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Decay Analysis of Some Fission Product Nuclides with Medium Half-lives

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Abstract

The half-lives of 22 fission product nuclides were measured. Their decay curves were obtained by the β-ray countings with end-window type gas flow proportional counters, and were analyzed with a non-linear least squares fitting programme using the IBM-7044 computer. The resulting half-life values are listed with those previously reported.

中程度の長さの半減期をもつ核分裂生成核種の崩壊曲線の解析

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要　旨

22種類の核分裂生成核種の半減期を測定した．崩壊曲線は，ガスフロー型の比例計数管をもちいるβ線測定をおこなって得た．それらを，非線形曲線の最小二乗法によって，IBM-7044電子計算機をもちいて解析した．解析結果を，すでに報告されている半減期の値と共に表示した．

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1. Introduction

Nuclear fission phenomena supply many nuclides that are hardly produced by any other means. They can therefore be a powerful mean of the study of nuclear properties. In the course of a study of the proton-induced fission of ^{238}U, a large number of fission product nuclides with medium half-lives were repeatedly separated and their yields were determined by measuring their radioactivity. Their half-lives were then determined with good precision as well as their intensities in the process of a least squares analysis of the β-decay curves. The resulting half-lives are summarized for nuclides in this text.

2. Experimental

The purified U_3O_8 powder was used as the target material, in which the content of ^{238}U was 99.3%. The target assembly was irradiated with protons of energies ranging from 13 to 55 MeV and several products from the proton-induced fission of ^{238}U were chemically separated. Details of the target preparation[1], the irradiation conditions[2], and the chemical procedure[3] are to be described elsewhere.

An aliquot of the solution containing an isolated element was deposited on the Mylar film and evaporated to dryness. The number of runs for a given element, in which the decay analysis was carried out, was 5 to 32. Decay analysis was performed by the β-ray countings obtained on end-window type gas flow proportional counters. The resolving time of the β counters was 1.5 μ sec.

The counting rate was adjusted not to exceed 50,000 cpm even at the beginning. A counting loss correction was taken into account, though practically negligible throughout the range of β measurement used.

The β counters were operated with purified methane gas. Their plateaus were at least 300 V long and the slopes were about 1% per 100 V. The plateau and the counting efficiency were checked once for 24 hr with the standard sources ^{137}Cs and ^{90}Sr-^{90}Y, as long as the measurements were being continued. Fluctuations in counting rates for the standard sources were less than 0.5% per 24 hr in most cases. The β countings were continued until the longest half-life among the expected components certainly analyzed out of the decay curve whenever possible. In order to investigate the purity of the prepared sources, the γ spectrum was taken with a $3'' \times 3''\phi$ NaI (Tl) scintillator connected to a multichannel pulse height analyzer.

3. Results and Discussion

Because of the rather long time required for the separation, nuclides with half-lives shorter than one day had decayed out by the time of the measurement. With nuclides accompanying daughters of shorter half-lives, such as ^{72}Zn, ^{132}Te, ^{140}Ba, and ^{144}Ce, β countings were usually started after transient equilibrium had been attained. Obtained decay curves were analyzed with

a non-linear least squares fitting programme using the IBM-7044 electronic computer. Details of the analyses are described below for individual nuclides.

A typical decay curve is presented for each element, in which the origin of the abscissa is appropriately chosen. In the case where a nuclide of interest is a γ-ray emitting nuclide and is produced with a sufficient intensity, the γ spectrum is also shown and the time at which it was taken is indicated with an arrow in the decay curve.

^{72}Zn: This nuclide is hardly produced by any other means. As shown in **Fig. 1** the decay curve consists of two components, ^{72}Zn and ^{65}Zn, since a known amount of the latter was added to the initial solution to know the chemical yield of zinc. Zinc-72 accompanies the daughter activity ^{72}Ga ($t_{1/2}$=14.1 hr). The first data point in the decay curve of **Fig. 1** deviated from the linear decay of ^{72}Zn. This came about because the transient equilibrium between ^{72}Zn and ^{72}Ga had not been attained by the time. In **Fig. 2**, the γ spectrum is shown, in which photopeaks belonging to both ^{72}Zn and ^{72}Ga are observed.

In the least squares fitting of the decay curve, the half-life of ^{65}Zn was fixed to 245 d[4]. The results of the two-component analyses are summarized for 5 runs in **TABLE 1**.

^{86}Rb: The best method to produce this isotope is the (n, γ) reaction and therefore the importance of the present result of ^{86}Rb may not be so great as in the case of ^{72}Zn. Thirty-two runs were repeated to prepare ^{86}Rb and perform β countings. The decay curve in **Fig. 3** shows the source contained an unknown minor component and therefore it was analyzed by two-component fitting for 19 runs. The resulting values for the half-life is listed in **TABLE 2**. No detectable peaks were observed in the γ spectra of the sources because of the extremely low yield of ^{86}Rb.

^{89}Sr: Thirty-two runs were carried out for this nuclide. Since both ^{89}Sr and ^{90}Sr existed in the strontium samples, the β countings were continued for 14 months from 3 months after the separation. The decay curve is given in **Fig. 4**, that was analyzed by two-component fitting with the longer half-life (^{90}Sr) being fixed to infinite. **TABLE 3** gives the list of the obtained half-life values.

^{91}Y: Thirty-two runs were carried out. No component but ^{91}Y was observed in the decay curve **(Fig. 5)**. The linearity of the decay curve was retained until the counting rate reduced to less than one-hundredth of the initial value. Only 11 values were used for the determination of the half-life of ^{91}Y, which are summarized in **TABLE 4**.

^{99}Mo: Results of eleven runs were available for the half-life determination. From the decay curve (cf. **Fig. 6**) impurities amounting 0.25% of ^{99}Mo was found existing at the beginning of the β counting. The two-component analyses gave the minor component a half-life value of about 40 days, fluctuating from source to source within 20%. The γ spectra did not show any peaks belonging to the impurities **(Fig. 7)** and therefore they were not positively identified. Half-life values obtained for ^{99}Mo are given in **TABLE 5**, together with those assigned to the minor component.

^{112}Pd and ^{111}Ag: Palladium-112 is hardly produced by any other types of the nuclear reaction but fission. Results of ten runs were available for half-life determination. The activity in the palladium samples was due to ^{112}Pd and ^{111}Ag. The latter was the daughter nuclide of ^{111m}Pd (5.5 hr). Since β measurements were started about four days after the separation, ^{111m}Pd had already decayed out. The decay curve (cf. **Fig. 8**) was therefore fitted to a two-component curve. Only five out

of ten runs gave satisfactory half-life values of ^{111}Ag from the statistical consideration. Results are summarized in TABLE 6. The obtained half-life value of ^{112}Pd somewhat smaller than the reported values. This is likely due to the effect of the short-lived component ^{109}Pd (13.5 hr), though the dissolution of the decay curve into three components was not successful. The observed half-life values for ^{111}Ag is not quite reliable because of its low intensity. The γ spectrum shown in **Fig. 9** indicates the ^{112}Pd spectrum.

^{115g}Cd and ^{115m}Cd: Twenty-one runs were carried out. The decay curves of cadmium samples revealed the sign of impurities with long half-lives besides ^{115g}Cd and ^{115m}Cd, though the amounts were trivial, when the energy of the incident protons was high (cf. **Fig. 10**). The decay curve was, therefore, analyzed by three-component fitting in which the intensity of the trivial impurity was fixed to be constant. Results are given in TABLE 7. The weighted mean was computed with 14 values for ^{115m}Cd while all 21 values were used for ^{115g}Cd. The γ spectrum (**Fig. 11**) was nothing but that of ^{115m}Cd.

^{132}Te and ^{129m}Te: Twenty-two runs were carried out. Fission is a superior mean to the (n, γ) reaction in regard to the capability of supplying cleaner ^{132}Te and ^{129m}Te. Existence of ^{127m}Te is nevertheless inevitable. The β measurements were continued for 430 days after the irradiation. Even at the end, decay curves did not reveal the half-life of ^{127m}Te. The decay curve (**Fig. 12**) was analyzed by three-component fitting with the half-life of ^{127m}Te being fixed to 105 d[3]. The weighted means were computed with 20 values for ^{129m}Te and with only 7 values for ^{132}Te. Results are given in TABLE 8. Two γ spectra are shown in **Fig. 13**; one before and the other after ^{132}Te has decayed out.

^{136}Cs: Results of nine runs were available for the half-life determination. ^{136}Cs, ^{134}Cs and ^{137}Cs were included in the cesium sample. Beta countings were continued for about 160 days initiating 40 days after the irradiation. Activities of ^{134}Cs and ^{137}Cs were regarded as constant during the period and the decay curve was decomposed into two components (**Fig. 14**), the intensity of the constant component was found less than 1% of that of ^{136}Cs. Results are shown in TABLE 9. The γ spectrum, showing that of ^{136}Cs, is given by **Fig. 15**.

^{140}Ba–^{140}La: Thirty-two runs were performed. The decay measurements were started after the transient equilibrium had been reached between ^{140}Ba and ^{140}La. The resulting decay curve showed that of a clean one-component system until the counting rate reduced to at least one-thousandth of the initial counting rate as is shown in **Fig. 16**. Obtained half-life values are listed in TABLE 10 and the γ spectrum which is exactly that of the equilibrated ^{140}Ba–^{140}La system is given by **Fig. 17**.

^{141}Ce and ^{144}Ce: Twenty-one runs were carried out. Cerium sources were measured both with and without an aluminium absorber. As a result of the two-component analysis, the decay curve gave a somewhat longer value for the half-life of ^{144}Ce when measured without an absorber whereas the one with an absorber gave a reasonable half-life to ^{144}Ce (**Fig. 18**). Results are summarized in TABLE 11. Reliability of the assigned value for the half-life of ^{144}Ce is thought to be rather small. The γ spectrum of the sample is given by **Fig. 19**.

^{143}Pr: Twenty-one runs were carried out. The linearity of the ^{143}Pr decay curve was kept over three decades as is show in **Fig. 20**. The weighted mean was computed with 17 values. Results are presented in TABLE 12.

^{147}Nd: Twenty-one runs were carried out. ^{147}Nd decays to the daughter ^{147}Pm which has a fairly long half-life compared to the parent. The decay curve, therefore, consisted of two components (cf. **Fig. 21**), whose half-life values are listed in **TABLE 13**. The weighted mean was calculated with 18 values. The γ spectrum of ^{147}Nd is shown in **Fig. 22**.

^{149}Pm and ^{148}Pm: Twenty-one runs were performed. Because of their low yields, the promethium samples suffer from the coexistence of weak β-ray emitting nuclides such as ^{147}Pm or ^{151}Pm. Therefore, the β counting was carried out with an aluminium absorber of 77.60 mg/cm^2 thick to cut those weak β rays and to avoid the complexity in the decay-curve analysis. As a consequence of this, decay curves with a single component were obtained in the case of low energy fission (**Fig. 23**), while another component due to ^{148m}Pm began to appear at a few tens MeV of excitation and its intensity rapidly increased with increasing excitation. Nineteen values were used to calculate the weighted mean for the ^{149}Pm half-life, whereas only 6 values were available for ^{148m}Pm. Results are summarized in **TABLE 14**. The γ spectrum consisted of the peaks mostly of ^{151}Pm except the 286 keV photo-peak of ^{149}Pm as seen in **Fig. 24**.

^{153}Sm: Twenty-one runs were carried out. Samarium samples were found to contain an unknown impurity by an order of 0.01% of the initial intensity of ^{153}Sm, whose half-life was estimated to about 45 days. A typical decay curve of the samarium source and the results of the two-component analyses of the decay curves are given by **Fig. 25** and **TABLE 15**, respectively. **Figure 26** shows the γ spectrum of a samarium sample.

