the error in the frequency value may have been underquoted.

A pleasant feature of this calculation is that so few of the experimental results examined are in conflict with the final values. It has been necessary to reject only a few results as being seriously inconsistent.

The corrections to experimental results were further classified according to type of experiment and it was found that the numerical values for the $d-p$ and $d-\alpha$ reaction Q values were in general slightly low and the probable errors in the $d-\alpha$ and mass spectrographic results appeared to be underquoted, but in no case were these deviations significant. Furthermore, a crude statistical test on Li's and Ogata's results seems to indicate that the agreement between these values is better than can normally be expected, so there is little point in using these results separately. It would however be useful for individual experimenters to compare their own results with the values quoted in Table III.

Decays of Ta¹⁸² and Ta¹⁸³†*

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The β^- decays of Ta¹⁸² and Ta¹⁸³ into excited states of W¹⁸² and W¹⁸³ have been studied using a curved crystal gamma-ray diffraction spectrometer and a homogeneous field, ring focusing beta-ray spectrometer. In each case de-excitation of the daughter nucleus gives rise to complex gamma-ray and conversion electron spectra. Energies and relative intensities of gamma rays and conversion lines arising from 27 transitions in W¹⁸² and 29 transitions in W¹⁸³ are presented. Internal conversion coefficients and multipolarities have been deduced for most of the transitions and together with the gamma-ray energies form the basis of decay schemes proposed for both W¹⁸² and W¹⁸³. The two decays are reported together be-

cause of the close experimental relationship which existed between them as a consequence of the method used for their production, namely, simultaneous production of Ta¹⁸² by single neutron capture and Ta¹⁸³ by double neutron capture from stable Ta¹⁸¹. A corollary result is the value 1.3×10^4 barns for the thermal neutron cross section of Ta¹⁸².

An interpretation of these results on W¹⁸² in terms of collective rotational motion has been given by A. Bohr and collaborators [Kgl. Danske Videnscab. Selskab, Mat.-fys. Medd. 29, No. 9 (1955)].

INTRODUCTION

IN regard to the decay of Ta¹⁸² this work is complementary to several earlier investigations,[1,2] its principal contributions being the investigation of a number of new gamma lines and the multipole assignments for most of the transitions, making possible the establishment of an energy level diagram for W¹⁸². For Ta¹⁸³ the results presented here provide the first detailed study of the decay of this isotope. They are in essential agreement with preliminary results[3] obtained earlier in this laboratory.

The Ta¹⁸³ used in this experiment was produced from stable Ta¹⁸¹ by double neutron capture. This process was practical because of the unusually large thermal neutron cross section[4] of Ta¹⁸² together with the high neutron flux available in the Materials Testing Reactor at Arco where the irradiation was performed.[5] At the same time, of course, Ta¹⁸² was produced. The ratio of the populations, N_3 and N_2 of Ta¹⁸³ and Ta¹⁸² which results after irradiation in a neutron flux, ψ, for a time, t, is (assuming the Ta¹⁸¹ population to be constant):

$$\frac{N_3}{N_2} = \frac{\sigma_2\psi}{\lambda_3}\left\{\frac{1-e^{-\lambda_3 t}-\lambda_3 t e^{-\frac{1}{2}(\lambda_3+\lambda_2+\sigma_2\psi)t}\left[\dfrac{\sinh\frac{1}{2}(\lambda_3-\lambda_2-\sigma_2\psi)t}{\frac{1}{2}(\lambda_3-\lambda_2-\sigma_2\psi)t}\right]}{1-e^{-(\lambda_2+\sigma_2\psi)t}}\right\}\to\sigma_2\psi/\lambda_3 \quad \text{as} \quad t\to\infty, \tag{1}$$

‡ Present address: Radiation Laboratory, University of California, Berkeley, California.
[1] Muller, Hoyt, Klein, and DuMond, Phys. Rev. 88, 775 (1952).
[2] Cork, Childs, Branyan, Rutledge, and Stoddard, Phys. Rev. 81, 642 (1951); J. W. Mihelich, Phys. Rev. 95, 626 (1954). Fowler, Kruse, Keshishian, Klotz, and Mellor, Phys. Rev. 94, 1082 (1954).
[3] DuMond, Hoyt, Marmier, and Murray, Phys. Rev. 92, 202 (1953).
[4] See Appendix I.
[5] We gratefully acknowledge the efforts of Dr. W. B. Lewis in arranging for irradiations in the Materials Testing Reactor, Arco, Idaho, under the auspices of the Phillips Petroleum Company.
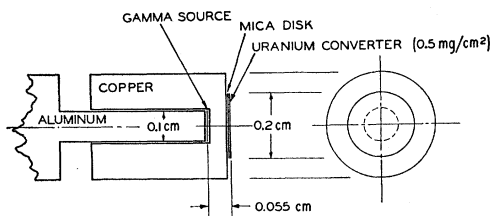
FIG. 1. External conversion assembly used for observation of photoelectrically converted gamma rays.

where σ_2 is the thermal neutron cross section of Ta[182] and λ_2 and λ_3 are the decay constants of Ta[182] and Ta[183] respectively. A nine-day irradiation was performed in a neutron flux of approximately 2.5×10^{14} neutrons/cm^2 sec. For 112-day Ta[182], $\lambda_2=7.1\times10^{-8}$ sec^{-1} and for 5.2-day Ta[183], $\lambda_3=1.5\times10^{-6}$ sec^{-1}. When one uses these values and the value 1.3×10^4 barns for σ_2, the activity ratio of Ta[183] to Ta[182] immediately after irradiation is found from Eq. (1) to be

$$\frac{N_3\lambda_3}{N_2\lambda_2}=25\approx\frac{1}{2}\frac{\sigma_2\psi}{\lambda_2}. \tag{2}$$

An order of magnitude reduction of either σ_2 or ψ would have made observation of the decay of Ta[183] difficult. But as it was, the high initial activity ratio together with the large difference in half-life of the two isotopes enabled essentially independent observations of the decays of both Ta[183] and Ta[182], in that order, using the same sources.

INSTRUMENTS, SOURCES AND METHODS

Two instruments were employed. One is a curved crystal gamma-ray diffraction spectrometer; the other is a homogeneous field ring-focusing beta-ray spectrometer.[6] The tantalum decays provided an excellent opportunity to exploit the combined use of these instruments, in that good sources could be prepared for both. The present results rest strongly on the combination of information obtained with them. In particular, precision gamma-ray energies obtained with the curved crystal spectrometer enabled identification of most of the conversion lines observed with the beta-ray spectrometer and internal conversion coefficients were obtained from the combination of gamma-ray and conversion line intensities.

