APPENDIX B. CHARACTERISTICS OF IMPORTANT RADIONUCLIDES

B.1 DISCUSSION

The following Table B.1 lists radionuclides whose characteristics are most often referenced in the variety of studies and evaluations discussed in Chapters 1–7. It includes isotopes for HLW, TRUW, LLW, and UMT as defined by EPA,[1] NRC,[2,3] and DOE.[4,5] The data in Table B.1 were obtained from refs. 6–9.

B.2 REFERENCES

1. U.S. Environmental Protection Agency, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," *Code of Federal Regulations*, 40 CFR Part 191 (July 1, 1997).

2. U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste," *Code of Federal Regulations*, 10 CFR Part 61 (Jan. 1, 1997).

3. U.S. Nuclear Regulatory Commission, "Biomedical Waste Disposal," *Fed. Regist*. **46**(47), 16230–16234 (Mar. 11, 1981).

4. U.S. Department of Energy, DOE Order 5820.2A, *Radioactive Waste Management*, Washington, D.C. (Sept. 26, 1988).

5. U.S. Department of Energy, Energy Information Administration, *Domestic Uranium Mining and Milling Industry 1992—Viability Assessment*, DOE/EIA-0477(92), Washington, D.C. (December 1993).

6. D. C. Kocher, *Radioactive Decay Data Tables*, DOE/TIC-11026, U.S. Department of Energy, Washington, D.C. (1981).

7. D. C. Kocher, *A Radionuclide Decay Data Base—Index and Summary Table*, NUREG/CR-1413, ORNL/NUREG-70, Oak Ridge National Laboratory, Oak Ridge, Tennessee (May 1980).

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

9. A. G. Croff, *ORIGEN2—A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code*, ORNL-5621, Oak Ridge National Laboratory, Oak Ridge, Tennessee (July 1980).

Table B.1. Characteristics of important radionuclides[a]

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	ϵ	γ and X	(MeV/dis)	(W/Ci)		
^{3}H	1	1.233E+01 y	β		0.00568		5.68E−03	3.37E−05	9.650E+03	^{3}He
^{14}C	6	5.730E+03 y	β		0.0495		4.95E−02	2.93E−04	4.457E+00	^{14}N
^{26}Al	13	7.2E+05 y	EC		0.4451	2.6758	3.079	1.825E−02	1.91E−02	^{26}Mg
^{32}Si	14	650 y	β		0.0647		2.10E−01	1.245E−03	1.719E+01	^{32}P
^{32}P	15	14.282 d	β		0.6947		6.95E−01	4.12E−03	2.853E+05	^{32}S
^{35}S	16	87.51 d	β		0.0486		4.86E−02	2.88E−04	4.263E+04	^{35}Cl
^{36}Cl	17	3.01E+05 y	β (98.1%); EC (1.9%)		0.2460		2.460E−01	1.458E−03	3.299E−02	^{36}Ar; ^{36}S
^{40}K	19	1.277E+09 y	β (89.33%): EC (10.67%)		0.4545	0.1559	6.104E−01	3.62E−03	6.983E−06	^{40}Ca; ^{40}Ar
^{45}Ca	20	163.8 d	β		0.0770		7.70E−02	4.56E−04	1.780E+04	^{45}Sc
^{46}Sc	21	83.83 d	β	0.1120	2.0095		2.122	1.257E−02	3.381E+04	^{46}Ti
^{51}Cr	24	27.704 d	EC		0.0031	0.0325	3.56E−02	2.11E−04	9.240E+04	^{51}V
^{54}Mn	25	312.20 d	EC		0.0034	0.8360	8.394E−01	4.975E−03	7.738E+03	^{54}Cr
^{55}Fe	26	2.73 y	EC		0.0038	0.0016	5.4E−03	3.2E−05	2.500E+03	^{55}Mn
^{59}Fe	26	44.496 d	β		0.1174	1.1882	1.3056	7.741E−03	4.918E+04	^{59}Co
^{57}Co	27	271.77 d	EC		0.0176	0.1252	1.428E−01	8.464E−01	8.456E+03	^{57}Fe
^{58}Co	27	70.92 d	EC		0.0336	0.9758	1.0094	5.99E−03	3.181E+04	^{58}Fe
^{60}Co	27	5.271 y	β		0.0958	2.5058	2.6016	1.541E−02	1.131E+03	^{60}Ni
^{60m}Co	27	10.47 min	IT (99.75%); β (0.25%)		0.0536	0.0066	6.02E−02	3.57E−04	2.993E+08	^{60}Co; ^{60}Ni
^{59}Ni	28	7.5E+04 y	EC		0.0043	0.0024	6.72E−03	3.98E−05	8.079E−02	^{59}Co
^{63}Ni	28	1.001E+02 y	β		0.0171		1.71E−02	1.01E−04	6.168E+01	^{63}Cu

