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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 Am series. Pertinent data are included in these charts.

The contact person for the individual sections welcomes any comments for corrections or any additions.

THE HISTORY OF THE

The first part of the history of the world is the history of the human race. It is a story of progress and struggle, of triumph and defeat. It is a story of the human mind and the human heart, of the human spirit and the human soul. It is a story of the human race and the human world.

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5.2 ALPHA

Contact Person: 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 | 2.1×10^{15} y | 23.8 | | 1.83 |
| 62 ^{147}Sm | 1.03×10^8 y | | | 2.46 |
| 62 ^{147}Sm | 1.06×10^{11} y | 15.0 | | 2.233 |
| 64 ^{148}Gd | 75.3 y | | | 3.183 |
| 64 ^{152}Gd | 1.79×10^6 y | | | 2.726 |
| 64 ^{152}Gd | 1.08×10^{14} y | 0.20 | | 2.14 |
| 66 ^{154}Dy | 2.9×10^6 y | | | 2.872 |
| 72 ^{174}Hf | 2.0×10^{15} y | 0.162 | | 2.50 |
| 76 ^{186}Os | 2.0×10^{15} y | 1.58 | | 2.80 |
| 78 ^{190}Pt | 6.0×10^{11} y | <0.02 | | 3.175 |
| 83 $^{210\text{m}}\text{Bi}$ | 3.00×10^6 y | | | 4.946(55.5%), 4.908(38.8%), 4.569(3.8%) |
| 83 $^{211}\text{Bi}(\text{AcC})$ | 2.14 m | | | 6.623(84%), 6.279(16%) |
| 83 $^{212}\text{Bi}(\text{ThC}')$ | 1.0092 h | | 3.954% | 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 $^{210}\text{Po}(\text{RaF})$ | 138.376 d | | | 5.305 |
| 84 $^{212}\text{Po}(\text{ThC}')$ | 298.0 ns | | | 8.784 |
| 84 ^{213}Po | 4.28 μs | | | 8.375 |

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

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

| Radionuclide | $t_{1/2}$ | Isotopic Abundance (%) | α Emission (when not 100%) | E_{MeV} |
|--|----------------------|------------------------|-----------------------------------|--|
| 84 $^{214}\text{Po}(\text{RaC}')$ | 163.69 μs | | | 7.687 |
| 84 $^{215}\text{Po}(\text{AcC})$ | 1.780 ms | | | 7.386 |
| 84 $^{216}\text{Po}(\text{ThA})$ | 150.0 ms | | | 6.779 |
| 84 $^{218}\text{Po}(\text{RaA})$ | 3.05 m | | | 6.003 |
| 85 ^{211}At | 7.215 h | | 41.7% | 5.868 |
| 85 ^{217}At | 32.3 ms | | | 7.067 |
| 86 $^{219}\text{Rn}(\text{}^{219}\text{Em})$ | 3.96 s | | | 6.819(80.9%), 6.553(12.2%),
6.425(7.5%) |
| 86 $^{220}\text{Rn}(\text{}^{220}\text{Em, Tn})$ | 55.6 s | | | 6.288 |
| 86 $^{222}\text{Rn}(\text{}^{222}\text{Em, Rn})$ | 3.825 d | | | 5.490 |
| 87 ^{221}Fr | 4.9 m | | | 6.341(83.4%), 6.243(1.3%),
6.127(15.1%) |
| 88 $^{223}\text{Ra}(\text{AcX})$ | 11.43 d | | | 5.747(9.5%), 5.716(52.5%),
5.607(24.2%), 5.540(9.2%), others |
| 88 $^{224}\text{Ra}(\text{ThX})$ | 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 $^{227}\text{Th}(\text{Rd Ac})$ | 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 $^{228}\text{Th}(\text{Rd Th})$ | 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 $^{230}\text{Th}(\text{Io})$ | 7.54×10^4 y | | | 4.688(76.3%), 4.621(23.4%) |

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

| Radionuclide | $t_{1/2}$ | Isotopic Abundance (%) | α Emission (when not 100%) | E_{MeV} |
|---------------------------|----------------------------|------------------------|-----------------------------------|---|
| 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(UIII) | 2.454 x 10 ⁵ y | 0.0055 | | 4.776(72.5%), 4.724(27.5%) |
| 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%) |

