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CRITICAL EVALUATION OF RADIOACTIVE DECAY CONSTANTS FOR ^{99}Mo, ^{144}Ce, ^{144}Pr AND ^{144}Pm

Yu.I. Grigoryan, L.L. Sokolovskij, F.E. Chukreev

I.V. Kurchatov Institute of Atomic Energy

Centre for Data on the Structure of the Atomic Nucleus and
on Nuclear Reactions, USSR State Committee on the
Utilization of Atomic Energy, Moscow, USSR

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Abstract

The decay schemes of ^{99}Mo, ^{144}Ce, ^{144}Pr, ^{144}Pm are reviewed on the basis of analysis of a large number of published experimental works. A knowledge of the decay constants of the first three nuclei, which are fission products, is of great importance in developing safeguards methods.

Quantities characterizing the ß-decay of ^{99}Mo, ^{144}Ce, ^{144}Pr and K-electron capture (^{144}Pm) are evaluated. Level schemes are plotted for the daughter nuclei. Evaluations are made in respect of the energies and intensities of γ-rays and conversion electrons accompanying ß-decay and K-electron capture, internal conversion coefficients and transition multipolarities, level energies, spins, parities, and lifetimes of the ground and excited states of ^{99}Tc, ^{144}Pr, and ^{144}Nd.

From the results obtained the ^{99}Mo–^{99}Tc mass difference can be deduced and a new value of 1358.0 ± 3.0 keV is established instead of the previously used value of 1372.2 ± 3.9 keV. The analagous quantity for the nuclei ^{144}Pr–^{144}Nd is taken as 2994.6 ± 3.2 keV instead of the value 2997.0 ± 3.0 keV.

INTRODUCTION

The interest of isobars with mass numbers 99 and 144 is due to the fact that they are close to the maxima in the cumulative fission yield curve for the isotopes of uranium, plutonium and thorium. A knowledge of the decay constants of the ^{99}Mo, ^{144}Ce, ^{144}Pr nuclei is of importance in developing safeguards methods.

The final nucleus of the 99 decay-chain is stable ^{99}Ru [1] (Fig.1). For the branch of the chain with mass number 144 the final nucleus is α-radioactive ^{144}Nd [1], with its long lifetime, of the order of 2×10^{15} years (Fig.2). At present, there are very few experimental data on decay of the 99 and 144 isobars shifted into the region of high neutron excess. The main reason for this is their short lifetimes, ranging from hundredths of a second to several tens of seconds. A great deal of work has been done on the decay of these nuclei; since, however, the results obtained are not always in good agreement, the wealth of experimental material needs to be generalized and evaluated.

In the present work we evaluated the energies and intensities of β-transitions, γ-quanta and conversion electrons, accompanying the β-decay of ^{99}Mo, ^{144}Ce, ^{144}Pr and the electron capture of ^{144}Pm. In addition, we evaluated the internal conversion coefficients, transition multipolarity, level energies, spins, parities and lifetimes of the ground states and excited states of daughter products of the isotopes in question.

With the results obtained in the evaluation it was possible to revise the level schemes of the product nuclei.

The experimental data were processed in order to obtain an evaluated mean value (weighted or unweighted) and to determine the uncertainty in this mean value. From an analysis of the internal and external uncertainties, which depend either on the σ_i of the particular measurement or, in general, on the deviation of X_i from $\overline{X}$, it was possible to pick out the experimental values with a systematic error or those for which the statistical error quoted by the authors of experimental work was too low, and to make an appropriate correction. Details of the method which we used for processing the experimental results will be given in a separate work [119].

The numerical values are given here in the form X, XX (X), where the figures in brackets represent the uncertainty in the last figures of the quantity referred to. In addition, the following symbols are used in the text:

(W) - weighted average value;

(U) - unweighted average value;

(A) - value adopted by the authors;

(T) - theoretical value.

2. DESCRIPTION OF ^{99}Mo DECAY SCHEME

2.1. ^{99}Mo ground state

Spin, parity - $\frac{1}{2}$,+.

$T_{\frac{1}{2}}$ = 66.05 (5) h [4-13] (WA)

$T_{\frac{1}{2}}$ = 66.6 (2) h [4-13] (U)

The energies and intensities of ß-transitions are given in Table I.

The ß-transition energies are found from the difference $Q_\beta - E_x = E_\beta$ where E_x is the level energy, E_β is the ß-transition limiting energy, Q_β is the recommended ß-decay total energy. From an analysis of the results given in works [2, 36-42] we obtained a ß-decay total energy for ^{99}Mo of 1358.0 ± 3.0 keV, which differs considerably from the previously used value of 1372.2 ± 3.9 keV [3].

