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TOTAL AND SPONTANEOUS FISSION HALF-LIVES FOR URANIUM, PLUTONIUM, AMERICIUM AND CURIUM NUCLIDES

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CONTENTS

Total and spontaneous fission half-lives for uranium, plutonium, americium and curium nuclides

Abstract - Measurements of the half-lives of some long-lived nuclides of elements Z = 92, 94, 95 and 96 have been compiled and evaluated. Recommended values are presented for $^{232-236,238}$U, for $^{236,238-242,244}$Pu, for ^{241,242m,243}Am, and for $^{242-248,250}$Cm. Values are presented for both spontaneous fission half-life and total half-life. Problems with reported uncertainties are also discussed.

INTRODUCTION

The long-lived nuclides of the uranium, plutonium, americium and curium elements are of interest for their use in nuclear reactors, for nuclear reactor burnup studies in waste management, and in certain safeguard applications, e.g., α counting is often used to determine the amount of material present. The total half-life, which for heavy elements is often synonomous with the half-life for α decay, and the half-life for spontaneous fission are evaluated for these various long-lived nuclides of interest. For many of these nuclides, there is also a decay mode of heavy fragment radioactivity (ref. 1). However in terms of the contribution to the total half-life value to be recommended, this heavy fragment radioactivity decay mode is usually much smaller than that of the spontaneous fission decay mode, although this is not true in all cases (ref. 2). Since the spontaneous fission decay mode half-life is usually only a small perturbation on the value of the half-life of the alpha decay mode, heavy fragment radioactivity decay will not be considered in this paper.

All of the various experiments have been reanalyzed and recommended half-life values are presented for $^{232-236,238}$U, $^{236,238-242,244}$Pu, ^{241,242m,243}Am, and for $^{242-248,250}$Cm. These recommended half-life values supersede preliminary estimates previously presented, in particular with respect to their reported uncertainties.

Total half-lives for the uranium nuclides were reviewed some years ago (ref. 3). At that time, ^{238}U was the only nuclide for which a spontaneous fission value was evaluated. More recently, the uranium and plutonium nuclides (ref. 4), and the americium and curium nuclides (ref. 5) were separately reviewed and values were recommended for both total and spontaneous fission half-lives.

It will be noted that many of the uncertainties recommended here considerably exceed, by up to an order of magnitude, uncertainties quoted by the individual authors in their publication; *e.g.* the total half-life of ^{238,240,241}Pu, ^{244,246}Cm and the spontaneous fission half-life of ^{244}Cm.

The general procedure followed in this paper has been to review each experiment and to revise the published values for the latest estimates of various parameters originally reported by the authors; *e.g.* improved data on branching ratios assumed, on the half-lives of other nuclides involved, etc. When detailed information on the uncertainties was available in each of these experiments, the standard deviation for the experiment was combined with one third of the systematic error to provide the uncertainty quoted in the table for each experiment. The result of this procedure should be that the limit of error of the half-life would be obtained from the sum of the systematic error plus three standard deviations; *i.e.* 3σ. Where there was no adequate discussion of the systematic error and the total error quoted was extremely small; *e.g.* 0.1 percent or less, a systematic error of 0.1 percent was estimated. One-third of this amount, about 350 parts per million (ppm), was added to the published error to obtain the figure tabulated in the various tables. The uncertainty listed for the recommended value in each table was calculated from a weighted average of the listed measurements using a variance weighting technique; either the reciprocal square of the author's reported uncertainty, or as revised according to the above scheme. Exceptions to the weighted average rule had to be made for some nuclides and will be discussed under the appropriate section for those nuclides. In such cases, recommendations were made using either a selected value considered superior to other listed measurements, or a weighted average was calculated for each of the different experimental techniques used and an unweighted average of these half-lives was recommended. All of the tables indicate the particular method chosen.

URANIUM ISOTOPES

In general, the recommended values for the half-lives of the various nuclides are obtained by weighting each reported value by the variance reported by the author for the experiment. In a few cases, values have been revised when the experiment was evaluated. In the case of ^{233}U, details were missing from Geidel'man's paper (ref. 6) such as the measured specific activity, the mass of ^{233}U assumed and the mass spectrometric analysis. As a result, the experiment could not be evaluated on the same basis as other measurements. The final uncertainty was increased by 50%, to account for the missing information.

In the case of ^{234}U, the measurement by DeBievre (ref. 7) used a variety of methods on 83 sources. Upon questioning some of the data, the authors agreed to revise the final value of the half-life as indicated in Table 6. This is one of the few experiments where multiple sources were prepared and measured. Lounsbury's results (ref. 8) have been revised for the specific activity of the other uranium nuclides due to better estimates of the respective half-lives. The problem of ^{232}U contamination was not discussed and the uncertainty was increased by 50% to account for this potential error in a source which is only 1% enriched in ^{234}U.

For the total half-life of ^{238}U, only one value is listed in the table. Earlier determinations were based on measurements of the specific activity of natural uranium samples and the assumption of secular equilibrium between ^{234}U and ^{238}U in those samples. In a radioactive decay chain, when a daughter nuclide has a much smaller half-life than its parent nuclide, at a time interval very long compared to the daughter's lifetime, the growth and decay of the daughter is controlled by the parent and the two nuclides are in secular equilibrium *i.e.*, their specific activities, $N\lambda$, are equal, where N is the number of atoms and λ is the decay constant (λ = natural logarithm 2 / half-life). Since the half-life of ^{234}U is only 10^5 years and the age of the earth is orders of magnitude greater, 10^9 years, all of the ^{234}U originally formed in natural uranium has long since decayed. The ^{234}U now present in uranium is due to the ^{238}U decay series, *i.e.*,

$$^{238}\mathrm{U}(\alpha) \rightarrow {}^{234}\mathrm{Th}(\beta) \rightarrow {}^{234}\mathrm{Pa}(\beta) \rightarrow {}^{234}\mathrm{U}.$$

In a closed system, the ^{238}U and the ^{234}U should be in secular equilibrium. This implies that a measurement of the specific activity of a natural uranium sample, when corrected for the small amount of ^{235}U activity ($\approx$2.2%) would provide a valid determination of the equal amounts of activity of ^{238}U and ^{234}U present. However, Holden (ref. 3) has shown that this assumption of secular equilibrium is not valid. There is a disequilibrium in uranium sources found in various parts of the world. The specific activity of natural uranium can vary by up to a factor of two in different sources. As a result, only the measurement by Jaffey (ref. 9) is given in the table and is the recommended value.