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	ϵ	γ and X	(MeV/dis)	(W/Ci)		
^{65}Zn	30	244.1 d	EC		0.0066	0.5838	5.90E−01	3.51E−03	8.237E+03	^{65}Cu
^{67}Ga	31	3.261 d	EC		0.0333	0.1549	1.882E−01	1.115E−03	5.975E+05	^{67}Zn
^{75}Se	34	119.77 d	EC		0.0134	0.3924	4.06E−01	2.41E−03	1.453E+04	^{75}As
^{79}Se	34	<6.5E+04 y			0.0529		5.29E−02	3.13E−04	6.966E−02	^{79}Br
^{85}Kr	36	1.072E+01 y	β		0.2505	0.0022	2.53E−01	1.50E−03	3.923E+02	^{85}Rb
^{86}Rb	37	18.66 d	β		0.6670	0.0945	7.62E−01	4.52E−03	8.138E+04	^{86}Sr
^{89}Sr	38	50.55 d	β		0.5829	0.0001	5.83E−01	3.46E−03	2.905E+04	^{89}Y
^{90}Sr	38	2.85E+01 y	β		0.1958		1.96E−01	1.16E−03	1.364E+02	^{90}Y
^{90}Y	39	2.671 d	β		0.9332		9.33E−01	5.54E−03	5.441E+05	^{90}Zr
^{91}Y	39	58.51 d	β		0.6039	0.0036	6.07E−01	3.60E−03	2.452E+04	^{91}Zr
^{93}Zr	40	1.53E+06 y	β		0.0471	0.0018	4.89E−02	2.90E−04	2.513E−03	^{93}Nb
^{95}Zr	40	64.02 d	β		0.1200	0.7337	8.54E−01	5.06E−03	2.148E+04	^{95}Nb
^{93m}Nb	41	1.36E+01 y	IT		0.0281	0.0018	2.99E−02	1.77E−04	2.826E+02	^{93}Nb
^{94}Nb	41	2.03E+04 y	β		0.1454	1.5715	1.7169	1.018E−02	1.873E−01	^{94}Mo
^{95}Nb	41	34.97 d	β		0.0435	0.7643	8.078E−01	4.788E−03	3.910E+04	^{95}Mo
^{93}Mo	42	3500 y	EC		0.0051	0.0107	1.58E−02	9.37E−05	1.10E+00	^{93}Nb
^{99}Mo	42	2.748 d	β		0.4076	0.2723	6.799E−01	4.028E−03	4.796E+05	^{99}Tc
^{99}Tc	43	2.13E+05 y	β		0.0846		8.46E−02	5.01E−04	1.695E−02	^{99}Ru
^{99m}Tc	43	6.006 h	IT		0.0142	0.1240	1.382E−01	8.186E−04	5.271E+06	^{99}Tc
^{103}Ru	44	39.254 d	β		0.1105	0.4851	5.96E−01	3.53E−03	3.227E+04	^{103}Rh
^{106}Ru	44	1.020 y	β		0.1004		1.004E−01	5.951E−04	3.346E+03	^{106}Rh
^{103m}Rh	45	56.12 min	IT		0.0375	0.0017	3.92E−02	2.32E−04	3.253E+07	^{103}Rh
^{106}Rh	45	2.17 h	β		0.3144	2.8826	3.197	1.894E−02	3.560E+09	^{106}Pd

