

5. RADIONUCLIDE DATA

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5. RADIONUCLIDE DATA

5.1 OVERVIEW

This section describes current radionuclide measurement techniques in use at EML and their associated data. A radionuclide is identified by its three principal characteristics: half-life, type of emission, and energy of the emission. Sometimes overlooked in the process are progeny radionuclides with their own particular characteristics.

In the 1960s, routine measurements were being performed at EML for α , β , and γ radionuclides. Measurements in both the Frisch grid ion chamber and the solid-state surface barrier detection systems were used to identify α energies in sources in properly calibrated systems. Contained in this section is a table of α emitters by energy, especially linked to the charts of the naturally occurring radionuclides, which assists in radionuclide identification in separated samples and in radionuclide purity checks.

Routine measurement of β emitters is performed on counters designed at EML. These counters have a very low background count rate due to anticoincidence counting techniques. The overall counting efficiencies are comparable to proportional counters. Radiochemical purity is typically assessed by decay measurements.

Use of NaI(Tl) γ spectrometry detection systems provides poorly resolved spectra compared with the Ge(Li) and intrinsic Ge systems presently in use. The resolution of these present systems require sophisticated computer algorithms to identify energies associated with particular radionuclides. It is most important that the energies and the branching ratios used at any facility be documented and a table of γ emitters in the environment is included.

Contained in the natural decay series are charts of three natural radionuclide series and the man-made americium series. Pertinent data are included in these charts.

5.2 ALPHA

Contact Person(s) : Isabel M. Fisenne

5.2.1 SCOPE

The tables on α emitters by atomic number and by energy have been developed for internal use at EML. The present tables are revisions compiled from the data given in Table of Radioactive Isotopes by Browne et al. (1986).

REFERENCE

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

ALPHA EMITTERS BY ATOMIC NUMBER

Most short-lived nuclides are included as principal members of
 the natural decay series (see Section 5.6)

Radionuclide	$t_{1/2}$	Isotopic Abundance (%)	α Emission (when not 100%)	E_{MeV}
60 ¹⁴⁴ Nd	2.1 x 10 ¹⁵ y	23.8		1.83
62 ¹⁴⁷ Sm	1.03 x 10 ⁸ y			2.46
62 ¹⁴⁷ Sm	1.06 x 10 ¹¹ y	15.0		2.233
64 ¹⁴⁸ Gd	75.3 y			3.183
64 ¹⁵² Gd	1.79 x 10 ⁶ y			2.726
64 ¹⁵² Gd	1.08 x 10 ¹⁴ y	0.20		2.14
66 ¹⁵⁴ Dy	2.9 x 10 ⁶ y			2.872
72 ¹⁷⁴ Hf	2.0 x 10 ¹⁵ y	0.162		2.50
76 ¹⁸⁶ Os	2.0 x 10 ¹⁵ y	1.58		2.80
78 ¹⁹⁰ Pt	6.0 x 10 ¹¹ y	<0.02		3.175
83 ^{210m} Bi	3.00 x 10 ⁶ y			4.946(55.5%), 4.908(38.8%), 4.569(3.8%)
83 ²¹¹ Bi(AcC)	2.14 m			6.623(84%), 6.279(16%)
83 ²¹² Bi(ThC')	1.0092 h		39.54%	6.090(26.8%), 6.051(70.2%), 5.768(1.7%), 5.707(1.1%)
84 ²⁰⁶ Po	8.83 d		5.45%	5.223
84 ²⁰⁸ Po	2.898 y			5.116
84 ²⁰⁹ Po	102.0 y			4.866
84 ²¹⁰ Po (RaF)	138.376 d			5.305
84 ²¹² Po (ThC')	298.0 ns			8.784
84 ²¹³ Po	4.28 μ s			8.375
84 ²¹⁴ Po(RaC')	163.69 μ s			7.687
84 ²¹⁵ Po(AcC)	1.780 ms			7.386
84 ²¹⁶ Po(ThA)	150.0 ms			6.779
84 ²¹⁸ Po(RaA)	3.05 m			6.003

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

Radionuclide	$t_{1/2}$	Isotopic Abundance (%)	α Emission (when not 100%)	E_{MeV}
85 ²¹¹ At	7.215 h		41.7%	5.868
85 ²¹⁷ At	32.3 ms			7.067
86 ²¹⁹ Rn(²¹⁹ Em)	3.96 s			6.819(80.9%), 6.553(12.2%), 6.425(7.5%)
86 ²²⁰ Rn(²²⁰ Em, Tn)	55.6 s			6.288
86 ²²² Rn(²²² Em, Rn)	3.825 d			5.490
87 ²²¹ Fr	4.9 m			6.341(83.4%), 6.243(1.3%), 6.127(15.1%)
88 ²²³ Ra(AcX)	11.43 d			5.747(9.5%), 5.716(52.5%), 5.607(24.2%), 5.540(9.2%), others
88 ²²⁴ Ra(ThX)	3.66 d			5.686(95.1%), 5.449(4.9%)
88 ²²⁶ Ra	1600.0 y			4.784(94.5%), 4.601(5.6%)
89 ²²⁵ Ac	10.0 d			5.829(51.6%), 5.793(18.1%), 5.791(8.6%), 5.731(10%), 5.637(4.5%), others
90 ²²⁷ Th(Rd Ac)	18.718 d			6.038%(24.5%), 5.978(23.4%), 5.757(20.3%), 5.714(4.9%), 5.710(8.2%), others
90 ²²⁸ Th(Rd Th)	1.913 y			5.423(72.7%), 5.341(26.7%)
90 ²²⁹ Th	7340.0 y			5.050(5.2%), 4.968(6.0%), 4.901(10.2%), 4.845(56.2%), 4.814(9.3%), others
90 ²³⁰ Th(Io)	7.54 x 10 ⁴ y			4.688(76.3%), 4.621(23.4%)
90 ²³² Th(Th)	1.405 x 10 ¹⁰ y	100.		4.010(77%), 3.952(23%)
91 ²³¹ Pa(Pa)	3.276 x 10 ⁴ y			5.059(11%), 5.029(20%), 5.013(25.4%), 4.951(22.8%), 4.734(8.4%), others
92 ²³⁰ U	20.8 d			5.889(67.4%), 5.818(32%), others
92 ²³² U	68.9 y			5.320(68.6%), 5.264(31.2%)
92 ²³³ U	1.592 x 10 ⁵ y			4.825(84.4%), 4.783(13.2%), others
92 ²³⁴ U(UII)	2.454 x 10 ⁵ y	0.0055		4.776(72.5%), 4.724(27.5%)

