Appendix B

Gamma-ray and X-ray Standards for Detector Calibration

This Appendix contains evaluated and recommended data on a selected set of radionuclides suitable for use in the energy and efficiency calibration of detectors. The data in the first edition of this book were taken from *X-Ray and Gamma-Ray Standards for Detector Calibration*, published by the International Atomic Energy Agency as IAEA TECDOC-619. Since that time, the data has been re-evaluated and extended within the international Decay Date Evaluation Project (DDEP). After much delay the updated data was published by the IAEA as XGAMMA (*X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications*) in late spring 2007.

Rather than reproduce the whole of that report, which is accessible on the internet at *http://www-nds.iaea.org/xgamma_standards/*, I have restricted myself to updating the data for nuclides in the original table. For convenience, the gamma-ray and X-ray standards, listed separately in XGAMMA, are here combined into one table.

Notes.

- The 'decay mode' shown is the major mode but is frequently not the only one.
- All half-lives are in days. This may appear cumbersome for the longer half-lives, but the year is not a unit approved for use with the SI. (A calendar year is of variable length; in the long term, 1 year [international symbol a] = 365.242 198 78 d, and this is sometimes used.)
- The uncertainties shown are estimated standard uncertainties, and refer to the uncertainty of the last one or two digits; thus 950.8 (9) means 950.8 ± 0.9 and 0.99935 (15) means 0.99935 ± 0.00015.
- In general, X-rays below 10 keV have been omitted.
- Where appropriate, emissions have been identified as particular X-rays or gamma-rays emitted by a particular daughter nuclide. Unidentified emissions are gamma-rays from the nuclide for which the data is quoted.

Table B.1 Gamma-ray and X-ray standards

Nuclide	Decay Mode	Half-life (d)	Emission ID	Energy (keV)	Emission Probability P?
^{22}Na	EC	950.57 (23)		511.00	1.798 (2)
				1274.537 (3)	0.9994 (14)
^{24}Na	?[?]?	0.62329 (6)		1368.626 (5)	0.999935 (5)
				2754.007 (11)	0.99872 (8)
^{46}Sc	?[?]	83.79 (4)	Ti K	4.51	0.000047 (2)
				889.271 (2)	0.999833 (5)
				1120.537 (3)	0.99986 (-4,+36)
^{51}Cr	EC	27.7009 (20)	V Ka	4.94 - 4.95	0.202 (3)
			V Kß	5.43 - 5.46	0.0269 (7)
				320.0835 (4)	0.0987 (5)
^{54}Mn	EC	312.29 (26)	Cr Ka	5.405 - 5.415	0.00227 (3)

			Cr Kß	5.947	0.000305 (7)
				834.838 (5)	0.999746 (11)
^{55}Fe	EC	1002.7 (23)	Mn Ka2	5.8877	0.0845 (14)
			Mn Ka1	5.8988	0.1656 (27)
			Mn Kß'1	6.49 - 6.54	0.034 (7)
^{56}Co	EC	77.236 (26)	Fe Ka2	6.39091 (5)	0.0753 (10)
			Fe Ka1	6.40391 (3)	0.1475 (17)
			Fe Kß'1	7.058 - 7.108	0.0305 (5)
				846.7638 (19)	0.999399 (23)
				977.363 (4)	0.01422 (7)
				1037.8333 (24)	0.1403 (5)
				1175.0878 (22)	0.02249 (9)
				1238.2736 (22)	0.6641 (16)
				1360.196 (4)	0.0428 (13)
				1771.327 (3)	0.1545 (4)
				2015.176 (5)	0.03017 (14)
				2034.752 (5)	0.07741 (13)
				2598.438 (4)	0.1696 (4)
				3009.559 (4)	0.01038 (19)
				3201.93 (11)	0.03203 (13)
				3253.402 (5)	0.0787 (3)
				3272.978 (6)	0.01855 (9)
				3451.119 (4)	0.00942 (6)
^{57}Co	EC	271.8 (5)	Fe Ka 2	6.39084	0.168 (3)
			Fe Ka1	6.40384	0.332 (5)
			Fe Kß'1	7.058 - 7.108	0.071 (2)
				14.41295 (31)	0.0915 (17)
				122.06065 (12)	0.8551 (6)
				136.47356 (29)	0.1071 (15)
^{58}Co	EC	70.86 (6)	Fe Ka	6.4	0.235 (3)
			Fe Kß	7.06	0.032 (10)
			Ni Ka	7.46 - 7.48	0.000098 (3)
			Ni Kß	8.26 - 8.33	0.0000136 (5)
				511	0.3 (4)
				810.759 (2)	0.9945 (1)
^{60}Co	?[?]	1925.23 (27)	Ni Ka	7.46 - 7.48	0.000098 (3)
			Ni Kß	8.26 - 8.33	0.0000136 (5)
				1173.228 (3)	0.9985 (3)
				1332.492 (4)	0.999826 (6)
^{65}Zn	EC	243.86 (20)	Cu Ka	8.03 - 8.05	0.347 (3)
			Cu Kß	8.90 - 8.98	0.0482 (7)
				511.00	0.0284 (4)
				1115.539 (2)	0.506 (22)
^{75}Se	EC	119.778 (29)	As L	1.28	0.0206 (7)
			As Ka2	10.508	0.1659 (23)
			As Ka1	10.5437	0.322 (4)
			As Kß	11.72 - 11.86	0.0764 (12)

