Appendix D

Selected Data on Nuclides

Nuclide	Natural Abundance (%)	Mass Difference $\Delta = M - A$ (MeV) (at. mass − at. mass No.)	Type of Decay	Half-Life	Major Radiations, Energies (MeV), and Frequency per Disintegration (%)
$^{1}_{0}n$	—	8.0714	β^-	12 min	β^-: 0.78 max
$^{1}_{1}H$	99.985	7.2890	—	—	—
$^{2}_{1}H$	0.015	13.1359	—	—	—
$^{3}_{1}H$	—	14.9500	β^-	12.3 y	β^-: 0.0186 max, no γ
$^{3}_{2}He$	0.00013	14.9313	—	—	—
$^{4}_{2}He$	99.99+	2.4248	—	—	—
$^{6}_{3}Li$	7.42	14.088	—	—	—
$^{7}_{3}Li$	92.58	14.907	—	—	—
$^{7}_{4}Be$	—	15.769	EC	53.3 d	γ: 0.478 (10.3%)
$^{10}_{5}B$	19.7	12.052	—	—	—
$^{11}_{6}C$	—	10.648	β^+ 99+%	20.38 min	β^+: 0.960 max (avg 0.386)
			EC 0.2%		γ: 0.511 (200%, $\gamma^{\pm}$)
$^{12}_{6}C$	98.892	0	—	—	—
$^{14}_{6}C$	—	3.0198	β^-	5730 y	β^-: 0.156 max (avg 0.0495), no γ
$^{14}_{7}N$	99.635	2.8637	—	—	—
$^{15}_{7}N$	0.356	0.100	—	—	—
$^{16}_{8}O$	99.759	−4.7366	—	—	—
$^{17}_{8}O$	0.037	−0.808	—	—	—
$^{22}_{10}Ne$	8.82	−8.025	—	—	—
$^{22}_{11}Na$	—	−5.182	β^+ 89.8%	2.602 y	β^+: 0.545 max (avg 0.215)
			EC 10.2%		γ: 0.511 (180%, $\gamma^{\pm}$), 1.275 (100%), Ne X rays

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$^{23}_{11}Na$	100.	−9.528	—	—	—
$^{24}_{11}Na$	—	−8.418	β^-	15.00 h	β^-: 1.390 max (avg 0.554) γ: 1.369 (100%), 2.754 (100%)
$^{24}_{12}Mg$	78.60	−13.933	—	—	—
$^{26}_{12}Mg$	11.3	−16.214	—	—	—
$^{26}_{13}Al$	—	−12.211	β^+ 81.8% EC 18.2%	7.16×10^5 y	β^+: 1.174 max (avg 0.544) γ: 0.511 (164%, $\gamma^\pm$), 1.130 (2.5%), 1.809 (100%), Mg X rays
$^{26m}_{13}Al$	—	−11.982	β^+	6.4 s	β^+: 3.21 max γ: 0.511 (200%, $\gamma^\pm$)
$^{32}_{15}P$	—	−24.303	β^-	14.29 d	β^-: 1.710 max (avg 0.695) No γ
$^{32}_{16}S$	95.0	−26.013	—	—	—
$^{35}_{16}S$	—	−28.847	β^-	87.44 d	β^-: 0.167 max (avg 0.0488) No γ
$^{37}_{16}S$	—	−27.0	β^-	5.06 min	β^-: 1.6 max (90%) 4.7 max (10%) γ: 3.09 (90%)
$^{38}_{16}S$	—	−26.8	β^-	2.87 h	β^-: 1.1 max (95%), 3.0 max (5%) γ: 1.88 (95%) Daughter radiations from ^{38}Cl
$^{35}_{17}Cl$	75.53	−29.015	—	—	—
$^{37}_{17}Cl$	24.47	−31.765	—	—	—
$^{35}_{18}Ar$	—	−23.05	β^+	1.8 s	β^+: 4.94 max γ: 0.511 (200%, $\gamma^\pm$), 1.22 (5%) 1.76 (2%)
$^{37}_{18}Ar$	—	−30.951	EC	35.02 d	γ: Cl X rays
$^{40}_{19}K$	0.0118	−33.533	β^- 89% EC 11%	1.28×10^9 y	β^-: 1.312 max (avg 0.585) γ: 1.461 (11%), Ar X rays
$^{42}_{19}K$	—	−35.02	β^-	12.36 h	β^-: 1.996 max (avg 0.822) (18%) 3.521 max (avg 1.564) (82%) γ: 1.525 (17.9%)
$^{55}_{25}Mn$	100	−57.705	—	—	—
$^{55}_{26}Fe$	—	−57.474	EC	2.70 y	γ: Mn X rays
$^{59}_{26}Fe$	—	−60.660	β^-	45.53 d	β^-: 0.131 max (avg 0.036) (1.3%) 0.273 max (avg 0.081) (45.3%) 0.465 max (avg 0.149) (53.2%) 1.565 max (0.2%) γ: 0.143 (1.0%), 0.192 (3.0%), 1.099 (56.1%), 1.292 (43.6%)
$^{57}_{27}Co$	—	−59.339	EC	270.9 d	γ: 0.014 (9%), 0.122 (86%), 0.136 (11%), Fe X rays
$^{60}_{27}Co$	—	−61.651	β^-	5.271 y	β^-: 0.318 max (avg 0.096) (99.92%) 1.491 max (0.08%) γ: 1.173 (99.98%), 1.332 (99.90%)
$^{57}_{28}Ni$	—	−56.10	EC 60% β^+ 40%	36.08 h	β^+: 0.843 max γ: 0.127 (13%), 0.511 (80%, $\gamma^\pm$), 1.38 (78%), 1.76 (7%), 1.92 (15%), Co X rays
$^{60}_{28}Ni$	26.16	−64.471	—	—	—
$^{65}_{29}Cu$	30.9	−67.27	—	—	—

