

Appendix D: Gamma-Ray Energies in the Detector Background and the Environment

Changes have been made to this list from the first edition (Table D.1 below). Gone are the ‘Chernobyl’ nuclides, because, under normal circumstances, these are no longer detected in background spectra. The number of gamma-rays emitted by the uranium and thorium decay series has been increased and the excitation products discussed in Chapter 13 included. Most of those are unlikely to be observed unless the count time is long or the detector very large.

Another feature removed from the list is the half-lives of the nuclides. The half-life is little help in identifying the source of a particular gamma-ray in the background. Either the emitting nuclide is of considerable half-life or, in many cases, is being supported by the decay of a longer-lived parent. In the case of excitations of the detector and its surroundings, the nuclide activity is maintained in a state of equilibrium by the flux of particles bombarding them.

The list now represents what is likely to be observed in a 200 000 s background spectrum measured by a 50 % detector housed in a typical commercial shield in a routine ground-level counting room in an ‘unremarkable’ geological area of the UK. ^{228}Ac and ^{214}Bi emit hundreds of gamma-rays with low emission probability not included in the list. From time to time, particular with very long counts, some of these may be detected.

- Peaks chosen for inclusion in the list are from:

(1) The primordial nuclides, ^{40}K , ^{235}U , ^{238}U and ^{232}Th and their daughters.

- (2) A few common reactor activation products that are often present in background.
- (3) A number of nuclides created by neutron reactions with the detector and shielding materials – the source of the neutrons involved might be cosmic or proximity to a nuclear reactor or accelerator.
- (4) The major ‘fluorescence’ X-rays from likely shielding materials – Pb, Sn, Cd and Cu.

- Data are taken from the following sources in order of priority (see Appendix A for details):

- DDEP data via the LARA database.
- IAEA XGAMMA data.
- For nuclides not listed in those sources, the on-line table of isotopes at <http://ie.lbl.gov/education/isotopes.htm>.
- For excited-state energies – US National Nuclear Data Center, ‘Levels and Gamma Search’ at <http://www.nndc.bnl.gov/nudat2/>.
- For X-ray energies and intensities – the LBNL data at <http://ie.lbl.gov/atomic/x2.pdf>.

- With the exception of a few cases where the quoted precision will not allow it, energies are rounded to two decimal places. Emission probabilities are quoted to the precision given in the source. For X-rays, the emission probabilities quoted are ‘intensity per 100 K-shell vacancies’.
- The most prominent background peaks seen in a shielded detector are in bold type.

Table D.1 Gamma-ray energies in the background and the environment

Energy	Nuclide ^a	P_{γ} (%)	Related peaks	Source of radiation
8.04	CuK α	29.3	8.91	Fluorescence from shielding
8.91	CuK β	4.7	8.04	Fluorescence from shielding
22.98	CdK α_2	24.5	23.17	Fluorescence from shielding
23.17	CdK α_1	46.1	22.98	Fluorescence from shielding
25.04	SnK α_2	24.7	25.27	Fluorescence from shielding
25.27	SnK α_1	45.7	25.04	Fluorescence from shielding
26.10	CdK β_1	7.69	22.98	Fluorescence from shielding
26.64	CdK β_2	1.98	22.98	Fluorescence from shielding
28.49	SnK β_1	7.99	25.27	Fluorescence from shielding
29.11	SnK β_2	2.19	25.27	Fluorescence from shielding
46.54	²¹⁰Pb	4.25	none	²³⁸U (²²⁶Ra) series
53.23	²¹⁴ Pb	1.060	295.22 (18.50), 351.93 (35.60)	²³⁸ U (²²⁶ Ra) series
53.44	^{73m} Ge	10.34	—	⁷² Ge(n, γ), ⁷⁴ Ge(n, 2n)
63.28	²³⁴Th	4.8	92.58 (5.58)	²³⁸U series
68.75	^{73s} Ge	—	—	⁷³ Ge(n, n') broad asymmetric peak
72.81	PbK α_2	27.7	74.97 (46.2)	Fluorescence and ²⁰⁸ Tl decay
74.82	BiKα_2	27.7	77.11 (46.2)	^{212,214}Pb decay
74.97	PbK α_1	46.2	72.81 (27.7)	Fluorescence and ²⁰⁸ Tl decay
77.11	BiKα_1	46.2	74.82 (27.7)	^{212,214}Pb decay
79.29	PoK α_1	46.1	—	Fluorescence and ^{212,214} Bi decay
81.23	²³¹ Th	0.90	—	²³⁵ U series
84.94	PbK β_1	10.7	74.97 (46.2)	Fluorescence and ²⁰⁸ Tl decay
87.30	PbK β_2	3.91	74.97 (46.2)	Fluorescence and ²⁰⁸ Tl decay
87.35	BiK β_1	10.7	74.82 (27.7)	^{212,214} Pb decay
89.78	BiK β_2	3.93	74.82 (27.7)	^{212,214} Pb decay
89.96	ThK α_2	28.1	93.35 (45.4)	²³⁵ U and ²²⁸ Ac decay
92.58	²³⁴Th	5.58	63.28 (4.8)	²³⁸U series – doublet
93.35	ThK α_1	45.4	89.96 (28.1)	²³⁵ U and ²²⁸ Ac decay
105.60	ThK β_1	10.7	93.35 (45.4)	²³⁵ U and ²²⁸ Ac decay
109.16	²³⁵ U	1.54	185.72 (57.2)	Primordial
112.81	²³⁴ Th	0.28	63.28 (4.8), 92.58 (5.58)	²³⁸ U series
122.32	²²³ Ra	1.192	269.49 (13.7)	²³⁵ U series
129.06	²²⁸ Ac	2.42	911.20 (25.8), 968.97 (15.8)	²³² Th series
139.68	^{75m} Ge	39	—	⁷⁴ Ge(n, γ), ⁷⁶ Ge(n, 2n)
143.76	²³⁵ U	10.96	—	Primordial
159.7	^{77m} Ge	10.33	—	⁷⁶ Ge(n, γ)
163.33	²³⁵ U	5.08	185.72 (57.2)	Primordial
174.95	^{71m} Ge	Very small	198.39 (\approx 100)	⁷⁰ Ge(n, γ) activation (summed-out)
185.72	²³⁵U	57.2	143.76 (10.96)	Primordial
186.21	²²⁶Ra	3.555	none	²³⁸U series
198.39	^{71m} Ge	Sum	—	⁷⁰ Ge(n, γ)

