

APPENDIX NUCLEAR SPECTROSCOPY STANDARDS

1. Gamma-ray Energy and Intensity Standards

Table 1 lists some γ -ray energy standards, from the evaluation of Helmer, et al.¹, and intensity standards, recommended by the IAEA Co-ordinated Research Programme^{2,3} (CRP), for calibration of γ -ray measurements. Most of the isotopes given here have half-lives of more than 30 days, and many are commercially available. The γ -ray energies are based on the *gold standard*, the 411.80205 17 keV transition from ¹⁹⁸Au decay. Uncertainties are intended to represent one standard deviation, and include the 0.3 ppm uncertainty in the definition of the electron volt relative to wavelength. The γ -ray energies reported in Table 1 are from absolute wavelength or curved-crystal spectrometer measurements, which are tied directly to the *gold standard*, and from the measurements of small γ -ray energy differences with Ge detectors. Energies that are rounded to the nearest 0.1-keV and tabulated without uncertainty are not recommended values; however, they have been included because these transitions are useful intensity calibration standards. Other, apparently precise, transition energies and intensities have been tabulated in the *Table of Isotopes*, but the reader should use these values with great caution because of unknown systematic uncertainties which may not have been included. Columns 1 and 2 show the isotope names and half-lives, respectively. Columns 3 and 4 list the γ -ray energies and intensities with their corresponding uncertainties (in italics) in the least significant digit(s).

¹ R.G. Helmer, C. van der Leun, and P.H.M. Van Assche, private communication, draft of a paper to be submitted to *Nucl. Instr. Meth.*, 1995; energies may change in the final publication.

² R. Vaninbroux, *Emission Probabilities of Selected Gamma Rays for Radionuclides Used as Detector-Calibration Standards*, report presented at the Advisory Group Meeting of the International Atomic Energy Agency (IAEA), Vienna (1985).

³ *X-ray and Gamma-ray Standards for Detector Calibration*, report by the Co-ordinated Research IAEA Programme, IAEA-TECDOC-619 (1991).

Table 1. Gamma-ray Energies and Absolute Intensities for Some Standard Sources

Source	Half-life	E_{γ} (keV)	I_{γ} (%)	Source	Half-life	E_{γ} (keV)	I_{γ} (%)
⁷ Be	53.29 d	477.6035 ²	10.45 ¹⁰	⁵⁹ Fe	44.503 d	142.651 ²	
²² Na	2.6019 y	1274.537 ⁷	99.935 ¹⁵			192.349 ⁵	
²⁴ Na	14.9590 h	1368.626 ⁵	99.9936 ¹⁵			1099.245 ³	
		2754.007 ¹¹	99.855 ⁵			1291.590 ⁶	
³⁵ Cl(n, γ)		517.07043 ²⁸	0.227 ²⁰	⁵⁶ Co	77.27 d	846.7638 ¹⁹	99.933 ⁷
		786.2975 ⁵	0.096 ⁹			1037.8333 ²⁴	14.13 ⁵
		788.4236 ⁵	0.150 ¹²			1175.0878 ²²	2.239 ¹¹
		1164.8587 ⁶	0.257 ²²			1238.2736 ²²	66.07 ¹⁹
		1600.8	0.034 ³			1360.196 ⁴	4.256 ¹⁵
		1951.1291 ¹⁵	0.187 ¹⁵			1771.327 ³	15.49 ⁵
		1959.345 ⁸	0.121 ¹⁰			2015.176 ⁵	3.029 ¹³
		2863.9	0.060 ⁵			2034.752 ⁵	7.771 ²⁷
		3061.7	0.035 ³			2113.092 ⁶	0.366 ⁶
		5715.2	0.051 ⁴			2212.898 ³	0.390 ⁷
		6110.8	0.197 ¹⁶			2213.092 ⁶	
		6619.4	0.081 ⁷			2598.437 ⁴	16.96 ⁶
		6627.5	0.046 ⁴			3009.558 ⁴	0.995 ²¹
		6977.6	0.0223 ²⁰			3201.930 ¹¹	3.13 ⁹
		7413.7	0.100 ⁸			3253.402 ⁵	7.62 ²⁴
		7790.0	0.086 ⁷			3272.977 ⁶	1.78 ⁶
		8578.2	0.0294 ²⁴			3451.119 ⁴	0.93 ⁴
⁴⁶ Sc	83.79 d	889.271 ²	99.9844 ¹⁶			3548.3	0.178 ⁹
		1120.537 ³	99.9874 ¹¹	⁵⁷ Co	271.79 d	14.4	9.16 ¹⁵
⁴⁴ Ti	49 y	67.8679 ¹⁸				122.06065 ¹²	85.60 ¹⁷
		78.3231 ¹³				136.47350 ²⁹	10.68 ⁸
⁵¹ Cr	27.702 d	320.0824 ⁴	9.86 ⁵	⁵⁸ Co	70.82 d	810.7594 ²⁰	99.45 ¹
⁵⁴ Mn	312.3 d	834.841 ⁴	99.9758 ²⁴			863.951 ⁶	0.69 ³
⁵⁶ Mn	2.5785 h	846.8	98.87 ³			1674.725 ⁷	0.519 ¹⁰
		1810.7	27.2 ⁸	⁶⁰ Co	5.2714 y	1173.228 ³	99.857 ²²
		2113.0	14.3 ⁴			1332.490 ⁶	99.983 ⁶
				⁶⁵ Zn	244.26 d	1115.539 ²	50.60 ²⁴