In the case of the spontaneous fission half-life for ^{238}U, results are presented for the specific activity as reported. Measurements using fission track detection in 2π geometry; *e.g.* mica-uranium, or lexan-uranium sandwiches have a problem with partial fission track fading in the geological materials (ref. 10). Fission track fading would underestimate the specific activity and lead to overestimating the half-life. These measurements do have half-lives which are from 10% to 30% too large compared to all other techniques. These experiments have not been included in the averaging because of this systematic error. Other techniques used in the measurement of ^{238}U have been separately weighted and the results averaged and converted into a half-life recommendation.

PLUTONIUM ISOTOPES

In the measurements of the plutonium nuclides, weighted averages have usually been recommended, except for cases where authors report exceedingly small absolute values for the overall uncertainty. In a later section, the problem of treating good measurements which are mutually exclusive will be addressed. If one applies weighted averages to determine the α half-life of ^{240}Pu, three of the five most recent measurements fall some ten standard deviations away from the recommended value. A half-life has been recommended on the basis of the unweighted average of the various techniques or methods utilized to measure this half-life.

If one used weighted averages for the total half-life of ^{241}Pu, all of the recent measurements that were performed at the accuracy level of tenths of one percent would carry no weight in the evaluation of this half-life. Since Strohm (ref. 11) quotes an absolute accuracy for the ^{241}Pu half-life of 488 parts per million, while examining only one sample, his result would eliminate all other careful measurements from consideration. An unweighted average of the various techniques was again recommended. In the case of the α half-life of ^{239}Pu, a single source was measured by a large number of laboratories using various techniques. The highly precise values reported had a range of results from the various laboratories which was an order of magnitude greater than the usual standard deviation quoted in most of these experiments. An unweighted average of the half-life for the various techniques was recommended.

For the α half-life of ^{242}Pu, the range of results was ten to fifteen times larger than the typical uncertainty quoted by the authors. A weighted average of the half-life was recommended, with the uncertainty calculated from the external error.

AMERICIUM ISOTOPES

Most of the recommended values for the americium half-lives are based on a weighted average of the reported results. In the case of ^{241}Am, the reported uncertainties were revised to insure that comparable experiments were treated with comparable weights.

For the spontaneous fission half-life of ^{241}Am, the range of reported results was larger than quoted uncertainties by more than an order of magnitude. A value was selected using the better measurements and the uncertainty was chosen so as to overlap the range of the most recent measurement.

CURIUM ISOTOPES

For spontaneous fission of ^{242}Cm, the measurement which should carry most of the weight in the evaluation completely disagrees with all other recent measurements by five to ten σ. A selected value was chosen with an uncertainty to encompass the range of recent measurements.

For the case of ^{244}Cm, the most accurate measurements, according to the published errors, disagree by sixteen σ. A weighted average was recommended with the uncertainty being controlled by the external error. Similar problems for total half-lives of ^{244,246}Cm were treated in the same manner.

DISCUSSION OF RESULTS

In most cases, the recommended values and uncertainties in the tables are based on variance weighted averages. Other recommendations are based on selecting the one good recent measurement of the particular half-life. In a few cases, the discrepancies in values and uncertainties quoted required the averaging of techniques to produce a reasonable recommendation. The recommended values listed in the following tables are given in units of either day (d) or year (a). Before concluding, a few words are in order on the problem of error estimation.

It has been noted above that various measurements in the tables quote uncertainties by authors such that they both disagree with and exclude many other good recent measurements from consideration. Undoubtedly, systematic errors have not been carefully considered in these publications. When experiments are performed at the level of five to ten percent accuracy, recording the number of counts is an important consideration. In Poisson statistics, increasing the number of counts can improve the overall accuracy, which varies inversely with the total number of counts. However, by the time that the overall accuracy reaches the level of one-half percent or better, the estimate of all systematic errors begins to control the total accuracy. The effort to continue to improve the statistical precision, by continuing to collect raw data points, does not significantly improve the total error, except superficially, in the absence of any effort to estimate the systematic error. If one uses variance weighting indiscriminately in such cases, one penalizes the authors who attempt the difficult task of estimating the systematic error, while benefiting the authors who make no such attempt to determine all of their sources of error, (an admittedly difficult task).

In the review of nuclear data by the International Atomic Energy Agency (ref. 12), their general comment on uncertainties included a statement questioning the validity of any presently stated uncertainties of less than 0.1% for half-lives.

The same criteria has also been applied here in a few cases. No half-life has been recommended with an accuracy of better than 0.1%; see the total half-life of ^{233}U as an example. The rationale for this rule is that systematic errors up to ten times smaller than the total statistical uncertainty quoted could have an appreciable effect on that total uncertainty, if there were a number of such errors. Recommending values at accuracy levels of a few hundred ppm would imply that all potential errors in the experiment at the level of ten ppm had been investigated, documented, and their effect on the result taken into account. An experiment, in which such a thorough study has been both performed and documented, has yet to be reported to my knowledge.

If one had a choice in designing the ideal experiment to measure the half-life, one would choose to determine many samples, using a number of duplicate instruments and utilizing a variety of different methods or techniques. This should provide the necessary information to correctly estimate the systematic error. Some effort toward this goal has been made in the last decade in the measurements on the half-life of ^{239}Pu and ^{240}Pu by the U.S. Half-life Evaluation Committee. However, this effort usually involved only one sample and for ^{239}Pu, one of the measurements was discarded because it was lower than the other results (ref. 13). It should be emphasized that this is never a sufficient reason of and by itself to discard data.

TABULATED RESULTS

Table 1. Spontaneous fission half-life of ^{232}U

Reference Author (Year)	As Reported $T_{½}/10^{13}$ a	Comments
Jaffey[14] (1951)	8. ± 5.5	
Segre[15] (1952)	> 0.8	Not used; Ionization Chamber
Recommended Value = 8. ± 6. x 10^{13} a;		*Selected Value*

Table 2. Total half-life of ^{232}U

Reference Author (Year)	As Revised $T_{½}/a$	Comments
James[16] (1949)	70.	Not used; Ingrowth with pulse analysis
Sellars[17] (1954)	73.6 ± 1.0	$2\pi\alpha$ counting; Mass spectrometry; Revised probable error to Standard deviation
Chilton[18] (1964)	72.1 ± 0.5	99.2% enriched sample; $2\pi\alpha$ counting; Coulometry
	71.4 ± 0.6	99.2% enriched sample; Calorimetry
Aggarwal[19] (1979)	68.90 ± 0.39	Specific activity; Relative activity to ^{233}U
Weighted Average = 70. ± 1. a;		*Recommended Value*

