Appendix B: Gamma- 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 have been re-evaluated and extended within the international Decay Date Evaluation Project (DDEP). After much delay, the updated data were 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 below 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 0.999 35 (15) means $0.999\,35 \pm 0.00015$.
- 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 are quoted.

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

Nuclide	Decay Mode	Half-life (d)	Emission, ID	Energy (keV)	Emission probability, P_γ
^{22}Na	EC	950.57 (23)		511.00	1.798 (2)
				1274.537 (3)	0.9994 (14)
^{24}Na	β^-	0.623 29 (6)		1368.626 (5)	0.999 935 (5)
				2754.007 (11)	0.998 72 (8)

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Table B.1 (Continued)

Nuclide	Decay Mode	Half-life (d)	Emission, ID	Energy (keV)	Emission probability, P_γ
^{46}Sc	β^-	83.79 (4)	Ti K	4.51	0.000 047 (2)
				889.271 (2)	0.999 833 (5)
				1120.537 (3)	0.999 86 (−4, +36)
^{51}Cr	EC	27.7009 (20)	V Kα	4.94–4.95	0.202 (3)
			V Kβ	5.43–5.46	0.0269 (7)
				320.0835 (4)	0.0987 (5)
^{54}Mn	EC	312.29 (26)	Cr Kα	5.405–5.415	0.002 27 (3)
			Cr Kβ	5.947	0.000 305 (7)
				834.838 (5)	0.999 746 (11)
^{55}Fe	EC	1002.7 (23)	Mn L	0.556–0.721	0.0066 (10)
			Mn Kα2	5.8877	0.0845 (14)
			Mn Kα1	5.8988	0.1656 (27)
			Mn Kβ′1	6.49–6.54	0.034 (7)
^{56}Co	EC	77.236 (26)	Fe Kα2	6.390 91(5)	0.0753 (10)
			Fe Kα1	6.403 91 (3)	0.1475 (17)
			Fe Kβ′1	7.058–7.108	0.0305 (5)
				846.7638 (19)	0.999 399 (23)
				977.363 (4)	0.014 22 (7)
				1037.8333 (24)	0.1403 (5)
				1175.0878 (22)	0.022 49 (9)
				1238.2736 (22)	0.6641 (16)
				1360.196 (4)	0.0428 (13)
				1771.327 (3)	0.1545 (4)
				2015.176 (5)	0.030 17 (14)
				2034.752 (5)	0.077 41 (13)
				2598.438 (4)	0.1696 (4)
				3009.559 (4)	0.010 38 (19)
				3201.93 (11)	0.032 03 (13)
				3253.402 (5)	0.0787 (3)
				3272.978 (6)	0.018 55 (9)
				3451.119 (4)	0.009 42 (6)
^{57}Co	EC	271.8 (5)	Fe Kα2	6.390 84	0.168 (3)
			Fe Kα1	6.403 84	0.332 (5)
			Fe Kβ′1	7.058–7.108	0.071 (2)
				14.412 95 (31)	0.0915 (17)
				122.060 65 (12)	0.8551 (6)
				136.473 56 (29)	0.1071 (15)
^{58}Co	EC	70.86 (6)	Fe Kα	6.4	0.235 (3)
			Fe Kβ	7.06	0.032 (10)
			Ni Kα	7.46–7.48	0.000 098 (3)
			Ni Kβ	8.26–8.33	0.000 013 6 (5)
				511	0.3 (4)
				810.759 (2)	0.9945 (1)
^{60}Co	β^-	1925.23 (27)	Ni Kα	7.46–7.48	0.000 098 (3)
			Ni Kβ	8.26–8.33	0.000 013 6 (5)
				1173.228 (3)	0.9985 (3)
				1332.492 (4)	0.999 826 (6)