Table 1. Gamma-ray Energies and Absolute Intensities (continued)

Source	Half-life	E_{γ} (keV)	I_{γ} (%)	Source	Half-life	E_{γ} (keV)	I_{γ} (%)
⁶⁶ Ga	9.49 h	833.5324 ²¹	6.03 ²³	^{110m} Ag	249.76 d	446.812 ³	3.72 ³
		1039.220 ³	37.9 ¹²			620.3547 ²²	
		1333.113 ⁵	1.23 ⁵			657.7600 ¹²	94.4 ¹
		1418.753 ⁵				677.6216 ¹³	10.40 ⁸
		1508.158 ⁷				687.0085 ²⁰	6.44 ³
		1918.329 ⁵	2.14 ⁸			706.6752 ¹⁷	16.6 ¹
		2189.616 ⁶	5.71 ²¹			744.2754 ¹⁸	4.70 ⁴
		2422.523 ⁷	1.96 ⁷			763.9420 ¹⁸	22.39 ⁸
		2751.835 ⁵	23.2 ¹¹			818.0243 ¹⁹	7.32 ⁴
		3228.800 ⁶	1.48 ¹²			884.6779 ¹³	72.7 ³
		3380.851 ⁶	1.40 ¹²			937.484 ⁴	34.31 ¹²
		3422.040 ⁸				1384.2921 ²²	24.25 ⁸
		3791.009 ⁶	1.02 ¹¹			1475.7790 ²⁴	3.99 ²
		4085.853 ⁹	1.14 ¹⁹			1505.0273 ²⁴	13.04 ⁴
		4295.7	3.5 ⁷			1562.2937 ¹⁸	
		4461.202 ⁹					
4806.005 ¹⁰	1.5 ⁴						
⁷⁵ Se	119.779 d	66.0518 ⁸	1.10 ²	¹⁰⁹ Cd	462.6 d	88.0336 ¹⁰	3.63 ²
		96.7340 ⁹	3.41 ⁴	¹¹¹ In	2.8049 d	171.3	90.78 ¹⁰
		121.1155 ¹¹	17.1 ¹			245.3	94.16 ⁶
		136.0001 ⁶	58.8 ³	^{115m} In	4.486 h	336.2	45.9 ²
		198.6060 ¹²	1.49 ¹	¹¹³ Sn	115.09 d	391.698 ³	64.89 ¹³
		264.6576 ⁹	59.0 ²	¹²⁵ Sn	9.64 d	1806.690 ¹⁶	
		279.5422 ¹⁰	25.0 ¹			1889.884 ¹⁶	
		303.9236 ¹⁰	1.31 ¹			2002.132 ¹³	
400.6572 ⁸	11.5 ¹			2201.002 ¹²			
⁸² Br	35.30 h	221.4788 ¹⁸		¹²⁴ Sb	60.20 d	602.7260 ²³	98.0 ¹
		554.346 ³				645.8520 ¹⁹	7.3 ¹
