

APPENDIX C. 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 using 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 from the *Table of Isotopes*, 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 and C. van der Leun, private communication, draft of a paper to be submitted to *Nucl. Instr. Meth.*, 1999.

² *X-ray and Gamma-ray Standards for Detector Calibration*, report by the Co-ordinated Research IAEA Programme, IAEA-TECDOC-619 (1991).

³ 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).

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	53.12 d	477.6035 ₂₀	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	1368.625 ₅	99.9936 ₁₅			1099.245 ₃	
		2754.008 ₁₁	99.855 ₅			1291.590 ₆	
³⁵ Cl(n, γ)		517.1	0.227 ₂₀	⁵⁶ Co	77.27 d	846.7638 ₁₉	99.933 ₇
		786.3	0.096 ₉			1037.8333 ₂₄	14.13 ₅
		788.4	0.150 ₁₂			1175.0878 ₂₂	2.239 ₁₁
		1164.9	0.257 ₂₂			1238.2736 ₂₂	66.07 ₁₉
		1600.8	0.034 ₃			1360.196 ₄	4.256 ₁₅
		1951.1	0.187 ₁₅			1771.327 ₃	15.49 ₅
		1959.3	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			2598.438 ₄	16.96 ₆
		6619.4	0.081 ₇			3009.559 ₄	0.995 ₂₁
		6627.5	0.046 ₄			3201.930 ₁₁	3.13 ₉
		6977.6	0.0223 ₂₀			3253.402 ₅	7.62 ₂₄
		7413.7	0.100 ₈			3272.978 ₆	1.78 ₆
		7790.0	0.086 ₇			3451.119 ₄	0.93 ₄
		8578.2	0.0294 ₂₄			3548.3	0.178 ₉
⁴⁶ Sc	83.79 d	889.271 ₂	99.9844 ₁₆	⁵⁷ Co	271.79 d	14.4130 ₄	9.16 ₁₅
		1120.537 ₃	99.9874 ₁₁			122.06065 ₁₂	85.60 ₁₇
⁴⁴ Ti	63 y	67.8688 ₁₇				136.47356 ₂₉	10.68 ₈
		78.3236 ₁₇		⁵⁸ Co	70.86 d	810.7593 ₂₀	99.45 ₁
⁵¹ Cr	27.7025 d	320.0824 ₄	9.86 ₅			863.951 ₆	0.69 ₃
⁵⁴ Mn	312.3 d	834.838 ₅	99.9758 ₂₄			1674.725 ₇	0.519 ₁₀
⁵⁶ Mn	2.5785 h	846.8	98.87 ₃ [†]	⁶⁰ Co	5.2714 y	1173.228 ₃	99.857 ₂₂
		1810.7	27.2 ₈ [†]			1332.492 ₄	99.983 ₆
		2113.0	14.3 ₄ [†]	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	^{108m} Ag	418 y	433.937 ⁴				
		1039.220 ³	37.9 ¹²			614.276 ⁴				
		1333.112 ⁵	1.23 ⁵			722.907 ¹⁰				
		1418.754 ⁵					^{110m} Ag	249.79 d	446.812 ³	3.72 ^{3 †}
		1508.158 ⁷				620.3553 ¹⁷				
		1918.329 ⁵	2.14 ⁸			657.7600 ¹¹			94.4 ^{1 †}	
		2189.616 ⁶	5.71 ²¹			677.6217 ¹²			10.40 ^{8 †}	
		2422.525 ⁷	1.96 ⁷			687.0091 ¹⁸			6.44 ^{3 †}	
		2751.835 ⁵	23.2 ¹¹			706.6760 ¹⁵			16.6 ^{1 †}	
		3228.800 ⁶	1.48 ¹²			744.2755 ¹⁸			4.70 ^{4 †}	
		3380.850 ⁶	1.40 ¹²			763.9424 ¹⁷			22.39 ^{8 †}	
		3422.040 ⁸				818.0244 ¹⁸			7.32 ^{4 †}	
		3791.009 ⁶	1.02 ¹¹			884.6781 ¹³			72.7 ^{3 †}	
		4085.853 ⁹	1.14 ¹⁹			937.485 ³			34.31 ^{12 †}	
		4295.7	3.5 ⁷			1384.2931 ²⁰			24.25 ^{8 †}	
		4461.202 ⁹				1475.7792 ²³			3.99 ^{2 †}	
4806.007 ¹⁰	1.5 ⁴	1505.0280 ²⁰	13.04 ^{4 †}							
		1562.2940 ¹⁸								
⁷⁵ Se	119.779 d	66.0518 ⁸	1.10 ²	¹⁰⁹ Cd	462.6 d	88.03360 ¹⁰			3.63 ²	
		96.7340 ⁹	3.41 ⁴			¹¹¹ In	2.8047 d	171.3	90.78 ¹⁰	
		121.1155 ¹¹	17.1 ¹	245.4	94.16 ³					
		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	2002.134 ¹²						
		400.6572 ⁸	11.5 ¹	2201.002 ¹²						
				2275.748 ¹⁰						
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				713.776 ⁴				
		698.368 ³				722.782 ³	11.3 ^{2 †}			
		776.513 ⁴				790.706 ⁷				
		827.820 ⁵				968.195 ⁴				
		1043.993 ⁵				1045.125 ⁴				
		1317.466 ⁴				1325.504 ⁴				
		1474.874 ⁵				1368.157 ⁵				
		1650.328 ⁵				1436.554 ⁷				
						1690.971 ⁴	48.5 ^{3 †}			
⁸⁴ Rb	32.77 d	881.6041 ¹⁶		¹²⁵ Sb	2.7582 y	2090.930 ⁷	5.66 ^{9 †}			
		1016.158 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	724.193 ³	44.15 ^{20 †}	600.597 ²	17.73 ¹⁸					
		756.7	54.50 ^{25 †}	606.713 ³	5.00 ⁵					
⁹⁴ Nb	2.03×10 ⁴ y	702.639 ⁴	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	765.803 ⁶	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 ²		
		140.511 ¹		1317.918 ⁶						
^{95m} Tc	61 d	204.1161 ¹⁷		1985.625 ⁶						
		582.0775 ²¹								
		786.1922 ²⁷								
		820.622 ⁷								
		835.146 ⁶								
^{99m} Tc	6.01 h	140.511 ¹	89.0 ^{2 †}							
¹⁰⁶ Ru	373.59 d	511.8534 ²³								

