

Appendix D

Gamma-ray energies in the detector background and the environment.

Changes have been made to this list from the first edition. 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 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 200 000 second 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 online 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 D1 Gamma-ray energies in the background and the environment

Energy	Nuclide	P?%	Related peaks	Source of radiation
8.04	CuK?	29.3	8.91	fluorescence from shielding
8.91	CuK?	4.7	8.04	fluorescence from shielding
22.98	CdK? γ	24.5	23.17	fluorescence from shielding
23.17	CdK? γ	46.1	22.98	fluorescence from shielding
25.04	SnK? γ	24.7	25.27	fluorescence from shielding
25.27	SnK? γ	45.7	25.04	fluorescence from shielding
26.10	CdK? γ	7.69	22.98	fluorescence from shielding
26.64	CdK? γ	1.98	22.98	fluorescence from shielding
28.49	SnK? γ	7.99	25.27	fluorescence from shielding
29.11	SnK? γ	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	$^{73\text{m}}\text{Ge}$	10.34		$^{72}\text{Ge}(\text{n},?)$, $^{74}\text{Ge}(\text{n},2\text{n})$
63.28	^{234}Th	4.8	92.58 (5.58)	^{238}U series
68.75	^{73}Ge			$^{73}\text{Ge}(\text{n},\text{n}')$ broad asymmetric peak
72.81	PbK? γ	27.7	74.97 (46.2)	fluorescence, and ^{208}Tl decay
74.82	BiK? γ	27.7	77.11 (46.2)	$^{212,214}\text{Pb}$ decay
74.97	PbK? γ	46.2	72.81 (27.7)	fluorescence, and ^{208}Tl decay
77.11	BiK? γ	46.2	74.82 (27.7)	$^{212,214}\text{Pb}$ decay
79.29	PoK? γ	46.1		fluorescence, and $^{212,214}\text{Bi}$ decay
81.23	^{231}Th	0.90		^{235}U series
84.94	PbK? γ	10.7	74.97 (46.2)	fluorescence, and ^{208}Tl decay
87.30	PbK? γ ,	3.91	74.97 (46.2)	fluorescence, and ^{208}Tl decay
87.35	BiK? γ	10.7	74.82 (27.7)	$^{212,214}\text{Pb}$ decay
89.78	BiK? γ	3.93	74.82 (27.7)	$^{212,214}\text{Pb}$ decay
89.96	ThK? γ	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	ThK? γ	45.4	89.96 (28.1)	^{235}U and ^{228}Ac decay
105.60	ThK? γ	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	$^{75\text{m}}\text{Ge}$	39		$^{74}\text{Ge}(\text{n},?)$, $^{76}\text{Ge}(\text{n},2\text{n})$
143.76	^{235}U	10.96		primordial
159.7	$^{77\text{m}}\text{Ge}$	10.33		$^{76}\text{Ge}(\text{n},?)$
163.33	^{235}U	5.08	185.72 (57.2)	primordial
174.95	$^{71\text{m}}\text{Ge}$	v. small	198.39 (~ 100)	$^{70}\text{Ge}(\text{n},?)$ 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	$^{71\text{m}}\text{Ge}$	sum		$^{72}\text{Ge}(\text{n},?)$, $^{74}\text{Ge}(\text{n},2\text{n})$
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 – Note1

278.26	^{64}Cu			$^{63}\text{Cu}(n,?)$, $^{65}\text{Cu}(n,2n)$ prompt ?
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	$^{115\text{m}}\text{Cd}/^{115\text{m}}\text{In}$	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	$^{116\text{m}}\text{In}$	27.7		$^{115}\text{In}(n,?)$ activation of In metal seal
447.60	^7Be	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 – Note1
511.00	Annihilation			Annihilation radiation (? +)
527.90	^{115}Cd	27.5	336.2(45.9)	$^{114}\text{Cd}(n,?)$ activation
558.46	^{114}Cd			$^{113}\text{Cd}(n,?)$ prompt ?
569.70	$^{207\text{m}}\text{Pb}$	97.87		$^{207}\text{Pb}(n,n')$
570.82	^{228}Ac	0.182	911.20 (25.8), 968.97 (15.8)	^{232}Th series
579.2	^{207}Pb			$^{207}\text{Pb}(n,n')$ prompt ?
583.19	^{208}Tl	30.6	2614.51 (35.85)	^{232}Th series – Note1
595.85	^{74}Ge			$^{74}\text{Ge}(n,n')$ 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			$^{63}\text{Cu}(n,n')$ prompt ?
689.6	^{72}Ge			$^{72}\text{Ge}(n,n')$ 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
803.06	^{206}Pb			$^{206}\text{Pb}(n,n')$ prompt ?
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		$^{26}\text{Mg}(n,?)$ or $^{27}\text{Al}(n,p)$ of encapsulation
846.77	^{56}Fe			$^{56}\text{Fe}(n,n')$
860.56	^{208}Tl	4.48	583.19 (30.6), 2614.51 (35.85)	^{232}Th series – Note1
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			$^{63}\text{Cu}(n,n')$ prompt ?
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	$^{234\text{m}}\text{Pa}$	1.021		^{238}U series (GRG empirical P?)
1014.44	^{27}Mg	28.0		$^{26}\text{Mg}(n,?)$ or $^{27}\text{Al}(n,p)$ 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,?) 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,?) 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,?)
2614.51	²⁰⁸Tl	35.85	583.19 (30.6)		²³²Th series; ²⁰⁸Pb(n,p) – Note1

Note1: emission probabilities for ²⁰⁸Tl are quoted relative to the ²²⁸Th parent and its other daughters

Note2: K_γX-ray peaks are always a composite with the K_γ, at lower energy, and K_γ, at higher. K_γX-rays are accompanied by K_γ and KO_{2,3}, both at higher energy.