

5.4 GAMMA

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5.4.1 SCOPE

Presented here is a tabulation of γ rays and nuclides that are common to environmental analyses. These data may be useful for interpreting either field or laboratory measurements.

As an aid in verifying nuclide identifications, two additional γ -ray lines are included when possible as E2 and E3.

The following special notations are used in the table:

Symbol	Meaning
%	ratio of γ -rays to disintegrations.
X	indicates X-ray.
KX, LX	sum of K or L X-rays.
D	indicates a doublet.
T	indicates a triplet.
*	indicates annihilation radiation.
Long	in half-life column is used for all members of the primordial series, % refers to U or Th decays

REFERENCE

Browne, E., R. B. Firestone and V. S. Shirley (Editors)
Table of Radioactive Isotopes
John Wiley and Sons, Inc., New York (1986)

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
14.4	⁵⁷ Co	9.5	272D	122.1	85.5	136.5	10.7	Activation
26.3	²⁴¹ Am	2.4	433Y	59.5	35.7	17.0LX	38.7	²⁴¹ Pu
30.0	¹⁴⁰ Ba	13.6	12.8D	162.7	6.2	304.9	4.3	Fallout
39.6	¹²⁹ I	7.5	1.6E7	30.0KX	70.8			Fission
39.9	²¹² Bi	1.1	Long	727.3	6.7	1620.7	1.5	²³² Th
40.6	⁹⁹ Mo	1.1	65.9H	18.3X	3.2	140.5	3.5	Fallout
46.5	²¹⁰ Pb	4.1	22.3Y					²³⁸ U
49.8	¹³² Te	14.4	78.2H	30.0KX	70.9	111.9	1.9	Fallout
53.2	¹³³ Ba	2.2	10.5Y	81.0	34.2	31.0KX	101.3	Activation
59.5	²³⁷ U	32.8	6.75D	101.1	26.0	208.0	22.0	Fallout
59.5	²⁴¹ Am	35.7	433Y	26.3	2.4	17.0LX	38.7	²⁴¹ Pu
60.0	¹⁵⁵ Eu	1.1	4.96Y	86.5	30.4	105.3	20.6	Fallout
61.5	²³⁹ Np	1.0	2.36D	14.3LX	56.1	101.0KX	38.9	Fallout
63.3	²³⁴ Th	3.8	Long	92.6D	5.4			²³⁸ U
66.9	¹³⁶ Cs	12.5	13.2D	34.0KX	17.6	86.4	6.3	Fission
74.8X	²¹⁴ Pb	6.5	Long	77.1X	11.0	87.3X	3.9	²³⁸ U
74.8X	²¹² Pb	10.5	Long	77.1X	17.7	87.2X	6.3	²³² Th
75.0X	²⁰⁸ Tl	3.6	Long	72.8X	2.1	84.8X	1.3	²³² Th
77.1X	²¹⁴ Pb	11.0	Long	74.8X	6.5	87.2X	3.9	²³⁸ U
77.1X	²¹² Pb	17.7	Long	74.8X	10.5	87.2X	6.3	²³² Th
79.6	¹³³ Ba	3.2	10.5Y	53.2	2.2			Activation
80.1	¹⁴⁴ Ce	1.1	285D	133.5	11.1	696.5	1.3	Fallout
80.2	¹³¹ I	2.6	8.04D	364.5	81.2	284.3	6.1	Fission
81.0	¹³³ Ba	34.2	10.5Y	276.4	7.3	79.6	3.2	Activation
81.0	¹³³ Xe	37.0	5.25D	79.6	0.2	31.0KX	40.1	Fission
84.3X	²²⁸ Th	1.2	1.91Y	12.3X	3.1			²³² Th
86.4	¹³⁶ Cs	6.3	13.2D	66.9	12.5	153.3	7.5	Fission
86.5	¹⁵⁵ Eu	34.0	4.96Y	105.3	20.6	60.0	1.1	Fallout
87.2X	²¹⁴ Pb	3.9	Long	77.1X	11.0	241.9	7.5	²³⁸ U
87.2X	²¹² Pb	6.3	Long	238.6	43.6	77.1X	17.7	²³² Th
88.0	¹⁰⁹ Cd	3.6	463D	23.0KX	99.8			Activation
90.0X	²²⁸ Ac	3.4	Long	93.4X	5.6	99.6	1.3	²³² Th
91.1	¹⁴⁷ Nd	28.0	11.0D	38.5KX	37.4	319.4	2.0	Fallout
92.6D	²³⁴ Th	5.4	Long	63.3	3.8			²³⁸ U
93.4X	²²⁸ Ac	5.6	Long	90.0X	3.4	99.6	1.3	²³² Th
97.1	²³⁷ U	16.0	6.75D	101.0	26.0	208.0	22.0	Fallout
99.6	²²⁸ Ac	1.3	Long	129.0	2.9	209.4	4.1	²³² Th

