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***Tables for the Ingrowth of
Daughter Products from the
Decay of Plutonium Isotopes
used in Heat Sources.***

F. X. Haas and A. R. Campbell

June 12, 1972

AEC Research and Development Report

Monsanto

MOUND LABORATORY

Miamisburg, Ohio
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Tables for the Ingrowth of Daughter Products from the Decay of Plutonium Isotopes used in Heat Sources.

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Abstract

This paper lists in tabular and graphic form the ingrowth of activities, as a function of time, of all of the daughter products formed in the decay of the plutonium isotopes found in heat sources. The data are calculated from published half-life values using the Bateman equation. The paper is intended as a ready reference for the determination of these ingrowth data.

TABLES FOR THE INGROWTH OF DAUGHTER PRODUCTS FROM THE DECAY
OF PLUTONIUM ISOTOPES USED IN HEAT SOURCES

Introduction

This report is intended to be a quick and easy guide for determining, as a function of time, the ingrowth of atoms and total activities of the daughters of all plutonium isotopes present in the heat source material used at Mound Laboratory. This information has been requested repeatedly, especially for the ingrowth of ^{208}Tl from the decay of ^{238}Pu , for the ingrowth of ^{241}Am from ^{241}Pu , and for the ingrowth of radon from all isotopes of plutonium. Hence, this document is intended as a ready reference for those persons needing such information.

Plutonium Decay Chains

The typical composition [1] of the plutonium metal used in the fabrication of the sources is shown in Table 1.

TABLE 1

<u>Plutonium Isotope</u>	<u>Concentration (wt %)</u>
^{238}Pu	0.0001
^{239}Pu	80.27
^{240}Pu	15.87
^{241}Pu	3.00
^{242}Pu	0.72
^{243}Pu	0.14

Figures 1, 2, 3, 4, 5, and 6 show the complete decay chains for the decay of ^{238}Pu , ^{239}Pu , ^{240}Pu , ^{241}Pu , and ^{242}Pu , respectively. The half-lives and branching ratios used in the calculations of the ingrowth are also in the figures. These values are taken from Reference 2 unless otherwise noted.

FIGURE 1 - Decay chain of ${}^{236}\text{Pu}$

(a) See Reference 4

(b) Intermediate value of range given in Reference 2

FIGURE 2 - Decay chain of ${}^{238}\text{Pu}$

FIGURE 3 - Decay chain of ^{239}Pu

FIGURE 4 - Decay chain of ${}^{240}_{94}\text{Pu}$

FIGURE 5 - Decay chain of ^{241}Pu

FIGURE 6 - Decay chain of ${}^{242}\text{Pu}$

Tables for Daughter Product Ingrowth

The tables which follow list the relative number of daughter atoms and relative intensities of the daughter activities per unit value of parent plutonium isotope. The numbers in the tables were obtained from the Bateman equation for the decay of radioactive nuclide chains [3] as programmed for a Hewlett Packard 9100B Calculator. The half-lives listed in Figures 1 through 6 were used with time conversions based on the ephemeris second (i.e., 31,556,925.9747 sec/yr and 86,400 sec/day). Calculations internal to the program were carried out with 14 digit precision. The final results were arbitrarily rounded to four significant digits even though some half-lives are not known to this accuracy. At times short compared to the half-lives involved, the terms in the Bateman equation may differ only in the 15 or greater digits in which case the 14 digit precision will give erroneous results. In such cases, those entries in the tables have been left blank. The first entry in a column can be considered as an upper limit for those blank entries in the same column.

In addition to the tables, plots of the data for the relative activities of the daughters are also included so that other times may be interpolated with ease.

The tables and figures are as follows:

- Table 2: Relative Number of Atoms for Members of the ^{236}Pu Decay Chain
- Table 3: Relative Activity for Members of the ^{236}Pu Decay Chain
- Table 4: Relative Number of Atoms for Members of the ^{238}Pu Decay Chain
- Table 5: Relative Activity for Members of the ^{238}Pu Decay Chain
- Table 6: Relative Number of Atoms for Members of the ^{239}Pu Decay Chain
- Table 7: Relative Activity for Members of the ^{239}Pu Decay Chain
- Table 8: Relative Number of Atoms for Members of the ^{240}Pu Decay Chain
- Table 9: Relative Activity for Members of the ^{240}Pu Decay Chain
- Table 10: Relative Number of Atoms for Members of the ^{241}Pu Decay Chain
- Table 11: Relative Activity for Members of the ^{241}Pu Decay Chain
- Table 12: Relative Number of Atoms for Members of the ^{242}Pu Decay Chain
- Table 13: Relative Activity for Members of the ^{242}Pu Decay Chain
- Figure 7: Plot of the Relative Activities of the Members of the ^{236}Pu Decay Chain
- Figure 8: Plot of the Relative Activities of the Members of the ^{238}Pu Decay Chain
- Figure 9: Plot of the Relative Activities of the Members of the ^{239}Pu Decay Chain
- Figure 10: Plot of the Relative Activities of the Members of the ^{240}Pu Decay Chain
- Figure 11: Plot of the Relative Activities of the Members of the ^{241}Pu Decay Chain
- Figure 12: Plot of the Relative Activities of the Members of the ^{242}Pu Decay Chain

Use of the Tables

Two examples are given to show the use of these tables.

Example 1 - What is the intensity of the 2614 keV gamma ray due to ^{208}Tl after ten years in a one kilogram plutonium metal heat source?