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

Radionuclide	$t_{1/2}$	Isotopic Abundance (%)	α Emission (when not 100%)	E_{MeV}
92 ²³⁵ U(AcU)	7.037 x 10 ⁸ y	0.7200		4.597(5%), 4.556(4.2%), 4.395(55%), 4.364(~11%), 4.218(5.7%), others
92 ²³⁶ U	2.342 x 10 ⁷ y			4.494(74%), 4.445(26%)
92 ²³⁸ U(UI)	4.468 x 10 ⁹ y	99.2745		4.196(77%), 4.147(23%)
93 ²³⁷ Np	2.14 x 10 ⁶ y			4.873(2.6%), 4.988(47%), 4.772(25%), 4.766(8%), 4.640(6.2%), others
94 ²³⁶ Pu	2.851 y			5.768(68.1%), 5.721(31.7%)
94 ²³⁸ Pu	87.74 y			5.499(71.6%), 5.456(28.3%)
94 ²³⁹ Pu	2.411 x 10 ⁴ y			5.156(73.2%), 5.143(15.1%), 5.105(10.6%)
94 ²⁴⁰ Pu	6563.0 y			5.168(73.5%), 5.124(26.4%)
94 ²⁴² Pu	3.763 x 10 ⁵ y			4.901(78%), 4.856(22.4%)
94 ²⁴⁴ Pu	8.26 x 10 ⁷ y			4.589(80.5%), 4.546(19.4%)
95 ²⁴¹ Am	432.7 y			5.486(85.2%), 5.443(12.8%), 5.388(1.4%)
95 ²⁴³ Am	7380.0 y			5.277(88%), 5.234(11%), 5.180(1.1%)
96 ²⁴⁰ Cm	27.0 d			6.291(70.6%), 6.248(28.8%)
96 ²⁴² Cm	162.94 d			6.113(74%), 6.070(25%)
96 ²⁴³ Cm	28.5 y			6.067(1.5%), 6.059(5%), 5.992(6.5%), 5.786(73.3%), 5.742(10.6%), others
96 ²⁴⁴ Cm	18.11 y			5.805(76.4%), 5.763(23.6%), others
96 ²⁴⁵ Cm	8500.0 y			5.362(93.2%), 5.304(5.0%), others
96 ²⁴⁶ Cm	4730.0 y			5.386(79%), 5.343(21%)
96 ²⁴⁷ Cm	1.56 x 10 ⁷ y			5.266(13.8%), 5.210(5.7%), 4.869(71%), 4.818(4.7%), others

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

Radionuclide	$t_{1/2}$	Isotopic Abundance (%)	α Emission (when not 100%)	E_{MeV}
96 ²⁴⁸ Cm*	3.40 x 10 ⁵ y		91.7%	5.078(81.9%), 5.035(18%)
97 ²⁴⁷ Bk	1380.0 y			5.795(5.5%), 5.712(17%), 5.687(13%), 5.532(45%), 5.501(7%), others
98 ²⁴⁶ Cf	1.487 d			6.750(78.0%), 6.709(21.8%)
98 ²⁴⁸ Cf	334.0 d			6.262(83.0%), 6.220(17.0%)
98 ²⁴⁹ Cf	350.6 y			6.194(2.2%), 6.140(1.1%), 5.945(4%), 5.903(2.8%), 5.812(84.4%), others
98 ²⁵⁰ Cf	13.09 y			6.031(84.5%), 5.989(15.1%)
98 ²⁵¹ Cf	898.0 y			6.074(2.7%), 6.014(11.6%), 5.851(27%), 5.812(4.2%), 5.677(35%), others
98 ²⁵² Cf*	2.646 y		96.9%	6.118(84%), 6.076(15.8%)
99 ²⁵² Es*	1.291 y		76.4%	6.632(79.8%), 6.562(13.5%), 6.483(2.2%), others
99 ²⁵³ Es	20.4 d			6.633(89.8%), 6.592(6.6%), others
99 ²⁵⁴ Es	275.7 d			6.427(93.1%), 6.416(1.8%), 6.357(2.6%)
99 ²⁵⁵ Es*	39.8 d		8.0%	6.300(87.5%), 6.260(10.0%), 6.213(2.5%)
100 ²⁵² Fm	1.058 d			7.04(~85%), 6.999(~15%)
100 ²⁵³ Fm*	3.00 d		12.0%	7.024(6.7%), 6.943(42.7%), 6.901(9.8%), 6.847(8.5%), 6.674(23.3%), others
100 ²⁵⁵ Fm	20.07 h			7.022(93.4%), 6.963(5.0%), others
100 ²⁵⁷ Fm	100.5 d			6.696(3.4%), 6.519(93.5%), 6.441(2.0%)
101 ²⁵⁸ Md	55.4 d			6.790(28%), 6.716(72%)

*Relative α -intensity normalized to 100 α -decays.