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
101.1	²³⁷ U	26.0	6.75D	59.5	32.8	208.0	22.0	Fallout
105.3	¹⁵⁵ Eu	20.6	4.96Y	86.5	34.0	60.0	1.1	Fallout
105.4X	²²⁸ Ac	2.0	Long	99.6	1.3	129.0	2.9	²³² Th
106.1	²³⁹ Np	22.7	2.36D	61.5	1.0	117.0KX	11.6	Fallout
109.2	²³⁵ U	1.5	70E7Y	93.4KX	5.5	143.8	10.5	Natural
111.9	¹³² Te	1.9	78.2H	49.8	14.4	116.4	1.9	Fallout
113.9	²³⁷ U	25.0	6.75D	101.1	26.0	208.0	22.0	Fallout
116.3	¹³² Te	1.9	78.2H	111.9	1.9	228.3	88.2	Fallout
121.8	¹⁵² Eu	28.4	13.3Y	344.3	26.6	244.7	7.5	Fallout
122.1	⁵⁷ Co	85.5	273D	136.5	10.7	14.4	9.5	Activation
123.1	¹⁵⁴ Eu	40.5	8.8Y	248.0	6.6	591.8	4.8	Fallout
127.2	¹⁰¹ Rh	73.0	3.3Y	198.0	70.8	325.2	13.4	Fallout
129.0	²²⁸ Ac	2.9	Long	99.6	1.3	209.4	4.1	²³² Th
133.5	¹⁴⁴ Ce	11.1	285D	696.5	1.3	80.1	1.1	Fallout
136.5	⁵⁷ Co	10.7	272D	122.1	85.5	14.4	9.5	Activation
138.0	¹³⁸ Cs	1.5	32.2M	227.7	1.5	462.8	30.7	¹³⁸ Xe
140.5	⁹⁹ Mo	3.5	65.9H	40.6	1.1	181.1	6.1	Fallout
140.5	^{99m} Tc	87.2	6.01H	18.4X	6.1	20.6X	1.2	⁹⁹ Mo
143.8	²³⁵ U	10.5	70E7Y	109.2	1.5	163.4	4.7	Natural
145.4	¹⁴¹ C	48.4	32.5D	37.0KX	17.4			Fission
151.2	^{85m} Kr	75.2	4.48H	304.9	13.7			Fission
153.3	¹³⁶ Cs	7.5	13.2D	86.4	6.3	164.0	4.6	Fission
153.9	¹³⁸ Xe	6.0	14.1M	242.7	3.5	258.4	31.5	Fission
162.7	¹⁴⁰ Ba	6.2	12.8D	304.9	4.3	30.0	13.6	Fallout
163.4	²³⁵ U	4.7	70E7Y	143.8	10.5	185.7	53.0	Natural
164.0	¹³⁶ Cs	4.6	13.2D	153.3	7.5	176.6	13.6	Fission
165.9	¹³⁹ Ce	79.9	138D	34.0KX	79.5			Activation
166.0	⁸⁸ Kr	3.1	2.84H	196.3	26.0	362.3	2.3	Fission
176.3	¹²⁵ Sb	6.8	2.73Y	427.9	29.4	380.4	1.5	Fallout
176.6	¹³⁶ Cs	13.6	13.2D	164.0	4.6	273.7	12.7	Fission
181.1	⁹⁹ Mo	6.1	65.9H	140.5	3.5	366.4	1.2	Fallout
185.7	²³⁵ U	53.0	70E7Y	143.8	10.5	205.3	4.7	Natural
186.1	²²⁶ Ra	3.3	1600Y					Natural
192.3	⁵⁹ Fe	3.1	44.5D	1099.3	56.5	1291.6	43.2	Activation
196.3	⁸⁸ Kr	26.0	2.84H	362.3	2.3	166.0	3.1	Fission
198.0	¹⁰¹ Rh	70.8	3.3Y	127.2	73.0	325.2	13.4	Fallout
205.3	²³⁵ U	4.7	70E7Y	185.7	53.0	143.8	10.5	Natural
208.0	²³⁷ U	22.0	6.75D	59.5	32.8	101.1	26.0	Fallout

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
209.4	²²⁸ Ac	4.1	Long	129.0	2.9	270.3	3.8	²³² Th
227.7	¹³⁸ Cs	1.5	32.2M	138.0	1.5	409.0	4.7	¹³⁸ Xe
228.2	²³⁹ Np	10.7	2.36D	106.1	22.7	277.6	14.2	Fallout
228.3	¹³² Te	88.2	78.2H	116.4	1.9	111.9	1.9	Fallout
233.2	^{133m} Xe	10.3	2.19D	30.0KX	56.3			Fission
238.6	²¹² Pb	43.6	Long	300.0	3.3			²³² Th
240.8	²²⁴ Ra	3.9	Long					²³² Th
241.9	²¹⁴ Pb	7.5	Long	295.1	19.2	352.0	37.1	²³⁸ U
242.7	¹³⁸ Xe	3.5	14.1M	153.9	6.0	258.4	31.5	Fission
244.7	¹⁵² Eu	7.5	13.3Y	121.8	28.4	344.3	26.6	Fallout
248.0	¹⁵⁴ Eu	6.6	8.8Y	123.1	40.5	591.8	4.8	Fallout
249.8	¹³⁵ Xe	90.0	9.10H	608.2	2.9	31.0KX	5.2	Fission
258.4	¹³⁸ Xe	31.5	14.1M	242.7	3.5	396.6	6.3	Fission
262.8	¹³² I	1.4	2.28H	505.9	5.0	522.7	16.1	¹³² Te
270.3	²²⁸ Ac	3.8	Long	209.4	4.1	328.0	3.5	²³² Th
273.7	¹³⁶ Cs	12.7	13.2D	176.6	13.6	340.6	48.6	Fission
276.4	¹³³ Ba	7.1	10.5Y	302.9	18.4	81.0	34.2	Activation
277.3	²⁰⁸ Tl	2.4	Long	510.6	7.8	583.0	30.9	²³² Th
277.6	²³⁹ Np	14.2	2.36D	228.2	10.7	315.9	1.6	Fallout
279.2	²⁰³ Hg	81.5	46.6D	74.6X	12.9			Fallout
284.3	¹³¹ I	6.1	8.04D	364.5	81.2	80.2	2.6	Fission
295.1	²¹⁴ Pb	19.2	Long	351.9	37.1	241.9	7.5	²³⁸ U
300.0	²¹² Pb	3.3	Long	238.6	43.6			²³² Th
302.9	¹³³ Ba	18.4	10.5Y	276.4	7.1	356.0	62.2	Activation
304.9	¹⁴⁰ Ba	4.3	12.8D	162.7	6.2	423.7	3.1	Fallout
304.9	^{85m} Kr	13.7	4.48H	151.2	75.1			Fission
315.9	²³⁹ Np	1.6	2.36D	277.6	14.2	334.3	2.1	Fallout
319.4	¹⁴⁷ Nd	2.0	11.0D	439.9	1.2	91.1	28.0	Fallout
320.1	⁵¹ Cr	9.8	27.7D					Activation
325.2	¹⁰¹ Rh	13.4	3.3Y	127.2	73.0	198.0	70.8	Fallout
328.0	²²⁸ Ac	3.5	Long	270.3	3.8	338.4	12.4	²³² Th
328.8	¹⁴⁰ La	20.7	40.3H	432.5	3.0	487.0	45.9	Fallout
334.3	²³⁹ Np	2.1	2.36D	315.9	1.6	61.5	1.0	Fallout
338.4	²²⁸ Ac	12.4	Long	328.0	3.5	409.6	2.2	²³² Th
340.6	¹³⁶ Cs	48.6	13.2D	273.7	12.7	818.6	99.8	Fission
344.3	¹⁵² Eu	26.6	13.3Y	244.7	7.5	411.1	2.2	Fallout
352.0	²¹⁴ Pb	37.1	Long	241.9	7.5	295.1	19.2	²³⁸ U
356.0	¹³³ Ba	62.2	10.5Y	302.9	18.4	383.8	8.9	Activation