^{208}Tl is a daughter of ^{238}Pu , which is present in the source material in a concentration of 0.0001 wt %; therefore, one milligram of ^{238}Pu is present in the one kilogram source. The original activity of ^{238}Pu at the time the source was fabricated is given by

$$\text{Activity} = N\lambda_{^{238}\text{Pu}}$$

where N = number of atoms of $^{238}\text{Pu} = N_0 W/M$
 N_0 = Avogadro's number = 6.023×10^{23} atoms/mole
 W = the weight of ^{238}Pu in grams
 M = the gram molecular weight
 $\lambda_{^{238}\text{Pu}} = (\ln 2)/(T_{1/2})_{^{238}\text{Pu}}$

$T_{1/2}$ = half-life of ^{238}Pu

For the source under consideration, the activity is 1.967×10^{10} dps. From Table 3, at the end of ten years, the ^{208}Tl activity is 1.067×10^{-2} of the original ^{238}Pu activity or 2.099×10^8 dps. Since the 2614 keV gamma ray is present [2] in 100% of the decays of ^{208}Tl , the intensity of the 2614 keV in the source is 2.099×10^8 gamma rays/sec. The intensity of the 583 keV transition, for instance, occurs in only 86% of the decays [2] of ^{208}Tl and its intensity would be 1.805×10^8 gamma rays/sec.

Example 2 - After eight years, what is the ratio of the intensities of the 59.6 keV gamma ray due to the ingrowth of ^{241}Am compared to the 43.5 keV gamma ray in typical ^{238}Pu material ignoring self-absorption for both gamma rays in the source?

The activity of ^{238}Pu when the source was fabricated is given by

$$\begin{aligned}\text{Activity} &= N\lambda_{238}\text{Pu} \\ &= (.8027W \times N_0/238) \lambda_{238}\text{Pu} \\ &= 5.082 \times 10^{11} \text{ W dps}\end{aligned}$$

where W = the weight in grams of the total plutonium present in the source.

The initial ^{241}Pu activity is

$$\begin{aligned}\text{Activity} &= N\lambda_{241}\text{Pu} \\ &= (.0072W \times N_0/241) \lambda_{241}\text{Pu} \\ &= 2.702 \times 10^{10} \text{ W dps}\end{aligned}$$

From Table 11, the relative activity of ^{241}Am after eight years is 0.01050 of the original activity of ^{241}Pu . From Table 4, the activity of ^{238}Pu has decreased to 0.9388 of its original activity. From Lederer et al. [2], the 59.6 keV transition following the decay of ^{241}Am occurs in 36% of the decays of ^{241}Am ; the 43.5 keV transition following the decay of ^{238}Pu occurs 0.038% of the time. Therefore, after eight years the ratio of the intensity of the 43.5 keV gamma ray from ^{238}Pu decay to the intensity of the 59.6 keV gamma ray from ^{241}Am decay is

$$\begin{aligned}R &= \frac{5.082 \times 10^{11} \times W \times 3.8 \times 10^{-4} \times .9388}{2.702 \times 10^{10} \times W \times .36 \times .01050} \\ R &= 1.78\end{aligned}$$

Similar examples can be worked for other daughter isotopes for other decay chains and for different time intervals.

Table 2

RELATIVE NUMBER OF ATOMS FOR MEMBERS OF THE ^{238}Pu DECAY CHAIN

time (yr)	^{238}Pu ($\times 1$)	^{234}U ($\times 1$)	^{230}Th ($\times 10^{-3}$)	^{226}Ra ($\times 10^{-5}$)	^{222}Rn ($\times 10^{-3}$)	^{218}Po ($\times 10^{-12}$)	^{214}Pb ($\times 10^{-5}$)	^{214}Bi ($\times 10^{-7}$)	^{210}Tl ($\times 10^{-9}$)	^{210}Po ($\times 10^{-18}$)	^{206}Pb ($\times 10^{-3}$)
0.5	0.8855	0.1142	0.2643	0.1306	0.2296	0.6020	0.1579	0.1498	0.2759	0.8017	.01514
1	0.7841	0.2148	0.9561	0.4861	0.8547	2.241	0.5901	0.5600	1.031	2.995	0.1162
2	0.6148	0.3812	3.140	1.620	2.848	7.467	1.970	1.870	3.443	10.00	0.8223
4	0.3780	0.6083	8.613	4.474	7.866	20.63	5.446	5.169	9.519	27.66	5.034
6	0.2324	0.7408	13.59	7.076	12.44	32.63	8.616	8.179	15.06	43.76	13.13
8	0.1429	0.8153	17.34	9.037	15.89	41.66	11.00	10.45	19.24	55.89	24.41
10	0.0879	0.8542	19.88	10.37	18.23	47.80	12.62	11.98	22.07	64.12	37.97
12	0.0540	0.8714	21.47	11.20	19.69	51.62	13.64	12.94	23.84	69.25	53.02
14	0.0332	0.8753	22.36	11.66	20.51	53.78	14.21	13.49	24.83	72.16	68.95
16	0.0204	0.8713	22.78	11.89	20.90	54.80	14.48	13.74	25.30	73.53	85.35
18	0.0126	0.8625	22.89	11.94	21.00	55.06	14.55	13.81	25.43	73.88	101.9
20	0.0077	0.8508	22.80	11.90	20.92	54.85	14.49	13.75	25.33	73.59	118.5
22	0.0047	0.8375	22.58	11.78	20.72	54.33	14.35	13.62	25.09	72.89	135.0
24	0.0029	0.8234	22.29	11.63	20.45	53.62	14.16	13.45	24.76	71.94	151.3
30	0.0007	0.7793	21.20	11.06	19.45	51.01	13.47	12.79	23.56	68.44	198.7
40	6×10^{-6}	0.7084	19.30	10.07	17.71	46.44	12.27	11.64	21.44	62.31	272.2
50	5×10^{-6}	0.6434	17.53	9.150	16.09	42.19	11.14	10.58	19.48	56.60	338.9
60	5×10^{-7}	0.5844	15.92	8.310	14.61	38.31	10.12	9.608	17.69	51.41	399.6
70	4×10^{-8}	0.5307	14.46	7.547	13.27	34.80	9.192	8.726	16.07	46.69	454.7
80	4×10^{-9}	0.4820	13.14	6.855	12.05	31.60	8.349	7.925	14.59	42.41	504.8
90	3×10^{-10}	0.4378	11.93	6.226	10.95	28.70	7.583	7.198	13.26	38.51	550.2
100	3×10^{-11}	0.3976	10.83	5.654	9.942	26.07	6.887	6.537	12.04	34.98	591.5
200	7.5×10^{-22}	0.1518	4.137	2.159	3.796	9.955	2.630	2.496	4.597	13.36	844.0