Table 3. Spontaneous fission half-life of ^{233}U

Reference Author (Year)	As Reported $T_{½}/10^{17}$ a	Comments
Segre[15] (1952)	> 2.7	Ionization Chamber
Aleksandrov[20] (1966)	1.2 ± 0.3	No mention of correction for ^{232}U. Just 0.03% of ^{232}U could account for discrepancy with other measurements.
von Gunten[21] (1981)	> 2.7	97.11% enriched; Rotating Bubble Chamber; Corrected for (α,n,f) reaction
Recommended Value = > 2.7 x 10^{17} a;		*Selected Value*

Table 4. Total half-life of ^{233}U

Reference Author (Year)	As Revised $T½/10^5$ a	Comments
Jaffey[22] (1974)	1.5910 ± 0.0015	99.477% enriched; Intermediate geometry α counting
Vaninbroukx[23] (1976)	1.5925 ± 0.0013	99.762% enriched; Low geometry ctg. 99.9986% enriched; liquid scint. ctg.
Geidel'man[6] (1979)	1.5937 ± 0.0017	98.112% enriched; 4π α–x coincidence; Uncertainty x 1.5 for missing details
Aggarwal[24] (1980)	1.5885 ± 0.0026	99.703% enriched; α counting and liquid scintillation counting

Recommended Value = 1.592 ± 0.002 x 10^5 a; *Weighted Average using uncertainty rule*

Table 5. Spontaneous fission half-life of ^{234}U

Reference Author (Year)	As Revised $T½/10^{16}$ a	Comments
Segre[15] (1952)	> 0.6	Not used; Ionization Chamber
Ghiorso[25] (1952)	1.6 ± 0.7	Not used; Revised; Ionization chamber
von Gunten[21] (1981)	1.42 ± 0.08	99.36% enriched; Rotating Bubble Chamber; Corrected for (α,n,f) reaction
Wang[26] (1987)	1.9 ± 0.15	99.84% enriched; Phosphate glass detector; ^{232}U Corrected for; Increased uncertainty by 50% to account for overestimate of the zenith angle of fission fragments

Weighted Average = 1.5 ± 0.2 x 10^{16} a; *Recommended Value*

Table 6. Total half-life of ^{234}U

Reference Author (Year)	As Revised $T½/10^5$ a	Comments
Fleming[27] (1952)	2.475 ± 0.049	Not used; Medium geometry α counting
White[28] (1965)	2.47 ± 0.06	Not used; α counting
Meadows[29] (1970)	2.439 ± 0.036	Not used; ≈1% enriched; Author withdrew data; 50% increase in Uncertainty for missing details
DeBievre[7] (1972)	2.450 ± 0.009	Enriched to 99.873%; Revised value, see text for a detailed discussion
Lounsbury[8] (1972)	2.458 ± 0.013	1.08% enriched; Revised value; Low geometry α counting
Geidel'man[30] (1980)	2.4604 ± 0.009	93.437% enriched; $4\pi\alpha$–x Coincidence; Revised uncertainty
	2.4570 ± 0.009	93.437% enriched; liquid scintillator; Revised uncertainty
Poenitz[31] (1983)	2.457 ± 0.006	Not used; Mass intercomparison; Confirms direct measurements

Weighted Average = 2.455 ± 0.006 x 10^5 a; *Recommended Value*

Table 7. Spontaneous fission half-life of ^{235}U

Reference Author (Year)	As Reported $T½/10^{18}$ a	Comments
Segre[15] (1952)	0.18	Not used; Ionization chamber
Aleksandrov[20] (1966)	0.35 ± 0.09	Not used; Fission track detectors
Gruetter[32] (1973)	> 1.8	Not used; No corrections Rotating bubble chamber;
von Gunten[21] (1981)	9.8 ± 2.8	99.76% enriched; Rotating bubble chamber Corrected for (α,n,f) reaction

Recommended Value = 1.0 ± 0.3 x 10^{19} a; *Selected Value*

Table 8. Total half-life of ^{235}U

Reference Author (Year)	As Reported $T_{1/2}/10^{8}$ a	Comments
Nier[33] (1939)	7.04 ± 0.31	^{207}Pb/^{206}Pb Ratio
Sayag[34] (1951)	6.94 ± 0.40	α counting
Fleming[27] (1952)	7.12 ± 0.31	α counting; medium geometry
Knight[35] (1950)	7.10 ± 0.32	α counting; 50% geometry
Wurger[36] (1957)	6.93 ± 0.27	α counting
White[28] (1965)	7.12 ± 0.18	α counting
Banks[37] (1966)	7.02 (+ 0.14 − 0.06)	^{207}Pb/^{206}Pb Ratio
Deruytter[38] (1965)	6.97 ± 0.19	α counting; silicon detector
Jaffey[9] (1971)	7.037 ± 0.011	α counting; intermediate geometry

Weighted Average = 7.04 ± 0.01 x 10^{8} a; *Recommended Value*

Table 9. Spontaneous fission half-life of ^{236}U

Reference Author (Year)	As Reported $T_{1/2}/10^{16}$ a	Comments
Jaffey[39] (1949)	2. ± 1.6	
Conde[40] (1971)	2.7 ± 0.3	^{238}U/^{236}U = 0.30 ± 0.03
von Gunten[21] (1981)	2.43 ± 0.13	99.68% enriched; Rotating bubble chamber; Corrected for (α,n,f) reaction
Belenky[41] (1983)	2.7 ± 0.4	Multiple neutron coincidence

Weighted Average = 2.5 ± 0.1 x 10^{16} a; *Recommended Value*

Table 10. Total half-life of ^{236}U

Reference Author (Year)	As Revised $T_{1/2}/10^{7}$ a	Comments
Jaffey[42] (1951)	2.46 ± 0.14	α counting; Increased uncertainty by 50% for missing details
Fleming[27] (1952)	2.391 ± 0.057	α counting; Increased uncertainty by 50% for missing details
Flynn[43] (1972)	2.3422 ± 0.0039	Revised uncertainty; Intermediate geometry α counting

Weighted Average = 2.342 ± 0.004 x 10^{7} a; *Recommended Value*

Table 11. Total half-life of ^{238}U

Reference Author (Year)	As Reported $T_{1/2}/10^{9}$ a	Comments
Jaffey[9] (1971)	4.468 ± 0.022	Intermediate geometry α counting