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
362.3	⁸⁸ Kr	2.3	2.84H	196.3	26.0	834.9	13.0	Fission
364.5	¹³¹ I	81.2	8.04D	637.0	7.3	284.3	6.1	Fission
366.4	⁹⁹ Mo	1.2	65.9H	181.1	6.1	739.5	12.1	Fallout
380.4	¹²⁵ Sb	1.5	2.73Y	176.3	6.8	427.9	29.4	Fallout
383.8	¹³³ Ba	8.9	10.5Y	356.0	62.2	302.9	18.4	Activation
396.6	¹³⁸ Xe	6.3	14.1M	258.4	31.5	401.5	2.2	Fission
401.5	¹³⁸ Xe	2.2	14.1M	434.6	20.3	396.6	6.3	Fission
402.6	⁸⁷ Kr	49.6	76.3M	845.5	7.3	673.9	1.9	Fission
409.0	¹³⁸ Cs	4.7	32.2M	227.7	1.5	462.8	30.7	¹³⁸ Xe
409.6	²²⁸ Ac	2.2	Long	338.4	12.4	463.1	4.6	²³² Th
411.1	¹⁵² Eu	2.2	13.3Y	344.3	26.6	444.0D	3.1	Fallout
415.3	¹⁰² Rh	2.1	2.89Y	418.5	10.6	420.4	3.2	Fallout
418.5	¹⁰² Rh	10.6	2.89Y	415.3	2.1	420.4	3.2	Fallout
420.4	¹⁰² Rh	3.2	2.89Y	418.5	10.6	475.1	95.0	Fallout
423.7	¹⁴⁰ Ba	3.1	12.8D	437.6	1.9	304.9	4.3	Fallout
427.9	¹²⁵ Sb	29.4	2.73Y	380.4	1.5	463.4	10.5	Fallout
432.5	¹⁴⁰ La	3.0	40.3H	487.0	45.9	328.8	20.7	Fallout
434.6	¹³⁸ Xe	20.3	14.1M	401.5	2.2	1114.3	1.5	Fission
437.6	¹⁴⁰ Ba	1.9	12.8D	537.3	24.4	423.7	3.1	Fallout
439.9	¹⁴⁷ Nd	1.2	11.0D	319.4	2.0	531.0	13.1	Fallout
444.0D	¹⁵² Eu	3.1	13.3Y	411.1	2.2	778.9	13.0	Fallout
446.8	^{110m} Ag	3.8	250D	657.8	94.6	620.4	2.8	Activation
462.8	¹³⁸ Cs	30.7	32.2M	547.0	10.8	409.0	4.7	¹³⁸ Xe
463.1	²²⁸ Ac	4.6	Long	409.6	2.2	755.3	1.3	²³² Th
463.4	¹²⁵ Sb	10.5	2.73Y	427.9	29.4	600.5	17.8	Fallout
468.7	^{102m} Rh	2.9	207D	475.1	46.0	556.6	1.9	Fallout
475.1	^{102m} Rh	46.0	207D	468.7	2.9	556.6	1.9	Fallout
475.1	¹⁰² Rh	95.0	2.89Y	628.1	8.5	420.5	3.2	Fallout
475.4	¹³⁴ Cs	1.5	2.06Y	563.2	8.4	569.3	15.4	Fission
477.6	⁷ Be	10.3	53.2D					Cosmic
487.1	¹⁴⁰ La	45.5	40.2H	751.9	4.3	432.6	2.9	Fallout
497.1	¹⁰³ Ru	89.5	39.6D	610.3	5.6			Fallout
505.9	¹³² I	5.0	2.28H	262.8	1.4	522.7	16.1	¹³² Te
510.6	²⁰⁸ Tl	7.8	Long	277.3	2.4	583.0	30.9	²³² Th
511.0	⁶⁵ Zn	2.9	244D	1115.5	50.8			Activation
511.0	⁵⁸ Co	30.0	70.9D	810.8	99.5			Activation

