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GAMMA-RAY CALIBRATION STANDARDS

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April 1971

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GAMMA-RAY CALIBRATION STANDARDS*

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April 1971

ABSTRACT

A collection of γ-ray energies and intensities is given that are suitable for use in the calibration of high resolution γ-ray spectrometers. The energy range included in this tabulation is 25 keV < E_γ < 3452 keV. Adopted values are given for gamma-ray energies based on weighted averages of the author's stated uncertainties. Relative γ-ray intensities are also given for ^{133}Ba, ^{182}Ta, and ^{56}Co. No attempt was made to establish weighted averages for the intensity values.

I. INTRODUCTION

With the development of high resolution Ge(Li) detectors coupled with highly stablized linear electronics and computer photopeak analysis of data, it has become possible to measure gamma-ray energies to a precision of better than 0.1 keV. However, to do this, it is necessary to have available a large number of standards known to tens of eV. Marion[1] compiled a list of such standards in 1968, but since that time there have been improvements in the measurements of standards, and their number has increased substantially. Because the newer information is scattered in the literature, it is the purpose of this report to collect and tabulate those measurements and references for standards that are routinely being used in our nuclear spectroscopy research. In the recent literature, the most extensive work has been that of Gunnink et al.[2,13]

Gamma-ray energies are listed by source in Table I. The original data are shown along with the reference. The "adopted values" that are given represent weighted averages (weighted inversely as the square of the author's stated uncertainties). The errors given are the larger of the σ values as defined below. E_i and σ_i are the author's stated energy and error, respectively.

$$\sigma^2 = \frac{1}{\sum_i 1/\sigma_i^2} \qquad \sigma^2 = \frac{1}{n-1} \sum_{i=1}^{n} (E_m - E_i)^2 \qquad E_m = \frac{\sum_i E_i/\sigma_i^2}{\sum_i 1/\sigma_i^2}$$

Marion's[1] values, which are also tabulated, often represent weighted averages of several measurements. In these cases the original measurements reported by Ref. 1 were used in obtaining the new weighted set of adopted values.

Table II lists gamma-ray energy and intensity measurements for ^{133}Ba, ^{182}Ta, and ^{56}Co. No attempt was made to establish a weighted set of intensity values. The energy values of Gunnink et al.[2] are used for ^{56}Co while weighted sets are given for ^{133}Ba and ^{182}Ta.

The ^{182}Ta low energy (84-265 keV) γ-ray intensity measurements[18] were made using a calibrated 10-cm^3 Ge(Li) detector. Details of these measurements are to be published later.

FOOTNOTES AND REFERENCES

*Work performed under the auspices of the U. S. Atomic Energy Commission.

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Table I. Gamma-ray energies used as calibration standards listed by source.

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted
^{241}Am	432.9 ± 0.8y	26.348 ± 0.010	1	
		26.345 ± 0.010	12	26.3465 ± 0.007
		59.543 ± 0.015	1	
		59.536 ± 0.010	13	59.538 ± 0.008
^{170}Tm	120d	84.2572 ± 0.0026	11	
		84.257 ± 0.003	12	84.257 ± 0.002
^{109}Cd	453d	88.034 ± 0.010	13	
		88.035 ± 0.006	9	
		88.036 ± 0.008	11	88.035 ± 0.004
^{57}Co	271.6 ± 0.5d	122.046 ± 0.020	13	
		122.061 ± 0.010	9	
		122.04 ± 0.02	14	122.055 ± 0.013
		136.465 ± 0.020	13	
		136.471 ± 0.010	9	
		136.47 ± 0.02	14	136.470 ± 0.008

(continued)

