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 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).

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[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. 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).

[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(%)
^{7}Be	53.29 d	477.6035 *2*	10.45 *10*
^{22}Na	2.6019 y	1274.537 *7*	99.935 *15*
^{24}Na	14.9590 h	1368.626 *5*	99.9936 *15*
		2754.007 *11*	99.855 *5*
^{35}Cl(n,γ)		517.07043 *28*	0.227 *20*
		786.2975 *5*	0.096 *9*
		788.4236 *5*	0.150 *12*
		1164.8587 *6*	0.257 *22*
		1600.8	0.034 *3*
		1951.1291 *15*	0.187 *15*
		1959.345 *8*	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	49 y	67.8679 *18*	
		78.3231 *13*	
^{51}Cr	27.702 d	320.0824 *4*	9.86 *5*
^{54}Mn	312.3 d	834.841 *4*	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*
		2213.092 *6*	
		2598.437 *4*	16.96 *6*
		3009.558 *4*	0.995 *21*
		3201.930 *11*	3.13 *9*
		3253.402 *5*	7.62 *24*
		3272.977 *6*	1.78 *6*
		3451.119 *4*	0.93 *4*
		3548.3	0.178 *9*
^{57}Co	271.79 d	14.4	9.16 *15*
		122.06065 *12*	85.60 *17*
		136.47350 *29*	10.68 *8*
^{58}Co	70.82 d	810.7594 *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*
		1332.490 *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(%)
^{66}Ga	9.49 h	833.5324 21	6.03 23
		1039.220 3	37.9 12
		1333.113 5	1.23 5
		1418.753 5	
		1508.158 7	
		1918.329 5	2.14 8
		2189.616 6	5.71 21
		2422.523 7	1.96 7
		2751.835 5	23.2 11
		3228.800 6	1.48 12
		3380.851 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	
		4806.005 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	
		827.825 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	724.192 4	44.15 20
		756.7	54.50 25
^{94}Nb	2.0×10^4 y	702.638 5	99.79 5
		871.114 3	99.86 5
^{95}Nb	34.975 d	765.8	99.81 3
^{99}Mo	65.94 h	40.58323 17	
		140.510 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	140.510 1	89.0 2
^{106}Ru	373.59 d	511.8534 23	
^{108m}Ag	127.0 y	433.937 4	
		614.276 4	
		722.906 10	
^{110m}Ag	249.76 d	446.812 3	3.72 3
		620.3547 22	
		657.7600 12	94.4 1
		677.6216 13	10.40 8
		687.0085 20	6.44 3
		706.6752 17	16.6 1
		744.2754 18	4.70 4
		763.9420 18	22.39 8
		818.0243 19	7.32 4
		884.6779 13	72.7 3
		937.484 4	34.31 12
		1384.2921 22	24.25 8
		1475.7790 24	3.99 2
		1505.0273 24	13.04 4
		1562.2937 18	
^{109}Cd	462.6 d	88.0336 10	3.63 2
^{111}In	2.8049 d	171.3	90.78 10
		245.3	94.16 6
^{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	
		2002.132 13	
		2201.002 12	
		2275.749 10	
^{124}Sb	60.20 d	602.7260 23	98.0 1
		645.8520 19	7.3 1
		713.777 4	
		722.783 4	11.3 2
		790.708 6	
		968.194 4	
		1045.125 4	
		1325.505 4	
		1368.156 5	
		1436.556 6	
		1690.971 4	48.5 3
		2090.930 6	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 2	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 3	
		1317.916 7	
		1985.623 8	
^{134}Cs	2.062 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

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

Source	Half-life	E_γ(keV)	I_γ(%)
^{133}Ba	10.52 y	53.1625 6	
		79.6139 13	
		80.9971 12	34.11 28
		160.6109 17	
		223.2373 14	
		276.3997 13	7.147 30
		302.8510 6	18.30 6
		356.0134 6	61.94 14
		383.8480 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	13.542 y	121.7817 3	28.37 13
		244.6975 8	7.53 4
		295.9390 7	
		344.2785 13	26.57 11
		367.7891 20	
		411.1165 13	2.238 10
		444.0	3.125 14
		778.9045 24	12.97 6
		867.378 4	4.214 25
		964.1	14.63 6
		1085.836 9	10.13 5
		1089.737 5	1.731 9
		1112.074 4	13.54 6
		1212.948 11	1.412 8
		1299.140 9	1.626 11
		1408.011 4	20.85 9
		1457.643 11	
^{154}Eu	8.593 y	123.0706 9	41.2 5
		247.9289 7	6.95 9
		591.755 3	4.99 6
		723.3009 22	20.2 2
		756.8020 23	4.58 6
		873.1839 23	12.24 15
		996.3	10.48 13
		1004.7	18.2 2
		1274.427 4	35.0 4
		1494.050 5	0.71 2
		1596.4804 27	1.81 2
^{153}Gd	241.6 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	

Source	Half-life	E_γ(keV)	I_γ(%)
^{161}Tb	6.88 d	25.65135 3	
		48.91533 5	
		57.1917 3	
		74.56669 6	
^{166m}Ho	1200 y	80.5725 13	
		184.4107 11	
		280.4630 23	
		300.741 3	
		410.956 3	
		451.540 4	
		529.825 4	
		570.995 5	
		670.526 4	
		711.697 3	
		752.280 4	
		778.827 6	
		810.286 4	
		830.565 4	
		875.663 7	
		950.988 4	
		1241.519 4	
		1282.102 5	
^{170}Tm	128.6 d	84.25474 8	
^{169}Yb	32.026 d	63.12044 4	
		93.61447 7	
		109.77924 4	
		118.18940 14	
		130.52293 6	
		177.21307 6	
		197.95675 7	
		261.07712 9	
		307.73586 10	
^{177m}Lu	160.4 d	105.3596 6	
		112.9499 5	
		121.6211 5	
		128.5031 5	
		136.7249 12	
		153.2844 5	
		171.8577 8	
		174.3992 5	
		177.0009 5	
		204.1053 5	
		208.3665 5	
		214.4340 6	
		218.1040 7	
		228.4839 6	
		233.8609 8	
		249.6742 10	
		268.7851 10	
		281.7874 9	
		296.4582 6	
		299.0507 17	
		305.5030 14	
		313.7253 21	
		319.0207 8	
		321.3164 16	
		327.6831 7	
		341.6434 10	
		367.4178 10	

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

Source	Half-life	E_γ(keV)	I_γ(%)
^{177m}Lu	(continued)	378.5031 *7*	
		385.0306 *9*	
		413.6638 *7*	
		426.4728 *24*	
		465.8418 *10*	
^{172}Hf	1.87 y	23.9330 *2*	
		78.7422 *6* @	
		81.7509 *5* @	
		90.6435 *19*	
^{182}Ta	114.43 d	65.71115 *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*
		156.38645 *30*	
		179.39381 *25*	
		198.35189 *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	125.358 *3*	
		162.853 *4*	
		234.156 *4*	
		592.0713 *28*	
		646.127 *4*	
		717.429 *4*	
		874.826 *4*	
		880.2814 *28*	
^{192}Ir	73.83 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*
		416.4678 *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*	
		1087.6842 *7*	
^{199}Au	3.139 d	49.82635 *12*	
		158.37851 *10*	
		208.20481 *12*	
^{203}Hg	46.612 d	279.194 *3*	81.48 *8*
^{203}Pb	51.873 h	279.194 *3*	
		401.320 *4*	
		680.514 *4*	
^{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*

@ In equilibrium with ^{172}Lu (6.70 d)
† In equilibrium with decay daughter isotopes