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HALF-LIVES OF LONG-LIVED ISOTOPES OF TRANSACTINIUM ELEMENTS FROM ^{228}Th TO ^{257}Fm

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HALF-LIVES OF LONG-LIVED ISOTOPES OF TRANSACTINIUM ELEMENTS (from ^{228}Th to ^{257}Fm)

V.M. Surin, Eh.F. Fomushkin

ABSTRACT

THE LONG-LIVED ISOTOPE HALF-DECAY PERIODS OF TRANSACTINIUM ELEMENTS (from ^{228}Th to ^{257}Fm). The experimental measurements and critical evaluation results of the long-lived isotope half-decay periods of transactinium elements (from ^{228}Th to ^{257}Fm) are given on July 1981 to be published in open literature and related to the natural radioactive decay. From the massif of the known half-decay periods the most reliable data were selected, received or evaluated and recommended for practical use; the calculations of isotope specific activities were performed on this data.

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INTRODUCTION

The half-life of a radioisotope is an extremely important constant which indicates the life-time of the isotope and determines its individual characteristics and behaviour in physical, chemical and technological processes. An exact knowledge of half-lives is especially important in reactor calculations. Since the discovery of the phenomena of the radioactivity, isotopism and isomerism of the chemical elements and the first experiments on the measurement of half-lives, a vast amount of material has been accumulated. Critical analysis of this material is by no means a simple task*/. Of course, the first stage here is the selection of published data for subsequent analysis and processing. There is great interest in information about isotopes which are finding increasingly wide application in nuclear power production, the national economy and scientific research. As a rule, these are among the longest-lived isotopes of the element in question.

The reliability and accuracy of data on half-lives has increased with the improvement of measuring methods, the most important of which are the various techniques for the measurement of the rate of radioactive decay, calorimetry, mass spectrometry, alpha- and gamma-spectroscopy, the isotopic dilution method, techniques based on interaction with neutrons, and so forth. Much attention has been paid to the group of isotopes used in relative measurements of half-lives, such as ^{233}U, ^{238}Pu, ^{239}Pu, ^{241}Am, ^{244}Cm, ^{252}Cf. By now, acceptable accuracies have been obtained for these isotopes. This has made it possible to detect the sources of systematic errors in studies which were conducted earlier. A favourable effect on work connected with the measurement of half-lives was exerted by refinement of isotope decay schemes, more precise determination of radiation energies and intensities, and also the accumulation of materials enriched in a basic isotope.

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*/ It is hard to imagine that, at least in specialized laboratories, there is no rigorous assessment and analysis of all communications but, to the best of our knowledge, there are no published surveys on this subject, although work of this kind is certainly being carried on [Ref. 2, p. 109].

During the past six years the International Atomic Energy Agency (IAEA), of which the Soviet Union is a member, has held two international advisory group meetings on the evaluation of nuclear data relating to transactinium isotopes, in particular data on half-lives. The first meeting was held at Karlsruhe (Federal Republic of Germany) in 1975 [1], the second at Cadarache (France) in 1979 [2]. The results of these meetings were summarized at the end of 1980 in a paper of A. Lorenz [3] containing a proposed recommended list of half-lives of isotopes from ^{228}Th to ^{253}Es*/. Six organizations have been enlisted for the work initiated and directed by the Agency on more precise determination of the half-lives of transactinium isotopes: the Central Bureau for Nuclear Measurements (Geel, Belgium), the Laboratoire de Métrologie des Rayonnements Ionisants (France), the Bhabha Atomic Research Centre (Trombay, India), the Japan Atomic Energy Research Institute, the Atomic Energy Research Establishment (Harwell, United Kingdom), the National Technical Laboratory (Idaho, USA).

A good deal of attention is paid to these questions in the United States, where a committee for half-life evaluation has been set up and is represented by a number of laboratories: the Mound Laboratory, the Argonne National Laboratory, the Los Alamos National Laboratory, the Lawrence National Laboratory in Livermore, the National Bureau of Standards and the Rocky Flats Laboratory.

Owing to the discrepancies in the experimental data, the above-mentioned committee organized and carried out carefully prepared complex measurements of the half-life of ^{239}Pu, drawing on all available mothodologies. A separate issue of the International Journal of Applied Radiation and Isotopes (vol. 29 No. 8 (1978)) is devoted to the results of these measurements. In 1978 the latest (seventh) edition of the Tables of Isotopes [4] appeared in the United States; this contained a selective compilation of data on half-lives, updating and supplementing the earlier edition [10]. In the Soviet literature the latest, far from complete, survey [5] of half-lives of transactinium isotopes contains data published up to 1974. In 1978 an analytical survey [6] was published on a number of nuclear contstants of

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*/ On the basis of these data, the IAEA Nuclear Data Committee recommend half-life values for certain isotopes [298].

transactinium isotopes of the fuel cycle, with data for 19 isotopes (from ^{232}Th to ^{252}Cf). A handbook [7] which appeared recently in the Soviet Union gives (together with other characteristics) the half-lives, recommended by the State Service for Standard Reference Data, of 13 radionuclides related to the actinides.

In this paper the authors summarize all the data known to them on the half-lives of the 46 longest-lived isotopes of the transactinium elements (from ^{228}Th to ^{257}Fm) published up to 1 July 1981 in the Soviet and non-Soviet literature. The paper presents all the results of original studies, compendia and accepted and recommended half-lives. Doubtful or erroneous data, and also results lending themselves readily to "correction" at the present time were deliberately not excluded. Apart from its practical value, such a selection of material is of definite methodological interest, affording an opportunity to observe clearly changes in ideas concerning half-lives and to single out stable trends. For example, the following conclusions can be drawn from the data presented in the paper:

- There is a visible need to determine more accurately the half-lives of many important isotopes (^{232}U, ^{237}Np, ^{241}Pu, ^{244}Pu, $^{242}Am^{m}$, ^{243}Cm, ^{245}Cm, ^{247}Cm, ^{247}Bk, ^{249}Bk, the isotopes of californium with the exception of ^{252}Cf, and others);
- The half-life of ^{232}Th is observed to be stable with systematic reduction of error;
- The absolute half-life values of ^{233}U, ^{234}U, ^{239}Pu, ^{241}Am, ^{245}Cm, ^{249}Cf are lower;
- The half-lives of ^{238}U, ^{236}Np, ^{244}Pu, ^{244}Cm, ^{246}Cm, ^{249}Bk, and ^{257}Fm are higher;
- There is an observable decrease in the half-life measurement errors for ^{232}Th, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{248}Cm, ^{249}Bk, ^{249}Cf, ^{250}Cf, ^{252}Cm, etc.

The factual material is presented in the form of tables (1-11) of a single type, including the year of publication, the half-life value, the uncertainty δ in the half-life, given for purposes of clarity as a percentage (most often for a confidence level $P = 0.68$), the method of half-life measurement, comment and literature source.

The data for each isotope are in most cases listed in a separate table. All the tables are accompanied by brief comments. In the case of some isotopes (^{229}Th, ^{235}Np, ^{236}Np^{m}, $^{243-247}$Cm, ^{247}Bk), owing to the limited information available the half-life data are presented in an explanatory text. The most reliable half-lives are set off in the last line of each table. For the most part they are based on recommendations [1-3, 7, 36] and in individual cases they are taken from original studies or evaluated by the authors of the present survey. Data on spontaneous fission, a detailed analysis of which is beyond the scope of this paper, are presented in the form of a summary table (No. 12) compiled largely from data in studies [1-7, 256]. Table 13 gives the accepted nuclear constants of long-lived isotopes of transuranium elements. Lastly, on the basis of the half-life values adopted or recommended in the paper, Table 14 presents the results of calculations of the specific activities of radioactive decay, spontaneous fission and the neutron radiation associatited with the latter.

The paper makes no claims to exhaustiveness. The available publications are to be found in numerous editions and the possibility that some of them have been omitted is fairly large. The authors will be grateful for any comments.

BRIEF COMMENTS ON THE TABLES

Isotopes of thorium (Z = 90). Since the publication of the survey in Ref. [5] there have been no communications concerning measurements of the half-lives of thorium isotopes, except for the paper of Meadows et. al. [18], in which the half-life of ^{230}Th was measured with an uncertainty of 0.4%. The data recommended at Cadarache (France) in 1979 [2, p. 49] are based on earlier studies. The need for reducing measurement errors is considered for ^{229}Th and ^{230}Th. The half-life of ^{232}Th is given with moderate accuracy. The only study of ^{229}Th [12] gave $T_{1/2}$ = 7340 (160) years. During the past 30 years, ^{229}Th has not attracted the attention of scientists.

Isotopes of protactinium (Z = 91). This paper includes information about two isotopes of protactinium with relative atomic masses of 231 and 233. Although ^{233}Pa cannot be considered long-lived in comparison with ^{231}Pa, it is of interest because it is often used as a tracer in radiochemistry

experiments. The measurement accuracies obtained for protactinium are fairly high, a fact which is apparently one of the reasons why there have been no new publications on the subject over the past 20 years.

Isotopes of uranium (Z = 92). Historically, these have formed the basis of nuclear power and have therefore been the subject of a large number of half-life measurements. ^{232}U has been less satisfactorily studied than the others: the last recommended value for its half-life was given with an uncertainty of 2.8% [2]. Careful experimental measurements of S.K. Aggarwal et al., carried out in 1979 by two independent radiomentric methods with an uncertainty of 0.57%, gave a half-life 4.5% lower than the recommended one, which should of course serve as a warning. Additional measurements are essential for ^{232}U. Most work has been done on ^{233}U and ^{234}U. The most recent measurements fall reliably within the limits of error. The error recommended for ^{234}U in Ref. [7] is somewhat on the low side, since it does not take into account all the known data satisfying the demands of mathematical statistics. The situation relating to the error in the half-life of ^{235}U is not fully clear, although all the latest recommendations converge on one and the same value: $T_{1/2} = 7.038 \times 10^5$ Y. The half-life of ^{236}U was reduced during the period 1951-1972 by approximately 5%. It is planned to carry out more exact measurements in the United Kingdom and Japan [2, p. 47]. Despite the difficulties of measurement, the half-life of the longest-lived isotope (^{238}U) has been measured with satisfactory accuracy.

Isotopes of neptunium (Z = 93). Neptunium has three known long-lived isotopes, with atomic masses of 235, 236 and 237. The present study also presents data on the short-lived ^{239}Np since this isotope, along with ^{233}Pa, is a convenient beta-active label and is often used in radiochemistry research. ^{235}Np, which disintegrates as a result of electron capture and alpha-decay, is an isotope that is not readily accessible. Its half-life needs to be determined accurately [98-101]. We have adopted a half-life of 403(4) h, based on the data in Refs [98, 101], and the ratio $\alpha/E = 1.4(2) \times 10^{-5}$, taken as a mean arithmetic value from Refs [99, 100]. The first approximate evaluation of the half-life of $^{236}Np^m$ (> 5000 Y) was made in 1955 [102]; the first experimental work on its measurement was

carried out in 1972; for beta-decay a partial half-life value of $1.29(^{+0.07}_{-0.05}) \times 10^6$ Y was obtained [103]. The proceedings of the two Advisory Group Meetings on Transactinium Isotope Nuclear Data [1, 2], and also the Tables of Isotopes [4], give $T_{1/2} = 1.15(12) \times 10^5$ Y (the effective period for beta decay and electron capture). It is difficult to understand the reason for the lack of interest in the exact determination of the half-life of ^{237}Np, which is readily accessible in the monoisotopic state. Up to now, the 20-year-old experimental value $T_{1/2} = 2.14(1) \times 10^6$ Y [107] has been passing on from one reference work to the next. Fresh measurements are planned at Harwell (United Kingdom) [2, p. 58].