ALPHA EMITTERS BY ENERGY (MeV)*

3.8-4.0	4.0-4.2	4.2-4.4	4.4-4.6	4.6-4.8	4.8-5.0	5.0-5.2	5.2-5.4	5.4-5.6	5.6-5.8	5.8-6.0	6.0-6.2	6.2-6.4
Uranium Series:												
	²³⁸ U			²³⁴ U		²¹⁰ Po		²²² Rn			²¹⁸ Po	
				²³⁰ Th								
				²²⁶ Ra								
Thorium Series:												
²³² Th	²³² Th						²²⁸ Th	²²⁸ Th	²¹² Bi	²¹² Bi	²²⁰ Rn	
								²²⁴ Ra	²²⁴ Ra			
Actinium Series:												
		²³⁵ U	²³⁵ U	²³¹ Pa	²³¹ Pa	²³¹ Pa			²²³ Ra			
									²²⁷ Th	²²⁷ Th	²²⁷ Th	
Americium Series:												
				²³⁷ Np			²⁴¹ Am	²⁴¹ Am	²²⁵ Ac	²²⁵ Ac	²²¹ Fr	²²¹ Fr
				²³³ U	²³³ U							
					²²⁹ Th	²²⁹ Th						
All Emitters:												
²³² Th	²³² Th	²³⁵ U	^{210m} Bi	²²⁶ Ra	²⁰⁹ Po	²⁰⁸ Po	²⁰⁶ Po	²²² Rn	²¹² Bi	²¹¹ At	²¹² Bi	²¹¹ Bi
	²³⁸ U		²³⁵ U	²³⁰ Th	^{210m} Bi	²²⁹ Th	²¹⁰ Po	²²³ Ra	²²³ Ra	²²⁵ Ac	²¹⁸ Po	²²⁰ Rn
			²³⁶ U	²³¹ Pa	²²⁹ Th	²³¹ Pa	²²⁸ Th	²²⁴ Ra	²²⁴ Ra	²²⁷ Th	²²¹ Fr	²²¹ Fr
			²⁴⁴ Pu	²³³ U	²³¹ Pa	²³⁹ Pu	²³² U	²²⁸ Th	²²⁵ Ac	²³⁰ U	²²⁷ Th	²⁴⁰ Cm
				²³⁴ U	²³³ U	²⁴⁰ Pu	²⁴¹ Am	²³⁸ Pu	²²⁷ Th	²⁴³ Cm	²⁴² Cm	²⁴⁸ Cf
				²³⁷ Np	²³⁷ Np	²⁴³ Am	²⁴³ Am	²⁴¹ Am	²³⁶ Pu	²⁴⁴ Cm	²⁴³ Cm	²⁵⁴ Es
					²⁴² Pu	²⁴⁸ Cm	²⁴⁵ Cm	²⁴⁷ Bk	²⁴³ Cm	²⁴⁹ Cf	²⁴⁹ Cf	²⁵⁵ Es
					²⁴⁷ Cm		²⁴⁶ Cm		²⁴⁴ Cm	²⁵⁰ Cf	²⁵⁰ Cf	
							²⁴⁷ Cm		²⁴⁷ Bk	²⁵¹ Cf	²⁵¹ Cf	
									²⁵¹ Cf		²⁵² Cf	

*A listing may denote more than one energy.

ALPHA EMITTERS BY ENERGY (MeV) -- (Cont'd)

6.4-6.6	6.6-.68	6.8-7.0	7.0-7.2	7.2-7.4	7.4-7.6	7.6-7.8	7.8-8.0	8.0-8.2	8.2-8.4	8.4-.86	8.6-8.8
Uranium Series:											
						²¹⁴ Po					
Thorium Series:											
	²¹⁶ Po										²¹² Po
Actinium Series:											
²¹⁹ Rn	²¹¹ Bi	²¹⁹ Rn		²¹⁵ Po							
Americium Series:											
			²¹⁷ At						²¹³ Po		
All Emmitters:											
²¹⁹ Rn	²¹¹ Bi	²¹⁹ Rn	²¹⁷ At	²¹⁵ Po		²¹⁴ Po			²¹³ Po		²¹² Po
²⁵² Es	²¹⁶ Po	²⁵² Fm	²⁵² Fm								
²⁵³ Es	²⁴⁶ Cf	²⁵³ Fm	²⁵³ Fm								
²⁵⁴ Es	²⁵² Es	²⁵⁵ Fm	²⁵⁵ Fm								
²⁵⁷ Fm	²⁵³ Es										
	²⁵³ Fm										
	²⁵⁷ Fm										
	²⁵⁸ Md										

SPECIFIC ACTIVITY OF SELECTED ALPHA EMITTERS
 (in order of ascending atomic numbers)

Nuclide	$t_{1/2}$ (y)	mCi mg ⁻¹	MBq mg ⁻¹
^{210m} Bi	3.00 x 10 ⁶	5.7 x 10 ⁻⁴	2.11 x 10 ⁻²
²⁰⁸ Po	2.898	593.1	2.19 x 10 ⁴
²⁰⁹ Po	102	16.8	6.22 x 10 ²
²²⁶ Ra	1600	0.989	3.66 x 10 ¹
²²⁸ Th	1.913	819.6	3.03 x 10 ⁴
²²⁹ Th	7340	0.213	7.88
²³⁰ Th	7.54 x 10 ⁴	2.062 x 10 ⁻²	7.63 x 10 ⁻¹
²³² Th	1.405 x 10 ¹⁰	1.0969 x 10 ⁻⁷	4.06 x 10 ⁻⁶
²³¹ Pa	3.276 x 10 ⁴	4.724 x 10 ⁻²	1.75
²³² U	68.9	22.4	8.29 x 10 ²
²³³ U	1.592 x 10 ⁵	9.64 x 10 ⁻³	3.57 x 10 ⁻¹
²³⁴ U	2.454 x 10 ⁵	6.225 x 10 ⁻³	2.30 x 10 ⁻¹
²³⁵ U	7.037 x 10 ⁸	1.922 x 10 ⁻⁶	7.11 x 10 ⁻⁵
²³⁶ U	2.342 x 10 ⁷	6.508 x 10 ⁻⁵	2.41 x 10 ⁻³
²³⁸ U	4.468 x 10 ⁹	3.36237 x 10 ⁻⁷	1.24 x 10 ⁻⁵
²³⁷ Np	2.140 x 10 ⁶	7.05 x 10 ⁻⁴	2.61 x 10 ⁻²
²³⁶ Pu	2.851	531.3	1.97 x 10 ⁴
²³⁸ Pu	87.74	17.119	6.33 x 10 ²
²³⁹ Pu	2.411 x 10 ⁴	6.204 x 10 ⁻²	2.30
²⁴⁰ Pu	6563	0.22696	8.40