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$^{65}_{30}Zn$	—	−65.92	EC 98.5% β^+ 1.5%	243.9 d	β^+: 0.330 max (avg 0.143) γ: 0.511 (3.0%, $\gamma^{\pm}$), 1.116 (51%), Cu X rays e^-: 1.107
$^{85}_{36}Kr$	—	−81.48	β^-	10.72 y	β^-: 0.687 max (avg 0.251) γ: 0.514 (0.43%)
$^{84}_{37}Rb$	—	−79.753	EC 70% β^+ 26% β^- 4%	32.77 d	β^+: 1.658 max (avg 0.756) (14%), 0.777 max (avg 0.338) (12%), β^-: 0.890 max (avg 0.331) γ: 0.511 (52%, $\gamma^{\pm}$), 0.882 (71%) Kr X rays
$^{90}_{38}Sr$	—	−85.95	β^-	29.12 y	β^-: 0.546 max (avg 0.196), no γ Daughter radiations from ^{90}Y
$^{85}_{39}Y$	—	−77.79	β^+ 70% EC 30%	5.0 h	β^+: 2.24 max γ: 0.231 (13%), 0.511 (140%, $\gamma^{\pm}$), 0.770 (8%), 2.16 (9%), Sr X rays e^-: 0.215
$^{86}_{39}Y$	—	−79.23	EC 67% β^+ 33%	14.74 h	β^+: 3.17 max (1.8%) and others; avg β^+ 0.759 γ: 0.443 (17%), 0.511 (66%, $\gamma^{\pm}$), 0.628 (33%), 0.703 (15%), 0.777 (22%), 1.077 (83%), 1.153 (31%), 1.854 (17%), 1.925 (21%), Sr X rays
$^{90}_{39}Y$	—	−86.50	β^-	64.0 h	β^-: 2.284 max (avg 0.935), no γ
$^{99}_{43}Tc$	—	−87.33	β^-	2.12×10^5 y	β^-: 0.294 max (avg 0.101), no γ
$^{99m}_{43}Tc$	—	−87.18	IT	6.02 h	γ: 0.140 (89%), Tc X rays e^-: 0.002, 0.119
$^{103}_{45}Rh$	100	−88.014	—	—	—
$^{103m}_{45}Rh$	—	−87.974	IT	56.12 min	γ: 0.040 (0.07%), Rh X rays e^-: 0.017, 0.037, 0.039
$^{103}_{46}Pd$	—	−87.46	EC	16.96 d	γ: 0.062 (0.001%), 0.295 (0.003%), 0.357 (0.022%), 0.497 (0.004%), Rh X rays Daughter radiations from ^{103m}Rh
$^{113}_{48}Cd$	12.26	−89.041	—	—	—
$^{114}_{48}Cd$	28.86	−90.018	—	—	—
$^{115}_{49}In$	95.70	−89.54	β^-	5.1×10^{15} y	β^-: 0.494 max (avg 0.152), no γ
$^{116m}_{49}In$	—	−88.14	β^-	54.15 min	β^-: 1.007 max γ: 0.417 (29%), 0.819 (11%), 1.097 (56%), 1.294 (84%), 1.507 (10%), 2.112 (16%)
$^{126}_{52}Te$	18.71	−90.05	—	—	—
$^{126}_{53}I$	—	−87.90	EC 60.2% β^- 36.5% β^+ 3.3%	13.02 d	β^-: 1.251 max (8%) and others; avg β^- 0.290 β^+: 1.130 max (avg 0.508) γ: 0.341 (39%), 0.491 (3%) 0.511 (6.6%, $\gamma^{\pm}$), 0.666 (33%), 0.754 (4%), Te X rays

