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INVESTIGATION OF THE GAMMA-RAY SPECTRUM AND TRANSITION INTENSITIES IN THE DECAY OF ^{182}Ta

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Abstract: The photon spectrum from the decay of ^{182}Ta was measured with a 14 cm^3 Ge(Li) detector of a resolution of 3.5 keV at the ^{60}Co energies. Using the relative intensities of gamma-ray lines determined from the spectrum, and the published data on the internal conversion spectrum, the total transition intensities were computed and the balance of intensities in the decay scheme was made. A discussion of the present knowledge of the decay scheme of ^{182}W is given.

1. Introduction

The decay of ^{182}Ta has been studied by many authors. Tantalum is practically a single isotope element, with a fairly large thermal neutron cross-section, long half-life and an abundant gamma-ray spectrum. It has been measured by all of the available methods such as those more convenient at lower energies, like the crystal diffraction method[4, 6, 7, 9, 18, 20, 21], and those suited for higher energies, like the Compton spectrometers[10, 11, 19], further by magnetic analysis of the internal[1, 3, 5, 15, 17, 25, 26] and external[2, 12, 13] conversion spectrum, and finally by scintillation[8] and solid state spectrometers[22, 23, 24]. Katharine Way[30] made recently a compilation and analysis of gamma-ray energies and intensities.

An inspection of the available data on the decay of ^{182}Ta shows that in some respects the knowledge of gamma-ray intensities is not very satisfactory. The situation could be summarised as follows.

A characteristic feature of the gamma ray spectrum in the decay of ^{182}Ta is an energy gap between 262 keV and 892 keV, dividing the spectrum into a low-energy part ($E_\gamma < 264$ keV) and a high-energy part, with $E_\gamma > 892$ keV. Only a few authors have measured the whole spectrum and corrected the results on intensities with the help of calibration curves covering both parts of the spectrum. Other authors measured only one part of the spectrum, or both but one at a time, conversion ratios or the balance of level intensities.

Two measurements of the total spectrum with the crystal diffraction method[6, 9], and one with the external conversion method[13] use conventional calibration curve corrections of relative intensities. Their results are shown in the first three columns of Table 1. The agreement between the relative intensities of the corresponding lines is poor, the differences being in some cases larger than 50%. Some of these differences could tentatively be attributed to unprecise calibration, while differences between the relative intensities of closely lying strong lines of 1122, 1222 and 1231 keV must be due to some other cause.

Voinova et al.[24] matched the two parts of the spectrum using the internal conversion data. From the intensities of internal conversion L_2 line in the 100 keV transition and of K lines in the 1122 and 1222 keV transitions measured by Grigoriev et al.[25] and with the help of theoretical values of internal conversion coefficients, they deduce the ratio gamma-ray intensities of 100 keV to 1122keV of 0.36 ± 0.02. It is difficult to estimate with confidence the error of such ratio determinations, since several factors can contribute. Some of these factors are not well known, as for instance the difference in line shapes, possible change of the spectrometer imaging properties, uncertainty of L-triplet separation, and various small, but possible, errors connected with the computation of theoretical values of the internal conversion coefficients.

K. Way matched the two parts of the spectrum by the requirements of the intensity balance at the 100 keV level. She obtained the ratio of gamma-ray intensities of 100 keV to 1122 keV of 0.4, a value that is 10% higher than the one obtained from the internal conversion data. This approach relies on the consistency of decay scheme intensities, which does not exclude the possibility of a systematic error.

The separate measurements of lower and higher energy parts agree better, as could be expected for reduced energy intervals. As can be see from Table 1, the relative values of intensities differ in most casses less than 20%.

The above analysis shows that it would be desirable to measure the total spectrum of ^{182}Ta with a Ge(Li) detector, connecting the upper and lower parts with a carefully determined intensity calibration curve. Such a measurement is reported below.