SPECIFIC ACTIVITY OF SELECTED ALPHA EMITTERS (Cont'd)
 (in order of ascending atomic numbers)

Nuclide	$t_{1/2}$ (y)	mCi mg ⁻¹	MBq mg ⁻¹
²⁴² Pu	3.763×10^5	3.962×10^{-3}	1.45×10^{-1}
²⁴¹ Am	432.7	3.428	1.27×10^2
²⁴³ Am	7380	0.1993	7.37
²⁴² Cm	4.461×10^{-1}	3311.4	1.23×10^5
²⁴³ Cm	28.5	51.6	1.91×10^3
²⁴⁴ Cm	18.11	80.90	2.99×10^3
²⁴⁵ Cm	8500	0.1717	6.35
²⁴⁸ Cm	3.40×10^5	4.24×10^{-3}	1.57×10^{-1}
²⁴⁷ Bk	1380	1.05	3.89×10^1
²⁴⁸ Cf	9.1444×10^{-1}	1579	5.84×10^4
²⁴⁹ Cf	350.6	4.095	1.52×10^2
²⁵⁰ Cf	13.08	109.3	4.04×10^3
²⁵¹ Cf	898	1.59	5.88×10^1
²⁵² Cf	2.645	536.3	1.98×10^4
²⁵² Es	1.291	1098	4.06×10^4
²⁵⁴ Es	7.54825×10^{-1}	1865	6.90×10^4

5.3 BETA

Contact Person(s) : Isabel M. Fisenne

5.3.1 SCOPE

The table of β emitters presented here is useful in identifying unknown β emitters whose energies and possibly half-lives have been determined by standard laboratory techniques, including the Harley-Hallden method (see Procedure A-01-R). It is also a handy guide to β emitting isotopes for applications requiring specific half-lives and/or energies.

The original table was developed by Hallden (1955). Since that time there have been three revisions based on "current" published compilations. The present table was compiled from the Table of Isotopes (Lederer and Shirley, 1978).

The emitter energy listings are the maximum β energy (E_{\max}). Isotopes decaying the emission of β particles of different energies are listed in the energy group corresponding to each E_{\max} , provided that the branch contributes $> 5\%$ of the total β emission. Isotopes with longer-lived parents are also listed under the parent half-life. In the case of multiple long-lived parents, the nuclide is listed under the half-life of the nearest long-lived parent, as well as its own half-life.

REFERENCES

Hallden, N. A.

"Beta Emitters by Energy and Half-life"
Nucleonics, 13, 78-79 (1955)

Lederer, C. and V. S. Shirley (Editors)

Table of Isotopes - Seventh Edition

John Wiley and Sons, New York, NY (1978)

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
6-12 h		²³⁴ Pa	¹⁵⁶ Sm ²¹² Pb ²²⁸ Ac ²⁴⁴ Am	⁶² Zn ⁹¹ Sr ¹³⁵ I ^{152m} Eu ¹⁷¹ Er ²¹² Pb ²²⁸ Ac ²³⁴ Pa ²³⁴ Pa	⁵² Fe ⁷⁷ Ge ^{82m} Rb ¹⁰¹ Pd ¹²⁷ Te ¹⁵⁶ Sm ¹⁷³ Tm ¹⁷³ Tm ^{180m} Ta	⁹¹ Sr ¹³⁵ I ¹³⁵ Xe ¹⁷¹ Er ²⁴⁵ Pu ²⁴⁵ Am	¹⁶³ Tb ¹⁸⁴ Ta ²⁰⁸ Tl ²²⁸ Ac	⁷³ Se ⁷⁷ Ge ⁹¹ Sr ¹³⁵ I ¹⁶³ Tb ¹⁸⁴ Ta	²⁰⁸ Tl ²¹² Bi	^{152m} Eu ²⁰⁸ Tl ²²⁸ Ac ²²⁸ Ac		⁷⁷ Ge ²¹² Bi ²²⁸ Ac	¹²⁸ Sb	⁹¹ Sr	⁹³ Y	⁶² Cu	⁶⁶ Ga
12 h-1 d		¹¹² Pd	²⁸ Mg ⁴³ K ⁹⁶ Nb ¹⁹⁷ Pt ²³⁶ Np ²⁴⁰ U	⁶⁴ Cu ⁶⁴ Cu ¹¹⁹ Te ¹³⁰ I ¹⁵⁹ Gd ¹⁸⁷ W ¹⁸⁷ W ¹⁸⁷ W ¹⁹⁷ Pt ^{200m} Au ²³⁶ Np ^{240m} Np ²⁴² Am ²⁴² Am ²⁴⁸ Bk	⁴³ K ⁶⁹ Zn ⁹⁰ Nb ⁹⁶ Nb ¹⁵⁷ Eu ¹⁵⁹ Gd ¹⁹⁷ Pt ^{240m} Np	⁵⁵ Co ¹⁰⁹ Pd ¹³⁰ I ¹⁵⁰ Eu ¹⁵⁷ Eu ¹⁵⁹ Gd	⁸⁶ Y ⁹⁷ Nb	²⁴ Na ¹³³ I ¹⁵⁷ Eu ¹⁸⁷ W ^{240m} Np	⁵⁵ Co ⁷² Ga ⁸⁶ Y ⁹⁰ Nb ^{240m} Np	⁷⁶ Br	⁴² K ⁹⁷ Zr ¹¹² Ag ¹⁵² Tb ¹⁸⁸ Re ¹⁹⁴ Ir	¹⁴² Pr ¹⁸⁸ Re ¹⁹⁴ Ir ^{240m} Np		⁷² Ga	²⁸ Al ¹⁵² Tb		⁴² K ⁷² Ga ⁷⁶ Br ¹¹² Ag ¹¹² Ag