		619.104 ³				713.777 ⁴	
		698.368 ³				722.783 ⁴	11.3 ²
		776.513 ⁴				790.708 ⁶	
		827.825 ⁵				968.194 ⁴	
		1043.993 ⁵				1045.125 ⁴	
		1317.466 ⁴				1325.505 ⁴	
		1474.874 ⁵				1368.156 ⁵	
		1650.328 ⁵				1436.556 ⁶	
		881.6041 ¹⁶				1690.971 ⁴	48.5 ³
⁸⁴ Rb	32.77 d	1016.158 ¹¹		¹²⁵ Sb	2.7582 y	2090.930 ⁶	5.66 ⁹
		1897.751 ¹¹				176.314 ²	6.85 ⁷
⁸⁵ Sr	64.84 d	514.0048 ²²	98.4 ⁴			380.5	1.518 ¹⁶
⁸⁸ Y	106.65 d	898.036 ⁴	94.0 ³			427.874 ⁴	29.7 ³
		1836.052 ¹³	99.36 ³			463.365 ⁴	10.48 ¹¹
⁹⁵ Zr	64.02 d	724.192 ⁴	44.15 ²⁰			600.597 ²	17.73 ¹⁸
		756.7	54.50 ²⁵			606.713 ²	5.00 ⁵
⁹⁴ Nb	2.0×10 ⁴ y	702.638 ⁵	99.79 ⁵			635.950 ³	11.21 ¹²
		871.114 ³	99.86 ⁵			671.441 ⁶	1.80 ²
⁹⁵ Nb	34.975 d	765.8	99.81 ³	¹²⁵ I	59.408 d	35.5	6.58 ⁸
⁹⁹ Mo	65.94 h	40.58323 ¹⁷		¹³² Cs	6.479 d	667.714 ³	
		140.510 ¹				1317.916 ⁷	
^{95m} Tc	61 d	204.1161 ¹⁷		¹³⁴ Cs	2.062 y	1985.623 ⁸	
		582.0775 ²¹				475.4	1.49 ²
		786.1922 ²⁷				563.2	8.36 ³
		820.622 ⁷				569.3	15.39 ⁶
		835.146 ⁶				604.7	97.63 ⁶
^{99m} Tc	6.01 h	1039.260 ⁶				795.8	85.4 ³
		140.510 ¹	89.0 ²			801.9	8.69 ³
¹⁰⁶ Ru	373.59 d	511.8534 ²³				1038.6	0.990 ⁵
^{108m} Ag	127.0 y	433.937 ⁴				1168.0	1.792 ⁷
		614.276 ⁴				1365.2	3.016 ¹¹
		722.906 ¹⁰		¹³⁷ Cs	30.07 y	661.657 ³	85.1 ²

Table 1. Gamma-ray Energies and Absolute Intensities (continued)

