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SUBJECT: Buildup and Decay Factors for Members of the U-232 Decay Chain

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FROM: E. D. Arnold

Abstract

Activity ratios for the important members of the U-232 chain are presented in tabular form. These ratios are presented for (1) initially pure U-232, (2) initially pure Th-228, and (3) initially pure Ra-224.

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Buildup and Decay Factors for Members of the U-232 Decay Chain

The following tables give values of the activity buildup and decay factors for the important members of the U-232 decay chain. These factors were evaluated rigorously using the ORACLE. The decay chain with evaluated members underlined is as follows:

The activity of each underlined member as a function of time was evaluated using equations having the general form of

$$N_{i,1} = N_1^0 \lambda_1 \lambda_2 \dots \lambda_{i-1} \sum_{j=1}^i \frac{e^{-\lambda_j t}}{\pi (\lambda_k - \lambda_j)}$$

where

$N_{i,1}$ = concentration of isotope i starting with pure (1).

N_1^0 = initial concentration of isotope (1).

λ_1 = radioactive decay constant for isotope 1.

t = decay time.

Table I lists the activity ratios as a function of decay time for U-232, Th-228, Ra-224, Pb-212, Bi-212, and TL-208 when U-232 is the only material present initially.

Table II lists the activity ratios as a function of decay time for Th-228, Ra-224, Pb-212, Bi-212, and TL-208 when Th-228 is the only material present initially.

Table III lists the activity ratios as a function of decay time for Ra-224, Pb-212, Bi-212, and TL-208 when Ra-224 is the only material present initially.

If a given fuel initially contained all three isotopes, the total activity as a function of time would have to be summed from all three tables using the appropriate initial activities for each isotope.

Table I

Buildup and Decay of U-232 and Daughter Product Activities Following Separation

Time After Separation Sec	Activity Ratios					
	A U-232 A ⁰ U-232	A Th-228 A ⁰ U-232	A Ra-224 A ⁰ U-232	A Pb-212 A ⁰ U-232	A Bi-212 A ⁰ U-232	A Tl-208 A ⁰ U-232
	α	α	α	β	($\beta + \alpha$)	β
0	1.000000	0.000	0.000	0.000	0.000	0.000
1 x 10 ⁴	0.999997	1.15177 x 10 ⁻⁴	1.26132 x 10 ⁻⁶	7.18548 x 10 ⁻⁸	2.37355 x 10 ⁻⁸	7.99886 x 10 ⁻⁹
2	0.999994	2.30342	5.00801 x 10 ⁻⁶	5.54453 x 10 ⁻⁷	2.92152 x 10 ⁻⁷	9.84552 x 10 ⁻⁸
3	0.999991	3.45492	1.11852 x 10 ⁻⁵	1.78280 x 10 ⁻⁶	1.13593 x 10 ⁻⁶	3.82808 x 10 ⁻⁷
4	0.999988	4.60628	1.97403	4.03295 x 10 ⁻⁶	2.85621	9.62543
5	0.999985	5.75751	3.06196	7.52255	5.70163	1.92145 x 10 ⁻⁶
6	0.999982	6.90862	4.37756	1.24288 x 10 ⁻⁵	9.87051	3.32636
7	0.999979	8.05957	5.91555	1.88879	1.55184 x 10 ⁻⁵	5.52970
8	0.999976	9.21040	7.67114	2.70057	2.27698	7.67342
9	0.999973	1.03611 x 10 ⁻³	9.63953	3.68642	3.17185	1.06891 x 10 ⁻⁵
1 x 10 ⁵	0.999970	1.15116	1.18161 x 10 ⁻⁴	4.85229	4.24353	1.43007
2	0.999941	2.30097	4.40726	2.67940 x 10 ⁻⁴	2.52102 x 10 ⁻⁴	8.49584
3	0.999911	3.44941	9.27007	6.63626	6.39172	2.15401 x 10 ⁻⁴
4	0.999881	4.59648	1.54435 x 10 ⁻³	1.20692 x 10 ⁻³	1.17543 x 10 ⁻³	3.96120
5	0.999851	5.74225	2.26658	1.86941	1.83227	6.17475
6	0.999822	6.88661	3.07268	2.62744	2.58577	8.41404
7	0.999792	8.02966	3.94579	3.46188	3.41659	1.15139 x 10 ⁻³
8	0.999762	9.17131	4.87240	4.35734	4.30915	1.45218
9	0.999732	1.03116 x 10 ⁻²	5.84165	5.30150	5.25100	1.76959
1 x 10 ⁶	0.999703	1.14506	6.84486	6.28446	6.23211	2.10022
2	0.999406	2.27667	1.77180 x 10 ⁻²	1.70809 x 10 ⁻²	1.70222 x 10 ⁻²	5.73648
3	0.999108	3.39499	2.89170	2.82664	2.82076	9.50596
4	0.998812	4.50017	4.00345	3.93774	3.93191	1.32505 x 10 ⁻²