Isotopes of plutonium (Z = 94). The role of plutonium in the nuclear power production of the advanced countries is growing every year. This is due primarily to the solution of problems relating to industrial-scale fast-neutron reactors [113]. For this reason an accurate knowledge of the nuclear characteristics of plutonium is becoming increasingly important.

Of the plutonium isotopes, those with atomic masses 238-242 have received most attention. In the case of the first three, high accuracies have been obtained in half-life measurements. For example, the United States Committee for Half-Life Evaluation is not planning studies on the subject of ^{238}Pu [126]. Under the IAEA programme [2, p. 47], however, work is planned in the United Kingdom, Belgium and Japan. It should be noted that the result of a carefully performed study which was published recently involves an error of 0.58%, which is ten times higher than that recommended in Ref. [2, ENSDF]. After the performance of complex measurements of ^{239}Pu in the United States [126] it is hard to expect the appearance of qualitatively new findings in the years immediately ahead. A striking fact is the good agreement between the earliest [128] and the latest [141, 142] measurements of the half-life of ^{239}Pu based on the use of calorimetry. Although a very large number of studies have been devoted to ^{241}Pu, its half-lives (β^-- and α-decay) are evaluated with an uncertainty of 1-1.5%, which is entirely inadequate, especially for correct reactor calculations. The extreme need for a more precise determination of the half-life of this isotope is

emphasized in the Review Report of C.W. Reich [2, p. 48], for which reason priority measurements were planned in the IAEA*/. At the moment, few data are available on the subject of ^{241}Pu. The reason for this would appear to be the difficulties in obtaining it in sufficient quantity with high isotopic purity.

Isotopes of americium (Z = 95). Interest in the transactinium elements, and particularly americium, is increasing as these elements begin to accumulate in research reactors [196]. Fully reliable half-life data are available only for ^{241}Am, which was used as a comparison isotope in many measurements of the half-life of ^{241}Pu (see Table 5.5). Special studies were carried out in connection with the international intercomparison of the specific activity of a dissolved sample of ^{241}Am [202]. In the case of $^{242}Am^{m}$, which exhibits a triple decay mechanism (isomeric transition, electron and alpha decay), little research has been carried on and as yet it is difficult to judge the reliability of the available data. Experimental determination of the half-lives of $^{242}Am^{m}$ [207] has been carried out with satisfactory accuracy but the results differ substantially from the data of preceding measurements. The situation with respect to ^{243}Am, for which the half-life error is estimated at 0.5%, is more or less favourable. All the measurements performed over the past 12 years yielded results coming within the limits of the indicated error.

Isotopes of curium (Z = 96). The bulk of the half-life measurement work is related to curium with atomic masses of 242 and 244. The required accuracies have been obtained for these two isotopes. Nevertheless, the Agency is planning studies with a view to more accurate determination of their half-lives [2, p. 48]. The remaining isotopes of curium, for which the errors in half-life determination are within the limits of 1-3%, require

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*/ The results of measurements performed by a group of scientists from India ($T_{1/2}$ = 14.52 ± 0.08 Y) were made known at the end of 1981 (see Aggarwal, S.K. et al., Radio Chem. Acta 29, 2/3 (1981) 65).

further research. For ^{243}Cm, only two studies have been carried out [215, 216]; the half-lives obtained were 32*/ and 29.0 ± 0.8 Y. The situation as regards ^{247}Cm is similar. The measurements of P.R. Fields et al. in 1963 [218] and 1971 [219] yielded half-lives of $(1.64 \pm 0.24) \times 10^7$ Y and $(1.56 \pm 0.05) \times 10^7$ Y. The latter study was carried out with enriched (99.4%) ^{247}Cm and hence this result would appear to be more reliable.

Isotopes of berkelium (Z = 97). Berkelium has two known long-lived isotopes, with atomic masses of 247 and 249. Of most interest in studies on the physico-chemical and other characteristics of berkelium is the longest-lived isotope, ^{247}Bk, but it is practically unavailable in significant quantities owing to the difficulties of obtaining it. When various starting materials (^{232}Th, ^{238}U, ^{239}Pu, etc.) are irradiated in a mixed beam of reactor neutrons, ^{247}Bk is not formed [5, p. 189]. There is only one study devoted to the measurement of its half-life [245]; in this, a value of 1380 ± 250 Y was obtained. The need for performing further studies is obvious.

Isotopes of californium (Z = 98). An analysis of data in the literature shows that the half-life of ^{252}Cf is the one that has been most reliably and carefully measured, but not so much so that an accuracy entirely satisfactory to scientists and practical workers has been achieved [2, p. 48]. This isotope accumulates in reactors and is already available in amounts of the order of tens and even hundreds of milligrams. Its major scientific and practical value is determined by its use as a portable source of spontaneous fission neutrons. ^{252}Cf was chosen as a standard with a recommended average number of neutrons per spontaneous fission event $\bar{\nu}_p$ (1972) [256]. The half-lives of ^{251}Cf and ^{254}Cf are quoted in the literature with very large errors. In many laboratories throughout the world work is being performed with a view to measuring and determining more precisely the value of $\bar{\nu}_p$ for ^{252}Cf [257, 258].

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*/ Corrected by taking account of the data in Ref. [217].

Isotopes of einsteinium (Z = 99). In the 25 years following the discovery of einsteinium and fermium, sophisticated and complex experiments were carried out for the purpose of obtaining their isotopes and singling out and investigating their nuclear characteristics [268]. Good agreement between the results of half-life measurements is observed first and foremost for ^{253}Es, and also for ^{255}Es. As a result of measurements in 1977 [272], the half-life of ^{252}Es proved to be 15-25% higher than shown by earlier data. Satisfactory agreement with respect to ^{254}Es is found in the final conclusions of recent studies [281, 282]. Thus it may be expected that there will be further improvements in the accuracy with which the half-lives of the longest-lived isotopes, ^{252}Es and ^{254}Es, are determined. All the measurements of ^{253}Es and ^{255}Es are consistent within the limits of error.

Isotopes of fermium (Z = 100). In this paper, data are given for two isotopes of fermium, ^{253}Fm and ^{257}Fm. The 1959-1967 measurement findings for ^{253}Fm lead to one and the same half-life value, namely 3.0 days, but the resulting errors are still too large. The half-life value for ^{257}Fm during the decade 1964-1973 was improved by 20%. The most recent measurement [294] needs to be confirmed. Further study of both isotopes is necessary.

Spontaneous fission. The accepted constants for the spontaneous fission of isotopes of transactinium elements (half-life and average number of prompt fission neutrons) which are required for calculating specific activities in terms of fragments and neutrons are given in Table 12. In the compilation of this table use was made mainly of the recommendations in Refs [1-3, 7], the material contained in surveys and evaluations [4-6] and data from some original studies.

Specific activities of the isotopes. For convenience in practical use, all the nuclear constants of isotopes of transactinium elements (status of July 1981) adopted in this paper are listed in Table 13. The calculations of the specific activities of the isotopes (see Table 14) were performed on the basis of these constants. This activity in terms of natural decay is linked to the decay constant λ and to the half-life by the relationship $A_{sp} = dN/dt = \lambda N(\ell n 2/T_{1/2})N$, where N is the number of nuclei of the isotope. For a sample of a radioisotope of mass 1 mg for $\ell n 2$, Avogadro's

number 6.022045×10^{23} mol^{-1} and a duration of one year (365.2422 days = 3.1557×10^{7} s), the expression given above is transformed into the following: $A_{sp} = 1.3227 \times 10^{13}\ 1/T_{1/2}M$, where A_{sp} is in disintegrations/(s·mg); the half-life is in years; M is the atomic mass of the isotope on the ^{12}C scale. The specific activity in terms of neutrons (A^{n}_{sp}) emitted by spontaneous fission is linked to the spontaneous fission activity (A^{sf}_{sp}) by the simple relationship $A^{n}_{sp} = A^{sf}_{sp}\ \bar{\nu}_{p}$.

The uncertainty in the specific activity of natural radioactive decay and spontaneous fission is determined only by the accepted uncertainty in half-life or the uncertainty in half-life of spontaneous fission. If the latter is calculated from the experimentally measured ratio of decay intensity and spontaneous fission for a known half-life, e.g. the ratio α/sf, the resulting uncertainty in specific activity is expressed by the sum $\Delta^2(A_{sp})_{res} = \delta^2_{T_{1/2}} + \delta^2_{\alpha/sf}$. In the calculation of the specific activity uncertainty for neutrons a further terms is added: $\Delta^2(A^{n}_{sp}) = \delta^2_{T_{1/2}} + \delta^2_{\alpha/sf} + \delta^2\ \bar{\nu}_{p}$.

HALF-LIFE TABLES

Legend: notation and abbreviations used in the tables

The following notation and abbreviations are used in the tables:

MSA	-	Measurement of specific activity
CM	-	Colorimetry
MS	-	Mass spectrometry
MID	-	Method of isotopic dilution
AS	-	Alpha spectrometry
GS	-	Gamma spectrometry
SCD	-	Semiconductor detector
LS	-	Liquid scintillator
PC	-	Proportional counter
GFC	-	Gas-flow counter
IC	-	Ionization chamber
AGC	-	Alpha, gamma-coincidences
BGC	-	Beta, gamma-coincidences
MRA	-	Measurement of activity in relation to the activity of an isotope with a known half-life
θ	-	Solid angle of recording
MLS	-	Method of least squares
α	-	Alpha decay
β	-	Beta decay
IT	-	Isomeric transition
SF	-	Spontaneous fission.

Half-life of ^{228}Th (Z = 90)

Table 1.1

Year	$T_{\frac{1}{2}}(\alpha)$, year	δ,%	Measurement method	Comments	Literature
1918	1,906	-	-	-	[8]
1956	1,910	0,10	MSA	Measurements over 2-yr period	[9]
1971	1,9131(3)	0,046	Gm (0.5473 Ci*/ ^{238}Th)	Measurements over 18-yr period	[11]
1975	1,913	0,10	-	Recommended	[1]
1979	1,9131	0,047	-	-"-	[2]
1980	1,913	0,10	-	-"-	[3]
1981	1,9131	0,047	-	Adopted from data of Ref. [2, ENSDF]	

*/ The curie (Ci) = 3.7×10^{10} Bq.