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

| Radionuclide | $t_{1/2}$ | Isotopic Abundance (%) | α Emission (when not 100%) | E_{MeV} |
|-----------------------|--------------------------|------------------------|-----------------------------------|---|
| 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 |
| 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 |

ALPHA EMITTERS BY ATOMIC NUMBER (Cont'd)

| Radionuclide | $t_{1/2}$ | Isotopic Abundance (%) | α Emission (when not 100%) | E_{MeV} |
|------------------------|-----------|------------------------|-----------------------------------|---|
| 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 ⁵² 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%) |

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:

238U 234U 230Th 226Ra 210Po 222Rn 218Po

Thorium Series:

232Th 228Th 228Th 224Ra 212Bi 212Bi 224Ra 220Rn

Actinium Series:

235U 235U 231Pa 231Pa 223Ra 227Th 227Th 227Th

Americium Series:

237Np 233U 229Th 241Am 241Am 225Ac 225Ac 221Fr 221Fr

All Emitters:

232Th 232Th 238U 235U 210mBi 226Ra 230Th 231Pa 233U 234U 237Np 206Po 210Po 228Th 232U 241Am 243Am 245Cm 246Cm 247Cm 208Po 229Th 231Pa 239Pu 240Pu 243Am 248Cm 209Po 210mBi 229Th 231Pa 233U 237Np 226Ra 230Th 231Pa 233U 234U 237Np 210mBi 235U 236U 244Pu 209Po 210mBi 226Ra 230Th 231Pa 233U 234U 237Np 226Ra 230Th 231Pa 233U 234U 237Np 206Po 210Po 228Th 232U 241Am 243Am 245Cm 246Cm 247Cm 222Rn 223Ra 224Ra 228Th 238Pu 241Am 247Bk 212Bi 223Ra 224Ra 225Ac 227Th 236Pu 243Cm 244Cm 247Bk 251Cf 211At 225Ac 227Th 230U 243Cm 244Cm 249Cf 250Cf 251Cf 212B 218Po 221Fr 227Th 242Cm 243Cm 249Cf 250Cf 251Cf 211Bi 220Rn 221Fr 240Cm 248Cf 254Es 255Es

* A listing may denote more than one energy.

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

| | | | | | | | | | | | |
|-------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 6.4-6.6 | 6.6-6.8 | 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 | 8.4-8.6 | 8.6-8.8 |
| Uranium Series: | | | | | | | | | | | |
| Thorium Series: | | | | | | | | | | | |
| Actinium Series: | | | | | | | | | | | |
| Americium Series: | | | | | | | | | | | |
| All Emitters: | | | | | | | | | | | |

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

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

Author: 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 4.5.2.1). 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 through 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 |
|------------------|------|---------|---|---|--|--|--|--|---------------------------------------|-----------------------------------|---|-----------------------------------|---------|---------------|---------|---------------------------------------|------|
| 6-12h | | 234Pa | 156Sm
212Pb
228Ac
244Am | 62Zn
91Sr
135I
152mEu
171Er
212Pb
228Ac
234Pa
234mPa | 52Fe
77Ge
82mRb
101Pd
127Te
156Sm
173Tm
173Tm
180mTa | 91Sr
135I
135Xe
171Er
245Pu
245Am | 163Tb
184Ta
208Tl
228Ac
245Pu
245Am | 73Se
77Ge
91Sr
135I
163Tb
184Ta | 208Tl
212Bi
228Ac | 152mEu
208Tl
228Ac
228Ac | | 77Ge
212Bi
228Ac | 128Sb | 91Sr | 93Y | 62Cu | 66Ga |
| 12h-1d | | 112Pd | 28Mg
43K
96Nb
197Pt
236Np
240U | 64Cu
64Cu
119Re
130I
159Cd
187W
187W
187W
197Pt
200mAu
236Np
240mNp
242Am
242Am
248Bk | 43K
69Zn
90Nb
96Nb
157Eu
159Cd
187W
197Pt
240mNp | 55Co
109Pd
130I
150Eu
157Eu
159Cd | 86Y
97Nb | 24Na
133I
157Eu
187W
240mNp | 55Co
72Ga
86Y
90Nb
240mNp | 76Br | 42K
97Zr
112Ag
152Tb
188Re
194Ir | 142Pr
189Re
194Ir
240mNp | 72Ga | 28Al
152Tb | | 42K
72Ga
76Br
112Ag
112Ag | |

