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Half-life of ^{232}U

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The half-life of ^{232}U was determined by two independent methods: a specific activity method and a relative activity method involving the half-life of ^{233}U. In the specific activity method, the α disintegration rate of ^{232}U was determined by liquid scintillation counting as well as by α proportional counting, and the number of atoms of ^{232}U was determined by isotope dilution mass spectrometry. The radiochemical purity of the purified ^{232}U was confirmed by α spectrometry. A half-life value of 69.00 ± 0.40 yr was obtained. In the relative activity method, synthetic mixtures were prepared using isotopes of ^{232}U and ^{233}U. The α activity ratios in these mixtures were determined by α spectrometry and the atom ratios were obtained by mass spectrometry. The α activity ratios and the atom ratios were such that these could be measured with a high precision and accuracy. A half-life value of 68.81 ± 0.38 yr was obtained using the half-life of ^{233}U as 1.592×10^5 yr. The average of these two independent determinations leads to a value of 68.90 ± 0.39 yr for the half-life of ^{232}U. The uncertainty given on the values is a combination of the one standard deviation on the average value and the error evaluated from estimates on various error components. The values reported earlier are significantly higher as compared to the half-life value obtained in this work.

[RADIOACTIVITY ^{232}U half-life, specific activity; measured: α activity by liquid scintillation counter and α proportional counter, uranium concentration by isotope dilution mass spectrometry; relative to the half-life of ^{233}U; measured: ^{232}U/^{233}U activity ratio by α spectrometry, ^{232}U/^{233}U atom ratio by mass spectrometry.]

I. INTRODUCTION

There are a few determinations reported for the half-life of ^{232}U. A value of 30 yr was estimated by Gofman and Seaborg[1] based on the growth of ^{232}U α activity from its β emitting parent ^{232}Pa, whereas a value of 70 yr was reported by James *et al.*[2] by studying the growth of ^{232}U from its α emitting parent ^{236}Pu. Sellers *et al.*[3] determined a half-life value of 73.6 ± 1.0 yr by the specific activity method. Chilton *et al.*[4] obtained a half-life value of 71.7 ± 0.9 yr by two independent methods: by calorimetry and by the specific activity method. In view of the large spread in the half-life values ranging from 70 to 74 yr determined more than a decade ago, it was considered worthwhile to determine more precisely and accurately the half-life of ^{232}U with the presently available facilities and experience.

In the present work the half-life of ^{232}U was determined by two independent methods: a specific activity method and a relative activity method using the half-life of ^{233}U. In the specific activity method the number of atoms of ^{232}U were determined by isotope dilution mass spectrometry and the α disintegration rate was obtained by liquid scintillation counting as well as by α proportional counting. The radiochemical purity of ^{232}U was confirmed by α spectrometry. The half-life of ^{232}U was calculated with the equation

$$-\frac{dN}{dt} = N\lambda , \tag{1}$$

where dN/dt denotes the α disintegration rate, N stands for the number of atoms, and λ is the decay constant. As can be seen from Eq. (1), the accuracy in the determination of half-life by this method depends upon the accuracy in determining (a) the number of atoms and (b) the α disintegration rate. As will be noted later, attempts were made to minimize the random errors and to check for systematic errors at various steps involving the determination of the disintegration rate and the number of atoms.

In the second method ^{233}U was selected as the reference nuclide mainly because its half-life is known accurately and it can be obtained in a high radiochemical as well as isotopic purity. Furthermore, it has high α specific activity, so that in the preparation of nearly weightless sources for α spectrometry the requirement of maintaining the α activity ratios of ^{232}U to ^{233}U between 0.5 and 1 could be met. The method involved the preparation of synthetic mixtures using ^{232}U and ^{233}U isotopes. The α activity ratios in these mixtures were determined by α spectrometry on electrodeposited sources using a silicon surface barrier detector, while the atom ratios were obtained by mass spectrometry. The half-life of ^{232}U was computed with the equation

$$\frac{A_{232}}{A_{233}}=\frac{N_{232}\lambda_{232}}{N_{233}\lambda_{233}}=\frac{N_{232}(T_{1/2})_{233}}{N_{233}(T_{1/2})_{232}}, \tag{2}$$

where the A's denote the activities.