205.31	²³⁵ U	5.01	185.72 (57.2)	Primordial
209.26	²²⁸ Ac	3.89	911.20 (25.8), 968.97 (15.8)	²³² Th series
238.63	²¹²Pb	43.6	300.09 (3.18)	²³²Th series
240.89	²²⁴ Ra	4.12	—	²³² Th series
242.00	²¹⁴ Pb	7.268	295.22 (18.50), 351.93 (35.6)	²³⁸ U (²²⁶ Ra) series
269.49	²²³ Ra	13.7	122.32 (1.192)	²³⁵ U series
270.24	²²⁸ Ac	3.46	911.20 (25.8), 968.97 (15.8)	²³² Th series
277.37	²⁰⁸ Tl	2.37	583.19 (30.6), 2614.51 (35.85)	²³² Th series ^b
278.26	⁶⁴ *Cu	—	—	⁶³ Cu(n, γ), ⁶⁵ Cu(n, 2n) prompt γ
295.22	²¹⁴Pb	18.50	351.93 (35.60)	²³⁸U (²²⁶Ra) series
299.98	²²⁷ Th	2.16	—	²³⁵ U series
300.07	²³¹ Pa	2.47	—	²³⁵ U series
300.09	²¹² Pb	3.18	238.63 (43.6)	²³² Th series
328.00	²²⁸ Ac	2.95	911.20 (25.8), 968.97 (15.8)	²³² Th series
336.24	^{115m} Cd/ ^{115m} In	45.9	527.90 (27.5)	Activation of Cd (daughter of ¹¹⁵ Cd)
338.28	²²³ Ra	2.79	—	²³⁵ U series
338.32	²²⁸ Ac	11.27	911.20 (25.8), 968.97 (15.8)	²³² Th series
351.06	²¹¹ Bi	12.91	—	²³⁵ U series
351.93	²¹⁴Pb	35.60	295.22 (18.50)	²³⁸U (²²⁶Ra) series
409.46	²²⁸ Ac	1.92	911.20 (25.8), 968.97 (15.8)	²³² Th series
416.86	^{116m} In	27.7	—	¹¹⁵ In(n, γ) activation of In metal seal
447.60	⁷ Be	10.44	None	Cosmic
462.00	²¹⁴ Pb	0.213	295.22 (18.50), 351.93 (35.6)	²³⁸ U (²²⁶ Ra) series
463.00	²²⁸ Ac	4.40	911.20 (25.8), 968.97 (15.8)	²³² Th series
510.7	²⁰⁸ Tl	6.29	583.19 (30.6), 2614.51 (35.85)	²³² Th series ^b
511.00	Annihilation	—	—	Annihilation radiation (β^+)
527.90	¹¹⁵ Cd	27.5	336.2(45.9)	¹¹⁴ Cd(n, γ) activation
558.46	¹¹⁴ *Cd	—	—	¹¹³ Cd(n, γ) prompt γ
569.70	^{207m} Pb	97.87	—	²⁰⁷ Pb(n, n')
570.82	²²⁸ Ac	0.182	911.20 (25.8), 968.97 (15.8)	²³² Th series
579.2	²⁰⁷ *Pb	—	—	²⁰⁷ Pb(n, n') prompt γ
583.19	²⁰⁸Tl	30.6	2614.51 (35.85)	²³²Th series^b
595.85	⁷⁴ *Ge	—	—	⁷⁴ Ge(n, n') broad asymmetric peak
609.31	²¹⁴Bi	45.49	1120.29 (14.907), 1764.49 (15.28)	²³⁸U (²²⁶Ra) series
661.66	¹³⁷ Cs	84.99	None	Fission
669.62	⁶³ *Cu	—	—	⁶³ Cu(n, n') prompt γ
689.6	⁷² *Ge	—	—	⁷² Ge(n, n') broad asymmetric peak
726.86	²²⁸ Ac	0.62	911.20 (25.8), 968.97 (15.8)	²³² Th series
727.33	²¹² Bi	6.74	1620.74 (1.51)	²³² Th series
755.31	²²⁸ Ac	1.00	911.20 (25.8), 968.97 (15.8)	²³² Th series
768.36	²¹⁴ Bi	4.891	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
794.95	²²⁸ Ac	4.25	911.20 (25.8), 968.97 (15.8)	²³² Th series