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} (%) ^{&}
¹³⁴ Cs	2.0648 y	475.4	1.49 ²	¹⁶⁰ Tb	72.3 d	86.7877 ³	
		563.2	8.36 ³			197.0341 ¹⁰	
		569.3	15.39 ⁶			215.6452 ¹¹	
		604.7	97.63 ⁶			298.5783 ¹⁷	
		795.8	85.4 ³			879.378 ²	
		801.9	8.69 ³			962.311 ³	
		1038.6	0.990 ⁵			966.166 ²	
		1168.0	1.792 ⁷			1177.954 ³	
		1365.2	3.016 ¹¹			1271.873 ⁵	
¹³⁷ Cs	30.07 y	661.657 ³	85.1 ²	¹⁶¹ Tb	6.88 d	25.65135 ³	
¹³³ Ba	10.51 y	53.1622 ⁶				48.91533 ⁵	
		79.6142 ¹²				57.1917 ³	
		80.9979 ¹¹	34.11 ²⁸	74.56669 ⁶			
		160.6120 ¹⁶		84.25474 ⁸			
		223.2368 ¹³		63.12044 ⁴			
		276.3989 ¹²	7.147 ³⁰	¹⁷⁰ Tm	128.6 d	93.61447 ⁸	
		302.8508 ⁵	18.30 ⁶			109.77924 ⁴	
		356.0129 ⁷	61.94 ¹⁴	¹⁶⁹ Yb	32.026 d	118.18940 ¹⁴	
		383.8485 ¹²	8.905 ²⁹			63.12044 ⁴	
		165.857 ³	79.87 ⁶			93.61447 ⁸	
¹³⁹ Ce	137.640 d	145.4433 ¹⁴	48.6 ^{4 †}			109.77924 ⁴	
¹⁴¹ Ce	32.501 d	696.505 ⁴				118.18940 ¹⁴	
¹⁴⁴ Ce	284.893 d	1489.148 ³				130.52293 ⁶	
		2185.645 ⁵				177.21307 ⁶	
¹⁵² Eu	13.537 y	121.7817 ³	28.37 ¹³			197.95675 ⁷	
		244.6974 ⁸	7.53 ⁴			261.07712 ⁹	
		295.9387 ¹⁷				307.73586 ¹⁰	
		344.2785 ¹²	26.57 ¹¹			23.9330 ²	
		367.7891 ²⁰				78.7422 ^{6 †}	
		411.1165 ¹²	2.238 ¹⁰			81.7509 ^{5 †}	
		444.0	3.125 ¹⁴			90.6434 ¹⁹	
		778.9045 ²⁴	12.97 ⁶			65.72215 ¹⁵	
		867.380 ³	4.214 ²⁵			67.74970 ¹⁰	
		964.1	14.63 ⁶			84.68024 ²⁶	
		1085.837 ¹⁰	10.13 ⁵			100.10595 ⁷	14.23 ^{25 †}
		1089.737 ⁵	1.731 ⁹			113.67170 ²²	
		1112.076 ³	13.54 ⁶			116.4179 ⁶	
1212.948 ¹¹	1.412 ⁸			152.42991 ²⁶	7.02 ^{8 †}		
1299.142 ⁸	1.626 ¹¹			156.3864 ³			
1408.013 ³	20.85 ⁹			179.39381 ²⁵			
1457.643 ¹¹				198.35187 ²⁹			
				222.1085 ³	7.57 ^{8 †}		
				229.3207 ⁶			
				264.0740 ³			
¹⁵⁴ Eu	8.593 y	123.0706 ⁹	41.2 ⁵			1121.290 ³	35.3 ^{2 †}
		247.9288 ⁷	6.95 ⁹			1157.302 ³	
		591.755 ³	4.99 ⁶			1189.040 ³	16.42 ^{10 †}
		723.3014 ²²	20.2 ²			1221.395 ³	27.20 ^{22 †}
		756.8020 ²³	4.58 ⁶			1231.004 ³	11.57 ^{8 †}
		873.1834 ²³	12.24 ¹⁵			1257.407 ³	
		996.3	10.48 ¹³			1273.719 ³	
		1004.7	18.2 ²			1289.145 ³	
		1274.429 ⁴	35.0 ⁴			1373.824 ³	
		1494.048 ⁵	0.71 ²			1387.390 ³	
		1596.4804 ²⁸	1.81 ²			125.3581 ⁹	
¹⁵³ Gd	240.4 d	69.67300 ¹³		¹⁸⁵ Os	93.6 d	162.852 ³	
		75.42213 ²³				234.156 ⁴	
		83.36717 ²¹				592.0722 ²²	
		89.48595 ²²				646.127 ⁴	
		97.43100 ²¹				717.4298 ²⁴	
		103.18012 ¹⁷				874.826 ⁴	
		172.85307 ¹⁹				880.2816 ²⁷	