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
511.0	²² Na	180.8	2.60Y	1274.5	99.9			Cosmic
511.9	¹⁰⁶ Ru	20.7	372D	1050.4	1.5	621.9	9.8	Fallout
514.0	⁸⁵ Sr	99.3	64.8D	13.4KX	50.6	15.0KX	8.7	Activation
522.7	¹³² I	16.1	2.28H	505.9	5.0	547.0	1.3	¹³² Te
526.6	^{135m} Xe	81.2	15.7M	30.0KX	14.0			Fission
531.0	¹⁴⁷ Nd	13.1	11.0D	439.9	1.2	319.4	2.0	Fallout
537.3	¹⁴⁰ Ba	24.4	12.8D	437.6	1.9	423.7	3.1	Fallout
547.0	¹³⁸ Cs	10.8	32.2M	462.8	30.7	871.7	5.1	¹³⁸ Xe
547.0	¹³² I	1.3	2.28H	522.7	16.1	621.2	~2.0	¹³² Te
556.6	^{102m} Rh	1.9	207D	475.1	46.0	628.1	5.5	Fallout
563.2	¹³⁴ Cs	8.4	2.06Y	475.4	1.5	569.3	15.4	Fission
569.3	¹³⁴ Cs	15.4	2.06Y	563.2	8.4	604.7	97.6	Fission
569.2	²⁰⁷ Pb	97.8	32.2Y	1063.1	74.9	1769.7	6.9	Fallout
583.0	²⁰⁸ Tl	30.9	Long	510.6	7.8	860.3	4.3	²³² Th
591.8	¹⁵⁴ Eu	4.8	8.8Y	248.0	6.6	692.5	1.7	Fallout
600.5	¹²⁵ Sb	17.8	2.73Y	463.4	10.5	606.6	5.0	Fallout
602.7	¹²⁴ Sb	97.8	60.2D	645.9	7.4	709.3	1.4	Fallout
604.7	¹³⁴ Cs	97.6	2.06Y	795.9	85.4	569.3	15.4	Fission
606.6	¹²⁵ Sb	5.0	2.73Y	600.5	17.8	635.9	11.3	Fallout
608.2	¹³⁵ Xe	2.9	9.10H	249.8	90.0	31.6KX	5.2	Fission
609.3	²¹⁴ Pb	46.1	Long	665.4	1.6	768.4	4.9	²³⁸ U
610.3	¹⁰³ Ru	5.6	39.3D	497.1	88.7			Fallout
620.4	^{110m} Ag	2.8	250D	657.8	94.6	446.8	3.8	Activation
621.2	¹³² I	~2.0	2.28H	547.1	1.3	630.3	13.8	¹³² Te
621.9	¹⁰⁶ Ru	9.8	372D	511.9	20.7	1050.4	1.5	Fallout
628.1	^{102m} Rh	5.5	207D	556.6	1.9	1103.2	2.9	Fallout
628.1	¹⁰² Rh	8.5	~2.9Y	475.1	95.0	631.3	56.0	Fallout
630.3	¹³² I	13.8	2.28H	621.2	~2.0	650.6	2.7	¹³² Te
631.3	¹⁰² Rh	56.0	~2.9Y	628.1	8.5	692.4	1.8	Fallout
635.9	¹²⁵ Sb	11.3	2.73Y	606.6	5.0	671.4	1.8	Fallout
637.0	¹³¹ I	7.3	8.04D	364.5	81.2	722.9	1.8	Fission
645.9	¹²⁴ Sb	7.4	60.2D	602.7	97.8	709.3	1.4	Fallout
650.6	¹³² I	2.7	2.28H	630.3	13.8	667.7	98.7	¹³² Te
657.8	^{110m} Ag	94.6	250D	620.4	2.8	677.6	10.4	Activation
661.7	¹³⁷ Cs	85.2	30.0Y	33.0KX	7.1			Fallout
665.4	²¹⁴ Pb	1.6	Long	609.3	46.1	768.4	4.9	²³⁸ U
667.7	¹³² I	98.7	2.28H	650.6	2.7	669.9	4.9	¹³² Te

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
669.9	¹³² I	4.9	2.28H	667.7	98.7	671.6	5.2	¹³² Te
671.4	¹²⁵ Sb	1.8	2.73Y	635.9	11.3	606.6	5.0	Fallout
671.6	¹³² I	5.2	2.28H	669.9	4.9	727.D	5.4	¹³² Te
673.9	⁸⁷ Kr	1.9	76.3M	845.5	7.3	402.6	49.6	Fission
677.6	^{110m} Ag	10.4	250D	657.8	94.6	687.0	6.4	Activation
687.0	^{110m} Ag	6.4	250D	677.6	10.4	706.7	16.4	Activation
692.4	¹⁰² Rh	1.8	~2.9Y	631.3	56.0	695.6	2.7	Fallout
692.5	¹⁵⁴ Eu	1.7	8.8Y	591.8	4.8	723.4	19.7	Fallout
695.6	¹⁰² Rh	2.7	~2.9Y	692.4	1.8	697.6	45.7	Fallout
696.5	¹⁴⁴ Ce	1.3	285D	133.5	11.1	80.1	1.1	Fallout
697.6	¹⁰² Rh	45.7	~2.9Y	766.9	34.0	695.6	2.7	Fallout
706.7	^{110m} Ag	16.4	250D	687.0	6.4	744.3	4.7	Activation
709.3	¹²⁴ Sb	1.4	60.2D	645.9	7.4	713.8	2.3	Fallout
713.8	¹²⁴ Sb	2.3	60.2D	709.3	1.4	722.8	10.9	Fallout
722.8	¹²⁴ Sb	10.9	60.2D	713.8	2.3	968.2	1.9	Fallout
722.9	¹³¹ I	1.8	8.04D	364.5	81.2	637.0	7.3	Fission
723.4	¹⁵⁴ Eu	19.7	8.8Y	692.5	1.7	756.8	4.3	Fallout
724.2	⁹⁵ Zr	44.1	64.0D	756.7	54.5			Fallout
727.0D	¹³² I	5.4	2.28H	671.6	5.2	728.7	1.1	¹³² Te
727.3	²¹² Bi	6.7	Long	39.9	1.1	1620.7	1.5	²³² Th
728.7	¹³² I	1.1	2.28H	727.0D	5.4	772.7	76.2	¹³² Te
739.5	⁹⁹ Mo	12.1	65.9H	366.4	1.2	777.9	4.4	Fallout
744.3	^{110m} Ag	4.7	250D	706.7	16.4	763.9	22.3	Activation
751.7	¹⁴⁰ La	4.3	40.3H	487.0	45.9	815.8	23.6	Fallout
755.3	²²⁸ Ac	1.3	Long	463.1	4.6	772.3	1.1	²³² Th
756.7	⁹⁵ Zr	54.5	64.0D	724.2	44.1			Fallout
756.8	¹⁵⁴ Eu	4.3	8.8Y	723.4	19.7	873.2	11.5	Fallout
763.1	²⁰⁸ Tl	0.6	Long	583.0	30.9	860.3	4.3	²³² Th
763.9	^{110m} Ag	22.3	250D	744.3	4.7	818.0	7.3	Activation
765.8	⁹⁵ Nb	99.8	35.0D					Fallout
766.9	¹⁰² Rh	34.0	~2.9Y	697.6	45.7	1046.6	34.0	Fallout
768.4	²¹⁴ Bi	5.0	Long	665.6	1.6	786.4D	0.3	²³⁸ U
772.3	²²⁸ Ac	1.1	Long	755.3	1.3	794.8	4.6	²³² Th
772.7	¹³² I	76.2	2.28H	728.7	1.1	780.1	1.2	¹³² Te
777.9	⁹⁹ Mo	4.4	65.9H	739.5	12.1	366.4	1.2	Fallout
778.9	¹⁵² Eu	13.0	13.3Y	444.0D	3.1	867.4	4.2	Fallout
780.1	¹³² I	1.2	2.28H	772.7	76.2	809.8	2.9	¹³² Te