Table I. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted
^{203}Hg	46.8 ± 0.2d	279.191 ± 0.008	1	
		279.179 ± 0.010	13	279.186 ± 0.009
^{113}Sn	115.2 ± 0.8d	391.688 ± 0.010	9	
		391.71 ± 0.02	23	391.692 ± 0.018
^{198}Au	2.7d	411.795 ± 0.009	1	
		411.792 ± 0.008	13	411.793 ± 0.006
^{137}Cs	30.5 ± 0.3y	661.635 ± 0.076	1	
		661.615 ± 0.030	2	661.618 ± 0.028
^{54}Mn	312.6 ± 0.3d	834.81 ± 0.03	1	
		834.84 ± 0.05[c]	2	834.81 ± 0.03
^{88}Y	107.4 ± 0.8d	898.04 ± 0.04	1	
		898.023 ± 0.065	13	
		898.010 ± 0.030	10	898.021 ± 0.023
		1836.13 ± 0.040	1	
		1836.127 ± 0.050	2	
		1836.030 ± 0.030[b,c]	10	1836.129 ± .031

(continued)

Table I. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted
^{60}Co	5.28 ± 0.01y	1173.23 ± 0.04	1	
		1173.231 ± 0.030	13	1173.231 ± 0.024
		1332.49 ± 0.04	1	
		1332.505 ± 0.025	2	1332.501 ± 0.021
^{22}Na	2.602 ± 0.005y	511.006 ± 0.002[c]	1	
		511.0041 ± 0.0016	15	511.0041 ± 0.0016
		1274.55 ± 0.04	1	
		1274.550 ± 0.040[c]	13	1274.55 ± 0.04
^{24}Na	15h	1368.526 ± 0.044	1	1368.526 ± 0.044
		1731.91 ± 0.12[c]	1	
		1732.130 ± 0.060[a]	2	1732.130 ± 0.060
		2753.92 ± 0.12	1	
		2754.142 ± 0.060	2	2754.098 ± 0.183

(continued)

Table I. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted
^{40}K	$1.26 \cdot 10^9$y	1460.75 ± 0.06	1	
		1460.9 ± 0.3	16	
		1460.95 ± 0.07	23	1460.836 ± 0.11
^{207}Bi	30y	569.653 ± 0.020	10	
		569.62 ± 0.06	1	569.650 ± 0.030
		1063.63 ± 0.030	10	
		1063.44 ± 0.090	1	(1063.611 ± 0.172)
		1769.71 ± 0.13[c]	1	
		1770.22 ± 0.040[c]	10	
		1770.06 ± 0.07	7	1770.06 ± 0.07
^{192}Ir	74.2d	295.938 ± 0.009	1	
		295.938 ± 0.010	2	295.938 ± 0.007
		308.429 ± 0.010	1	
		308.440 ± 0.010	2	308.435 ± 0.008
		316.486 ± 0.010	1	
		316.490 ± 0.010	2	316.488 ± 0.007

(continued)

Table I. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted
^{192}Ir (continued)		468.053 ± 0.014	1	
		468.060 ± 0.010	2	468.058 ± 0.008
		588.557 ± 0.017	1	588.557 ± 0.017
		604.385 ± 0.017	1	
		604.378 ± 0.020	2	604.382 ± 0.013
		612.435 ± 0.017	1	
		612.430 ± 0.020	2	612.433 ± 0.013
^{110m}Ag	253d	446.77 ± 0.04	5	
		446.790 ± 0.020	10	446.786 ± 0.020
		620.22 ± 0.03	5	
		620.310 ± 0.020	10	620.282 ± 0.068
		657.71 ± 0.03	5	
		657.720 ± 0.020	10	
		657.75 ± 0.04	14	657.722 ± 0.022

(continued)

Table I. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted
^{110m}Ag (continued)		677.55 ± 0.03	5	
		677.580 ± 0.020	10	
		677.58 ± 0.05	14	677.572 ± 0.017
		686.80 ± 0.03	5	
		686.950 ± 0.030	10	
		686.95 ± 0.05	14	686.886 ± .088
		706.68 ± 0.04	5	
		706.650 ± 0.020	10	
		706.63 ± 0.06	14	706.654 ± 0.025
		744.19 ± 0.04	5	
		744.260 ± 0.030	10	
		744.23 ± 0.07	14	744.234 ± 0.036
		763.88 ± 0.04	5	
		763.920 ± 0.030	10	
		763.93 ± 0.07	14	763.908 ± 0.027

(continued)