As is evident from Eq. (2), the accuracy in determining the half-life by this method depends on three factors: (a) atom ratios, (b) α activity ratios, and (c) the half-life of ^{233}U. In the present work synthetic mixtures were prepared to achieve the atom ratios ^{232}U/^{233}U close to unity so that these could be determined with a high precision and accuracy. In further dilution of these mixtures with measured amounts of ^{233}U solution, the α activity ratios of ^{232}U to ^{233}U were kept between 0.5 and 1 to minimize the contribution due to energy degradation from the high energy α peak (^{232}U) to the low energy α peak (^{233}U) while still achieving a high statistical accuracy in counting under both the α peaks. Furthermore, different values of α activity ratios in various mixtures provided a check for any significant bias in the peak area computation which might arise from the energy degradation.

II. ISOTOPES USED

The isotopes used in the work were analyzed mass spectrometrically for determining the isotopic composition. The data on the isotopes used are given in Table I.

III. EXPERIMENTAL DETAILS ON THE HALF-LIFE DETERMINATION OF ^{232}U BY SPECIFIC ACTIVITY METHOD

A. Purification of ^{232}U

The purification of ^{232}U from its daughter activities was carried out using solvent extraction and ion exchange procedures. ^{232}U was extracted from its solution in about 2 M HNO_3 using 30% TBP diluted with xylene. It was then stripped from the TBP phase by using 0.1 M $(NH_4)_2CO_3$ solution. The purified solution of ^{232}U was evaporated to dryness and taken up in about 10 M HCl. It was loaded onto an ion exchange column containing Dowex 1× 8 resin (200–400 mesh, in the chloride form). The column was washed with 10 M HCl several times to remove small traces of ^{228}Th and other daughter activities still persisting. ^{232}U was eluted from the column with 0.1 M HCl. The purified solution was evaporated to dryness, converted to the nitrate medium, and finally taken up in 1 : 50 HNO_3. Immediately after the ion exchange step, quadruplicate samples were prepared for α proportional counting and liquid scintillation counting. The planchets and the vials were counted in the respective α counters. This measurement was required to correct for the growth of daughter activities in ^{232}U for the time that elapsed up to the preparation and counting of actual samples. The radiochemical purity of the purified ^{232}U was confirmed by α spectrometry; it was found to be completely free from ^{228}Th and its daughters.

B. Determination of the α disintegration rate

The α disintegration rate of ^{232}U was determined by liquid scintillation counting as well as by α proportional counting.[5] Owing to the high α specific activity of the stock solution of ^{232}U, a double dilution in duplicate was carried out. From each of the second dilutions (IA, IB; IIA, IIB) five sources were prepared by transferring about 100 mg of the solution onto electropolished stainless steel planchets. Known aliquots were also placed into liquid scintillation vials. Various dilutions and preparations of samples for counting were done on weight basis using polyethylene weight burettes rather than on volume basis so as to avoid errors in calibration of glassware and in pipetting. Duplicate dilutions were carried out at each step with a view to checking any error in dilution and weighing. The planchets and the liquid scintillation vials were counted for a time sufficient to accumulate more than 10^5 counts. The count rate for each

TABLE I. Isotopic composition and pulse height analysis of isotopes used.

	Isotope used					
		^{232}U			^{233}U	
Mass number	Atom percent	Weight percent	% total α activity[a]	Atom percent	Weight percent	% total α activity
232	16.524	16.178 ± 0.05	99.998 95	0.000 156 6	0.000 156 ± 0.000 002	0.3462 ± 0.0030[b]
233	0.3751	0.368 8 ± 0.004	0.10×10^{-2}	99.703	99.701 ± 0.01	99.654 ± 0.010[b,c]
234	0.0107	0.010 57 ± 0.0005	0.19×10^{-4}	0.237 0	0.238 0 ± 0.003	
235	1.1545	1.145 0 ± 0.008	0.70×10^{-6}	0.013 36	0.013 47 ± 0.000 4	0.30×10^{-5}[a]
238	81.936	82.298 ± 0.02	0.79×10^{-5}	0.046 6	0.047 60 ± 0.000 8	0.16×10^{-5}[a]

[a] Calculated from the mass ratios and the latest recommended half-life values (Ref. 8).

[b] Obtained from the α particle pulse height analysis of a ^{233}U isotope.

[c] Combined activity due to ^{233}U and ^{234}U as the α peaks corresponding to these isotopes were not resolved.