Table 3

RELATIVE ACTIVITY FOR MEMBERS OF THE ^{238}Pu DECAY CHAIN

Time (yr)	^{238}Pu ($\times 1$)	^{232}U ($\times 10^{-2}$)	^{228}Th ($\times 10^{-2}$)	^{224}Ra ($\times 10^{-2}$)	^{220}Rn ($\times 10^{-2}$)	^{216}Po ($\times 10^{-2}$)	^{212}Pb ($\times 10^{-2}$)	^{212}Bi ($\times 10^{-2}$)	^{208}Tl ($\times 10^{-2}$)	^{212}Po ($\times 10^{-2}$)
0.5	0.8855	0.4520	0.03944	0.03735	0.03734	0.03734	0.03707	0.03705	0.01334	0.02372
1	0.7841	0.8503	0.1427	0.1390	0.1390	0.1390	0.1386	0.1385	0.04985	0.08861
2	0.6148	1.509	0.4685	0.4633	0.4632	0.4631	0.4626	0.4625	0.1665	0.2958
4	0.3780	2.408	1.285	1.279	1.279	1.280	1.279	1.279	0.4603	0.8183
6	0.2324	2.932	2.028	2.024	2.023	2.024	2.023	2.023	0.7282	1.295
8	0.1429	3.227	2.587	2.584	2.584	2.584	2.583	2.585	0.9303	1.653
10	0.0879	3.381	2.966	2.966	2.965	2.965	2.963	2.963	1.067	1.897
12	0.0540	3.449	3.204	3.203	3.202	3.202	3.203	3.201	1.153	2.049
14	0.0332	3.465	3.336	3.334	3.336	3.336	3.336	3.337	1.201	2.135
16	0.0204	3.449	3.399	3.397	3.399	3.399	3.400	3.399	1.223	2.175
18	0.0126	3.414	3.416	3.415	3.415	3.415	3.416	3.416	1.230	2.186
20	0.0077	3.368	3.402	3.403	3.402	3.402	3.402	3.401	1.225	2.177
22	0.0047	3.315	3.369	3.369	3.370	3.370	3.369	3.369	1.213	2.156
24	0.0029	3.259	3.326	3.326	3.326	3.326	3.325	3.327	1.197	2.128
30	0.0007	3.085	3.163	3.163	3.163	3.164	3.163	3.164	1.139	2.025
40	6×10^{-5}	2.804	2.880	2.880	2.880	2.880	2.881	2.879	1.037	1.843
50	5×10^{-6}	2.547	2.616	2.617	2.617	2.617	2.616	2.617	0.9419	1.674
60	5×10^{-7}	2.313	2.375	2.376	2.376	2.376	2.376	2.377	0.8554	1.521
70	4×10^{-8}	2.101	2.158	2.158	2.158	2.158	2.158	2.158	0.7770	1.381
80	4×10^{-9}	1.908	1.961	1.960	1.960	1.960	1.960	1.960	0.7055	1.255
90	3×10^{-10}	1.733	1.780	1.780	1.781	1.780	1.780	1.780	0.6412	1.139
100	3×10^{-11}	1.574	1.616	1.617	1.617	1.616	1.617	1.617	0.5822	1.035
200	7.5×10^{-22}	0.6009	0.6173	0.6174	0.6157	0.6175	0.6175	0.6174	0.2223	0.3953

Table 4

RELATIVE NUMBER OF ATOMS FOR MEMBERS OF THE ^{238}Pu DECAY CHAIN

Time (yr)	^{238}Pu ($\times 1$)	^{234}U ($\times 10^{-2}$)	^{230}Th ($\times 10^{-7}$)	^{226}Ra ($\times 10^{-12}$)	^{222}Rn ($\times 10^{-17}$)	^{218}Po ($\times 10^{-21}$)	^{214}Pb ($\times 10^{-19}$)	^{214}Bi ($\times 10^{-18}$)	^{214}Po ($\times 10^{-26}$)	^{210}Pb ($\times 10^{-13}$)	^{210}Bi ($\times 10^{-16}$)	^{210}Po ($\times 10^{-15}$)
0.5	0.9961	0.3940	0.0276	0.043	0.0775							
1	0.9921	0.7864	0.1105	0.064	0.0919							
2	0.9843	1.567	0.4408	0.359	0.2762							
4	0.9689	3.108	1.754	1.869	1.255	0.863	0.1220	0.0024	0.0162			
6	0.9537	4.626	3.926	7.492	4.910	26.50	2.394	1.660	2.317	0.1866	0.06135	0.1034
8	0.9388	6.120	6.942	16.44	10.73	58.88	5.211	3.740	5.204	0.2390	0.09333	0.1673
10	0.9241	7.591	10.79	31.56	20.57	113.4	10.01	7.276	10.09	0.4128	0.2065	0.4168
12	0.9096	9.038	15.46	54.07	35.24	194.7	17.15	12.50	17.38	0.7225	0.4222	0.9333
14	0.8954	10.46	20.93	85.39	55.66	307.8	27.07	19.81	27.51	1.255	0.7753	1.790
16	0.8813	11.87	27.20	127.1	82.85	458.2	40.32	29.54	41.00	2.080	1.327	3.167
18	0.8675	13.25	34.25	179.8	117.2	648.8	57.05	41.83	58.07	3.188	2.067	5.042
20	0.8539	14.61	42.06	245.4	160.0	886.0	77.90	57.17	79.35	4.724	3.104	7.673
22	0.8406	15.94	506.4	325.3	212.2	1175	103.3	75.80	105.2	6.782	4.485	11.22
24	0.8274	17.26	599.5	420.8	274.5	1520	133.6	98.13	136.2	9.476	6.288	15.88
30	0.7891	21.09	92.26	812.7	530.2	2937	258.1	189.6	263.1	22.08	14.76	38.04
40	0.7292	27.08	159.9	1886	1231	6821	599.4	440.5	611.2	64.41	43.19	113.4
50	0.6739	32.61	243.8	3613	2359	13070	1148	844.0	1171	146.3	98.23	260.6
60	0.6227	37.73	342.5	6122	3997	22150	1946	1430	1985	282.7	189.9	507.5
70	0.5754	42.45	455.1	9535	6226	34490	3031	2228	3091	488.8	328.5	882.3
80	0.5318	46.82	580.4	13960	9117	50510	4438	3262	4527	780.1	524.3	1414
90	0.4914	50.85	717.4	19500	12740	70570	6201	4558	6324	1171	787.2	2129
100	0.4541	54.58	865.4	26250	17150	95000	8347	6136	8513	1676	1127	3054
200	0.2062	79.35	2788	175800	114800	636200	55910	41090	57020	15490	10420	28520