Half-life of ^{230}Th (Z = 90)

Table 1.2

Year	$T_{\frac{1}{2}} \cdot 10^{-4}$ y (α),	δ,%	Measurement method	Comments	Literature
1924	11	-	-	-	[13]
1927	13	-	-	-	[14]
1930	8,23	3,0	By equilibrium ^{222}Rn	-	[15]
1949	8,0	3,3	MSA, MS	Mixtures of $^{230,232}ThO_2$	[16]
1962	7,52	2,1	CM	-	[17]
1975	7,7	3,9	-	Recommended	[1]
1979	7,7	3,9	-	-"-	[2, c.49]
1980	7,538(1)	0,40	MSA, SCD, MS	^{230}Th > 99%	[18]
1980	7,7	3,9	-	Recommended	[3]
1981	7,53	1,0	-	Mean arithmetic value taken from data of Refs [17, 18]	

HALF-LIFE OF ^{232}Th (Z = 90)

TABLE 1.3

YEAR	$T_{1/2} \cdot 10^{-10}$ (α), y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1938	1,89	2,0	By absolute decay rate	-	[19]
1956	1,42	4,9	GS, by absolute rate of γ-radiation of ^{208}Tl in equilibrium	Three aged samples	[20]
1956	1,45	3,4	MSA, IS, AS (for E_α peak = 3.98 MeV)	-	[21]
1956	1,39	2,2	By absolute decay rate	Nuclear photoemulsions	[22]
1960	1,410	1,1	MSA, AS, 2π-IC	-	[23]
1975	1,405	0,43	-	Recommended	[1]
1978	1,405	0,64	-	Evaluation	[5]
1979	1,405	0,43	-	Recommended	[2]
1980	1,405	0,43	-	- " -	[3]
1981	1,405	0,43	-	Adopted from data of Refs [1-3]	

HALF-LIFE OF ^{231}Pa (Z = 91)

TABLE 2.1

YEAR	$T_{1/2} \cdot 10^{-4}$ (α), y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1931	3,2	-	-		[24]
1932	3,2	10	Comparison of ionization currents from Pa and U in an electroscope	Samples from 1 mg Pa_2O_5 and 1 mg U_3O_8	[25]
1949	3,43	0,86	MSA, GFC	-	[26]
1961	3,248	0,87	CM	Sample of 0.358 g Pa_2O_5	[27]
1968	3,284	0,71	MSA	-	[28]
1969	3,2713	0,34	CM	Sample of 193 mg Pa_2O_5	[29, 30]
1975	3,276	0,34	-	Recommended	[1]
1979	3,276	0,34	-	- " -	[2]
1980	3,276	0,34	-	- " -	[3]
1981	3,276	0,34	-	Adopted from data of Refs [1-3]	-

HALF-LIFE OF ^{233}Pa (Z = 91)

TABLE 2.2

YEAR	$T_{1/2}(\beta^-)$, D	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1941	27,4	1,5	By decay curve	-	[31]
1956	27,0	0,37	By decay curve, 4π γ-IC, β-PC	Measurements over period of 321 D	[32]
1957	26,95	0,11	-	-	[33]
1975	27,0	0,37	-	Recommended	[1]
1979	27,0	0,37	-	- " -	[2]
1980	27,0	0,37	-	- " -	[3]
1981	27,0	0,37	-	Adopted from data of Refs [1-3]	-

HALF-LIFE OF ^{232}U (Z = 92)

TABLE 3.1

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1954	73,6	1,4	MSA, Ar/CO_2-PC, MID, MS	-	[34]
1964	72,1	0,69	MSA	$^{231}Pa(n,\gamma)^{232}Pa \xrightarrow{\beta^-} {}^{232}U$, ^{232}U 99,24%	
	71,4	0,84	CM		
	71,7	0,68	-	Mean value (P = 0.68)	[35]
1975	72	1,4	-	Recommended	[1]
1976	72	2,8	-	Recommended	[36]
1978	71,8	0,97	-	Evaluation	[6]
1979	72	2,8	-	Recommended	[2, p.49]
1979	69,00	0,06	MSA, PC, LS, MID, MS	-	
	68,81	0,55	MRA, AS, MS	In relation to ^{233}U	[37]
	68,90	0,57	-	Mean value	
1980	72	1,4	-	Recommended	[3]
1981	72	1,4	-	Adopted from data of Ref. [3]	-

HALF-LIFE OF ^{233}U (Z = 92)

TABLE 3.2

YEAR	$T_{1/2} \cdot 10^{-3}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1945	1,63	-	-	-	[38]
1949	1,620	0,62	MSA, 2π-IC, MS	-	[39, 149]
1955	1,615	0,25	MSA, 2π-IC	-	[40]
1958	1,611	0,5	MSA, 2π-IC	-	[41]
1959	1,626	0,49	MSA, IC, θ = const	No account taken of corrections for errors and absorption	[42]
1961	1,615	0,56	MSA, PC, θ = const	^{233}U 70.48(7)%	[43]
1967	1,621	0,20	MSA, LS	-	[44]
1967	1,540	0,065	CM	^{233}U 96.92%	[45]
1968	1,553	0,64	MSA, PC (θ = const), IC, MS	-	[46]
1969	1,588	0,44	MSA, PC (θ << 1)	-	[47]
1969	1,583	0,44	MSA, PC (θ << 1)	-	[48]
1969	1,598	1,5	-	Evaluation	[49]
1974	1,5911	0,094	MSA, 2π-PC, AS, SCD, MS	-	[50]
1975	1,592	0,13	-	Recommended	[1]
1976	1,5925	0,25	MSA, PC (θ << 1), LS	-	[51]
1976	1,592	0,19	-	Recommended	[36]
1978	1,598	0,50	-	Evaluation	[6]
1979	1,592	0,13	-	Evaluation	[52]
1979	1,592	0,13	-	Recommended	[2, p.49]
1979	1,5987	0,069	MSA, AS, $4\pi\alpha X$-coincidences	^{233}U, 98.11%, uncertainty for P = 0.68	[53]
1980	1,5885	0,47	MSA, PC, LS, AS, MS, MID	^{233}U 99.7%	[54]
1980	1,592	0,13	-	Recommended	[3]
1981	1,592	0,13	-	Adopted from data of Refs [1-3]	-

TABLE 3.3

HALF-LIFE OF ^{234}U (Z = 92)

YEAR	$T_{1/2} \cdot 10^{-5}$ (α), y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
1930	3,4	-	-	-	[55]
1932	~0,1	-	By α-particle path length	-	[56]
1934	1,7	-	MSA	-	[57]
1939	2,7	-	MS, measurement of $^{238}U/^{234}U$ isotopic ratio	Natural U	[58]
1946	2,51	3,0	-	-	[59]
1946	2,29	6,1	MS, measurement of $^{234}U/^{238}U$ isotopic ratio	Natural U, enriched in ^{234}U, Half-life of ^{238}U taken as $= 4.51 \times 10^9$ Y	[60]
	2,35	6,0	MSA, MS		
1949	2,69	1,5	MSA, AS, MS	$^{238}U \xrightarrow{\alpha} {}^{234m}Th \xrightarrow{\beta^-} {}^{234}Pa \xrightarrow{\beta^-} {}^{234}U$	[61]
	2,67	1,5			
1949	2,522	0,32	MSA, N_2-IC, MS	-	[62]
1952	2,520	0,32	MSA, N_2-IC, MS	-	[63]
1952	2,475	0,65	MSA, IC, MS	^{234}U 95.99%	[64]
1958	2,50	1,0	MID, AS	Enriched U	[41]
1965	2,47	1,2	MSA	Enriched ^{234}U	[65]
1968	2,483	0,20	-	-	[66]
1969/1971	2,444	0,49	-	-	[67,71]
1969	2,488	0,64	-	Assumed	[49]
1970	2,460	2,0	-	-	[68]
1970	2,439	0,57	-	-	[69]
1970	2,444	0,57	-	-	[70]
1971	2,444	0,49	MSA, CH_4-PC(θ<<1), MID, MS	^{238}U Standard	[71]
1971	2,446	0,29	MSA, PC (θ<<1), LS, MID, MS	100 samples with contents of 0.168 - 99.87% ^{234}U	[72]
1974	2,446	0,29	-	Evaluation	[73]
1975	2,445	0,70	-	Assumed	[74]
1975	2,446	0,29	-	Recommended	[1]
1976	2,446	0,29	-	-"-	[36]
1978	2,444	0,20	-	Evaluation	[6]
1979	2,445	0,41	-	Recommended	[2]
1980	2,445	0,20	-	-"-	[7]
1980	2,446	0,29	-	-"-	[3]
1981	2,445	0,41	-	ADOPTED FROM DATA OF REF. [2]	

TABLE 3.4

HALF-LIFE OF ^{235}U (Z = 92)

YEAR	$T_{1/2} \cdot 10^{-8}$ (α), y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
1929	4,2	-	By content of stable lead in uranium ores	-	[75] cited in Ref. [58]
1930	2,7	-			[76]
1932, 1934	4	-			[77]
1933, 1934	4,45	-			[78]
1937	7,0 ± 6,3	-			[79]
1939	7,13	-	MS, measurement of $^{238}U/^{235}U$ isotopic ratio	Nacural U	[58]

Table 3.4 (contd.)

YEAR	$T_{1/2} \cdot 10^{-8}$ (α) y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
I949	8,8	I2,5	MSA, N_2-IC, MS	-	[62]
I950	7,I0	2,3	MSA	Enriched ^{235}U	[80]
I95I	6,94	3,6	Comparison of the activities of ^{235}U and ^{234}U	Natural U	[8I]
I952	7,I8	2,2	MSA, IC, MS	^{235}U 99.94%	[63,64]
I957	6,84	2,2	Comparison of the activities of ^{234}U, ^{235}U and ^{238}U, AS	Natural U	[82]
I957	7,I0	2,2	MSA	-	[83]
I963	6,92	I,3	Analysis of α spectrum of natural U	-	[84]
I965	6,97	I,0	MSA, SCD	Natural U	[85]
I965	7,I3	I,3	MSA	Enriched ^{235}U	[65]
I966	7,022	+I,0; −0,4	Measurement of Pb/U ratio in natural uranium	-	[86]
I969	7,I0	I,5	-	Evaluation	[49]
I97I	7,038I	0,068	MSA, PC, AS, SCD, MS	-	[87]
I974	6,85	I,3	MSA, PC (θ<<1), AS, SCD	99.999% ^{235}U (see criticism in Ref. [89])	[88]
I974	7,038	0,068	-	Evaluation	[73]
I975	7,038	0,I0	-	Recommended	[1]
I976	7,038	0,28	-	-"-	[36]
I978	7,03	0,28	-	Evaluation	[6]
I979	7,038	0,07I	-	-"-	[52]
I979	7,038	0,07I	-	Recommended	[2]
I980	7,038	0,I0	-	-"-	[3]
I98I	7,038	0,07I	-	Adopted from data in Ref. [2, ENSDF]	-

HALF-LIFE OF ^{236}U (Z = 92)

TABLE 3.5

YEAR	$T_{1/2} \cdot 10^{-7}$ (α), y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
I943	2	-	MRA, AS	In relation to ^{235}U	Cited in [90]
I95I	2,457	0,8I	MSA, 2π-Ar/CO_2-IC, MS	^{236}U 55-59%, "weighing" by thermal neutron fission relative to ^{235}U	[90]
I952	2,39I	0,75	MSA, IC, MS	^{236}U 96.65%	[64]
I972	2,34I5	0,060	MSA, GFC(θ<1), AS, SCD	-	[91]
I974	2,34	0,85	-	Evaluation	[73]
I975	2,342	0,I7	-	Recommended	[1]
I976	2,34	0,85	-	-"-	[36]
I978	2,34I	0,30	-	Evaluation	[6]
I979	2,34I6	0,I7	-	Assumed	[52]
I979	2,34I6	0,I7	-	Recommended	[2]
I980	2,342	0,I7	-	-"-	[3]
I98I	2,34I6	0,I7	-	Adopted from data in Ref. [2, ENSDF]	-

HALF-LIFE OF ^{238}U (Z = 92)

TABLE 3.6

YEAR	$T_{1/2} \cdot 10^{-9}$ (α), y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
1932	4,508	0,40	MSA, IC	Natural U	[92]
1935	4,46	I,I	MSA, IC	-"-	[93]
1939	4,56	-	MSA, MS	-"-	[58]
1941	4,514	0,20	MSA, 2π -IC	-"-	[94]
1949	4,511; 4,489	0,11; 0,22	MSA, N_2-IC, MS	-	[62]
1955	4,507	0,20	MSA, MS	Overestimate of data of Ref. [92] Natural U	[95]
1957	4,56	0,66	MSA, 2π -IC	-	[96]
1959	4,457	0.22	MSA, LS	-	[97]
1971	4,4683	0,05	MSA, PC(θ<1), AS, SCD, MS	^{238}U> 99.98%	[87]
1974	4,468	0,22	-	Evaluation	[73]
1975	4,468	0,090	-	Recommended	[1]
1976	4,468	0,22	-	-"-	[86]
1978	4,47	0,22	-	Evaluation	[6]
1979	4,468	0,067	-	-"-	[52]
1979	4,468	0,067	-	Recommended	[2]
1980	4,468	0,090	-	-"-	[3]
1981	4,468	0,090	- -	Adopted from data of Refs [1-3]	-