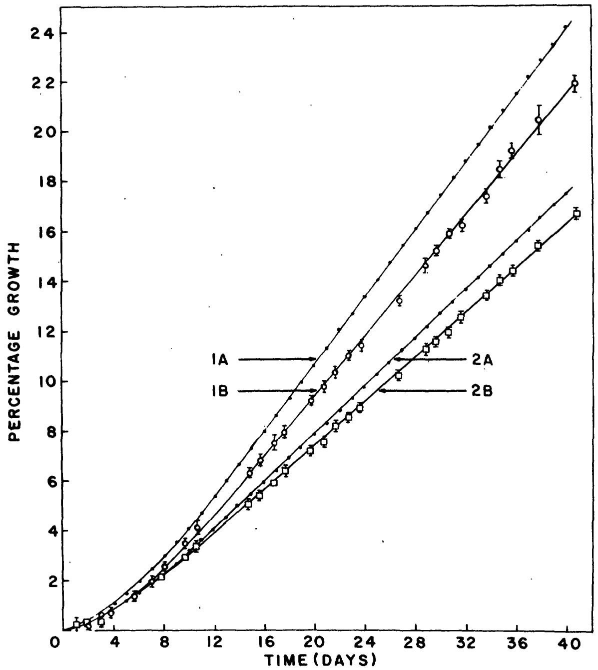


FIG. 1. Growth of daughter activity in ^{232}U. Curve 1A obtained theoretically by considering all daughters; 1B experimentally determined (liquid scintillation counting). Curve 2A obtained theoretically by considering α emitting daughters only; 2B experimentally determined (α proportional counting).

sample was about 20 000 dpm so that the dead time correction was negligible. The efficiencies of the α proportional counter and liquid scintillation counter were calibrated by using an ^{241}Am standard solution obtained from IAEA. The corrections due to back scattering and self-absorption were assumed to be the same, since the same lot of stainless steel planchets and liquid scintillator (freshly prepared) were used for sample preparation as well as for checking the efficiency of the counters. Furthermore, the amount of uranium on the planchet was extremely small (a few ng of uranium) and there was no visible residue on the planchet. A correction for the growth of daughter activities in ^{232}U for the period that elapsed from the time of purification up to the counting of samples was applied on the basis of growth curves (1B, 2B) obtained experimentally as shown in Fig. 1. The samples were counted on three different days and the disintegration rate obtained after correcting for the growth of daughter activities from the various counting data agreed within 0.1%. Figure 1 compares the growth of daughter activities in ^{232}U obtained experimentally and theoretically. The difference between the theoretical curve 1A and the experimental curve 1B can be explained by the fact that the efficiencies for counting α's and β's in the liquid scintillation counter are not the same, the efficiency for counting β's being less than that for α particles. The curve 2A has been obtained theoretically by excluding the growth of β emitting daughters (^{212}Pb and ^{212}Bi) as these are not counted in the setup used for α proportional counting. The difference between the theoretical curve 2A and the experimental curve 2B can be attributed to the fact that it is not possible to account for the contribution of gaseous daughters (^{220}Rn, ^{216}Po, ^{212}Po) quantitatively to the counting rate owing to their escape probability in the gas flow α proportional counter. It was for these reasons that the growth curves were determined experimentally and used. The results on the α counting of ^{232}U solution are given in Table II.

C. Determination of the number of ^{232}U atoms

The number of atoms of ^{232}U in the stock solution were determined by isotope dilution mass spectrometry.[6] A Varian MAT CH-5 mass spectrometer with a thermionic source and a double rhenium filament assembly was used. The instrument has a resolution of 425 (at 10% valley definition) measured at around mass 238 and an abundance

TABLE II. Results on the determination of the α disintegration rate of ^{232}U stock solution.

	By liquid scintillation counting		By α proportional counting	
Dilution number	Number of vials	Activity[a] dpm/g of solution × 10^{-7}	Number of planchets	Activity[a] dpm/g of solution × 10^{-7}
IA	5	6.2813 ± 0.0069[b]	5	6.2765 ± 0.0259[b]
IB	5	6.2796 ± 0.0039	5	6.3065 ± 0.0133
IIA	5	6.2728 ± 0.0031	5	6.2872 ± 0.0084
IIB	5	6.2836 ± 0.0136	5	6.2717 ± 0.0125
Average		(6.2793 ± 0.0023[c]) × 10^7		(6.2855 ± 0.0077[c]) × 10^7

[a] These values have been corrected for the growth of daughter activities from ^{232}U for the time that elapsed after the purification of ^{232}U up to the time of counting.

[b] Standard deviation calculated from $s^2=\sum_{i=1}^{n}(x_i-\bar{x})^2/(n-1)$ with $n=5$.

[c] Standard error computed as $s/\sqrt{n}$, where $s^2=\sum_{i=1}^{n}(\bar{x}_i-\bar{\bar{x}})^2/(n-1)$ with $n=4$.

TABLE III. Results on the concentration determination of uranium by isotope dilution mass spectrometry.