^{156}Eu: Thirty-two runs were carried out. It is expected that other europium isotopes with long half-lives, such as ^{155}Eu, ^{154}Eu, and ^{152}Eu, remain after ^{156}Eu has decayed out. The decay of the europium activity was followed over 400 days to find the tail of the decay curve after ^{156}Eu has disappeared being constant over 200 days. It follows that ^{154}Eu (16y) and ^{152}Eu (12y) were the main components rather than ^{155}Eu (1.81y), though the yields of the former nuclides were expected rather small because they are shielded nuclides. This is partly because the β rays of ^{155}Eu were greatly attenuated for their extreme weakness. The decay was therefore fitted to a two-component curve by fixing the longer half-life to infinity as shown in **Fig. 27**. The resulting half-life values of ^{156}Eu are listed in **TABLE 16**. The weighted mean was calculated with 26 values. The γ spectrum observed with a europium source is displayed in **Fig. 28**, that is practically the spectrum of ^{156}Eu.

^{161}Tb and ^{160}Tb: The total chain yields of mass numbers 160 and 161 are very small in the proton induced fission of ^{238}U. Moreover, ^{160}Tb is a shielded nuclide, whose yield is too small to be found in the low energy fission. Decay curves in only nine out of thirty-two runs were, therefore, analyzed by the two-component fitting, whereas the rest were analyzed as the one-component, ^{161}Tb, decay. **Figure 29** represents one of the two-component decay curves. Obtained halflife values are summarized in **TABLES 17**. The weighted mean for the ^{161}Tb half-life was obtained with 28 values, while the ^{160}Tb half-life was calculated using 9 values.

In summary, the average value found for the above each element is listed in **TABLE 18**, together with values previously reported. Quoted errors in the presently observed half-lives are the greater of either

$$\sigma=\left\{\sum_i\frac{(t_i-\bar{t})^2}{\sigma_i^2}\Big/\sum_j\frac{1}{\sigma_j^2}(n-1)\right\}^{1/2}$$

or

$$\sigma=\left(\sum_i \frac{1}{\sigma_i^2}\right)^{-1/2}$$

where t_i and σ_i are the ith observed half-life and its standard deviation, and $\bar{t}$ is the weighted mean of the n values of t_i. The half-lives we have given in TABLE 18 are quite reasonable compared to the reported values, and are considered to be of great reliability because of a large number of repeated runs, the long counting-duration and the small associated error, except those assigned to ^{132}Te, ^{144}Ce and ^{160}Tb.

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Tables

TABLE 1 Observed half-life values of ^{72}Zn. The half-life of ^{65}Zn was fixed to 245d.

Run No.	Half-life
403	46.66±0.30 hr
404	46.55±0.25
405	46.77±0.43
406	46.32±0.29
408	46.96±0.43
Average	46.59±0.14 hr

TABLE 2 Observed half-life values of ^{86}Rb.

Run No.	Half-life	Run No.	Half-life
202	18.37 ±0.12 d	401	18.42 ±0.29 d
204	18.50 ±0.58	403	18.54 ±0.24
301	18.64 ±0.12	404	18.92 ±0.34
302	18.663±0.084	405	18.28 ±0.28
303	18.607±0.081	406	18.51 ±0.47
304	18.828±0.096	407	18.27 ±0.35
305	18.63 ±0.12	408	18.24 ±0.48
306	18.64 ±0.15	409	18.39 ±0.86
307	18.47 ±0.14		
309	18.52 ±0.29	Average	18.613±0.035 d
310	18.38 ±0.47		

TABLE 3 Observed half-life values of ^{89}Sr. Activity of the long component, ^{90}Sr, was set constant during the measurement.

Run No.	Half-life	Run No.	Half-life
201	50.85±0.31 d	308	50.09±0.21 d
202	51.02±0.24	309	49.62±0.25
203	51.19±0.22	310	50.38±0.43
204	51.27±0.35	311	49.95±0.44
205	51.12±0.30	401	50.69±0.49
206	51.13±0.35	402	51.01±0.35
207	51.13±0.25	403	50.63±0.35
208	51.05±0.26	404	50.67±0.27
209	51.05±0.29	405	50.62±0.35
210	51.03±0.46	406	51.17±0.48
301	49.86±0.24	407	51.66±0.48
302	50.11±0.33	408	50.26±0.87
303	50.10±0.21	409	51.08±0.45
304	49.97±0.19	410	51.00±0.44
305	50.13±0.23	411	50.96±0.52
306	50.37±0.19		
307	50.42±0.29	Average	50.55±0.09 d

TABLE 4 Observed half-life values of ^{91}Y.

Run No.	Half-life	Run No.	Half-life
206	58.68±0.24 d	307	58.53 ±0.16 d
301	58.48±0.16	308	58.40 ±0.16
302	58.44±0.21	309	58.57 ±0.20
303	58.54±0.16	310	58.63 ±0.18
304	58.52±0.22	311	58.47 ±0.21
305	58.31±0.27	Average	58.509±0.057 d

TABLE 5 Observed half-life values of ^{99}Mo.

Run No.	Half-life	Run No.	Half-life
401	66.91±0.76 hr	407	66.14±0.39 hr
402	67.19±0.35	408	66.80±0.62
403	65.61±0.32	409	66.40±0.32
404	66.67±0.28	410	66.07±0.31
405	66.35±0.30	411	66.86±0.22
406	66.35±0.28	Average	66.47±0.13 hr

TABLE 6 Observed half-life values of ^{112}Pd and ^{111}Ag.

Run No.	Half-lives	
	^{112}Pd	^{111}Ag
401	20.19 ±0.14 hr	7.21 ±0.22 d
402	20.17 ±0.15	
403	20.10 ±0.18	7.25 ±0.17
404	20.14 ±0.36	7.30 ±0.24
405	20.16 ±0.20	7.43 ±0.12
406	20.7 ±2.1	7.55 ±0.28
407	20.34 ±0.13	
408	19.49 ±0.94	
409	19.75 ±0.14	
411	19.3 ±0.89	
Average	20.116±0.061 hr	7.356±0.080 d

TABLE 7 Observed half-life values of ^{115g}Cd and ^{115m}Cd.

Run No.	Half-lives	
	^{115g}Cd	^{115m}Cd
201	53.40 ±0.09 hr	44.76±0.49 d
202	53.21 ±0.26	43.87±0.99
203	53.18 ±0.17	43.65±0.92
204	53.35 ±0.15	45.26±0.85
205	53.33 ±0.13	45.64±0.70
206	53.42 ±0.23	
207	53.31 ±0.20	
208	53.25 ±0.18	45.1 ±1.1
209	53.57 ±0.14	45.5 ±1.0
210	53.48 ±0.33	
301	53.45 ±0.24	45.0 ±1.1
302	53.57 ±0.23	44.4 ±1.1
303	53.11 ±0.38	45.1 ±2.2
304	53.41 ±0.23	44.4 ±1.3
305	53.54 ±0.24	44.3 ±1.7
306	53.74 ±0.26	44.4 ±2.0
307	53.36 ±0.22	44.3 ±1.1
308	54.10 ±0.48	
309	53.23 ±0.26	
310	53.76 ±0.67	
311	52.87 ±0.26	
Average	53.379±0.042 hr	44.79±0.25 d

TABLE 8 Observed half-life values of ^{132}Te and ^{129m}Te. The half-life of ^{127m}Te was fixed to 105d.

Run No.	Half-lives	
	^{132}Te	^{129m}Te
301		33.18±0.22 d
302		33.76±0.32
303		32.71±0.34
304		33.09±0.23
305		33.19±0.32
306	79.7 ±1.2 hr	33.03±0.28
307	78.7 ±1.5	33.11±0.38
308		33.45±0.31
309	78.80±0.79	33.23±0.30
311	79.8 ±1.4	33.04±0.49
401	79.5 ±6.0	34.36±0.63
402		34.26±0.38
403		33.93±0.37
404		34.32±0.41
405		34.23±0.52
406		34.51±0.50
407		34.09±0.46
408		34.26±0.28
410	77.9 ±1.2	33.95±0.41
411	78.1 ±1.2	33.94±0.48
Average	78.80±0.46 hr	33.52±0.12 d

TABLE 9 Observed half-life values of ^{136}Cs. Activity of the long component, ^{137}Cs, was set constant.

Run No.	Half-life	Run No.	Half-life
401	13.025±0.062 d	408	12.943±0.045 d
403	13.116±0.078	409	13.017±0.075
404	12.953±0.054	410	12.979±0.087
405+406	13.025±0.050	411	13.05 ±0.31
407	12.981±0.083		
		Average	12.995±0.022 d

TABLE 10 Observed half-life values of ^{140}Ba.

Run No.	Half-life	Run No.	Half-life
201	12.790±0.059 d	308	12.769±0.036 d
202	12.784±0.044	309	12.773±0.054
203	12.767±0.051	310	12.779±0.033
204	12.786±0.053	311	12.754±0.025
205	12.848±0.045	401	12.851±0.049
206	12.913±0.047	402	12.842±0.046
207	12.784±0.049	403	12.835±0.034
208	12.815±0.036	404	12.812±0.051
209	12.794±0.039	405	12.814±0.035
210	12.761±0.037	406	12.851±0.040
301	12.769±0.015	407	12.817±0.041
302	12.780±0.029	408	12.821±0.040
303	12.750±0.027	409	12.819±0.034
304	12.768±0.018	410	12.827±0.042
305	12.784±0.029	411	12.848±0.039
306	12.785±0.028		
307	12.764±0.030	Average	12.789±0.006 d

TABLE 11 Observed half-life values of ^{141}Ce and ^{144}Ce. Two sets of data are given for the ^{144}Ce half-life, one without and the other with an aluminium absorber of 25.03 mg/cm² thick.

Run No.	Half-lives		
	^{141}Ce	^{144}Ce	^{144}Ce with Al
201	32.40±0.56 d	308±15 d	
202	33.33±0.51	308±14	
203	32.94±0.70	305±17	
204	33.27±0.51	307±13	
205	33.8 ±1.1	322±33	
206	32.87±0.41	306±11	
207	32.23±0.65	304±18	
208	32.74±0.42	303±11	
209	32.91±0.64	305±12	
210	33.02±0.58	299±15	
301	32.15±0.75	301±16	287.1±9.1 d
302	32.21±0.55	313±14	289.4±6.0
303	32.37±0.59	312±15	304.6±9.4
304	32.52±0.56	319±15	287.1±6.4
305	31.70±0.78	287±19	279.9±9.1
306	32.19±0.45	289±5	302 ±18
307	31.99±0.73	299±15	271 ±10
308	31.79±0.63	292±13	297 ±13
309	32.49±0.75	304±16	289 ±12
310	31.83±0.69	300±14	288.3±7.1
311	32.48±0.70	306±15	288 ±47
Average	32.57±0.13 d	300±3 d	288.0±2.7 d

TABLE 12 Observed half-life values of ^{143}Pr.

Run No.	Half-life	Run No.	Half-life
201	13.549±0.067 d	301	13.545±0.098 d
202	13.551±0.067	302	13.523±0.096
203	13.589±0.063	303	13.540±0.089
204	13.533±0.072	305	13.58 ±0.12
205	13.607±0.056	306	13.573±0.082
206	13.588±0.064	307	13.54 ±0.10
208	13.562±0.047	309	13.536±0.097
209	13.592±0.049	311	13.53 ±0.14
210	13.519±0.076		
		Average	13.565±0.017 d

TABLE 13 Observed half-life values of ^{147}Nd.