Table 1.
RELATIVE INTENSITIES OF GAMMA-RAYS FROM THE DECAY OF ^{182}Ta

Energy (keV)	Murray et al.[6]	Sumbaye	Rude, Sujkowski[13]	Daniel et al.[15]	Edwards et al.[16]	Vitman et al.[19]	Korkman et al.[23]	Voinova et al.[24]	Our results
31.7									
42.7					0.62 ± 0.03				
65.7	40			7.2 ± 0.4	7.2 ± 0.4				
67.7				107 + 5	106 ± 5				
84.7				7.5 ± 0.5	6.8 ± 0.3			6.4 ± 0.6	6.7 ± 1
100.1			67.2 ± 3,8	38 ± 2.5	38			36 ± 4	38 ± 2
113.7				4.7 ± 0.3				4.6 ± 0.8	4.9 ± 0.25
116.4				1.18 ± 0.10	1.14 ± 0.07			1.0 ± 0.2	1.0 ± 0.07
152.4	35	18.2	33.2 ± 2.6	16.2 ± 0.7	18.5 + 0.7			18.2 ± 2.0	19.7 ± 1.1
156.4	11.5	7.2	13.7 ± 3.5	6.1 ± 0.3	7.2 ± 0.3			6.9 + 0.8	7.5 ± 0.7
179.4	16	8.7	19.5 ± 3.8	8.4 ± 0.4	8.3 ± 0.4			8.0 ± 0.9	8.7 ± 0.4
198.3	7.5	4.5	7.7 ± 1.3	3.8 ± 0.3	3.9 ± 0.2			3.7 ± 0.4	4.2 ± 0.2
222.1	35	21.4	29.2 ± 1.3	19.8 ± 0.6	20.4 ± 0.8			19.2 ± 2.2	21.5 ± 1.0
229.3	20	9.8	14.2 ± 0.9	8.6 ± 0.4	10.0 ± 0.4			9.3 ± 1.1	10.3 + 0.6
264.1	22	9.1	13.4 ± 4.1	8.8 ± 0.6	9.8 ± 0.4			8.9 ± 1.0	10 ± 0.5
892						1.74 ± 0.26			
927						0.96 ± 0.24		1.8 ± 0.4	1.5 ± 0.3
960						5.4 ± 0.3	7.7 ± 2.5	0.8 ± 0.5	1.0 ± 0.1
1002						1.2 ± 0.2	1	4.9 ± 0.7	5.4 ± 1.0
1044								0.7 ± 0.5	0.6 ± 0.1
1122	100	100	100 ± 4.1			100	100	100	100 ± 3
1157	6.5	7.1	4.2 ± 0.9			4.1 ± 1.2	2.62 ± 0.15	2.8 ± 0.4	2.6 ± 0.2
1189	45	56.8	47.5 ± 1.9			44.3 ± 1.5	47.1 ± 2.0	46.5 ± 5	47.2 ± 1.5
1222	95	161	81.0 ± 4.7			77 ± 6	83.4 ± 3.0	76 ± 8	78.0 ± 2.4
1231	50		29.1 ± 1.9			26 ± 5	28.0 ± 1.0	33 ± 3	32.3 ± 1.0
1258			5.1 ± 0.9			3.8 ± 0.3	3.83 ± 0.15	4.1 ± 0.6	4.27 ± 0.14
1274						1.5 ± 0.3	1.61 ± 0.15	2.0 ± 0.3	1.92 ± 0.08
1289			2.9			3.7 ± 0.2	3.60 ± 0.15	4.4 ± 0.6	4.06 ± 0.14
1342						0.60 ± 0.09	0.77 ± 0.05	0.70 ± 0.10	0.75 ± 0.03
1374						0.52 ± 0.09	0.69 ± 0.14	0.72 ± 0.10	0.69 ± 0.03
1388						0.25 ± 0.09	0.18 ± 0.04	0.28 ± 0.04	0.24 ± 0.02
1410						0.115 ± 0.015	0.13 ± 0.06	0.11 ± 0.02	0.14 ± 0.03
1454						0.094 ± 0.012	0.14 ± 0.06	0.19 ± 0.05	0.12 ± 0.03

Note: Fourth and fifth colums were normalised at 100 keV, and the other at 1122 keV gamma-ray intensity.

2. Experimental technique

The sources of ^{182}Ta were obtained by cathode sputtering of inactive tantalum to a thickness of about 50 $\mu g/cm^2$ on a 2 mg/cm^2 thick aluminium foil which was subsequently irradiated in a flux of 10^{13} thermal neutrons/cm^2 s. The foil was cut into samples of 1.5 × 1.5 mm^2, which were fixed to lucite holders.

The lithium drifted germanium detector was prepared in our laboratory from monocrystals supplied by Hoboken. The cylindrical detector had the depletion depth of 7.7 mm, and the axial length of 32.6 mm, corresponding to an active volume of 14 cm^3. ORTEC electronic equipment together with a 512-channel analyser were used. The line-width was 3.5 keV at the energies of ^{60}Co gamma-rays.

The efficiency calibration curve was obtained combining two kinds of informations. A set of intensity calibrated sources supplied by IAEA (^{241}Am, ^{57}Co, ^{203}Hg, ^{22}Na, ^{137}Cs, ^{54}Mn, ^{60}Co and ^{88}Y) served to draw the basic calibration curve. This curve was checked and precision somewhat improved with intensity ratios of cascade transitions in ^{180m}Hf and ^{46}Sc. The errors due to the calibration were estimated to be 2% in the high energy region 6% for 120 keV $< E <$ 300 keV and 11% below 120 keV.

3. Gamma-ray spectrum

The spectrum was measured in several ways, first the total, then partially the lower part, the upper part and the middle one connecting the two. Two series of measurements were made. Three partial spectra obtained are shown in Figs. 1—3.

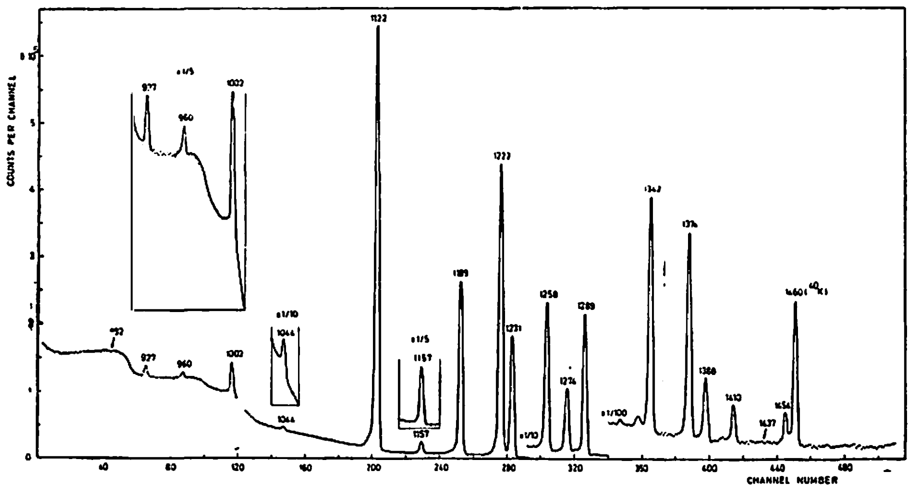

Fig. 1 — Low energy region of gamma-ray spectrum of ^{182}Ta. Numbers above the peaks or indicated by arrows are energies of photons in keV.

