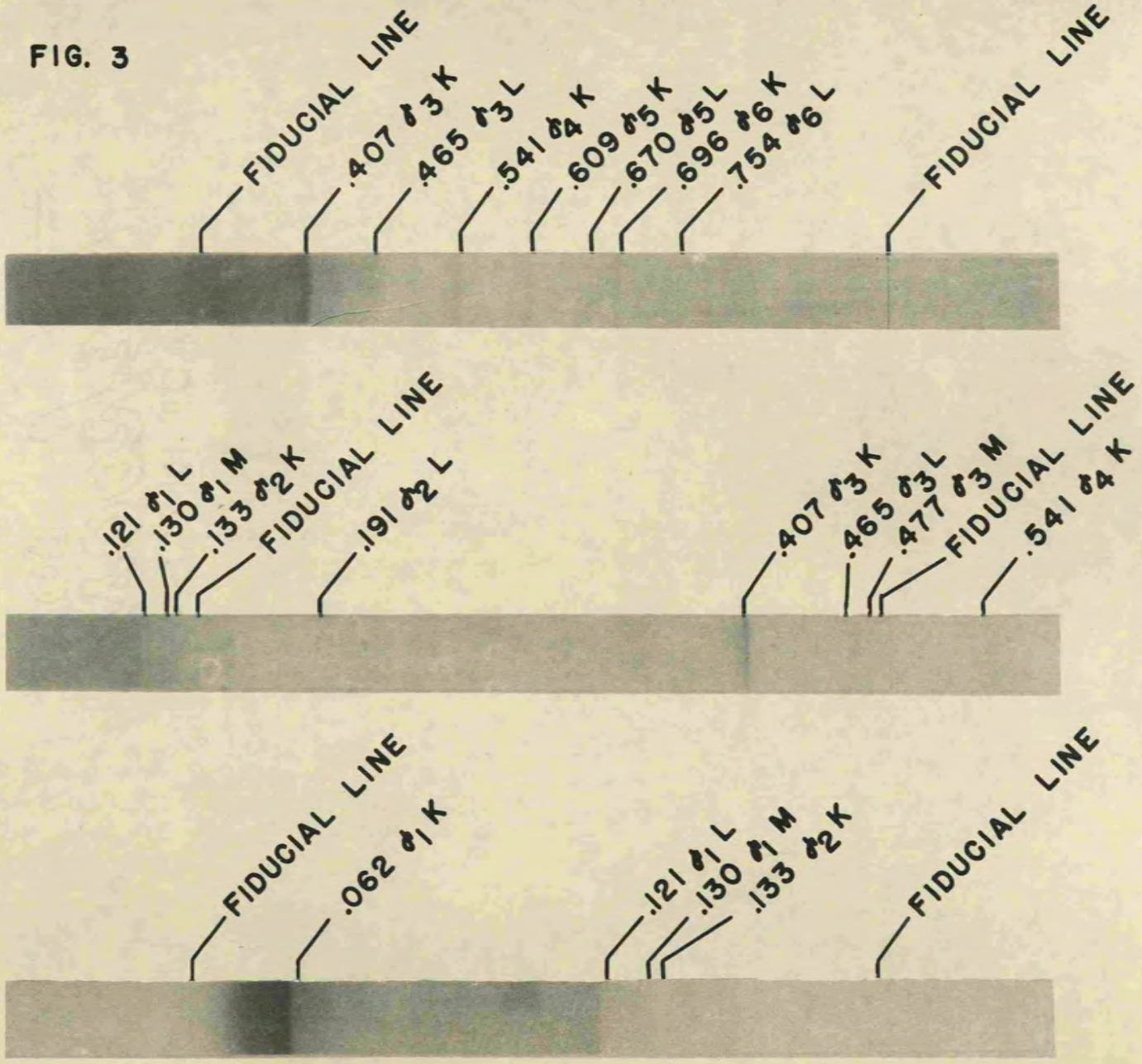

$\left(\frac{\text{INTENSITY}}{p^2 F}\right)^{\frac{1}{2}}$
I
II
III
IV
1.0
1.6
2.2
2.8
3.4
TOTAL ENERGY (in units of mc^2)

FIG. 3


FIDUCIAL LINE
.407 δ3 K
.465 δ3 L
.541 δ4 K
.609 δ5 K
.670 δ5 L
.696 δ6 K
.754 δ6 L
FIDUCIAL LINE
.121 δ1 L
.130 δ1 M
.133 δ2 K
FIDUCIAL LINE
.191 δ2 L
.407 δ3 K
.465 δ3 L
.477 δ3 M
FIDUCIAL LINE
.541 δ4 K
FIDUCIAL LINE
.062 δ1 K
.121 δ1 L
.130 δ1 M
.133 δ2 K
FIDUCIAL LINE

spectrum measurements points were taken close enough together to determine the energies of the conversion lines superimposed on the spectrum. This data is in agreement with the "picture" data to within a permissable error.