^{65}Zn	EC	243.86 (20)	Cu Kα	8.03–8.05	0.347 (3)
			Cu Kβ	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 Kα2	10.508	0.1659 (23)
			As Kα1	10.5437	0.322 (4)
			As Kβ	11.72–11.86	0.0764 (12)
				66.0518 (8)	0.011 12 (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 Kα2	13.3359(2)	0.1716 (17)
			Rb Kα1	13.3955 (1)	0.3304 (29)
			Rb Kβ′1	14.95–15.09	0.0804 (10)
			Rb Kβ′2	15.19–15.21	0.0093 (4)
				514.0048 (22)	0.985 (4)
^{88}Y	EC	106.625 (24)	Sr Kα2	14.098(1)	0.173 (22)
			Sr Kα1	14.1652 (2)	0.332 (4)
			Sr Kβ′1	15.8359 (4)	0.0821 (12)
			Sr Kβ′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 Kα2	16.5213	0.0316 (7)
			Nb Kα1	16.6152	0.0604 (12)
			Nb Kβ′1	18.618	0.0156 (5)
			Nb Kβ′2	18.953	0.0023 (1)
				30.77 (2)	0.000 559 (16)
^{94}Nb	β^-	7.3 (9) × 10^6	—	702.639 (4)	0.998 15 (6)
				871.114 (3)	0.998 92 (3)
^{95}Nb	β^-	34.991 (6)	Mo Kα2	17.374	0.000 286 (9)
			Mo Kα1	17.479	0.000 546 (17)
			Mo Kβ′1	19.59–19.77	0.000 143 (5)
			Mo Kβ′2	19.96–20.00	0.000 022 (11)
				765.803 (6)	0.998 08 (7)
^{109}Cd	EC	461.4 (12)	Ag Kα2	21.9906(2)	0.2899 (25)
			Ag Kα1	22.1632 (1)	0.547 (4)
			Ag Kβ′1	24.912–25.146	0.1514 (18)
			Ag Kβ′2	25.457–25.512	0.0263 (10)
				88.0336 (11)	0.036 26 (20)
^{111}In	EC	2.8049 (6)	Cd Kα2	22.9843	0.236 (2)
			Cd Kα1	23.1738	0.444 (3)
			Cd Kβ′1	26.061–26.304	0.124 (4)
			Cd Kβ′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 Kα2	24.002	0.2785 (22)
			In Kα1	24.2097	0.522 (4)

Table B.1 (Continued)

Nuclide	Decay Mode	Half-life (d)	Emission, ID	Energy (keV)	Emission probability, P_γ
			In Kβ′1	27.238–27.499	0.146 (12)
			In Kβ′2	27.861–27.940	0.0284 (2)
				255.134 (10)	0.0211 (8)
				391.698 (3)	0.6494 (17)
^{125}Sb	β^-	1007.48 (21)	Te Kα2	27.202 (2)	0.191 (7)
			Te Kα1	27.4726 (2)	0.357 (12)
			Te Kβ′1	30.945–31.236	0.102 (4)
			Te Kβ′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)	0.017 83 (16)
^{125}I	EC	59.402 (14)	Te Kα2	27.202 (2)	0.397 (6)
			Te Kα1	27.4726 (2)	0.74 (11)
			Te Kβ′1	30.945–31.241	0.212 (4)
			Te Kβ′2	31.701–31.812	0.0459 (14)
				35.4919 (5)	0.0667 (17)
^{133}Ba	EC	3848.7 (12)	Cs Kα2	30.625	0.34 (4)
			Cs Kα1	30.973	0.628 (7)
			Cs Kβ′1	34.92–35.26	0.182 (2)
			Cs Kβ′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	β^-	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)	0.030 17 (12)
^{137}Cs	β^-	$1.099\ (4) \times 10^4$	Ba L	3.954–5.973	0.009 (5)
			Ba Kα2	31.8174	0.0195 (4)
			Ba Kα1	32.1939	0.0359 (7)
			Ba Kβ′1	36.31–36.67	0.010 55 (22)
			Ba Kβ′2	37.26–37.43	0.002 66 (8)
				661.657 (3)	0.8499 (20)
^{139}Ce	EC	137.642 (20)	La Kα2	33.0344 (2)	0.225 (3)
			La Kα1	33.4421 (1)	0.412 (4)
			La Kβ′1	37.721–38.095	0.123 (18)
			La Kβ′2	38.730–38.910	0.0311 (6)
				165.8575 (11)	0.799 (4)