Sample number	Concentration (μg of uranium/g of solution)
1	7.840 76
2	7.842 07
3	7.845 52
4	7.819 43
5	7.829 03
6	7.826 62
Average	7.833 90 ± 0.0042 [a]

[a] Standard error of the mean calculated as $s/\sqrt{n}$, where $s^2=\sum_{i=1}^{n}(x_i-\bar{x})^2/(n-1)$ with $n=6$.

sensitivity greater than 10^5.

The mass discrimination factor was calibrated by analyzing isotopic standards of uranium obtained from the National Bureau of Standards (U.S.), and was found to be 0.0036 per mass unit.

^{233}U was used as spike and was calibrated against a fresh chemical assay standard of uranium prepared from U_3O_8 (SRM-950). The aliquot sizes of sample, standard, and spike taken were such that the atom ratios (^{232}U/^{233}U or ^{238}U/^{233}U) were close to unity. The data on the concentration measurement of ^{232}U are given in Table III.

D. Calculation of the half-life of ^{232}U

The half-life of ^{232}U was computed with Eq. (1). From Table II the α disintegration rate of ^{232}U as determined by liquid scintillation counting is 6.2793×10^7 dpm/g of solution, and from Table III the concentration of total uranium in ^{232}U solution is 7.8339×10^{-6} g uranium/g solution. Taking the weight percent of ^{232}U in uranium as 16.178 from Table I, the half-life of ^{232}U can be calculated as

$$T_{1/2}=\frac{{}^{232}N\ln2}{dN/dt}$$

$$=\frac{7.8339\times10^{-6}\times0.161\,78\times6.022\,04\times10^{23}\times\ln2}{232.04\times6.2793\times10^{7}\times365.242\times1440}$$

$$=69.04\ \mathrm{yr}.$$

From α proportional counting, $dN/dt=6.2855\times10^7$ dpm/g solution (Table II). Hence $T_{1/2}=68.97$ yr.

IV. EXPERIMENTAL DETAILS ON THE HALF-LIFE DETERMINATION OF ^{232}U BY THE RELATIVE ACTIVITY METHOD USING THE HALF-LIFE OF ^{233}U

A. Preparation of synthetic mixtures

Six synthetic mixtures were prepared by mixing known aliquots of purified ^{232}U and ^{233}U solutions in clean, dry, and preweighed 25 ml volumetric flasks. The mixtures were diluted to a known weight with about 1 M HNO_3. The amounts of ^{232}U and ^{233}U solutions taken were so as to obtain the ^{232}U/^{233}U atom ratio close to unity. Known aliquots from each of these synthetic mixtures were transferred to separate clean glass vials. A precalculated and known aliquot of ^{233}U solution was added to each of the vials for obtaining the α activity ratio of ^{232}U to ^{233}U between 0.5 and 1. The solutions from the volumetric flasks were used for mass spectrometry and those from the vials were used for α spectrometry. The weights of the solutions used for the preparation of synthetic mixtures for mass spectrometry and α spectrometry are given in Table IV.