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
785.5	²¹² Bi	1.1	Long	727.3	6.7	1620.7	1.5	²³² Th
786.4	²¹⁴ Bi	0.3	Long	768.4	4.9	806.2	1.2	²³⁸ U
794.8	²²⁸ Ac	4.6	Long	772.3	1.1	830.6	0.6	²³² Th
795.8	¹³⁴ Cs	85.4	2.06Y	604.7	97.8	801.9	8.7	Fission
802.0	¹³⁴ Cs	8.7	2.06Y	795.9	85.4	1038.6	1.0	Fission
806.2	²¹⁴ Bi	1.2	Long	786.4	0.3	934.0	3.2	²³⁸ U
809.8	¹³² I	2.9	2.28H	780.1	1.2	812.3	5.6	¹³² Te
810.8	⁵⁸ Co	99.5	70.9D	511.0	30.0			Activation
812.3	¹³² I	5.6	2.28H	809.8	2.9	877.2	1.1	¹³² Te
815.8	¹⁴⁰ La	23.6	40.3H	751.7	4.3	867.8	5.6	Fallout
818.0	^{110m} Ag	7.3	250D	763.9	22.3	884.7	72.7	Activation
818.6	¹³⁶ Cs	99.8	13.2D	340.6	48.6	1048.1	79.7	Fission
830.6	²²⁸ Ac	0.6	Long	794.8	4.6	835.6	1.7	²³² Th
834.8	⁵⁴ Mn	100.0	312.2D					Fallout
834.9	⁸⁸ Kr	13.0	2.84H	362.3	2.3	985.8D	1.3	Fission
835.6	²²⁸ Ac	1.7	Long	830.6	0.6	840.4	0.9	²³² Th
840.4	²²⁸ Ac	0.9	Long	835.6	1.7	904.3	0.9	²³² Th
845.5	⁸⁷ Kr	7.3	76.3M	673.9	1.9	1175.5	1.1	Fission
860.3	²⁰⁸ Tl	4.3	Long	2614.4	35.8	583.0	30.9	²³² Th
867.4	¹⁵² Eu	4.2	13.3Y	778.9	13.0	964.1	14.5	Fallout
867.8	¹⁴⁰ La	5.6	40.3H	815.8	23.6	919.6	2.7	Fallout
871.7	¹³⁸ Cs	5.1	32.2M	547.0	10.8	1009.8	29.8	¹³⁸ Xe
873.2	¹⁵⁴ Eu	11.5	8.8Y	756.8	4.3	996.3	10.3	Fallout
877.2	¹³² I	1.1	2.28H	812.3	5.6	954.6	18.1	¹³² Te
884.7	^{110m} Ag	72.7	250D	818.0	7.3	937.5	34.4	Activation
898.1	⁸⁸ Y	92.7	107D	1836.1	99.4			Activation
898.0	⁸⁸ Rb	14.1	17.8M	1836.1	21.4	2677.9	2.0	⁸⁸ Kr
904.3	²²⁸ Ac	0.9	Long	840.4	0.9	911.2	29.0	²³² Th
911.2	²²⁸ Ac	29.0	Long	966.0D	23.2	840.4	0.9	²³² Th
919.6	¹⁴⁰ La	2.7	40.3H	867.8	5.6	925.2	7.0	Fallout
925.2	¹⁴⁰ La	7.1	40.3H	487.0	45.9	919.6	2.7	Fallout
934.0	²¹⁴ Bi	3.2	Long	1120.3	15.0	806.2	1.2	²³⁸ U
937.5	^{110m} Ag	34.4	250D	1384.3	24.3	884.7	72.7	Activation
954.6	¹³² I	18.1	2.28H	877.2	1.1	1136.2	3.0	¹³² Te
964.1	¹⁵² Eu	14.5	13.3Y	1085.9	9.9	867.4	4.2	Fallout
964.6	²²⁸ Ac	5.8	Long	969.0	17.4	911.2	29.0	²³² Th
968.2	¹²⁴ Sb	1.9	60.2D	1045.1	1.9	722.8	10.9	Fallout