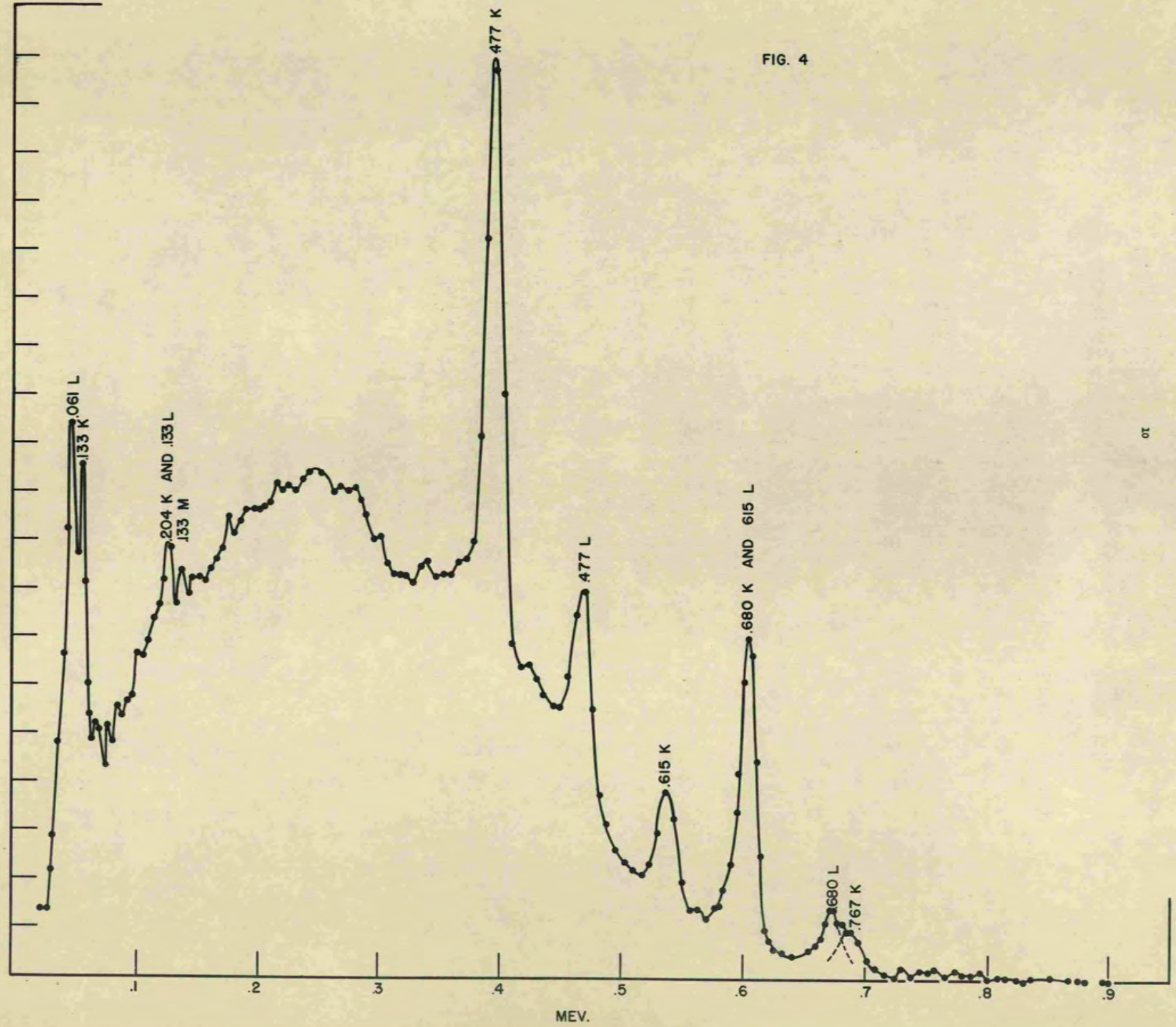
TABLE I

Conversion Electrons and Gamma-rays in 24.1 hr W^{187}

Gamma-ray	Conversion lines observed	Estimated Intensity of conversion lines	Energy of conversion Lines (Mev)	Best value of gamma-ray energy (Mev)
1	K	Very strong	.062	.133
	L	Strong	.121	
	M	Medium	.130	
2	K	Medium	.133	.204
	L	Faint	.191	
3	K	Strong	.407	.478
	L	Weak	.465	
	M	Faint	.477	
4	K	Medium	.541	.615
5	K	Weak	.609	.680
	L	Faint	.670	
6	K	Very weak	.696	.767
	L	Very faint	.754	