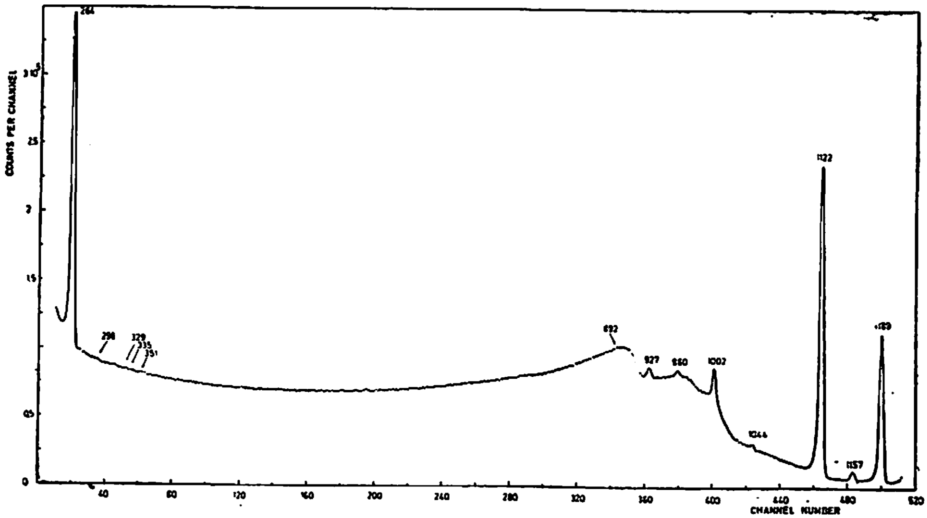

Fig. 2 — Middle energy region of gamma-ray spectrum of ^{182}Ta. Numbers above the peaks or indicated by arrows are energies of photons in keV.

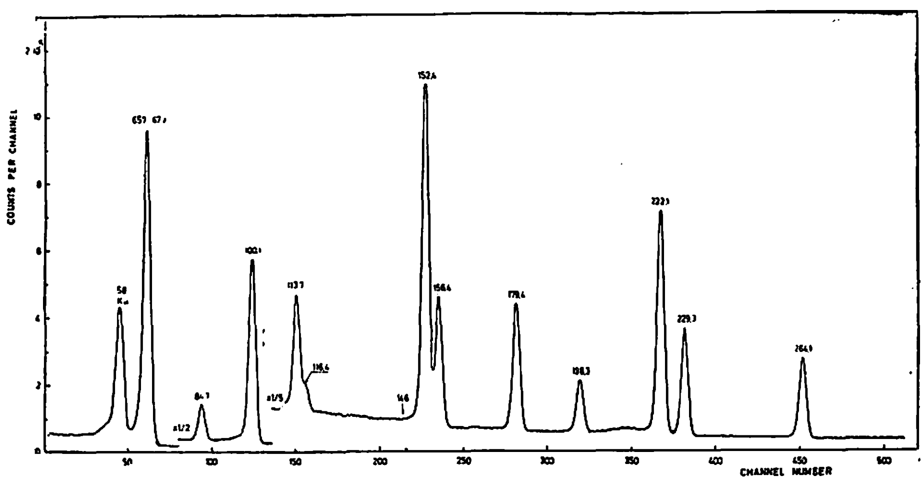

Fig. 3 — High-energy region of gamma-ray spectrum of ^{182}Ta. Numbers above the peaks or indicated by arrows are energies of photons in keV.

Table 2.
TOTAL TRANSITION INTENSITIES IN THE DECAY OF ^{182}Ta

E (keV)	Conversion shell	Conversion line intensity			Mean values of total internal conv. lines	Relative intersity of conv. electrons	Gamma-ray relative intensity	Total transition intensity	
		Grigoriev et al.[25]	Daniel et al.[15]	Nilson et al.[26]				Relative	Absolute
1	2	3	4	5	6	7	8	9	10
31.7	L M	890±69 —	— —	769±46 132±40 901±60	900±60	2.71±0.18	1.29±0.19	4.00±0.26	1.4±0.1
42.7	L	127±12	— —	74±18 19±5	110±22	0.33±0.07	0.66±0.11	0.99±0.13	0.36±0.05
65.7	L M N+O	5190±305 1760±100 510± 70 7460±329	8100±1782 1550± 279 — 9650±1804	6380±351 1526±198 57± 25 7963±403	8360±1390	25.2±5.66	7.7 ±1	33±5.7	11.8±2.0
67.7	L M N+O	6640±225 1440± 70 430± 50 8510±241	9500±1200 1900± 258 400+ 288 11800±1260	6450±348 1995±399 429± 73 8874±534	9730±1390	29.3±4.2	112±17	141±18	50.6±6.5
84.7	K L M N+O	15400±2000 3190± 136 850± 50 270± 20 19810±2005	3870± 453 720± 86 130± 22	12170±1582 3407± 106 873± 55 204± 31 16654±1574	18322±2550	54.8±7.7	6.7±1	61.5±7.8	22.1±2.8
100.1	K L M N+O	10300± 600 27200± 735 ~~9400~~± 400 2300± 100 49200±1035	28200±2340 7500± 700 ~~1900~~± 194	9790±597 29410±274 7175±215 2075± 93 48450±700	48432±1250	146±3.8	38.3±2	184.3±4.3	68.6±4.7