^{152}Eu	EC β^-	4941 (7)	Sm Kα2	39.5229	0.208 (3)
			Sm Kα1	40.1186	0.377 (5)
			Sm Kβ'1	45.289–45.731	0.1178 (19)
			Sm Kβ'2	46.575–46.813	0.0304 (8)
				121.7817 (3)	0.2841 (13)
				244.6974 (8)	0.0755 (4)
			β^-	344.2785 (12)	0.2658 (12)
			β^-	411.1165 (12)	0.022 37 (10)
				443.965 (3)	0.031 25 (14)
			β^-	778.9045 (24)	0.1296 (6)
				867.38 (3)	0.042 41 (23)
				964.072 (18)	0.1462 (6)
				1085.837 (10)	0.1013 (6)
			β^-	1089.737 (5)	0.017 31 (10)
				1112.076 (3)	0.134 (6)
				1212.948 (11)	0.014 15 (9)
			β^-	1299.142 (8)	0.016 32 (9)
				1408.013 (3)	0.2085 (9)
^{154}Eu	β^-	3138.1 (14)	Gd Kα2	42.3093	0.072 (2)
			Gd Kα1	42.9967	0.13 (3)
			Gd Kβ'1	48.556–49.053	0.041 (1)
			Gd Kβ'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)	0.008 62 (8)
				1274.429 (4)	0.349 (3)
				1596.4804 (28)	0.017 83 (17)
^{155}Eu	β^-	1736 (6)	—	26.531 (21)	0.003 16 (22)
			Gd Kα2	42.3093	0.067 (13)
			Gd Kα1	42.9967	0.1205 (23)
				45.299 (10)	0.0131 (5)
			Gd Kβ'1	48.556–49.053	0.0384 (11)
			Gd Kβ'2	49.961–50.219	0.0098 (3)
				60.0086 (10)	0.0122 (5)
				86.0591 (10)	0.001 54 (17)
				86.5479 (10)	0.307 (3)
				105.3083 (10)	0.211 (6)
^{198}Au	β^-	2.695 (7)	Hg Kα2	68.8952 (12)	0.008 09 (8)
			Hg Kα1	70.8196 (12)	0.013 72 (12)
			Hg Kβ'1	79.82–80.76	0.004 66 (8)
			Hg Kβ'2	82.43–83.03	0.001 36 (4)
				411.802 05 (17)	0.9554 (7)
				675.8836 (7)	0.008 06 (7)
				1087.6842 (7)	0.001 59 (3)
^{203}Hg	β^-	46.594 (12)	Tl L	8.953–14.738	0.0543 (9)
			Tl Kα2	70.8325 (8)	0.0375 (4)

Table B.1 (Continued)

Nuclide	Decay Mode	Half-life (d)	Emission, ID	Energy (keV)	Emission probability, P_γ
			Tl Kα1	72.8725 (8)	0.0633 (6)
			Tl Kβ′1	82.118–83.115	0.0215 (4)
			Tl Kβ′2	84.838–85.530	0.0064 (2)
				279.1952 (10)	0.8148 (8)
^{207}Bi	EC	1.18 (3) $\times 10^4$	Pb L	9.18–15.84	0.332 (14)
			Pb Kα2	72.805	0.2169 (24)
			Pb Kα1	74.97	0.365 (4)
			Pb Kβ′1	84.451–85.470	0.1246 (23)
			Pb Kβ′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	α	698.6 (23)	Tl Ll	8.953	0.001 69 (9)
(With its daughters in equilibrium.			Pb L	9.184–15.216	0.0104 (2)
^{208}Tl emission probabilities have			Tl Lα	10.172–10.268	0.0326 (17)
been adjusted for ^{212}Bi branching)			Tl Lβη	10.994–12.643	0.0272 (15)
			Ra Lα	12.196–12.339	0.0286 (15)
			Ra Lβη	13.662–15.447	0.047 (3)
			Tl Lγ	14.291–14.738	0.005 (2)
			Ra Lγ	17.848–18.412	0.0102 (6)
			Pb Kα2	72.8049 (8)	0.0077 (2)
			Bi Kα2	74.8157 (9)	0.107 (3)
			Pb Kα1	74.97 (9)	0.013 (3)
			Bi Kα1	77.1088 (10)	0.179 (5)
				84.373 (3)	0.0117 (5)
			Pb Kβ′1	84.451–85.470	0.0044 (2)
			Bi Kβ′1	86.835–87.862	0.0612 (20)
			Pb Kβ′2	87.238–88.003	0.001 34 (5)
			Bi Kβ′2	89.732–90.522	0.0187 (7)
			^{212}Pb	115.183 (5)	0.006 23 (22)
				131.612 (4)	0.001 24 (6)
				215.985 (4)	0.002 26 (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	β^-	2.35 (4)	Pu Kα1	99.525	0.135 (4)
(Data from DDEP)			Pu Kα2	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	α	1.5785 (23) $\times 10^5$	Np Ll	11.89 (2)	0.008 48 (10)
			Np Lα	13.9 (2)	0.1303 (10)
			Np Lβη	17.81 (2)	0.1886 (15)
			Np Lγ	20.82 (2)	0.0481 (4)

				26.3446 (2)	0.024 (3)
				33.1963 (3)	0.001 21 (3)
				59.5409 (1)	0.3578 (9)
^{243}Am	α	2.692 (8) × 10^6	Np Ll	11.871	0.004 45 (14)
			Np Lα	13.761–13.946	0.0705 (20)
			Np Lη	15.861	0.001 26 (4)
			Np Lβ	16.109–17.992	0.0818 (16)
			Np Lγ	20.784–21.491	0.0197 (4)
				43.53 (2)	0.0589 (10)
				74.66 (2)	0.672 (12)