Source	Half-life	E_{γ} (keV)	I_{γ} (%)	Source	Half-life	E_{γ} (keV)	I_{γ} (%)			
¹³³Ba	10.52 y	53.1625 ⁶		¹⁶¹Tb	6.88 d	25.65135 ³				
		79.6139 ¹³				48.91533 ⁵				
		80.9971 ¹²	34.11 ²⁸			57.1917 ³				
		160.6109 ¹⁷				74.56669 ⁶				
		223.2373 ¹⁴				80.5725 ¹³	^{166m}Ho	1200 y	184.4107 ¹¹	
		276.3997 ¹³	7.147 ³⁰			280.4630 ²³				
		302.8510 ⁶	18.30 ⁶			300.741 ³				
		356.0134 ⁶	61.94 ¹⁴			410.956 ³				
		383.8480 ¹²	8.905 ²⁹			451.540 ⁴				
		¹³⁹Ce	137.640 d			165.857 ³			79.87 ⁶	529.825 ⁴
¹⁴¹Ce	32.501 d			145.4433 ¹⁴	48.6 ⁴	570.995 ⁵				
		¹⁴⁴Ce	284.893 d	696.505 ⁴		670.526 ⁴				
1489.148 ³				711.697 ³						
2185.645 ⁵				752.280 ⁴						
¹⁵²Eu	13.542 y			121.7817 ³	28.37 ¹³	778.827 ⁶				
				244.6975 ⁸	7.53 ⁴	810.286 ⁴				
				295.9390 ⁷		830.565 ⁴				
				344.2785 ¹³	26.57 ¹¹	875.663 ⁷				
				367.7891 ²⁰		950.988 ⁴				
				411.1165 ¹³	2.238 ¹⁰	1241.519 ⁴				
				444.0	3.125 ¹⁴	1282.102 ⁵				
		778.9045 ²⁴	12.97 ⁶	¹⁷⁰Tm	128.6 d	84.25474 ⁸				
		867.378 ⁴	4.214 ²⁵			¹⁶⁹Yb	32.026 d	63.12044 ⁴		
		964.1	14.63 ⁶					93.61447 ⁷		
1085.836 ⁹	10.13 ⁵	109.77924 ⁴								
1089.737 ⁵	1.731 ⁹	118.18940 ¹⁴								
1112.074 ⁴	13.54 ⁶	130.52293 ⁶								
1212.948 ¹¹	1.412 ⁸	177.21307 ⁶								
1299.140 ⁹	1.626 ¹¹	197.95675 ⁷								
1408.011 ⁴	20.85 ⁹	261.07712 ⁹								
1457.643 ¹¹		307.73586 ¹⁰								
¹⁵⁴Eu	8.593 y	123.0706 ⁹	41.2 ⁵	^{177m}Lu	160.4 d	105.3596 ⁶				
		247.9289 ⁷	6.95 ⁹			112.9499 ⁵				
		591.755 ³	4.99 ⁶			121.6211 ⁵				
		723.3009 ²²	20.2 ²			128.5031 ⁵				
		756.8020 ²³	4.58 ⁶			136.7249 ¹²				
		873.1839 ²³	12.24 ¹⁵			153.2844 ⁵				
		996.3	10.48 ¹³			171.8577 ⁸				
		1004.7	18.2 ²			174.3992 ⁵				
		1274.427 ⁴	35.0 ⁴			177.0009 ⁵				
		1494.050 ⁵	0.71 ²			204.1053 ⁵				
1596.4804 ²⁷	1.81 ²	208.3665 ⁵								
¹⁵³Gd	241.6 d	69.67300 ¹³		214.4340 ⁶						
		75.42213 ²³		218.1040 ⁷						
		83.36717 ²¹		228.4839 ⁶						
		89.48595 ²²		233.8609 ⁸						
		97.43100 ²¹		249.6742 ¹⁰						
		103.18012 ¹⁷		268.7851 ¹⁰						
		172.85307 ¹⁹		281.7874 ⁹						
		86.7877 ³		296.4582 ⁶						
¹⁶⁰Tb	72.3 d	197.0341 ¹⁰		299.0507 ¹⁷						
		215.6452 ¹¹		305.5030 ¹⁴						
		298.5783 ¹⁷		313.7253 ²¹						
		879.378 ²		319.0207 ⁸						
		962.311 ³		321.3164 ¹⁶						
		966.166 ²		327.6831 ⁷						
		1177.954 ³		341.6434 ¹⁰						
		1271.873 ⁵		367.4178 ¹⁰						