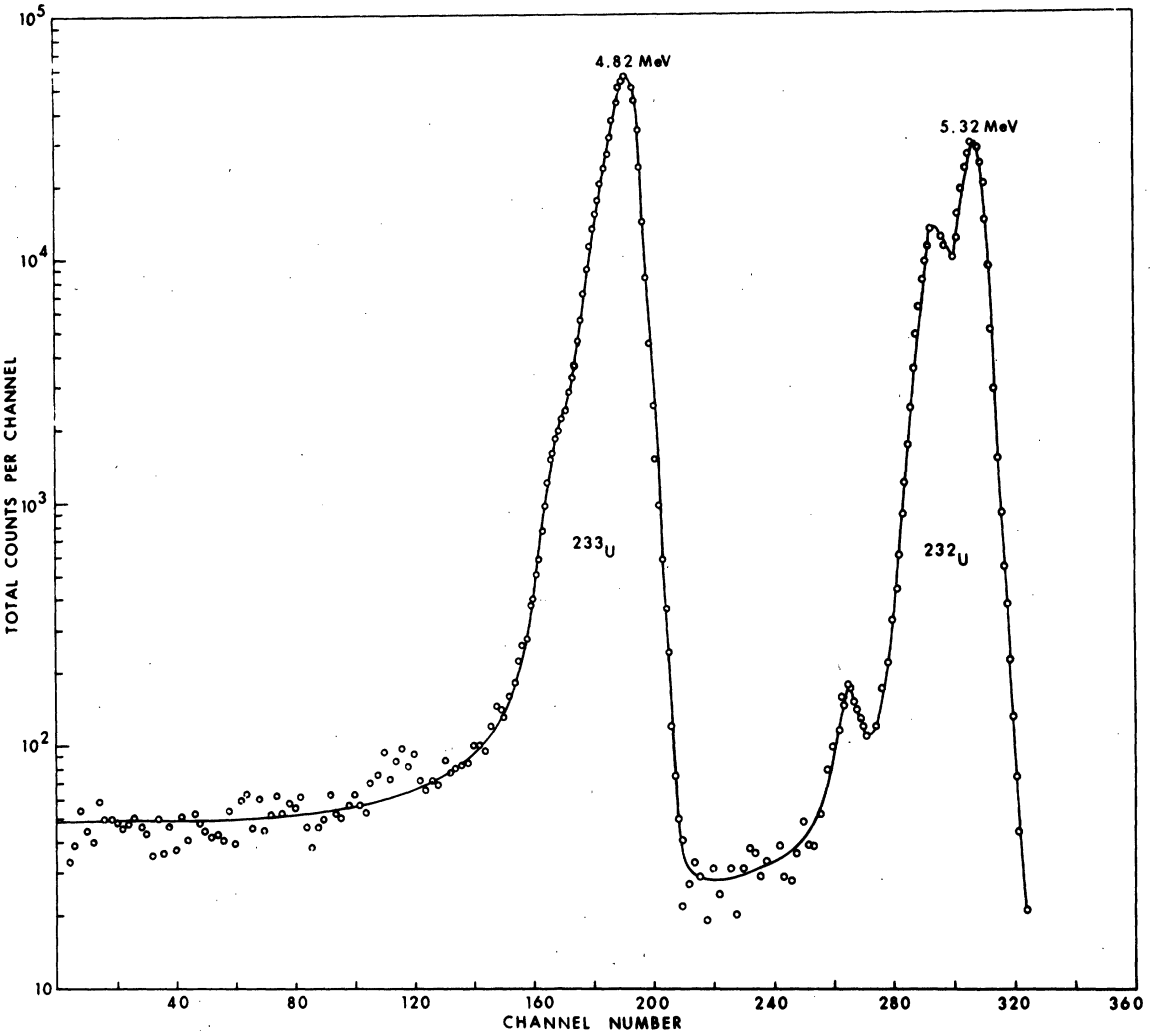
B. α spectrometry

The synthetic mixtures in the vials were evaporated to near dryness and taken up in dilute HNO_3

TABLE IV. Weights of the solutions used for the preparation of synthetic mixtures for mass spectrometry and α spectrometry. All weights are in grams.

Synthetic mixture code number	$(W_1)_{232}$	$(W_2)_{233}$	W	W_{al}	$(W_3)_{233}$ [a]
SM-32-I	1.799 20	0.255 95	16.258 35	0.330 70	16.930 05
SM-32-II	1.339 55	0.208 10	17.452 95	0.468 80	14.822 35
SM-32-III	1.583 30	0.233 60	16.793 70	0.359 25	12.848 40
SM-32-IV	1.508 95	0.180 15	17.698 90	0.463 15	15.392 95
SM-32-V	1.642 85	0.183 40	17.501 90	0.359 10	12.867 35
SM-32-VI	1.647 95	0.200 75	20.536 05	0.453 15	10.124 45

[a] Dilution, in duplicate, from the ^{233}U stock solution was made. Aliquot $(W_2)_{233}$ for samples I–III was taken from one dilution and for samples IV–VI from the other dilution. The weights $(W_3)_{233}$ entered here correspond to the amount of ^{233}U diluted solution after considering the aliquot weight taken from the stock solution and the corresponding dilution factor. The notations $(W_1)_{232}$, $(W_2)_{233}$, W, W_{al}, and $(W_3)_{233}$ are as defined in Sec. IV D.



FIG; 2. The α particle energy spectrum of an SM-32-V uranium sample.

for source preparation. Two α sources were prepared from each of the mixtures by electrodeposition from an aqueous nitric acid medium (pH about 2) using an electropolished stainless steel disk as the cathode. The source thickness was about 1 μg/cm^2.