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	ϵ	γ and X	(MeV/dis)	(W/Ci)		
^{107}Pd	46	6.5E+06 y	β			0.0093	9.3E−03	5.5E−05	5.143E−04	^{107}Ag
^{110}Ag	47	24.6 s	β (99.70%); EC (0.30%)		1.1842	0.0316	1.216	7.208E−03	4.169E+09	^{110}Cd; ^{110}Pd
^{110m}Ag	47	249.76 d	β (98.64%); IT (1.36%)		0.0755	2.7392	2.815	1.669E−02	4.750E+03	^{110}Cd; ^{110}Ag
^{113}Cd	48	9.3E+15 y	β		0.0933		9.13E−02	5.412E−04	3.402E−13	^{113}In
^{113m}Cd	48	1.37E+01 y	β (99.9%); IT (0.1%)			0.1834	1.83E−01	1.08E−03	2.168E+02	^{113}In; ^{113}Cd
^{115m}Cd	48	44.6 d	β		0.6029	0.0329	6.36E−01	3.76E−03	2.546E+04	^{115}In
^{111}In	49	2.807 d	EC		0.0340	0.4053	4.393E−01	2.604E−03	4.157E+05	^{111}Cd
^{113m}In	49	1.658 h	IT		0.1340	0.2555	3.89E−01	2.31E−03	1.673E+07	^{113}In
^{114m}In	49	49.51 d	IT (95.7%); EC (4.3%)		0.1431	0.0943	2.37E−01	1.40E−03	2.313E+04	^{114}In; ^{114}Cd
^{113}Sn	50	115.09 d	EC		0.1394	0.2808	4.20E−01	2.48E−03	1.004E+04	^{113}In
^{117m}Sn	50	13.61 d	IT		0.1613	0.1580	3.19E−01	1.89E−03	7.969E+04	^{117}Sn
^{119m}Sn	50	293.0 d	IT		0.0783	0.0114	8.97E−02	5.32E−04	4.478E+03	^{119}Sn
^{121m}Sn	50	5.5E+01 y	IT (77.6%); β (22.4%)		0.0352	0.0050	4.02E−02	2.43E−04	5.912E+01	^{121}Sn; ^{121}Sb
^{123}Sn	50	129.2 d	β		0.5222	0.0069	5.29E−01	3.14E−03	8.219E+03	^{123}Sb
^{125}Sn	50	9.64 d	β		0.8110	0.3124	1.123	6.656E−03	1.084E+05	^{125}Sb
^{126}Sn	50	~1E+05 y	β		0.1249	0.0573	1.82E−01	1.08E−03	2.837E−02	^{126}Sb
^{124}Sb	51	60.20 d	β		0.3897	1.8523	2.242	1.329E−02	1.749E+04	^{124}Te
^{125}Sb	51	2.73 y	β		0.1257	0.4434	5.69E−01	3.37E−03	1.032E+03	^{125}Te
^{126}Sb	51	12.4 d	β		0.3527	2.7496	3.102	1.839E−02	8.360E+04	^{126}Te
^{126m}Sb	51	19.0 min	β (86%); IT (14%)		0.6323	1.5484	2.181	1.292E−02	7.854E+07	^{126}Te; ^{126}Sb
^{123m}Te	52	119.7 d	IT		0.1020	0.1482	2.502E−01	1.482E−03	8.870E+03	^{123}Te
^{125m}Te	52	58 d	IT		0.1106	0.0361	1.467E−01	8.690E−04	1.801E+04	^{125}Te
^{127}Te	52	9.35 h	β		0.2248	0.0048	2.30E−01	1.36E−03	2.639E+06	^{127}I