Run No.	Half-life	Run No.	Half-life
201	11.042±0.055 d	304	10.972±0.038 d
202	11.049±0.048	305	10.944±0.032
203	10.998±0.073	306	10.900±0.045
204	10.96 ±0.19	307	11.066±0.046
205	11.041±0.074	308	11.021±0.028
207	10.960±0.100	309	11.007±0.044
209	11.058±0.056	310	10.919±0.046
301	10.971±0.026	311	11.005±0.076
302	10.986±0.046		
303	10.952±0.039	Average	10.980±0.010 d

TABLE 14 Observed half-life values of ^{149}Pm and ^{148}Pm, measured with an aluminium absorber of 77.60 mg/cm^2 thick.

Run No.	Half-lives	
	^{149}Pm	^{148}Pm
301	52.87±0.72 hr	39.9±1.5 d
302		42.3±1.1
303		41.8±2.6
304	52.61±0.50	39.0±4.3
305	52.92±0.43	
306	52.75±0.36	
307	53.45±0.22	42 ±11
308	53.06±0.53	
309	53.21±0.34	
310	52.80±0.31	
311	52.06±0.72	
401	53.52±0.53	
402	52.7 ±1.0	39.3±5.3
403	53.09±0.53	
404	53.35±0.46	
405	53.88±0.29	
406	52.99±0.38	
407	52.99±0.74	
408	52.87±0.70	
409	52.70±0.48	
410	51.94±0.41	
Average	53.08±0.11 hr	41.4±0.8 d

TABLE 15 Observed half-life values of ^{153}Sm.

Run No.	Half-life	Run No.	Half-life
201	46.37 ±0.11 hr	302	46.12 ±0.21 hr
202	46.81 ±0.14	303	46.53 ±0.20
203	46.418±0.088	304	46.51 ±0.30
204	46.07 ±0.35	305	46.38 ±0.21
205	46.493±0.081	306	46.35 ±0.20
206	46.26 ±0.21	307	46.35 ±0.12
207	46.57 ±0.23	308	46.79 ±0.24
208	46.52 ±0.25	309	46.36 ±0.17
209	46.27 ±0.14	310	46.53 ±0.16
210	46.40 ±0.36	311	46.06 ±0.23
301	46.79 ±0.22		
		Average	46.439±0.078 hr

TABLE 16 Observed half-life values of ^{156}Eu.

Run No.	Half-life	Run No.	Half-life
201	15.239±0.082	310	14.96 ±0.12 d
202	15.270±0.081	401	15.24 ±0.12
203	15.216±0.050	402	15.08 ±0.15
205	15.21 ±0.14	403	15.03 ±0.14
206	15.478±0.081	404	15.261±0.097
209	15.17 ±0.24	405	15.158±0.085
210	15.41 ±0.20	406	15.176±0.060
301	15.02 ±0.13	407	15.054±0.054
302	14.98 ±0.22	408	15.259±0.057
303	14.92 ±0.19	409	15.12 ±0.11
304	15.12 ±0.12	410	15.073±0.080
306	15.09 ±0.12	411	15.25 ±0.12
307	14.917±0.099		
308	15.04 ±0.12	Average	15.169±0.024 d

TABLE 17 Observed half-life values of ^{161}Tb and ^{160}Tb.

Run No.	Half-lives	
	^{161}Tb	^{160}Tb
201	6.80 ±0.14 d	
202	6.82 ±0.12	
203	7.02 ±0.18	
204	6.789±0.092	
205	7.19 ±0.15	
206	6.795±0.094	
207	7.17 ±0.43	
208	6.76 ±0.13	
209	6.89 ±0.18	
301	6.95 ±0.13	72.8±1.6 d
302	6.94 ±0.11	75.5±1.8
303	6.974±0.080	
304	6.911±0.081	74.9±3.5
305	6.951±0.048	
306	6.948±0.050	
307	6.972±0.061	
308	6.964±0.057	
309	6.847±0.041	
310	7.046±0.038	
311	7.022±0.060	
401	6.57 ±0.10	
402	6.75 ±0.13	70.6±3.7
403	6.51 ±0.13	
404	6.630±0.098 d	73.6±6.3 d
405	6.61 ±0.11	69 ±11
406	6.50 ±0.12	
409	6.776±0.086	70.1±9.6
410		70 ±15
411	6.75 ±0.22	76 ±12
Average	6.903±0.019 d	73.5±1.1 d

TABLE 18 Half-lives of some fission product nuclides.

Nuclide	Half-life	Occurence	Counting duration	Detector	Chemical treatment	Computer analysis	No. of runs	Reference
^{72}Zn	49 hr	Bi, Pb(d, f); 190MeV-d		GM	CS, ppt	no		6
	50 hr	^{75}As+d(150MeV)		GM	CS	no		7
	(49±1) hr	^{235}U(n, f)	28 d	GM	ppt	no		8
	(46.5±0.1) hr	^{232}Th(p, f)		NaIW	SE, ppt	no		9
	36.5 hr	Ge(γ, α)		NaI	IE	no		10
	(46.5±0.1) hr	Th(p, f)	~30 d	NaI	IE	no		11
	(46.6±0.2) hr	^{238}U(p, f)	60 d	PR	IE, DP	yes	5	present work
^{86}Rb	(18±1) d	Rb(n, γ)		IC	ppt	no		12
	(19.5±1.0) d	Sr(d, α)	$4t_{1/2}$	IC	no	no		13
	19.5 d	Rb(n, γ)		GM	no	no		14
	(18.64±0.04) d	f.p.	$9t_{1/2}$	β	IE, ppt	no	8	15
	(18.66±0.03) d	Rb(n, γ)	79 d	$4\pi\beta$	RC	no		16
	(18.68±0.07) d	Rb(n, γ)	$5t_{1/2}$	GM	PF	no		17
	(18.7±0.5) d	Rb(n, γ)	150 d	$4\pi\beta$-SC	no	no		18
	(18.61±0.04) d	^{238}U(p, f)	$12t_{1/2}$	PR	IE, DP	yes	19	present work
^{89}Sr	54 d							19
	(55±5) d	Sr(d, p), Sr(n, γ)		IC	ppt	no		20
	54.5 d							21
	55 d	Sr(n, γ)		GM	no	no		14
	55 d	Bi, Pb(d, f); 190MeV-d		GM	ppt	no		6
	53 d	^{235}U(n, f)	600 d	GM	CS	no		22
	54 d	U(p, f); 340MeV-p		GM	ppt	no		23
	(50.5±0.2) d	U(n_{th}, f)	350 d	β	ppt	no		24
	(51±1) d	U(p, f); 170MeV-p	$4t_{1/2}$	β	CS	no	17	25
	(50.36±0.18) d	^{88}Sr(n, γ), ER	310 d	$4\pi\beta$	ppt	yes		26
	(53.6±0.4) d	^{88}Sr(n, γ), ER		GM	no	no		27
	50 d	^{239}Pu(n_{th}, f)		$4\pi\beta$-PR	CS	no		28
	(52.7±0.5) d		377 d	$2\pi\beta$-PR	PF	yes		29
	(50.55±0.09) d	^{238}U(p, f)	600 d	PR	IE, DP	yes	32	present work
^{91}Y	57 d							30
	57 d							31
	57 d							32
	61 d							21
	57 d	Bi, Pb(d, f); 190MeV-d		GM	ppt	no		6
	57 d	U(n, f)	28 d	GM	CS	no		33
	(61±1) d			NaI, PS		no		34
	(58.5±1.0) d	f.p., supplied by ORNL	60 d	NaI, PS	PF	no		35
	(58.3±0.8) d	U(n, f)		SC	IE, ppt	no		36
	(59.1±0.2) d	f.p.	$2t_{1/2}$	$2\pi\beta$-PR	CS	yes		37
	(58.8±0.2) d	U(n_{th}, f)	389 d	PR	IE	yes		38
	59 d	^{239}Pu(n_{th}, f)		$4\pi\beta$-PR	CS	no		28
	~58.5 d	supplied by ORNL		NaI		no		39
	(58.51±0.06) d	^{238}U(p, f)	$7t_{1/2}$	PR	IE, DP	yes	11	present work

Nuclide	Half-life	Occurence	Counting duration	Detector	Chemical treatment	Computer analysis	No. of runs	Reference
^{99}Mo	(67±2) hr	Mo(n, γ)	30 d	IC	ppt	no		40
	(64±1) hr	Mo(n, γ)			CS	no		41
	67 hr	Mo(n, γ)		GM	no	no		14
	63.5 hr	^{100}Mo(γ, n)						42
	68.3 hr	Mo(n, γ)			no	no		43
	67 hr	Bi, Pb(d, f); 190MeV-d		GM	ppt	no		6
	67 hr	U(p, f); 340MeV-p		GM	ppt	no		23
	(66.00±0.15) hr	U(n, f), Mo(n, γ)	$>3t_{1/2}$	PR	CS	no		44
	(66.96±0.09) hr	Mo(n, γ)	$5.4t_{1/2}$	IC	CS	no		17
	(67.2±0.2) hr	^{235}U, ^{238}U, ^{239}Pu (n, f); 14.6MeV-n		β	CS	no		45
	68.3 hr	^{232}Th(γ, f); 10MeV-γ	several $t_{1/2}$	β	ppt	no		46
	66.1 hr	Mo(n, γ)		PR	PF			47
	68.2 hr	^{239}Pu(n, f)	$6t_{1/2}$	$4\pi\beta$-PR	CS	no		28
	(66.7±0.1) hr	^{98}Mo(n, γ), ER	32 d	NaIW	CS	yes		48
	(66.69±0.06) hr	U(n, f), Mo(n, γ)	$3—5t_{1/2}$	$4\pi\gamma$-IC	CS	yes		49
	(66.5±0.2) hr	^{238}U(p, f)	90 d	PR	IE, DP	yes	11	present work
^{111}Ag	~7.5 d	Pd(d, n)	21 d	IC	CS, ppt	no		50
	7.5 d	Pd(d, p), (d, n), Cd(n, p)		IC	CS, ppt	no		51
	7.5 d	U(n, f); fast n			CS, ppt	no		52
	7.5 d	Cd(n, p)				no		53
	7.5 d	Bi, Pb(d, f); 190MeV-p		GM	CS, ppt	no		6
	7.6 d	Cd(γ, p)			CS	no		54
	7.5 d	Pd(n, γ)$\xrightarrow{\beta}$	42 d	NaI	ppt	no		55
	7.5 d	Sb(d, sp); 100MeV-d		GM	ppt	no		56
	(7.50±0.13) d	Pd(n, γ)$\xrightarrow{\beta}$	~42 d			no		57
	7.6 d	f.p.	~90 d	β	CS	no		58
	7.6 d	Pd(n, γ)$\xrightarrow{\beta}$	$3t_{1/2}$		IE, CF	no		59
	(7.36±0.08) d	^{238}U(p, f)	34 d	PR	IE, ppt	yes	5	present work
^{112}Pd	21 hr	f.p.	7 d	GM	ppt	no		60
	21 hr	U(p, f); 340MeV-p		GM	ppt	no		23
	(21.0±0.5) hr	Th(d, f); 25MeV-d		NaI	CS	no		61
	21 hr	^{239}Pu(n_{th}, f)		$4\pi\beta$-PR	CS	no		28
	(20.12±0.06) hr	^{238}U(p, f)	$12t_{1/2}$	PR	IE, ppt	yes	10	present work
^{115}Cd	56 hr	Cd(d, p)		IC	CS	no		62
	67 hr	Cd(n, γ)		GM	no	no		14
	(57.5±2.0) hr	^{116}Cd(γ, n)		β		no		63
	55.2 hr	Bi, Pb(d, f); 190MeV-d		GM	ppt	no		6
	55.9 hr	U(n_{th}, f)	$5t_{1/2}$	GM	CS	no		64
	(53±1) hr	Cd(n, γ), (γ, n), ^{235}U(n, f); thermal and 14MeV-n	two decades	PR	CS	no		65