Table D.1 (Continued)

Energy	Nuclide ^a	P _γ (%)	Related peaks	Source of radiation
803.06	²⁰⁶ Pb	—	—	²⁰⁶ Pb(n, n') prompt γ
806.17	²¹⁴ Bi	1.262	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
832.01	²¹¹ Pb	3.52	—	²³⁵ U series
835.71	²²⁸ Ac	1.61	911.20 (25.8), 968.97 (15.8)	²³² Th series
839.04	²¹⁴ Pb	0.587	295.22 (18.50), 351.93 (35.6)	²³⁸ U (²²⁶ Ra) series
843.76	²⁷ Mg	71.8	—	²⁶ Mg(n, γ) or ²⁷ Al(n, p) of encapsulation
846.77	⁵⁶ Fe	—	—	⁵⁶ Fe(n, n')
860.56	²⁰⁸ Tl	4.48	583.19 (30.6), 2614.51 (35.85)	²³² Th series ^b
911.20	²²⁸Ac	25.8	968.97 (15.8)	²³²Th series
934.06	²¹⁴ Bi	3.096	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
962.06	⁶³ Cu	—	—	⁶³ Cu(n, n') prompt γ
964.77	²²⁸ Ac	4.99	911.20 (25.8), 968.97 (15.8)	²³² Th series
968.97	²²⁸Ac	15.8	911.20 (25.8)	²³²Th series
1001.03	^{234m} Pa	1.021	—	²³⁸ U series (GRG empirical P _γ)
1014.44	²⁷ Mg	28.0	—	²⁶ Mg(n, γ) or ²⁷ Al(n, p) of encapsulation
1063.66	^{207m} Pb	88.5	—	²⁰⁷ Pb(n, n')
1097.3	¹¹⁶ In	56.2	1293.54 (84.4)	¹¹⁵ In(n, γ) activation of In metal seal
1115.56	⁶⁵ Cu	—	—	⁶⁵ Cu(n, n')
1120.29	²¹⁴ Bi	14.907	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
1155.19	²¹⁴ Bi	1.635	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
1173.23	⁶⁰ Co	99.85	1332.49 (99.98)	Activation
1238.11	²¹⁴ Bi	5.827	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
1293.54	¹¹⁶ In	84.4	1097.3 (56.2)	¹¹⁵ In(n, γ) activation of In metal seal
1332.49	⁶⁰ Co	99.98	1173.23 (99.85)	Activation
1377.67	²¹⁴ Bi	3.967	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
1407.98	²¹⁴ Bi	2.389	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
1459.14	²²⁸ Ac	0.83	911.20 (25.8), 968.97 (15.8)	²³² Th series
1460.82	⁴⁰K	10.66	None	Primordial
1588.20	²²⁸ Ac	3.22	911.20 (25.8), 968.97 (15.8)	²³² Th series
1620.74	²¹² Bi	1.51	727.33 (6.74)	²³² Th series
1630.63	²²⁸ Ac	1.51	911.20 (25.8), 968.97 (15.8)	²³² Th series
1729.60	²¹⁴ Bi	2.843	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
1764.49	²¹⁴Bi	15.28	609.31 (45.49), 1764.49 (15.28)	²³⁸U (²²⁶Ra) series
1847.42	²¹⁴ Bi	2.023	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
2204.21	²¹⁴ Bi	4.913	609.31 (45.49), 1764.49 (15.28)	²³⁸ U (²²⁶ Ra) series
2224.57	² H	—	—	¹ H(n, γ)
2614.51	²⁰⁸Tl	35.85	583.19 (30.6)	²³²Th series; ²⁰⁸Pb(n, p)^b

^a Kβ₁ X-ray peaks are always a composite with the Kβ₃, at lower energy, and Kβ₅, at higher. Kβ₂ X-rays are accompanied by Kβ₄ and KO_{2,3}, both at higher energy.

^b Emission probabilities for ²⁰⁸Tl are quoted relative to the ²²⁸Th parent and its other daughters.

^c GRG, Gordon R. Gilmore.