The photoelectron distribution cruve, Fig. 4, is one of four such curves obtained with different source arrangements. Although these curves differ slightly in the width, and to a smaller extent in the height, of the photoelectron lines, the energies of the lines obtained from the different curves are well within the experimental error. These values are also in good agreement with those obtained from both sets of conversion electron data. The photoelectron data, summarized in Tables II and III, was obtained from all four curves. The relative intensities of the photoelectron lines,

FIG. 4


.061 L
.133 K
.204 K AND .133 L
.133 M
477 K
477 L
.615 K
.680 K AND 615 L
.680 L
.767 K
.1
.2
.3
.4
.5
.6
.7
.8
.9
MEV.

determined from their heights, were in agreement with the intensities obtained from the areas under each line. In order to obtain the relative intensities of the gamma-rays from this data the cross section curves given in Heitler[16] were used. As the internal conversion coefficients are not known, the actual number of transitions corresponding to each gamma-ray cannot be computed.

With one exception, all of the observed photo lines can be attributed to gamma-rays detected by means of their internal conversion lines. This one line, at 0.046 Mev, could be either the K line from a 0.127 Mev gamma-ray or the L line from a 0.061 Mev gamma-ray. A gamma-ray of 0.061 Mev is essential to one of the possible decay schemes. However, no conversion electrons are observed corresponding to gamma-rays of either of these energies, and, since 0.061 Mev is the K-L separation in Re, this line could be from the Re X-rays.

The 0.133 Mev gamma-ray deserves special mention. Its conversion lines are very much stronger than the others observed and so, even if this gamma-ray occurs in all of the disintegrations, it is very highly converted.

One expects that for a metastable gamma-ray transition, the spin change associated with it should be 2 or larger. It is well known that the conversion coefficient increases strongly with increasing spin change. Consequently, as has been pointed out by DeBenedetti and McGowen[9], this 0.133 Mev gamma-ray is probably the one associated with the .65 microsecond level they observed following beta-decay of the 24.1 hr W.

TABLE II

Photoelectron Lines from 24.1 hr W^{187}

Energy of line (Mev)	Interpretation
0.046	0.061 L or 0.127 K
0.056	0.133 K
0.122	0.133 L and 0.204 K
0.133	0.133 M
0.396	0.478 K
0.467	0.478 L
0.538	0.615 K
0.604	0.615 L and 0.680 K
0.673	0.680 L
0.689	0.767 K

TABLE III

Summary of 24.1 hr Tungsten Radiations

Component	Energy	Intensity
β_1	1.318 ± 0.013	$\geq$ 12 per cent
β_2	0.627 ± 0.010	$\geq$ 65 per cent
β_3	≈ 0.38	$\leq$ 23 per cent
γ_0	0.061 ± 0.002 or $0.127 \pm .002$	
γ_1	0.133 ± 0.001	
γ_2	0.204 ± 0.002	< 0.05
γ_3	0.478 ± 0.005	1.00
γ_4	0.615 ± 0.006	0.44
γ_5	0.680 ± 0.007	1.43
γ_6	0.767 ± 0.008	0.16

The gamma-ray intensities given are not corrected for internal conversion. Intensities obtained for the low energy lines involve such large errors that they are meaningless.