Nuclide	Half-life	Occurence	Counting duration	Detector	Chemical treatment	Computer analysis	No. of runs	Reference
^{115}Cd	53 hr	U(p, f); 340MeV-p		GM	ppt	no		23
	53 hr	^{232}Th(γ, f); 10MeV-γ	several $t_{1/2}$	β	ppt	no		46
	(53.5±0.1) hr	Cd(n, γ)	$5t_{1/2}$	$4\pi\gamma$-IC	no	yes		37
	(53.8±1.8) hr	^{114}Cd(n, γ)		β-SP		no		66
	(53.38±0.04) hr	^{238}U(p, f)	complete	PR	IE, DP	yes	21	present work
^{115m}Cd	(43±3) d	^{114}Cd(n, γ)	150 d	GM	CS	no	4	67
	43 d	^{114}Cd(n, γ)		GM	no	no		14
	43 d	Bi, Pb(d, f); 190MeV-p		GM	ppt	no		6
	42.6 d	^{114}Cd(n, γ)	90 d			no		68
	(44±1) d	^{239}Pu(n, f)	$8t_{1/2}$	GM	CS	no		69
	43 d	Cd(n, γ), (γ, n), (n, f)	$<t_{1/2}$	PR	CS	no		70
	43 d	U(p, f); 340MeV-p		GM	ppt	no		23
	(44.2±0.5) d	^{235}U(n, f)	7y	PR	CS	no		71
	(44.8±0.3) d	^{238}U(p, f)	450 d	PR	IE, DP	yes	14	present work
^{129m}Te	(32±2) d	Te(d, p), (n, γ), (n, 2n), (γ, n)	230 d	IC, GM	CS	no	2 each	72
	35.5 d	^{128}Te(n, γ)				no		42
	30 d	Sb(d, n)			CS	no		73
	32 d	^{235}U(n_{th}, f)			CS	no		74
	33.5 d	^{128}Te(n, γ), ER	300 d			no		75
	41 d	^{128}Te(d, p), ER		β	ppt	no		76
	(33±1) d	^{128}Te(n, γ), ER	short	β	ppt	no		77
	33 d	^{239}Pu(n, f)		$4\pi\beta$-PR	CS	no		28
	(34.1±0.2) d	(p, f); 19GeV-p		NaI, β	CS, MS			78
	(33.52±0.12) d	^{238}U(p, f)	400 d	PR	IE, DP	yes	20	present work
^{132}Te	77 hr	U(n, f); 14MeV-n	one decade	IC	ppt	no		79
	77.7 hr	^{235}U(n_{th}, f)			CS	no		74
	(75±3) hr	f.p.	4 points	MS		no		80
	(77±5) d	U(n, f)		NaI	ppt	no		81
	78.5 d	^{239}Pu(n_{th}, f)		$4\pi\beta$-PR	CS	no		28
	(78.2±0.8) hr	(p, f); 600MeV- and 19GeV-p		NaI, β	CS, MS			78
	(78.8±0.5) hr	^{238}U(p, f)	complete	PR	IE, DP	yes	7	present work
^{136}Cs	(13±2) d	U(n_{th}, f)	4—5$t_{1/2}$	GM	CS	no		82
	12.9 d	U(d, f); 190MeV-d	$6t_{1/2}$	GM	CS, MS	no		83
	13 d	U(p, f); 340MeV-p		GM	ppt	no		23
	(13.5±0.5) d	^{136}Ba(n, p); 340MeV-p	complete	PR	CS	no		84
	(12.9±0.3) d	^{138}Ba(d, α)		NaI	IE	no	8	85
	(13.00±0.02) d	^{238}U(p, f)	250 d	PR	IE, DP	yes	9	present work
^{140}Ba	12.5 d	U(n_{th}, f)		β-SP		no		86
	(12.8±0.05) d	^{239}Pu(n_{th}, f)	$12t_{1/2}$	GM	CS	no	2	87

Nuclide	Half-life	Occurence	Counting duration	Detector	Chemical treatment	Computer analysis	No. of runs	Reference
^{140}Ba	13.4 d	U(n_{th}, f)		PHSP	CS	no		88
	12.8 d	U(p, f); 340MeV-p		GM	ppt	no		23
	12.8 d	^{232}Th(γ, f); 10MeV-γ	several $t_{1/2}$	β	ppt	no		46
	(12.789±0.006) d	^{238}U(p, f)	four decades	PR	IE, DP	yes	32	present work
^{141}Ce	30 d	^{138}Ba(α, n), ^{140}Ce(d, p), ^{142}Ce(n, 2n), ^{141}Pr(n, p), ^{140}Ce(n, γ)			no	no		89
	(30.6±0.7) d	Ce+d, Ce+n, Ba+α	~500 d	IC	CS	no		90
	30 d	Bi, Pb(d, f); 190MeV-d		GM	ppt	no		6
	28 d	supplied by ORNL		β-SP				91
	(33.11±0.23) d	Ce(n, γ)	403 d	GM	no	no		92
	(32.5±0.2) d	Ce(n, γ)	$7t_{1/2}$	IC	CS	no		93
	29 d	U(p, f); 660MeV-p		β	IE, ppt	no		94
	(32±2) d	^{142}Ce(n, 2n), ^{141}Pr(n, p)	complete	PR	CS	no		84
	(32.6±0.2) d	^{238}U(p, f)	600 d	PR	IE, DP	yes	21	present work
^{144}Ce	(232±3) d	f.p.	$2t_{1/2}$	PR	CS	no		95
	275 d	f.p.	660 d	GM	CS			96
	295 d		70 d	β-SP		no		97
	(284.4±1) d		180 d	IC		no		98
	275 d	U(p, f); 340MeV-p	180 d	GM	ppt	no		23
	(284.5±1.0) d	f.p.	$8t_{1/2}$	PR	CS	no		99
	(285±2) d	f.p.	4y	$4\pi\beta$-PR	CS	no		100
	(277±4) d		$0.1t_{1/2}$	IC		no		101
	(283.8±0.6) d		1300 d	$2\pi\beta$-PR	PF	yes		29
	(287.5±3.5) d		48 hr	IC		no		102
	(284.9±0.8) d	U(n, f)	$3.1t_{1/2}$	PR	CS	yes		49
	(284.8±1.0) d	f.p.		IC, $4\pi\beta$, NaI	CS			103
	(288±3) d	^{238}U(p, f)	600 d	PR	IE, DP	yes	11	present work
^{143}Pr	13.5 d	^{142}Ce(d, p), (n, γ)$\xrightarrow{\beta}$			no	no		89
	(13.5±0.1) d	Ce+d	130 d	IC	CS	no		90
	(13.7±0.1) d	supplied by ORNL	70 d	GM		no		104
	13.8 d	f.p.	$8t_{1/2}$	β	IE	no		105
	13.5 d	U(p, f); 340MeV-p		GM	ppt	no		23
	13.6 d	Ce(n, γ)$\xrightarrow{\beta}$	$3t_{1/2}$	$4\pi\beta$	ppt	no		106
	13.95 d	^{142}Ce(n, γ)$\xrightarrow{\beta}$, ER	32 d	IC	no	no		107
	(13.59±0.04) d	Pr(n, γ)		PR	SE	no		108
	(13.76±0.05) d	U(p, f)	$2.2t_{1/2}$	GM	CS	no		17
	13.5 d	U(p, f); 660MeV-p		β	IE, ppt	no		94
	(11.14±0.06) d	f.p.	~$10t_{1/2}$	GM	IE, ppt	no	7	109
	(13.59±0.10) d	U(n, f)	118 d	PR	IE	yes		38
	(13.55±0.02) d	U(n, f)	$10t_{1/2}$	PR	SE	yes		110
	(13.57±0.02) d	^{238}U(p, f)	three decades	PR	IE, DP	yes	17	present work

Nuclide	Half-life	Occurence	Counting duration	Detector	Chemical treatment	Computer analysis	No. of runs	Reference
^{147}Nd	10 d	Nd+d, p, n			CS	no		111
	11 d	f.p.		GM	IE	no		112
	11.8 d	Nd(n, γ)		GM, PR	no			113
	(11.0±0.3) d	f.p.	$7t_{1/2}$	β	IE	no		114
	(11.6±0.3) d	Nd(n, γ)	several $t_{1/2}$	β-SP	no	no		115
	(11.1±0.5) d	Nd(n, γ)	$5t_{1/2}$	β-Sp $\bar{c}$ GM	no	no		116
	(11.9±0.3) d	Nd(n, γ)		PHSP	no	no		117
	(11.6±0.3) d	Nd(n, γ)	60 d		no	no		118
	11 d	U(d, f); 340MeV-d	$3t_{1/2}$	GM	ppt	no		23
	(11.06±0.04) d	U(n, f)	$6.3t_{1/2}$	IC	CS	no		17
	11.1 d							119
	10.5 d	U(p, f); 660MeV-p		β	IE, ppt	no		94
	(11.5±0.5) d	^{148}Nd(n, 2n)	complete	PR	CS	no	2	84
	(11.02±0.05) d	U(n, f)	239 d	PR	IE	yes		38
	(10.98±0.01) d	^{238}U(p, f)	450 d	PR	IE, DP	yes	18	present work
^{148m}Pm	(42±1) d	^{148}Nd(p, n), ER; 8.9MeV-p			CS	no		120
	48 d	^{148}Nd(p, n), ER; 6MeV-p		GM, IC	CS	no		121
	43 d	^{238}U(p, f); 370MeV-p		GM	ppt	no		23
	(45.8±2.9) d	^{148}Nd(p, n), ER; 12MeV-p	70 d	GM	IE	no		122
	(41.8±0.2) d	^{147}Pm(f.p.) (n, γ)	250 d	IC, PR, NaI	IE	no		123
	(45.5±0.5) d	^{148}Nd(p, n), ER		GM ($\bar{c}$ AB)		no		124
	(40.6±0.4) d	^{147}Pm(f.p.) (n, γ)	400 d	PR $\bar{c}$ AB	IE, ppt	no	3	125
	(41.4±0.8) d	^{238}U(p, f)	200 d	PR $\bar{c}$ AB	IE, DP	yes	6	present work
^{149}Pm	55 hr	f.p.	57.3 hr		CS, MS	no		126
	(47±1) hr	Nd(n, γ)$\xrightarrow{\beta}$	28 d	GM	IE	no		127
	(48±3) hr	Nd(n, γ)$\xrightarrow{\beta}$	several $t_{1/2}$	β-SP	no	no		115
	(50±3) hr	Nd(n, γ)$\xrightarrow{\beta}$	300 hr		no	no		118
	(54.4±1.1) hr	^{150}Nd(p, 2n), ER			IE	no		120
	47 hr	U(p, f); 340MeV-p		GM	ppt	no		23
	54 hr	U(p, f); 660MeV-p		β	IE, ppt	no		94
	(53.09±0.09) hr	^{148}Nd(n, γ)$\xrightarrow{\beta}$, ER	58 d	PR, $4\pi\beta$	IE	no	4+2	128
	(52.8±0.3) hr	^{148}Nd(n, γ)$\xrightarrow{\beta}$, ER	4 d	β-SP	no	no		129
	(53.07±0.10) hr	U(n, f)	64 d	PR	IE	yes		38
	(53.08±0.10) hr	^{148}Nd(n, γ)$\xrightarrow{\beta}$	5 d	$4\pi\beta$-PR	IE	no		130
	(53.08±0.11) hr	^{238}U(p, f)	four decades	PR	IE, DP	yes	19	present work
^{153}Sm	47 hr	Sm+d, p, n			CS	no		111
	(47±1) hr	Sm+d, n			no	no		131
	46 hr	Sm(n, γ)		β-SP	no	no		132
	46 hr	Sm(n, γ)		GM	no	no		14
	47 hr	^{235}U, ^{239}Pu(n, f)	13 d	GM	CS	no		133
	(46.5±1) hr	Sm(n, γ)		PHSP	no	no		117