The gamma-ray spectrometer and techniques for its operation have been described in detail elsewhere.[1] The gamma-ray spectrometer requires a line source, short compared to the 2-meter focal length of the crystal, bisected by and perpendicular to the plane of reflection. The actual source was a solid tantalum wire 3 cm long, 0.028 cm in diameter with a total initial activity of approximately 10 curies. The resolution obtained with

[6] DuMond, Kohl, Bogart, Muller, and Wilts, Office of Naval Research Special Technical Report, No. 16, March, 1952 (unpublished).

this source was only slightly poorer than the limiting resolution obtainable with an ideal source. The minimum wavelength difference resolvable with a crystal diffraction spectrometer is a constant, for a particular source, so that the energy resolution expressed as a fraction of the gamma-ray energy, $\Delta E/E$, is proportional to the gamma-ray energy, E. In this experiment the resolution was given by

$$\Delta E/E=0.3E\times10^{-4}, \tag{3}$$

where E is expressed in kev.

All of the gamma-ray energies below 900 kev were obtained by the usual method of comparing or matching line profiles obtained by reflection from opposite sides of the crystal planes and were calibrated from the W $K\alpha_1$ x-ray, a strong line arising from K-conversion in the daughter isotopes W[182] and W[183]. A lower limit of one twentieth of the resolution or 10 ev, whichever is larger, is believed to be a figure for absolute gamma-ray energy uncertainty large enough to include any systematic error or uncertainty in the calibrating x-ray energy. Counting statistics were sufficiently good so that the uncertainties for gamma-ray energies below 900 kev listed in the subsequent table are actually this lower limit.

With the observed gamma rays emerging in a direction essentially perpendicular to the axis of the wire, absorption in the gamma-ray spectrometer source was small enough so that observations down to about 30 kev, the low-energy limit of the instrument, could be made. As well as absorption in the source it was necessary to consider other factors, however, notably the reflection coefficient of the crystal and efficiency of the gamma-ray detecting device (a scintillation counter) in order to obtain relative gamma-ray intensities. The variation of the overall correction to observed intensities amounted to a factor of 10 so that uncertainties in the determina-
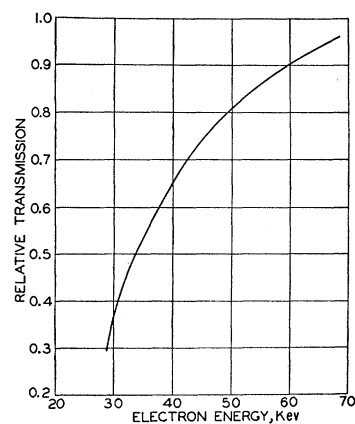

FIG. 2. Window transmission of the Geiger counter used in the beta-ray spectrometer. The counter had a circular, unsupported mica end window 3 cm in diameter, 0.7 mg/cm^2 thick. Electrons were incident at 45° to the window normal, resulting in an effective thickness of 1.1 mg/cm^2.
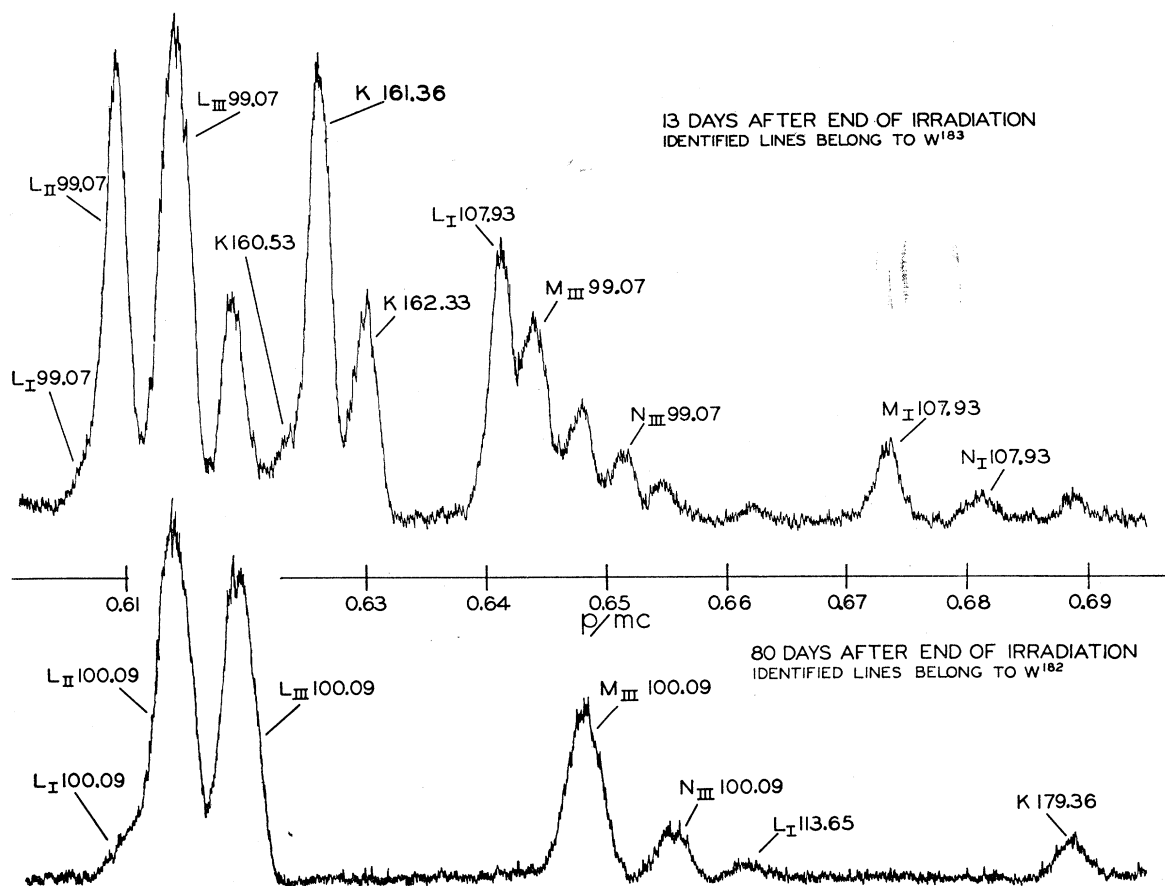
FIG. 3. A representative portion of the internal conversion line spectra of W^{182} and W^{183} as it appeared shortly after and long after the end of neutron irradiation of the source. The presentation was obtained by continuous chart recording of the output of a counting rate device. In the later run the beta-ray spectrometer was set for a higher transmission resulting in a resolution somewhat poorer than that obtained in the earlier run.

tion of the foregoing factors resulted in rather large uncertainties for the relative gamma-ray intensities. Below 110 kev the uncertainty was of the order of 30 percent; above 110 kev but below 900 kev, 15 percent.