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
969.0	²²⁸ Ac	17.4	Long	911.2	29.0	1459.2	1.1	²³² Th
985.8	⁸⁸ Kr	1.3	2.84H	1141.4	1.3	834.9	13.0	Fission
996.3	¹⁵⁴ Eu	10.3	8.8Y	1004.8	17.9	873.2	11.5	Fallout
1001.0	^{234m} Pa	0.7	Long	766.4	0.2	742.8	0.1	²³⁸ U
1004.8	¹⁵⁴ Eu	17.9	8.8Y	1274.5	35.5	996.3	10.3	Fallout
1009.8	¹³⁸ Cs	29.8	32.2M	1147.3	1.2	871.7	5.1	¹³⁸ Xe
1038.6	¹³⁴ Cs	1.0	2.06Y	1167.9	1.8	802.0	8.7	Fission
1045.1	¹²⁴ Sb	1.9	60.2D	1325.5	1.6	968.2	1.9	Fallout
1046.6	¹⁰² Rh	33.0	2.9Y	1103.2	4.4	766.9	34.0	Fallout
1048.1	¹³⁶ Cs	79.7	13.2D	818.6	99.8	1235.4	19.8	Fission
1050.4	¹⁰⁶ Ru	1.5	372D	511.9	20.7	621.9	9.8	Fallout
1063.1	²⁰⁷ Bi	74.9	32.2Y	569.2	97.8	1769.7	6.9	Fallout
1085.9	¹⁵² Eu	9.9	13.3Y	1112.1	13.6	964.1	14.	Fallout
1099.3	⁵⁹ Fe	56.5	44.5D	1291.6	43.2	192.3	3.1	Fallout
1103.2	^{102m} Rh	2.9	207D	556.6	1.9	628.1	5.5	Fallout
1103.2	¹⁰² Rh	4.4	2.9Y	1046.6	33.0	1112.9	18.9	Fallout
1112.1	¹⁵² Eu	13.6	13.3Y	1085.9	9.9	1212.9	1.4	Fallout
1112.9	¹⁰² Rh	18.	2.9Y	1046.6	33.0	1103.2	4.4	Fallout
1114.3	¹³⁸ Xe	1.5	14.1M	1768.4	16.7	434.6	20.3	Fission
1115.5	⁶⁵ Zn	50.8	244D	511.0	2.9			Activation
1120.3	²¹⁴ Bi	15.0	Long	1155.2	1.7	934.0	3.2	²³⁸ U
1136.2	¹³² I	3.0	2.28H	954.6	18.1	1143.6	1.4	¹³² Te
1141.4	⁸⁸ Kr	1.3	2.84H	1369.4	1.5	985.8D	1.3	Fission
1143.6	¹³² I	1.4	2.28H	1136.2	3.0	1173.3	1.1	¹³² Te
1147.3	¹³⁸ Cs	1.2	32.2M	1009.8	29.8	1343.6	1.1	¹³⁸ Xe
1155.2	²¹⁴ Bi	1.7	Long	1238.1	5.9	1120.3	15.0	²³⁸ U
1167.9	¹³⁴ Cs	1.8	2.06Y	1038.6	1.0	1365.2	3.0	Fission
1173.2	⁶⁰ Co	99.9	5.27Y	1332.5	100.0			Activation
1173.3	¹³² I	1.1	2.28H	1143.6	1.4	1290.8	1.1	¹³² Te
1175.5	⁸⁷ Kr	1.1	76.3M	1740.6	2.0	845.5	7.3	Fission
1212.9	¹⁵² Eu	1.4	13.3Y	1112.1	13.6	1299.2	1.6	Fallout
1235.4	¹³⁶ Cs	19.8	13.2D	818.6	99.8	1048.1	79.7	Fission
1238.1	²¹⁴ Bi	5.9	Long	1155.2	1.7	1281.0	1.5	²³⁸ U
1274.5	²² Na	99.9	2.60Y	511.0	181.0			Cosmic
1274.5	¹⁵⁴ Eu	35.5	8.8Y	1004.8	17.9	1596.6	1.8	Fallout
1281.0	²¹⁴ Bi	1.5	Long	1238.1	5.9	1377.7	4.0	²³⁸ U
1290.8	¹³² I	1.1	2.28H	1173.3	1.1	1295.4	2.0	¹³² Te
1291.6	⁵⁹ Fe	43.2	44.5D	1099.3	56.5	192.3	3.1	Activation

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
1293.6	⁴¹ Ar	99.2	1.83H					Activation
1295.4	¹³² I	2.0	2.28H	1290.8	1.1	1372.1	2.5	¹³² Te
1299.2	¹⁵² Eu	1.6	13.3Y	1212.9	1.4	1408.0	20.8	Fallout
1325.5	¹²⁴ Sb	1.6	60.2D	1045.1	1.9	1368.2	2.7	Fallout
1332.5	⁶⁰ Co	100.0	5.27Y	1173.2	99.9			Activation
1343.6	¹³⁸ Cs	1.1	32.2M	1147.3	1.2	1435.8	76.3	¹³⁸ Xe
1365.2	¹³⁴ Cs	3.0	2.06Y	1167.9	1.8	1038.6	1.0	Fission
1368.2	¹²⁴ Sb	2.7	60.2D	1325.5	1.6	1436.7	1.3	Fallout
1368.6	²⁴ Na	100.0	14.7H	2754.1	99.9			Activation
1369.4	⁸⁸ Kr	1.5	2.84H	1141.4	1.3	1518.4	2.2	Fission
1372.1	¹³² I	2.5	2.28H	1295.4	2.0	1398.6	7.1	¹³² Te
1377.7	²¹⁴ Bi	4.0	Long	1281.0	1.5	1401.5	1.4	²³⁸ U
1384.3	^{110m} Ag	24.3	250D	1475.8	4.0	937.5	34.4	Activation
1398.6	¹³² I	7.1	2.28H	1372.1	2.5	1442.5	1.4	¹³² Te
1401.5	²¹⁴ Bi	1.4	Long	1377.7	4.0	1408.0	2.5	²³⁸ U
1408.0	²¹⁴ Bi	2.5	Long	1401.5	1.4	1509.2	2.2	²³⁸ U
1408.0	¹⁵² Eu	20.8	13.3Y	1299.2	1.6	1212.9	1.4	Fallout
1435.8	¹³⁸ Cs	76.3	32.2M	1343.6	1.1	2218.0	15.2	¹³⁸ Xe
1436.6	¹²⁴ Sb	1.3	60.2D	1368.2	2.7	1691.0	47.1	Fallout
1442.5	¹³² I	1.4	2.28H	1398.6	7.1	1921.1	1.2	¹³² Te
1459.2	²²⁸ Ac	1.1	Long	1499.0D	1.6	969.0	17.4	²³² Th
1460.8	⁴⁰ K	10.7	1.3E9					Natural
1475.8	^{110m} Ag	4.0	250D	1384.3	24.3	1505.0	13.0	Activation
1499.0D	²²⁸ Ac	1.6	Long	1459.2	1.1	1588.2	3.6	²³² Th
1505.0	^{110m} Ag	13.0	250D	1475.8	4.0	1562.3	1.0	Activation
1509.2	²¹⁴ Bi	2.2	Long	1408.0	2.5	1661.3	1.2	²³⁸ U
1518.4	⁸⁸ Kr	2.2	2.84H	1369.4	1.5	1529.8	10.9	Fission
1529.8	⁸⁸ Kr	10.9	2.84H	1518.4	2.2	2029.9	4.5	Fission
1588.2	²²⁸ Ac	3.6	Long	1499.0D	1.6	1630.5	2.0	²³² Th
1596.5	¹⁴⁰ La	95.4	40.3H	487.0	45.9	2521.7	3.4	Fallout
1596.6	¹⁵⁴ Eu	1.7	8.8Y	1274.5	35.5	1004.8	17.9	Fallout
1620.7	²¹² Bi	1.5	Long	727.3	6.7	785.5	1.1	²³² Th
1630.5	²²⁸ Ac	2.0	Long	1588.2	3.6	1499.0D	1.6	²³² Th
1661.3	²¹⁴ Bi	1.2	Long	1509.2	2.2	1729.6	3.1	²³⁸ U
1691.0	¹²⁴ Sb	47.1	60.2D	2090.9	5.5	1436.7	1.3	Fallout