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1		
1-3 d	²³¹ Th	⁶⁶ Ni	⁶⁷ Cu	⁴⁸ Sc	⁵⁷ Ni	¹⁴³ Ce	⁶⁹ Ge	¹²² Sb	⁶⁶ Cu	⁷⁶ As	¹²² Sb	⁹⁰ Y	⁷⁶ As	⁶⁶ Cu		⁷⁶ As	⁷² Ga		
		⁷² Zn	⁶⁷ Cu	⁶⁷ Cu	⁷¹ As	¹⁴⁹ Pm	⁸³ Sr	¹³¹ Te	⁷² Ga	¹⁶⁶ Ho			¹³¹ Te		⁷² Ga			⁷² As	
		¹⁰⁵ Rh	⁷² Zn	⁷⁷ As	¹⁴³ Ce	¹⁵¹ Pm	⁹⁹ Mo	¹⁴⁰ La	¹³¹ Te	¹⁶⁶ Ho			¹⁴⁰ La		⁷² As				
		¹⁷² Er	⁸² Br	⁷⁹ Kr	¹⁴⁹ Pm	¹⁸⁹ Re	¹¹⁵ Cd	¹⁴³ Ce			¹⁷² Tm								
		¹⁷² Tm	⁹⁹ Mo	¹⁰⁵ Rh	¹⁵¹ Pm	¹⁹⁸ Au					¹⁷² Tm								
		²³¹ Th	¹²¹ Sn	¹¹⁵ Cd	¹⁵¹ Pm		¹⁴⁰ La					¹⁷² Tm							
		²³¹ Th	^{131m} Te	^{131m} Te	¹⁵¹ Pm		¹⁴³ Ce												
		²³¹ Th	¹⁵¹ Pm	¹⁴⁰ La	¹⁵³ Sm		¹⁵¹ Pm												
		²³⁸ Np	¹⁷² Er	¹⁴³ Ce	¹⁵³ Sm		¹⁵¹ Pm												
		²³⁸ Np	¹⁷² Tm	¹⁵¹ Pm	¹⁷² Tm		¹⁹³ Os												
		²³⁸ Np	²³² Pa	¹⁵³ Sm	¹⁸⁹ Re		²²⁶ Ac												
			²³⁹ Np	¹⁹³ Os	¹⁹³ Os		²³⁸ Np												
			²³⁹ Np	¹⁹³ Os	²²⁶ Ac		^{245m} Es												
			²³⁹ Np		²³⁹ Np														
			^{245m} Es																

Note: Where the symbol for a nuclide appears more than once in any grouping it indicates emission of more than one energy.

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
3-5 d	¹⁷⁵ Yb	¹³² Te ¹⁹⁹ Au ¹⁹⁹ Au	⁴⁷ Sc ¹⁶⁶ Dy ¹⁶⁶ Dy ¹⁷⁵ Yb ¹⁹⁹ Au ²¹⁴ Bi	⁴⁷ Ca ⁴⁷ Sc ¹²⁷ Te ²¹⁴ Pb	⁸⁹ Zr ¹²⁷ Sb ¹³² I ²¹⁴ Pb	¹³² I ¹⁸⁶ Re ¹⁸⁶ Re ²¹⁴ Bi	¹²⁷ Sb ¹³² I	¹²⁷ Sb ¹²⁴ I ¹²⁷ Sb ¹³² I ²¹⁴ Bi	¹²⁴ I ¹⁶⁶ Ho ¹⁶⁶ Ho ²¹⁴ Bi	⁴⁷ Ca	¹²⁴ I ¹³² I	¹⁴⁰ Pr	¹³⁴ La				²¹⁴ Bi
5-10 d	²³⁷ U	¹⁷⁷ Lu ¹⁹⁶ Au ²³⁷ U	¹³¹ I ¹³³ Xe ¹⁶¹ Tb ¹⁶⁹ Er ¹⁷⁷ Lu ¹⁸³ Ta	⁵² Mn ¹¹¹ Ag ¹³¹ I ¹⁶¹ Tb ¹⁶¹ Tb ¹⁸³ Ta		¹¹¹ Ag ¹⁴⁸ Pm	²¹⁰ Bi				¹⁴⁸ Pm		¹²⁵ Sn ¹⁴⁸ Pm	⁷² As			⁷² As
10-13 d		²⁴⁶ Pu	¹⁴⁰ Ba ¹⁴⁷ Nd ²⁴⁶ Pu	¹⁴⁰ La ²⁰⁹ Pb ²¹¹ Pb	¹⁴⁰ Ba ¹⁴⁷ Nd	¹⁴⁰ Ba	¹⁴⁰ La	¹⁴⁰ La ²⁰⁷ Tl ²¹¹ Pb ²¹³ Bi ²⁴⁶ Am	¹⁴⁰ La ²⁴⁶ Am		¹²⁶ Sb	¹⁴⁰ La ²⁴⁶ Am					
13-15 d			¹²⁶ I ¹³⁶ Cs ²²⁵ Ra	¹³⁶ Cs	¹²⁶ I	¹⁴³ Pr	¹²⁶ I			³² P							

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
15-20 d		¹⁹¹ Os ²⁵³ Cf	¹⁵⁶ Eu ¹⁵⁶ Eu	⁴⁸ V ²³⁰ Pa	⁷⁴ As ⁸⁶ Rb	⁷⁴ As	¹⁵⁶ Eu	⁷⁴ As		⁸⁶ Rb			¹⁵⁶ Eu				
20-30 d		³³ P ²³³ Pa ²³³ Pa ²³³ Pa ²³⁴ Th ²³⁴ Th ²³⁴ Pa		²³³ Pa ²³⁴ Pa ²³⁴ Pa			²³⁴ Pa										⁸² Rb
30-40 d		⁹⁵ Nb ¹⁰³ Ru ¹⁰³ Ru	¹⁴¹ Ce	¹⁴¹ Ce	⁸⁴ Rb	¹²⁹ Te		¹²⁹ Te	⁸⁴ Rb ^{129m} Te								

Note: Where the symbol for a nuclide appears more than once in any grouping it indicates emission of more than one energy.