The beta-ray spectrometer makes use of a nearly homogeneous magnetic field provided by a set of coils designed to approximate a winding on the surface of a prolate spheroid having a constant number of turns per unit length along the major axis of the spheroid. With a small electron source located on the axis of the spheroid, a circular aperture concentric with the axis defines a solid angle of acceptance about a coaxial cone with a half angle of 45°. A circular resolving slit is located at the second order ring focus. An electron counter is placed on the axis in the region beyond the resolving slit where the electron trajectories intersect the axis. The 45° acceptance angle results in a maximum solid angle of acceptance, for a given resolution, for this type of instrument.[7] The homogeneity of the magnetic field permits the use of an absorption-type proton resonance system for its measurement and stabilization.

[7] J. W. M. DuMond, Rev. Sci. Instr. 20, 160 (1949).

A disk-shaped source is used in the beta-spectrometer, its diameter corresponding to the desired resolution. One of the assemblies used for observation of externally, or photoelectrically, converted electrons is shown in Fig. 1. The gamma-ray source was a tantalum disk 0.0025 cm thick, 0.1 cm in diameter. The nine-day irradiation described above produced an initial activity of about 100 millicuries in this disk. The converter used for gamma energies below 400 kev was a disk of uranium 0.5 mg/cm^2 thick, 0.2 cm in diameter.

The diameter and thickness of the converter needed to obtain a practical converting efficiency in the presence of a high Compton background arising largely from high-energy gamma rays in W^{182} set a limit to the resolution of low-energy external conversion lines. Reliable observations of relative intensities of low-energy external conversion lines could be made for only the five most intense gamma rays in the spectrum of W^{183} above 240-kev gamma-ray energy. The relative gamma-ray intensities deduced from these observations by correction for the energy dependence of the photoelectric cross section in uranium and the effect of anisotropy of

TABLE I. Data for transitions in W^{182} and W^{183}.

Initial and final energy levels	γ-ray energy (kev)	γ-ray intensity	α_K	α_{LI}	α_{LII}	α_{LIII}	α_{total}	Decay[b] fraction percent	Multi-polarity
				Transitions in W^{183}					
IH	40.97±0.01	2.2	...	11.5	...	0.8	18	10	$M1$
BA	46.48±0.01	22	...	7.4	1.05	0.5	11	62	$M1$
CB	52.59±0.01	24	...	3.8	0.9	0.55	6.5	43	$M1$
FE	82.92±0.01	1.1	...	1.4	...	...	(9)	2.5	$(M1)$
FD	84.70±0.02	7.0	...	1.1	...	...	(8)	14.5	$M1$
CA	99.07±0.02	22	1.4	...	1.55	1.45	5.0	32	$E2$
GD	101.94±0.02	0.95	5.4	...	...	...	6.5	1.7	$M1$
(c)	102.49±0.02	0.4	35	6.0	...	...	45	4.5	$M2$
HG	103.14±0.02	0.3	...	...	...	...	6.5	0.6	$(E2)$
DC	107.93±0.02	35	3.8	0.6	...	...	4.5	49	$M1$
EC	109.73±0.02	1.7	...	...	...	...	(4.0)	(3.0)	$(M1)$
HF	120.38±0.02	0.3	2.1	...	...	...	2.7	0.25	$M1$
(c)	142.25±0.03	1.5	...	0.35	...	...	2	1.1	$M1$
IG	144.12±0.03	8.5	1.65	0.30	...	...	2	6.0	$M1$
DB	160.53±0.04	10.5	0.4	...	(d)	(d)	0.75	4.0	$E2$
IF	161.36±0.04	31	1.15	(d)	...	...	1.4	18	$M1$
EB	162.33±0.04	16.5	1.10	(d)	...	...	1.4	10	$M1$
FC	192.64±0.06	0.9	0.65	...	...	...	0.75	0.4	$M1$
HE	203.27±0.06	0.9	0.65	...	...	...	0.75	0.4	$M1$
HD	205.06±0.06	3.5	0.6	0.13	...	...	0.7	1.4	$M1$
EA	208.81±0.07	2.6	0.7	...	...	...	0.8	1.1	$M1$
GC	209.87±0.07	16.5	0.22	...	0.065	0.03	0.35	5.0	$E2$
IE	244.26±0.09	34	0.15	...	...	...	0.2	10	$E2$
ID	246.05±0.09	100	0.38[a]	0.07	...	...	0.45	35	$M1$
FA	291.71±0.13	20	0.07	...	0.023	...	0.09	5.0	$E2$
HC	313.03±0.15	30	0.22	0.035	...	...	0.26	8.5	$M1$
IC	354.04±0.2	40	0.14	0.025	...	...	0.17	11.5	$M1$
HB	365.60±0.2	3.5	...	...	...	...	...	0.8	$(M1)$
IB	406.58±0.25	4.0	...	...	...	...	...	0.9	$(E2)$

a These are experimental values except for the α_{total} in which theoretical values were used whenever significant conversion coefficients were not determined experimentally. Experimental M and N shell conversion coefficients from Table II are included in the appropriate α_{total}. All conversion coefficients are normalized by the assumption that the K-conversion coefficient for transition ID, 246.05 kev in W^{183}, has the theoretical value for an $M1$ transition.

b Normalized so that the sum of the decay fractions into the ground state is 100 percent. A decay fraction is proportional to $(1+\alpha_{total})$ times the γ-ray intensity.

c These transitions do not appear in the decay scheme proposed for W^{183} (Fig. 8) although on the basis of half-life they definitely belong to the decay of Ta^{183}.

d The L-conversion lines of transitions DB, IF, and EB in W^{183} formed a strong but unresolved group. A hypothetical composition of the group with intensities of the components based on theoretical L-conversion coefficients for the assigned multipolarities produced a group profile closely resembling the observed profile. No other multipolarity assignments led to hypothetical profiles resembling the actual one at all.

electron emission for this converting assembly were in agreement with those obtained with the gamma spectrometer and have not been listed separately.