HALF-LIFE OF ^{237}Np (Z = 93)

TABLE 4.1

YEAR	$T_{1/2} \cdot 10^{-6}$ (α), y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
1942	3	-	$^{237}U/^{237}Np$ activities ratio	-	[104]
1943	6	-	MSA	-	[105]
1948	2,2	4,5	MSA	First separation of pure ^{237}Np compounds	[106]
1960	2,14	0,47	MSA, PC, LS	Np concentration determined by coulometric titration	[107]
1975	2,14	0,47	-	Recommended	[1]
1978	2,14	0,47	-	Assumed	[6]
1979	2,14	0,47	-	Recommended	[2]
1980	2,14	0,47	-	-"-	[7]
1980	2,14	0,47	-	-"-	[3]
1981	2,14	0,47	- -	Adopted from data of Refs [1-3, 6, 7]	-

HALF-LIFE OF ^{239}Np (Z = 93)

TABLE 4.2

YEAR	$T_{1/2}(\beta^-)$, d	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
1956	2,346	0,17	Decay curve and ^{239}Pu build-up	Assumed half-life of ^{239}Pu = 24 400 Y	[108]
1959	2,34	0,85	Decay curve	Measurement of β-spectra	[109]
1959	2,359	0,42	Decay curve, semiconductor counter	Uncertainty for P = 0.99 Correlated with data of Ref. [108]	[110]

TABLE 4.2 (continued)

YEAR	$T_{1/2}(\beta^-)$, D	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
I966	2,354	0,34	GS, NaI(Tl)-spectrometer, β^--decay, Geiger counter	Recording of E_γ, of equiv. 225 and 280 kev	[II]
I969	2,346	0,I7	Decay curve	Collection of ^{239}Np recoil atoms in electric field upon decay of ^{243}Am	[II2]
I975	2,354	0,25	-	Recommended	[1]
I979	2,355	0,I7	-	- " -	[2]
I980	2,347	0,I3	-	- " -	[7]
I980	2,354	0,25	-	- " -	[3]
I98I	2,355	0,I7	-	Adopted from data of Ref. [2]	-

HALF-LIFE OF ^{236}Pu (Z = 94)

TABLE 5.1

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
I95I	2,7	II	Decay curve	^{238}Pu and other impurities	[II4]
I957	2,85I	0,28	Decay rate measurement, CH_4-GFC	$^{235}U(d,n)^{236}Np \xrightarrow{\beta^-} ^{236}Pu$	[II5]
I975	2,85I	0,28	-	Recommended	[1]
I978	2,86	0,70	-	Evaluation	[6]
I979	2,85I	0,28	-	Recommended	[3]
I980	2,85	0,35	-	- " -	[7]
I980	2,85I	0,28	-	- " -	[3]
I98I	2,85I	0,28	-	Adopted from data of Refs [1-3]	-

HALF-LIFE OF ^{238}Pu (Z = 94)

TABLE 5.2

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
I950	89,3 89,59	I,0 0,4I	MSA, 2π-Ar/CO_2-IC	In relation to activity of standard samples of ^{239}Pu. Measurements over period of 2.6 Y	[II6]
I956	86	3,5	-	Calculated value	[II7]
I957	86,4I	0,58	MID, AS, α-decay of ^{242}Cm	Overestimate relative to ^{239}Pu	[II8]
I965	87,60	0,068	CM	-	[II9]
I969	87,75	0,057	CM	-	[I20]
I970	87,22	0,60	CM	Measurements over period of 13 Y	[I2I]
I972	87,77	0,034	CM	-	[I22]
I974	87,77	0,023	CM	-	[I23]
I974	87,8	0,9I	-	Evaluation	[73]
I975	87,74	0,I0	-	Recommended	[1]
I976	87,8	0,9I	-	- " -	[36]
I976	86,98	0,23	MSA, 4$\pi\alpha$-counter and measurements at $\theta \ll 1$	Uncertainty for P = 0.67	[I24]

TABLE 5.2 (continued)

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
I977	87,7I	0,057	MSA, PC(ϵ = const), AS, SCD	$^{242}Cm \rightarrow ^{238}Pu$, label - ^{240}Pu	[I25]
I978	87,77	0,068	-	Evaluation	[6]
I978	87,74	0,046	-	Recommended	[I26]
I979	87,7	0,28	-	Evaluation	[2, p.74]
I979	87,74	0,046	-	Recommended	[2, p.49]
I980	87,74	0,I0	-	- " -	[3]
I980	87,74	0,057	-	- " -	[7]
I98I	87,98	0,58	MRA (^{239}Pu), AS, SCD, MS	Mixtures of ^{238}Pu - ^{239}Pu. Assumed half-life of ^{239}Pu 24110 Y	[I27]
I98I	87,74	0,I0	-	Adopted from data of Ref. [3]	-

HALF-LIFE OF ^{239}Pu (Z = 94)

TABLE 5.3

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
I945	24400	2,0	MSA	-	Cited in [27,49, 29]
I947	24II0	0,50	CM (metallic Pu)	Measurement of evaporation rate of liquid N; uncertainty reduced for P = 0.68	[I28]
I949	24400	0,29	MSA. 2π-counting	Weighed samples of metallic Pu, $PuCl_3$, $PuBr_3$	[I29]
I949	24300	I,5	MSA		Cited in [I37]
I95I	24360	0,4I	MSA, PC(ϵ << 1)	Weighed samples of PuF_3, ^{239}Pu (57.6-100%)	-"-
I954	24400	2,0	MSA	-	[I30]
I955	24I00	0,24	MSA	-	[40]
I958	24400	0,33	-	Assumed	[4I]
I959	24390	0,I2	MSA	^{239}Pu 9I.26-99.II%	[I3I]
I959	244I3	0,I2	MSA, PC (ϵ << 1)	Weighed samples of $Pu(SO_4)_2$ and $PuCl_3$, ^{239}Pu 99.9%	[I32]
I965	24I94	0,I0	CM (differential isothermal calorimeter)	1.5 kg sample metallic Pu, ^{239}Pu 93 and 94%	[I33]
I966	24350	0,25	MSA. LS (in relation to ^{240}Pu)	Weighed samples of metallic Pu, ^{239}Pu 94.4%	[I34]
I967	24386	0,2I	CM (differential isothermal calorimeter)	Overestimate of data of Ref. [133]	[45]
I969	24380	0,2I	-	Recommended	[49]
I970	24065	0,33	CM (differential isothermal calorimeter)	Two pieces of metallic Pu, 1 kg each, with respective enrichments of 93 and 97%	[I35,I36]
I974	24300	0,I0	-	Evaluation	[73]
I975	24060	0,079	4$\pi\alpha$X-coincidences	^{239}Pu 99.978%, uncertainty corrected for P = 0.68	[I37]

Table 5.3 (ctd)

YEAR	$T_{1/2}(\alpha)$, y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1975	24118	0,33	MSA, PC ($\theta \ll 1$)	Weighed preparations of Cs_2PuCl_6, ^{239}Pu 99.1%	[138]
1975	24110	0,12	-	Recommended	[1]
1976	24173	0,19	MSA	^{239}Pu 97.6%	[139]
1976	24100	0,41	-	Recommended	[86]
1977	24131	0,066	MSA, PC(θ=const), MID, MS	Labels for MID - $^{233,238}U$ MS-measurements by daughter ^{235}U, ^{239}Pu 99.98%	[140]
1978	24101	0,041	CM	Uncertainty corrected for P = 0.66, ^{239}Pu 99.26%	[141]
1978	24102	0,083	CM	^{239}Pu 99.26%	[142]
1978	24112	0,07 0,21	MSA, SCD, LS	Uncertainty equal to standard deviation, uncertainty equal to the systematic error, ^{239}Pu 99.26%	[148]
1978	24124,2 24138,6 24131	0,056 0,057 0,066	MSA MID, MS -	^{239}Pu 99.26% By daughter ^{235}U Assumed average	[144]
1978	24019* 24089	0,087 0,095	MSA MID, MS	^{239}Pu, 99.26%	[145]
1978	24164	0,058 0,070	MID, MS, by daughter ^{235}U	Uncertainty equal to standard deviation, uncertainty corrected for P = 0.68, ^{239}Pu 99.26%	[146]
1978	24090	0,17	-	Evaluation	[6]
1978	24119	0,108	All methods in use	Recommended, averaging of data of Refs [141-146], except those marked * in Ref. [145]	[125]
1978	24133	0,058	-	Assumed	[147]
1979	24085- 24100 24100	0,12 0,12 0,12	MSA($\theta \ll 1$), AS, MS MSA, LS, MID, MS	^{239}Pu 99.98%, average	[148]
1979	24115	0,33	-	Evaluation	[2, p.74]
1979	24110	0,042	-	Recommended	[2, p.49]
1980	24110	0,12	-	- " -	[3]
1980	24113	0,054	-	- " -	[7]
1980	24110	0,12	-	- " -	[149]
1981	24088	0,21	MSA	Solutions of Cs_2PuCl_6, ^{239}Pu 99.03%	[29]
1981	24110	0,12	-	ADOPTED FROM DATA OF REFS [1, 3, 149]	

TABLE 5.4

HALF-LIFE OF ^{240}Pu (Z = 94)

YEAR	$T_{1/2}(\alpha)$, y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1951	6580	0,61	Genetic equilibrium MS, by the isotopic ratios $^{240}Pu/^{239}Pu$ and $^{236}U/^{235}U$	-	[150]
1953	6300	9,5	MSA	-	[151]
1954	6240	1,9	MSA	-	Цит.в [152]
1956	6600	1,5	MSA	-	[152]

Table 5.4 (contd.)

YEAR	$T_{1/2}$ (α), Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1958	6580	1	-	Assumed	[41]
1959	6620	0,76	MSA	-	[131]
1967	6524	0,15	CM (Calve microcalorimeter)	Experiment, ^{240}Pu 95.7%. 0.6 g sample of PuO_2.	[45]
	6537	0,15	-	Assumed	
1974	6550	1,1	-	Evaluation	[73]
1974	6524	0,15	-	Assumed	[122]
1975	6550	0,31	-	Recommended	[1]
1976	6550	1,1	-	-"-	[86]
1978	6569	0,091	MSA, PC, MS	Pu concentration determined by redox titration	[147]
1978	6540	0,15	-	Estimate	[6]
1979	6537	0,15	-	Recommended	[2,p.49]
1980	6550	0,31	-	-"-	[8]
1980	6560	0,15	-	-"-	[7]
1981	6537	0,15	-	Adopted from data in Ref. [2,EMSDE]	-

TABLE 5.5

HALF-LIFE OF ^{241}Pu (Z = 94)

YEAR	$T_{1/2}$ (β), Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1948	~10	-	-	Approximate evaluation	[153]
1950	14	-	By ^{241}Am build-up		[154]
1958	13,0	0,76	By ^{241}Am build-up; assumed half-lives: ^{241}Am 470 Y, ^{240}Pu 6600 Y and ^{239}Pu 24360 Y; AS, MS	Uncertainty corrected for P=0.68. The uncertainties of the assumed half-lives do not enter into the uncertainty figure.	[155]
1956	12,77	2,2	GS (for E_γ = 60 keV for ^{241}Am), Xe-PC	Assumed half-life of ^{241}Am = 470 Y	[156]
1957	13,29	0,98	By ^{241}Am build-up	Assumed half-life of ^{241}Am 458.1(5) Y	[157]
1960	13,24	1,8	PC, AS, ^{241}Am build-up	^{241}Pu 77%. Half-life of ^{241}Am = 461.3 Y	[158]
1961	13,3	2,3	From α/β^- ratio	-	[159]
1966	13,68	2,6	Reactivity of ^{241}Pu	-	[160]
1966	13,59	3,4	MS	-	[161]
1967	14,4	1,4	Decay curve. Measurements over period of 2 Y.	Relative to activity of Pu isotopic standard of US Bureau of Standards.	[162]
1967	14,08	2,1	-	Averaging of data of Refs [155, 156, 158] for adjusted half-life of ^{241}Am = 432.7 Y.	[162]
1968	14,0	2,1	Radiochemical determination	Assumed half-life of ^{241}Am = 436(3) Y.	[163]
1968	14,98	2,2	MS, from changes in ^{241}Pu content with time.	Mixture of ^{240}Pu - ^{241}Pu - ^{242}Pu.	[164]
1969	14,5	3,4	-	Evaluation	[49]
1970	14,6	2,7	MS	-	[165]

Table 5.5 (cont.)