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 |
|------------------|-------------------|---|---|---|---|---|---|--|--|--|-------------------|---|------------------|--|------------------|------------------|--------------------------------------|
| 1-3d | 231 Th | 66 ^{Ni}
72 ^{Zn}
105 ^{Rh}
172 ^{Zr}
172 Tm
231 Th
231 Th
231 Th
238 ^{Np}
238 ^{Np}
238 ^{Np} | 67 ^{Cu}
67 ^{Cu}
72 ^{Zn}
82 ^{Br}
99 ^{Mo}
121 ^{Sn}
131 ^{Te}
151 ^{Pm}
172 ^{Er}
232 ^{Pa}
239 ^{Np}
239 ^{Np}
239 ^{Np}
254 ^{Mz} | 48 ^{Gc}
67 ^{Cu}
77 ^{As}
79 ^{Kr}
105 ^{Rh}
115 ^{Cd}
131 ^{Te}
140 ^{La}
143 ^{Ce}
151 ^{Pm}
153 Sm
172 Tm
189 ^{Re}
193 ^{Os}
193 ^{Os} | 57 ^{Ni}
71 ^{As}
143 ^{Ce}
149 ^{Pm}
151 ^{Pm}
149 ^{Pm}
151 ^{Pm}
151 ^{Pm}
153 Sm
153 Sm
172 Tm
189 ^{Re}
193 ^{Os}
226 ^{Ac}
239 ^{Np} | 143 ^{Ce}
149 ^{Pm}
151 ^{Pm}
189 ^{Re}
198 ^{Au} | 69 ^{Ga}
83 ^{Sr}
99 ^{Mo}
115 ^{Cd}
140 ^{La}
143 ^{Ce}
151 ^{Pm}
151 ^{Pm} | 122 ^{Gb}
131 ^{Te}
140 ^{La}
143 ^{Ce} | 66 ^{Cu}
72 ^{Ga}
131 ^{Te}
140 ^{La} | 76 ^{As}
166 ^{Ho}
166 ^{Ho}
172 Tm
172 Tm | 122 ^{Gb} | 90 ^Y
131 ^{Te}
140 ^{La} | 76 ^{As} | 66 ^{Cu}
72 ^{Ga}
72 ^{As} | 76 ^{As} | 76 ^{As} | 72 ^{Ga}
72 ^{As} |

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 |
|------------------|-------|-------------------------|---|--|--------------------------------|---------------------------------|---|---------------------------------|---------------------------------|---------|----------------|----------------|---------|---------|---------|---------|-------|
| 3-5d | 175Yb | 132Te
199Au
199Au | 47Sc
166Dy
166Dy
175Yb
199Au
214Bi | 47Ca
47Sc
127Te
214Pb | 89Zr
127Sb
132I
214Pb | 132I
186Re
186Re
214Bi | 127Sb
132I | 127Sb
127Sb
132I
214Bi | 124I
166Ho
166Ho
214Bi | 47Ca | 124I
132I | 140Pr | 134La | | | | 214Bi |
| 5-10d | 237U | 177Lu
196Au
237U | 131I
133Xe
161Tb
169Zr
177Lu | 52Mn
111Ag
131I
161Tb
161Tb
183Ta | 111Ag
148Pm | 210Bi | | | | 148Pm | | 125Sn
148Pm | 72As | | | | 72As |
| 10-13d | | 246Pu | 140Ba
147Nd
246Pu | 140La
209Pb
211Pb | 140Ba
147Nd | 140Ba | 140La
207Tl
211Pb
213Bi
246Am | 140La
246Am | 140La
246Am | 126Sb | 140La
246Am | | | | | | |
| 13-15d | | | 126I
136Cs
225Ra | 136Cs | 126I
143Pr | 126I | | | | 32P | | | | | | | |