Using a much thicker thorium converter (10 mg/cm²), relative intensities between several of the gamma rays above 1 Mev in the spectrum of W^{182} were determined with an uncertainty on the order of 15 percent. Normalization of this group of intensities relative to those for the lower energy transitions in W^{182} was established with an auxiliary NaI scintillation crystal spectrometer by comparing the intensity of the unresolved group of high-energy lines relative to the intensity of the 100.09 kev gamma-ray (transition BA).

The sources used for observation of internal conversion lines were prepared by evaporation of irradiated tantalum on a mica backing. The radioactive tantalum was heated to a temperature near but below its melting point at about 3000°C. Heating for a few seconds sufficed to evaporate a tantalum deposit on a thin sheet of mica. Subsequently disks were punched from the mica 0.1 cm in diameter. The activity of the sources so obtained was on the order of 100 microcuries corresponding to thicknesses on the order of 50 μg/cm². This figure is consistent with the observation that source broadening of the lowest energy conversion line at 28 kev was small compared to 0.7 percent energy resolution. No attempt was made to produce sources with thin backings since the large number of conversion lines prevented any interpretable study of the shapes of continuous beta spectra.

An end-window Geiger counter was used with a circular, unsupported mica window 3 cm in diameter, 0.7 mg/cm² thick. The window was concentric with the spectrometer axis so that the electron trajectories entered with an angle of incidence of 45° giving the window an effective thickness of about 1.1 mg/cm². Observation of the shape of the continuous beta spectrum of Cs^{137} in a preliminary experiment, using

TABLE I.—*Continued.*

Initial and final energy levels	γ-ray energy (kev)	γ-ray intensity	α_K	α_{LI}	α_{LII}	α_{LIII}	α_{total}	Decay[b] fraction percent	Multi-polarity
				Transitions in W^{182}					
ED	33.36±0.01	Weak	...	...	...	...	...	...	(E1)
HG	42.71±0.01	Weak	...	...	...	...	...	...	(E1)
KJ	65.71±0.01	7.5	...	2.8	0.4	0.23	4.0	11.0	M1(+E2)
FD	67.74±0.01	85	...	0.17	0.07	0.07	0.31	31	E1
HF	84.67±0.02	5	...	1.8	0.6	0.5	(8)	13.0	M1(+E2)
BA	100.09±0.02	40	1.5	0.13	1.45	1.35	5.0	65	E2
JH	113.66±0.02	7.5	1.7	0.4	0.07	...	2.2	7.0	M1
KI	116.40±0.02	1.7	...	...	...	...	...	...	...
HD	152.41±0.03	35	0.07	...	...	...	0.07	11.0	E1
JG	156.37±0.04	11.5	Small	...	...	...	...	(3.5)	(E1)
KH	179.36±0.05	16	0.41	0.17		0.05	0.58	7.5	M1+E2
JF	198.31±0.06	7.5	0.24	...	0.11	0.07	0.36	2.9	E2
KG	222.05±0.07	35	0.06	0.01	...	...	0.07	11.5	E1
CB	229.27±0.08	20	0.16	...	0.05	0.03	0.24	7.5	E2
KF	264.09±0.10	22	0.11	...	0.04	0.02	0.17	7.5	E2
EC	927 ±1	...	...	...	...	...	...	0.5	(E3)
FC	960 ±1	...	...	...	...	...	...	0.5	(E3)
GC	1003 ±1	...	...	$K/L=7.0$			0.006	2.4	(M1+E2)
DB	1122 ±1	100	0.005	$K/L=6.7$			0.006	29	M1+E2
EB	1155 ±1	6.5	0.004	...	...	...	0.005	1.9	(M2)
FB	1189 ±1	45	0.006	$K/L=6.5$			0.007	13.5	M2+E3
DA	1222 ±1	95	0.003	$K/L=6.0$			0.0035	28	E2
GB	1231 ±1	50	0.003	...	...	...	0.0035	14	E2
FA	1289 ±1	...	...	$K/L=6.6$			...	(5.0)	(M2)
HA	1375 ±2	...	...	...	...	...	...	(0.25)	(E3)
IA	1437 ±4	...	...	...	...	...	...	(0.25)	...
KB	1454 ±4	...	...	...	...	...	...	(0.25)	(M2+E3)

this same counter, and comparison of the result with the well known shape of the spectrum[8] yielded the relative transmission curve shown in Fig. 2 which cuts off completely at about 25 kev. Essentially the only correction applied to observed relative intensities of internal conversion lines was that required by this transmission curve. Above 50 kev uncertainties for relative intensities of conversion lines were of statistical origin and on the order of 10 percent for weaker lines. Below 50 kev the uncertainty was larger because of the counter transmission.

The momentum resolution obtained for internal conversion lines was 0.25 percent to 0.35 percent depending on the size of the source used. The uncertainty assigned to most of the conversion line energies corresponded to about ⅓ of the momentum resolution or 100 ev, whichever was larger. This accuracy was sufficient in most cases to enable identification of the conversion lines by comparison with precision gamma-ray energies from the curved crystal spectrometer.

For the group of transitions around 1 Mev in the spectrum of W^{182} the resolution of the gamma-ray spectrometer was insufficient to permit good energy measurements. The gamma-ray energies given for those

transitions are based entirely on high-resolution measurements of their internal conversion line spectra.

It should be noted that uncertainties described above for both relative intensities and energies are not standard deviations. They represent the maximum possible errors which it is believed might exist.

TABLE II. M- and N-shell internal conversion coefficients for a few transitions in W^{182} and W^{183}.

Initial and final energy levels	γ-ray energy (kev)	M-shell conversion coefficient[a]	N-shell conversion coefficient[a]	Multi-polarity
		Transitions in W^{183}		
BA	46.48	1.5 (I)	0.45 (I)	M1
CB	52.59	0.9 (I)	0.25 (I)	M1
FD	84.70	0.2 (I)	...	M1
CA	99.07	0.7 (III)	0.2 (II and/or III)	E2
DC	107.93	0.15 (I)	0.04 (I)	M1
IG	144.12	0.10 (I)	...	M1
		Transitions in W^{182}		
KJ	65.71	0.8 (I)	...	M1+(E2)
FD	67.74	0.06 (I)	0.014	E1
HF	84.67	0.65 (I)	0.15 (I)	M1+(E2)
BA	100.09	0.7 (III)	0.2 (II and/or III)	E2

[a] Roman numeral in parenthesis after conversion coefficient indicates subshell.