YEAR	$T_{1/2}(\beta^-)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I969, I970	I4,63	I,8	Changes in ^{241}Pu reactivity with time	Measurements over period of 2.5 Y	[I66, I67]
I970	I4,25; I4,3I	0,70	Measurement of α/β^- ratio	-	[I68]
I97I	I5,I6	I,3	MS	Solution of linear decay equation by MLS	[I69, I70]
I973	I4,56	I,0	By accumulation of ^{241}Am	Measurements of the same samples of ^{241}Pu by six laboratories over period of 5.5 Y	[I7I, I72]
I973	I4,89	0,74	MS		
I974	I4,355	0,049	CM	Assumed half-lives of ^{239}Pu = 24065(50) Y, ^{240}Pu = 6524(10) Y, ^{241}Am = 432.7(7) Y	[I22]
I974	I4,4	I,4	-	-	[I73]
I974	I4,5	3,4	-	Evaluation	[73]
I974/ I975	I5,02	I,0	MS	-	[I74]
I976	I4,44; I4,3I	0,97; 0,84	Measurement of α/β^- ratios	-	[I75]
I975, I976	I4,7	2,7	-	Recommended	[I, 36]
I978	I4,60; I4,60	0,96; 0,68	Measurement of α/β^- ratios, build-up of ^{241}Am	-	[I76]
I978	I4,45	2,I	-	Evaluation	[I77]
I978	I4,4	I,4	-	"	[5]
I978	I4,7	2,7	-	Recommended	[I77]
I979	I4,4	I,4	-	Evaluation	[52]
I979	I4,5	3,4	-	"	[2, p.74]
I979	I4,30; I4,60	0,98; 0,68	MS Growth in ^{241}Am activity	-	[2, p.58]
I979	I4,4	I,4	-	Recommended	[2, p.49]
I980	I4,7	2,7	-	"	[3]
I980	I4,64	0,82	-	"	[7]
I980	I4,42	0,62	Growth in ^{241}Am activity	-	[I78]
I98I	I4,44	0,42	AS, SCD		
I980	I4,379	0,090	MS, decrease in $^{241}Pu/^{242}Pu$ isotopic ratio	Measurements up to 3.6 Y	[I79]
I98I	I4,4	I,4	-	Adopted from data of Ref. [2, ENSDF]	-

HALF-LIFE OF ^{241}Pu (Z = 94)

TABLE 5.6

YEAR	$T_{1/2} \cdot 10^{-3}(\alpha)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I950	~ 4	-	Rate of α-decay	-	[I54]
I955	~ 2,9	-	Activity of ^{237}U in equilibrium	-	[I80]
I956	3,8	I,6	Daughter ^{237}U	-	[I52]
I958	6,42	5	-	-	[41]
I960	5,72; $\alpha/\beta^- = 2,3I \cdot I0^{-5}$	I,7 2,6	AS, PC, build-up of ^{241}Am	Assumed half-lives: ^{239}Pu = 24400 Y, ^{240}Pu = 6600 Y, ^{241}Am = 461.3 Y, ^{241}Pu 77%	[I58]
I963	3,9	I0	-	-	[I8I]

Table 5.6 (conc.)

YEAR	$T_{1/2} \cdot 10^{-5}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
I966	5,8	I,7	GS, Ge/Li-SCD, by accumulation of ^{241}Am (E_γ = 59 keV) and ^{237}U (E_γ = 208 keV). Method does not require high ^{241}Pu enrichment	Calibrated SCD for pure ^{241}Am and ^{237}U. Assumed half-lives: ^{240}Am = 458 Y and $(^{241}Pu)_{\beta^-}$ = 13.2 Y	[182]
I968	$\alpha/\beta^- = 2{,}45 \cdot 10^{-5}$	8,3	AS, SCD ($\vartheta = 2 \times 10^{-3}$), by growth of ^{241}Am peak	Assumed half-life of ^{241}Am = 432.7(7) Y	[183]
I975	$\alpha/\beta^- = 2{,}45 \cdot 10^{-5}$	3,3	-	Recommended	[1]
I978	6,0	3,3	-	Evaluation	[6]
I979	6,04	I,0	-	"	[2, p.58]
I980	$\alpha/\beta^- = 2{,}45 \cdot 10^{-5}$	3,3	-	Recommended	[3]
I980	6,04; $\alpha/\beta^- = 2{,}45 \cdot 10^{-5}$	I,0; 0,4I	-	"	[7]
I98I	6,04	I,0		Adopted from data of Refs [2, 7]	-

HALF-LIFE OF ^{242}Pu (Z = 94)

TABLE 5.7

YEAR	$T_{1/2} \cdot 10^{-5}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
I950	5	-	-	Approximate evaluation	[184]
I950	9	-	MSA, AS	-	[185]
I954	3,8	-	-	Assumed	[186]
I956	3,38	2,6	MRA (^{240}Pu), AS, MS	Assumed half-life of ^{240}Pu = 6580 Y	[II7]
I956	3,79	I,3	MSA		[152]
I956	3,73	I,3	MRA (^{238}Pu), IC, AS, MS	Assumed half-life of ^{238}Pu = 89.6 Y	[187]
I958	3,79	I,3	-		[4I]
I969	3,869	0,4I	MSA, MID, MS, in relation to ^{239}Pu	Assumed half-life of ^{239}Pu = 24401.5(21.2) Y	[188]
I970	3,66	I,4	MRA (^{238}Pu)	Assumed half-life of ^{238}Pu = 87.40(4) Y	[189]
I974	3,87	I,3	-	Evaluation	[73]
I975	3,76	0,53	-	Recommended	[1]
I976	3,87	I,3	-	"	[36]
I976	3,763	0,23	CM (preparations of PuF_3, PuF_4, PuO_2)	^{242}Pu 99.91%	[190]
I976	3,702	0,I8	MSA, 4$\pi\alpha$X-coincidences	^{242}Pu 95.9%. Pu concentration determined by coulometric titration	[191]
I977	3,763	0,78	MRA (^{238}Pu)	Assumed half-life of ^{239}Pu = 24290(70) Y	[192]
I978	3,76	0,53	-	Recommended	[177]
I978	3,76	I,6	-	Evaluation	[6]
I979	3,763	0,53	-	"	[52]
I979	3,754	0,67	-	-	[193]
I979	3,76	0,80	-	Assumed	[2, p.75]
I979	3,763	0,53	-	Recommended	[2, p.49]
I980	3,76	0,53	-	"	[3]
I98I	3,763	0,53		Adopted from data of Ref. [2, ENSDF]	-

TABLE 5.8

HALF-LIFE OF ^{244}Pu (Z = 94)

YEAR	$T_{1/2} \cdot 10^{-7}(\alpha)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I956	7,6	26	1. From γ-radiation of ^{240}Np after separation of daughter ^{240}U from ^{244}Pu, NaI(Tl)	-	[194]
			2. From β^--radiation of ^{240}Np after separation from mixture of ^{240}U - ^{240}Np; PC, anticoincidences, AS. MS	Calibration by ^{32}P and ^{90}Y; assumed half-life of ^{242}Pu $3.9(1) \times 10^5$ Y	
I956	7,5	27	By daughter ^{240}U	-	[152]
I966	8,I8	3,2	AS, SCD, MS, $^{244}Pu/^{242}Pu$ and $^{244}Pu/^{240}Pu$ isotopic ratios	Samples of 54.3 and 68.1% ^{244}Pu. For half-life of ^{242}Pu $3.79(5) \times 10^5$ Y, ^{240}Pu 6580(40) Y	[195]
I969	8,28	I,2	MSA, MID, MS	Assumed half-life of ^{242}Pu $3.869(16) \times 10^5$ Y and ^{239}Pu 24401.5(21.2) Y	[188]
I975	8,2	I,2	-	Recommended	[1]
I976	8,2	I,2	-	- " -	[36]
I979	8,26	I,I	-	Evaluation	[52]
I979	8,26	I,I	-	Recommended	[2]
I980	8,2	I,2	-	- " -	[3]
I98I	8,26	I,I	-	ADOPTED FROM DATA OF REF. [2, ENSDF]	-

TABLE 5.I

HALF-LIFE OF ^{241}Am (Z = 95)

YEAR	$T_{1/2}(\alpha)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I95I	498	5	MSA	$AmF_3 \rightarrow AmO_2$ — microweights	[197]
I952	470	+I,I; -2,I	MSA	5 μg AmO_2 samples	[198]
I956	46I,3	0,37	MSA (θ<<1)	-	[199]
I957	458,I	0,II	MSA	-	[157]
I958	457,7	0,39	MSA	-	[200]
I967	432,7	0,I6	CM (differential isothermal calorimeter)	^{241}Am 99.6 and 99.9%	[45,201]
I968	433	I,6	CM, MS	-	[202]
I968	436,6	0,69	Radiochemical determination	-	[163]
I974	432,8	0,36	MSA, 4πα-counter, AS	Uncertainty reduced for P = 0.68	[204]
I974	432	0,98	-	Evaluation	[73]
I974	432,5; 435,0	0,I6; 0,I6	CM	Assumed half-lives: ^{239}Pu 24065(50) Y, ^{240}Pu 6524(10) Y	[122]
I975	432,6	0,I4	-	Recommended	[1]
I975	432,0	0,046	CM (measured 5 times)	AmO_2+La→Am(77 mg)→sublimation	[205]
I976	432	0,98	-	Recommended	[36]
I978	432,7	0,I4	-	Evaluation	[6]
I979	432,2	0,I2	-	- " -	[52]
I979	432	0,46	-	Assumed	[2, p.75]

TABLE 6.1 (continued)

YEAR	$T_{1/2}$ (α), Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I979	432,2	0,I2	-	Recommended by ENSDF	[2, p.49]
I980	432,6	0,I4	-	Recommended	[3]
I980	432,I	0,069	-	- " -	[7]
I98I	432,2	0,I2	-	Adopted from data of [2, ENSDF]	-

HALF-LIFE OF $^{242}Am^{m}$ (Z = 95)

TABLE 6.2

YEAR	TYPE OF DECAY	$T_{1/2}$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I959	IT	I52	4,6	MS, build-up of ^{242}Pu	In relation to half-life of ^{243}Am = 7951 Y	[206]
	ε	960	5,2	-		
	α	32000	5,0	MS, build-up of ^{238}Np		
I959	IT	I4I	5,0	MSA	-	Cited in [206]
I975	α/IT	$4,76.10^{-3}$	2,9	-	Recommended	[I]
	IT	I52	4,6	-		
I979	IT	I52	4,6	-	Evaluation	[52]
I979	IT	I4I	I,4	MSA, 4π-PC, AS, SCD, build-up of ^{242}Cm	Assumed half-life of ^{242}Cm - 162.8(4) D	[207]
	α/IT	$4,5.10^{-3}$	2,2	-		
	α	3I200	I,6	-	Assumed half-life of ^{241}Am - 432.6(6) Y	
I979	IT	I52	4,6	-	Recommended	[2, p.49]
I980	IT	I52	4,6	-	- " -	[3]
	α/IT	$4,76.10^{-3}$	2,9	-		
I98I	IT	I42	I,7	-	Assumed as weighted mean value from data of Refs [206, 207], with allowance for Student's coefficient for P = 0.68	-
	α/IT	$4,59.10^{-3}$	3,6	-		
	α	3I300	3,0	-		
	ε	960	5,2	-	Adopted from data of Ref. [206]	-