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	ϵ	γ and X	(MeV/dis)	(W/Ci)		
^{127m}Te	52	109 d	IT (97.6%); β (2.4%)		0.0821	0.0111	9.32E−02	5.52E−04	9.432E+03	^{127}Te; ^{127}I
^{129}Te	52	1.160 h	β		0.5422	0.0624	6.05E−01	3.58E−03	2.094E+07	^{129}I
^{129m}Te	52	33.6 d	IT (64%); β (36%)		0.2663	0.0370	3.03E−01	1.80E−03	3.013E+04	^{129}Te; ^{129}I
^{123}I	53	13.2 h	EC		0.0276	0.1729	2.005E−01	1.188E−03	1.940E+06	^{123}Te
^{125}I	53	60.14 d	EC		0.0179	0.0423	6.02E−02	3.57E−04	1.737E+04	^{125}Te
^{129}I	53	1.57E+07 y	β		0.0556	0.0248	8.04E−02	4.77E−04	1.765E−04	^{129}Xe
^{131}I	53	8.040 d	β		0.1913	0.3826	5.74E−01	3.40E−03	1.240E+05	^{131}Xe
^{133}Xe	54	5.245 d	β		0.1363	0.0459	1.82E−01	1.08E−03	1.872E+05	^{133}Cs
^{134}Cs	55	2.062 y	β		0.1639	1.5555	1.719	1.019E−02	1.294E+03	^{134}Ba
^{135}Cs	55	3.0E+06 y	β		0.0563		5.63E−02	3.32E−04	1.151E−03	^{135}Ba
^{137}Cs	55	3.017E+01 y	β (94.6%); β (5.4%)			0.1708	1.71E−01	1.01E−03	8.698E+01	^{137m}Ba; ^{137}Ba
^{133}Ba	56	1.054E+01 y	EC		0.0547	0.4045	4.592E−01	2.722E−03	2.500E+02	^{133}Cs
^{137m}Ba	56	2.552 min	IT		0.0652	0.5991	6.64E−01	3.94E−03	5.379E+08	^{137}Ba
^{141}Ce	58	32.50 d	β		0.1707	0.0770	2.48E−01	1.47E−03	2.848E+04	^{141}Pr
^{144}Ce	58	284.9 d	β		0.0918	0.0192	1.11E−01	6.58E−04	3.190E+03	^{144}Pr
^{143}Pr	59	13.58 d	β		0.3156		3.16E−01	1.87E−03	6.731E+04	^{143}Nd
^{144}Pr	59	17.28 min	β		1.2091	0.0289	1.238	7.338E−03	7.555E+07	^{144}Nd
^{144m}Pr	59	7.2 min	IT (99.96%); β (0.04%)		0.0464	0.0121	5.85E−02	3.43E−04	1.814E+08	^{144}Pr; ^{144}Nd
^{146}Pm	61	5.53 y	EC (66.1%); β (33.9%)		0.0928	0.7542	8.47E−01	5.02E−03	4.428E+02	^{146}Nd; ^{146}Sm
^{147}Pm	61	2.6234 y	β		0.6196		6.20E−02	3.67E−04	9.270E+02	^{147}Sm
^{148}Pm	61	5.370 d	β		0.7235	0.5747	1.298	7.691E−03	1.643E+05	^{148}Sm
^{148m}Pm	61	41.29 d	β (95.4%); IT (4.6%)		0.1695	1.9861	2.156	1.278E−02	2.136E+04	^{148}Sm; ^{148}Pm