[8] J. S. Osaba, Phys. Rev. **76**, 345 (1949).

RESULTS

Data from the beta-ray spectrometer were taken by continuous chart recording of the output of a pulse integrator. In Fig. 3 is shown a representative portion of the original recordings of the spectra of W^{182} and W^{183} as it appeared 13 and 80 days after the end of the nine-day irradiation of the source. In the earlier run the conversion lines of W^{183} are outstanding whereas in the later run they are almost completely gone. In the later run the beta-ray spectrometer was set for a higher transmission resulting in a resolution somewhat poorer than that in the earlier run.

In Table I energies and relative intensities of gamma rays and experimental K- and L-shell internal conversion coefficients are presented for 27 transitions in W^{182} and 29 transitions in W^{183}. Values for total conversion coefficients are also listed. These, however, contain theoretical values[9,10] wherever significant conversion coefficients were not determined experimentally. In the appropriate cases, experimental M- and N-shell conversion coefficients from Table II are also included in the α_{total}. The decay fractions for the transitions are proportional to $(1+\alpha_{total})$ times the gamma-ray intensity and are normalized so that, according to the proposed decay schemes (see Figs. 7 and 8), the total decay fraction into the ground state is 100 percent.
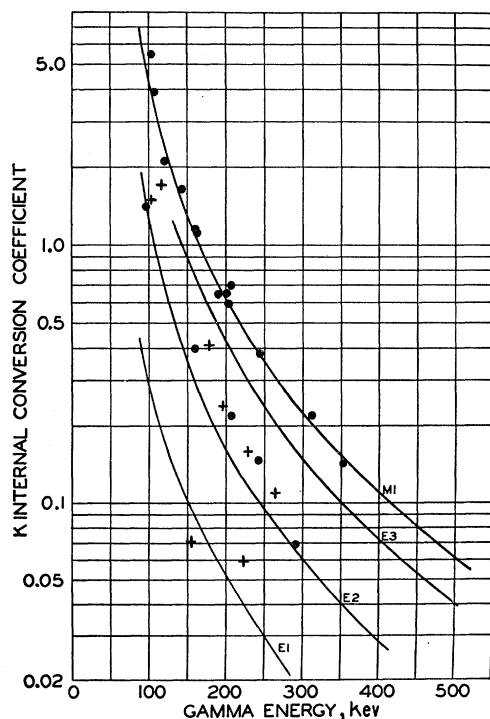

FIG. 4. Comparison of theoretical (curves) and experimental K-shell internal conversion coefficients for $E1$, $E2$, and $M1$ transitions in W^{182} (crosses) and W^{183} (circles).

[9] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. 83, 79 (1951).
[10] Gellman, Griffith, and Stanley, Phys. Rev. 85, 944 (1952).

Since it was not possible to study the shapes of beta spectra because of the large number of conversion lines, only end point energies can be given. In the decay of Ta^{183} the principal beta spectrum has an end point energy of 615 ± 10 kev. Weak spectra of higher energy were observed, their combined intensity corresponding to less than 5 percent of the total decays. No decomposition of these weaker spectra was possible but the end point of the most energetic spectrum definitely lies below 1 Mev.

In the decay of Ta^{182} the principal beta spectrum has its end point at 510 ± 10 kev. There is evidence for two other spectra of appreciable intensity and lower energy. Their end-point energies could not be determined with sufficient certainty to be useful because of the difficulties of decomposition in the presence of many conversion lines.

NORMALIZATION OF INTERNAL CONVERSION COEFFICIENTS

Up to a common normalization factor the internal conversion coefficients are determined by the ratios of relative internal conversion line and gamma-ray intensities. The normalization of the conversion coefficients listed in Tables I and II was established by the assumption that the K-conversion coefficient for transition ID, 246.05 kev in W^{183} had the theoretical value for an $M1$ transition of that energy. The K/L ratio for transition ID is 5.4 and L-conversion takes place almost entirely in the L_I subshell, definitely indicating a magnetic transition. Since both the K-conversion line and the gamma ray are among the stronger lines it is highly probable that it is an $M1$ transition. The only likely admixture is $E2$. If the transition were $E2$, conversion in the L_{III} subshell would give rise to a resolvable line which, from the theoretical conversion coefficient for a transition of this energy, would have an expected intensity of 10.2 on the scale used for relative conversion line intensities. There was no L_{III} contribution with an intensity >1.5 which places an upper limit of about 15 percent on the possible amount of $E2$ admixture. With a ratio of 3.8:1 between the $M1$ and $E2$ K-conversion coefficients this implies that the normalization could be as much as 10 percent too large.

An independent check of the foregoing normalization was made by calculating the absolute value of the K-conversion coefficient for one of the transitions in W^{183} from the ratio of intensities of its internally and externally converted K lines, the ratio of strengths of sources used for internal and external conversion and the converting efficiency of the external conversion assembly. Transition IC, 354.04 kev afforded the best case for applying the check. The absolute value of its K-conversion coefficient so obtained was 0.135, in reasonable agreement with the value 0.143 based on the foregoing normalization. The accuracy of the calculation was limited, however, by large uncertainty in the calculation of the converting efficiency of the external
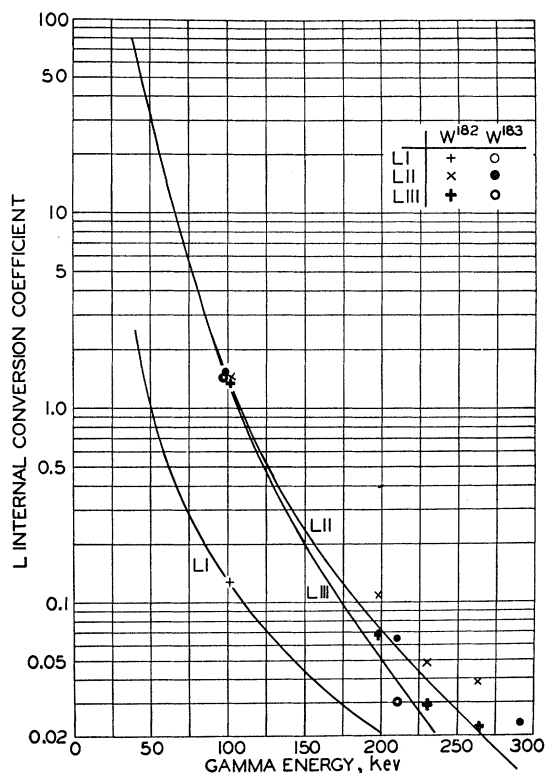
FIG. 5. Comparison of theoretical (curves) and experimental L-shell internal conversion coefficients for $E2$ transitions in W^{182} (crosses) and W^{183} (circles).

conversion assembly. For this reason the result could be regarded only as a check against gross error and not as an accurate basis for normalization.