HALF-LIFE OF ^{243}Am (Z = 95)

TABLE 6.3

YEAR	$T_{1/2}(\alpha)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I953	3800	6,3	AS, MS	-	[208]
I954	7600	4,9	Magnetic α-spectrometer	-	[209-2II]
I958	795I	0,60	MS, MSA	-	[200]
I959	7720	2,0	AS, MS	Assumed half-life of ^{241}Am - 458.1(5) Y	[206]
I960	7650	0,65	AS, IC, MID, MS	Idem	[2I2]
I968	7390	0,68	AS, SCD	Independent measurement	[203]
	7340	0.82		In relation to half-life of ^{241}Am - 433(7) Y	
	7370	0,54		Mean value	
I974	7380	0,23	MSA, 4πα-counter, AS, SCD, MS	Assumed half-life of ^{241}Am - 432.7(7) Y, I7 measurements of α-spectra, uncertainty corrected for P = 0.68	[2I3]
I975	7380	0,54	-	Recommended	[I]

TABLE 6.3 (continued)

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1978	7875	0,47	-	Evaluation	[6]
1979	7380	0,54	-	Recommended	[2]
1980	7358	0,57	MSA, AS, SCD, MID, MS	Mixtures of ^{241}Am - ^{243}Am	[214]
1980	7380	0,54	-	Recommended	[3]
1980	7370	0,27	-	- " -	[7]
1981	7380	0,54	-	Adopted from data of Refs. [1-3]	-

TABLE 7.1

HALF-LIFE OF ^{242}Cm (Z = 96)

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1948	~150	-	-	Predicted	[220]
1950	162,5	1,2	MSA, PC, AS, relative to α-peaks of ^{241}Am and ^{242}Cm	Measurements over period of one year	[221]
1954	162,46	0,09	MSA, PC (ε = const)	Measurements over period of 230 D	[222]
1957	162,7	0,061	-	Cited in Ref. [118]	[224]
1965	163,1	0,25	MSA, 2π-flow counter	Measurements over period of 3.3 Y	[225]
1975	163,2	0,12	CM (two samples 5 mg each)	Measurements over period of 287 D	[226]
1975	162,8	0,25	-	Recommended	[1]
1977	162,76	0,025	By build-up of ^{238}Pu with half-life of 87.74(4) D	Measurements over period of 262 D	[124]
1978	163,2	0,13	-	Evaluation	[6]
1979	162,8	0,25	-	- " -	[52]
1979	163,28	0,99	MSA, PC, SCD, measurement of spontaneous fission	Measurements over period of 120 D (work still going on)	[227]
1979	162,8	0,31	-	Assumed	[2, p.75]
1979	162,8	0,25	-	Recommended by ENSDF	[2, p.49]
1980	162,8	0,25	-	Recommended	[3]
1980	163,0	0,12	-	- " -	[7]
1981	162,8	0,25	-	Adopted from data of Ref. [3]	

TABLE 7.2

HALF-LIFE OF ^{244}Cm (Z = 96)

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1954	17,9	2,8	MS, by daughter Pu		[228,229]
1954	18,4	2,7	-	Average of earlier data	
1954	19,2	3,1	AS, MS	Calculated in relation to half-life of ^{242}Cm = 162.5 D	[230]
1961	17,59	0,34	MSA, MS		[231]
1964	18,11	0,39	By decay curve	Cited in Ref. [233]	[232]
1968	18,099	0,085	By decay curve, IC, AS, MS	Mixture of ^{242}Cm 0.05%, measurement over period of 7 Y	[234]

TABLE 7.2 CONTINUED

YEAR	$T_{1/2}(\alpha)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
1970	18,097	0,083	-	Assumed	[235]
1972	18,18 18,12	0,22 0,17	CM	Measurements over period of 2 Y Assumed, taking into account Ref. [234], uncertainty for P = 0.68	[236]
1975	18,11	0,11	-	Recommended	[1]
1978	18,11	0,17	-	Evaluation	[6]
1979	18,11	0,11	-	Assumed	[2, p.75]
1979	18,11	0,11	-	Recommended by ENSDF	[2, p.49]
1980	18,11	0,17	-	Recommended	[7]
1980	18,11	0,11	-	-"-	[3]
1981	18,11	0,11	-	Adopted from data of Refs [1-3]	

HALF-LIFE OF ^{245}Cm (Z = 96)

TABLE 7.3

YEAR	$T_{1/2}(\alpha)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
1954	11500	48	MSA	In relation to half-life of ^{244}Cm = 17.6 Y	[228]
1955	14300	20	MSA, AS	-	[237]
1957	7500	25	-	-	[238]
1961	9320	3,0	MSA, AS	-	[231]
1969	8265	2,2	MSA, MS	In relation to half-life of ^{244}Cm = 18.099 (15) Y	[239]
1971	8532	0,62	MSA, AS, MS	^{245}Cm 65.8 and 76.5%, assumed half-life of ^{244}Cm = 18.099 (15) Y	[240]
1981	8532	0,62	-	Adopted from data of Ref. [240]	-

HALF-LIFE OF ^{246}Cm (Z = 96)

TABLE 7.4

YEAR	$T_{1/2}(\alpha)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
1954	4000	15	MSA	Assumed half-life of ^{244}Cm = 17.6 Y	[228]
1955	2300	20	MSA, AS		[237]
1956	6620	5,3	MRA (rel. to ^{250}Cf)	Assumed half-life of ^{250}Cf = 9.3 Y	[241]
1961	5480	3,1	MSA, MS	Relative to half-life of ^{244}Cm = 17.6 Y	[231]
1969	4711	0,46	MSA, MS	For half-life of ^{244}Cm = 18.099 (15) Y	[239]
1971	4820	0,41	MSA, AS, MS	^{246}Cm 94.7 and 95.6%, for half-life of ^{244}Cm = 18.099 (15) Y	[240]

Table 7.4 (continued)

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1971	4655	0,86	MSA	Absolute measurements	[242]
1975	4730	2,1	-	Recommended	[1]
1977	4852	1,6	MSA, MS (rel. to ratios $^{244}Cm/^{246}Cm$ and $^{240}Pu/^{242}Pu$)	Assumed half-life of ^{244}Cm 18.099 Y	[243]
1980	4730	2,1	-	Recommended	[3]
1981	4762	0,34	-	WEIGHTED MEAN VALUE BASED ON REFS [239, 240, 242, 243]	-

TABLE 7.5

HALF-LIFE OF ^{248}Cm (Z = 96)

YEAR	$T_{1/2}\cdot10^{-5}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1954	4,7	8,5	MRA (rel. to ^{252}Cf)	Assumed half-life of ^{252}Cf = 2.2 Y	[241]
1968	4,0	7,5	-	-	[244]
1969	3,52 (eff.) 3,84 (partial)	4,0 1,0	MS, MRA (rel. to ^{244}Cm)	For half-life of ^{244}Cm = 18.099(15) Y	[239]
1971	3,61 (eff.) 3,94 (partial)	1,7 1,0	MSA, AS, MS, SCD	For half-life of ^{244}Cm = 18.099(15) Y, ^{248}Cm 95.2%	[240]
1971	3,703	0,86	MSA	Absolute measurements	[242]
1980	3,397 (eff.) 3,703 (partial)	0,94 0,95	-	Recommended	[3]
1981	3,397 (eff.) 3,703 (partial)	0,94 0,95	-	ADOPTED FROM DATA OF REF. [3]	-

TABLE 8.1

HALF-LIFE OF 249 Bk (Z = 97)

YEAR	TYPE OF DECAY	$T_{1/2}$	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1954	β^-	~270 D	-	Decay curve	-	[246,247]
1954	β^-	~1 Y	-	Decay rate	-	[248]
1954	β^-	290 D	6,9	Decay curve	-	[249]
	α/β^-	~10^{-5}	-	^{249}Cf build-up		
1957	β^-	314 D	2,5	Decay rate	Measurement over period of ~ 1 $T_{1/2}$	[250]
	α/β^-	$2,2\cdot10^{-5}$	14	^{249}Cf build-up		
	α	$3,98\cdot10^{4}$ Y	14	-		
1969	α/β^-	$1,45\cdot10^{-5}$	5,5	Build-up of ^{249}Cf, LS, AS, measurement of β^--activity (2 PC)	For $T^{\beta^-}_{1/2}$ (^{249}Bk) = 314(8) D	[251]
	α	$6,04\cdot10^{4}$ Y	5,8			
1974	β^-	325 D	2,2	Decay curve, PC	Measurement over period of 1 Y; PC calibration by ^{14}C	[252]
1980	β^-	~323 D	-	-	Recommended	[3]
	α/β^-	$1,45\cdot10^{-5}$	5,5	-		
	α	$6,04\cdot10^{4}$ Y	5,8	-		

Table 8.I (cont.)

YEAR	TYPE OF DECAY	$T_{1/2}$	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I980	β^-	329 D	0,6I	Decay curve	Measurements of 30 samples, uncertainty reduced for P = 0.67	[253]
I98I	β^-	328 D	0,9I	-	Weighted mean value based on data of Refs [249, 250, 252 and 253], error = estimated scatter. Adopted from data of Ref.[3]	-
	α	$6,04.10^4$ Y	5,8	-		-

HALF-LIFE OF ^{249}Cf (Z = 98)

TABLE 9.1

YEAR	$T_{\frac{1}{2}}(\alpha)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I954	~400	-	By growth of α-activity of a ^{249}Bk sample	-	[247]
I954	550	27	Idem and by rate of β-decay of ^{249}Bk	Pure ^{249}Bk	[248]
I954	470	2I	Build-up of ^{249}Cf in ^{249}Bk sample	^{249}Bk sample: 2.3×10^3 disintegrations/s	[249]
I957	360	II	MS, AS, IC, AGC, decay rate of ^{249}Bk	-	[250]
I969	345	4,3	AS, PC, growth of α-activity of a ^{249}Bk sample	-	[251]
I969	352	I,7	MSA, MS	Rel. to half-life of ^{252}Cf 2.731(7) Y	[239]
I973	350,6	0,60	MSA, 2π-PC, AS, SCD, MS	Sample: 385 μg ^{249}Cf, complexometric titration	[254]
I977	366	I,6	MSA, absolute α-counting, MS	Isotopic label - ^{252}Cf	[255]
I980	350,6	0,60	-	Recommended	[3]
I98I	352,2	0,62	-	Weighted mean value based on data of Refs [239, 250, 251, 254, 255]	-

HALF-LIFE OF ^{250}Cf (Z = 98)

TABLE 9.2

YEAR	$T_{\frac{1}{2}}(\alpha)$, Y	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
I954	~I2	-	α-decay rate of ^{250}Cf and β-decay rate of parent ^{250}Bk	-	[247]
I954	9,4	24	MSA, AS	-	[248]
I954	I0,0	24	MSA, MS, AS, rel. to ^{252}Cf	Assumed half-life of ^{252}Cf = 2.2(2) Y	[249]
I957	I0,9	7,3	MSA, MS, from ratio $^{250}Cf/^{252}Cf$	-	[250]
I965	I3,2	3,8	Decay rate of ^{254}Fm and build-up of ^{246}Cm, MSA, IC, AS, SCD	$^{254}Fm \rightarrow ^{250}Cf \rightarrow ^{246}Cm$	[233]
I969	I3,08	0,69	MSA, MS, by ref. to ^{252}Cf	Assumed half-life of ^{252}Cf - 2.731(7) Y	[239]

Table 9.2 (cont.)