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
40-50 d		⁵⁹ Fe ²⁰³ Hg	⁵⁹ Fe ^{148m} Pm ¹⁸¹ Hf	^{148m} Pm ^{148m} Pm					^{115m} Cd								
50-100 d		³⁵ S ⁹⁵ Nb ¹²⁴ Sb ¹⁶⁰ Tb ¹⁹² Ir ²⁵³ Cf	⁴⁶ Sc ⁵⁸ Co ⁹⁵ Zr ⁹⁵ Zr ¹⁶⁰ Tb ¹⁸⁵ W ¹⁸⁸ W	¹²⁴ Sb ¹⁶⁰ Tb ¹⁹² Ir ¹⁹² Ir	¹⁶⁰ Tb	¹²⁴ Sb		⁵⁶ Co ⁸⁹ Sr	⁹¹ Y ¹²⁴ Sb		¹¹⁴ In ¹⁸⁸ Re	¹⁸⁸ Re	¹²⁴ Sb				
100-150 d			¹⁸² Ta	¹²⁷ Te ¹⁸² Ta	¹⁷⁰ Tm	¹⁷⁰ Tm		¹²³ Sn									
150-200 d		⁴⁵ Ca ¹⁷⁷ Lu	¹⁷⁷ Lu														
200-250 d							¹⁰² Rh										
250 d-1 y	^{110m} Ag	¹⁴⁴ Ce ²⁴⁹ Bk	¹⁴⁴ Ce	^{110m} Ag	²⁵⁰ Bk					⁶⁸ Ga ²⁵⁰ Bk						¹⁴⁴ Pr	
1-2 y	¹⁰⁶ Rh ¹⁷¹ Tm											¹⁰⁶ Rh					¹⁰⁶ Rh ¹⁰⁶ Rh

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
2-3 y	¹³⁴ Cs	¹²⁵ Sb ¹⁴⁷ Pm	¹²⁵ Sb ¹²⁵ Sb	²² Na ¹²⁵ Sb ¹³⁴ Cs													
3-5 y		¹⁵⁵ Eu ¹⁵⁵ Eu			²⁰⁴ Tl												
5-10 y	¹⁹⁴ Os ²²⁸ Ra ²²⁸ Ra	¹⁵⁴ Eu	⁶⁰ Co ²²⁸ Ac	¹⁵⁴ Eu ²²⁸ Ac	¹⁴⁶ Pm ¹⁵⁴ Eu		²²⁸ Ac			¹⁵⁴ Eu ²²⁸ Ac ²²⁸ Ac	¹⁹⁴ Ir	¹⁹⁴ Ir ²²⁸ Ac					

Note: Where the symbol for a nuclide appears more than once in any grouping it indicates emission of more than one energy.

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
10-20 y	³ H ²⁴¹ Pu			⁸⁵ Kr ¹¹³ Cd ¹⁵² Eu ¹⁵⁴ Eu				¹⁵² Eu		¹⁵⁴ Eu							
20-30 y	²¹⁰ Pb ²¹⁰ Pb ²²⁷ Ac			⁹⁰ Sr			²¹⁰ Bi					⁹⁰ Y					
30-50 y				¹³⁷ Cs			¹³⁷ Cs	⁴⁴ Sc									
50-100 y	¹⁵¹ Sm		^{121m} Sn														
>100 y	⁶³ Ni ⁹³ Zr ¹⁰⁷ Pd ^{166m} Ho ¹⁸⁷ Re ²²⁷ Ac ²²⁸ Ra ²²⁸ Ra ²³¹ Th	¹⁴ C ³² Si ⁷⁹ Se ⁸⁷ Rb ⁹⁹ Tc ¹²⁶ Sn ¹²⁹ I ¹³⁵ Cs ¹³⁸ La ²³¹ Th ²³¹ Th	⁹⁴ Nb ⁹⁸ Tc ¹¹⁵ In ¹⁸² Ta ²²⁵ Ra	¹⁰ Be ³⁹ Ar ¹⁷⁶ Lu ¹⁸² Ta ²³³ Pa ²⁴² Am ²⁴² Am	³⁶ Cl ¹⁵⁸ Tb		²⁶ Al ²³⁸ Np	⁴⁰ K		³² P	¹²⁶ Sb	^{234m} Pa					

BETA EMITTERS BY HALF-LIFE AND ENERGY (E_{MAX} IN MeV) - (Cont'd)

T _{1/2}	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.1	2.1-2.3	2.3-2.5	2.5-2.7	2.7-2.9	2.9-3.1	>3.1
		²³¹ Th															
		²³³ Pa															
		²³³ Pa															
		²³⁴ Th															
		²³⁴ Th															

Note: Where the symbol for a nuclide appears more than once in any grouping it indicates emission of more than one energy.

5.4 GAMMA

Contact Person(s) : Colin G. Sanderson

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 Bi	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 Bi	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 Bi	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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John Wiley and Sons, Inc., New York (1986)

Siegbahn, K.
Alpha, Beta, and Gamma Ray Spectroscopy
North-Holland Publishing, Co., Amsterdam (1965)

Wapstra, A. H., G. J. Nijgh and R. Van Lieshout
Nuclear Spectroscopy Tables
North-Holland Publishing, Co., Amsterdam (1959)

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)	
			$K_{\beta 1}$	$K_{\beta 2}$
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 _{B1}	K _{B2}
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 _{β1} '	K _{β2} '
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