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$^{131}_{53}I$	—	−87.441	β^-	8.05 d	β^-: 0.248 max (avg 0.069) (2%) 0.334 max (avg 0.097) (7%) 0.606 max (avg 0.192) (89%) 0.807 max (0.6%) γ: 0.080 (2.6%), 0.284 (6.1%), 0.364 (81%), 0.637 (7.3%), 0.723 (1.8%) e^-: 0.046, 0.330
$^{126}_{54}Xe$	0.090	−89.15	—	—	Daughter radiations from ^{131m}Xe
$^{137}_{55}Cs$	—	−86.9	β^-	30.0 y	—
$^{137}_{56}Ba$	11.3	−88.0	—	—	β^-: 1.174 max (5%) 0.512 max (avg 0.173) (95%) γ: 0.662 (85%, ^{137m}Ba), Ba X rays e^-: 0.624, 0.656
$^{137m}_{56}Ba$	—	−87.4	IT	2.55 min	—
$^{191}_{76}Os$	—	−36.4	β^-	15.4 d	γ: 0.662 (90%), Ba X rays e^-: 0.624, 0.656 β^-: 0.142 max (avg 0.038) γ: 0.129 (26%), Ir X rays e^-: 0.029, 0.031, 0.039, 0.053 Daughter radiations from ^{191m}Ir included above
$^{191m}_{77}Ir$	—	−36.5	IT	4.94 s	γ: 0.129 (26%), Ir X rays e^-: 0.029, 0.031, 0.039, 0.053
$^{197}_{79}Au$	100	−31.17	—	—	—
$^{198}_{79}Au$	—	−29.59	β^-	2.696 d	β^-: 0.225 max (avg 0.079) (1%) 0.961 max (avg 0.315) (99%) γ: 0.412 (96%), 0.676 (1%), 1.088 (0.2%), Hg X rays e^-: 0.329, 0.398
$^{198}_{80}Hg$	10.2	−30.97	—	—	—
$^{203}_{80}Hg$	—	−25.26	β^-	46.60 d	β^-: 0.213 max (avg 0.058) γ: 0.279 (82%), Tl X rays
$^{205}_{81}Tl$	70.50	−23.81	—	—	—
$^{205}_{82}Pb$	—	−23.77	EC	1.43×10^7 y	γ: Tl L X rays
$^{206}_{82}Pb$	25.1	−23.79	—	—	—
$^{210}_{82}Pb$	—	−14.73	β^-	22.3 y	β^-: 0.017 max (avg 0.004) (80%) 0.063 max (avg 0.016) (20%) γ: 0.047 (4%), Bi X rays e^-: 0.030, 0.043 Daughter radiations from ^{210}Bi, ^{210}Po
$^{214}_{82}Pb$	—	−0.15	β^-	26.8 min	β^-: 1.024 max (6%) and others; avg β^- 0.219 γ: 0.053 (1%), 0.242 (7%), 0.295 (19%), 0.352 (37%), 0.786 (1%) e^-: 0.037, 0.049 Daughter radiations from ^{214}Bi, ^{214}Po
$^{210}_{83}Bi$	—	−14.79	β^-	5.012 d	β^-: 1.162 max (avg. 0.389), no γ
$^{214}_{83}Bi$	—	−1.19	β^-	19.9 min	β^-: 3.27 max (18%) and others; avg β^- 0.638 γ: 0.609 (46%), 1.120 (15%), 1.765 (15%),
$^{210}_{84}Po$	—	−15.95	α	138.38 d	α: 5.305 (100%) γ: 0.802 (0.0011%)