Table 5

RELATIVE ACTIVITY FOR MEMBERS OF THE ^{238}Pu DECAY CHAIN

Time (yr)	^{238}Pu ($\times 1$)	^{234}U ($\times 10^{-6}$)	^{230}Th ($\times 10^{-11}$)	^{226}Ra ($\times 10^{-12}$)	^{222}Rn ($\times 10^{-12}$)	^{218}Po ($\times 10^{-12}$)	^{214}Pb ($\times 10^{-12}$)	^{214}Bi ($\times 10^{-12}$)	^{214}Po ($\times 10^{-12}$)	^{210}Pb ($\times 10^{-12}$)	^{210}Bi ($\times 10^{-12}$)	^{210}Po ($\times 10^{-12}$)
0.5	0.9961	1.401	0.3029	0.0024	0.0065							
1	0.9921	2.795	1.213	0.0035	0.0077							
2	0.9843	5.570	4.838	0.0197	0.0232	0.0131	0.0210	0.00056	0.0027			
4	0.9689	11.05	19.25	0.1024	0.1053	0.0959	0.1034	0.0816	0.0827	0.0227		
6	0.9537	16.44	43.09	0.4106	0.4119	0.4012	0.4125	0.3891	0.3914	0.0803	0.03925	0.02396
8	0.9388	21.75	76.19	0.9010	0.9001	0.8915	0.8979	0.8767	0.8792	0.1029	0.05970	0.03876
10	0.9241	26.98	118.4	1.730	1.726	1.717	1.725	1.705	1.705	0.1777	0.1321	0.09658
12	0.9096	32.13	169.7	2.963	2.956	2.948	2.955	2.930	2.936	0.3110	0.2701	0.2163
14	0.8954	37.18	229.7	4.680	4.669	4.660	4.664	4.644	4.648	0.5401	0.4960	0.4148
16	0.8813	42.19	298.5	6.966	6.950	6.937	6.947	6.924	6.927	0.8952	0.8489	0.7338
18	0.8675	47.10	375.9	9.854	9.831	9.823	9.830	9.805	9.811	1.372	1.322	1.168
20	0.8539	51.93	461.6	13.45	13.42	13.41	13.42	13.40	13.41	2.033	1.986	1.778
22	0.8406	56.66	555.8	17.83	17.80	17.79	17.80	17.77	17.77	2.919	2.869	2.600
24	0.8274	61.35	658.0	23.06	23.11	23.01	23.02	23.00	23.01	4.078	4.022	3.680
30	0.7891	74.97	1013	44.54	44.48	44.47	44.47	44.44	44.45	9.503	9.442	8.814
40	0.7292	96.26	1755	103.4	103.3	103.3	103.3	103.3	103.3	27.72	27.63	26.28
50	0.6739	115.9	2676	198.0	197.9	197.9	197.8	197.8	197.8	62.97	62.84	60.38
60	0.6227	134.1	3759	335.5	335.3	335.4	335.3	335.2	335.4	121.7	121.5	117.6
70	0.5754	150.9	4995	522.6	522.3	522.2	522.3	522.3	522.2	210.4	210.1	204.4
80	0.5318	166.4	6370	765.1	764.8	764.7	764.7	764.6	764.8	335.7	335.4	327.6
90	0.4914	180.8	7873	1069	1069	1068	1068	1068	1068	504.0	503.6	493.3
100	0.4541	194.0	9498	1439	1439	1438	1438	1438	1438	721.3	720.9	707.6
200	0.2062	282.1	30600	9635	9630	9632	9634	9632	9633	6667	6666	6608