1	2	3	4	5	6	7	8	9	10
113,7	K	3200±200	3374+1080	4013±264					
	L	1300±80	785+196	847±41					
	M	—	240±22	233+27					
	N+O	—	60+18	72+13					
			4459±1098	5165±269	4815±1130	14.5±3.3	4.9+0.25	19.4+3.3	7.0±1.2
116.4	K	100	240+86	67±16					
		20	15+	7±4					
		120	255+90	74±16	150±95	0.45±0.29	1.0±0.07	1.45±0.30	0.52±0.11
152.4	K	700±40	630±88	622±43					
	L	82±5	106±9	120+23					
		—	20+7	—					
			756±88	742±50	774±100	2.3±0.3	19.7±1.1	22.0±1.1	7.9±0.4
156.4	K	335±30		220±53					
	L	31+3	34+5	33+14					
		336±30	—	253±55	311+63	0.9±0.2	7.5±0.7	8.4±0.7	3.0±0.25
179.4	K	1720±90	1714+108	1720±93					
	L	387±12	391±17	421±32					
	M	110±7	135+11	116±18					
	N+O	52+4	35±7	24+11					
		2269±91	2275+110	2281±101	2275±175	6.9±0.5	8.7±0.4	15.6±0.6	5.6±0.2
198.3	K	233±15	228+15	230±24					
	L	130±6	156±23	163+22					
	M+N		42+5	46+8					
			426±28	439±34	424±46	1.3±0.1	4.2±0.2	5.5+0.2	2.0±0.1
222.1	K	244+15	270+15	272+19					
		35±4	58±5	63±8					
		279±16	328+16	335+21	314±31	0.9±1.0	21.5±1.0	22.4±1	8.0+0.4

1	2	3	4	5	6	7	8	9	10
229.3	K L M+N	341± 20 192± 8	363±24 205±16	407±30 179±15 70±15 656±37	632±51	1.9±0.2	10.3±0.6	12.2±0.6	4.4±0.2
264.1	K L M	218± 10 114± 7 31± 3 363± 13	268±11 122± 9 28± 4 418±15	244±24 111±16 —	389±34	1.2±0.1	10 ±0.5	11.2±0.5	4.0±0.2
892	K L		0.28±0.09 —		0.28±0.09	0.0008± ±0.00006	—	—	—
927	K L	— —	3±0.7 —		3±0.7	0.009±0.002	1.5±0.3	1.51±0.3	0.54±0.10
960	K L	— —	3.3±0.7 0.9±0.2 4.2±0.7		4.2±0.7	0.013±0.002	1.0±0.1	1.01±0.1	0.36±0.04
1002	K L	— —	7±0.7 0.9±0.2 7.9±0.7		7.9±0.7	0.024±0.002	5.4±1.0	5.42±1	1.94±0.36
1044	K L	— —	0.9±0.2 — 0.9±0.2		0.9±0.2	0.003± ±0.0006	0.6±0.1	0.60±0.1	0.22±0.04
1113	K	0.2±0.07	0.09±0.02	—	0.14±0.07				
1122	L K M	100± 12±2 4± 116±	100±4 16±1 —		118±5	0.36±0.02	100±3	100.4±3	36±1

1	2	3	4	5	6	7	8	9	10
1157	K	4.2 ± 0.9	5.4 ± 0.7	—	4.8 ± 1.2	0.015 ± 0.004	2.6 ± 0.2	2.6 ± 0.2	0.93 ± 0.07
1189	K L	66 ± 3 8.4 ± 0.5 74.4 ± 3.1	66.5 ± 2.6 9.8 ± 0.7 76.3 ± 2.7		75.3 ± 4.1	0.23 ± 0.01	47.2 ± 1.5	47.4 ± 1.5	17.0 ± 0.5
1222	K L	63 ± 3 9.6 ± 1.0 72.6 ±	65.6 ± 2.2 —		73.9 ± 3.8	0.22 ± 0.01	78.0 ± 2.4	78.2 ± 2.4	28.1 ± 0.9
1231	K L	25.4 ± 1.0 3.6 ± 0.4 29.0 ± 3.2	2.6 ± 1		29.3 ± 1.5	0.088 ± 0.005	32.3 ± 1.0	32.4 ± 1.0	11.6 ± 0.4
1258	K	3.4 ± 0.4	3.5 ± 1.5		3.4 ± 1.6	0.01 ± 0.005	4.27 ± 0.14	4.28 ± 0.14	1.54 ± 0.05
1274	K	—	0.22 ± 0.09		0.22 ± 0.09	0.0006 ± ± 0.0003	1.92 ± 0.08	1.92 ± 0.08	0.69 ± 0.03
1289	K	11.9 ± 1.0	11 ± 2	—	11 ± 2	0.033 ± 0.006	4.06 ± 0.14	4.10 ± 0.15	1.47 ± 0.05
1342	K+L	—	0.74 ± 0.11	—	0.74 ± 0.11	0.002 ± ± 0.0003	0.75 ± 0.03	0.75 ± 0.03	0.27 ± 0.01
1374	K+L	—	0.65 ± 0.21	—	0.65 ± 0.21	0.002 ± ± 0.0006	0.69 ± 0.03	0.69 ± 0.03	0.25 ± 0.01
1388	K	—	0.1 ± 0.07	—	0.10 ± 0.07	3.10^{-4} ± ± 2.10^{-4}	0.24 ± 0.02	0.24 ± 0.02	0.086 ± 0.007
1410		—	—	—	—	—	0.14 ± 0.03	0.14 ± 0.03	0.050 ± 0.011
1437		—	—	—	—	—	—	—	—
1454							0.12 ± 0.03	0.12 ± 0.03	0.043 ± 0.11