				66.0518 (8)	0.01112 (12)
				96.734 (9)	0.0342 (3)
				121.1155 (11)	0.172 (3)
				136.0001 (6)	0.582 (7)
				198.606 (12)	0.0148 (4)
				264.6576 (9)	0.589 (3)
				279.5422 (10)	0.2499 (13)
				303.9236 (10)	0.01316 (8)
				400.6572 (8)	0.1147 (9)
^{85}Sr	EC	64.851 (5)	Rb Ka2	13.3359 (2)	0.1716 (17)
			Rb Ka1	13.3955 (1)	0.3304 (29)
			Rb Kß'1	14.95 - 15.09	0.0804 (10)
			Rb Kß'2	15.19 - 15.21	0.0093 (4)
				514.0048 (22)	0.985 (4)
^{88}Y	EC	106.625 (24)	Sr Ka2	14.098 (1)	0.173 (22)
			Sr Ka1	14.1652 (2)	0.332 (4)
			Sr Kß'1	15.8359 (4)	0.0821 (12)
			Sr Kß'2	16.0847 (6)	0.0107 (4)
				898.036 (4)	0.939 (23)
				1836.052 (13)	0.9938 (3)
^{93m}Nb	IT	5.73 (22) × 10^{3}	Nb Ka2	16.5213	0.0316 (7)
			Nb Ka1	16.6152	0.0604 (12)
			Nb Kß'1	18.618	0.0156 (5)
			Nb Kß'2	18.953	0.0023 (1)
				30.77 (2)	0.000559 (16)
^{94}Nb	?[?]	7.3 (9) × 10^{6}		702.639 (4)	0.99815 (6)
				871.114 (3)	0.99892 (3)
^{95}Nb	?[?]	34.991 (6)	Mo Ka2	17.374	0.000286 (9)
			Mo Ka1	17.479	0.000546 (17)
			Mo Kß'1	19.59 - 19.77	0.000143 (5)
			Mo Kß'2	19.96 - 20.00	0.000022 (11)
				765.803 (6)	0.99808 (7)
^{109}Cd	EC	461.4 (12)	Ag Ka2	21.9906 (2)	0.2899 (25)
			Ag Ka1	22.1632 (1)	0.547 (4)
			Ag Kß'1	24.912 - 25.146	0.1514 (18)
			Ag Kß'2	25.457 - 25.512	0.0263 (10)
				88.0336 (11)	0.03626 (20)
^{111}In	EC	2.8049 (6)	Cd Ka2	22.9843	0.236 (2)
			Cd Ka1	23.1738	0.444 (3)
			Cd Kß'1	26.061 - 26.304	0.124 (4)
			Cd Kß'2	26.64 - 26.70	0.023 (1)
				171.28 (3)	0.9066 (25)
				245.35 (4)	0.9409 (6)
^{113}Sn	EC	115.09 (4)	In Ka2	24.002	0.2785 (22)
			In Ka1	24.2097	0.522 (4)
			In Kß'1	27.238 - 27.499	0.146 (12)