Recommended Value = 4.47 ± 0.02 x 10^{9} a; *Selected Value*

Table 12. Spontaneous fission half-life of ^{238}U

Reference Author (Year)	As Reported/(10^{-17} a^{-1}) Specific Activity	Comments
Whitehouse[44] (1950)	8.38 ± 0.52	Ionization Chamber
Segre[15] (1952)	8.60 ± 0.29	Ionization Chamber
Fleischer[45] (1964)	6.85 ± 0.20	Not used; Mica-uranium Sandwich
Roberts[46] (1968)	7.03 ± 0.11	Not used; Mica-uranium Sandwich
Spadavecchia[47] (1967)	8.42 ± 0.10	Rotating Bubble Chamber
von Gunten[48] (1969)	8.66 ± 0.22	Fission Products from ^{238}U
Galliker[49] (1970)	8.46 ± 0.06	Rotating Bubble Chamber
Storzer[50] (1970)	8.49 ± 0.76	Fission Tracks in Dated Uranium Glass
Kleeman[51] (1971)	6.8 ± 0.6	Not used; Lexan-uranium Sandwich
Thury[52] (1971)	8.66 ± 0.43	Third Order Coincidence
Leme[53] (1971)	7.30 ± 0.16	Not used; Mica-uranium Sandwich
Khan[54] (1973)	6.82 ± 0.55	Not used; Mica-uranium Sandwich
Ivanov[55] (1975)	7.12 ± 0.32	Not used; Mica-uranium Sandwich
Emma[56] (1975)	7.2 ± 0.2	Not used; Mica-uranium Sandwich
Wagner[57] (1975)	8.7 ± 0.6	Fission Tracks in Dated Uranium Glass
Thiel[58] (1976)	8.57 ± 0.42	Fission Tracks in Dated Uranium Glass
Kase[59] (1978)	8.22 ± 0.20	Ionization Chamber
Popeko[60] (1980)	7.9 ± 0.4	Multiple Neutron Coincidence
Spaggiari[61] (1980)	9.26 ± 0.17	Not used; Mica-uranium Sandwich
Baptista[62] (1981)	6.6 ± 0.2	Not used; Mica-uranium Sandwich
Hadler[63] (1981)	8.6 ± 0.4	Not used; Mica-uranium Sandwich
de Carvalho[64] (1982)	11.8 ± 0.7	Not used; Fission Tracks (Ordinary Glass)
Belenky[41] (1983)	8.35 ± 0.40	Multiple Neutron Coincidence
Vartanian[65] (1984)	8.23 ± 0.43	Not used; Fission Tracks in Plastic, Uranium Foils
Ivanov[66] (1985)	8.29 ± 0.27	Double Ionization Chamber

Recommended Half-life Value = 8.2 ± 0.1 x 10^{15} a; *Unweighted Average of Techniques*

Table 13. Spontaneous fission half-life of ^{236}Pu

Reference Author (Year)	As Revised $T_{1/2}/10^9$ a	Comments
Ghiorso[25] (1952)	3.4 ± 1.2	Not used; Revised value Ionization chamber
Selickij[67] (1988)	2.09 ± 0.06	Two sources; Fragment detection in 2π geometry

Recommended Value = 2.1 ± 0.1 x 10^9 a; *Selected Value*

Table 14. Total half-life of ^{236}Pu

Reference Author (Year)	As Reported $T_{1/2}$/a	Comments
James[16] (1949)	2.7 ± 0.3	α counting
Hoffman[68] (1957)	2.85 ± 0.10	α counting
Nakanishi[69] (1984)	2.87 ± 0.01	Activity Ratios; Silicon Surface Barrier Detector

Weighted Average = 2.87 ± 0.01 a; *Recommended Value*

Table 15. Alpha half-life of ^{238}Pu

Reference Author (Year)	As Revised $T_{1/2}$/a	Comments
Jaffey[70] (1950)	89.59 ± 0.44	2π α counter; Revised uncertainty
Mech[71] (1956)	86 ± 3.5	Relative activity to ^{240}Pu
Hoffman[72] (1957)	86.41 ± 0.32	α counting; Revised uncertainty
Stohm[11] (1974)	87.77 ± 0.053	Calorimetry; Revised uncertainty
Polyukov[73] (1976)	86.98 ± 0.23	4π, low geometry α counting Revised uncertainty
Diamond[74] (1977)	87.71 ± 0.06	α counting; Revised uncertainty
Sevostijanov[75] (1981)	86.54 ± 0.33	α counting; Revised uncertainty
Aggarwal[76] (1981)	87.98 ± 0.25	Relative activity to ^{239}Pu Revised uncertainty
Weighted Average = 87.7 ± 0.1 a;		*Recommended Value*

Table 16. Spontaneous fission half-life of ^{238}Pu

Reference Author (Year)	As Revised $T_{1/2}/10^{10}$ a	Comments
Segre[15] (1952)	3.8	Not used; Revised; Ionization Chamber
Jaffey[77] (1949)	4.7 ± 0.6	Revised Value;
Druin[78] (1961)	5.1 ± 0.6	Revised; Nuclear Photographic Emulsions
Hastings[79] (1972)	4.77 ± 0.14	α/fission Ratio Silicon Surface Barrier Detectors
Gay[80] (1975)	4.63 ± 0.12	Fission Fragment Coincidences in Mica
Selickij[67] (1988)	5.01 ± 0.21	4 sources; Fragment Detection in 2π Geometry
Weighted Average = 4.75 ± 0.09 x 10^{10} a;		*Recommended Value*

Table 17. Spontaneous fission half-life of ^{239}Pu

Reference Author (Year)	As Reported $T_{1/2}/10^{15}$ a	Comments
Segre[15] (1952)	5.5	Not used; Ionization Chamber
Druzhinin[81] (1985)	7.8 ± 1.6	α/fission activity
Recommended Value = 8. ± 2. x 10^{15} a;		*Selected Value*

Table 18. Total half-life of ^{239}Pu

Reference Author (Year)	As Revised $T_{1/2}/10^{4}$ a	Comments
Aleksandrov[82] (1975)	2.4060 ± 0.0019	4π α−x coincidence; Revised uncertainty
Glover[83] (1975)	2.4115 ± 0.0080	Not used *; Low geometry α counting
Jaffey[84] (1977)	2.4124 ± 0.0014	Intermediate geometry α counting;
	2.4139 ± 0.0013	Isotope dilution mass spectrometry
Lucas[85] (1978)	2.4112 ± 0.0033	α counting; Revised uncertainty
Gunn[86] (1978)	2.4102 ± 0.0010	Calorimetry; Revised uncertainty
Marsh[87] (1978)	2.4164 ± 0.0017	Mass spectrometry; Revised uncertainty
Seabaugh[88] (1978)	2.4101 ± 0.0010	Calorimetry; Revised uncertainty
Prindle[89] (1978)	2.4089 ± 0.0019	Mass spectrometry; Revised uncertainty
	2.4019 ± 0.0015	α counting; Revised uncertainty
Vaninbroukx[90] (1978)	2.4085 ± 0.0014	Not used *; Low geometry α counting
	2.4114 ± 0.0013	Not used *; Liquid scintillator
Brown[91] (1981)	2.4088 ± 0.0025	Low geometry α counting; Revised uncertainty
		* Experiments considered preliminary.
Recommended Value = 2.410 ± 0.003 x 10^{4} a;		*Unweighted average of techniques with uncertainty rule invoked*