Although we have accumulated large statistics we did not find the lines of 146.2 and 351 keV reported by Bashandy et al.[17], nor the lines of 296.2, 329.6 and 335.2 keV reported by Fowler et al.[5]. The very weak transition of 892 keV found in the electron conversion spectrum[15] is also not visible in our spectrum. At the high energy end we haven't found the line of 1437 keV[19, 25], which would have been visible if its intensity were higher than 0.01% of the intensity of 1122 keV line.

The intensities are presented in Table 1 together with intensities reported recently by five other groups[15, 18, 19, 23, 24]. The results of Edwards et al.[18] and Daniel et al.[15] are normalised to the relative intensity of 38 for the gamma--ray of 100 keV, while those of Vitman et al.[19] and Korkman et al.[23] to the relative intensity of 100 for the 1122 keV gamma-ray. The errors quoted are due to statistics and to the uncertainty of the calibration curve.

Our results in the low energy region are closest to those of Edwards et al.[18]. Only in one case the difference amounts to 7.7% otherwise it is less than 6%. Within the error, our intensities agree with those of Voinova et al.[12] over the whole spectrum.

4. *Total transition intensities*

The intensities of the electron-conversion and of gamma-ray transitions in the decay of ^{182}Ta, that were used in the present study, are shown in Table 2. The most precise measurements of the total internal conversion spectrum, reported so far, were made by Grigoriev et al.[25] and by Daniel et al.[15]. They are reproduced in Table 2, taking the intensity of the 1122 keV K-conversion line as 100. Also shown are the recent measurements of the lower-energy part of the internal-conversion spectrum, made by Nilsson et al.[26]. These authors have normalised their relative intensities at the 222 keV K-conversion line. We have also normalised their values to those of Daniel et al. at the same point.

For the pure E2 transition of 100 keV (from the first excited to the ground state), which has the highest intensity and plays an important role in the balance of intensities, Daniel et al.[15] do not give the intensity of K-conversion line, the difference of intensities of L lines is 5%, and that of M lines rises to 25%. Therefore, we prefered to derive the total internal conversion coefficient from the theoretical value for the L shell and from our measurements of the K/L, M/L and (N + 0)/M ratios[31]. The data are shown in Table 3.

For other transitions which are in most cases of mixed multipolarity, we have taken the mean values of total internal conversion intensities obtained by the three groups and normalised them to the theoretical conversion coefficient for the 1222 keV pure E2 transition. The values of relative total transition intensities so obtained are given in column 9 of Table 2.

In order to complete the Tables with low energy transitions which we have not measured, the photon intensities of the 67.7 keV, 65.7 keV and 42.7 keV transitions were taken from Edwards et al.[18], normalised to the value of 38.3 for the intensity of the 100 keV gamma-ray transition. Since there are no precise measurements of the photon intensity of the 31.7 keV transition, we have used the theoretical internal conversion coefficient, assuming that it is a pure E1 transition.

The precision of total intensities which are given in column 9 of Table 2 varies from one energy region to another. It is particularly unsatisfactory for some low-energy transitions, which have relatively high intensity, such as the 65.7, 67.7 and 84.7 keV transitions. This is due to the error of both the photon and electron intensity measurements.

Table 3.

THE TOTAL INTERNAL CONVERSION COEFFICIENTS FROM THE THEORETICAL VOLUE FOR THE L-SHELL AND FROM AUR MEASUREMENTS OF THE K/L, M/L AND (N + 0)/M RATIOS

	Theory	Exp.
L-shell	2.346	—
K/L	0.40	0.40 ± 0.04
M/L	0.242	0.24 ± 0.02
(N+O)/M	—	0.27 ± 0.03
Total	4.0	—

The internal conversion electron transitions contribute about 30% of total transition intensities. Therefore, it is important to know precisely their intensities. An inspection of columns 3—5 of Table 2 shows that this does not appear to be the case. Even for the high-intensity transitions errors sometimes do not overlap. As another illustration of precision one can take L/M ratios for low energies and K/L ratios for higher energies. They are given in Table 4.

Differences between the results are large. Some of them remain unexplained and more precise measurements would be very desirable.

The transition intensities expressed in percents per decay can be obtained by the requirement that the sum of the intensities to the ground state equals 100%. Since the beta decay of ^{182}Ta to the ground rotational band of ^{182}W is negligible ($< 0.15\%$), the percentages can also be obtained by the requirement that the sum of all gamma transitions to the ground rotational band states equals 100%. The ratio between the absolute intensities and those given in column 9 of Table 2 calculated in two different ways, equals 0.359 and 0.356, the first figure corresponding to ground state transition taken as standard. The two values differ by 0.8% and we have used the first one to calculate absolute intensities given in column 10 of Table 2.