Table 6

RELATIVE NUMBER OF ATOMS FOR MEMBERS OF THE ^{239}Pu DECAY CHAIN

Time (yr)	^{239}Pu ($\times 1$)	^{235}U ($\times 10^{-4}$)	^{231}Th ($\times 10^{-15}$)	^{231}Pa ($\times 10^{-12}$)	^{227}Ac ($\times 10^{-15}$)	^{227}Th ($\times 10^{-17}$)	^{223}Ra ($\times 10^{-16}$)	^{219}Rn ($\times 10^{-23}$)	^{215}Po ($\times 10^{-27}$)	^{211}Pb ($\times 10^{-20}$)	^{211}Bi ($\times 10^{-21}$)	^{207}Tl ($\times 10^{-21}$)
0.5	.9999	.1421	.0578									
1	.9999	.2842	.1160	.007								
2	.9999	.5684	.2326	.041								
4	.9999	1.137	.4656	.217	.0051			.0033	.0143	.0032	.0016	.0033
6	.9998	1.705	.6986	.483	.0118	.0013	.0042	.0064	.0300	.0052	.0028	.0055
8	.9998	2.273	.9316	.886	.0495	.0100	.0535	.0281	.1232	.0169	.0098	.0210
10	.9997	2.841	1.165	1.376	.0861	.0183	.1055	.0495	.2206	.0283	.0165	.0365
12	.9997	3.410	1.398	1.996	.1570	.0344	.2054	.0898	.3976	.0501	.0297	.0655
14	.9996	3.978	1.631	2.710	.2407	.0532	.3242	.1377	.6109	.0761	.0452	.0998
16	.9995	4.546	1.864	3.534	.3492	.0782	.4793	.2010	.8938	.1104	.0657	.1454
18	.9995	5.114	2.096	4.481	.4954	.1119	.6901	.2861	1.271	.1565	.0932	.2065
20	.9994	5.682	2.329	5.524	.6652	.1510	.9326	.3842	1.707	.2096	.1249	.2768
22	.9994	6.250	2.562	6.699	.8831	.2006	1.244	.5106	2.268	.2780	.1659	.3678
24	.9993	6.818	2.795	7.983	1.137	.2588	1.609	.6583	2.926	.3581	.2139	.4738
30	.9992	8.522	3.494	12.46	2.121	.4847	3.026	1.231	5.473	.6684	.3996	.8857
40	.9989	11.36	4.658	22.17	4.708	1.080	6.754	2.742	12.19	1.486	.8887	1.971
50	.9986	14.20	5.822	34.65	8.624	1.981	12.41	5.030	22.36	2.725	1.630	3.615
60	.9983	17.04	6.985	49.87	13.99	3.215	20.15	8.166	36.30	4.423	2.646	5.868
70	.9980	19.87	8.149	67.88	20.94	4.817	30.21	12.24	54.39	6.627	3.965	8.792
80	.9977	22.71	9.311	88.66	29.53	6.796	42.63	17.27	76.75	9.352	5.595	12.41
90	.9974	25.54	10.47	112.2	39.81	9.165	57.50	23.29	103.5	12.61	7.545	16.73
100	.9972	28.38	11.64	138.5	51.85	11.94	74.90	30.33	134.8	16.43	9.828	21.79
200	.9943	56.68	23.24	553.0	270.9	62.45	392.2	158.8	705.8	85.98	51.44	114.1
400	.9887	113.0	46.35	2205	1255	289.5	1818	736.2	3273	398.7	238.5	529.0
600	.9831	169.1	69.33	4945	2964	683.6	4294	1738	7728	941.5	563.3	1249
800	.9775	224.8	92.17	8761	5390	1243	7809	3162	14050	1712	1024	2272
1000	.9720	280.2	114.9	13640	8525	1966	12350	5001	22230	2708	1620	3594

Table 7

RELATIVE ACTIVITY FOR MEMBERS OF THE ^{239}Pu DECAY CHAIN

Time (yr)	^{239}Pu ($\times 1$)	^{235}U ($\times 10^{-8}$)	^{231}Th ($\times 10^{-8}$)	^{231}Pa ($\times 10^{-12}$)	^{227}Ac ($\times 10^{-12}$)	^{227}Th ($\times 10^{-12}$)	^{223}Ra ($\times 10^{-12}$)	^{219}Rn ($\times 10^{-12}$)	^{215}Po ($\times 10^{-12}$)	^{211}Pb ($\times 10^{-12}$)	^{211}Bi ($\times 10^{-12}$)	^{207}Tl ($\times 10^{-12}$)
0.5	.9999	.0488	.0484									
1	.9999	.0976	.0972	.0052								
2	.9999	.1953	.1949	.0308								
4	.9999	.3906	.3900	.1629	.0058			.0063	.0062	.0115	.0094	.0089
6	.9998	.5857	.5853	.3625	.0133	.0066	.0003	.0124	.0130	.0186	.0169	.0147
8	.9998	.7808	.7805	.6649	.0560	.0490	.0417	.0541	.0533	.0601	.0581	.0563
10	.9997	.9763	.9752	1.033	.0972	.0894	.0822	.0952	.0955	.1006	.0980	.0977
12	.9997	1.171	1.171	1.498	.1773	.1684	.1601	.1728	.1721	.1786	.1763	.1753
14	.9996	1.367	1.367	2.034	.2718	.2605	.2526	.2650	.2645	.2705	.2682	.2674
16	.9995	1.562	1.561	2.652	.3943	.3830	.3736	.3868	.3869	.3922	.3899	.3893
18	.9995	1.757	1.756	3.363	.5594	.5477	.5378	.5505	.5502	.5561	.5535	.5529
20	.9994	1.952	1.951	4.146	.7511	.7421	.7268	.7393	.7389	.7448	.7419	.7413
22	.9994	2.147	2.146	5.027	.9972	.9819	.9695	.9825	.9818	.9879	.9855	.9850
24	.9993	2.342	2.342	5.991	1.284	1.267	1.254	1.267	1.267	1.272	1.270	1.269
30	.9992	2.927	2.927	9.351	2.395	2.373	2.358	2.369	2.370	2.375	2.373	2.372
40	.9989	3.902	3.902	16.64	5.315	5.286	5.264	5.274	5.277	5.281	5.278	5.278
50	.9986	4.878	4.877	26.00	9.738	9.696	9.683	9.679	9.679	9.684	9.682	9.680
60	.9983	5.854	5.852	37.43	15.80	15.74	15.70	15.71	15.71	15.72	15.72	15.72
70	.9980	6.826	6.827	50.94	23.64	23.58	23.54	23.55	23.54	23.55	23.55	23.55
80	.9977	7.801	7.800	66.54	33.37	33.26	33.22	33.23	33.22	33.23	33.23	33.23
90	.9974	8.774	8.771	84.20	44.95	44.85	44.81	44.81	44.80	44.81	44.81	44.81
100	.9972	9.749	9.752	103.9	58.52	58.44	58.38	58.36	58.35	58.37	58.36	58.36
200	.9943	19.47	19.47	415.0	305.9	305.7	305.7	305.4	305.5	305.5	305.5	305.5
400	.9887	38.82	38.83	1654	1417	1417	1417	1417	1417	1417	1417	1417
600	.9831	58.09	58.08	3711	3347	3346	3347	3344	3345	3345	3345	3345
800	.9775	77.22	77.22	6575	6086	6084	6086	6084	6082	6084	6084	6084
1000	.9720	96.25	96.25	10240	9626	9623	9625	9623	9623	9624	9624	9624