5.6 NATURAL DECAY SERIES

Contact Person(s) : Isabel M. Fisenne

5.6.1 SCOPE

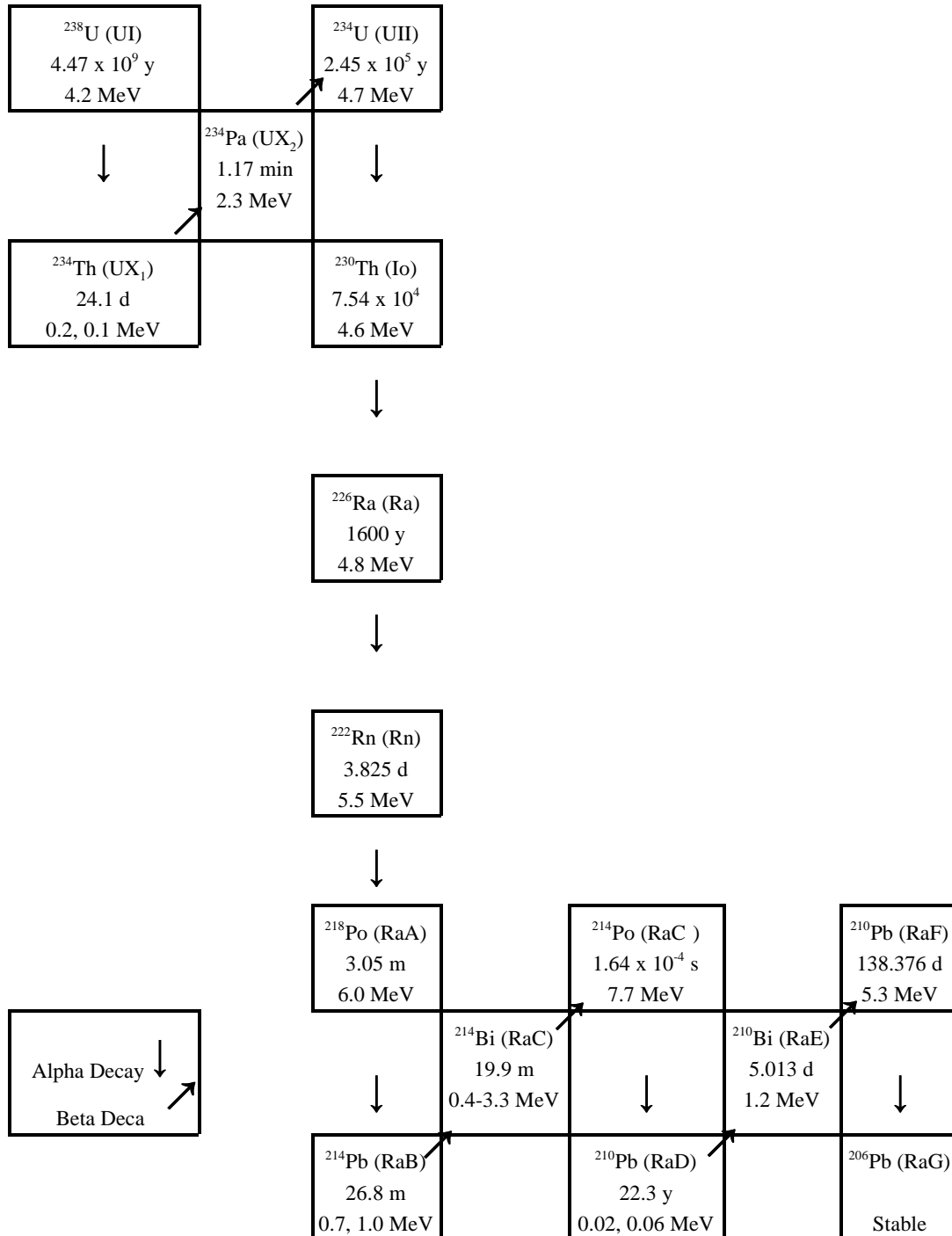
Charts of the four heavy element series are given in this section. These are the three natural series and the artificial Am series.

Data for half-lives and energies have been taken from Browne et al. (1986). Energies are given in order of abundance and include only the major emissions. Branching in the chains that amount to one percent or less are also omitted.