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1980	13,08	0,69	-	Recommended	[3]
1981	13,08	0,69	-	Adopted from data of Refs [3, 239]	-

HALF-LIFE OF ^{251}Cf (Z = 98) TABLE 9.3

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1957	~800	-	MS, by isotopic ratio $^{246}Cm/^{247}Cm$	-	[250]
1961	1600	-	-	Cited in Ref. [211]	[259]
1965	892	9,9	MS, by isotopic ratios $^{250}Cf/^{251}Cf$ and $^{246}Cm/^{247}Cm$	Sample: 3 x 10^{-10} g pure Cf	[261,260]
1969	900	5,6	MSA, MS	Assumed half-life of ^{252}Cf = 2.731(7) Y	[239]
1981	900	5,6	-	Adopted from data of Ref. [239]	-

HALF-LIFE OF ^{252}Cf (Z = 98) TABLE 9.4

YEAR	$T_{1/2}(\alpha)$, Y	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
1954	~2	-	Decay curve, measurements over period of several months	Calculated evaluation	[247]
1954	2,1	19	AS, decay rate measurements	-	[248]
1954	2,2	9,1	Decrease in spontaneous fission rate	Measurements over period of 3 months	[249]
1957	2,55	5,9	MSA by α-decay and spontaneous fission	Measurements over period of 700 D	[250]
1965	2,646(eff.) 2,731(partial)	0,15 0,26	MSA, IC, AS, SCD, MS	-	[238]
1969	2,681	0,23	Neutron measurements	-	[262]
1969	2,621	0,23	"	Requirement of data of Ref. [262]	[263]
1973	2,659	0,38	Analysis of decay curve	Samples of ^{252}Cf, 47 and 52%	[264]
1974	2,628	0,38	Neutron measurements in graphite sphere (part of state standard unit of neutron flux)	Calibration by neutrons of Ra-Be source, three ^{252}Cf sources	[265]
1974	2,64	0,76	-	Estimate	[79]
1974	2,638	0,27	Neutron measurements in Mn bath	Measurements over period of ~ 4.5 Y	[266]
1976	2,64	0,76	-	Recommended	[36]
1976	2,637	0,19	Neutron measurements	Mn bath method	[267]
1978	2,638(eff.) 2,722(partial)	0,15 0,18	-	Estimate	[6]
1979	2,638	0,38	-	Recommended	[2]
1980	2,64(eff.) 2,72(partial)	0,38 0,37	-	"	[3]
1981	2,638 (eff.) 2,722 (partial)	0,38 0,38	-	Adopted from data of Refs [2, ENSDF] and [6]	-

TABLE 10.1

HALF-LIVES OF ^{252}Es AND ^{253}Es (Z = 99)

YEAR	$T_{1/2}(\alpha)$, D	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
			^{252}Es		
I956	~I40	-	By decay of peak E_α = 6.64 MeV	$^{249}Bk(\alpha,xn)^{252}Es$	[269]
I956	40I	5	By decay of peak E_α = 6.631 MeV ^{252}Es relative to peak, E_α = 6.49 MeV ^{254}Es	$^{252}Cf(d,2n)^{252}Es$	[270]
I973	350	I4		Mixtures of ^{253}Es and ^{254}Es	[271]
I977	47I,7	0,40	GS, Ge/Li-SCD. By decay of peak E_γ = 785 keV [E-capture ^{252}Es for E/α = 22(2)%]	Calibration of Ge/Li-SCD by ^{137}Cs, measurements over period of 3Y	[272]
I98I	408	I0	-	Assumed as weighted mean value for data of Refs [270-272]	-
			^{253}Es		
I954	20	-	By decay curve	Einsteinium from products of thermonuclear explosion Mike	[273] [274]
I954	I9,3	I,6			
I956	20,03	0,050	Decay curve, CH_4-GFC, AS, IC($\Delta E_{\frac{1}{2}}$ = 0.63%), PC(β^-), NaI/Tl(γ), KI/Tl(α), AGC, BGC	Measurements over period of 2 $T_{\frac{1}{2}}$	[275]
I966	20,7	I,4	Decay curve, IC, Si-SCD, measurements over a period of 3-12 $T_{\frac{1}{2}}$	Einsteinium from products of Par and Barbel thermonuclear explosions	[276]
I966	20,47	0,098	-	-	[277]
I968	20,462	0,I3	-	-	[4]
I980	20,47	0,098	-	Recommended	[3]
I98I	20,47	0,098	-	Adopted from data of Refs [3, 277]	

TABLE 10.2

HALF-LIVES OF ^{254}Es AND ^{255}Es (Z = 99)

YEAR	$T_{1/2}$, D	δ,%	MEASUREMENT METHOD	COMMENTS	LITERATURE
			^{254}Es (α-decay)		
I955	~2	-	-	-	[278]
I955	272	-	-	-	[279]
I956	~320	-	AS, by decay of peak E_α = 6.42 MeV, IC($\Delta E_{\frac{1}{2}}$ = 0.63%), CH_4-GFC, PC(β^-), NaI/Tl(γ), KI/Tl(α), AGC, BGC	-	[275]
I958	480	I5	AS, IC, by decay of peak E_α = 6.42 MeV	Measurement over period of 500 D	[280]
I966	272	0,37	By decay of daughter ^{250}Bk, calibrated NaI(Tl)-detector		[281]
	280	0,54			
	276	2,2	By α-decay of ^{254}Es, AS	Mean value	
I975	276,0	0,I8	By E_γ = 989.0 keV) Peaks of	^{254}Es 99.5%. Measurements over period of 2 Y	[282]
	275,4	0,I8	By E_γ = 1028.6-1031.8 keV) daughter		
	275,7	0,I8	Mean value) ^{250}Bk		
I98I	276	2,0	-	Adopted from data of Refs [281, 282]	-

Table 10.2 (cont.)

YEAR	$T_{1/2}$, D	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
			^{255}Es (β^- - 91,5%, α - 8,5%)		
1954	30	-	By decay curve	From products of thermonuclear explosion Mike	[273]
1966	38,3	0,78	-	-	[277]
1966	39,8	3,0	AS, activity ratio $^{255}Fm/^{253}Es$	Einsteinium from products of thermonuclear explosions Par and Barbel. For half-life of ^{253}Es = 20.03(1) D	[276]
1966	38	7,9	From decay curves of ^{255}Fm after separation from exposed ^{254}Es	Measurements over period of 7 D	[283]
1981	38,9	2,1		Adopted from data of Refs [276, 284]	-

HALF-LIVES OF ^{253}Fm AND ^{257}Fm (Z = 100) TABLE 11

YEAR	TYPE OF DECAY	$T_{1/2}$, D	δ, %	MEASUREMENT METHOD	COMMENTS	LITERATURE
				^{253}Fm		
1956	ε	>10	-	-	$^{252}Cf(\alpha,3n)^{253}Fm$	[284]
1957	ε	4,5	22	AS, IC, by ^{253}Es build-up rate (E_α = 6.94 MeV)	-	[285]
	α/ε	0,105	9,5			
1959	ε	3,0	6,7	AS, by ^{253}Es build-up rate (E_α = 6.95 MeV)	-	[286]
	α/ε	0,105	9,5			
1963	ε	3,0	33	-	-	[287, 288]
1967	ε	3,0	4,0	GS, by decay of photopeak (E_γ = 271.8 keV)	-	[289]
	α/ε	0,12	8,3	By ^{253}Es build-up	-	
1981	ε	3,0	4,0	-	Adopted from data of Ref. [289]	-
	α/ε	0,12	8,3			
				^{257}Fm		
1964	α	79	10,1	AS with incorporation of data on ^{253}Es build-up	$^{257}Fm \xleftarrow{\alpha} {}^{253}Cf \xleftarrow{\beta^-} {}^{253}Es \xrightarrow[20\ D]{\alpha}$ Measurements over period of 100 D	[290]
1965	α	80	6,2	From variation in shape of α-spectrum		[291]
1966	α	94	10,6	From decay rate over 270 D (from products of thermonuclear explosions Par and Barbel)	For ^{253}Es half-life = 20.0 or 20.7 D and ^{253}Cf = 17.6 D	[276]
1966	α	97	10,3	-	Best value, reactor fermium	[292]
1967	α	85	31	Measurement of spontaneous fission	Measurements over period of 4.5 months	[293]
1973	α	100,5 (eff.)	0,20	MSA, IC	-	[294]
1981	α	97,2	3,3		Adopted from data of Refs [276, 292, 294], δ-evaluation of scattering	-

TABLE 12

CONSTANTS ADOPTED FOR THE SPONTANEOUS FISSION OF ISOTOPES OF TRANSURANIUM ELEMENTS

ISOTOPE	$T_{1/2}$, Y	$\bar{\nu}_p$, NEUTR./SF
^{230}Th	1,5(1,5)·10^{17} [3]	-
^{232}Th	>1·10^{21} [4]	2,13(20) [256]
^{231}Pa	≥1,1·10^{16} [4]	-
^{232}U	8,0(6,2)·10^{13} [3]	-
^{233}U	1,22(28)·10^{17} [3]	1,5(calc.) [6]
^{234}U	2,04(1,02)·10^{16} [3]	1,8(calc.) [6]
^{235}U	3,5(9)·10^{17} [4]	1,7(calc.) [6]
^{236}U	2,0(1,0)·10^{16} [3]	1,89(5) [6]
^{238}U	8,20(9)·10^{15} [3]	1,99(3) [6]
^{237}Np	>1·10^{18} [4]	1,9(calc.) [5]
^{236}Pu	3,5(1)·10^{9} [7]	2,11(13) [6]
^{238}Pu	4,77(14)·10^{10} [7]	2,20(7) [6]
^{239}Pu	5,5(5)·10^{15} [3]	(2,3; 2,24) (calc.) [5]
^{240}Pu	1,27(4)·10^{11} [7]	2,14(2) [6]
^{241}Pu	~3·10^{15} [6]	2,3(calc.) [6]
^{242}Pu	6,9(3)·10^{10} [7]	2,12(1) [6]
^{244}Pu	6,56(32)·10^{10} [3]	2,29(19) [256]
^{241}Am	1,1(2)·10^{14} [7]	2,4(calc.) [5]
^{242m}Am	9,5(3,6)·10^{11} [3]	-
^{243}Am	3,35(31)·10^{13} [3]	2,5(calc.) [6]
^{242}Cm	6,1(2)·10^{6} [7]	2,50(6) [5]
^{244}Cm	1,344(4)·10^{7} [7]	2,69(1) [5]
^{246}Cm	1,809(38)·10^{7} [3]	2,907(15) [256]
^{248}Cm	4,112(41)·10^{6} [3]	3,173(25) [295]
^{249}Bk	1,86(10)·10^{9} [3]	3,395(26) [296]
^{249}Cf	6,98(14)·10^{10} [3]	3,4(4) [256]
^{250}Cf	1,70(7)·10^{4} [3]	3,52(9) [256]
^{252}Cf	85,38(39) [3]	3,737(8) [6, 257]
^{254}Cf	0,1656(5) [4]	3,89(5) [256]
^{253}Es	6,44(22)·10^{5} [3]	-
^{254}Es	>2,5·10^{7} [5]	-
^{255}Es	2,44(14)·10^{3} [5]	-
^{257}Fm	130,7(2,7) [294]	4,01(13) [256]