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	ϵ	γ and X	(MeV/dis)	(W/Ci)		
^{151}Sm	62	9.0E+01 y	β		0.1251		1.25E−01	7.41E−04	2.631E+01	^{151}Eu
^{152}Eu	63	1.333E+01 y	EC (72.08%); β (27.92%)		0.1275	1.1628	1.290	7.646E−03	1.729E+02	^{152}Sm; ^{152}Gd
^{154}Eu	63	8.8 y	β		0.2794	1.2531	1.532	9.081E−03	2.699E+02	^{154}Gd
^{155}Eu	63	4.96 y	β		0.0650	0.0633	1.28E−01	7.59E−04	4.651E+02	^{155}Gd
^{153}Gd	64	241.6 d	EC		0.0399	0.1015	1.414E−01	8.381E−04	3.526E+03	^{153}Eu
^{157}Tb	65	150 y	EC		0.0031	0.0050	8.10E−03	4.802E−05	1.519E+01	^{157}Gd
^{158}Tb	65	150 y	EC (82%) β (18%)				9.02E−01	5.347E−03	1.508E+01	^{158}Gd; ^{158}Dy
^{160}Tb	65	72.3 d	β		0.2535	1.1271	1.381	8.186E−03	1.129E+04	^{160}Dy
^{169}Yb	70	32.02 d	EC		0.1117	0.3121	4.238E−01	2.512E−03	2.414E+04	^{169}Tm
^{175}Hf	72	70.0 d	EC		0.0439	0.3646	4.085E−01	2.422E−03	1.066E+04	^{175}Lu
^{181}Hf	72	42.39 d	β		0.1943	0.5441	7.54E−01	4.47E−03	1.702E+04	^{181}Ta
^{182}Ta	73	115.0 d	β		0.2073	1.3011	1.508	8.940E−03	6.253E+03	^{182}W
^{187}Re	75	4.6E+10 y	β		0.0007		2.59	1.535E−02	3.823E−08	^{187}Os
^{192}Ir	77	73.831 d	β (95.4%); EC (4.6%)		0.2162	0.8137	1.030	6.105E−03	9.211E+03	^{192}Pt; ^{192}Os
^{201}Tl	81	3.046 d	EC		0.0481	0.0924	1.40E−01	8.30E−04	2.132E+05	^{201}Hg
^{207}Tl	81	4.77 min	β		0.4931	0.0022	4.95E−01	2.93E−03	1.904E+08	^{207}Pb
^{208}Tl	81	3.053 min	β		0.5979	3.3742	3.972	2.354E−02	2.945E+08	^{208}Pb
^{209}Pb	82	3.253 h	β		0.1980		1.98E−01	1.17E−03	4.544E+06	^{209}Bi
^{210}Pb	82	2.232E+01 y	β		0.0343		3.43E−02	2.029E−04	7.630E+01	^{210}Bi
^{211}Pb	82	36.1 min	β		0.4523	0.0678	5.20E−01	3.083E−03	2.468E+07	^{211}Bi
^{212}Pb	82	10.64 h	β		0.1752	0.1453	3.20E−01	1.90E−03	1.389E+06	^{212}Bi
^{211}Bi	83	2.14 min	α (99.727%); β (0.273%)	6.5505	0.0099	0.0467	6.607	3.916E−02	4.184E+08	^{207}Tl; ^{211}Po

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	ϵ	γ and X	(MeV/dis)	(W/Ci)		
^{212}Bi	83	1.0092 h	α (35.94%); β (64.06%)	2.1740	0.5025	0.1061	2.783	1.649E−02	1.465E+07	^{208}Tl; ^{212}Po
^{213}Bi	83	45.59 min	α (2.16%); β (97.84%)	0.1268	0.4563	0.0825	6.66E−01	3.95E−03	1.934E+07	^{209}Tl; ^{213}Po
^{209}Po	84	102 y	α (99.74%) EC (0.26%)				4.9645	2.943E−01	1.68E+01	^{205}Pb; ^{209}Bi
^{210}Po	84	138.4 d	α	5.3044			5.304	3.144E−02	4.493E+03	^{206}Pb
^{212}Po	84	2.98E−07 s	α	8.7844			8.784	5.207E−02	1.774E+17	^{208}Pb
^{213}Po	84	4.2E−06 s	α	8.3757			8.375	4.964E−02	1.261E+16	^{209}Pb
^{215}Po	84	1.780E−03 s	α	7.3864			7.386	4.378E−02	2.948E+13	^{211}Pb
^{216}Po	84	1.50E−02 s	α	6.7785			6.779	4.018E−02	3.482E+11	^{212}Pb
^{217}At	85	3.23E−02 s	α	7.0657		0.0002	7.066	4.189E−02	1.610E+12	^{213}Bi
^{219}Rn	86	3.96 s	α	6.8122	0.0064	0.0560	6.875	4.076E−02	1.301E+10	^{215}Po
^{220}Rn	86	55.6 s	α	6.2878		0.0005	6.288	3.727E−02	9.223E+08	^{216}Po
^{222}Rn	86	3.825 d	α	5.4892		0.0004	5.490	3.255E−02	1.538E+05	^{218}Po
^{221}Fr	87	4.9 min	α	6.3571	0.0084	0.0277	6.393	3.789E−02	1.772E+08	^{217}At
^{223}Fr	87	21.8 min	β		0.3805	0.0542	4.35E−01	2.85E−03	3.868E+07	^{223}Ra
^{223}Ra	88	11.43 d	α	5.6972	0.0731	0.1348	5.905	3.500E−02	5.121E+04	^{219}Rn
^{224}Ra	88	3.66 d	α	5.6751	0.0022	0.0103	5.688	3.372E−02	1.593E+05	^{220}Rn
^{225}Ra	88	14.2 d	β		0.1057	0.0137	1.19E−01	7.08E−04	3.920E+04	^{225}Ac
^{226}Ra	88	1.600E+03 y	α	4.7741	0.0035	0.0067	4.784	2.836E−02	9.887E−01	^{222}Rn
^{228}Ra	88	5.75 y	β		0.0116		1.16E−02	6.88E−05	2.340E+02	^{228}Ac
^{225}Ac	89	10.0 d	α	5.7501	0.0257	0.0176	5.793	3.434E−02	5.803E+04	^{221}Fr
^{227}Ac	89	2.177E+01 y	β (98.62%); α (1.38%)	0.0673	0.0125	0.0002	8.00E−02	4.74E−04	7.233E+01	^{227}Th; ^{223}Fr
^{228}Ac	89	6.13 h	β		0.4292	0.9269	1.356	8.038E−03	2.242E+06	^{228}Th
^{227}Th	90	18.718 d	α	5.9022	0.0543	0.1113	6.068	3.597E−02	3.073E+04	^{223}Ra
^{228}Th	90	1.913 y	α	5.3992	0.0201	0.0034	5.423	3.214E−02	8.196E+02	^{224}Ra
^{229}Th	90	7.340E+03 y	α	4.8620		0.0343	4.896	2.902E−02	2.127E−01	^{225}Ra