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 |
|-----------|------|---|---|---|--------------------------------------|-------------------|-------------------|-------------------|---------------------------------------|------------------|---------|---------|-------------------|---------|---------|---------|------------------|
| 15-20d | | ¹⁹¹ Os
²⁵³ Cf | ¹⁵⁶ Tu
¹⁵⁶ Tu | ⁴⁸ V
⁷⁴ As
⁸⁶ Rb | ⁷⁴ As
⁸⁶ Rb | ⁷⁴ As | ¹⁵⁶ Tu | ⁷⁴ As | | ⁸⁶ Rb | | | ¹⁵⁶ Tu | | | | |
| 20-30d | | ³³ P
²³³ Pa
²³³ Pa
²³³ Pa
²³⁴ Th
²³⁴ Th
²³⁴ Pa | ²³³ Pa
²³⁴ Pa
²³⁴ Pa | ²³³ Pa
²³⁴ Pa
²³⁴ Pa | | | ²³⁴ Pa | | | | | | | | | | ⁸² Rb |
| 30-40d | | ⁹⁵ Nb
¹⁰³ Ru
¹⁰³ Ru | ¹⁴¹ Ce | ¹⁴¹ Ce | ⁸⁴ Rb | ¹²⁹ Te | | ¹²⁹ Te | ⁸⁴ Rb
^{129mTc} | | | | | | | | |

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 |
|------------------|------|---|---|----------------------------------|---------|---------|---------|--------------|--------------|---------------|----------------|---------|---------|---------|---------|---------|----------------|
| 40-50d | | 59Fe
203Hg | 59Fe
148mPm
181Hf | 148mPm
148mPm | | | | | 115mCd | | | | | | | | |
| 50-100d | | 35S
95Nb
124Sb
160Tb
192Ir
160Tb
192Ir
253Cf
186W | 46Sc
58Co
95Zr
95Zr
160Tb
186W | 124Sb
160Tb
192Ir
192Ir | 160Tb | 124Sb | | 56Co
89Sr | 91Y
124Sb | | 114In
188Re | 188Re | 124Sb | | | | |
| 100-150d | | | 182Tm | 127Te
182Tm | 170Tm | 170Tm | | 123Sn | | | | | | | | | |
| 150-200d | | 45Ca
177Lu | 177Lu | | | | 102Rh | | | | | | | | | | |
| 200-250d | | | | | | | | | | | | | | | | | |
| 250d-1y | | 144Ce
249Bk | 144Ce | 110mAg | 250Bk | | | | | 68Ga
250Bk | | | | | 144Pr | | |
| 1-2y | | | | | | | | | | | | | 106Rh | | | | 106Rh
106Rh |

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 |
|------------------|-------------------------|----------------|----------------|------------------------|----------------|---------|---------|---------|-------------------------|-------------------------|----------------|---------|---------|---------|---------|---------|------|
| 2-3y | 134Cs | 125Sb
147Pm | 125Sb
125Sb | 22Na
125Sb
134Cs | | | | | | | | | | | | | |
| 3-5y | | 155Eu
155Eu | | 204Tl | | | | | | | | | | | | | |
| 5-10y | 194Os
228Ra
228Ra | 154Eu | 60Co
228Ac | 154Eu
228Ac | 146Pm
154Eu | 228Ac | | | 154Eu
228Ac
228Ac | 194Ir
228Ac
228Ac | 194Ir
228Ac | | | | | | |

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 |
|------------------|--|--|---|---|---------------------------------------|---------------------------------------|-------------------|-------------------|-----------------|---|-----------------|---------|---------|---------|---------|---------|------|
| 10-20y | ³ H
²⁴¹ Pu | | | ⁸⁵ Kr
¹¹³ Cd
¹⁵² Eu
¹⁵⁴ Eu
⁹⁰ Sr | | | | ¹⁵² Eu | | ¹⁵⁴ Eu | | | | | | | |
| 20-30y | ²¹⁰ Pb
²¹⁰ Pb
²²⁷ Ac | | | ⁹⁰ Sr | | | ²¹⁰ Bi | | | | ⁹⁰ Y | | | | | | |
| 30-50y | | | | ¹³⁷ Cs | | | ¹³⁷ Cs | ⁴⁴ Sc | | | | | | | | | |
| 50-100y | ¹⁵¹ Sm | | ¹²¹ mSn | | | | | | | | | | | | | | |
| >100y | 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: 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 | Activity |
| 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 | Activity |
| 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 | | | Activity |
| 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 | Activity |
| 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 | | | Activity |
| 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 |
| 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 |