Nuclide	Half-life	Occurence	Counting duration	Detector	Chemical treatment	Computer analysis	No. of runs	Reference
^{153}Sm	(47.0±0.3) hr	^{152}Sm(n, γ), ER	7 d	β-SP	no	no		134
	47 hr	U(p, f); 340MeV-p		GM	ppt	no		23
	(47.1±0.1) hr	^{152}Sm(n, γ), ER	$7t_{1/2}$	β-SP, NaI	no	no	4	119
	(45±3) hr	^{154}Sm(n, 2n), etc.	150min	PR	no	no		135
	48 hr	U(p, f); 660MeV-p		β	IE, ppt	no		94
	(46.7±1.6) hr							136
	(45±8) hr	^{154}Sm(n, 2n)	complete	PR	CS	no		84
	(46.16±0.09) hr	^{152}Sm(n, γ), ER	240 hr	NaI	no	yes	4	137
	(47.1±0.1) hr	^{152}Sm(n, γ), ER	$9t_{1/2}$	4πβ-PR	CS	no		138
	(46.5±0.5) hr	U(n, f)	96 d	PR	IE	yes		38
	(46.8±0.1) hr	Sm(n, γ)	$2.1t_{1/2}$	GM	no	yes		49
	(46.44±0.08) hr	^{238}U(p, f)	four decades	PR	IE, DP	yes	21	present work
^{156}Eu	15.4 d	^{155}Eu(n, γ)	15.8 d (4pt.)	PP	MS	no		139
	15.4 d	f.p.	100 d	GM c̄ AB	CS	no		140
	(14±1) d	^{155}Eu(n, γ)		β-SP	no	no		141
	15.4 d	U(p, f); 340MeV-p		GM	ppt	no		23
	14.6 d	U(p, f); 660MeV-p		β	IE, ppt	no		94
	(15.18±0.10) d	^{156}Gd(d, n)	75 d	PR	CS	yes		142
	(15.21±0.24) d							143
	(15.11±0.05) d	U(n, f), ^{158}Gd+d, ER, ^{160}Gd+d, ER; 14MeV-d	630 d	PR	CS	yes		144
	(15.17±0.03) d	^{238}U(p, f)	400 d	PR	IE, DP	yes	26	present work
^{160}Tb	72 d	Sm+n		PP	MS	no		139
	77.3 d	^{159}Tb(n, γ)		GM, PR	no	no		113
	72 d	Gd(d, 2n)	70 d	CC	no	no		145
	(71±1) d	Tb(n, γ)	90 d		no	no		146
	76.0 d	supplied by ORNL	$3t_{1/2}$			no		147
	(72.3±0.5) d	^{159}Tb(n, γ)	$7t_{1/2}$	β-SP	no	no		148
	74 d	U(p, f); 340MeV-p		GM	ppt	no		23
	71 d	^{159}Tb(n, γ)	90 d	PR	IE	no		149
	(72.1±0.3) d	^{159}Tb(n, γ)	468 d	PR	IE	yes		38
	(73.5±1.1) d	^{238}U(p, f)	180 d	PR	IE, DP	yes	9	present work
^{161}Tb	8.6 d	Tb(n, γ)		GM	no	no		14
	(6.75±0.1) d	^{160}Gd(n, γ)$\xrightarrow{\beta}$			IE	no		150
	(7.2±0.2) d	Gd+n	65 d	SC	IE	no		151
	(6.8±0.1) d	^{160}Gd(n, γ)$\xrightarrow{\beta}$	$6t_{1/2}$	β-SP	no	no		152
	(7.2±0.5) d	Gd(n, γ)$\xrightarrow{\beta}$		NaI, β-SP		no		153
	6.8 d	U(p, f); 340MeV-p		GM	ppt	no		23
	7.15 d	^{160}Gd(n, γ)$\xrightarrow{\beta}$, ER		β-SP	no	no		154
	(6.9±0.1) d	^{160}Gd(n, γ)$\xrightarrow{\beta}$	40 d	β-SP	no	no		155
	6.8 d	Tb(n, γ)	one decade	PR	IE	no		149
	(7.20±0.07) d	^{160}Gd(n, γ)$\xrightarrow{\beta}$, ER		4πβ	IE	no		156

Nuclide	Half-life	Occurence	Counting duration	Detector	Chemical treatment	Computer analysis	No. of runs	Reference
^{161}Tb	(6.88±0.10) d	^{160}Gd(n, γ)$\xrightarrow{\beta}$	91 d	PR	IE	yes		38
	(7.3±0.6) d	Gd(n, γ)$\xrightarrow{\beta}$	11 d	NaI	IE	no		157
	(6.90±0.02) d	^{238}U(p, f)	180 d	PR	IE, DP	yes	28	present work

Note :

Occurence	f.p.	fission products
	ER	enriched isotope
Detector	GM	G.M. counter
	PR	gas flow proportional counter
	$4\pi\beta$	$4\pi\beta$ counter
	$4\pi\beta$-PR	$4\pi\beta$ proportional counter
	$4\pi\beta$-SC	$4\pi\beta$ scintillator
	$2\pi\beta$-PR	$2\pi\beta$ proportional counter
	β	β counter
	IC	ionization chamber
	PS	plastic scintillator
	PP	photographic plate
	β-SP	β spectrometer
	β-SP $\bar{c}$ GM	β spectrometer with G.M. counter
	PHSP	photographic magnetic spectrometer
	NaI	NaI(Tl) scintillator
	NaIW	well-type NaI(Tl) scintillator
	$4\pi\gamma$-IC	$4\pi\gamma$ ionization chamber
	CC	cloud chamber observation
	SC	special-type counter
	MS	mass spectrometer
	$\bar{c}$ AB	with an absorber
Chemical treatment	CS	chemical separation
	ppt	precipitate or precipitation
	SE	solvent extraction
	IE	ion exchange
	DP	deposition
	RC	recrystallization
	PF	purification
	MS	mass separator

Figures

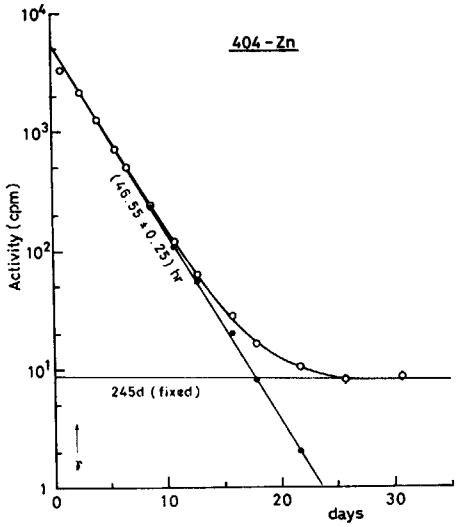

Fig. 1 The decay curve obtained with a zinc source. An arrow indicates the time at which the γ spectrum of **Fig. 2** was taken.

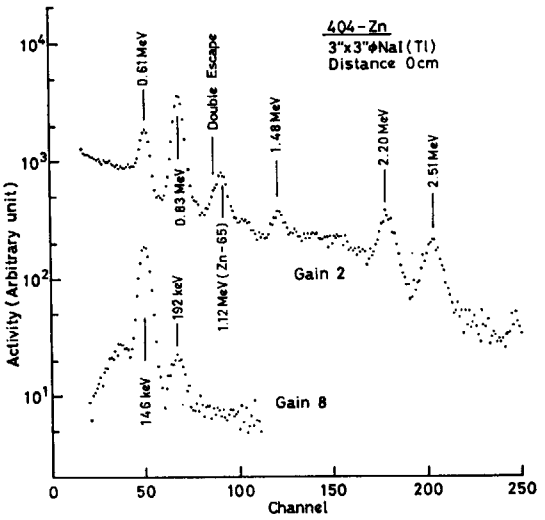

Fig. 2 Gamma spectra with a zinc source observed with two different gains.

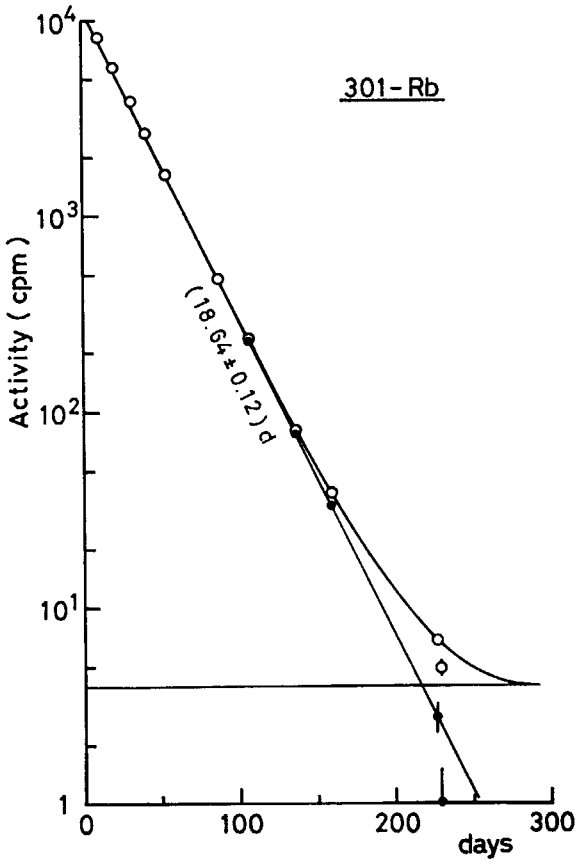

Fig. 3 The decay curve of a rubidium source.

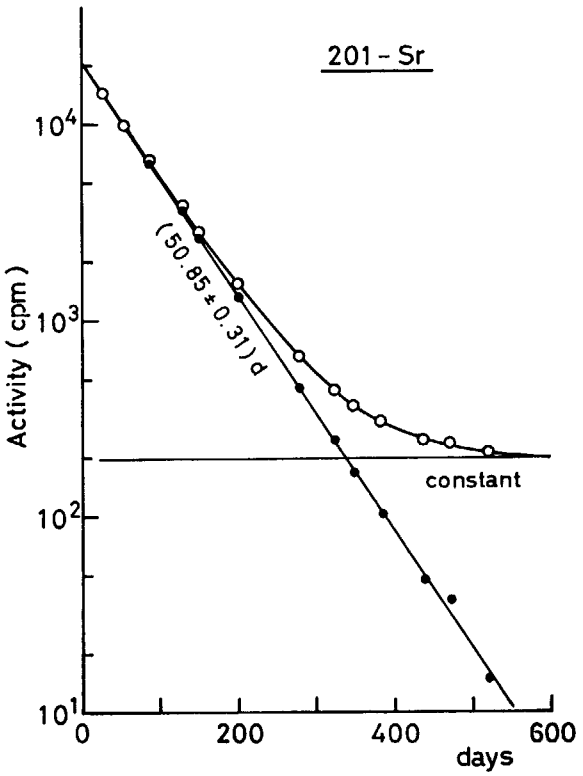

Fig. 4 The decay curve of a strontium source.