Table I. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted
^{110m}Ag (continued)		818.00 ± 0.04	5	
		817.995 ± 0.030	10	
		817.95 ± 0.08	14	817.993 ± 0.031
		884.67 ± 0.04	5	
		884.650 ± 0.030	10	
		884.68 ± 0.04	6	
		884.69 ± 0.05	14	884.667 ± 0.019
		937.48 ± 0.04	5	
		937.450 ± 0.030	10	
		937.48 ± 0.04	6	
		937.54 ± 0.07	14	937.472 ± 0.042
		1384.22 ± 0.04	5	
		1384.240 ± 0.040	10	
		1384.26 ± 0.05	6	1384.237 ± 0.025
		1475.73 ± 0.04	5	
		1475.710 ± 0.040	10	
		1475.76 ± 0.07	6	1475.726 ± 0.027

(continued)

Table I. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted
^{110m}Ag (continued)		1504.9 ± 0.08	5	
		1504.945 ± 0.040	10	
		1505.01 ± 0.07	6	1504.951 ± 0.055
		1562.22 ± 0.06	5	
		1562.255 ± 0.050	10	
		1562.35 ± 0.08	6	1562.261 ± 0.069
^{108m}Ag	127 ± 7y	434.0 ± 0.10	5	
		433.94 ± 0.06	14	433.956 ± 0.051
		614.37 ± 0.10	5	
		722.95 ± 0.08	5	
		722.87 ± 0.06	14	722.899 ± 0.059
^{228}Th	1.910y[d]	39.85 ± 0.01	1(^{212}Bi)	
		238.624 ± 0.009	1(^{212}Pb)	
		510.723 ± 0.020	1(^{208}Tl)	

(continued)

Table I. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted
^{228}Th (continued)		583.139 ± 0.023	1(^{208}Tl)	
		727.1 ± 0.1	1(^{212}Bi)	
		727.08 ± 0.07		727.09 ± 0.06
		785.37 ± 0.08	7(^{212}Bi)	
		763.13 ± 0.08	7(^{208}Tl)	
		860.37 ± 0.08	7(^{208}Tl)	
		893.43 ± 0.09	7(^{212}Bi)	
		1078.62 ± 0.10	7(^{212}Bi)	
		1592.696 ± 0.050[a]	2(^{208}Tl)	
		1620.50 ± 0.10	7(^{212}Bi)	
		2614.47 ± 0.10	1(^{208}Tl)	
		2614.708 ± 0.050	2	2614.66 ± 0.20

(continued)

Table I. (continued)

[a]Since these values are for double-escape pair peaks, care, as warned by Gunnink *et al.*,[2] should be employed if using them.

[b]The calibration is from the double-escape peak. See Ref. 10.

[c]This is not included in the adopted value given.

[d]^{228}Th energies listed are from daughters in ^{228}Th decay chain.

Table II. Gamma-ray energies and intensities used as calibration standards listed by source

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted	γ-Ray Intensity Relative	Refs.
^{133}Ba	7.2y	53.18 ± 0.04	1		3.78 ± 0.09	19
		53.17 ± 0.01	8	53.171 ± 0.010	3.81 ± .10	8
		79.60 ± 0.05	1			
		79.63 ± 0.03	8		4.50 ± .40	8
		80.997 ± 0.006	1			
		80.99 ± 0.01	8		55.3 ± 3.0[c]	8
		80.998 ± 0.008	9			
		160.66 ± 0.06	1		1.21 ± 0.05	19
		160.63 ± 0.02	8	160.633 ± 0.027	1.12 ± 0.05	8
		223.37 ± 0.23[e]	1		0.803 ± 0.042	19
		223.12 ± 0.01	8	223.12 ± 0.01	0.78 ± 0.04	8
		276.46 ± 0.2[e]	1		11.61 ± 0.17	19
		276.45 ± 0.02	8		11.6 ± 0.2	8
		276.397 ± 0.012	9	276.411 ± 0.041		

(continued)