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

| Energy | Nuclide | % | T 1/2 | E2 | % | E3 | % | Origin |
|--------|--------------------|------|-------|--------|------|--------|------|-------------------|
| 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 | Activity |
| 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 | Activity |
| 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 Ce | 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 | | | Activity |
| 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 | Activity |
| 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 |
| 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 |

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

| Energy | Nuclide | % | T 1/2 | E2 | % | E3 | % | Origin |
|--------|--------------------|------|-------|-------|------|--------|------|-------------------|
| 276.4 | ¹³³ Ba | 7.1 | 10.5Y | 302.9 | 18.4 | 81.0 | 34.2 | Activity |
| 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 | Activity |
| 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 | | | | | Activity |
| 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 | Activity |
| 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 | Activity |
| 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 | Activity |

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

| Energy | Nuclide | % | T 1/2 | E2 | % | E3 | % | Origin |
|--------|--------------------|-------|-------|--------|------|--------|------|-------------------|
| 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 | | | Activity |
| 511.0* | ⁵⁸ Co | 30.0 | 70.9D | 810.8 | 99.5 | | | Activity |
| 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 | Activity |
| 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 | Activity |
| 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 |

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

| Energy | Nuclide | % | T 1/2 | E2 | % | E3 | % | Origin |
|--------|--------------------|------|-------|--------|------|--------|------|-------------------|
| 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 | Activity |
| 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 |
| 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 | Activity |
| 687.0 | ^{110m} Ag | 6.4 | 250D | 677.6 | 10.4 | 706.7 | 16.4 | Activity |
| 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 | Activity |
| 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 | Activity |
| 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 | Activity |
| 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 |

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

| Energy | Nuclide | % | T 1/2 | E2 | % | E3 | % | Origin |
|--------|--------------------|-------|--------|--------|------|--------|------|-------------------|
| 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 |
| 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 | | | Activity |
| 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 | Activity |
| 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 | Activity |
| 898.1 | ⁸⁸ Y | 92.7 | 107D | 1836.1 | 99.4 | | | Activity |
| 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 | Activity |
| 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 |
| 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 |

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

| Energy | Nuclide | % | T 1/2 | E2 | % | E3 | % | Origin |
|--------|--------------------|-------|-------|--------|-------|--------|------|-------------------|
| 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 | 14.5 | 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 | 18.9 | 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 | | | Activity |
| 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 | | | Activity |
| 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 | Activity |
| 1293.6 | ⁴¹ Ar | 99.2 | 1.83H | | | | | Activity |
| 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 | | | Activity |
| 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 |

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

| Energy | Nuclide | % | T 1/2 | E2 | % | E3 | % | Origin |
|---------|--------------------|-------|-------|---------|------|---------|------|-------------------|
| 1368.6 | ²⁴ Na | 100.0 | 14.7H | 2754.1 | 99.9 | | | Activity |
| 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 | Activity |
| 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 | Activity |
| 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 | Activity |
| 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 |
| 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 |

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

| Energy | Nuclide | % | T 1/2 | E2 | % | E3 | % | Origin |
|--------|-------------------|------|-------|--------|-------|--------|------|-------------------|
| 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 | 76.3 | ¹³⁸ Xe |
| 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 | | | Activity |
| 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: 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 electron. 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
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 | |
| 33 | As | 10.5 | 11.7 | |
| 34 | Se | 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 |

| Z | Element | K_{α}^{-} | Energy
(keV)
$K_{\beta 1}'$ | $K_{\beta 2}'$ |
|----|---------|------------------|-----------------------------------|----------------|
| 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 |
| 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 |

| Z | Element | K_{α}^{-} | Energy (keV) | |
|-----|---------|------------------|------------------------|------------------------|
| | | | $K_{\beta 1}^{\prime}$ | $K_{\beta 2}^{\prime}$ |
| 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 |
| 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 |

