

### Units and Conversion Factors

1 Curie (Ci) = $3.7 \times 10^{10}$ decays/sec	1 eV = $1.6 \times 10^{-12}$ ergs
1 mCi = $3.7 \times 10^7$ decays/sec	1 Becquerel (Bq) = 1 decay/sec
1 $\mu$ Ci = 37000 decays/sec	1 Rad = 100 ergs/g
1 REM = 1 Rad (RBE)	1 Gray (Gy) = 1 Joule/Kg = 100 Rad

### Properties of common Gamma Sources used in our Laboratory

Isotope	Half-life	Gamma Energy (KeV)	Yield
$Cs^{137}$	30 years	661.657	0.85
$Na^{22}$	2.62 years	511.0034	1.8
		1274.54	1.0
$Mn^{54}$	303 days	834.848	1.0
$Co^{60}$	5.27 years	1173.237	1.0
		1332.501	1.0
$K^{40}$	$1.277 \times 10^9$ years	1460.83	0.1062

### Properties of some Beta Sources used in our Class

Isotope	Half-life	Maximum Energy (KeV)	Yield
$H^3$	12.26 years	18.6	1.0
$C^{14}$	5730 years	156	1.0
$P^{32}$	14.3 days	1709	1.0
$S^{35}$	87.4 days	167	1.0
$I^{131}$	8.04 days	806	1.0
$K^{40}$	$1.277 \times 10^9$ years	1312.1	0.8928

**Mass Attenuation Coefficients of Selected Materials**  
in units of  $cm^2/g$

Energy (KeV)	Water	Lead	Aluminum	Bone	Muscle	Air
10	5.18	133.0	26.3	20.3	5.27	4.99
15	1.58	115.0	7.93	6.32	1.63	1.55
20	0.775	85.7	3.41	2.79	0.793	0.752
30	0.370	29.7	1.12	0.962	0.373	0.349
40	0.267	14.0	0.567	0.512	0.268	0.248
50	0.227	7.81	0.369	0.349	0.227	0.208
60	0.206	4.87	0.280	0.274	0.205	0.188
80	0.184	2.33	0.203	0.209	0.183	0.167
100	0.171	5.40	0.171	0.180	0.170	0.154
150	0.151	1.97	0.138	0.149	0.149	0.136
200	0.137	0.991	0.122	0.133	0.136	0.123
300	0.119	0.404	0.104	0.114	0.118	0.107
400	0.106	0.231	0.0927	0.102	0.105	0.0955
500	0.0968	0.161	0.0844	0.0927	0.0960	0.0870
600	0.0896	0.125	0.0780	0.0857	0.0888	0.0805
800	0.0786	0.0885	0.0684	0.0752	0.0779	0.0707
1000	0.0707	0.0708	0.0613	0.0676	0.0700	0.0636
1500	0.0575	0.0517	0.0500	0.0550	0.0570	0.0518

Isotope	half-life	gamma energies
$U^{238}$	$4.468 \times 10^9$ years	—
$Th^{234}$	24.1 days	63.3 (4.47%) 92.38 (2.60%) 92.80 (2.56%)
$Pa^{234m}$	1.17 minutes	765 (0.207%) 1001 (0.59%)
99.8% 0.13% $Pa^{234}$	6.75 hours	100 (50%) 700 (24%) 900 (70%)
$U^{234}$	$2.47 \times 10^5$ years	53.2 (0.123%)
$Th^{230}$	$8.0 \times 10^4$ years	67.7 (0.373%)
$Ra^{226}$	1602 years	186.2 (3.50%)
$Rn^{222}$	3.823 days	510 (0.076%)
$Pc^{218}$	3.05 minutes	—
99.98% 0.02% $Pb^{214}$	26.8 minutes	53.2 (1.1%) 242.0 (7.46%) 295.2 (19.2%) 351.9 (37.1%) 785.9 (1.09%)
$At^{218}$	2 seconds	—
$Bi^{214}$	19.7 minutes	609.3 (46.1%) 768.4 (4.89%) 806.2 (1.23%) 934.1 (3.16%) 1120.3 (15.0%) 1238.1 (5.92%) 1377.7 (4.02%) 1408.0 (2.48%) 1509.2 (2.19%) 1764.5 (15.9%)
99.98% 0.02% $Po^{214}$	164 microsec	806.2 (1.23%) 799 (0.014%)
$Tl^{210}$	1.3 minutes	296 (80%) 795 (100%) 1310 (21%)
$Pb^{210}$	21 years	46.5 (4.05%)
$Bi^{210}$	5.01 days	—
$Po^{210}$	138.4 days	803 (0.0011%)
$Pb^{206}$	Stable	