			In Kß'2	27.861 - 27.940	0.0284 (2)
				255.134 (10)	0.0211 (8)
				391.698 (3)	0.6494 (17)
^{125}Sb	?[?]	1007.48 (21)	Te Ka2	27.202 (2)	0.191 (7)
			Te Ka1	27.4726 (2)	0.357 (12)
			Te Kß'1	30.945 - 31.236	0.102 (4)
			Te Kß'2	31.701 - 31.774	0.0221 (10)
				176.314 (2)	0.0682 (7)
				380.452 (8)	0.0152 (15)
				427.874 (4)	0.2955 (24)
				463.365 (4)	0.1048 (9)
				600.597 (2)	0.1776 (18)
				606.713 (3)	0.0502 (5)
				635.95 (3)	0.1132 (10)
				671.441 (6)	0.01783 (16)
^{125}I	EC	59.402 (14)	Te Ka2	27.202 (2)	0.397 (6)
			Te Ka1	27.4726 (2)	0.74 (11)
			Te Kß'1	30.945 - 31.241	0.212 (4)
			Te Kß'2	31.701 - 31.812	0.0459 (14)
				35.4919 (5)	0.0667 (17)
^{133}Ba	EC	3848.7 (12)	Cs Ka2	30.625	0.34 (4)
			Cs Ka1	30.973	0.628 (7)
			Cs Kß'1	34.92 - 35.26	0.182 (2)
			Cs Kß'2	35.82 - 35.97	0.046 (1)
				53.1622 (6)	0.0214 (3)
				79.6142 (12)	0.0265 (5)
				80.9979 (11)	0.329 (3)
				276.3989 (12)	0.0716 (5)
				302.8508 (5)	0.1834 (13)
				356.0129 (7)	0.6205 (19)
				383.8485 (12)	0.0894 (6)
^{134}Cs	?[?]	753.5 (10)		563.243 (3)	0.0837 (3)
				569.327 (3)	0.1538 (4)
				604.72 (3)	0.9765 (18)
				795.83 (3)	0.855 (3)
				801.945 (4)	0.087 (3)
				1365.186 (4)	0.03017 (12)
^{137}Cs	?[?]	1.099 (4) × 10^{4}	Ba L	3.954 - 5.973	0.009 (5)
			Ba Ka2	31.8174	0.0195 (4)
			Ba Ka1	32.1939	0.0359 (7)
			Ba Kß'1	36.31 - 36.67	0.01055 (22)
			Ba Kß'2	37.26 - 37.43	0.00266 (8)
				661.657 (3)	0.8499 (20)
^{139}Ce	EC	137.642 (20)	La Ka2	33.0344 (2)	0.225 (3)
			La Ka1	33.4421 (1)	0.412 (4)
			La Kß'1	37.721 - 38.095	0.123 (18)
			La Kß'2	38.730 - 38.910	0.0311 (6)
				165.8575 (11)	0.799 (4)

^{152}Eu	EC ?[?]	4941 (7)	Sm Ka2	39.5229	0.208 (3)
			Sm Ka1	40.1186	0.377 (5)
			Sm Kß'1	45.289 - 45.731	0.1178 (19)
			Sm Kß'2	46.575 - 46.813	0.0304 (8)
				121.7817 (3)	0.2841 (13)
				244.6974 (8)	0.0755 (4)
			?[?]	344.2785 (12)	0.2658 (12)
			?[?]	411.1165 (12)	0.02237 (10)
				443.965 (3)	0.03125 (14)
			?[?]	778.9045 (24)	0.1296 (6)
				867.38 (3)	0.04241 (23)
				964.072 (18)	0.1462 (6)
				1085.837 (10)	0.1013 (6)
			?[?]	1089.737 (5)	0.01731 (10)
				1112.076 (3)	0.134 (6)
				1212.948 (11)	0.01415 (9)
			?[?]	1299.142 (8)	0.01632 (9)
				1408.013 (3)	0.2085 (9)
^{154}Eu	?[?]	3138.1 (14)	Gd Ka2	42.3093	0.072 (2)
			Gd Ka1	42.9967	0.13 (3)
			Gd Kß'1	48.556 - 49.053	0.041 (1)
			Gd Kß'2	49.961 - 50.219	0.0108 (3)
				123.0706 (9)	0.404 (5)
				247.9288 (7)	0.0689 (7)
				591.755 (3)	0.0495 (5)
				692.4205 (18)	0.0179 (3)
				723.3014 (22)	0.2005 (21)
				756.802 (23)	0.0453 (5)
				873.1834 (23)	0.1217 (12)
				996.262 (6)	0.105 (10)
				1004.725 (7)	0.1785 (17)
				1246.121 (4)	0.00862 (8)
				1274.429 (4)	0.349 (3)
				1596.4804 (28)	0.01783 (17)
^{155}Eu	?[?]	1736 (6)		26.531 (21)	0.00316 (22)
			Gd Ka2	42.3093	0.067 (13)
			Gd Ka1	42.9967	0.1205 (23)
				45.299 (10)	0.0131 (5)
			Gd Kß'1	48.556 - 49.053	0.0384 (11)
			Gd Kß'2	49.961 - 50.219	0.0098 (3)
				60.0086 (10)	0.0122 (5)
				86.0591 (10)	0.00154 (17)
				86.5479 (10)	0.307 (3)
				105.3083 (10)	0.211 (6)
^{198}Au	?[?]	2.695 (7)	Hg Ka2	68.8952 (12)	0.00809 (8)
			Hg Ka1	70.8196 (12)	0.01372 (12)
			Hg Kß'1	79.82 - 80.76	0.00466 (8)
			Hg Kß'2	82.43 - 83.03	0.00136 (4)
				411.80205 (17)	0.9554 (7)
				675.8836 (7)	0.00806 (7)