| Year | 1987 | 1988 | 1989 | 1990 |
|------|------|------|------|------|
| 1987 | 100 | 100 | 100 | 100 |
| 1988 | 100 | 100 | 100 | 100 |
| 1989 | 100 | 100 | 100 | 100 |
| 1990 | 100 | 100 | 100 | 100 |
| 1991 | 100 | 100 | 100 | 100 |
| 1992 | 100 | 100 | 100 | 100 |
| 1993 | 100 | 100 | 100 | 100 |
| 1994 | 100 | 100 | 100 | 100 |
| 1995 | 100 | 100 | 100 | 100 |
| 1996 | 100 | 100 | 100 | 100 |
| 1997 | 100 | 100 | 100 | 100 |
| 1998 | 100 | 100 | 100 | 100 |
| 1999 | 100 | 100 | 100 | 100 |
| 2000 | 100 | 100 | 100 | 100 |
| 2001 | 100 | 100 | 100 | 100 |
| 2002 | 100 | 100 | 100 | 100 |
| 2003 | 100 | 100 | 100 | 100 |
| 2004 | 100 | 100 | 100 | 100 |
| 2005 | 100 | 100 | 100 | 100 |
| 2006 | 100 | 100 | 100 | 100 |
| 2007 | 100 | 100 | 100 | 100 |
| 2008 | 100 | 100 | 100 | 100 |
| 2009 | 100 | 100 | 100 | 100 |
| 2010 | 100 | 100 | 100 | 100 |
| 2011 | 100 | 100 | 100 | 100 |
| 2012 | 100 | 100 | 100 | 100 |
| 2013 | 100 | 100 | 100 | 100 |
| 2014 | 100 | 100 | 100 | 100 |
| 2015 | 100 | 100 | 100 | 100 |
| 2016 | 100 | 100 | 100 | 100 |
| 2017 | 100 | 100 | 100 | 100 |
| 2018 | 100 | 100 | 100 | 100 |
| 2019 | 100 | 100 | 100 | 100 |
| 2020 | 100 | 100 | 100 | 100 |
| 2021 | 100 | 100 | 100 | 100 |
| 2022 | 100 | 100 | 100 | 100 |

5.6 NATURAL DECAY SERIES

Contact Person: Isabel M. Fisenne

5.6.1 SCOPE

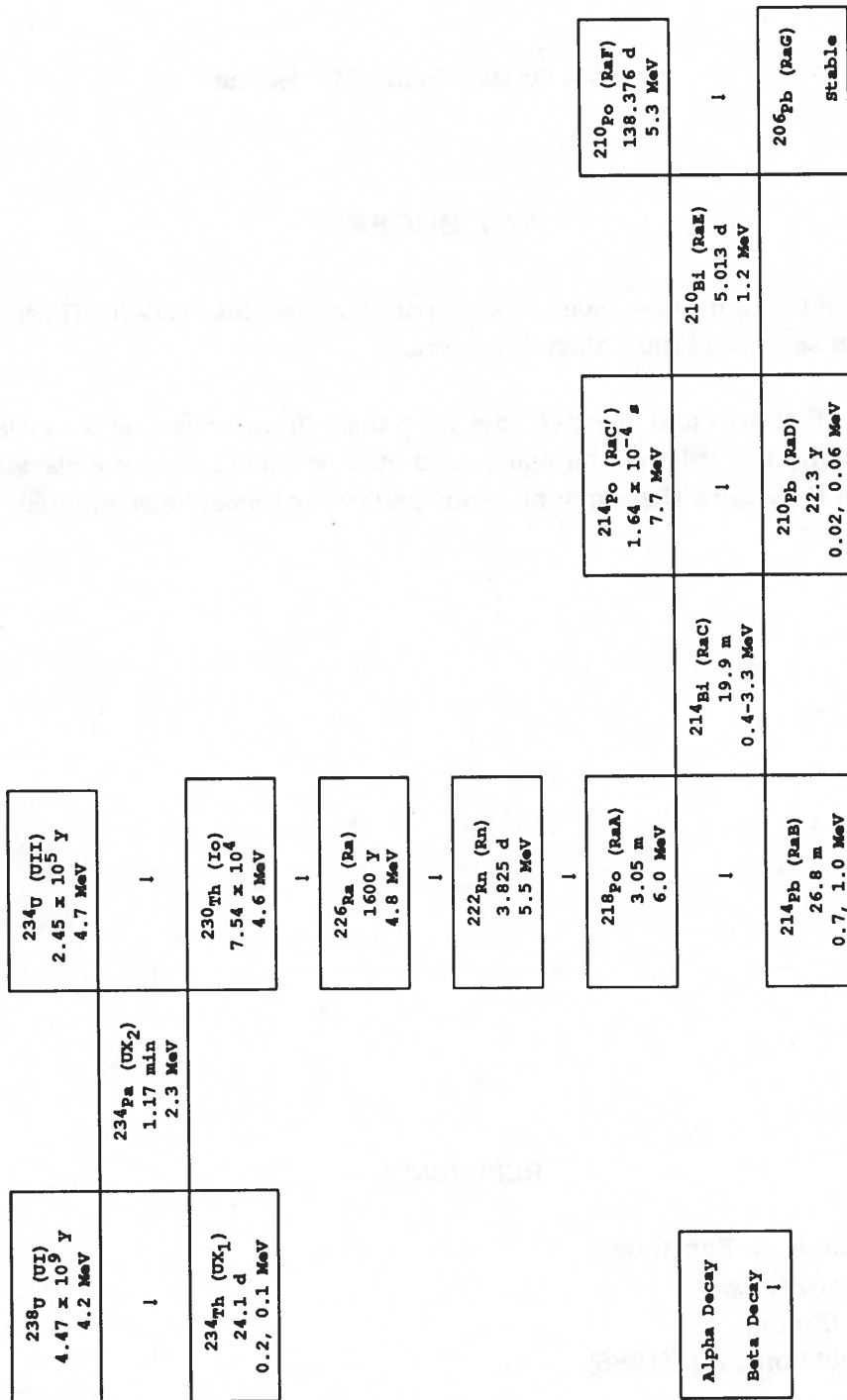
Charts of the four heavy element series are given in this section. These are the three natural series and the artificial Am series.