Table 19. Spontaneous fission half-life of ^{240}Pu

Reference Author (Year)	As Revised $T_{1/2}/10^{11}$ a	Comments
Kindermann[92] (1953)	1.314 ± 0.026	Not used; Low geometry α counting
Barclay[93] (1954)	1.225 ± 0.030	Not used; Low geometry α counting
Chamberlain[94] (1954)	1.20	Not used; Low geometry α counting
Mikheev[95] (1959)	1.20	Not used; α counting; gas scintillator
Watt[96] (1962)	1.34 ± 0.015	Not used; Low geometry α counting
Malkin[97] (1963)	1.45 ± 0.02	Not used; α counting; gas scintillator
White[98] (1967)	1.27 ± 0.05	Not used; No details available
Fieldhouse[99] (1967)	1.176 ± 0.025	Not used; Revised; Spontaneous Fission neutron emission rates
Budtz-Jorgensen[100] (1980)	1.15 ± 0.03	Fragment spectra; ionization chamber
Androsenko[101] (1984)	1.15 ± 0.03	Spontaneous fission neutron Emission rates
Selickij[67] (1988)	1.17 ± 0.03	Two Sources; Fragment detection in 2π geometry
Weighted Average = 1.16 ± 0.02 x 10^{11} a;		*Recommended Value*

Table 20. Total half-life of ^{240}Pu

Reference Author (Year)	As Revised $T_{1/2}/10^{3}$ a	Comments
Inghram[102] (1951)	6.505 ± 0.045	Not used; Mass spectrometry
Butler[103] (1956)	6.600 ± 0.100	Not used; α counting
Dokuchaev[104] (1959)	6.610 ± 0.055	Not used; Low geometry α counting
Oetting[105] (1967)	6.533 ± 0.010	Not used; Calorimetry; Revised value
Jaffey[106] (1978)	6.569 ± 0.006	Intermediate geometry α counting
Rudy[107] (1984)	6.5524 ± 0.0017	Calorimetry
Lucas[108] (1984)	6.5522 ± 0.0052	α counting
Steinkruger[109] (1984)	6.571 ± 0.007	Low geometry α counting
Beckman[110] (1984)	6.574 ± 0.0062	Mass spectrometry; revised uncertainty
Recommended Value = 6.56 ± 0.01 x 10^{3} a;		*Unweighted Average of Techniques With Uncertainty Range Extended*

Table 21. Spontaneous fission half-life of ^{241}Pu

Reference Author (Year)	As Reported $T_{1/2}/10^{16}$ a	Comments
Druzhinin[81] (1985)	< 6.	α/f activity measured
Recommended Value < 6. x 10^{16} a		*Selected Value*

Table 22. Alpha half-life of ^{241}Pu

Reference Author (Year)	As Revised $T_{1/2}/10^{5}$ a	Comments
Bigham[111] (1958)	6.35 ± 0.32	α spectrometry relative to $^{239 + 240}$Pu
Brown[112] (1960)	5.84 ± 0.12	Revised value; α spectrometry/total Pu α emission
Smith[113] (1961)	5.97 ± 0.20	Revised value; α/β branching, α spectrometry
Bertolini[114] (1966)	5.98 ± 0.10	Revised; Growth method; Ge(Li) detectors
Ahmad[115] (1968)	5.88 ± 0.21	α/γ coincidence
Gunnink[116] (1976)	5.85 ± 0.075	γ emission probabilities; Ge(Li) detectors
Vaninbroukx[117] (1978)	6.04 ± 0.06	α spectrometry; ingrowth method Solid state detectors
Weighted Average = 5.96 ± 0.04 x 10^{5} a;		*Recommended Value*

Table 23. Total half-life of ^{241}Pu

Reference Author (Year)	As Revised $T_{1/2}$/a	Comments
Strohm[11] (1974)	14.355 ± 0.007	Calorimetry
Whitehead[118] (1977)	14.56 ± 0.15	Ingrowth of ^{241}Am γ ray
Garner[119] (1979)	14.38 ± 0.07	Mass spectrometry
Vaninbroukx[120] (1978)	14.60 ± 0.10	Ingrowth of ^{241}Am γ ray
Aggarwal[121] (1980)	14.42 ± 0.09	α spectrometry
Marsh[122] (1980)	14.38 ± 0.06	Mass spectrometry
Aggarwal[123] (1981)	14.52 ± 0.08	α spectrometry
Aggarwal[124] (1981)	14.44 ± 0.06	α spectrometry, α proportional counting
Aggarwal[125] (1982)	14.32 ± 0.06	Mass spectrometry; Revised uncertainty
DeBievre[126] (1983)	14.33 ± 0.02	Mass spectrometry
Hiyama[127] (1984)	14.29 ± 0.15	Mass spectrometry
Aggarwal[128] (1985)	14.38 ± 0.02	Mass spectrometry
Timofeev[129] (1986)	14.57 ± 0.10	Mass spectrometry

Recommended Value = 14.4 ± 0.1 a; *Unweighted Average of Techniques*

Table 24. Spontaneous fission half-life of ^{242}Pu

Reference Author (Year)	As Revised $T_{1/2}/10^{10}$ a	Comments
Studier[71] (1956)	6.7 ± 0.7	Quoted by Mech[71]
Butler[130] (1956)	6.65 ± 0.10	α/fission ratio
Mech[71] (1956)	6.79 ± 0.19	Revised Value for ^{242}Pu α $T_{1/2}$
Druin[78] (1961)	6.6 ± 0.7	Gas scint.; Relative to ^{238}Pu α $T_{1/2}$
Malkin[97] (1963)	7.45 ± 0.17	Gas scintillator; Specific activity
Meadows[131] (1977)	6.74 ± 0.05	α/fission ratio
Khan[132] (1980)	7.43	Not used; Mica fission track detector
Selickij[67] (1988)	6.86 ± 0.26	Fission fragment detection in 2π geometry