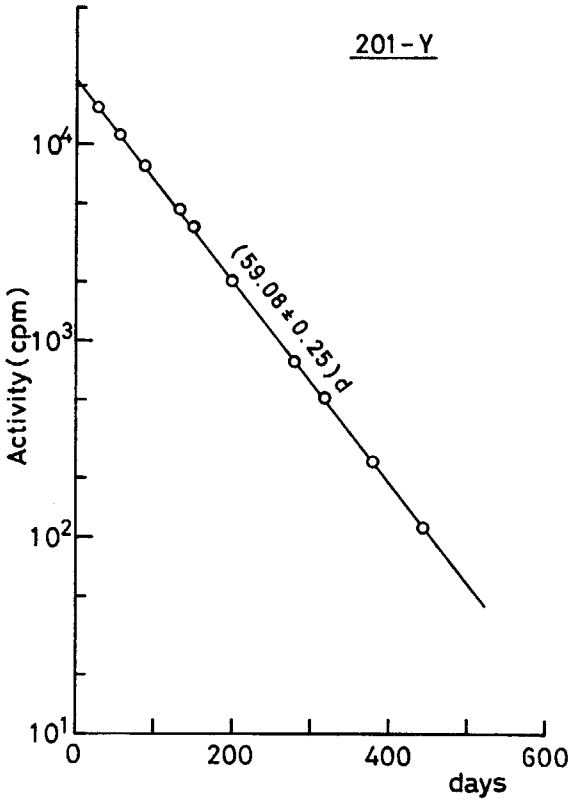

Fig. 5 The decay curve of a yttrium source.

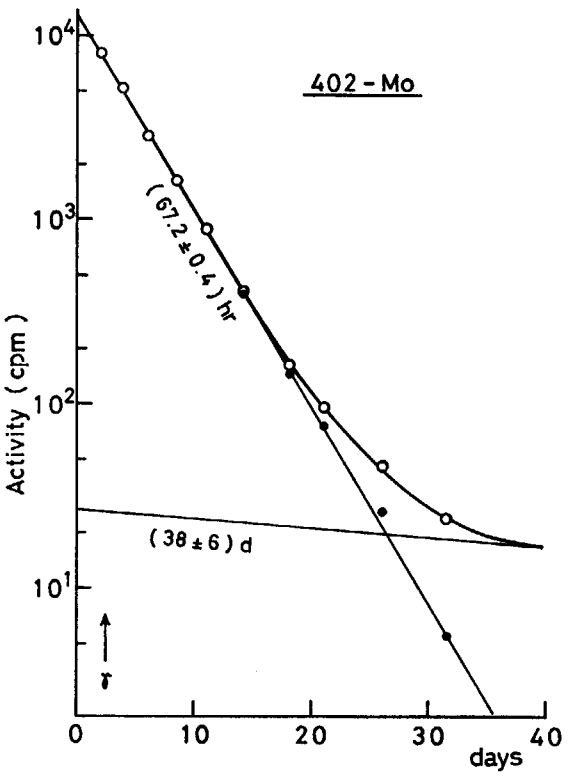

Fig. 6 The decay curve of a molybdenum source. An arrow indicates the time at which the γ spectrum of Fig. 7 was taken.

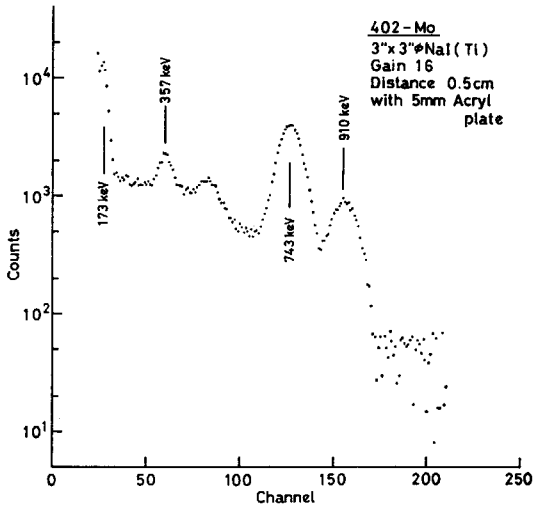

Fig. 7 The γ spectrum of a molybdenum source.

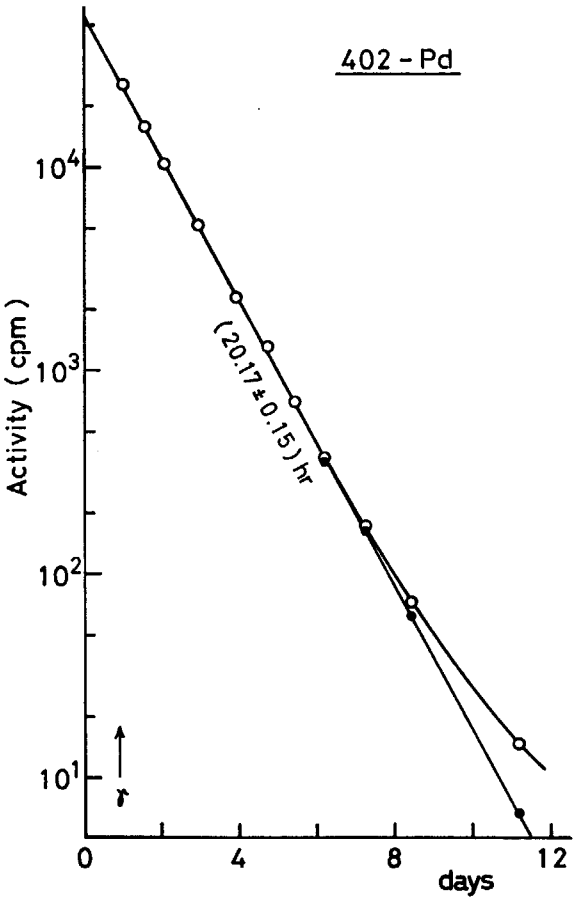

Fig. 8 The decay curve of a palladium source. An arrow indicates the time at which the γ spectrum of Fig. 9 was taken.

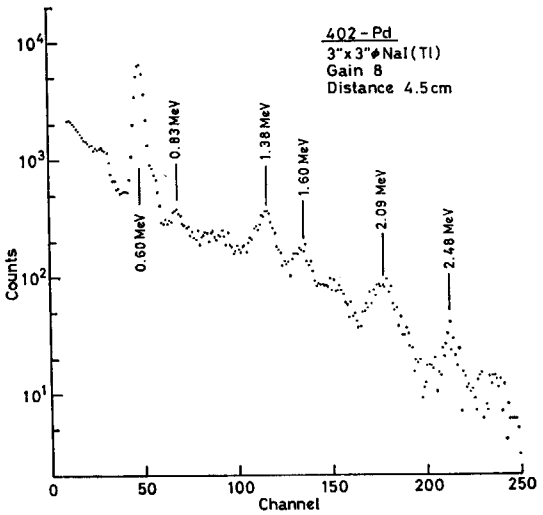

Fig. 9 The γ spectrum of a palladium source.

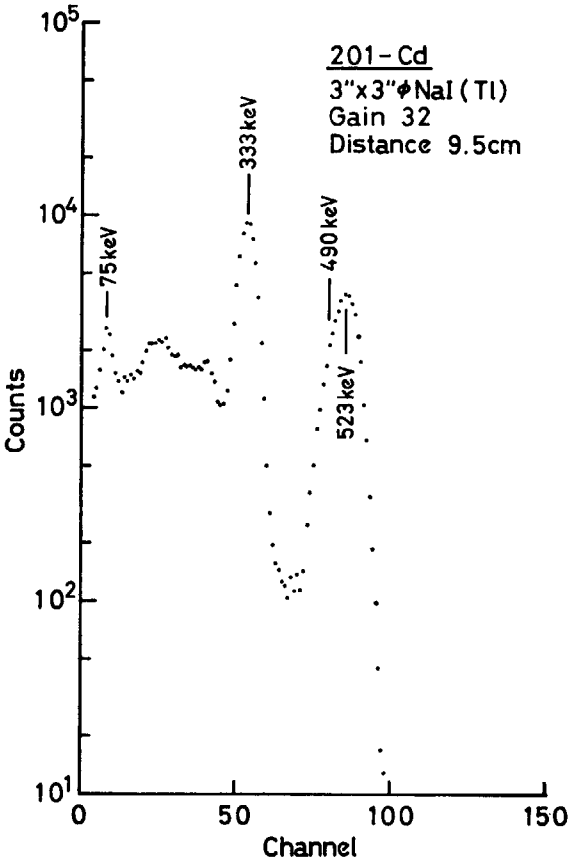

Fig. 11 The γ spectrum of a cadmium source.

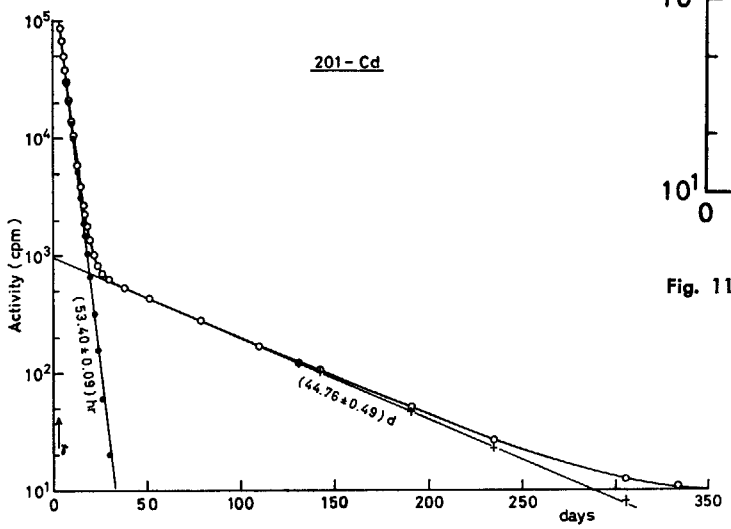

Fig. 10 The decay curve of a cadmium source. An arrow indicates the time at which the γ spectrum of Fig. 11 was taken.

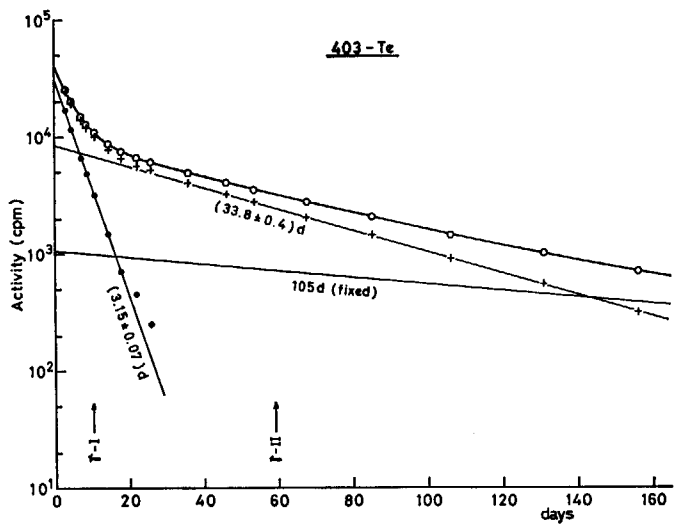

Fig. 12 The decay curve of a tellurium source. Arrows indicate the time at which the two γ spectra of Fig. 13 were taken.