The new Q_β was obtained by evaluating the 142 keV level energy of ^{99}Tc and the limiting energy of the strongest (83%) ß-transition to this state (1215 keV). The most significant result used to determine this ß-transition energy was that given in Ref. [2] (1971). The authors of the latter work obtained a very accurate limiting energy for this ß-group - 1214 (1) keV. We looked at other works published by the same authors on the ß-decay of ^{111}Ag and ^{187}W [43,44], using the same method as in the work on ^{99}Mo. Careful consideration of Refs [2, 43, 44] showed that there is no systematic error in the results of Ref. [2], and that these results can be used with confidence.

Only three ß-groups were observed experimentally; the remaining ß-transitions could not be observed owing to their low intensity. However, analysis of the balance of γ-radiation intensities from ^{99}Mo decay suggests that there are several more weak ß-transitions which are forbidden only to a slight extent.

2.2. ^{99}Tc level scheme (Fig. 3)

Table II gives the energies and intensities of γ-transitions and conversion electrons.

$^{99}_{43}Tc$ ground state

Spin, parity - 9/2,+

$T_{\frac{1}{2}} = 2.13\ (8) \times 10^5$ years [17-19] (WA).

140 keV level

Spin, parity - 7/2,+

$T_{\frac{1}{2}} = 0.16\ (2) \times 10^{-9}$ sec [20-21] (WA).

A transition to the ground state is observed.

142 keV level

Spin, parity - $\frac{1}{2}$,-

$T_{\frac{1}{2}} = 6.019\ (7)$ h [8, 22-27] (WA).

$T_{\frac{1}{2}} = 6.025\ (9)$ h [8, 22-27] (U).

A transition to the ground state is observed. There is a strong unobserved transition with energy 2.11 keV to the 142 keV state with a conversion coefficient of 10^{10} (T). A ß-transition of energy 1215 keV to this state is observed.

181 keV level

Spin, parity - 5/2,+

$T_{\frac{1}{2}}$ = 3.53 (6) x 10^{-9} sec [28-32, 49] (WA).

Transitions to states with energies 0 and 140 keV are observed.

509 keV level

Spin, parity - 3/2,-

$T_{\frac{1}{2}}$ = ?

A transition to the 142 keV state is observed.

A ß-transition with energy 849 keV to this state is observed.

534 keV level

Spin, parity - ?

$T_{\frac{1}{2}}$ = ?

There are weak transitions to and from this state observed only in γ-γ coincidence experiments. These transitions are not indicated in the level scheme (see Table II). The existence of a weak ß-transition with energy 824 keV is assumed.

671 keV level

Spin, parity - $\frac{5}{2}$,-

$T_{\frac{1}{2}}$ = ?

A transition to the 142 keV state is observed. The existence of a weak ß-transition with energy 687 keV is assumed.

761 keV level

Spin, parity - (7/2, 9/2),+ [33].

$T_{\frac{1}{2}}$ = ?

Transitions to the 0 and 140 keV states are observed.

In reference [34] negative parity is associated with the 761 keV level, but in the same work the multipolarity of the transition to the 140 keV state (7/2 +) was determined as MI.

The existence of a weak ß-transition with energy 597 keV is assumed.

920 keV level

Spin, parity - 3/2,+

$T_{\frac{1}{2}} \leqslant 0.2 \times 10^{-9}$ sec [28].

Transitions to the 142, 181 and 509 keV states are observed.

A ß-transition with energy 437 keV to this state is observed.

1004 keV level

Spin, parity - 3/2,-

$T_{\frac{1}{2}} = ?$

Transitions to the 142 and 181 keV states are observed.

The existence of a weak ß-transition with energy 354 keV is assumed.

1072 keV level

Spin, parity - 5/2,- [35]

$T_{\frac{1}{2}} = ?$

The transitions by which this level was identified were observed only in γ-γ coincidence experiments. These transitions are not indicated in the scheme (see Table II).

The existence of a weak ß-transition with energy 285 keV is assumed.

1129 keV level

Spin, parity - (1/2, 3/2),-

$T_{\frac{1}{2}} = ?$

Transitions to the 142 and 671 keV states are observed.

The existence of a weak ß-transition with energy 228 keV is assumed.

1142 keV level

Spin, parity - 3/2,-

$T_{\frac{1}{2}} = ?$

Transitions to the 140, 181 and 761 keV states are observed.

The existence of a weak ß-transition with energy 216 keV is assumed.

1198 keV level

Spin, parity - (1/2, 3/2),-

$T_{\frac{1}{2}} = ?$

Transitions to the 142 and 181 keV states are observed.

The existence of a weak ß-transition with energy 160 keV is assumed.

The energies and intensities of the γ-transitions, the internal conversion coefficients, the multipolarity of the transitions were evaluated from the results obtained in Refs [28, 33-37, 41, 42, 45-51].