Weighted Average = 6.77 ± 0.07 x 10^{10} a; *Recommended Value*

Table 25. Total half-life of ^{242}Pu

Reference Author (Year)	As Reported $T_{1/2}/10^{5}$ a	Comments
Butler[130] (1956)	3.649 ± 0.05	Not used; Relative α activity to ^{238}Pu
Butler[103] (1956)	3.790 ± 0.05	Not used; Ion Chamber energy analysis
Mech[71] (1956)	3.855 ± 0.100	Not used; Relative α activity to ^{240}Pu
Bemis[133] (1969)	3.823 ± 0.016	Relative α activity to ^{239}Pu
Durham[134] (1970)	3.674 ± 0.07	Relative α activity to ^{238}Pu
Osborne[135] (1976)	3.763 ± 0.009	Calorimetry
Bulyanitsa[136] (1976)	3.702 ± 0.014	$4\pi\alpha$–x coincidence
Meadows[131] (1977)	3.708 ± 0.024	Relative α activity to ^{239}Pu
Aggarwal[137] (1979)	3.754 ± 0.025	Relative α activity to ^{239}Pu and ^{238}Pu

Weighted Average = 3.75 ± 0.02 x 10^{5} a; *Recommended Value*

Table 26. Spontaneous fission half-life of ^{244}Pu

Reference Author (Year)	As Revised $T_{1/2}/10^{10}$ a	Comments
Fields[138] (1955)	2.5 ± 0.8	Not used; Ionization chamber
Fields[139] (1966)	6.67 ± 0.32	Revised value
Gokhberg[140] (1977)	6.8 ± 0.8	No details
Khan[132] (1980)	7.32	Not used; Fission track detector
Moore[141] (1982)	6.56 ± 0.30	Ion chamber; α counting; α spectrometry
Weighted Average = 6.6 ± 0.2 x 10^{10} a;		*Recommended Value*

Table 27. Total half-life of ^{244}Pu

Reference Author (Year)	As Revised $T_{1/2}/10^{7}$ a	Comments
Butler[130] (1956)	6.65 ± 0.10	Not used; Relative α activity to ^{238}Pu
Diamond[142] (1956)	7.3 ± 2.	Revised; anti-coincidence prop. counter
Butler[103] (1956)	7.6 ± 2.	α counting
Fields[139] (1966)	8.12 ± 0.26	Revised value
Bemis[133] (1969)	7.99 ± 0.10	Revised; Relative activity to ^{239}Pu
Weighted Average = 8.00 ± 0.09 x 10^{7} a;		*Recommended Value*

Table 28. Spontaneous fission half-life of ^{241}Am

Reference Author (Year)	As Reported $T_{1/2}/10^{14}$ a	Comments
Segre[15] (1952)	> 0.14	Not used; Ionization chamber
Mikheev[95] (1960)	> 2.	Not used; Gas scintillator
Druin[143] (1961)	2.3 ± 0.8	Gas scintillator
Galliker[49] (1970)	0.90 ± 0.04	Rotating bubble chamber
Gold[144] (1970)	1.147 ± 0.024	Mica fission track detector
Paul[145] (1986)	1.8 ± 0.4	Mica fission track detector
Moody[146] (1987)	0.64	Phosphate glass track detector
Recommended Value = 1.0 ± 0.4 x 10^{14} a;		*Selected Value; Uncertainty overlaps range*

Table 29. Total half-life of ^{241}Am

Reference Author (Year)	As Revised $T_{1/2}$/a	Comments
Hall[147] (1958)	458.1 ± 0.5	Not used; Low geometry α counting
Wallman[148] (1958)	457.7 ± 1.8	Not used; Low geometry α counting
Oetting[149] (1967)	432.7 ± 0.7	Calorimetry
Stone[150] (1968)	436.6 ± 3.0	Low geometry α counting
Brown[151] (1968)	433. ± 7.	Coulometric α counting
	434.4 ± 3.6	Relative Activity to ^{243}Am
Jove[152] (1972)	426.3 ± 2.1	Calorimetry
Strohm[11] (1974)	432.5 ± 1.0	Calorimetry (power decay); Revised uncertainty
	435.0 ± 1.0	Calorimetry (specific power); Revised uncertainty
Polyukhov[153] (1974)	432.8 ± 1.6	4π α counting; Revised uncertainty
Ramthun[154] (1975)	432.0 ± 0.7	Calorimetry; Revised Uncertainty
Weighted Average = 432.7 ± 0.6 a;		*Recommended Value*

Table 30. Spontaneous fission half-life of ^{242m}Am

Reference Author (Year)	As Revised $T_{1/2}/10^{12}$ a	Comments
Caldwell[155] (1967)	1.0 ± 0.4	Not used; Revised; Fission-Fragment - Neutron coincidence
Zelenkov[156] (1986)	> 3.0	α/fission; Silicon surface barrier detectors
Recommended Value = > 3. x 10^{12} a;		*Selected Value*

Table 31. Partial half-lives of ^{242m}Am

Reference Author (Year)	As Revised $T_{1/2}$/a	Comments
Street[157] (1950)	10000.	α decay branch
Hoff[158] (1955)	850.	Electron capt. decay branch
Barnes[159] (1959)	29000. ± 1450.	Revised Value; α decay branch
	960. ± 50.	Electron capt. branch
	152. ± 7.	Total half-life
Henderson[159] (1959)	182. ± 8.	β decay branch; quoted by Barnes[159]
Zelenkov[160] (1980)	171. ± 2.	β decay branch
	31200. ± 500.	α decay branch
	140.8 ± 1.7	Total half-life
Weighted Average = 141. ± 2. a;		*Recommended Value*

Table 32. Total half-life of ^{243}Am

Reference Author (Year)	As Revised $T_{1/2}/10^{3}$ a	Comments
Street[157] (1950)	10.	Not used; Daughter growth
Diamond[161] (1953)	8.1 ± 0.6	Not used; Revised value; Relative activity to ^{241}Am
Wallman[148] (1958)	7.95 ± 0.05	Not used; Low geometry α counting
Barnes[159] (1959)	7.29 ± 0.16	Not used; Relative activity to ^{241}Am
Beadle[162] (1960)	7.22 ± 0.05	Not used; Revised value; Relative activity to ^{241}Am
Brown[151] (1968)	7.34 ± 0.065	Relative activity to ^{241}Am
	7.39 ± 0.05	Coulometric α counting
Polyukhov[163] (1974)	7.38 ± 0.034	α counting; Relative activity to ^{241}Am
Aggarwal[164] (1980)	7.36 ± 0.042	Revised; relative activity to ^{241}Am
Weighted Average = 7.37 ± 0.02 x 10^{3} a;		*Recommended Value*