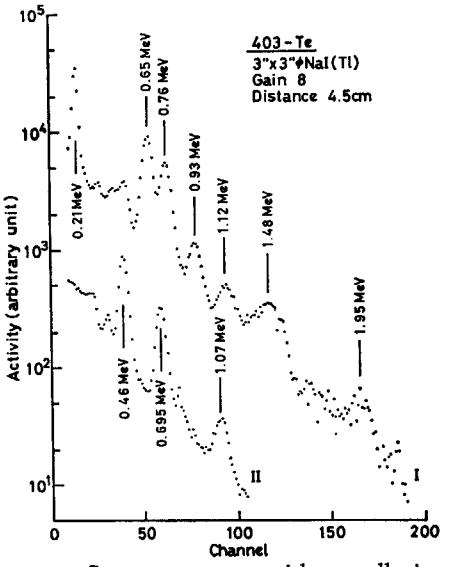

Fig. 13 Gamma spectra with a tellurium source observed at two different time.

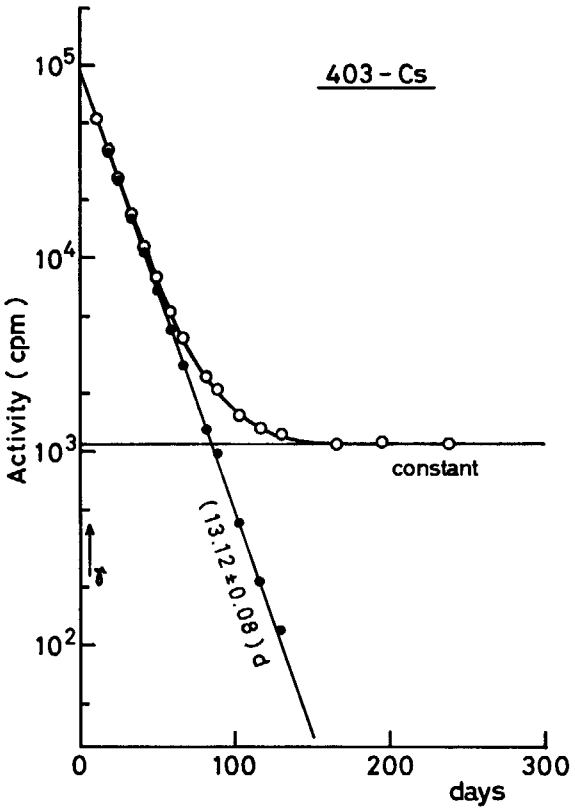

Fig. 14 The decay curve of a cesium source. An arrow indicates the time at which the γ spectrum of Fig. 15 was taken.

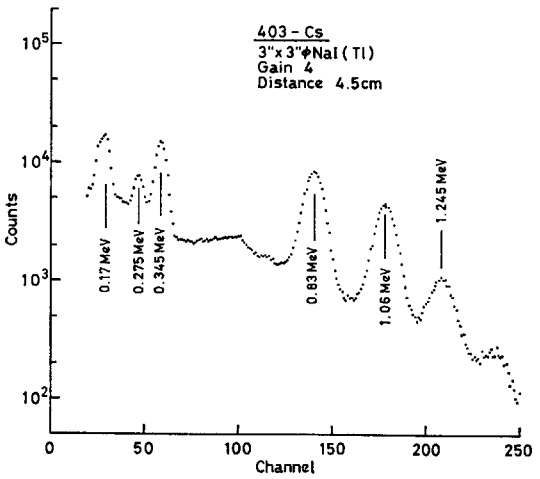

Fig. 15 The γ spectrum of a cesium source.

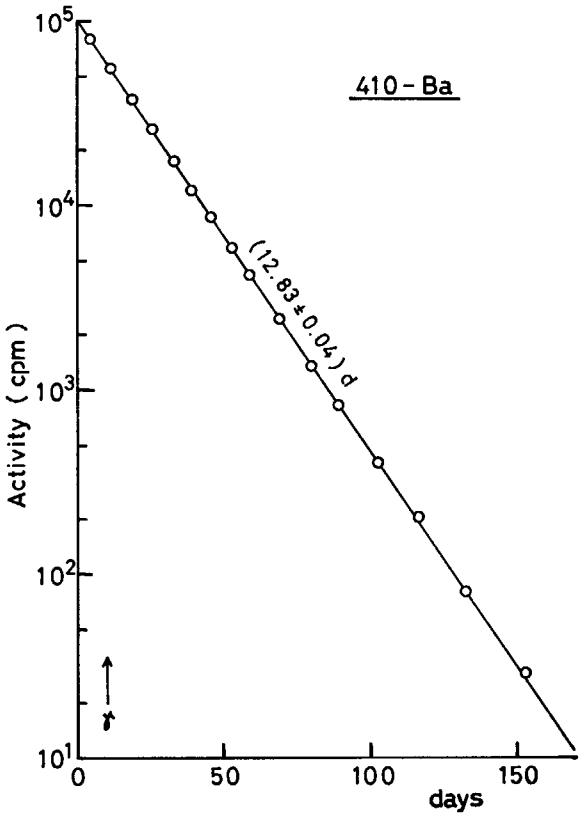

Fig. 16 The decay curve of a barium source. An arrow indicates the time at which the γ spectrum of Fig. 17 was taken.

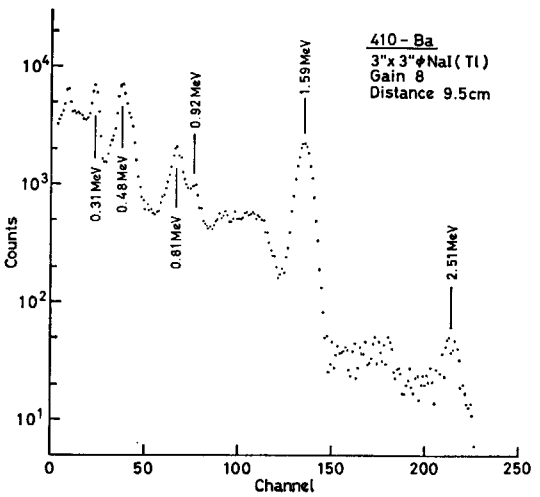

Fig. 17 The γ spectrum of a barium source.

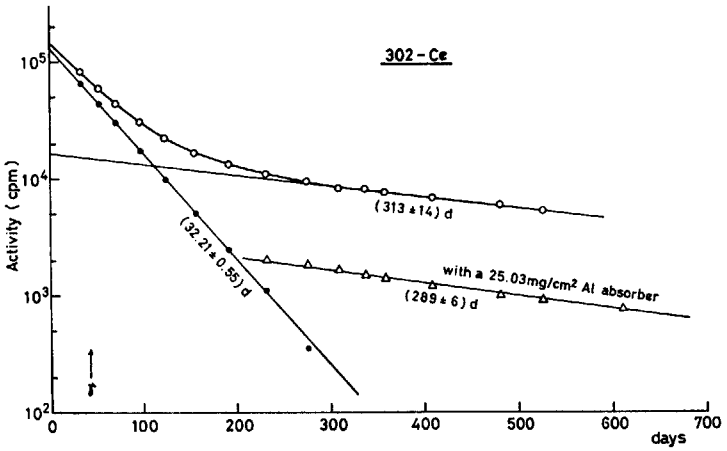

Fig. 18 Decay curves of a cerium source; one without and the other with an aluminium absorber. An arrow indicates the time at which the γ spectrum of Fig. 19 was taken.

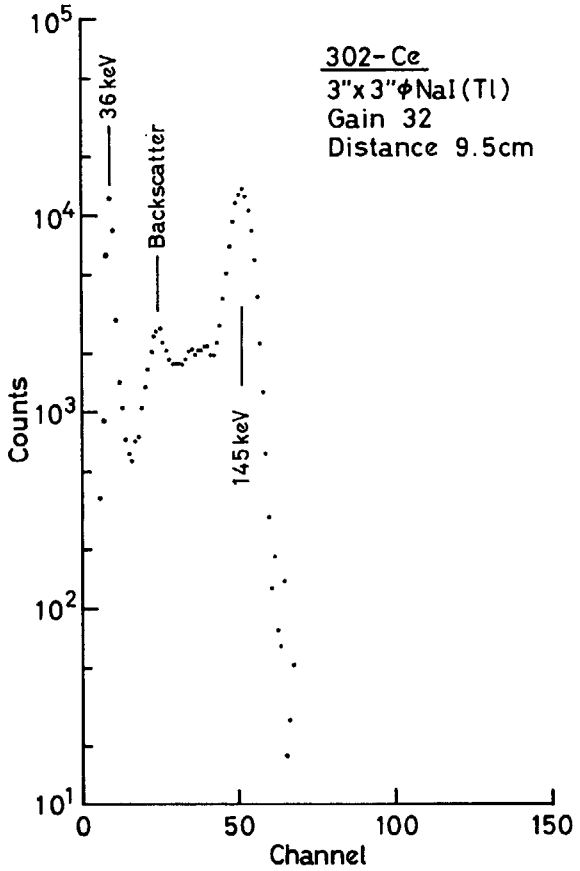

Fig. 19 The γ spectrum of a cerium source.

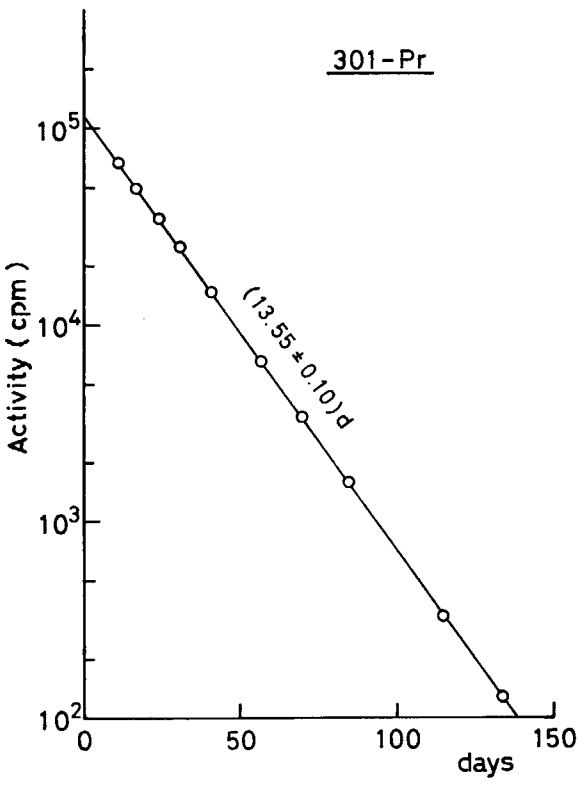

Fig. 20 The decay curve of a praseodymium source.

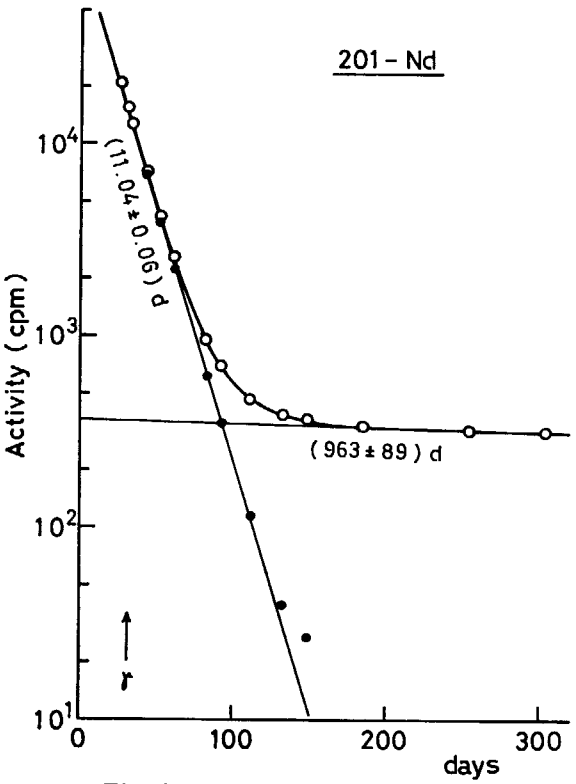

Fig. 21 The decay curve of a neodymium source. An arrow indicates the time at which the γ spectrum of Fig. 22 was taken.