MULTIPOLARITY ASSIGNMENTS

Multipolarity assignments were made largely on the basis of the comparison of observed and theoretical[9,10] K- and L-shell internal conversion coefficients shown in Figs. 4–6. In several cases, however, it can be seen that the comparison is ambiguous requiring additional arguments. For example, the arguments used in the case of W^{183} will be given in detail.

Except for the 102.49-kev transition all of the observed K-conversion coefficients for transitions in W^{183} differ by large factors from theoretical values for all multipolarities except $M1$, $E2$, and $E3$. Even with large uncertainty in the observed coefficients, however, and possibilities of admixtures (especially $E2$ and $M1$), the fact that K/L ratios below 350 kev are much larger, on the whole, for magnetic than for electric transitions enabled elimination of the $E3$ possibility for all those transitions appearing to be $M1$ from their K-conversion coefficients and for which L-conversion data were also available. Transitions DC, IG, IF, EB, HD, ID, HC, and IC are examples of this situation.

Furthermore L-conversion below 350 kev occurs almost entirely in the L_I subshell for $M1$ transitions and

almost entirely in the L_{II} and L_{III} subshells for $E2$ transitions. The low-energy transitions BA and CB are not K-converted, of course, but in both cases all three L-conversion lines were observed, the L_I lines predominating with conversion coefficients consistent with theoretical $M1$ values. On this basis, these two transitions were interpreted as $M1$. (Transitions IH and FD were assigned multipolarity $M1$ in the same way but are not essential to the ensuing argument.)

From the proposed decay scheme it may be verified that the ten $M1$ transitions just considered form a network connecting all levels of the scheme. Therefore, from only this much of the data (but among the more reliable parts) one can conclude that there is no parity change throughout the scheme. This conclusion eliminates any further possibility of $E3$ transitions being part of the scheme.

On this basis, other transitions for which no L-conversion data were available, but which from their K-conversion coefficients appeared to be $M1$ transitions were freely identified as such. The same procedure applied in the interpretation of the $E2$–$E3$ ambiguities. In these cases, however, there was also evidence of predominant L-conversion in the L_{II} or L_{III} subshells with conversion coefficients consistent with theoretical $E2$ values. Transition IE, 244.26 kev was an exception, its L-conversion lines being unresolved with the large L_I
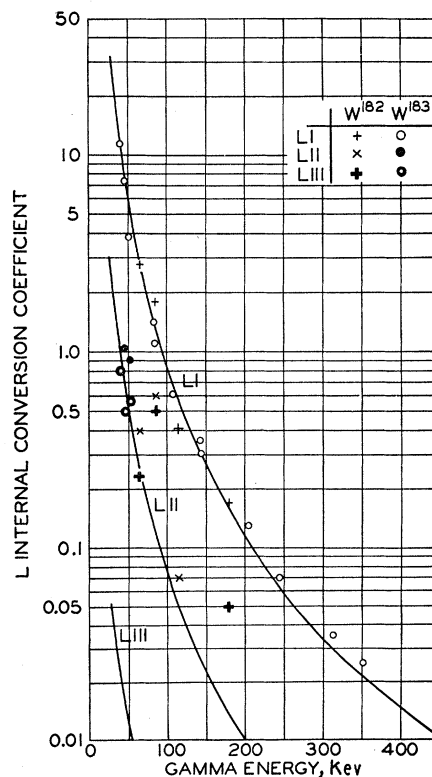

FIG. 6. Comparison of theoretical (curves) and experimental L-shell internal conversion coefficients for $M1$ transitions in W^{182} (crosses) and W^{183} (circles).

line of transition ID, 246.05 kev so that its $E2$ assignment could be based only on the K-conversion coefficient.

Only the 102.49-kev transition was assigned other than $M1$ or $E2$ multipolarity. This transition does not