Table 4.
L/M RATIOS FOR SOME LOW AND K/L RATIOS FOR SOME HIGHER ENERGY TRANSITIONS

E (keV)	Grigoriev et al.[25]	Daniel et al.[15]	Nilsson et al.[26]	% of decay
		L/M		
65.7	6.4	5.2	4.18	9
67.7	4.6	5.0	3.22	10.6
		K/L		
84.7	4.7	—	3.6	19.6
100.0	0.379	—	0.333	54
113.7	2.48	4.30	4.74	5.2
152.4	8.5	6.0	6.2	0.8
156.4	11	—	6.7	0.3
179.4	4.4	4.1	3.4	2.4
198.3	1.8	1.5	1.4	0.5
222.1	7.0	4.6	4.3	0.2
229.3	1.8	1.8	2.3	0.7

Balance of intensities. — The errors of the absolute total transition intensities as given in column 10 of Table 2 do not permit a precise balance of intensities. We give the balance of intensities in Table 5, together with values found by K. Way[30]. It is interesting to compare our results with those of K. Way, because in her compilatory work a different approach was used. Most important difference is with regard to photon intensities, because she matched upper and lower energy regions by requiring an intensity balance at the 100 keV level.

Comparison shows that the two sets of figures agree quite well. The fact that the balance is not obtained at 100 keV level is of particular interest. The transition intensity arriving to the level is much higher than that leaving it. It is not sure that this is due to low precision of electron intensity data. Only one low energy transition is involed in intensities feeding the level, the one of 229 keV, which has so low intensity, that the error should be such larger than the one quoted to produce the difference in balance which we get. On the other hand, the total coefficient of internal conversion which we used for 100 keV level is somewhat larger than theoretical, which makes it improbable that the electrons are the cause of improper balance. This indicates that the calibration curve for Ge(Li) photon intensity measurements requires more careful analysis and tests before we become sure that high and low energies are properly connected.

5. Branching ratios

Transition intensities in 1 Mev region can be used to calculate branching ratios and obtain parameters, such as z factors, in order to test theoretical models. It has been evident for some time[32] that z factors are not identical, as required by phenomenological analysis of Bohr and Mottelson. From the experimental point of view, the precision is often lacking in the determination of M1 admixtures. They have been so far derived mainly from internal conversion coefficient measurements, which are not sufficiently sensitive in the high energy region. We shall illustrate it by the transitions from the first two levels of vibrational band of ^{182}W.

In order to obtain internal conversion coefficients, K-conversion lines of 1002, 1122, 1222 and 1231 keV transitions were measured in 50-cm radius iron-free double-focusing spectrometer. They are shown in Fig. 4. As 1222 keV transition is a pure electric quadrupole, its theoretical internal conversion coefficient can be used to obtain internal conversion coefficients for the other three transitions by comparing relative electron and photon intensities. When determinating the internal conversion coefficients, the problem appeared in the case of 1002 keV line. The intensity of this transition can be estimated only approximately. The results are shown in Table 6 together with values of internal conversion coefficients found by the other authors. We have also indicated possible M1 admixture when upper errors are taken into account.

For transitions from the level 3^+ the possible M1 admixture may have the values between 0 and 50% what is the case in the results obtained by various authors. From our experiments it follows that mixing from M1 in E2 can be not more than 5%. This can be settled only by angular correlation measurements in which high energy photons will be detected by Ge(Li) spectrometers.

The experimentally obtained ratios of reduced transition probabilities for E2 from the levels 2_2^+ and 3^+ are given in Table 7[33] shows the corresponding theoretical values obtained by Preston-Kiang[35], Belyak-Zaikin[36], Greiner et al.[37, 38], Davydov-Ovčarenko[39] and Bès et al.[40].

Table 5.
BALANCE OF TRANSITION INTENSITIES IN THE DECAY OF ^{182}Ta

Level	E (keV)	»in« Transition intensities Way[30]	»in« Transition intensities Our results	»Out« E (keV)	»Out« Transition intensities Way[30]	»Out« Transition intensities Our results	»Out« minus »in« Way[30]	»Out« minus »in« Our results	»in exp«
1	2	3	4	5	6	7	8	9	10
Ground state	100.1	69	68.6 ±4.1						
	1222	28	28.1 ±0.9						
	1258	1.6	1.54 ±0.05						
	1289	1.4	1.47 ±0.05						
	1374	0.22	0.25 ±0.01						
	1410	—	0.050±0.011						
	1437	—	—						
		100.2	100.0 ±5.8						
100.0	229.3	4.0	4.4 ±0.2	101,1	69	68.6±3.8			
	1122	35	36.0 ±1.0						
	1158	1.4	0.93 ±0.07						
	1189	16	17.0 ±0.5						
	1231	12	11.6 ±0.4						
	1274	0.8	0.69 ±0.03						
	1343	0.2	0.27 ±0.01						
	1388	0.1	0.086±0.007						
	1454	0.1	0.043±0.011						
		69.6	71.0 ±1.2		69	68.6±3.8	0.6	2.4	
329	892	0.1	—	229,3	4.0	4.4±0.2			
	928	0.7	0.54 ±0.10						
	960	0.3	0.36 ±0.04						
	1002	2.1	1.94 ±0.36						
	1044	0.4	0.22 ±0.04						
		3.6	3.1 ±0.4		—	4.4±0.2	0.4	0.35	1.35
1222	67.7	52	50.6 ±6.5	892	0.1				
	152.4	7.7	7.9 ±0.4	1122	35	36.0±1.0			
				1222	28	28.1±0.9			
		59.7	58.5 ±6.5		63.1	64.1±1.4	3.4	5.61	5.61