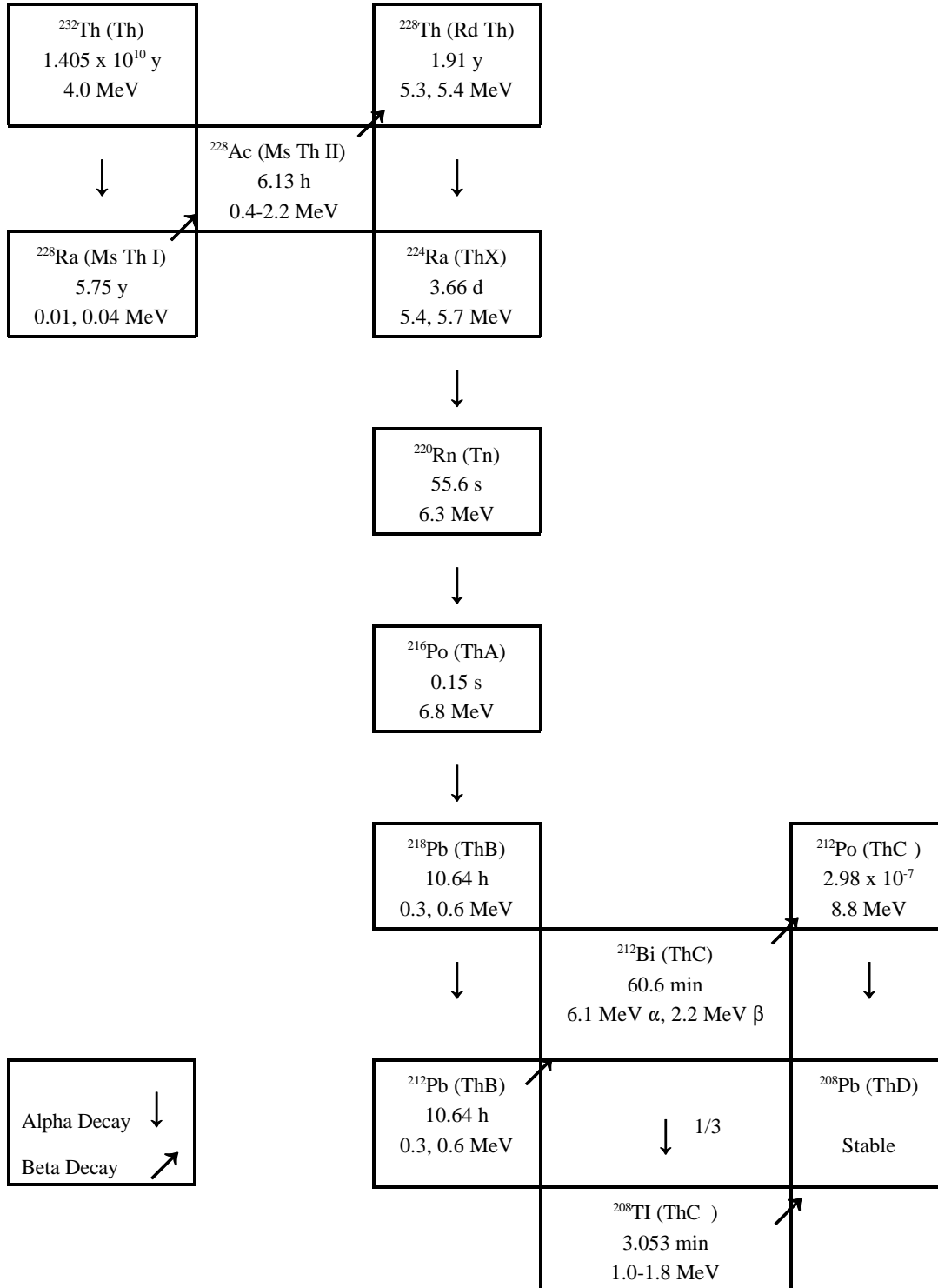
REFERENCE

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

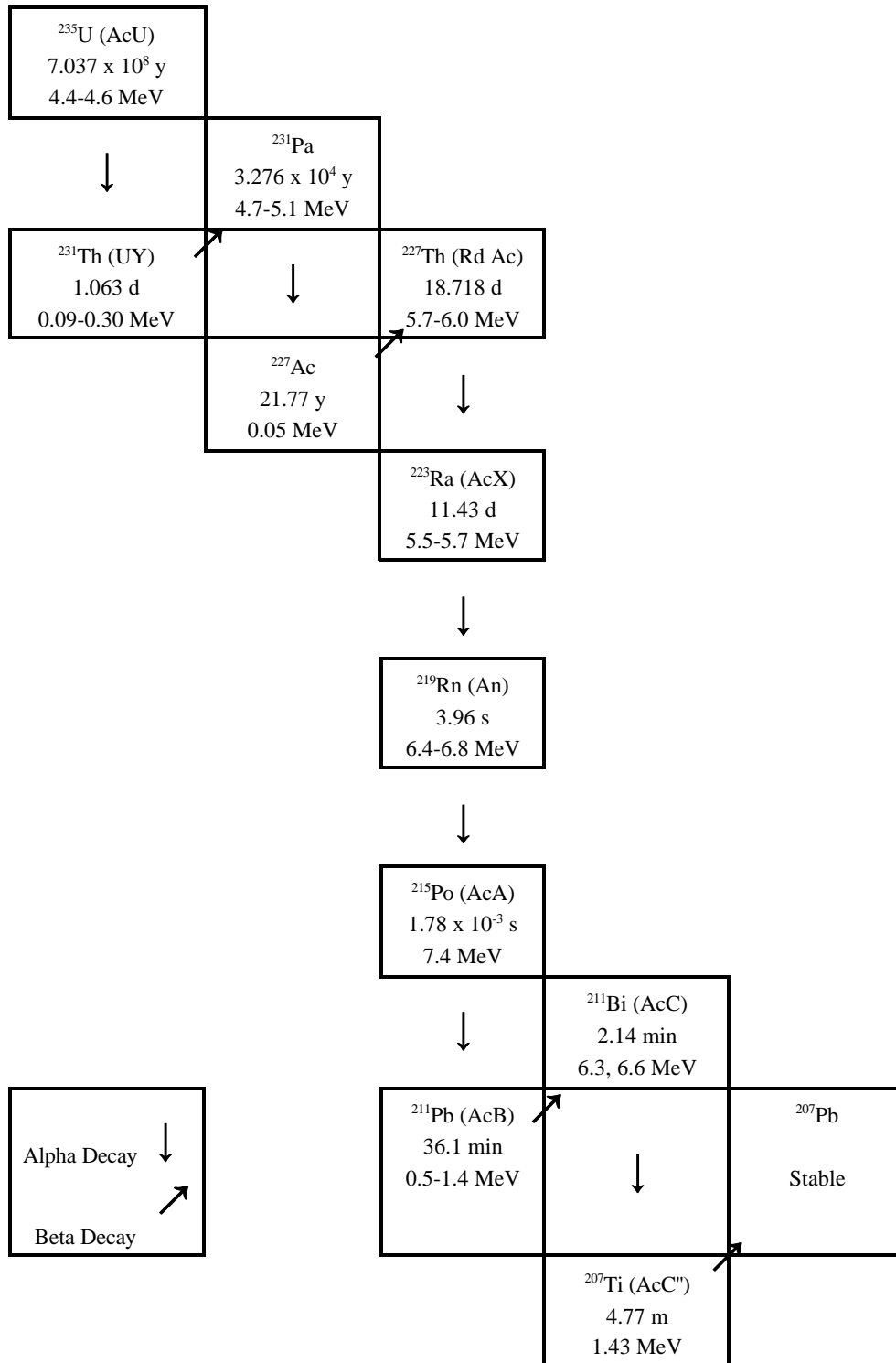
Principal Members of the Uranium Series



Principal Members of the Thorium Series



Principal Members of the Actinium Series



Principal Members of the Americium Series