Table 33. Spontaneous fission half-life of ^{243}Am

Reference Author (Year)	As Reported $T_{1/2}/10^{14}$ a	Comments
Aleksandrov[165] (1966)	> 0.33 ± 0.03	Glass fission track detector
Grozdev[166] (1966)	2. ± 0.5	Glass fission track detector
Recommended Value = 2.0 ± 0.5 x 10^{14} a;		*Selected Value*

Table 34. Spontaneous fission half-life of ^{242}Cm

Reference Author (Year)	As Revised $T_{½}/10^6$ a	Comments
Hanna[167] (1951)	7.2 ± 0.2	Fission fragment counting, Ion chamber
Armani[168] (1967)	6.82 ± 0.18	Revised value; Li-I fission neutron counting
Zhang[169] (1979)	7.46 ± 0.06	Mica fission track detector
Raghuraman[170] (1982)	7.15 ± 0.15	Solid state track detector
Umezawa[171] (1982)	6.89 ± 0.17	Mica fission track detector
Zelenkov[156] (1986)	6.98 ± 0.33	Revised value; α/fission Silicon surface barrier detectors
Recommended Value = 7.0 ± 0.2 x 10^6 a;		*Selected Value; Uncertainty covers the range of recent measurements*

Table 35. Total half-life of ^{242}Cm

Reference Author (Year)	As Revised $T_{½}$/d	Comments
Hanna[172] (1950)	162.5 ± 1.	Low geometry α spectrometry
Glover[173] (1954)	162.46 ± 0.33	Revised uncertainty; Low geometry α counting
Hutchinson[174] (1954)	163.0 ± 1.8	Calorimetry
Flynn[175] (1965)	163.1 ± 0.4	Revised value; 2π α counting
Kerrigan[176] (1975)	163.2 ± 0.2	Calorimetry
Diamond[177] (1977)	162.76 ± 0.10	Revised uncertainty; Intermediate geometry α counting
Zhang[169] (1979)	163.02 ± 0.17	Revised uncertainty; Low geometry α counting
Jadhav[178] (1980)	162.13 ± 2.25	α spectrometry, solid state detector
Usuda[179] (1981)	161.35 ± 0.16	2π α counting; Revised uncertainty
Aggarwal[180] (1982)	162.82 ± 0.27	Relative activity to ^{244}Cm; Revised uncertainty
	163.17 ± 0.12	α counting; Revised uncertainty
Wiltshine[181] (1984)	163.03 ± 0.22	Low geometry α counting; Revised uncertainty
Weighted Average = 162.8 ± 0.2 d;		*Recommended Value*

Table 36. Spontaneous fission half-life of ^{243}Cm

Reference Author (Year)	As Reported $T_{½}/10^{11}$ a	Comments
Polynov[182] (1987)	5.5 ± 0.9	Mica fission track detector
Recommended Value = 5.5 ± 0.9 x 10^{11} a;		*Selected Value*

Table 37. Total half-life of ^{243}Cm

Reference Author (Year)	As Revised $T_{½}$/a	Comments
Asaro[183] (1953)	35.	Not used; No details
Choppin[184] (1958)	28.4 ± 0.8	Revised value for the ^{244}Cm $T_{½}$
Timofeev[185] (1986)	29.13 ± 0.10	Relative activity to ^{244}Cm
Weighted Average = 29.1 ± 0.1 a;		*Recommended Value*

Table 38. Spontaneous fission half-life of ^{244}Cm

Reference Author (Year)	As Revised $T_{1/2}/10^{7}$ a	Comments
Ghiorso[25] (1952)	1.39 ± 0.20	Revised value; Ionization chamber
Malkin[186] (1963)	1.46 ± 0.05	Gas scintillator
Metta[187] (1965)	1.346 ± 0.006	α/spontaneous fission ratio
Armani[168] (1967)	1.33 ± 0.03	Li-I fission neutron counter
Barton[188] (1970)	1.250 ± 0.007	Low geometry fission fragment counting
Hastings[189] (1972)	1.343 ± 0.006	α/fission ratio; Silicon surface barrier detector
Weighted Average = 1.32 ± 0.02 x 10^{7} a;		*Recommended Value*

Table 39. Total half-life of ^{244}Cm

Reference Author (Year)	As Revised $T_{1/2}$/a	Comments
Stevens[190] (1954)	19.2 ± 0.6	Not used; Relative activity to ^{242}Cm
Friedman[191] (1954)	17.9 ± 0.5	Not used; Relative activity to ^{242}Cm
Carnall[192] (1961)	17.59 ± 0.067	Specific activity; Revised uncertainty
Bentley[193] (1968)	18.099 ± 0.032	2π and low geometry α counting; Revised uncertainty
Kerrigan[194] (1972)	18.13 ± 0.037	Calorimetry; Revised uncertainty
Polyukhov[195] (1982)	18.24 ± 0.247	Specific activity; Revised uncertainty
Weighted Average = 18.1 ± 0.1 a;		*Recommended Value*

Table 40. Spontaneous fission half-life of ^{245}Cm

Reference Author (Year)	As Reported $T_{1/2}/10^{12}$ a	Comments
Druzhinin[196] (1985)	1.4 ± 0.2	α/fission ratio
Recommended Value = 1.4 ± 0.2 x 10^{12} a;		*Selected Value*

Table 41. Total half-life of ^{245}Cm

Reference Author (Year)	As Revised $T_{1/2}/10^{3}$ a	Comments
Hulet[197] (1954)	20.	Not used; Daughter x-rays measured
Friedman[191] (1954)	11.3 ± 5.	Not used; Revised value; Relative activity to ^{244}Cm
Browne[198] (1955)	14.3 ± 2.9	Not used; α counting
Huizenga[199] (1957)	7.5 ± 1.9	Not used; No details H.Diamond, private communication
Carnall[192] (1961)	9.32 ± 0.28	Not used; Relative activity to ^{244}Cm
Metta[200] (1969)	8.265 ± 0.180	Relative activity to ^{244}Cm
MacMurdo[201] (1971)	8.538 ± 0.071	Revised uncertainty; Relative activity to ^{244}Cm
Polyukhov[195] (1982)	8.445 ± 0.100	Relative activity to ^{244}Cm
Weighted Average = 8.48 ± 0.06 x 10^{3} a;		*Recommended Value*