### U-238 Decay series: Characteristic X-rays

Isotope	half-life	X-ray energies(KeV)
$U^{238}$	$4.468 \times 10^9$ years	16.2(8%)
$Th^{234}$	24.1 days	16.7 (10%)
$Pa^{234m}$	1.17 minutes	17.2 (0.42%)
99.8% 0.13% $Pa^{234}$	6.75 hours	—
$U^{234}$	$2.47 \times 10^5$ years	12.97 (3.66%) 16.2 (4.87%) 18.98 (1.05%)
$Th^{230}$	$8.0 \times 10^4$ years	15.2 (8.5%)
$Ra^{226}$	1602 years	14.3 (0.858%) 81.1 (0.192%) 83.8 (0.319%) 94.6 (0.11%)
$Rn^{222}$	3.823 days	—
$Po^{218}$	3.05 minutes	—
99.98% 0.02% $Pb^{214}$	26.8 minutes	13.0 (13.8%) 74.8.0 (6.41%) 77.1 (10.8%) 87.1 (3.71%) 89.6 (1.12%)
$At^{218}$	2 seconds	—
$Bi^{214}$	19.7 minutes	13.4 (0.552%) 76.9 (0.351%) 79.3 (0.588%) 89.5 (0.203%)
99.98% 0.02% $Po^{214}$	164 microsec	—
$Tl^{210}$	1.3 minutes	—
$Pb^{210}$	21 years	13.0 (24.3%)
$Bi^{210}$	5.01 days	—
$Po^{210}$	138.4 days	—
$Pb^{206}$	Stable	—

Isotope	half-life	gamma energies
$Th^{232}$	$1.405 \times 10^{10}$ years	63.8 (0.267%)
$Ra^{228}$	6.7 years	—
$Ac^{228}$	6.13 hours	57.7 (0.487%) 99.5 (1.28%) 129.0 (2.42%) 154.0 (0.737%) 209.3 (3.88%) 270.2 (3.43%) 328.0 (2.95%) 338.3 (11.3%) 409.5 (1.94%) 463.0 (4.44%) 772 (1.50%) 794.9 (4.36%) 835.7 (1.61%) 911.2 (26.6%) 964.8 (5.11%) 969.0 (16.2%) 1588.2 (3.27%)
$Th^{228}$	1.91 years	84.4 (1.22%)
$Ra^{224}$	3.64 days	241.0 (3.97%)
$Rn^{220}$	55 seconds	550 (0.07%)
$Po^{216}$	0.15 seconds	—
$Pb^{212}$	10.64 hours	238.6 (43.6%) 300.0 (3.34%)
$Bi^{212}$	60.6 minutes	39.9 (1.1%) 727.3 (6.65%) 785.4 (1.72%) 1620.5 (2.32%)
64.06% 35.94% $Po^{212}$ $Tl^{208}$	304 nsec 3.1 minutes	— 277.4 (6.31%) 510.77 (22.6%) 583.2 (84.5%) 763.1 (1.81%) 860.6 (12.4%)
$Pb^{208}$	stable	