IV. DISCUSSION

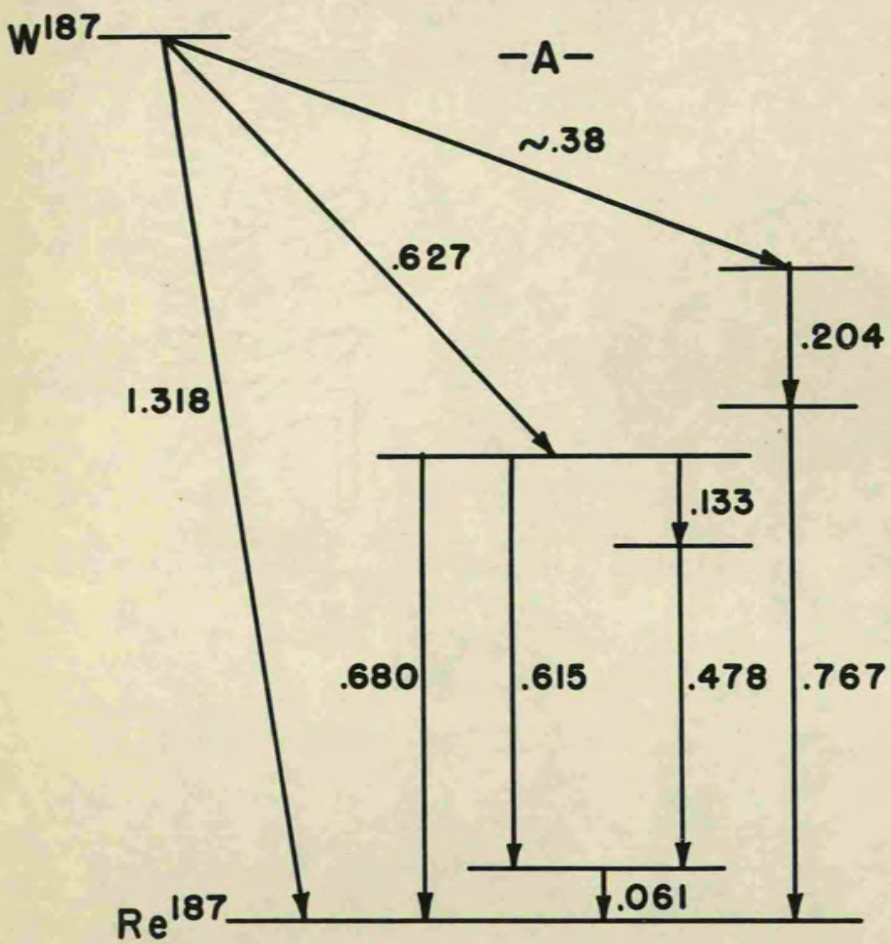
The results obtained in the high energy region for the W^{187} radiations are in essential agreement with those of Peacock and Wilkinson[12], apart from our observation of a 0.767 Mev gamma-ray. However, the agreement with other authors is not too good. To begin with, neither conversion

lines nor photoelectron lines were observed corresponding to the 0.086 and 0.101 Mev gamma-rays reported by Valley. While the 0.133 gamma obviously is the same one he reports as 0.135 Mev, the 0.061 and/or 0.127 Mev gamma-ray is entirely outside of the possible values he gives for the other two. With regard to the high energy gamma-rays, Schwartz and Pool find one of 0.860 Mev and Mandeville gives 0.94 Mev as the highest energy one. Should either or both of these be present the photoelectron data would indicate they are much less intense than the 0.767 gamma.

All of the data pertinent to the construction of a decay scheme is contained in Table III. In order to construct such a scheme certain considerations should be pointed out. First, the difference between the end points of β_1 and β_2 is less than 0.767 Mev. Thus there must be a level either above the one into which β_2 decays, or one below the one into which β_1 decays. The first of the alternatives is supported by the work of Clark indicating that no gamma-rays are in coincidence with β_1. This means that β_1 decays to the ground state. Now the sum of the energies of β_3, γ_2, and γ_6, 1.35 Mev, is approximately the energy of β_1. Thus one arrives at the decay scheme A, in Fig. 5, from which it is apparent, in order that Clark's results be consistent with the existance of the 0.767 Mev gamma-ray, a third beta-ray group must exist.

Indicated above is the possibility that the 0.061 gamma-rays are in reality Re X-rays. A decay scheme not involving the 0.061 gamma-ray and retaining the idea that no gamma-rays are in coincidence with β_1 could not be made. If one considers decay schemes in which gamma-rays are in coincidence with β_1, one obtains B in Fig. 2. We were not able to construct a reasonable decay scheme in which both the 0.061 gamma and the $\approx$ 0.38 beta-ray group are not included.