Table 42. Total half-life of ^{246}Cm

Reference Author (Year)	As Revised $T_{1/2}/10^{3}$ a	Comments
Friedman[191] (1954)	3.9 ± 0.6	Not used; Revised value; Relative activity to ^{244}Cm
Browne[198] (1955)	2.3 ± 0.46	Not used; α counting
Butler[202] (1956)	6.62 ± 0.32	Not used; Relative activity
Carnall[192] (1961)	5.48 ± 0.17	Not used; Relative activity to ^{244}Cm
Metta[200] (1969)	4.711 ± 0.022	Relative activity to ^{244}Cm
MacMurdo[201] (1971)	4.82 ± 0.02	Relative activity to ^{244}Cm
McCracken[203] (1971)	4.654 ± 0.04	Specific activity
Polyukhov[204] (1976)	4.852 ± 0.076	Relative activity to ^{244}Cm
Weighted Average = 4.76 ± 0.04 x 10^{3} a;		*Recommended Value*

Table 43. Spontaneous fission half-life of ^{246}Cm

Reference Author (Year)	As Reported $T_{1/2}/10^{7}$ a	Comments
Fields[205] (1956)	> 1.24	Not used; Estimated value from the α/fission ratio
Fried[206] (1956)	2.0 ± 0.8	Not used; Fission counting; Estimated the mass
Metta[200] (1969)	1.80 ± 0.01	α/fission ratio; 2π chamber, semi-conductor
MacMurdo[201] (1971)	1.85 ± 0.02	α/fission ratio
Weighted Average = 1.81 ± 0.02 x 10^{7} a;		*Recommended Value*

Table 44. Total half-life of ^{247}Cm

Reference Author (Year)	As Reported $T_{1/2}/10^{7}$ a	Comments
Diamond[207] (1957)	> 4.	Not used; Daughter growth method
Fields[208] (1963)	1.64 ± 0.24	Daughter growth method
Fields[209] (1971)	1.56 ± 0.05	Relative α activity
Weighted Average = 1.56 ± 0.05 x 10^{7} a;		*Recommended Value*

Table 45. Spontaneous fission half-life of ^{248}Cm

Reference Author (Year)	As Reported $T_{1/2}/10^{6}$ a	Comments
Butler[202] (1956)	4.6 ± 0.5	Not used; Specific fission activity
Metta[200] (1969)	4.22 ± 0.12	α/fission ratio; 2π chamber, semi-conductor
MacMurdo[201] (1971)	4.20 ± 0.05	Relative activity to ^{244}Cm
McCracken[203] (1971)	4.115 ± 0.034	Specific fission activity; Ion chamber
Weighted Average = 4.15 ± 0.03 x 10^{6} a;		*Recommended Value*

Table 46. Total half-life of ^{248}Cm

Reference Author (Year)	As Reported $T_{1/2}/10^5$ a	Comments
Schuman[210] (1968)	4.0 ± 0.3	Not used; α half-life
Metta[200] (1969)	3.52 ± 0.04	α half-life reported = 3.84 ± 0.04
MacMurdo[201] (1971)	3.60 ± 0.04	α half-life reported = 3.94 ± 0.04
McCracken[203] (1971)	3.40 ± 0.03	α half-life reported = 3.703 ± 0.032
Weighted Average = 3.48 ± 0.06 x 10^5 a;		*Recommended Value*

Table 47. Spontaneous fission half-life of ^{250}Cm

Reference Author (Year)	As Reported $T_{1/2}/10^4$ a	Comments
Huizenga[199] (1957)	2.3	Not used; Estimated value
CRG[211] (1966)	1.74 ± 0.24	Not used; Preliminary PAR bomb shot results
Metta[212] (1967)	1.13 ± 0.05	Ion chamber; PAR bomb shot results
Recommended Value = 1.13 ± 0.05 x 10^4 a;		*Selected Value*

Table 48. Total half-life of ^{250}Cm

Reference Author (Year)	As Reported $T_{1/2}/10^4$ a	Comments
This work (1987)	1.13 ± 0.05	Spontaneous fission half-life
β systematics	≈ 10.	Estimated partial half-life for β decay Q_β = 37 ± 13 keV (see Wapstra[213])
α systematics	≈ 20.	Estimated partial half-life for α decay Q_α = 5.197 ± 0.021 MeV (see Wapstra[213])
Recommended Value ≈ 9.7 x 10^3 a;		*Value calculated from partial half-lives*

Table 49. Recommended half-lives and uncertainties

Reference Nuclide	$T_{1/2}$ (total) (Years)	$T_{1/2}$ (spont.fiss.) (Years)	Reference Nuclide	$T_{1/2}$ (total) (Years)	$T_{1/2}$ (spont.fiss.) (Years)
^{232}U	70. ± 1.	8. ± 6. x 10^{13}	^{244}Pu	8.00 ± 0.09 x 10^7	6.6 ± 0.2 x 10^{10}
^{233}U	1.592 ± 0.002 x 10^5	> 2.7 x 10^{17}	^{241}Am	432.7 ± 0.6	1.0 ± 0.4 x 10^{14}
^{234}U	2.455 ± 0.006 x 10^5	1.5 ± 0.2 x 10^{16}	^{242m}Am	141. ± 2.	> 3. x 10^{12}
^{235}U	7.04 ± 0.01 x 10^8	1.0 ± 0.3 x 10^{19}	^{243}Am	7.37 ± 0.02 x 10^3	2.0 ± 0.5 x 10^{14}
^{236}U	2.342 ± 0.004 x 10^7	2.5 ± 0.1 x 10^{16}	^{242}Cm	162.8 ± 0.2 Days	7.0 ± 0.2 x 10^6
^{238}U	4.47 ± 0.02 x 10^9	8.2 ± 0.1 x 10^{15}	^{243}Cm	29.1 ± 0.1	5.5 ± 0.9 x 10^{11}
^{236}Pu	2.87 ± 0.01	2.1 ± 0.1 x 10^9	^{244}Cm	18.1 ± 0.1	1.32 ± 0.02 x 10^7
^{238}Pu	87.7 ± 0.1	4.75 ± 0.09 x 10^{10}	^{245}Cm	8.48 ± 0.06 x 10^3	1.4 ± 0.2 x 10^{12}
^{239}Pu	2.410 ± 0.003 x 10^4	8. ± 2. x 10^{15}	^{246}Cm	4.76 ± 0.04 x 10^3	1.81 ± 0.02 x 10^7
^{240}Pu	6.56 ± 0.01 x 10^3	1.16 ± 0.02 x 10^{11}	^{247}Cm	1.56 ± 0.05 x 10^7	--------
^{241}Pu	14.4 ± 0.1	< 6. x 10^{16}	^{248}Cm	3.48 ± 0.06 x 10^5	4.15 ± 0.03 x 10^6
^{242}Pu	3.75 ± 0.02 x 10^5	6.77 ± 0.07 x 10^{10}	^{250}Cm	≈ 9.7 x 10^3	1.13 ± 0.05 x 10^4

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