A 50 mm^2 silicon surface barrier detector mounted in a vacuum chamber and coupled to a 400 channel analyzer was used for recording the α spectra of the sources. The system has a resolution of 20 KeV full width at half maximum (FWHM) at 5.50 MeV. Each of the sources was counted twice for a sufficiently long time to achieve good counting statistics. Earlier experience has shown that the accuracy in computing the α activity ratios from an α spectrum on a weightless electrodeposited source is mainly dependent on the ratio of the counts in the high energy peak to those in the low energy peak. If this ratio is less than or about 1, then the contribution of α activity to the low energy peak arising from the energy degradation of the high energy peak is negligible. Peak areas in these cases can be obtained accurately by directly summing the counts in the channels under the peaks. It has also been checked in these cases by a nonlinear least squares fit[7] that the correction due to α energy degradation from the high energy peak to the low energy peak is negligible and lies well within the counting statistics. In order to determine the precision and accuracy achievable in α activity ratio measurement, synthetic mixtures were prepared from ^{232}U and ^{233}U solutions, and it was found that following the conditions described above, an accuracy of 0.5% or better can be achieved while the precision is ±0.2%. A typical α spectrum obtained is shown in Fig. 2, and the

TABLE V. Results on the α spectrometric and mass spectrometric measurements in synthetic mixtures used for determining ^{232}U half-life by relative activity method.

Synthetic mixture code number	^{232}U/^{233}U α activity ratio[a]	^{232}U/^{233}U atom ratio
SM-32-I	0.5999 ± 0.0008[b]	0.8242 ± 0.0012[c]
SM-32-II	0.6740 ± 0.0016	0.7560 ± 0.0008
SM-32-III	0.7328 ± 0.0006	0.7957 ± 0.0023
SM-32-IV	0.5798 ± 0.0018	0.7985 ± 0.0015
SM-32-V	0.5932 ± 0.0016	0.8539 ± 0.0020
SM-32-VI	0.8114 ± 0.0016	0.7836 ± 0.0009

[a] The α activity ratios have been corrected for α activity due to the presence of ^{234}U in enriched isotopes used for preparing synthetic mixtures as ^{233}U and ^{234}U α peaks were not resolved during α spectrometry. Correction has also been applied due to the growth of ^{228}Th in ^{232}U which contributes α counts in ^{232}U peak.

[b] Standard deviation calculated from $s^2=\sum_{i=1}^{n}(x_i-\bar{x})^2/(n-1)$ with $n=4$ as two sources were prepared from each mixture and α spectrum from each source was recorded twice.

[c] Standard deviation from various mass spectrometric runs.

results on the measurement of α activity ratios are given in Table V.

C. Mass spectrometry

The synthetic mixtures in the volumetric flasks were analyzed for ^{232}U/^{233}U atom ratios by mass spectrometry. The results are given in Table V.

D. Calculation of the half-life of ^{232}U

As given earlier, Eq. (2) can be used for computing the half-life of ^{232}U provided the atom ratios and the α activity ratios are determined from the solution in the same flask or vial. If the ^{232}U/^{233}U atom ratio is kept close to unity in a synthetic mixture, then the ^{232}U/^{233}U α activity ratio becomes very high (>2000). Thus, the requirement of having a ^{232}U/^{233}U α activity ratio between 0.5 and 1 necessitated the addition of ^{233}U. This required a small correction to be applied owing to the presence of ^{232}U in the isotope of ^{233}U which could be computed accurately from the aliquot sizes taken for preparing the synthetic mixtures and the isotope ratios determined experimentally.

Let $(W_1)_{232}$ and $(W_2)_{233}$ be the aliquot weights taken from the solutions of ^{232}U and ^{233}U isotopes, respectively, and diluted to a known weight W in a volumetric flask. If $(W_3)_{233}$ denotes the amount of ^{233}U solution added to an aliquot W_{al} taken in a vial from the solution in the volumetric flask, then the number of atoms of ^{232}U in the vial used for α spectrometry is given by

$$N_{232}=\frac{(W_1)_{232}}{W}W_{\text{al}}(C_{232})_{232}+\frac{(W_2)_{233}}{W}\times W_{\text{al}}(C_{232})_{233}+(W_3)_{233}(C_{232})_{233}\,, \tag{3}$$

where the C's denote the number of atoms of ^{232}U per gram of the stock solution. The subscripts outside the parentheses denote the isotope used. A similar expression can be written for N_{233} by replacing C_{232} with C_{233}. Substituting the values of N_{232} and N_{233} in Eq. (2), we get