appear to be part of the main scheme although on the basis of half-life it definitely belongs to the decay of Ta^{183}. Its large K-conversion coefficient is consistent with theoretical values for either $M2$ or $E4$. Its K/L ratio equal to 5.5, however, indicates a magnetic
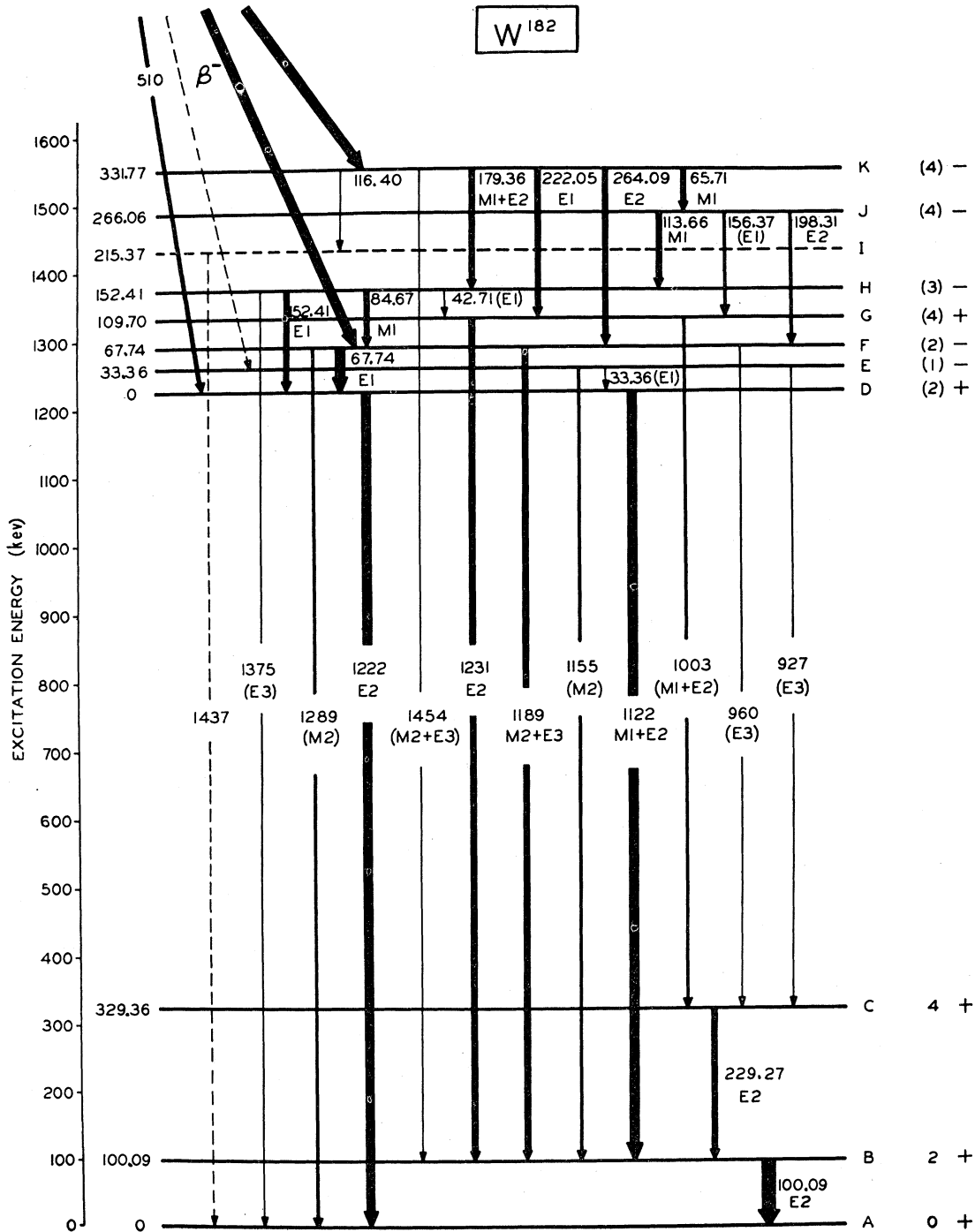

FIG. 7. Proposed decay scheme for W^{182}. Relative decay fractions of the transitions are indicated by the weight of the lines. Multipolarities in parenthesis were inferred from the diagram. Spins in parenthesis are uncertain, representing what is believed to be the most reasonable of a large number of possible sets of spin assignments.
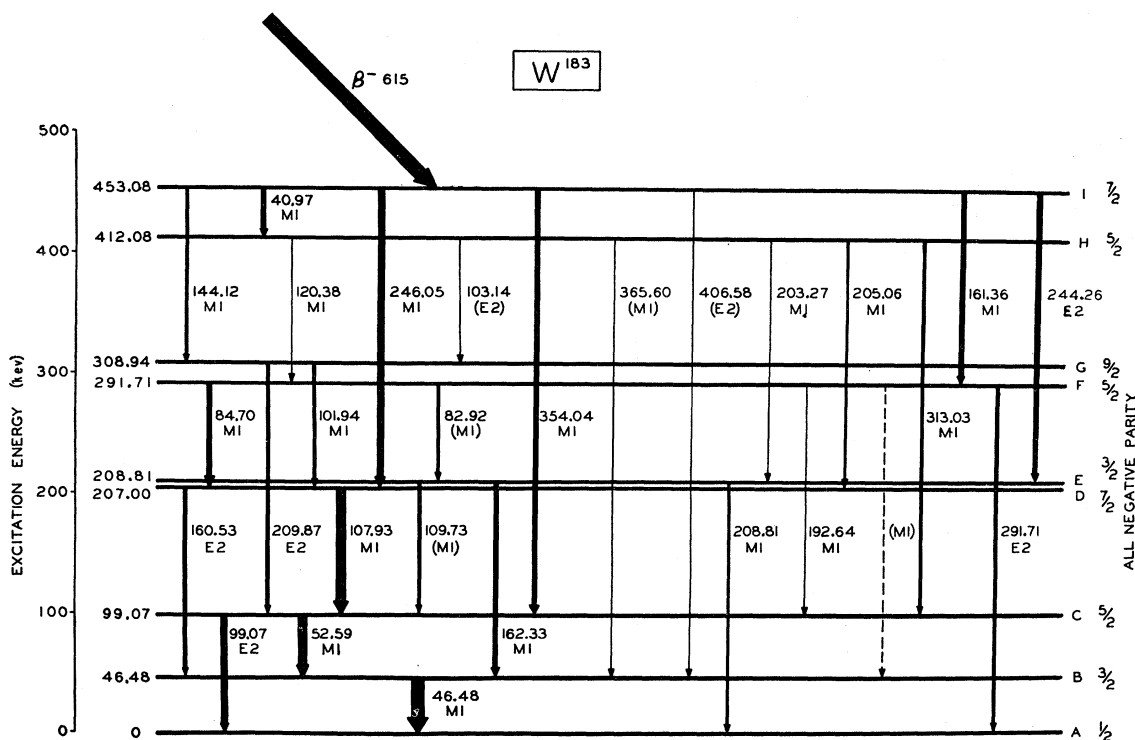
FIG. 8. Proposed decay scheme for W¹⁸³. Relative decay fractions of the transitions are indicated by the weight of the lines. Multipolarities in parenthesis were inferred from the diagram.

transition so it was assigned $M2$ multipolarity. From this result one would again conclude that the transition was not part of the main scheme because of the parity change required by an $M2$ transition.

For those transitions where the multipolarity has been inferred from the decay scheme, there was insufficient conversion data to make any assignment. The inferred multipolarities are consistent, however, in the sense that they result in the prediction of no conversion lines with intensities large enough to have been observed, or else observable lines so predicted would have been unresolved with much larger lines of other transitions so that their existence could not have been verified.

Similar arguments were used in the case of W¹⁸².