				1087.6842 (7)	0.00159 (3)
^{203}Hg	?$^{?}$-	46.594 (12)	Tl L	8.953 - 14.738	0.0543 (9)
			Tl Ka2	70.8325 (8)	0.0375 (4)
			Tl Ka1	72.8725 (8)	0.0633 (6)
			Tl Kß'1	82.118 - 83.115	0.0215 (4)
			Tl Kß'2	84.838 - 85.530	0.0064 (2)
				279.1952 (10)	0.8148 (8)
^{207}Bi	EC	1.18 (3) × 10^{4}	Pb L	9.18 - 15.84	0.332 (14)
			Pb Ka2	72.805	0.2169 (24)
			Pb Ka1	74.97	0.365 (4)
			Pb Kß'1	84.451 - 85.470	0.1246 (23)
			Pb Kß'2	87.238 - 88.003	0.0376 (10)
				569.698 (2)	0.9776 (3)
				1063.656 (3)	0.7458 (49)
				1770.228 (9)	0.0687 (3)
^{228}Th	? ?	698.6 (23)	Tl Ll	8.953	0.00169 (9)
with its daughters in equilibrium. ^{208}Tl emission probabilities have been adjusted for ^{212}Bi branching.			Pb L	9.184 - 15.216	0.0104 (2)
			Tl La	10.172 - 10.268	0.0326 (17)
			Tl Lß?	10.994 - 12.643	0.0272 (15)
			Ra La	12.196 - 12.339	0.0286 (15)
			Ra Lß?	13.662 - 15.447	0.047 (3)
			Tl L?	14.291 - 14.738	0.005 (2)
			Ra L?	17.848 - 18.412	0.0102 (6)
			Pb Ka2	72.8049 (8)	0.0077 (2)
			Bi Ka2	74.8157 (9)	0.107 (3)
			Pb Ka1	74.97 (9)	0.013 (3)
			Bi Ka1	77.1088 (10)	0.179 (5)
				84.373 (3)	0.0117 (5)
			Pb Kß'1	84.451 - 85.470	0.0044 (2)
			Bi Kß'1	86.835 - 87.862	0.0612 (20)
			Pb Kß'2	87.238 - 88.003	0.00134 (5)
			Bi Kß'2	89.732 - 90.522	0.0187 (7)
			^{212}Pb	115.183 (5)	0.00623 (22)
				131.612 (4)	0.00124 (6)
				215.985 (4)	0.00226 (20)
			^{212}Pb	238.632 (2)	0.436 (3)
			^{208}Tl	277.37 (3)	0.0237 (11)
			^{212}Pb	300.09 (1)	0.0318 (13)
			^{208}Tl	583.187 (2)	0.3055 (17)
			^{212}Bi	727.33 (1)	0.0674 (12)
			^{212}Bi	785.37 (9)	0.0111 (1)
			^{208}Tl	860.56 (3)	0.0448 (4)
			^{212}Bi	1620.74 (1)	0.0151 (3)
			^{208}Tl	2614.511 (10)	0.3585 (7)
^{239}Np	?$^{?}$?	2.35 (4)	Pu Ka1	99.525	0.135 (4)
Data from DDEP			Pu Ka2	103.734	0.214 (6)
				106.125 (2)	0.259 (3)
				228.183 (1)	0.1132 (22)
				277.599 (1)	0.144 (1)
	?				

^{241}Am	?	1.5785 (23) × 10^{5}	Np Ll	11.89 (2)	0.00848 (10)
			Np La	13.9 (2)	0.1303 (10)
			Np Lß?	17.81 (2)	0.1886 (15)
			Np L?	20.82 (2)	0.0481 (4)
				26.3446 (2)	0.024 (3)
				33.1963 (3)	0.00121 (3)
				59.5409 (1)	0.3578 (9)
^{243}Am	?	2.692 (8) × 10^{6}	Np Ll	11.871	0.00445 (14)
			Np La	13.761 - 13.946	0.0705 (20)
			Np L?	15.861	0.00126 (4)
			Np Lß	16.109 - 17.992	0.0818 (16)
			Np L?	20.784 - 21.491	0.0197 (4)
				43.53 (2)	0.0589 (10)
				74.66 (2)	0.672 (12)