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.

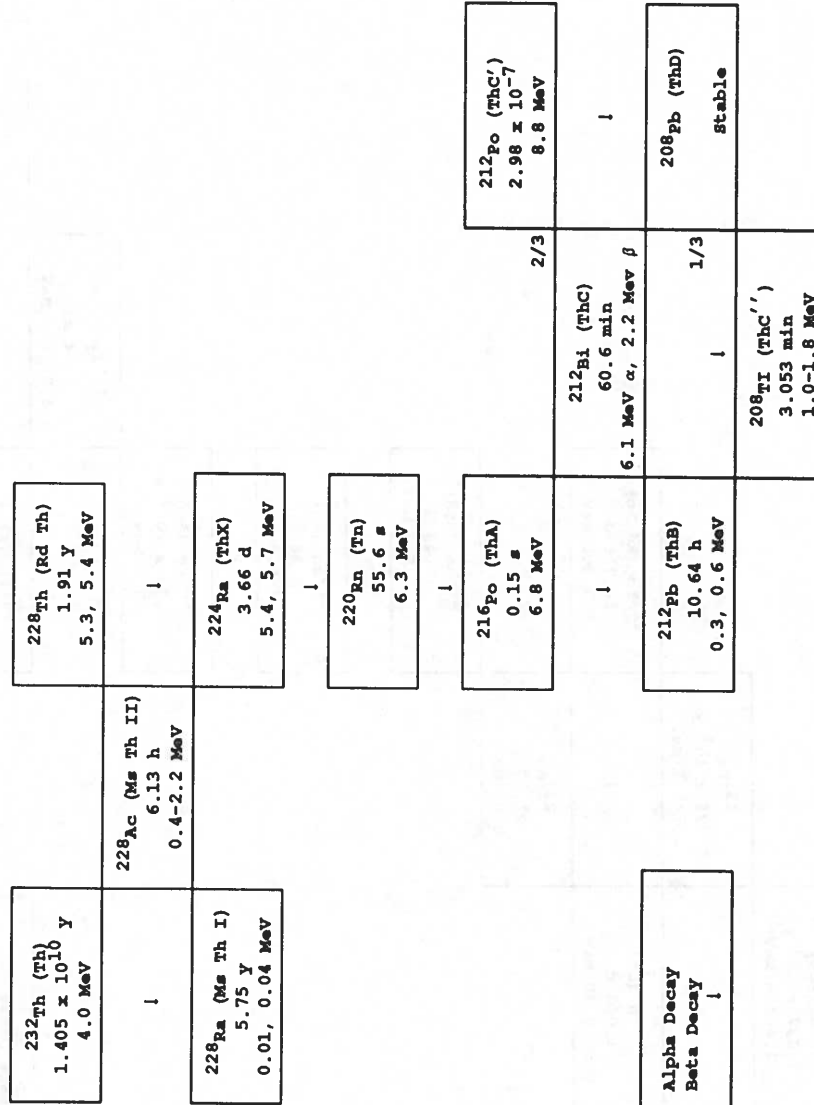
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Table of Radioactive Isotopes
Shirley, V. S. (Editor)
John Wiley and Sons, Inc. (1986)