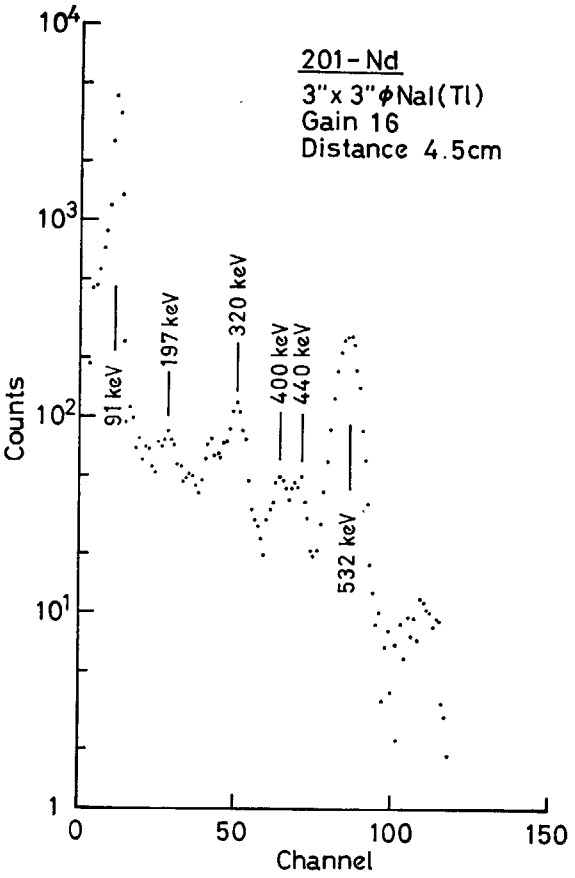

Fig. 22 The γ spectrum of a neodymium source.

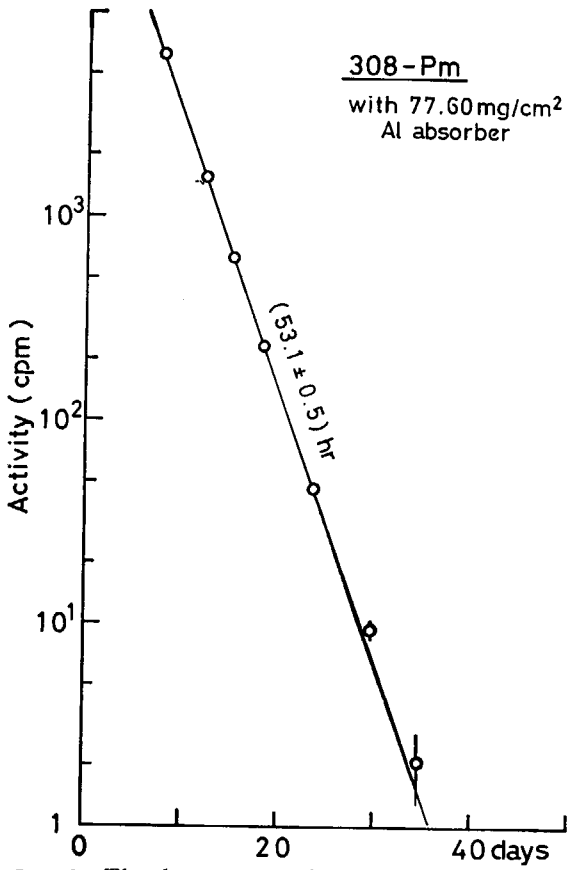

Fig. 23 The decay curve of a promethium source measured with an aluminium absorber of 77.60 mg/cm² thick.

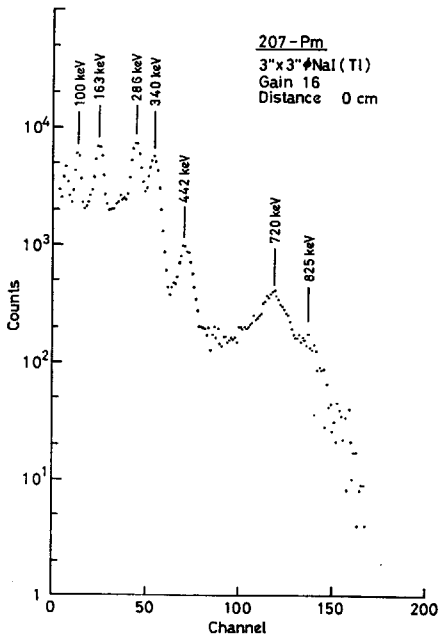

Fig. 24 The γ spectrum of a promethium source.

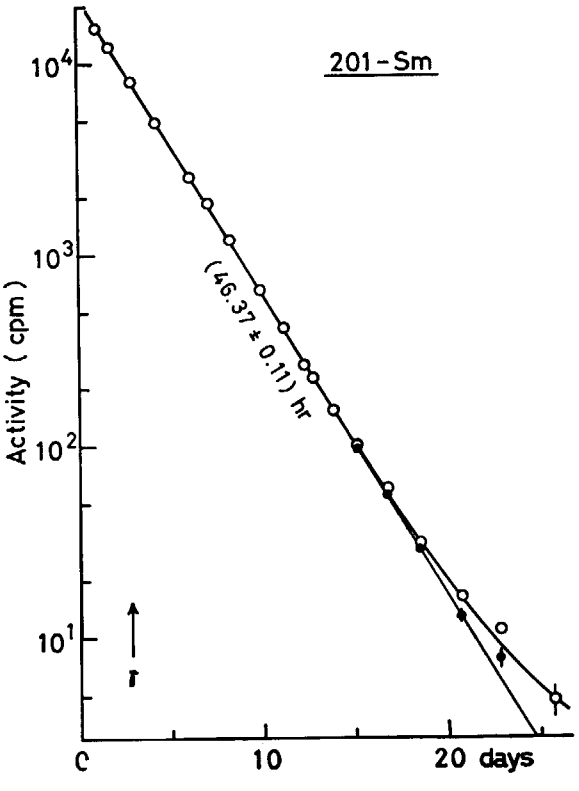

Fig. 25 The decay curve of a samarium source. An arrow indicates the time at which the γ spectrum of Fig. 26 was taken.

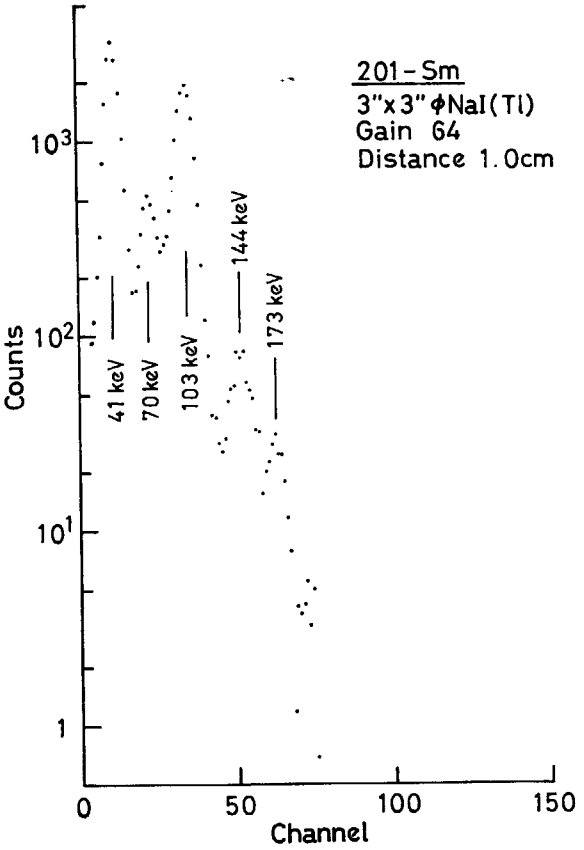

Fig. 26 The γ spectrum of a samarium source.

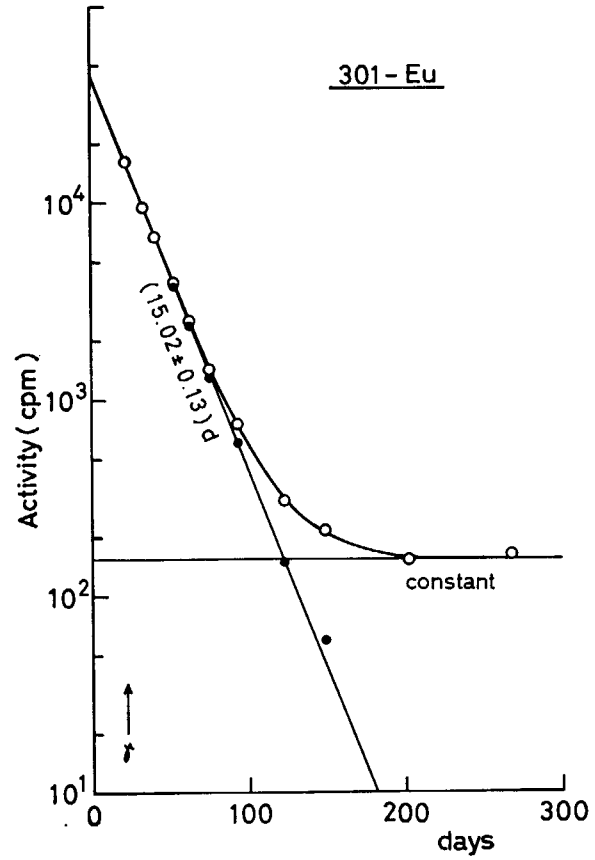

Fig. 27 The decay curve of a europium source. An arrow indicates the time at which the γ spectrum of Fig. 28 was taken.

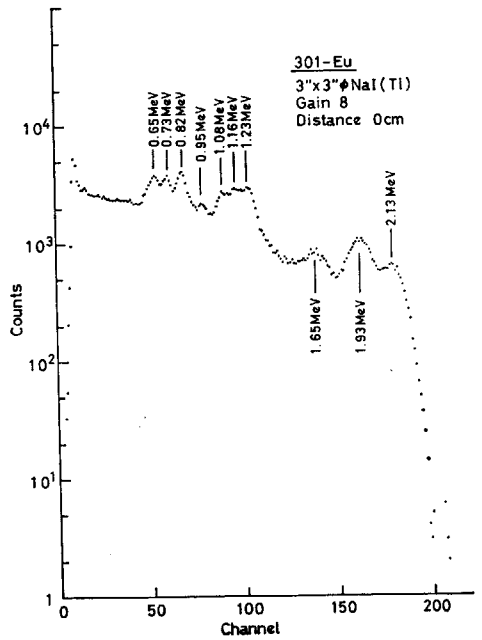

Fig. 28 The γ spectrum of a europium source.

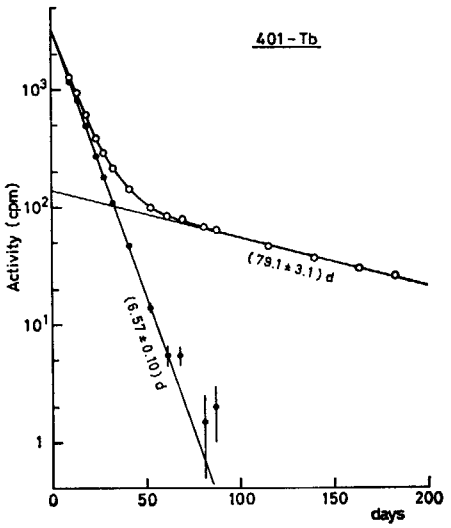

Fig. 29 The decay curve of a terbium source.