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$^{214}_{84}$Po	—	−4.47	α	164 μs	α: 7.69 γ: 0.800 (0.010%)
$^{218}_{84}$Po	—	8.38	α (99.98%) β^- (0.02%)	3.05 min	α: 6.003 β^-: 0.256 max Daughter radiations from ^{214}Pb, ^{214}Bi, ^{214}Po
$^{219}_{86}$Rn	—	8.85	α	3.96 s	α: 6.82 (80%), 6.55 (12%), 6.42 (7%) γ: 0.271 (10%), 0.402 (7%), Po X rays
$^{220}_{86}$Rn	—	10.61	α	55.6 s	α: 6.29 γ: 0.55 (0.07%) Daughter radiations from ^{216}Po
$^{222}_{86}$Rn	—	16.39	α	3.8235 d	α: 5.490 γ: 0.510 (0.078%) Daughter radiations from ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po
$^{226}_{88}$Ra	—	23.69	α	1600 y	α: 4.602 (5.5%), 4.785 (94.4%) γ: 0.186 (3.3%), 0.262 (0.005%), Rn X rays e^-: 0.088, 0.170 Daughter radiations from ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po
$^{235}_{92}$U	0.720	40.93	α	7.038×10^8 y	α: 4.218 (6%), 4.326 (5%), 4.366 (18%), 4.400 (56%), 4.417 (2%), 4.505 (2%), 4.558 (4%), 4.599 (5%) γ: 0.109 (2%), 0.144 (11%), 0.163 (5%), 0.186 (54%), 0.202 (1%), 0.205 (5%), Th X rays e^-: 0.016, 0.020 Daughter radiations from ^{231}Th, etc.
$^{238}_{92}$U	99.276	47.33	α	4.468×10^9 y	α: 4.149 (23%), 4.198 (77%) γ: 0.050 (0.070%), Th X rays e^-: 0.030, 0.033, 0.046, 0.050 Daughter radiations from ^{234}Th, ^{234m}Pa, etc.
$^{239}_{94}$Pu	—	48.60	α	24,065 y	α: 5.105 (11%), 5.143 (15%), 5.156 (74)% γ: 0.010 (0.001%), 0.039 (0.006%), 0.052 (0.021%), 0.099 (0.001%), 0.129 (0.006%), 0.375 (0.002%), 0.414 (0.002%), U X rays e^-: 0.009, 0.013, 0.018, 0.022, 0.031, 0.034, 0.047 Daughter radiations from ^{235}U, etc.

Source: Most of the decay data were obtained with the utility code, DEXRAX: K. F. Eckerman, R. J. Westfall, J. C. Ryman, and M. Cristy, *Nuclear Decay Data Files of the Dosimetry Research Group*, ORNL/TM-12350, Oak Ridge National Laboratory, Oak Ridge, Tenn. (December 1993). See also K. F. Eckerman, R. J. Westfall, J. C. Ryman, and M. Cristy, "Availability of Nuclear Decay Data in Electronic Form, Including Beta Spectra not Previously Published," *Health Phys.* **67**, 338–345 (1994). The author is grateful to Dr. Eckerman for his substantial help. Values of the mass differences, Δ, are from the *Radiological Health Handbook*, U.S. Public Health Service Publ. No. 2016, Bureau of Radiological Health, Rockville, Md. (1970).