Table I (Continued)

Time After Separation Sec	Activity Ratios					
	A U-232 A ⁰ U-232 α	A Th-228 A ⁰ U-232 α	A Ra-224 A ⁰ U-232 α	A Pb-212 A ⁰ U-232 β	A Bi-212 A ⁰ U-232 ($\beta + \alpha$)	A Tl-208 A ⁰ U-232 β
5	0.998515	5.59231	5.10269	5.03641	5.03064	1.69533
6	0.998218	6.67162	6.18904	6.12223	6.11651	2.06126
7	0.997921	7.73827	7.26263	7.19528	7.18962	2.42290
8	0.997624	8.79232	8.32361	8.25567	8.25006	2.78027
9	0.997328	9.83398	9.37202	9.30365	9.29810	3.13346
1×10^7	0.997031	0.108634	0.104082	0.103392	0.103337	3.48246×10^{-2}
2	0.994072	0.205126	0.201206	0.200468	0.200418	6.75409
3	0.991121	0.290799	0.287442	0.286661	0.286615	9.65893
4	0.988178	0.366831	0.363975	0.363156	0.363114	0.122369
5	0.985245	0.434272	0.431861	0.431009	0.430971	0.145237
6	0.982320	0.494057	0.492043	0.491610	0.491126	0.165510
7	0.979404	0.547019	0.545359	0.544451	0.544420	0.183470
8	0.976497	0.593902	0.592558	0.591627	0.591598	0.199369
9	0.973598	0.635369	0.634305	0.633357	0.633328	0.213432
1×10^8	0.970708	0.672009	0.671195	0.670229	0.670205	0.225859
2	0.942273	0.864727	0.865292	0.864240	0.864228	0.291245
3	0.914672	0.906531	0.907506	0.906449	0.906443	0.305471
4	0.887879	0.901192	0.902275	0.901240	0.901235	0.303716
5	0.861871	0.881503	0.882596	0.881590	0.881579	0.297092
6	0.836624	0.857799	0.858873	0.857899	0.857890	0.289109
7	0.812118	0.833345	0.834394	0.833441	0.833431	0.280866
8	0.788329	0.809145	0.810166	0.809240	0.809235	0.272712
9	0.765237	0.785508	0.786503	0.785604	0.785598	0.264747
1×10^9	0.742821	0.762522	0.763485	0.762613	0.762603	0.256997

