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SELECTION OF RADIATION SOURCES FOR CALIBRATION OF GAMMA-RAY SPECTROMETERS

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ABSTRACT

Regarding the problem of the selection of radioactive sources for γ-ray spectrometer calibration, the Ba-133 decay has been considered as an example. Due to the scarcity of existing experimental data, their interpretation is ambiguous. High uncertainty for γ-ray intensities is the consequence.

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SELECTION OF RADIATION SOURCES FOR CALIBRATION OF GAMMA-RAY SPECTROMETERS

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The recently published IAEA technical report [1] presents the results of a co-ordinated research programme aimed at developing a standard for the calibration of X-ray and gamma-ray spectrometers.

The list of recommended sources includes ^{133}Ba, for which the standard X-ray and gamma-ray intensity values are given.

Table 1 gives the evaluated gamma-ray emission probability values for ^{133}Ba decay.

This evaluation, as the authors of the report point out, was obtained from the balance in the decay scheme, taking into account previously published values for the internal conversion coefficients. This procedure is open to some doubt since these internal conversion coefficients were obtained using specific assumptions concerning the multipolarities of the relevant nuclear transitions and the penetration factors. In certain respects, the decay of ^{133}Ba is unique. The evaluation in Ref. [4] ascribes anomalously high penetration factors to the 79.623[1] and 80.997 keV transitions (4 and 6.5 respectively). These penetration factors can not be determined experimentally but are calculated on the basis of the difference between the measured internal conversion coefficient and the calculated value.

The data evaluation in Ref. [4] is based entirely on the assumption that the 356.017 keV transition is pure E2, which is by no means confirmed by direct experiments.

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[1] Here and subsequently, the photon energies given correspond to those used in Ref. [4].

Table 1.

Photon energy, keV	Emission probability, photon/decay
80,998±0,005	0,3411±0,0028
276,398±0,001	0,07147±0,00030
302,853±0,001	0,1830±0,0006
356,017±0,002	0,6194±0,0014
389,851±0,003	0,8905±0,00029

Table 2.
Data on conversion electron relative intensities used in the work

Transition energy, keV	Relative intensities
53,161	K:L1=840±160:85±12; L1:L2=7,4±1,3
79,6[illegible]	K:L1:L2:L3=285±20:36±3:4,4±0,8:2,8±0,6
80,997	K:L1:L2:L3=100:12,9±0,4:1,94±0,06:1,44±0,05
160,613	K:L1:L2:L3=11,1±0,3:1,08±0,09:0,54±0,05:0,51±0,04
223,224	K:L=7,8±0,8
276,398	K:L=5,4±0,3
302,853	K:L=6,9±0,3
356,017	K:L=6,1±0,3
383,851	K:L=6,1±0,4

The question arises as to how far this assumption affects the interpretation of the experimental data, for it is precisely this assumption which is "responsible" for the anomalously high penetration factors. This paper is devoted to a study of this problem.

The methods described in Refs. [2, 3], which are based on the solution of linear programming problems, were used to analyse the experimental data on the decay of ^{133}Ba. These methods have the advantage that, once the results from different types of experiments have been written in the form of a system of linear restrictions, their compatibility and the consistency of their interpretation can be checked.

First of all, the consistency of the interpretation of the experiments on the measurement of internal conversion was analysed. The data from Ref. [4] on the intensities of conversion electrons arising during the decay of ^{133}Ba were used in the analysis. These are given in Table 2.

Data derived from angular photon correlations, and data on the absolute values of the internal conversion co-efficients obtained from the absolute count of K X-rays and photons, were not included in the analysis of the possible transition multipolarity values. The data obtained from angular correlations are not fully consistent owing to the possible influence of magnetic fields in the material, and absolute count of photons is not terribly reliable owing to the difficulties of such experiments.

Table 3.

Transition energy, keV	Possible multipolarities	Limit for X	Transition between states
53,161	(100-X)M1+XE2	0,28<X<0,54	437→383
	(100-X)E1+XM2	0,81<X<1,21	
79,623	(100-X)M1+XE2	0,16<X<0,34	160→81
80,997	(100-X)M1+XE2	2,45<X<2,86	81→0
160,613	(100-X)M1+XE2	49,8<X<56,6	160→0
223,224	(100-X)M1+XE2	X<22,1	383→160
	(100-X)E1+XM2	X<6,05	
276,398	(100-X)M1+XE2	X>73,3	437→160
	(100-X)E1+XM3	X<18,4	
	(100-X)M2+XE3	X<29,9	
302,853	(100-X)M1+XE2	9,1<X<63,0	383→81
	(100-X)E1+XM2	1,85<X<100	
	(100-X)M2+XE3	X<2,9	
356,017	(100-X)M1+XE2	X>63,5	437→81
	(100-X)E2+XM3	X<11,6	
	(100-X)M2+XE3	X<32,8	
383,851	(100-X)M1+XE2	X<79,1	383→0

The data in Table 2 were processed using the CNVANL program package in order to obtain the possible transition multipolarities and the maximum values for the contributions of the various multipoles. The results of this analysis are shown in Table 3.

During the second stage of work, a complete system of restrictions was put together, including both the results given in Table 3 and the gamma-ray intensities given in Ref. [1] which were used by the working group. Only the results of those experiments where data are given for all photons were considered. All these data on gamma-ray intensities were regarded as relative.

In addition, the data from Ref. [4] on the intensity ratios of K conversion electrons were included in a system of additional restrictions. The first check revealed that these data were not consistent for K conversion electrons from the 80.997 and 356.017 keV transitions. Doubling the uncertainty of this ratio eliminates the contradiction in the data and makes the system of restrictions consistent. The peculiarity of the 80.997 keV transition is that in its neighbourhood, at a distance of less than 500 eV, there is another transition, the 79.623 keV transition; any inaccuracy in the instrumental shape of the electron spectrum line leads to incorrect consideration of the contribution of electrons from both transitions. This does not contradict general statistical criteria - one in ten values can have an error which exceeds the statistical error. Moreover, a condition was introduced into this system of restrictions to the

Table 4.