Table II. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted	γ-Ray Intensity Relative	Refs.
^{133}Ba (continued)		303.08 ± 0.2[e]	1		29.75 ± 0.29	19
		302.93 ± 0.03	8		29.6 ± 0.3	8
		302.851 ± .015	9	302.867 ± 0.065		
		356.27 ± 0.14[e]	1		100.	19
		356.09 ± 0.04	8		100.	8
		356.005 ± 0.017	9	356.018 ± 0.073		
		384.10 ± 0.18[e]	1		14.18 ± 0.26	19
		383.83 ± 0.03	8		14.1 ± 0.3	8
		383.851 ± 0.020	9	383.845 ± 0.017		
^{182}Ta	115d	84.257 ± 0.003	12		7.6 ± 0.4	18
		84.678 ± 0.003	17			
		100.106 ± 0.003	12		40.2 ± 1.0	18
		100.104 ± 0.002	3[d]	100.105 ± 0.002		
		152.435 ± 0.003	3[d]		20.5 ± 0.51	18
		156.387 ± 0.003	3[d]		7.63 ± 0.19	18
		179.393 ± 0.004	3[d]		8.81 ± 0.22	18
		198.358 ± 0.008	17		4.15 ± 0.11	18

(continued)

Table II. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted	γ-Ray Intensity Relative	Refs.
^{182}Ta (continued)		222.109 ± 0.005	3[d]		21.30 ± 0.56	18
		229.322 ± 0.008	3[d]		10.27 ± 0.27	18
		264.072 ± 0.009	3[d]		10.10 ± 0.26	18
		891.982 ± 0.015	4		0.15 ± 0.02	4
		927.995 ± 0.015	4		1.79 ± 0.09	4
		959.730 ± 0.015	4		1.02 ± 0.06	4
		1001.694 ± 0.015	4		5.98 ± 0.3	4
		1044.409 ± 0.015	4		0.69 ± 0.08	4
		1113.398 ± 0.052	4		1.13 ± 0.10	4
		1121.298 ± 0.013	4		100.	4,18
		1121.28 ± 0.12	3			
		1121.31 ± 0.04	6	1121.299 ± 0.016		
		1157.311 ± 0.013	4		1.84 ± 0.35	4
		1158.080 ± 0.015	4		0.99 ± 0.28	4
		1189.046 ± 0.013	4		47.4 ± 0.7	4
		1189.03 ± 0.2	3			
		1189.06 ± 0.04	6	1189.047 ± 0.015		

(continued)

Table II. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted	γ-Ray Intensity Relative	Refs.
^{182}Ta (continued)		1221.399 ± 0.013	4		79.3 ± 1.2	4
		1221.42 ± 0.10	3			
		1221.42 ± 0.04	6	1221.401 ± 0.019		
		1231.010 ± 0.013	4		33.4 ± 0.5	4
		1257.412 ± 0.013	4		4.33 ± 0.07	4
		1273.725 ± 0.013	4		1.90 ± 0.04	4
		1289.147 ± 0.013	4		4.05 ± 0.07	4
		1342.714 ± 0.051	4		0.75 ± 0.02	4
		1373.825 ± 0.013	4		0.66 ± 0.02	4
		1387.396 ± 0.013	4		0.217 ± 0.01	4
		1410.100 ± 0.100	4		0.117 ± 0.008	4
		1453.115 ± 0.013	4		0.123 ± 0.010	4
^{56}Co	77d	846.79 ± 0.030	20		100.	20
		846.782 ± 0.060	2		100.	22
		846.76 ± 0.05	1		100.	1
		846.741 ± 0.025	21	846.782 ± 0.060[b]	100.	21
		1037.91 ± 0.030	20		14.302 ± .170	20
		1037.851 ± 0.060	2		13.08 ± 0.35	22
		1037.97 ± 0.07	1		13.02 ± 0.35	1
		1037.84 ± 0.05	21	1037.851 ± 0.060[b]	12.9 ± 0.5	21

(continued)