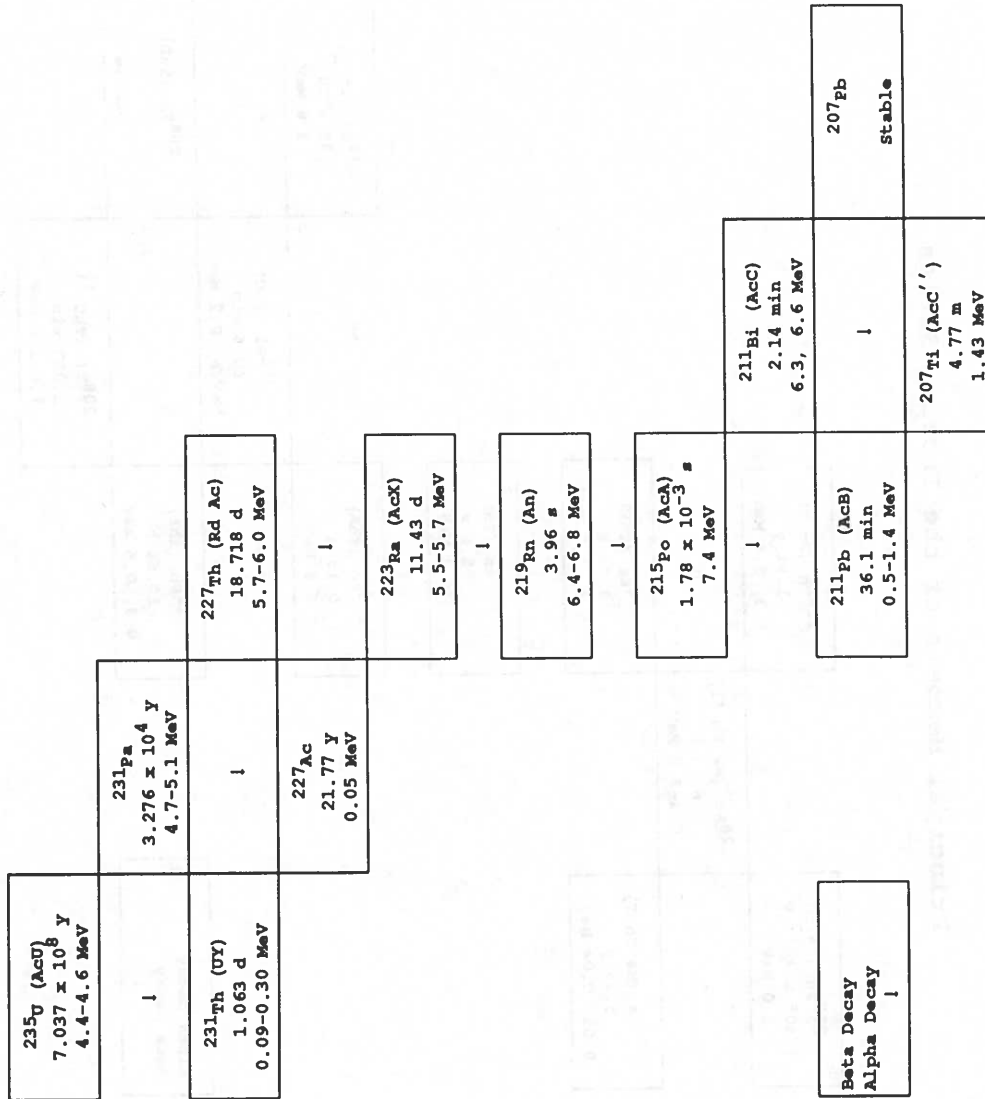
Principal Members of the Uranium Series



Principal Members of the Thorium Series



Principal Members of the Actinium Series



Principal Members of the Americium Series