1	2	3	4	5	6	7	8	9	10
1258	31.7 116.4	— 0.6	1.4 ±0.1 0.52 ±0.11 1.92 ±0.15	927 1157 1258	0.7 1.4 1.6 3.7	0.54 ±0.10 0.93* ±0.07 1.54 ±0.05 3.01 ±0.1	—	1.09	1.09
1289	84.7 198.3 264.1	24 2.0 3.6 29.6	22.1 ±2.8 2.0 ±0.1 4.0 +0.2 28.1 ±2.8	31.7 67.7 960 1189 1289	— 52 0.3 16 1.4	1.4 ±0.1 50.6 ±6.5 0.36 ±0.04 17.0 ±0.5 1.47 ±0.05 70.8 ±6.6	40.1	42.8	42.8
1331	42.7 156.4	0.4 3.1 7.6 11.1	0.36 ±0.5 3.00 +0.25 8.0 ±0.4 11.36 ±0.26	1002 1231	2.1 12 14.1	1.94 ±0.36 11.6* ±0.4 13.54 ±0.4	3	2.18	2.18
1374	113.7 179.4	8.3 5.9 14.2	7.0 ±1.2 5.6 +0.2 12.6 ±1.2	42.7 84.7 116.4 152.4 1044 1274 1374	0.4 24 0.6 7.7 0.4 0.8 0.2 34.1	0.36 ±0.05 22.1 ±2.8 0.52 ±0.11 7.9 ±0.4 0.22 ±0.04 0.69 ±0.03 0.25 ±0.01 32.0 ±2.9	19.9	19.4	19.4
1443				1113 1343	— 0.2 0.2	— 0.27 ±0.01 0.27 ±0.01			0.27
1488	65.7	11.4	11.8 ±2.0	113.7 156.4 198.3 1388	8.3 3.1 2.0 0.1 13.5	7.0 ±1.2 3.0 ±0.25 2.0 ±0.1 0.086 ±0.07 12.1 ±1.3	2.1		
1534				65.7 179.3 222.1 264.1 1454	11.4 5.9 7.6 3.6 0.1 28.6	11.8 ±2.0 5.6 ±0.2 8.0 ±0.4 4.0 ±0.2 0.043 ±0.011 29.4 ±2.1			23.35

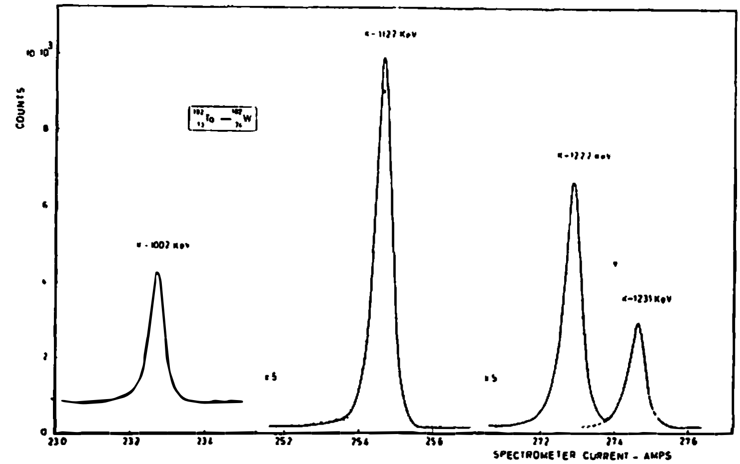

Fig. 4 — K-Conversion electron spectrum.

6. *Results and discussion*

The relative intensities of the gamma-rays. The relative intensities of the gamma-rays and four internal conversion lines of ^{182}W, are presented in Table 1 and Table 6. The results are compared with those obtained by different methods of the other authors. This served as a starting point for a critical examination of our present knowledge of ^{182}Ta decay, which can be summarized in the following way:

— although the number of measurements of ^{182}Ta will soon reach the mark 100 our knowledge of intensities balance is not precise within 1—2%;

— Ge(Li) spectrometer is able to resolve practically all the lines in the spectrum, what means that the intensities with any desired precision can be known provided sufficient statistics are accumulated. For one reason or another the patience and measurement time seem to be generally lacking. In this way a large statistic reported for photon measurements of ^{182}Ta gamma-rays is accumulated. The transitions with energies higher than 100 keV contributing to absolute intensities more than 10% were measured with a statistical error smaller than 3%. Those contributing from 1—5% were measured (with the two exceptions) with an error smaller than 5%. If such a precision was available in photon energy region around and below 100 keV, as well as in the electron spectrum measurements, it would be possible to make the intensities balance with a precision of 1—2%;

— for photon energies lower than 100 keV, the calibration curve is not very precise, background is very high and resolutions lower, so an instrument such as crystal diffraction spectrometers, are more convenient;
— the knowledge of electron intensities has to be much improved;
— the knowledge of high energy photon intensities will be more useful for precise tests of nuclear models, when angular correlation measurements with Ge(Li) in one arm, give a more precise information about possible M1 admixtures.