Table II. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted	γ-Ray Intensity Relative	Refs.
^{56}Co (continued)		1175.13 ± 0.050	20		2.302 ± 0.025	20
		1175.085 ± 0.070	2		1.73 ± 0.13	22
		1175.026 ± 0.13	1		1.86 ± 0.23	1
		1175.1 ± 0.1	21	1175.085 ± 0.070[b]	2.26 ± 0.23	21
		1238.30 ± 0.020	20		67.638 ± 0.680	20
		1238.290 ± 0.040	2		68.3 ± 1.4	22
		1238.34 ± 0.09	1		69.35 ± 1.47	1
		1238.28 ± 0.06	21	1238.290 ± 0.040[b]	67.8 ± 1.5	21
		1360.22 ± 0.030	20		4.340 ± 0.045	20
		1360.219 ± 0.040	2		4.15 ± 0.12	22
		1360.35 ± 0.090	1		4.38 ± 0.16	1
		1360.26 ± 0.04	21	1360.219 ± .040[b]	4.16 ± 0.21	21
		1771.41 ± 0.030	20		15.778 ± 0.160	20
		1771.33 ± 0.06	2		14.95 ± 0.40	22
		1771.57 ± 0.10	1		15.30 ± 0.53	1
		1771.38 ± 0.15	21	1771.33 ± 0.06[b]	16.5 ± 0.8	21
		2015.36 ± 0.030	20		3.095 ± 0.031	20
		2015.33 ± 0.07	2		2.78 ± 0.14	22

(continued)

Table II. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted	γ-Ray Intensity Relative	Refs.
^{56}Co (continued)		2015.49 ± 0.20	1		2.93 ± 0.16	1
		2015.24 ± 0.12	21	2015.33 ± 0.07[b]	2.99 ± 0.20	21
		2034.92 ± 0.030	20		7.952 ± 0.080	20
		2034.90 ± 0.06	2		7.56 ± 0.21	22
		2035.03 ± 0.12	1		7.33 ± 0.30	1
		2034.82 ± 0.10	21	2034.90 ± 0.06[b]	8.2 ± 0.6	21
		2598.58 ± 0.030	20		16.851 ± 0.170	20
		2598.52 ± 0.05	2		16.55 ± 0.44	22
		2598.80 ± 0.12	1		16.77 ± 0.57	1
		2598.53 ± 0.06	21	2598.52 ± 0.05[b]	18.0 ± 0.9	21
		3202.30 ± 0.080	20		3.030 ± 0.030	20
		3202.18 ± 0.07	2		3.03 ± 0.14	22
		3202.25 ± 0.19	1		3.15 ± 0.16	1
		3202.1 ± 0.2	21	3202.18 ± 0.07[b]	3.2 ± 0.35	21
		3253.62 ± 0.040	20		7.392 ± 0.074	20
		3253.61 ± 0.06	2		7.35 ± 0.21	22
		3253.82 ± 0.15	1		7.70 ± 0.34	1
		3253.5 ± 0.2	21	3253.61 ± 0.06[b]	7.7 ± 0.9	21

(continued)

Table II. (continued)

Isotope	Half-Life	γ-Ray Energy keV	Refs.	Adopted	γ-Ray Intensity Relative	Refs.
^{56}Co (continued)		3273.26 ± 0.08	20		1.756 ± 0.018	20
		3273.16 ± 0.07	2		1.72 ± 0.13	22
		3273.38 ± 0.18	1		1.55 ± 0.11	1
		3273.08 ± 0.10	21	3273.16 ± 0.07[b]	1.71 ± 0.25	21
		3451.56 ± 0.20	20		0.875 ± 0.009	20
		3451.29 ± 0.10	2		0.85 ± 0.07	22
		3452.18 ± 0.22	1		0.88 ± 0.10	1
		3451.5 ± 0.3	21	3451.29 ± 0.1[b]	0.93 ± 0.20	21
		1576.561 ± 0.050[a]	2			
		2180.17 ± 0.07[a]	2			
		2231.60 ± 0.06[a]	2			
		2251.15 ± 0.07[a]	2			
		2429.28 ± 0.10[a]	2			

[a]Since these values are for double-escape pair peaks, care, as warned by Gunnink et al.,[2] should be employed if using them.

[b]This not a weighted value, but that of Ref. 2.

[c]This is an adopted value from previous works. See Ref. 8 for details.

[d]These energy values are averaged results of Refs. 17,24 as calculated in Ref. 3.

[e]This not included in the adopted value given.

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