Table 1. Gamma-ray Energies and Absolute Intensities (continued)

Source	Half-life	E_{γ} (keV)	I_{γ} (%)	Source	Half-life	E_{γ} (keV)	I_{γ} (%)								
^{177m}Lu (continued)		378.5031 ⁷		¹⁹²Ir	73.83 d	136.34257 ²⁶									
		385.0306 ⁹				205.79430 ⁹									
		413.6638 ⁷				295.95650 ¹⁵	28.7 ¹								
		426.4728 ²⁴				308.45507 ¹⁷	29.8 ¹								
		465.8418 ¹⁰				316.50618 ¹⁷	83.0 ³								
		¹⁷²Hf	1.87 y			23.9330 ²		416.4678 ⁷		468.06885 ²⁶	47.7 ²				
						78.7422 ⁶ [®]		484.5751 ⁴		588.5810 ⁷	4.49 ²				
						81.7509 ⁵ [®]		604.41105 ²⁵	8.11 ⁴	612.46215 ²⁶	5.28 ³				
						90.6435 ¹⁹		884.5365 ⁷		¹⁹⁸Au	2.69517 d	411.80205 ¹⁷	95.6 ⁵		
						¹⁸²Ta	114.43 d	65.71115 ¹⁵				675.8836 ⁷		¹⁹⁹Au	3.139 d
		67.74970 ¹⁰						49.82635 ¹²		158.37851 ¹⁰					
		84.68024 ²⁶						208.20481 ¹²		²⁰³Hg	46.612 d	279.194 ³	81.48 ⁸		
		100.10595 ⁷	14.23 ²⁵					²⁰³Pb	51.873 h			279.194 ³			
113.67170 ²²		680.514 ⁴		²¹⁰Pb	22.3 y					46.539 ¹					
116.4179 ⁶		7.02 ⁸	²⁰⁷Bi					31.55 y	569.698 ²	97.74 ³					
152.42991 ²⁶		7.57 ⁸		1063.656 ³	74.5 ²										
156.38645 ³⁰			1770.228 ⁹	6.87 ⁴											
179.39381 ²⁵			²²⁸Th[†]	1.9131 y	84.4	1.22 ²									
198.35189 ²⁹					238.6	43.5 ⁴									
222.1085 ³					241.0	4.10 ⁵									
229.3207 ⁶					277.4	2.30 ³									
264.0740 ³					300.1	3.25 ³									
1121.290 ³	35.3 ²				510.8	8.18 ¹⁰									
1157.302 ³					583.187 ²	30.6 ²									
1189.040 ³	16.42 ¹⁰				727.3	6.69 ⁹									
1221.395 ³	27.20 ²²				860.6	4.50 ⁴									
1231.004 ³	11.57 ⁸				1620.7	1.49 ⁵									
1257.407 ³					2614.511 ¹⁰	35.86 ⁶									
1273.719 ³			²³⁹Np	2.3565 d	106.1	26.7 ⁴									
1289.145 ³					228.2	11.12 ¹⁵									
1373.824 ³					277.6	14.31 ²⁰									
1387.390 ³			²⁴¹Am	432.2 y	26.3446 ²	2.4 ¹									
¹⁸⁵Os	93.6 d	125.358 ³				59.5409 ²	36.0 ⁴								
		162.853 ⁴				²⁴³Am	7370 y	43.5	5.94 ¹¹						
		234.156 ⁴		74.7	67.4 ¹⁰										
		592.0713 ²⁸													
		646.127 ⁴													
		717.429 ⁴													
		874.826 ⁴													
880.2814 ²⁸															

[®] In equilibrium with ¹⁷²Lu (6.70 d)

[†] In equilibrium with decay daughter isotopes