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 ^{198}Au 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).

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[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. Vaninbroukx, *Emission Probabilities of Selected Gamma Rays for Radionuclides Used as Detector-Calibration Standards*, report presented at the Advisory Groug 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(%) &
^{7}Be	53.12 d	477.6035 *20*	10.45 *10* †
^{22}Na	2.6019 y	1274.537 *7*	99.935 *15*
^{24}Na	14.9590 h	1368.625 *5*	99.9936 *15*
		2754.008 *11*	99.855 *5*
^{35}Cl(n,γ)		517.1	0.227 *20*
		786.3	0.096 *9*
		788.4	0.150 *12*
		1164.9	0.257 *22*
		1600.8	0.034 *3*
		1951.1	0.187 *15*
		1959.3	0.121 *10*
		2863.9	0.060 *5*
		3061.7	0.035 *3*
		5715.2	0.051 *4*
		6110.8	0.197 *16*
		6619.4	0.081 *7*
		6627.5	0.046 *4*
		6977.6	0.0223 *20*
		7413.7	0.100 *8*
		7790.0	0.086 *7*
		8578.2	0.0294 *24*
^{46}Sc	83.79 d	889.271 *2*	99.9844 *16*
		1120.537 *3*	99.9874 *11*
^{44}Ti	63 y	67.8688 *17*	
		78.3236 *17*	
^{51}Cr	27.7025 d	320.0824 *4*	9.86 *5*
^{54}Mn	312.3 d	834.838 *5*	99.9758 *24*
^{56}Mn	2.5785 h	846.8	98.87 *3* †
		1810.7	27.2 *8* †
		2113.0	14.3 *4* †
^{59}Fe	44.503 d	142.651 *2*	
		192.349 *5*	
		1099.245 *3*	
		1291.590 *6*	
^{56}Co	77.27 d	846.7638 *19*	99.933 *7*
		1037.8333 *24*	14.13 *5*
		1175.0878 *22*	2.239 *11*
		1238.2736 *22*	66.07 *19*
		1360.196 *4*	4.256 *15*
		1771.327 *3*	15.49 *5*
		2015.176 *5*	3.029 *13*
		2034.752 *5*	7.771 *27*
		2113.092 *6*	0.366 *6*
		2212.898 *3*	0.390 *7*
		2598.438 *4*	16.96 *6*
		3009.559 *4*	0.995 *21*
		3201.930 *11*	3.13 *9*
		3253.402 *5*	7.62 *24*
		3272.978 *6*	1.78 *6*
		3451.119 *4*	0.93 *4*
		3548.3	0.178 *9*
^{57}Co	271.79 d	14.4130 *4*	9.16 *15*
		122.06065 *12*	85.60 *17*
		136.47356 *29*	10.68 *8*
^{58}Co	70.86 d	810.7593 *20*	99.45 *1*
		863.951 *6*	0.69 *3*
		1674.725 *7*	0.519 *10*
^{60}Co	5.2714 y	1173.228 *3*	99.857 *22*
		1332.492 *4*	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(%) &
^{66}Ga	9.49 h	833.5324 *21*	6.03 *23*
		1039.220 *3*	37.9 *12*
		1333.112 *5*	1.23 *5*
		1418.754 *5*	
		1508.158 *7*	
		1918.329 *5*	2.14 *8*
		2189.616 *6*	5.71 *21*
		2422.525 *7*	1.96 *7*
		2751.835 *5*	23.2 *11*
		3228.800 *6*	1.48 *12*
		3380.850 *6*	1.40 *12*
		3422.040 *8*	
		3791.009 *6*	1.02 *11*
		4085.853 *9*	1.14 *19*
		4295.7	3.5 *7*
		4461.202 *9*	
		4806.007 *10*	1.5 *4*
^{75}Se	119.779 d	66.0518 *8*	1.10 *2*
		96.7340 *9*	3.41 *4*
		121.1155 *11*	17.1 *1*
		136.0001 *6*	58.8 *3*
		198.6060 *12*	1.49 *1*
		264.6576 *9*	59.0 *2*
		279.5422 *10*	25.0 *1*
		303.9236 *10*	1.31 *1*
		400.6572 *8*	11.5 *1*
^{82}Br	35.30 h	221.4788 *18*	
		554.346 *3*	
		619.104 *3*	
		698.368 *3*	
		776.513 *4*	
		827.820 *5*	
		1043.993 *5*	
		1317.466 *4*	
		1474.874 *5*	
		1650.328 *5*	
^{84}Rb	32.77 d	881.6041 *16*	
		1016.158 *11*	
		1897.751 *11*	
^{85}Sr	64.84 d	514.0048 *22*	98.4 *4*
^{88}Y	106.65 d	898.036 *4*	94.0 *3*
		1836.052 *13*	99.36 *3*
^{95}Zr	64.02 d	724.193 *3*	44.15 *20* †
		756.7	54.50 *25* †
^{94}Nb	2.03×10^4 y	702.639 *4*	99.79 *5*
		871.114 *3*	99.86 *5*
^{95}Nb	34.975 d	765.803 *6*	99.81 *3*
^{99}Mo	65.94 h	40.58323 *17*	
		140.511 *1*	
^{95m}Tc	61 d	204.1161 *17*	
		582.0775 *21*	
		786.1922 *27*	
		820.622 *7*	
		835.146 *6*	
		1039.260 *6*	
^{99m}Tc	6.01 h	140.511 *1*	89.0 *2* †
^{106}Ru	373.59 d	511.8534 *23*	