Table 8

RELATIVE NUMBER OF ATOMS FOR MEMBERS OF THE ^{240}Pu DECAY CHAIN

Time (yr)	^{240}Pu ($\times 1$)	^{235}U ($\times 10^{-3}$)	^{232}Th ($\times 10^{-3}$)	^{228}Ra ($\times 10^{-18}$)	^{228}Ac ($\times 10^{-22}$)	^{228}Th ($\times 10^{-18}$)
0.5	.9999	.0537				
1	.9999	.1053		.0386	.0482	
2	.9998	.2107	.01	.0426	.0518	
4	.9996	.4213	.03	.0442	.0543	
6	.9994	.6318	.05	.0490	.0568	
8	.9992	.8424	.09	.0537	.0631	
10	.9990	1.053	.15	.0637	.0746	
12	.9987	1.263	.19	.0678	.0780	0.0194
14	.9985	1.474	.28	.0901	.1006	0.0243
16	.9983	1.684	.37	.1071	.1189	0.0277
18	.9981	1.894	.49	.1419	.1550	0.0356
20	.9979	2.105	.61	.1738	.1881	0.0432
22	.9977	2.315	.72	.2061	.2214	0.0504
24	.9975	2.525	.89	.2557	.2742	0.0635
30	.9968	3.155	1.39	.4119	.4376	0.1026
40	.9958	4.205	2.44	.7748	.8157	0.1941
50	.9948	5.253	3.81	1.289	1.352	0.3297
60	.9937	6.301	5.48	1.943	2.035	0.5039
70	.9927	7.347	7.46	2.748	2.875	0.7230
80	.9916	8.392	9.75	3.695	3.864	0.9820
90	.9906	9.436	12.34	4.788	5.005	1.282
100	.9895	10.48	15.22	6.014	6.285	1.620
200	.9792	20.85	60.65	26.22	27.38	7.267
400	.9587	41.26	241.0	109.2	113.9	30.70
600	.9387	61.25	538.5	247.9	258.7	70.02
800	.9192	80.82	950.7	441.2	460.5	124.9
1000	.9000	99.98	1475	687.9	718.0	195.0

Table 9

RELATIVE ACTIVITY FOR MEMBERS OF THE ^{240}Pu DECAY CHAIN

Time (yr)	^{240}Pu ($\times 1$)	^{238}U ($\times 10^{-6}$)	^{234}Th ($\times 10^{-15}$)	^{226}Ra ($\times 10^{-15}$)	^{228}Ac ($\times 10^{-15}$)	^{228}Th ($\times 10^{-15}$)
0.5	.9999	.0145				
1	.9999	.0290		.0379	.0454	
2	.9998	.0580	.0047	.0418	.0487	
4	.9996	.1160	.0140	.0434	.0511	
6	.9994	.1740	.0233	.0481	.0535	
8	.9992	.2319	.0420	.0527	.0593	
10	.9990	.2899	.0700	.0626	.0702	
12	.9987	.3478	.0887	.0665	.0734	.0667
14	.9985	.4057	.1307	.0885	.0948	.0837
16	.9983	.4636	.1727	.1051	.1119	.0953
18	.9981	.5215	.2287	.1394	.1458	.1226
20	.9979	.5794	.2847	.1707	.1770	.1487
22	.9977	.6373	.3360	.2024	.2084	.1738
24	.9975	.6952	.4153	.2510	.2580	.2187
30	.9968	.8687	.6487	.4045	.4118	.3534
40	.9958	1.158	1.139	.7610	.7676	.6688
50	.9948	1.446	1.778	1.266	1.272	1.136
60	.9937	1.735	2.557	1.908	1.915	1.736
70	.9927	2.023	3.481	2.670	2.705	2.491
80	.9916	2.310	4.550	3.629	3.636	3.383
90	.9906	2.598	5.759	4.702	4.709	4.417
100	.9895	2.885	7.103	5.906	5.914	5.581
200	.9792	5.740	28.30	25.75	25.75	25.04
400	.9587	11.36	112.5	107.2	107.2	105.8
600	.9387	16.86	251.3	243.4	243.5	241.2
800	.9192	22.25	443.7	433.3	433.3	430.3
1000	.9000	27.53	688.5	675.5	675.6	671.9

Table 10

RELATIVE NUMBER OF ATOMS FOR MEMBERS OF THE ^{241}Pu DECAY CHAIN

Time (yr)	^{241}Pu ($\times 1$)	^{241}Am ($\times 1$)	^{237}Np ($\times 10^{-4}$)	^{233}Pa ($\times 10^{-11}$)	^{233}U ($\times 10^{-5}$)	^{229}Th ($\times 10^{-11}$)	^{225}Ra ($\times 10^{-17}$)
0.5	0.9762	0.02382	0.09528	0.02186			
1	0.9529	0.04705	0.3780	0.1058	0.00038		
2	0.9080	0.09182	1.487	0.4626	0.00275		
4	0.8245	0.1749	5.759	1.889	0.02336		
6	0.7487	0.2500	12.55	4.191	0.07900		
8	0.6798	0.3180	21.62	7.284	0.1854		
10	0.6173	0.3794	32.75	11.09	0.3566		
12	0.5606	0.4349	45.74	15.55	0.6058		
14	0.5090	0.4850	60.41	20.58	0.9438		
16	0.4622	0.5301	76.60	26.15	1.381	0.0214	0.01
18	0.4197	0.5709	94.15	32.19	1.927	0.0340	0.0500
20	0.3811	0.6076	112.9	38.66	2.591	0.0513	0.1671
22	0.3460	0.6407	132.8	45.51	3.380	0.0745	0.2709
24	0.3142	0.6704	153.7	52.72	4.300	0.1053	0.4348
30	0.2353	0.7426	221.5	76.07	7.911	0.2558	1.272
40	0.1452	0.8201	346.6	119.2	17.03	0.7782	4.140
50	8.965×10^{-2}	0.8622	481.0	165.6	30.37	1.767	9.570
60	5.535×10^{-2}	0.8826	620.2	213.7	48.17	3.454	18.89
70	3.417×10^{-2}	0.8897	761.5	262.5	70.47	5.958	32.65
80	2.109×10^{-2}	0.8886	903.3	311.5	97.38	9.527	52.32
90	1.302×10^{-2}	0.8825	1044	360.3	128.9	14.32	78.76
100	8.038×10^{-3}	0.8735	1184	408.6	164.9	20.56	113.2
200	6.461×10^{-5}	0.7519	2481	856.4	763.1	203.3	1121
400	4.174×10^{-5}	0.5467	4532	1565	3068	1733	9561
600	2.697×10^{-13}	0.3975	6024	2081	6508	5695	31430
800	1.743×10^{-17}	0.2890	7108	2455	10770	12870	71030
1000	1.126×10^{-21}	0.2102	7897	2728	15630	23790	131300