Table 6.
COMPARISON OF THE CONVERSION COEFFICIENTS AND M1 ADMIXTURE OBTAINED BY DIFFERENT GROUPS

	Energy (keV)	1002	1122	1231
Daniel et al.[15]	$\alpha_k \times 10^3$	—	3.2 ± 0.2	2.3 ± 0.3
	M1%	—	5 ± 5	$0 {}^{+4}_{-20}$
Starodubcev et al.[14]	$\alpha_k \times 10^3$	5.8 ± 0.8	3.16 ± 0.2	2.62 ± 0.20
	M1%	42 ± 16	5 ± 5	5 ± 8
Vitman et al.[19]	$\alpha_k \times 10^3$	3.7 ± 0.4	2.9 ± 0.3	2.9 ± 0.7
	M1%	0 ± 8	$0 {}^{+5}_{-10}$	16 ± 28
Korkman et al.[23]	$\alpha_k \times 10^3$	$3.00 {}^{+1.00}_{-0.80}$	3.28 ± 0.15	3.18 ± 0.18
	M1%	$0 {}^{+6}_{-30}$	8 ± 4	27 ± 7
Our results	$\alpha_k \times 10^3$	< 3.95	3.0 ± 0.1	2.6 ± 0.1
	M1%	< 5	0 ± 3	4 ± 4
Theoretical coefficients	E2	3.70	2.98	2.50
	M1	8.71	6.59	5.03

Some comments about the level scheme. It has been found that the levels of 100 keV and 329.4 keV belong to the main rotation band with spins 2^+ and 4^+, while the levels 1222 keV and 1331 keV belong to the gamma-rotational band with $K = 2$. The level of 1222 keV has $I\pi = 2^+$ and level of 1331 keV has $I\pi = 3^+$.

The ratios of reduced transition probabilities for E2-transitions from the levels 2_2^+ and 3^+ have been measured and compared with theoretical data

Table 7.
REDUCED TRANSITION PROBABILITIES

	Our results	Preston Kiang[35]	Belyak Zaikin[36]	Greiner et al.[37, 38]	Davydov Ovčarenko[39]	Bès et al.[40]	Z_2
$\frac{B(E2;22-0)}{B(E2;22-20)}$	0.51 ± 0.03	0.51	0.53	0.43	0.51	0.56	0.054 ± 0.007
$\frac{B(E2;3-21)}{B(E2;3-41)}$	1.76 ± 0.14	1.34	1.42	0.07	1.29	1.52	0.026 ± 0.005

(see Table 7). All these investigated transitions are of the same type: electrical quadrupoles, and they lead from the gamma rotational band to the main rotational band. For different ratios of reduced transitions probabilities one should expect the same value of z. However from the Table 7 it can be seen that the values of z are rather different. This dispersion of the z-values may be due to same approximation in the theory or to inaccuracy of measurements of the mixture of M1 in these transitions[33].

Table 8.
REDUCED TRANSITION PROBABILITIES

	Our results	Preston Kiang[35]	Faessler Greiner[37, 38]
$\frac{B(E2;23-0)}{B(E2;23-21)}$	1.08 ± 0.09	0.46	0.03
$\frac{B(E2;23-0)}{B(E2;23-41)}$	0.62 ± 0.14	0.14	0.01
$\frac{B(E2;23-21)}{B(E2;23-41)}$	0.58 ± 0.12	0.31	0.06

The energy level of 1258 keV has $I\pi = 2^+$ and $K = 0$. All the transitions from this level can be taken as pure $E2$-transitions. If one assumes that this level belong to the beta-vibrational band, than the question about the positions of the other levels of the same band (0^+, 4^+) should be answered. If we take that the moment of inertia of beta-band J_s is equal to the moment of inertia of the main rotational band J_0, as the result we get that the energy of the level 4^+ should be 1487 keV[41]. In the decay scheme of ^{182}W there is a level of 1443 keV with a $I\pi = 4^+$. Assuming that the levels 1258 keV and 1443 keV belong to the beta-band, from the expression:

$$E_I = E_0 + A\,I\,(I+1)$$

it follows that the energy of the level with $I\pi = 0^+$ should be about 1180 keV. The ratios of reduced transition probabilities for E2-transitions starting from the level 2_3^+ are given in the Table 8. There is no agreement between experimental and theoretical data. This disagreement can be explained if the energy level of 1258 keV does not belong to the beta-vibrational band.

The levels of 1289 keV, 1374 keV and 1488 keV have $K = 2$ and $I\pi = 2^-$, 3^-, 4^- and belong to the same rotational band. The level 1289 keV has negative parity and it can be octupole vibration state or two-body state. According to the Gallagher and Soloviev[42] theory it is more probable that this state is two-body state.

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ISTRAŽIVANJE SPEKTRA GAMA ZRAKA I PRIJELAZNIH INTENZITETA RASPADA ^{182}Ta

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Sadržaj

Mjerio se je spektar fotona raspada ^{182}Ta pomoću detektora 14 cm^3 Ge(Li) s razlučivanjem 3.5 keV za energije ^{60}Co.

Upotrebljeni su relativni intenziteti linija gama zraka, koji su određeni iz spektra, zatim su izračunati ukupni intenziteti prijelaza i upoređeni s već objavljenim analognim podacima.

U radu se također iznosi sadašnje poznavanje sheme raspada ^{182}W.