$$\begin{aligned}\frac{A_{232}}{A_{233}}&=\frac{(T_{1/2})_{233}}{(T_{1/2})_{232}}\,\frac{\dfrac{(W_1)_{232}}{W}W_{\text{al}}(C_{232})_{232}+\dfrac{(W_2)_{233}}{W}W_{\text{al}}(C_{232})_{233}+(W_3)_{233}(C_{232})_{233}}{\dfrac{(W_1)_{232}}{W}W_{\text{al}}(C_{233})_{232}+\dfrac{(W_2)_{233}}{W}W_{\text{al}}(C_{233})_{233}+(W_3)_{233}(C_{233})_{233}}\\&=\frac{(T_{1/2})_{233}}{(T_{1/2})_{232}}\,\frac{\dfrac{(W_1)_{232}}{W}W_{\text{al}}Y_1+\dfrac{(W_2)_{233}}{W}W_{\text{al}}R_{Sp}{}^{2/3}+(W_3)_{233}R_{Sp}{}^{2/3}}{\dfrac{(W_1)_{232}}{W}W_{\text{al}}Y_2+\dfrac{(W_2)_{233}}{W}W_{\text{al}}+(W_3)_{233}}\,,\end{aligned} \tag{4}$$

where $Y_1=(C_{232})_{232}/(C_{233})_{233}$ and $Y_2=(C_{233})_{232}/(C_{233})_{233}$ and are calculated from

$$Y_1=\frac{(W_2)_{233}}{(W_1)_{232}}\,\frac{R_M{}^{2/3}-R_{Sp}{}^{2/3}}{1-R_M{}^{2/3}/R_S{}^{2/3}}\,, \tag{5}$$

$$Y_2=Y_1/R_S{}^{2/3}\,. \tag{6}$$

In Eqs. (4)–(6), $R_S{}^{2/3}$, $R_{Sp}{}^{2/3}$, and $R_M{}^{2/3}$ denote the ^{232}U/^{233}U atom ratios in the ^{232}U isotope, ^{233}U isotope, and synthetic mixture, respectively, and are determined experimentally.

All aliquots were taken by weight using a semimicro Mettler balance. All weighings were done on the same day to avoid any correction arising from the evaporation loss of different solutions.

A small correction of 0.15% was applied to the observed α activity in the ^{233}U peak due to the presence of ^{234}U in the ^{233}U isotope, as pulse analysis could not resolve ^{233}U and ^{234}U α peaks. A correction of about 0.1% was applied to correct for the growth of ^{228}Th (5.34 MeV, abundance ≈ 29%) which contributes at the

TABLE VI. Summary of ^{232}U half-life measurements.

By specific activity method		By relative activity method using the half-life of ^{233}U	
From liquid scintillation counting data	From α proportional counting data	Synthetic mixture code number	Half-life of ^{232}U (yr)
		SM-32-I	68.937
		SM-32-II	68.860
		SM-32-III	68.783
69.04 ± 0.22[a]	68.97 ± 0.23[a]	SM-32-IV	68.796
		SM-32-V	68.744
		SM-32-VI	68.764
Average	69.00 ± 0.23	Average	68.81 ± 0.029[b]

[a] Computed by combining one standard deviation on the average value of disintegration rate (Table II), concentration of uranium (Table III), and weight percent of ^{232}U (Table I).

[b] Standard error of the mean calculated as $s/\sqrt{n}$, where $s^2=\sum_{i=1}^{n}(x_i-\bar{x})^2/(n-1)$ with $n=6$.

TABLE VII. Estimates of errors (1σ).

		Specific activity method	
Serial number	Quantity	Error (in percent)	Remarks
1	Counter efficiency	0.44	Includes error in source preparation (0.1%), counting statistics (0.3%), and uncertainty in the concentration of ^{241}Am standard solution (0.3%)
2	Correction to the α disintegration rate for the growth of daughter activities in ^{232}U	0.10	Based on the agreement in the counting data taken on different dates
3	Concentration of uranium standard used for ^{233}U spike calibration	0.10	Standard solution prepared from SRM-950
4	Concentration of ^{233}U spike	0.10	Obtained experimentally
	Combined error	0.47	

		Relative activity method		
Serial number	Quantity	Approximate value	Error (in percent)	Remarks
1	A_{232}/A_{233}	1	0.50	Evaluated from experiments conducted by making synthetic mixtures
2	$R_S{}^{2/3}$	44.053	0.50	Evaluated experimentally
3	$R_{Sp}{}^{2/3}$	0.000 001 57	1.50	Evaluated experimentally
4	$R_M{}^{2/3}$	1	0.20	Evaluated experimentally
5	$(W_1)_{232}$	1.5 g	0.003 3	Error of ±0.000 05 g
6	$(W_2)_{233}$	0.200 g	0.025	Error of ±0.000 05 g
7	W	17 g	0.000 29	Error of ±0.000 05 g
8	$W_{\rm al}$	0.400 g	0.012	Error of ±0.000 05 g
9	$(W_3)_{233}$	15 g	0.005 6[a]	Error of ±0.000 05 g
10	$(T_{1/2})_{233}$	1.592×10^5 yr	0.13	Ref. 8
	Y_1	0.13	0.202	Computed by error propagation in Eq. (5)
	Y_2	0.002 95	0.54	Computed by error propagation in Eq. (6)
	Combined error		0.55	Computed by error propagation in Eq. (4)

[a] Calculated after considering dilution factor and aliquot weight.