TABLE 13

SUMMARY TABLE OF ADOPTED NUCLEAR CONSTANTS OF LONG-LIVED ISOTOPES OF TRANSURANIUM ELEMENTS

ISOTOPE	TYPE OF DECAY	HALF-LIFE, Y	$\bar{\nu}_p$, NEUTR./SF	ISOTOPE	TYPE OF DECAY	HALF-LIFE, Y	$\bar{\nu}_p$, NEUTR./SF
^{228}Th	α	1,9131(9)	-	^{233}Pa	β^-	27,0(1) D	-
^{229}Th	α	7340(160)	-	^{232}U	α	72(1)	-
^{230}Th	α	7,530(75)·10^{4}	-		SF	8,0(6,2)·10^{13}	-
	SF	1,5(1,5)·10^{17}	-	^{233}U	α	1,592(2)·10^{5}	-
^{232}Th	α	1,405(6)·10^{10}	-		SF	1,22(28)·10^{17}	1,5
	SF	>1·10^{21}	2,13(20)	^{234}U	α	2,445(10)·10^{5}	-
^{231}Pa	α	3,276(11)·10^{4}	-		SF	2,04(1,02)·10^{16}	1,8
	SF	≥1,1·10^{16}	-	^{235}U	α	7,038(5)·10^{8}	-

TABLE 13 (continued)

ISOTOPE	TYPE OF DECAY	HALF-LIFE, Y	$\bar{\nu}_p$, NEUTR./SF
^{235}U	SF	$3,5(9)\cdot10^{17}$	I,7
^{236}U	α	$2,34I6(39)\cdot10^{7}$	-
	SF	$2,0(I,0)\cdot10^{16}$	I,89(5)
^{238}U	α	$4,468(4)\cdot10^{9}$	-
	SF	$8,20(9)\cdot10^{15}$	I,99(3)
^{235}Np	E	4I0(I0) D	-
	α/E	$I,4\cdot10^{-5}$	-
^{236m}Np	β^-+E	$I,I5(I2)\cdot10^{5}$	-
	β^-	$I,29(+0,07)\cdot10^{6}$	-
		(-0,09)	-
^{237}Np	α	$2,I4(I)\cdot10^{6}$	-
	SF	$>I\cdot10^{18}$	I,9
^{239}Np	β^-	2,355(4) D	-
^{236}Pu	α	2,85I(8)	-
	SF	$3,5(I)\cdot10^{9}$	2,II(I3)
^{238}Pu	α	87,74(9)	-
	SF	$4,77(I4)\cdot10^{10}$	2,20(7)
^{239}Pu	α	24II0(30)	-
	SF	$5,5(5)\cdot10^{15}$	2,3
^{240}Pu	α	6537(I0)	-
	SF	$I,27(4)\cdot10^{11}$	2,I4(2)
^{241}Pu	β^-	I4,4(2)	-
	α	$6,04(6)\cdot10^{5}$	-
	α/β^-	$2,46(I)\cdot10^{-5}$	-
	SF	$\sim3\cdot10^{15}$	2,3
^{242}Pu	α	$3,763(20)\cdot10^{5}$	-
	SF	$6,9(3)\cdot10^{10}$	2,I2(I)
^{244}Pu	α	$8,26(9)\cdot10^{7}$	-
	SF	$6,56(32)\cdot10^{10}$	2,29(I9)
^{241}Am	α	432,2(5)	-
	SF	$I,I(2)\cdot10^{14}$	2,4
^{242m}Am	IT (?)	I42(4)	-
	α	$3,I3(9)\cdot10^{4}$	-
	E	960(50)	-
	SF	$9,5(3,6)\cdot10^{11}$	-
^{243}Am	α	7380(40)	-
	SF	$3,35(3I)\cdot10^{13}$	2,5
^{242}Cm	α	I62,8(4) D	-

ISOTOPE	TYPE OF DECAY	HALF-LIFE, Y	$\bar{\nu}_p$, NEUTR./SF
^{242}Cm	SF	$6,I(2)\cdot10^{6}$	2,50(6)
^{243}Cm	α	29,0(8)	-
^{244}Cm	α	I8,II(2)	-
	SF	$I,344(4)\cdot10^{7}$	2,69(I)
^{245}Cm	α	8532(53)	-
^{246}Cm	α	4762(I6)	-
	SF	$I,809(38)\cdot10^{7}$	2,907(I5)
^{247}Cm	α	$I,60(4)\cdot10^{7}$	-
^{248}Cm	α+ SF	$3,397(32)\cdot10^{5}$ (eff.)	-
	α	$3,703(35)\cdot10^{5}$ (partial)	-
	SF	$4,II2(4I)\cdot10^{6}$	3,I73(25)
^{247}Bk	α	I380(250)	-
^{249}Bk	β^-	328(3) D	-
	α/β^-	$I,45(8)\cdot10^{-5}$	-
	α	$6,04(35)\cdot10^{4}$	-
	SF	$I,86(I0)\cdot10^{9}$	3,395(26)
^{249}Cf	α	352,2(2,2)	-
	SF	$6,98(I4)\cdot10^{10}$	3,4(4)
^{250}Cf	α	I3,08(9)	-
	SF	$I,70(7)\cdot10^{4}$	3,52(9)
^{251}Cf	α	900(50)	-
^{252}Cf	α+ SF	2,638(I0) (eff.)	-
	α	2,722(I0) (partial)	-
	SF	85,38(39)	3,737(8)
^{254}Cf	α/SF	$3,I(I,6)\cdot10^{-3}$	-
	SF	60,5(2) D	3,89(5)
^{252}Es	α	408(42) D	-
^{253}Es	α	20,47(2) D	-
	SF	$6,44(22)\cdot10^{5}$	-
^{254}Es	α	276(6) D	-
	SF	$>2,5\cdot10^{7}$	-
^{255}Es	β^-	38,9(8) D	-
	α/β^-	$\sim9,3\cdot10^{-2}$	-
	SF	$2,44(I4)\cdot10^{3}$	-
^{253}Fm	E	3,0(I) D	-
	α/E	0,I2(I)	-
^{257}Fm	α	97,2(3,2) D	-
	SF	I30,7(2,7)	4,0I(I3)

Comment. New data on the SF half-lives for U isotopes have been published by G. von Gunter, A. Gruyter et al. (Phys. Rev., 1981, 23 C, p. 1110). The method was based on the use of a spinner detector.

TABLE 14

SPECIFIC ACTIVITIES OF LONG-LIVED TRANSACTINIUM ELEMENTS (MASS 1 mg)

Isotope	Radioactive decay		Spontaneous fission	
	Type of decay	Disintegrations/s	SF/s	Neutrons/s
^{228}Th	α	3,032(1)·10^{10}	-	-
^{229}Th	α	7,87(17)·10^{6}	-	-
^{230}Th	α	7,64(8)·10^{5}	4(4)·10^{-7}	
^{232}Th	α	4,06(2)	<6·10^{-11}	<1,3·10^{-10}
^{231}Pa	α	1,748(6)·10^{6}	≤5·10^{-6}	-
^{233}Pa	β^-	7,678(28)·10^{11}	-	-
^{232}U	α	7,92(11)·10^{8}	7,1(5,5)·10^{-4}	-
^{233}U	α	3,565(4)·10^{5}	4,6(1,1)·10^{-7}	~7·10^{-7}
^{234}U	α	2,311(9)·10^{5}	2,8(1,4)·10^{-6}	~5·10^{-6}
^{235}U	α	79,96(6)	1,6(4)·10^{-7}	~3·10^{-7}
^{236}U	α	2,393(4)·10^{3}	2,8(1,4)·10^{-6}	5,3(2,6)·10^{-6}
^{238}U	α	12,44(1)	6,8(7)·10^{-6}	1,35(3)·10^{-5}
^{235}Np	E	5,01(12)·10^{10}	-	-
	α	7,0·10^{5}	-	-
^{236m}Np	β^- + E	4,87(51)·10^{5}	-	-
	β^-	4,34(+23)·10^{4} (-17)	-	-
^{237}Np	α	2,607(12)·10^{4}	<6·10^{-8}	<1·10^{-7}
^{239}Np	β^-	8,581(15)·10^{12}	-	-
^{236}Pu	α	1,966(6)·10^{10}	16,0(5)	33,8(2,3)
^{238}Pu	α	6,333(6)·10^{8}	1,16(3)	2,55(11)
^{239}Pu	α	2,295(3)·10^{6}	1,00(9)·10^{-5}	~2,3
^{240}Pu	α	8,429(13)·10^{6}	0,434(14)	0,929(31)
^{241}Pu	β^-	3,81(5)·10^{9}	~1,8·10^{-5}	~4·10^{-5}
	α	9,08(9)·10^{4}	-	-
^{242}Pu	α	1,452(8)·10^{5}	0,792(34)	1,68(7)
^{244}Pu	α	636(7)	0,826(40)	1,89(18)
^{241}Am	α	1,270(2)·10^{8}	5,00(91)·10^{-4}	~1·10^{-3}
^{242m}Am	IT	3,85(6)·10^{8}	5,8(2,2)·10^{-2}	-
	α	1,75(5)·10^{6}	-	-
	E	5,69(30)·10^{7}		
^{243}Am	α	7,374(40)·10^{6}	1,62(15)·10^{-3}	~4·10^{-3}
^{242}Cm	α	1,226(3)·10^{11}	9,0(3)·10^{3}	2,25(9)·10^{4}
^{243}Cm	α	1,876(52)·10^{9}	-	-
^{244}Cm	α	2,993(3)·10^{9}	4,032(12)·10^{3}	1,085(5)·10^{4}
^{245}Cm	α	6,326(39)·10^{6}	-	-
^{246}Cm	α	1,129(4)·10^{7}	2,97(6)·10^{3}	8,63(19)·10^{3}
^{247}Cm	α	3,35(8)·10^{3}	-	-
^{248}Cm	α	1,440(14)·10^{5}	1,30(1)·10^{4}	4,12(5)·10^{4}
^{247}Bk	α	3,38(70)·10^{7}	-	-
^{249}Bk	β^-	5,913(54)·10^{10}	28,6(1,5)	97,1(5,3)
	α	8,79(51)·10^{5}	-	-
^{249}Cf	α	1,508(9)·10^{8}	0,761(15)	2,6(3)
^{250}Cf	α	4,044(28)·10^{9}	3,11(13)·10^{6}	1,09(5)·10^{7}
^{251}Cf	α	5,85(32)·10^{7}	-	-
^{252}Cf	α	1,928(7)·10^{10}	6,146(28)·10^{8}	2,297(12)·10^{9}
^{254}Cf	α	9,7(5,0)·10^{8}	3,143(10)·10^{11}	1,22(2)·10^{12}

Table No. 14 (cont.)

Isotope	Radioactive decay		Spontaneous fission	
	Type of decay	Disintegrations/s	SF/s	Neutrons/s
^{252}Es	α	$4,70(47)\cdot10^{10}$	-	-
^{253}Es	α	$9,325(9)\cdot10^{11}$	$8,12(28)\cdot10^{4}$	-
^{254}Es	α	$6,89(15)\cdot10^{10}$	$<2,1\cdot10^{3}$	-
^{255}Es	β^-	$4,9(1,0)\cdot10^{11}$	$2,13(12)\cdot10^{7}$	-
	α	$\sim4,6\cdot10^{10}$	-	-
^{253}Fm	E	$6,86(25)\cdot10^{12}$	-	-
	α	$7,63(70)\cdot10^{11}$	-	-
^{257}Fm	α	$1,93(6)\cdot10^{11}$	$8,94(8)\cdot10^{8}$	$1,58(6)\cdot10^{9}$

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