Table 10 (continued)

Time (yr)	^{225}Ac ($\times 10^{-17}$)	^{221}Fr ($\times 10^{-20}$)	^{217}At ($\times 10^{-24}$)	^{213}Bi ($\times 10^{-19}$)	^{213}Po ($\times 10^{-28}$)	^{203}Tl ($\times 10^{-22}$)	^{209}Pb ($\times 10^{-19}$)
0.5							
1							
2							
4							
6							
8							
10							
12							
14							
16	0.0207	0.0442	0.0529	0.0488	0.07012	0.04902	0.07731
18	0.0648	0.0596	0.0707	0.0642	0.09174	0.06404	0.1430
20	0.1307	0.0805	0.0937	0.0871	0.1240	0.08615	0.2276
22	0.2052	0.1081	0.1239	0.1116	0.1623	0.1120	0.3562
24	0.3106	0.1468	0.1678	0.1502	0.2186	0.1511	0.5026
30	0.8617	0.3315	0.3745	0.3305	0.4803	0.3383	1.263
40	2.818	0.9765	1.100	0.9641	1.402	0.9889	3.932
50	6.471	2.200	2.470	2.160	3.143	2.222	8.960
60	12.76	4.290	4.814	4.206	6.124	4.329	17.58
70	22.04	7.389	8.289	7.241	10.55	7.454	30.37
80	35.31	11.81	13.25	11.57	16.86	11.91	48.62
90	53.15	17.76	19.92	17.39	25.34	17.91	73.15
100	76.40	25.50	28.60	24.98	36.38	25.72	105.1
200	757.1	252.4	283.1	247.2	360.0	254.5	1041
400	6458	2153	2414	2108	3070	2171	8880
600	21230	7078	7939	6931	10100	7137	29200
800	47990	16000	17940	15660	22810	16130	65980
1000	88720	29570	33170	28960	42180	29820	122000

Table 11

RELATIVE ACTIVITY FOR MEMBERS OF THE ^{241}Pu DECAY CHAIN

Time (yr)	^{241}Pu ($\times 1$)	^{241}Am ($\times 10^{-3}$)	^{237}Np ($\times 10^{-9}$)	^{233}Pa ($\times 10^{-9}$)	^{233}U ($\times 10^{-12}$)	^{229}Th ($\times 10^{-12}$)	^{225}Ra (10^{-12})
0.5	0.9762	0.7869	0.0640	0.0425			
1	0.9529	1.554	0.2538	0.2057	0.00034		
2	0.9080	3.033	0.9988	0.8993	0.00244		
4	0.8245	5.778	3.867	3.673	0.02072		
6	0.7487	8.260	8.428	8.147	0.07007		
8	0.6798	10.50	14.52	14.16	0.1645		
10	0.6173	12.53	21.99	21.56	0.3163		
12	0.5606	14.37	30.71	30.22	0.5373		
14	0.5090	16.02	40.56	40.01	0.8372		
16	0.4622	17.51	51.43	50.83	1.225	0.0419	0.004
18	0.4197	18.85	63.22	62.57	1.710	0.0656	0.0177
20	0.3811	20.07	75.83	75.17	2.298	0.1004	0.0593
22	0.3460	21.16	89.20	88.47	2.998	0.1459	0.0961
24	0.3142	22.15	103.2	102.5	3.814	0.2062	0.1542
30	0.2353	24.53	148.7	147.9	7.017	0.5008	0.4510
40	0.1452	27.09	232.7	231.8	15.11	1.524	1.468
50	8.965×10^{-2}	28.48	322.9	322.0	26.94	3.459	3.394
60	5.535×10^{-2}	29.16	416.5	415.5	42.71	6.763	6.699
70	3.417×10^{-2}	29.39	511.4	510.4	62.51	11.66	11.58
80	2.109×10^{-2}	29.35	606.6	605.5	86.38	18.65	18.56
90	1.302×10^{-2}	29.15	701.3	700.3	111.4	28.04	27.93
100	8.038×10^{-3}	28.86	795.3	794.3	146.3	40.26	40.14
200	6.461×10^{-3}	24.84	1666	1665	676.9	398.0	397.6
400	4.174×10^{-3}	18.06	3043	3043	2721	3392	3391
600	2.697×10^{-3}	13.13	4045	4045	5773	11150	11150
800	1.743×10^{-3}	9.549	4773	4773	9556	25190	25190
1000	1.126×10^{-3}	6.943	5303	5302	13870	46580	46570

Table 11 (continued)