Source	Half-life	E_γ(keV) #	I_γ(%) &
^{108m}Ag	418 y	433.937 *4*	
		614.276 *4*	
		722.907 *10*	
^{110m}Ag	249.79 d	446.812 *3*	3.72 *3* †
		620.3553 *17*	
		657.7600 *11*	94.4 *1* †
		677.6217 *12*	10.40 *8* †
		687.0091 *18*	6.44 *3* †
		706.6760 *15*	16.6 *1* †
		744.2755 *18*	4.70 *4* †
		763.9424 *17*	22.39 *8* †
		818.0244 *18*	7.32 *4* †
		884.6781 *13*	72.7 *3* †
		937.485 *3*	34.31 *12* †
		1384.2931 *20*	24.25 *8* †
		1475.7792 *23*	3.99 *2* †
		1505.0280 *20*	13.04 *4* †
		1562.2940 *18*	
^{109}Cd	462.6 d	88.03360 *10*	3.63 *2*
^{111}In	2.8047 d	171.3	90.78 *10*
		245.4	94.16 *3*
^{115m}In	4.486 h	336.2	45.9 *2* †
^{113}Sn	115.09 d	391.698 *3*	64.89 *13*
^{125}Sn	9.64 d	1806.690 *16*	
		1889.884 *16*	
		2002.134 *12*	
		2201.002 *12*	
		2275.748 *10*	
^{124}Sb	60.20 d	602.7260 *23*	98.0 *1* †
		645.8520 *19*	7.3 *1* †
		713.776 *4*	
		722.782 *3*	11.3 *2* †
		790.706 *7*	
		968.195 *4*	
		1045.125 *4*	
		1325.504 *4*	
		1368.157 *5*	
		1436.554 *7*	
		1690.971 *4*	48.5 *3* †
		2090.930 *7*	5.66 *9* †
^{125}Sb	2.7582 y	176.314 *2*	6.85 *7*
		380.5	1.518 *16*
		427.874 *4*	29.7 *3*
		463.365 *4*	10.48 *11*
		600.597 *2*	17.73 *18*
		606.713 *3*	5.00 *5*
		635.950 *3*	11.21 *12*
		671.441 *6*	1.80 *2*
^{125}I	59.408 d	35.5	6.58 *8*
^{132}Cs	6.479 d	667.714 *2*	
		1317.918 *6*	
		1985.625 *6*	