Exp./ photon	3/4	4/4	5/5	6/6	7/6	12/9	14/15	20/21	21/22	Eval.
53,16	2,042	2,054	2,024	1,918	1,937	2,039	2,007	2,061	2,096	2,058
	2,220	2,228	2,917	2,063	2,091	2,388	2,178	2,175	2,206	2,133
79,62	2,414	2,416	2,507	2,623	2,578	2,444	2,487	2,307	2,393	2,498
	2,660	2,652	2,620	2,828	2,781	2,789	2,715	2,509	2,570	2,654
81,00	32,91	32,89	32,77	33,02	33,11	32,90	32,92	32,90	32,98	32,98
	33,21	33,19	33,13	33,36	33,44	33,27	33.29	33,18	33,23	33,17
160,61	0,5954	0,6038	0,6241	0,5659	0,5829	0,6004	0,5791	0,5928	0,6023	0,6110
	0,6492	0,6521	0,6517	0,6098	0,6288	0,6571	0,6248	0,6723	0,6323	0,6324
223,23	0,3882	0,4203	0,4421	0,4039	0,4018	0,4228	0,4218	0,4062	0,4081	0,4313
	0,4451	0,4647	0,4723	0,4356	0,4331	0,4674	0,4494	0,4614	0,4290	0,4474
276,40	6,734	6,738	7,006	6,481	6,272	6,629	6,696	6,697	6,707	6,836
	7,158	7,162	7,309	6,973	6.749	7,180	7,069	7,070	7,043	7,026
302,85	17,25	17,31	17,92	16,46	16,11	16,98	17,01	17,15	17,13	17,52
	18,30	18,37	18,97	17,71	17,34	18,32	18,06	18,17	17,95	17,97
356,02	58,56	58,77	60,55	55,51	54,51	57,49	57,50	58,54	58,51	59,36
	62,13	62,35	62,89	59,73	58,67	62,26	61,02	61,52	60,79	60,77
383,85	8,428	8,481	8,612	8,091	7,836	8,270	8,260	8,512	80,368	8,530
	8,915	8,972	9,240	8,654	8,387	8,927	8,738	8,910	8,739	8,741

effect that there is no beta decay into the ground state of ^{133}Cs. This is a natural requirement since this decay has not been observed experimentally, and beta transition between the $1/2^+$ and $7/2^+$ states is strongly forbidden. The full system of restrictions consisted of 124 equations with 119 unknowns.

Subject to the above restrictions, the problems of seeking the minimum and maximum intensity values for each photon were solved for each of the working group's experiments (see Ref. [1]). The results of these calculations are given in Table 4.

The top line of the table indicates the numbering of the experiments considered, which corresponds to the numbering in Ref. [1]. The evaluated gamma-ray intensities are also given here (see the column headed "Eval."). The table presents the maximum and minimum intensities for each photon (photon/100 decays) consistent with the system of restrictions. However, it should of course be borne in mind that all the gamma-rays cannot simultaneously have the maximum or minimum intensities.

First and foremost, the solution of this system has shown that all transitions in the decay considered can only have even parity.

The permissible limits of change in the gamma-ray intensity having been studied, the same system of restrictions and the evaluated data from Ref. [1] were used to solve the problem of minimizing the sum of the absolute values of the relative deviations from the average experimental values. The solution of this problem was not unique. It was found that three solutions differing in the multipolarity of the 276.398 and 356.017 keV transitions described the experimental results for the ^{133}Ba decay almost equally well. These solutions are shown in Table 5.

The degree of agreement of these solutions is approximately identical. At the same time, solution 2 agrees slightly better with the experiment, but the difference can hardly be termed decisive. The data on the gamma-ray intensities for these three solutions are given in Table 6.

Table 5.

Photon energy, keV	Solution		
	1	2	3
276,398	0,26M1+0,733E2	E2	0,267M1+0,733E2
356,017	0,977E2+0,003M3	0,365M1+0.635E2	0,207M1+0,793E2

Table 6.

Photon energy, keV	Solution		
	1	2	3
53,16	2,123	2,116	2,125
79,62	2,538	2,545	2.539
81,00	33,12	33,13	33,12
160,61	0,6204	0,6227	0,6202
223,23	0,4337	0,4400	0,4378
276,40	6,993	6,942	6.997
302,85	17,88	17,83	17,83
356,02	60,33	60,16	60,39
383,85	8,674	8,649	8.683

Clearly, discarding the assumption that the 356.02 keV transition is a pure E2 transition does not result in a conflict with the experimental data. Moreover, by dropping this assumption we also can discard the anomalously high penetration factor values. Of course, different values must be assigned to the spins of the excited states of ^{133}Cs. The change in the level scheme for ^{133}Cs can be kept to a minimum by assuming that its 437 keV excited state has a spin of $3/2^+$ and not $1/2^+$, although other variants cannot be ruled out. However, the spin of the excited state is not a quantity which can be directly determined by experiment. In this instance, its value was obtained in Ref. [4] from an analysis of the transition multipolarities.

From Table 6 it follows that the difference in the gamma-ray intensities for the various multipolarity mixtures permitted by the experimental data on ^{133}Ba decay is substantially greater than the uncertainty given in Ref. [1] (see Table 1).

Moreover, in the light of the above, we feel that the validity of accuracy given in Ref. [1] should be carefully studied in all cases where conversion electrons play an appreciable role in the decay process.

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