Time (yr)	^{225}Ac ($\times 10^{-14}$)	^{221}Fr ($\times 10^{-14}$)	^{217}At ($\times 10^{-14}$)	^{213}Bi ($\times 10^{-14}$)	^{213}Po ($\times 10^{-14}$)	^{209}Tl ($\times 10^{-14}$)	^{209}Pb ($\times 10^{-14}$)
0.5							
1							
2							
4							
6							
8							
10							
12							
14							
16	0.0109	0.06960	0.07427	0.07847	0.07571	0.001684	0.02951
18	0.0340	0.09384	0.09926	0.1032	0.09905	0.002200	0.05460
20	0.0686	0.1268	0.1315	0.1401	0.1339	0.002960	0.08688
22	0.1078	0.1702	0.1739	0.1795	0.1753	0.003847	0.1360
24	0.1630	0.2311	0.2356	0.2415	0.2360	0.005192	0.1918
30	0.4523	0.5220	0.5258	0.5315	0.5186	0.01167	0.4818
40	1.479	1.538	1.544	1.550	1.514	0.03397	1.501
50	3.397	3.463	3.467	3.473	3.393	0.07633	3.420
60	6.697	6.754	6.759	6.763	6.612	0.1487	6.711
70	11.57	11.63	11.64	11.64	11.39	0.2561	11.59
80	18.53	18.60	18.61	18.61	18.20	0.4093	18.56
90	27.90	27.96	27.97	27.97	27.36	0.6153	27.92
100	40.10	40.15	40.16	40.16	39.28	0.8835	40.11
200	397.4	397.4	397.5	397.5	388.7	8.744	397.4
400	3390	3390	3390	3390	3315	74.57	3390
600	11140	11150	11150	11150	10900	245.2	11150
800	25190	25190	25190	25190	24630	554.1	25190
1000	46570	46570	46570	46570	45540	1024	46570

Table 12

RELATIVE NUMBER OF ATOMS FOR MEMBERS OF THE ^{242}Pu DECAY CHAIN

Time (yr)	^{242}Pu ($\times 1$)	^{238}U ($\times 10^{-5}$)	^{234}Th ($\times 10^{-15}$)	^{234}Pa ($\times 10^{-20}$)	^{234}U ($\times 10^{-13}$)
0.5	1.0000	.0896	.0106	.0360	
1	1.0000	.1791	.0237	.0804	
2	1.0000	.3582	.0499	.1693	
4	1.0000	.7164	.1023	.3470	.071
6	1.0000	1.075	.1547	.5248	.136
8	1.0000	1.433	.2071	.7025	.133
10	1.0000	1.791	.2595	.8803	.169
12	1.0000	2.149	.3119	1.058	.256
14	1.0000	2.507	.3644	1.236	.330
16	1.0000	2.866	.4168	1.413	.444
18	1.0000	3.224	.4692	1.591	.480
20	1.0000	3.582	.5216	1.769	.539
22	1.0000	3.940	.5740	1.947	.669
24	1.0000	4.298	.6264	2.124	.793
30	.9999	5.373	.7836	2.658	1.351
40	.9999	7.164	1.046	3.546	2.292
50	.9999	8.955	1.308	4.435	3.522
60	.9999	10.75	1.570	5.324	4.989
70	.9999	12.54	1.832	6.212	6.748
80	.9999	14.33	2.094	7.101	8.836
90	.9998	16.12	2.356	7.989	11.19
100	.9998	17.91	2.618	8.878	13.78
200	.9996	35.82	5.237	17.76	55.04
400	.9993	71.62	10.48	35.53	220.0
600	.9989	107.4	15.71	53.29	494.8
800	.9986	143.2	20.95	71.04	879.6
1000	.9982	178.9	26.18	88.78	1373

Table 13

RELATIVE ACTIVITY FOR MEMBERS OF THE ^{242}Pu DECAY CHAIN

Time (yr)	^{242}Pu ($\times 1$)	^{233}U ($\times 10^{-15}$)	^{234}Th ($\times 10^{-15}$)	^{234}Pa ($\times 10^{-15}$)	^{234}U ($\times 10^{-13}$)
0.5	1.0000	.1376	.1116	.1116	
1	1.0000	.2753	.2491	.2491	
2	1.0000	.5505	.5243	.5244	
4	1.0000	1.101	1.075	1.075	.1992
6	1.0000	1.652	1.625	1.625	.3817
8	1.0000	2.202	2.175	2.176	.3732
10	1.0000	2.753	2.726	2.726	.4743
12	1.0000	3.303	3.277	3.277	.7184
14	1.0000	3.854	3.828	3.827	.9261
16	1.0000	4.404	4.378	4.378	1.246
18	1.0000	4.955	4.929	4.929	1.267
20	1.0000	5.505	5.479	5.479	1.513
22	1.0000	6.055	6.030	6.030	1.877
24	1.0000	6.606	6.580	6.580	2.225
30	.9999	8.258	8.232	8.232	3.791
40	.9999	11.01	10.98	10.98	6.432
50	.9999	13.76	13.74	13.74	9.884
60	.9999	16.51	16.49	16.49	14.00
70	.9999	19.27	19.24	19.24	18.94
80	.9999	22.02	21.99	21.99	24.80
90	.9998	24.77	24.75	24.75	31.39
100	.9998	27.52	27.50	27.50	38.67
200	.9996	55.05	55.01	55.01	154.5
400	.9993	110.1	110.0	110.0	617.5
600	.9989	165.1	165.1	165.1	1389
800	.9986	220.1	220.0	220.0	2468
1000	.9982	275.0	275.0	275.0	3856

FIGURE 7 - Plot of the relative activities of the members of the ^{236}Pu decay chain.

FIGURE 8 - Plot of the relative activities of the members of the ^{238}Pu decay chain.

FIGURE 8 - Continuation of the plot on the preceding page (^{238}Pu decay chain).

FIGURE 9 - Plot of the relative activities of the members of the ^{239}Pu decay chain.

FIGURE 9 - Continuation of the plot on the preceding page (^{239}Pu decay chain).

FIGURE 10 - Plot of the relative activities of the members of the ^{240}Pu decay chain.

FIGURE 10 - Continuation of the plot on the preceding page (^{240}Pu decay chain).

FIGURE 11 - Plot of the relative activities of the members of the ^{241}Pu decay chain.

FIGURE 11 - Continuation of the plot on the preceding page (^{241}Pu decay chain).

FIGURE 12 - Plot of the relative activities of the members of the ^{242}Pu decay chain.

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