Table II

Buildup and Decay of Th-228 and Daughter Product Activities Following Separation

Time After Separation Sec.	Activity Ratios				
	A Th-228 A ⁰ Th-228	A Ra-224 A ⁰ Th-228	A Pb-212 A ⁰ Th-228	A Bi-212 A ⁰ Th-228	A Tl-208 A ⁰ Th-228
0	1.0	0.00	0.00	0.00	0.00
1.0 x 10 ⁴	0.999885	2.18174 x 10 ⁻²	1.86642 x 10 ⁻³	7.93466 x 10 ⁻⁴	2.67398 x 10 ⁻⁴
2.0	0.999770	4.31567 x 10 ⁻²	6.99375 x 10 ⁻³	4.35185 x 10 ⁻³	1.46657 x 10 ⁻³
3.0	0.999655	6.40283 x 10 ⁻²	1.47641 x 10 ⁻²	1.07478 x 10 ⁻²	3.62201 x 10 ⁻³
4.0	0.999539	8.44428 x 10 ⁻²	2.46635 x 10 ⁻²	1.95247 x 10 ⁻²	6.57982 x 10 ⁻³
5.0	0.999524	0.104410	3.62650 x 10 ⁻²	3.02262 x 10 ⁻²	1.01862 x 10 ⁻²
6.0	0.999309	0.123939	4.92132 x 10 ⁻²	4.24615 x 10 ⁻²	1.43095 x 10 ⁻²
7.0	0.999194	0.143040	6.32142 x 10 ⁻²	5.59049 x 10 ⁻²	1.88400 x 10 ⁻²
8.0	0.999079	0.161722	7.80232 x 10 ⁻²	7.02853 x 10 ⁻²	2.36861 x 10 ⁻²
9.0	0.998964	0.179995	9.34383 x 10 ⁻²	8.53786 x 10 ⁻²	2.87726 x 10 ⁻²
1.0 x 10 ⁵	0.998849	0.197866	0.109292	0.100999	3.40367 x 10 ⁻²
2	0.997699	0.356376	0.270914	0.262750	8.85468 x 10 ⁻²
3	0.996551	0.483310	0.412494	0.405705	0.136723
4	0.995403	0.584914	0.527838	0.522359	0.176035
5	0.994258	0.666197	0.620469	0.616078	0.207618
6	0.993113	0.731179	0.694608	0.691094	0.232899
7	0.991970	0.783084	0.753867	0.751057	0.253106
8	0.990828	0.824498	0.801183	0.798938	0.269242
9	0.989687	0.857496	0.838914	0.837123	0.282110
1.0 x 10 ⁶	0.988548	0.883742	0.868958	0.867532	0.292358
2	0.977227	0.971200	0.970118	0.970004	0.326891
3	0.966036	0.970854	0.971277	0.971307	0.327330
4	0.954973	0.960925	0.961509	0.961555	0.324044
5	0.944037	0.950052	0.950647	0.950694	0.320384
6	0.933226	0.939185	0.939777	0.939824	0.316721
7	0.922539	0.928443	0.929016	0.929063	0.313094
8	0.911974	0.917799	0.918378	0.918343	0.309509
9	0.901530	0.907288	0.907861	0.907905	0.305964

Table II (Continued)

Time After Separation Sec.	Activity Ratios				
	$\frac{A \text{ Th-228}}{A^0 \text{ Th-228}}$	$\frac{A \text{ Ra-224}}{A^0 \text{ Th-228}}$	$\frac{A \text{ Pb-212}}{A^0 \text{ Th-228}}$	$\frac{A \text{ Bi-212}}{A^0 \text{ Th-228}}$	$\frac{A \text{ Tl-208}}{A^0 \text{ Th-228}}$
1.0×10^7	0.891206	0.896898	0.897463	0.897508	0.302460
2	0.794248	0.799322	0.799826	0.799864	0.269554
3	0.707838	0.712360	0.712809	0.712844	0.240228
4	0.630829	0.634854	0.635258	0.635290	0.214093
5	0.562199	0.565790	0.566146	0.566174	0.190801
6	0.501035	0.504236	0.504554	0.504578	0.170043
7	0.446525	0.449377	0.449660	0.449682	0.151543
8	0.397946	0.400488	0.400740	0.400760	0.135056
9	0.354651	0.356916	0.357141	0.357160	0.120363
1.0×10^8	0.316067	0.318087	0.318287	0.318303	0.107268
2	9.98986×10^{-2}	0.100537	0.100600	0.100605	3.39039×10^{-2}
3	3.15747×10^{-2}	3.17763×10^{-2}	3.17963×10^{-2}	3.17979×10^{-2}	1.07159×10^{-2}
4	9.97972×10^{-3}	1.00435×10^{-2}	1.00498×10^{-2}	1.00503×10^{-2}	3.38695×10^{-3}
5	3.15426×10^{-3}	3.17441×10^{-3}	3.17641×10^{-3}	3.17651×10^{-3}	1.07048×10^{-3}
6	9.96960×10^{-4}	1.00333×10^{-3}	1.00396×10^{-3}	1.00401×10^{-3}	3.38351×10^{-4}
7	3.15106×10^{-4}	3.17119×10^{-4}	3.17319×10^{-4}	3.17336×10^{-4}	1.06942×10^{-4}
8	9.95949×10^{-5}	1.00231×10^{-4}	1.00294×10^{-4}	1.00299×10^{-4}	3.38008×10^{-5}
9	3.14787×10^{-5}	3.16798×10^{-5}	3.16998×10^{-5}	3.17014×10^{-5}	1.06834×10^{-5}
1.0×10^9	9.94938×10^{-6}	1.00129×10^{-5}	1.00193×10^{-5}	1.00197×10^{-5}	3.37664×10^{-6}

