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.

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

Energy	Nuclide[a]	$P\gamma$ (%)	Related peaks	Source of radiation
8.04	CuKα	29.3	8.91	Fluorescence from shielding
8.91	CuKβ	4.7	8.04	Fluorescence from shielding
22.98	CdKα_2	24.5	23.17	Fluorescence from shielding
23.17	CdKα_1	46.1	22.98	Fluorescence from shielding
25.04	SnKα_2	24.7	25.27	Fluorescence from shielding
25.27	SnKα_1	45.7	25.04	Fluorescence from shielding
26.10	CdKβ_1	7.69	22.98	Fluorescence from shielding
26.64	CdKβ_2	1.98	22.98	Fluorescence from shielding
28.49	SnKβ_1	7.99	25.27	Fluorescence from shielding
29.11	SnKβ_2	2.19	25.27	Fluorescence from shielding
46.54	**^{210}Pb**	**4.25**	**none**	**^{238}U (^{226}Ra) 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	**^{234}Th**	**4.8**	**92.58 (5.58)**	**^{238}U series**
68.75	^{73*}Ge	—	—	^{73}Ge(n, n′) broad asymmetric peak
72.81	PbKα_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	PbKα_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	PoKα_1	46.1	—	Fluorescence and ^{212,214}Bi decay
81.23	^{231}Th	0.90	—	^{235}U series
84.94	PbKβ_1	10.7	74.97 (46.2)	Fluorescence and ^{208}Tl decay
87.30	PbKβ_2	3.91	74.97 (46.2)	Fluorescence and ^{208}Tl decay
87.35	BiKβ_1	10.7	74.82 (27.7)	^{212,214}Pb decay
89.78	BiKβ_2	3.93	74.82 (27.7)	^{212,214}Pb decay
89.96	ThKα_2	28.1	93.35 (45.4)	^{235}U and ^{228}Ac decay
92.58	**^{234}Th**	**5.58**	**63.28 (4.8)**	**^{238}U series – doublet**
93.35	ThKα_1	45.4	89.96 (28.1)	^{235}U and ^{228}Ac decay
105.60	ThKβ_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	**^{235}U**	**57.2**	**143.76 (10.96)**	**Primordial**
186.21	**^{226}Ra**	**3.555**	**none**	**^{238}U 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	**^{212}Pb**	**43.6**	**300.09 (3.18)**	**^{232}Th 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	**^{214}Pb**	**18.50**	**351.93 (35.60)**	**^{238}U (^{226}Ra) 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	**^{214}Pb**	**35.60**	**295.22 (18.50)**	**^{238}U (^{226}Ra) 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	**^{208}Tl**	**30.6**	**2614.51 (35.85)**	**^{232}Th series**[b]
595.85	^{74*}Ge	—	—	^{74}Ge(n, n$'$) broad asymmetric peak
609.31	**^{214}Bi**	**45.49**	**1120.29 (14.907), 1764.49 (15.28)**	**^{238}U (^{226}Ra) 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]	$P\gamma$ (%)	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	**^{228}Ac**	**25.8**	**968.97 (15.8)**	**^{232}Th 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	**^{228}Ac**	**15.8**	**911.20 (25.8)**	**^{232}Th 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	**^{40}K**	**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	**^{214}Bi**	**15.28**	**609.31 (45.49), 1764.49 (15.28)**	**^{238}U(^{226}Ra) 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	**^{208}Tl**	**35.85**	**583.19 (30.6)**	**^{232}Th series; ^{208}Pb(n, p)**[b]

[a] $K\beta_1$ X-ray peaks are always a composite with the $K\beta_3$, at lower energy, and $K\beta_5$, at higher. $K\beta_2$ X-rays are accompanied by $K\beta_4$ and $KO_{2,3}$, both at higher energy.
[b] Emission probabilities for ^{208}Tl are quoted relative to the ^{228}Th parent and its other daughters.
[c] GRG, Gordon R. Gilmore.