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
1729.6	²¹⁴ Bi	3.1	Long	1764.5	15.9	1661.3	1.2	²³⁸ U
1740.6	⁸⁷ Kr	2.0	76.3M	1175.5	1.1	2011.9	2.9	Fission
1764.5	²¹⁴ Bi	15.9	Long	1729.6	3.1	1847.4	2.1	²³⁸ U
1768.4	¹³⁸ Xe	16.7	14.1M	1114.3	1.5	1850.9	1.4	Fission
1769.7	²⁰⁷ Bi	6.9	32.2Y	1063.1	74.9	569.2	97.8	Fallout
1836.1	⁸⁸ Rb	21.4	17.8M	2677.9	2.0	898.1	14.1	⁸⁸ Kr
1836.1	⁸⁸ Y	99.4	107D	898.1	92.7			Other
1847.4	²¹⁴ Bi	2.1	Long	1764.5	15.9	2118.5	1.2	²³⁸ U
1850.9	¹³⁸ Xe	1.4	14.1M	1768.4	16.7	2004.8	5.4	Fission
1921.1	¹³² I	1.2	2.28H	1442.5	1.4	2002.4	1.1	¹³² Te
2002.4	¹³² I	1.1	2.28H	1921.1	1.2	1442.5	1.4	¹³² Te
2004.8	¹³⁸ Xe	5.4	14.1M	1850.9	1.4	2015.9	12.3	Fission
2011.9	⁸⁷ Kr	2.9	76.3M	1740.6	2.0	2556.0D	13.1	Fission
2015.9	¹³⁸ Xe	12.3	14.1M	2004.8	5.4	2079.3	1.4	Fission
2029.9	⁸⁸ Kr	4.5	2.84H	1529.8	10.9	2035.5	3.7	Fission
2035.5	⁸⁸ Kr	3.7	2.84H	2029.9	4.5	2195.8	13.2	Fission
2079.3	¹³⁸ Xe	1.4	14.1M	2015.9	12.3	2252.3	2.3	Fission
2090.9	¹²⁴ Sb	5.5	60.2D	1436.6	1.3	1691.0	47.1	Fallout
2118.5	²¹⁴ Bi	1.2	Long	1847.4	2.1	2204.1	5.0	²³⁸ U
2195.8	⁸⁸ Kr	13.2	2.84H	2035.5	3.7	2231.8	3.4	Fission
2204.1	²¹⁴ Bi	5.0	Long	2447.7	1.6	2118.5	1.2	²³⁸ U
2217.8	¹³⁸ Cs	15.2	32.2M	1435.8	76.3	2639.4	7.6	¹³⁸ Xe
2231.8	⁸⁸ Kr	3.4	2.84H	2195.8	13.2	2392.1	34.6	Fission
2252.3	¹³⁸ Xe	2.3	14.1M	2079.3	1.4	2015.9	12.3	Fission
2392.1	⁸⁸ Kr	34.6	2.84H	2231.8	3.4	2195.8	13.2	Fission
2447.7	²¹⁴ Bi	1.6	Long	2204.1	5.0	2118.5	1.2	²³⁸ U
2521.7	¹⁴⁰ La	3.4	40.3H	1596.5	96.4	487.0	45.9	Fallout
2556D	⁸⁷ Kr	13.1	76.3M	2011.9	2.9	1740.6	2.0	Fission
2614.4	²⁰⁸ Tl	35.8	Long	860.3	4.3	583.0	30.9	²³² Th
2639.4	¹³⁸ Cs	7.6	32.2M	2217.8	15.2	1435.8	76.	¹³⁸ Xe

TABLE OF γ RAYS AND NUCLIDES COMMON TO ENVIRONMENTAL ANALYSES (Cont'd)

Energy	Nuclide	%	T _{1/2}	E2	%	E3	%	Origin
2677.9	⁸⁸ Rb	2.0	17.8M	1836.1	21.4	898.1	14.1	⁸⁸ Kr
2754.0	²⁴ Na	99.9	14.7H	1368.6	100.0			Activation
6129.2	¹⁶ N	68.8	7.13S	7115.2	4.7			Other
7115.2	¹⁶ N	4.7	7.13S	6129.2	68.8			Other

5.5 X-RAY

Contact Person(s) : Colin G. Sanderson

5.5.1 SCOPE

This section presents a table of X-ray energies which are useful for radiochemical analyses.