PROPOSED DECAY SCHEMES AND SPIN ASSIGNMENTS

Proposed decay schemes for W¹⁸² and W¹⁸³ are shown in Figs. 7 and 8. The internal ordering of the levels in the scheme for W¹⁸³ depends entirely on energy relationships among the transitions and is unambiguous. Relationships among observed gamma-ray line energies, such as CA=CB+BA or IF+FD=IH+HD (see Table I and Fig. 8), formed the basis from which the level scheme was inferred. The chance of accidental relationships of this type depends of course on the precision of the gamma-ray energies. An analysis, based on the expected number of "true" energy relationships compared to the

expected number of "accidental" ones, indicated a very high statistical significance for the proposed scheme (Fig. 8). The ambiguity resulting from the possibility of inversion of the whole level system, however, could not be removed by means of energy considerations, since no beta spectrum with an energy higher than that of the main beta spectrum was sufficiently strong to enable measurement of its end point energy. But with the proposed orientation of the scheme there exists the unique set of spin assignments shown, starting with a ground state spin of $\frac{1}{2}$ (determined spectroscopically),[11] which satisfies all of the spin change requirements established by the multipolarity assignments. With the scheme inverted no satisfactory set of spin assignments exists.

In the case of W¹⁸² the internal ordering of seven of the group of eight highest levels is also unambiguous and based on relationships among the gamma-ray energies together with considerations of spin and parity change. Level I is very uncertain. The two lowest levels of the scheme and their relation to the upper group, including the orientation of the whole upper group, are determined essentially by energy differences among the high-energy transitions. The energies of levels E through K are more certain relative to level D than to the ground state since their connection to the ground state involves only high-energy transitions with rather large uncertainties. With the proposed orientation, feeding and bleeding decay

[11] G. R. Fowles, Phys. Rev. **78**, 744 (1950).

fractions for the various levels are in reasonable agreement while with the inverse orientation there are serious disagreements in this respect.

The spin assignments for levels B and C are definite while that for level D may be questionable because of uncertainties in the conversion data for transitions DA and DB. For the levels above D there are many possible sets of spin assignments compatible with the multi-polarities of the transitions. The proposed assignment, however, appears to be the most reasonable in terms of several interrelated arguments.

There is supporting evidence from coincidence work by Mihelich[2] that transitions DB, FB, and GB in W^{182} are in coincidence with transition BA while transition DA is not. The proposed decay schemes are also consistent with evidence from Coulomb excitation experiments[12] that energy levels about 100 kev above the ground states do in fact exist in both W^{182} and W^{183} and should decay to the ground states by $E2$ transitions. Recent experiments by Huus et al.[13] confirms the existence of the 46-kev level in W^{183}. It is interesting to note that most of the levels of W^{182} (Fig. 7) can be described by the model of collective motion.[14] Such an interpretation has been given by Alaga, Alder, Bohr, and Mottelson.[15]

ACKNOWLEDGMENTS

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APPENDIX

A lower limit of 10^4 barns for the thermal neutron cross section of Ta^{182} was given in a preliminary report.[3] This figure was based on a measurement of the ratio of intensities of total electron emission from Ta^{183} and Ta^{182}. It appeared as a lower limit because of assumptions made concerning average conversion properties of the two isotopes, at that time unknown.

From the present results it was possible to make a better calculation of this cross section by a different method giving the value 1.3×10^4 barns. The activity ratio of Ta^{183} to Ta^{182} immediately after irradiation was

[12] McClelland, Mark, and Goodman, Phys. Rev. 93, 904 (1954).
[13] T. Huus et al. (to be published).
[14] A. Bohr and B. R. Mottelson, Phys. Rev. 90, 717 (1953).
[15] Alaga, Alder, Bohr, and Mottelson, "Intensity rules for nuclear data and gamma transitions to rotational states," Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 29, No. 9 (1955).
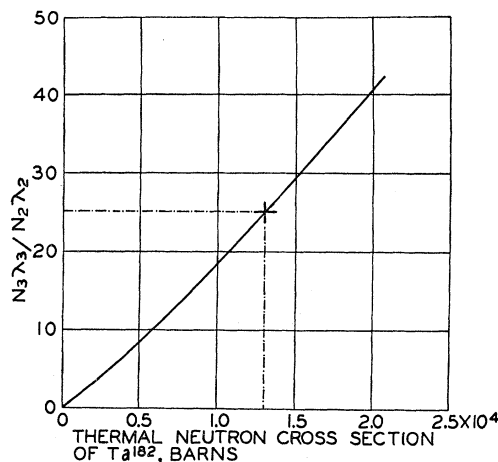
FIG. 9. Activity ratio, $N_3\lambda_3/N_2\lambda_2$, of Ta^{183} to Ta^{182} calculated from Eq. (1) as a function of σ_2, the thermal neutron cross section of Ta^{182}, for a nine-day irradiation in a flux of 2.5×10^{14} neutrons/cm^2 sec. The cross corresponds to the measured value of $N_3\lambda_3/N_2\lambda_2$, indicating the value 1.3×10^{14} barns for σ_2.

calculated from the observed intensity ratio of the K-conversion line of transition ID, 246.05 kev in W^{183} and the L_{III}-conversion line of transition BA, 100.09 kev in W^{182} using experimental decay fractions and internal conversion coefficients for these transitions. The relation is

$$\frac{N_3\lambda_3}{N_2\lambda_2} = \frac{\delta_{BA}}{\delta_{ID}} \frac{[\alpha_{LIII}/(1+\alpha_T)]_{BA}}{[\alpha_K/(1+\alpha_T)]_{ID}} \frac{(I_K)_{ID}}{(I_{LIII})_{BA}}, \quad (4)$$

where I_K and I_{LIII} are the relative intensities of the two conversion lines under consideration corrected to the time at the end of the irradiation. $(I_K)_{ID}/(I_{LIII})_{BA}$ was 15.5. Using decay fractions and internal conversion coefficients from Table I, Eq. (4) gives $N_3\lambda_3/N_2\lambda_2 = 25$. The curve of Fig. 9 gives the value of $N_3\lambda_3/N_2\lambda_2$ as a function of σ_2 calculated from Eq. (1) for the nine-day irradiation in a thermal neutron flux of 2.5×10^{14} neutrons/cm^2 sec which was actually performed. Comparison of the calculated and observed activity ratios gives the value 1.3×10^4 barns for σ_2 with an uncertainty of about ± 30 percent.

Using essentially the same method, Mihelich, in an earlier report,[16] gave an expression for σ_2 which, evaluated with decay fractions from Table I, gives a cross section about 20 times that reported here.

[16] J. W. Mihelich, Phys. Rev. 91, 427 (1953).