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

Source	Half-life	E_γ(keV) #	I_γ(%) &
^{134}Cs	2.0648 y	475.4	1.49 2
		563.2	8.36 3
		569.3	15.39 6
		604.7	97.63 6
		795.8	85.4 3
		801.9	8.69 3
		1038.6	0.990 5
		1168.0	1.792 7
		1365.2	3.016 11
^{137}Cs	30.07 y	661.657 3	85.1 2
^{133}Ba	10.51 y	53.1622 6	
		79.6142 12	
		80.9979 11	34.11 28
		160.6120 16	
		223.2368 13	
		276.3989 12	7.147 30
		302.8508 5	18.30 6
		356.0129 7	61.94 14
		383.8485 12	8.905 29
^{139}Ce	137.640 d	165.857 3	79.87 6
^{141}Ce	32.501 d	145.4433 14	48.6 4 †
^{144}Ce	284.893 d	696.505 4	
		1489.148 3	
		2185.645 5	
^{152}Eu	13.537 y	121.7817 3	28.37 13
		244.6974 8	7.53 4
		295.9387 17	
		344.2785 12	26.57 11
		367.7891 20	
		411.1165 12	2.238 10
		444.0	3.125 14
		778.9045 24	12.97 6
		867.380 3	4.214 25
		964.1	14.63 6
		1085.837 10	10.13 5
		1089.737 5	1.731 9
		1112.076 3	13.54 6
		1212.948 11	1.412 8
		1299.142 8	1.626 11
		1408.013 3	20.85 9
		1457.643 11	
^{154}Eu	8.593 y	123.0706 9	41.2 5
		247.9288 7	6.95 9
		591.755 3	4.99 6
		723.3014 22	20.2 2
		756.8020 23	4.58 6
		873.1834 23	12.24 15
		996.3	10.48 13
		1004.7	18.2 2
		1274.429 4	35.0 4
		1494.048 5	0.71 2
		1596.4804 28	1.81 2
^{153}Gd	240.4 d	69.67300 13	
		75.42213 23	
		83.36717 21	
		89.48595 22	
		97.43100 21	
		103.18012 17	
		172.85307 19	
^{160}Tb	72.3 d	86.7877 3	
		197.0341 10	
		215.6452 11	
		298.5783 17	
		879.378 2	
		962.311 3	
		966.166 2	
		1177.954 3	
		1271.873 5	
^{161}Tb	6.88 d	25.65135 3	
		48.91533 5	
		57.1917 3	
		74.56669 6	
^{170}Tm	128.6 d	84.25474 8	
^{169}Yb	32.026 d	63.12044 4	
		93.61447 8	
		109.77924 4	
		118.18940 14	
		130.52293 6	
		177.21307 6	
		197.95675 7	
		261.07712 9	
		307.73586 10	
^{172}Hf	1.87 y	23.9330 2	
		78.7422 6 ‡	
		81.7509 5 ‡	
		90.6434 19	
^{182}Ta	114.43 d	65.72215 15	
		67.74970 10	
		84.68024 26	
		100.10595 7	14.23 25 †
		113.67170 22	
		116.4179 6	
		152.42991 26	7.02 8 †
		156.3864 3	
		179.39381 25	
		198.35187 29	
		222.1085 3	7.57 8 †
		229.3207 6	
		264.0740 3	
		1121.290 3	35.3 2 †
		1157.302 3	
		1189.040 3	16.42 10 †
		1221.395 3	27.20 22 †
		1231.004 3	11.57 8 †
		1257.407 3	
		1273.719 3	
		1289.145 3	
		1373.824 3	
		1387.390 3	
^{185}Os	93.6 d	125.3581 9	
		162.852 3	
		234.156 4	
		592.0722 22	
		646.127 4	
		717.4298 24	
		874.826 4	
		880.2816 27	

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

Source	Half-life	E_γ(keV) #	I_γ(%) &
^{192}Ir	73.831 d	136.34257 *26*	
		205.79430 *9*	
		295.95650 *15*	28.7 *1* †
		308.45507 *17*	29.8 *1* †
		316.50618 *17*	83.0 *3* †
		416.4688 *7*	
		468.06885 *26*	47.7 *2* †
		484.5751 *4*	
		588.5810 *7*	4.49 *2* †
		604.41105 *25*	8.11 *4* †
		612.46215 *26*	5.28 *3* †
		884.5365 *7*	
^{198}Au	2.69517 d	411.80205 *17*	95.6 *5*
		675.8836 *7*	0.806 *7*
		1087.6842 *7*	0.159 *3*
^{199}Au	3.139 d	49.82635 *12*	
		158.37851 *10*	
		208.20481 *12*	
^{203}Hg	46.612 d	279.1952 *10*	81.48 *8*
^{203}Pb	51.873 h	279.1952 *10*	
		401.320 *4*	
		680.515 *3*	
^{210}Pb	22.3 y	46.539 *1*	
^{207}Bi	31.55 y	569.698 *2*	97.74 *3*
		1063.656 *3*	74.5 *2*
		1770.228 *9*	6.87 *4*
^{228}Th@	1.9131 y	84.4	1.22 *2*
		238.6	43.5 *4*
		241.0	4.10 *5*
		277.4	2.30 *3*
		300.1	3.25 *3*
		510.8	8.18 *10*
		583.187 *2*	30.6 *2*
		727.3	6.69 *9*
		860.6	4.50 *4*
		1620.7	1.49 *5*
		2614.511 *10*	35.86 *6*
^{239}Np	2.3565 d	106.1	26.7 *4*
		228.2	11.12 *15*
		277.6	14.31 *20*
^{241}Am	432.2 y	26.3446 *2*	2.4 *1*
		59.5409 *2*	36.0 *4*
^{243}Am	7370 y	43.5	5.94 *11*
		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 ^{172}Lu (6.70 d).
@ In equilibrium with decay daughter isotopes.