A number of nuclides emit X-rays as part of their decay scheme. These X-rays may be counted with Ar proportional counters with Ge planar or n-type Ge co-axial detectors or with thin crystal NaI(Tl) scintillation counters. In both cases, spectral measurements can be made and both qualitative and quantitative information obtained on the sample.

K Shell vacancies are filled by a higher shell election. In the process an energy $E_k - E_x$ is liberated either as an X-ray or an Auger electron. The most important X-ray transitions are designated as,

$$K_{\alpha 1} = K - L_{III}$$

$$K_{\alpha 2} = K - L_{II}$$

$$K_{\beta 1} = K - M_{III}$$

$$K_{\beta 2} = K - N_{III}$$

$$K_{\beta 3} = K - M_{II}$$

$$K_{\beta 4} = K - N_{II}$$

$$K_{\beta 5} = K - M_{IV}$$

With moderate resolution only $K_{\beta 1}'$ and $K_{\beta 2}'$ can be resolved,

$$K_{\beta 1}' = K_{\beta 1} + K_{\beta 3} + K_{\beta 5}$$

$$K_{\beta 2}' = K_{\beta 2} + K_{\beta 4}$$

The same is true for K_{α}

$$K_{\alpha} = K_{\alpha 1} + K_{\alpha 2}$$

The present table lists the values for K_{α} , $K_{\beta 1}'$ and $K_{\beta 2}'$. Electron binding energies used in this table were based on the tabulations of Wapstra et al. (1959) and Siegbahn (1965).

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Wapstra, A. H., G. J. Nijgh and R. Van Lieshout
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Z	Element	K_{α}	Energy (keV)	
			$K_{\beta 1}$	$K_{\beta 2}$
3	Li	0.05		
4	Be	0.11		
5	B	0.18		
6	C	0.28		
7	N	0.40		
8	O	0.53		
9	F	0.68		
10	Ne	0.85		
11	Na	1.04		
12	Mg	1.25		
13	Al	1.49		
14	Si	1.74		
15	P	2.01		
16	S	2.31		
17	Cl	2.62		
18	Ar	2.96	3.19	
19	K	3.31	3.59	
20	Ca	3.69	4.01	
21	Sc	4.09	4.46	
22	Ti	4.51	4.93	
23	V	4.95	5.43	
24	Cr	5.42	5.95	
25	Mn	5.90	6.49	
26	Fe	6.40	7.06	
27	Co	6.93	7.65	
28	Ni	7.47	8.26	
29	Cu	8.03	8.91	
30	Zn	8.63	9.57	
31	Ga	9.24	10.3	
32	Ge	9.88	11.1	

Z	Element	K_{α}	Energy (keV)	$K_{\beta 2}$
			$K_{\beta 1}$	
33	As	10.5	11.7	
34	Si	11.2	12.5	
35	Br	11.9	13.3	
36	Kr	12.6	14.1	
37	Rb	13.4	15.0	
38	Sr	14.1	15.8	16.1
39	Y	14.9	16.7	17.0
40	Zr	15.7	17.7	18.0
41	Nb	16.6	18.6	19.0
42	Mo	17.4	19.6	20.0
43	Te	18.3	20.6	21.0
44	Ru	19.2	21.6	22.1
45	Rh	20.2	22.7	23.2
46	Pd	21.1	23.8	24.3
47	Ag	22.1	24.9	25.5
48	Cd	23.1	26.1	26.6
49	In	24.1	27.3	27.9
50	Sn	25.1	28.4	29.1
51	Sb	26.3	29.7	30.4
52	Te	27.3	31.0	31.7
53	I	28.5	32.3	33.0
54	Xe	29.6	33.6	34.4
55	Cs	30.8	34.9	35.8
56	Ba	32.0	36.4	37.2
57	La	33.3	37.8	38.7
58	Ce	34.5	39.3	40.2
59	Pr	35.9	40.7	41.8
60	Nd	37.2	42.3	43.3
61	Pm	38.5	43.8	44.9
62	Sm	39.8	45.4	46.6

Z	Element	K_{α}	Energy (keV)	$K_{\beta 2}$
			$K_{\beta 1}$	
63	Eu	41.3	47.0	48.2
64	Cd	42.7	48.7	49.9
65	Tb	44.1	50.4	51.7
66	Dy	45.6	52.1	53.4
67	Ho	47.1	53.8	55.3
68	Er	48.7	55.6	57.1
69	Tm	50.3	57.5	59.0
70	Yb	51.9	59.4	60.9
71	Lu	53.5	61.3	62.9
72	Hf	55.2	63.2	64.9
73	Ta	57.1	65.2	67.0
74	W	58.8	67.2	69.1
75	Re	60.6	69.3	71.2
76	Os	62.4	71.4	73.4
77	Ir	64.3	73.6	75.6
78	Pt	66.2	75.7	77.8
79	Au	68.2	78.0	80.1
80	Hg	70.1	80.1	82.5
81	Tl	72.1	82.4	84.9
82	Pb	74.2	84.7	87.3
83	Bi	76.3	87.1	89.8
84	Po	78.4	89.6	92.3
85	At	80.5	92.7	95.0
86	Rn	82.8	94.7	97.5
87	Fr	85.0	97.3	100.2
88	Ra	87.3	99.9	103.0
89	Ac	89.7	102.6	105.7

Z	Element	K _α	Energy (keV)	K _{β2}
			K _{β1}	
90	Th	92.1	105.3	108.6
91	Pa	94.5	108.1	111.4
92	U	97.0	111.0	114.5
93	Np	99.5	113.9	117.5
94	Pu	102.1	116.9	120.5
95	Am	104.7	119.9	123.6
96	Cm	107.5	123.0	126.9
97	Bk	110.2	126.2	130.2
98	Cf	113.0	129.4	133.5
99	Es	115.9	132.7	136.9
100	Fm	118.8	136.0	140.4
101	Md	122.8	139.4	144.9
102	No	124.8	142.7	147.5
103	Lw	127.9	146.2	151.2
104		130.5	149.7	154.5