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	ϵ	γ and X	(MeV/dis)	(W/Ci)		
^{230}Th	90	7.54E+04 y	α	4.6651		0.0004	4.665	2.765E−02	2.109E−02	^{226}Ra
^{231}Th	90	1.0633 d	β	0.1732		0.0295	2.03E−01	1.21E−03	5.316E+05	^{231}Pa
^{232}Th	90	1.405E+10 y	α	4.0056		0.0002	4.006	2.375E−02	1.097E−07	^{228}Ra
^{234}Th	90	24.10 d	β		0.0158	0.0094	2.52E−02	1.49E−04	2.316E+04	^{234}Pa
^{231}Pa	91	3.276E+04 y	α	4.9230	0.0483	0.0399	5.011	2.970E−02	4.723E−02	^{227}Ac
^{233}Pa	91	27.0 d	β		0.1941	0.2042	3.98E−01	2.36E−03	2.075E+04	^{233}U
^{234m}Pa	91	1.17 min	β (99.87%); IT (0.13%)		0.8227	0.0121	8.35E−01	4.95E−03	6.868E+08	^{234}U; ^{234}Pa
^{232}U	92	6.89E+01 y	α	5.3065		0.0002	5.307	3.146E−02	2.140E+01	^{228}Th
^{233}U	92	1.592E+05 y	α	4.8141	0.0055	0.0013	4.821	2.857E−02	9.680E−03	^{229}Th
^{234}U	92	2.454E+05 y	α	4.7732		0.0001	4.773	2.829E−02	6.248E−03	^{230}Th
^{235}U	92	7.037E+08 y	α	4.3785	0.0426	0.1561	4.577	2.713E−02	2.161E−06	^{231}Th
^{236}U	92	2.342E+07 y	α	4.4793	0.0108	0.0015	4.492	2.662E−02	6.469E−05	^{232}Th
^{238}U	92	4.468E+09 y	α	4.1945	0.0095	0.0013	4.205	2.492E−02	3.362E−07	^{234}Th
^{236}Np	93	1.550E+05 y	EC (91%); β (8.9%); α (0.20%)		0.1967	0.1411	3.38E−01	2.00E−03	1.317E−02	^{236}U; ^{236}Pu; ^{232}Pa
^{237}Np	93	2.140E+06 y	α	4.7604	0.0640	0.0327	4.857	2.879E−02	7.049E−04	^{233}Pa
^{239}Np	93	2.355 d	β		0.2521	0.1740	4.26E−01	2.53E−03	2.320E+05	^{239}Pu
^{236}Pu	94	2.851 y	α	5.7521	0.0126	0.0020	5.767	3.418E−02	5.313E+02	^{232}U
^{238}Pu	94	8.774E+01 y	α	5.4871	0.0099	0.0018	5.499	3.2593E−02	1.712E+01	^{234}U
^{239}Pu	94	2.411E+04 y	α	5.1011		0.0001	5.101	3.024E−02	6.216E−02	^{235}U
^{240}Pu	94	6.563E+03 y	α	5.1549			5.155	3.056E−02	2.279E−01	^{236}U
^{241}Pu	94	1.44E+01 y	β	0.0001		0.0052	5.3E−03	3.2E−05	1.030E+02	^{241}Am
^{242}Pu	94	3.763E+05 y	α	4.8901	0.0081	0.0014	4.900	2.904E−02	3.818E−03	^{238}U
^{244}Pu	94	8.26E+07 y	α (99.875%); SPF (0.125%)	4.5751	0.0007	0.0001	4.576	2.712E−02	1.774E−05	^{240}U; (fission products)
^{241}Am	95	4.327E+02 y	α	5.4801	0.0304	0.0287	5.539	3.283E−02	3.432E+00	^{237}Np
^{242}Am	95	16.01 h	β (82.7%); EC (17.3%)		0.1781	0.0180	1.96E−01	1.16E−03	8.084E+05	^{242}Cm; ^{242}Pu