FIG. 5


W187
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1.318
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.615
.478
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Re187

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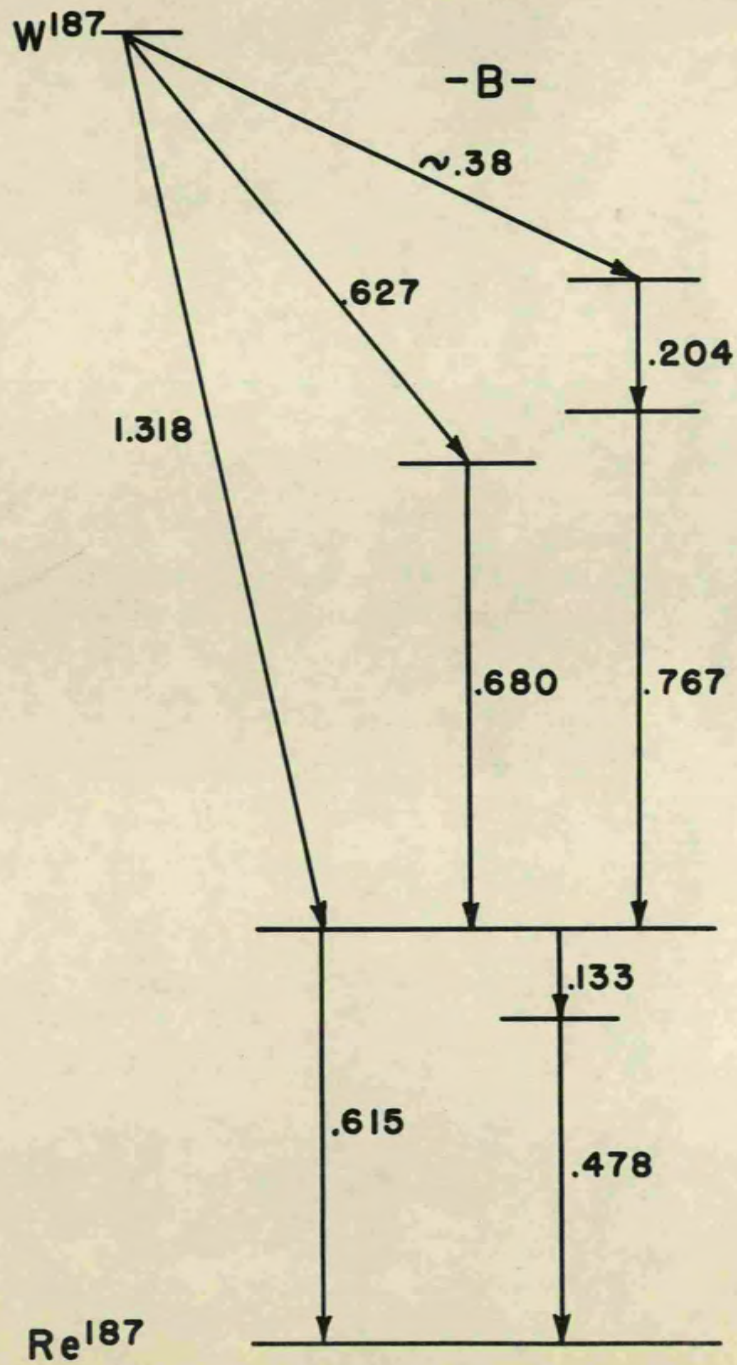
W187
-B-
~.38
.627
.204
1.318
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Re187

V. ACKNOWLEDGEMENT

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CAPTIONS FOR FIGURES

Fig. 1

Momentum distribution of the W^{187} beta-rays. Curve I is the data from which the open circle Kurie plot in Fig. 2 was made. Curve II is the "allowed type" spectrum with a maximum energy 1.318 Mev. It is normalized to fit the data above 0.63 Mev. From Curve III, obtained by subtracting Curve II from Curve I, one obtains the end point of the second spectrum, 0.627 Mev. Curve IV is an "allowed type" spectrum normalized to fit Curve III above 0.38 Mev. When it is subtracted from Curve III the $\approx$ 0.38 Mev spectrum remains. The relative intensities of the various components were obtained from these curves.

Fig. 2

Kurie plot showing the decomposition of the continuous spectrum into its various components. The open and closed circles represent, respectively, data from sources $\approx$ 10 mg/cm^2 and $\approx$ 30 mg/cm^2. The two sets of data <u>are not</u> normalized.

Fig. 3

Typical examples of the W^{187} conversion electron pictures taken with the photographic spectrometer. The energy range covered in the three pictures is approximately from 0.018 to 1.2 Mev. Each line is labeled with its energy, the gamma-ray it is produced by and the shell in which it is converted. Some of the weaker lines, not discernable in the reproductions, are not indicated.

Fig. 4

Distribution of photoelectrons ejected from a gold radiator by the W^{187} gamma-rays. The Compton electron background has not been subtracted. The line marked 0.061 L might also arise from a 0.127 Mev gamma-ray or the Re X-rays produced in the process of internal conversion of the gamma-rays.

Fig. 5

Two possible decay schemes for W^{187}.

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