### Th-232 Decay Series X-Ray radiation

Isotope	half-life	gamma energies
$Th^{232}$	$1.405 \times 10^{10}$ years	15.2 (8%)
$Ra^{228}$	6.7 years	—
$Ac^{228}$	6.13 hours	16.2 (36.2%) 90.0 (1.02%) 93.4 (1.66%) 105.2 (0.575%) 108.3 (0.195%)
$Th^{228}$	1.91 years	15.2 (9.7%)
$Ra^{224}$	3.64 days	14.3 (0.398%) 81.1 (0.0126%) 83.8 (0.209%)
$Rn^{220}$	55 seconds	—
$Po^{216}$	0.15 seconds	—
$Pb^{212}$	10.64 hours	13.0 (15.3%) 74.8 (10.5%) 77.1 (17.6%) 87.1 (6.1%) 89.6 (1.84%)
$Bi^{212}$	60.6 minutes	12.2 (8.2%)
64.06% $Po^{212}$ 35.94% $Tl^{208}$	304 nsec 3.1 minutes	— 12.6 (2.96%) 72.8 (2.03%) 75.0 (3.43%) 84.7 (1.18%) 87.1 (0.348%)
$Pb^{208}$	stable	

Isotope	half-life	gamma energy (KeV)
$U^{235}$	$7.038 \times 10^8$ years	143.8 (10.96%) 163.33 (5.08%) 185.7 (57.2%) 205.3 (5.01%)
$Th^{231}$	25.5 hours	25.64 (14.5%) 84.2 (6.6%)
$Pa^{231}$	$3.25 \times 10^4$ years	27.4 (10.3%) 300 (2.47%) 303 (2.87%)
$Ac^{227}$	21.6 years	70 (0.08%)
98.6% 1.4% $Th^{227}$	1.82 days	50.1 (8.0%) 236.0 (12.3%) 256.3 (7.0%) 300 (2.3%) 329.9 (2.7%)
$Fr^{223}$	22 minutes	50.1 (36%) 79.7 (9.1%) 234.8 (3%)
$Ra^{223}$	11.43 days	144.2 (3.22%) 154.2 (5.62%) 158.6 (0.69%) 269.5 (13.7%) 323.9 (3.93%) 338.3 (2.79%)
$Rn^{219}$	4 seconds	271.2 (10.8%) 401.8 (6.37%)
$Po^{215}$	1.78 millisec	—
$Pb^{211}$	36.1 minutes	404.9 (3.78%) 427.1 (1.75%) 832.0 (3.52%)
$Bi^{211}$	2.15 minutes	351.1 (12.95%)
0.28% 99.7% $Po^{211}$	0.52 seconds	569.6 (0.0016%) 897.8 (0.26%)
$Tl^{207}$	4.79 minutes	897 (0.16%)
$Pb^{207}$	stable	

### U-235 Decay Series X-Ray decays

Isotope	half-life	gamma energy (KeV)
$U^{235}$	$7.038 \times 10^8$ years	16.2 (31%) 90.0 (3.56%) 93.4 (5.81%) 105.2 (2.01%)
$Th^{231}$	25.5 hours	16.7 (96%)
$Pa^{231}$	$3.25 \times 10^4$ years	15.7 (44.8%)
$Ac^{227}$	21.6 years	—
98.6% 1.4% $Th^{227}$	18.2 days	15.2 (42%) 85.4 (1.86%) 88.5 (3.06%) 99.8 (1.06%)
$Fr^{223}$	22 minutes	15.2 (23.9%) 85.4 (1.69%) 88.5 (2.8%)
$Ra^{223}$	11.43 days	14.3 (24.5%) 81.1 (15%) 83.8 (24.9%) 94.6 (8.59%) 97.3 (2.8%)
$Rn^{219}$	4 seconds	13.4 (1.01%)
$Po^{215}$	1.78 millisec	—
$Pb^{211}$	36.1 minutes	—
$Bi^{211}$	2.15 minutes	12.2 (1.02%) 72.9 (1.25%)
0.28% 99.7% $Po^{211}$	0.52 seconds	—
$Tl^{207}$	4.79 minutes	—
$Pb^{207}$	stable	—