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	ϵ	γ and X	(MeV/dis)	(W/Ci)		
^{242m}Am	95	1.41E+02 y	IT (99.55%); α (0.45%)	0.0232	0.0403	0.0049	6.84E−02	4.05E−04	9.718E+00	^{242}Am; ^{238}Np
^{243}Am	95	7.380E+03 y	α	5.2656		0.0481	5.3137	3.1496E−02	1.993E−01	^{239}Np
^{242}Cm	96	162.94 d	α	6.0434	0.0090	0.0018	6.0542	3.5886E−02	3.306E+03	^{238}Pu
^{243}Cm	96	2.85E+01 y	α (99.76%); EC (0.24%)	5.8380	0.1129	0.1316	6.083	3.605E−02	5.162E+01	^{239}Pu; ^{243}Am
^{244}Cm	96	1.811E+01 y	α	5.7965		0.0016	5.798	3.437E−02	8.090E+01	^{240}Pu
^{245}Cm	96	8.5E+03 y	α	5.3631	0.1342	0.1178	5.615	3.329E−02	1.717E−01	^{241}Pu
^{246}Cm	96	4.73E+03 y	α	5.3764	0.0072	0.0014	5.385	3.192E−02	3.072E−01	^{242}Pu
^{247}Cm	96	1.56E+07 y	α	4.9475		0.3152	5.263	3.119E−02	9.278E−05	^{243}Pu
^{248}Cm	96	3.40E+05 y	α (91.74%); SPF (8.26%)	4.6524			4.6524	2.7577E−02	4.251E−03	^{244}Pu; (fission products)
^{252}Cf	98	2.645 y	α (96.908%); SPF (3.092%)	5.9308	0.0051	0.0011	5.9370	3.5191E−02	5.378E+02	^{248}Cm; (fission products)

[a]Based on refs. 6–9.

[b]y = years; d = days; h = hours; min = minutes; and s = seconds.

[c]α = alpha decay; β = negative beta decay; EC = electron capture; IT = isomeric transition (radioactive transition from one nuclear isomer to another of lower energy); and SPF = spontaneous fission.

[d]α = alpha decay; ϵ = total electron emissions; and γ and X = gamma and X-ray photons.

[e]The sum of the average energies for different radiation types in MeV/disintegration or W/Ci (includes alpha and beta particles, discrete electrons, and photons). The "value" indicates the amount of energy (heat) that could be deposited in a radioactive material from each decay event if none of the radiation escaped from the material. Neutrinos are not included.