Table III

Buildup and Decay of Ra-224 and Daughter Product Activities Following Separation

Time After Separation Sec.	Activity Ratios			
	A Ra-224 A ⁰ Ra-224	A Pb-212 A ⁰ Ra-224	A Bi-212 A ⁰ Ra-224	A Tl-208 A ⁰ Ra-224
0	1.0	0.00	0.00	0.00
1.0 x 10 ⁴	0.978206	0.163633	1.79904 x 10 ⁻²	6.06276 x 10 ⁻³
2.0	0.956887	0.296619	4.81530 x 10 ⁻²	1.62276 x 10 ⁻²
3.0	0.936033	0.404107	0.385097	0.129778
4.0	0.915633	0.490393	0.450358	0.151771
5.0	0.895677	0.559062	0.523553	0.176437
6.0	0.876157	0.613100	0.584607	0.197013
7.0	0.857062	0.655001	0.632812	0.213258
8.0	0.838383	0.686843	0.669949	0.225773
9.0	0.820111	0.710359	0.697860	0.235179
1.0 x 10 ⁵	0.802238	0.726993	0.718128	0.242009
2.0	0.643586	0.702292	0.707644	0.238476
3.0	0.516309	0.582907	0.589241	0.198574
4.0	0.414203	0.470825	0.476240	0.160493
5.0	0.332289	0.378236	0.382636	0.128948
6.0	0.266575	0.303521	0.307060	0.103479
7.0	0.213857	0.243510	0.246351	8.30203 x 10 ⁻²
8.0	0.171564	0.195356	0.197634	6.66027 x 10 ⁻²
9.0	0.137635	0.156722	0.158550	5.34314 x 10 ⁻²
1.0 x 10 ⁶	0.110416	0.125729	0.127195	4.28647 x 10 ⁻²
2.0	1.21917 x 10 ⁻²	1.38824 x 10 ⁻²	1.40444 x 10 ⁻²	4.73296 x 10 ⁻³
3.0	1.34616 x 10 ⁻³	1.53284 x 10 ⁻³	1.55072 x 10 ⁻³	5.22593 x 10 ⁻⁴
4.0	1.48638 x 10 ⁻⁴	1.69250 x 10 ⁻⁴	1.71224 x 10 ⁻⁴	5.77025 x 10 ⁻⁵
5.0	1.64120 x 10 ⁻⁵	1.86880 x 10 ⁻⁵	1.89060 x 10 ⁻⁵	6.37132 x 10 ⁻⁶
6.0	1.81214 x 10 ⁻⁶	2.06345 x 10 ⁻⁶	2.08753 x 10 ⁻⁶	7.03498 x 10 ⁻⁷
7.0	2.00090 x 10 ⁻⁷	2.27838 x 10 ⁻⁷	2.30496 x 10 ⁻⁷	7.76772 x 10 ⁻⁸
8.0	2.20931 x 10 ⁻⁸	2.51570 x 10 ⁻⁸	2.54504 x 10 ⁻⁸	8.57678 x 10 ⁻⁹
9.0	2.43943 x 10 ⁻⁹	2.77773 x 10 ⁻⁹	2.81014 x 10 ⁻⁹	9.47017 x 10 ⁻¹⁰
1.0 x 10 ⁷	2.69353 x 10 ⁻¹⁰	3.06706 x 10 ⁻¹⁰	3.10284 x 10 ⁻¹⁰	1.04566 x 10 ⁻¹⁰
2.0	7.25508 x 10 ⁻²⁰	8.26119 x 10 ⁻²⁰	8.35758 x 10 ⁻²⁰	2.81650 x 10 ⁻²⁰
3.0	1.95417 x 10 ⁻²⁹	2.22518 x 10 ⁻²⁹	2.25113 x 10 ⁻²⁹	7.58631 x 10 ⁻³⁰

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