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} (%) ^{&}
¹⁹² Ir	73.831 d	136.34257 ²⁶		²¹⁰ Pb	22.3 y	46.539 ¹	
		205.79430 ⁹				²⁰⁷ Bi	31.55 y
		295.95650 ¹⁵	28.7 [†]	1063.656 ³	74.5 ²		
		308.45507 ¹⁷	29.8 [†]	1770.228 ⁹	6.87 ⁴		
		316.50618 ¹⁷	83.0 [‡]	²²⁸ Th [@]	1.9131 y	84.4	1.22 ²
		416.4688 ⁷				238.6	43.5 ⁴
		468.06885 ²⁶	47.7 ²			241.0	4.10 ⁵
		484.5751 ⁴				277.4	2.30 ³
		588.5810 ⁷	4.49 ²			300.1	3.25 ³
		604.41105 ²⁵	8.11 ⁴			510.8	8.18 ¹⁰
		612.46215 ²⁶	5.28 ³			583.187 ²	30.6 ²
		884.5365 ⁷				727.3	6.69 ⁹
¹⁹⁸ Au	2.69517 d	411.80205 ¹⁷	95.6 ⁵	860.6	4.50 ⁴		
		675.8836 ⁷	0.806 ⁷	1620.7	1.49 ⁵		
		1087.6842 ⁷	0.159 ³	2614.511 ¹⁰	35.86 ⁶		
¹⁹⁹ Au	3.139 d	49.82635 ¹²		²³⁹ Np	2.3565 d	106.1	26.7 ⁴
		158.37851 ¹⁰				228.2	11.12 ¹⁵
		208.20481 ¹²				277.6	14.31 ²⁰
²⁰³ Hg	46.612 d	279.1952 ¹⁰	81.48 ⁸	²⁴¹ Am	432.2 y	26.3446 ²	2.4 ¹
²⁰³ Pb	51.873 h	279.1952 ¹⁰				59.5409 ²	36.0 ⁴
		401.320 ⁴		43.5	5.94 ¹¹		
		680.515 ³		74.7	67.4 ¹⁰		

[#] From reference 1 when listed with uncertainty. Otherwise rounded to the nearest 0.1 keV.

[&] From reference 2, except where indicated.

[†] From reference 3.

[‡] In equilibrium with ¹⁷²Lu (6.70 d).

[@] In equilibrium with decay daughter isotopes.