TABLE VIII. Comparison of various ^{232}U half-life values.

Authors	Year	Method	Half-life value (yr)
Gofman and Seaborg (Ref. 1)	1949	Growth of ^{232}U α activity from ^{232}Pa	30
James *et al.* (Ref. 2)	1949	Growth of ^{232}U α activity from ^{236}Pu	70
Sellers *et al.* (Ref. 3)	1954	$2\pi\alpha$ counting; ^{232}U determination by isotope dilution mass spectrometry	73.6 ± 1.0
Chilton *et al.* (Ref. 4)	1964	(i) Calorimetry	71.4 ± 0.6
		(ii) $2\pi\alpha$ counting; U determination by coulometry	72.1 ± 0.5
Present work	1978	(i) $2\pi\alpha$ counting and liquid scintillation counting; U determination by isotope dilution mass spectrometry	69.00 ± 0.40[a]
		(ii) Relative to the half-life of ^{233}U using α spectrometry and mass spectrometry	68.81 ± 0.38[a,b]

[a] The error given is a combination of the standard deviation on the average value given in Table VI and the combined error listed in Table VII.

[b] The half-life of ^{232}U calculated by using $T_{1/2}$ for ^{233}U$=1.592\times10^5$ yr, Ref. 8.

^{232}U peak.

The half-life of ^{232}U was calculated with Eq. (4). The half-life values obtained from different synthetic mixtures are given in Table VI. As an example, the half-life of ^{232}U is calculated using the data for synthetic mixture SM-32-I. For this mixture, $(W_1)_{232}=1.799\,20$, $(W_2)_{233}=0.255\,95$, $W=16.258\,35$, $W_{\text{al}}=0.330\,70$, $(W_3)_{233}=16.930\,05$ (from Table IV); $R_M{}^{2/3}=0.8242$, $A_{232}/A_{233}=0.5999$ (from Table V); $R_S{}^{2/3}=44.0522$, $R_{Sp}{}^{2/3}=0.000\,001\,57$ (from data given in Table I). Substituting the values in Eqs. (4)–(6), we obtain

$$Y_1=\frac{0.255\,95}{1.799\,20}\times\frac{0.8242-0.000\,001\,57}{1-0.8242/44.0522}=0.119\,48,\quad Y_2=0.119\,48/44.0522=0.002\,712\,3\,,$$

$$0.5999=\frac{1.592\times10^5}{(T_{1/2})_{232}}\,\frac{\dfrac{1.799\,20}{16.258\,35}\times0.330\,70\times0.119\,48+\dfrac{0.255\,95}{16.258\,35}\times0.330\,70\times0.000\,001\,57+16.930\,05\times0.000\,001\,57}{\dfrac{1.799\,20}{16.258\,35}\times0.330\,70\times0.002\,712\,3+\dfrac{0.255\,95}{16.258\,35}\times0.330\,70+16.930\,05}$$

$$=\frac{1.592\times10^5}{(T_{1/2})_{232}}\;\frac{0.004\,372\,67+0.000\,000\,008\,1+0.000\,026\,60}{0.000\,099\,26+0.005\,206\,10+16.930\,05}$$

$$(T_{1/2})_{232}=\frac{1.592\times10^5\times0.004\,399\,2}{0.5999\times16.935\,35}$$

$$=68.937\text{ yr}\,.$$

V. RESULTS AND DISCUSSION

The half-life of ^{232}U determined by the specific activity method is 69.00 ± 0.40 yr. The error has been calculated by combining one standard deviation on the average value given in Table VI and the combined error listed in Table VII.

A value of 68.81 ± 0.38 yr is obtained for the half-life of ^{232}U by the relative activity method using the half-life of ^{233}U as 1.592×10^5 yr. The error given has been calculated by combining one standard deviation on the average value given in Table VI and the combined error listed in Table VII.

The various published values on the half-life of ^{232}U are given in Table VIII. The recommended value from the present work for the half-life of ^{232}U is 68.90 ± 0.39 yr. The values reported earlier are significantly higher as compared to the half-life value obtained in this work.

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