3. DESCRIPTION OF ^{144}Ce DECAY SCHEME

3.1. $^{144}_{58}$Ce ground state

Spin, parity - 0,+.

$T_{\frac{1}{2}}$ = 284.3 (3) d [11, 52-59] (W).

The energies and intensities of the ß-transitions are shown in Table III [61, 62, 65, 69, 70, 73, 74, 80-82]. The values taken were found in the same way as in establishing the decay scheme for ^{99}Mo, 15.6 keV. The 215.6 keV transition was not observed experimentally.

3.2. ^{144}Pr level scheme (Fig. 4)

The energies and intensities of γ-transitions and conversion electrons are given in Table IV [1, 60-79, 105, 117].

^{144}Pr ground state

Spin, parity - 0,- [63, 72, 83, 84].

$T_{\frac{1}{2}}$ = 17.29 (3) min (W).

A ß-transition with energy 315.6 keV to this state is observed.

59 keV level

Spin, parity - 3,-.

$T_{\frac{1}{2}}$ = 7.2 (2) min [64].

There is a strong transition to the ground state accompanied by a strong internal conversion. Measurements [64] showed that the population of the 1510 keV level in ^{144}Nd, upon decay of the ^{144}Pr ground state, does not correspond to the intensity of the discharge of this level (Fig. 5), and the authors consequently suggest the existence of a weak ß-transition from the ^{144}Pr 59 keV level to the

^{144}Nd 1510 keV level with a probability of 0.05 (3)%.

80 keV level

Spin, parity - 1,-

$T_{\frac{1}{2}}$ = 136 (16) nsec [85, 86] (W).

A transition to the ground state is observed. There is a ß-transition with energy 235.5 keV to this level.

99 keV level

Spin, parity - 2,-

$T_{\frac{1}{2}}$ = 660 (60) nsec [85, 86] (W).

Transitions are observed to the ground state and to the 59 keV level. There is a weak ß-transition with energy 215.6 keV to this level.

133 keV level

Spin, parity - 1,-

$T_{\frac{1}{2}}$ = 7 (4) nsec [85].

Transitions to the 0.80 and 99 keV states are observed.

This level is populated in the ß-decay of ^{144}Ce by a 182.1 keV transition.

4. DESCRIPTION OF THE ^{144}Pr DECAY SCHEME

4.1. ^{144}Pr ground state

Spin, parity - 0,- [63, 72, 83, 84].

$T_{\frac{1}{2}}$ = 17.29 (3) min [64, 87-89] (W).

The energies and intensities of the ß-transitions are shown in Table V [60, 64, 68, 74, 77, 80, 82, 84, 90-92, 96, 102].

4.2. ^{144}Nd level scheme from decay of ^{144}Pr (Fig. 5).

The energies and intensities of the γ-transitions, the transition multipolarities and conversion coefficients are given in Table VI [64, 75, 77, 89-93, 96-104, 108-110, 112].

^{144}Nd ground state

Spin, parity - 0,+.

$T_{\frac{1}{2}} = 2.1\ (4) \times 10^{15}$ y [84].

$Q_{\alpha} = 1901\ (7)$ keV

$Q_{\beta} = -2370\ (40)$ keV [3]

α-decay is observed in ^{140}Ce. There is a strong β-transition with energy 2994.6 keV to this level.

696 keV level

Spin, parity, - 2,+

$T_{\frac{1}{2}} = 4.9$ nsec

A transition to the ground state is observed. A β-transition with energy 2298.1 keV to this level is observed.

1510 keV level

Spin, parity - 3,-

A transition to the 696 keV state is observed. A β-transition to this level is possible from the ^{144}Pr isomer state (59 keV) with intensity 0.0007(4) transitions per 100 ^{144}Pr disintegrations.

1560 keV level

Spin, parity - 2,+

A transition to the 696 keV state is observed. There is a weak β-transition with energy 1434.3 keV to this level.

2084 keV level

Spin and parity are not clearly determined. There is a transition to the 696 keV level. There is a weak β-transition with energy 909.9 keV to this level.

2185 keV level

Spin, parity - 1,-

Transitions are observed to the ground state and to levels with energy 696, 1510 and 1560 keV. There is a β-transition with energy 809.9 keV to this level.

2655 keV level

Spin and parity are not determined.

The level is identified by a weak transition to the ground state. It is excited by a weak ß-transition with energy 340 keV.

5. DESCRIPTION OF ^{144}Pm DECAY SCHEME

5.1. ^{144}Pm ground state. Decays to ^{144}Nd by electron capture

Spin, parity - (5.6),-

$T_{\frac{1}{2}}$ = 363 (18) d [106, 107] (W).

5.2. Scheme of ^{144}Nd levels excited upon electron capture (^{144}Pm) (Fig. 5)

The γ-transition intensities and energies, together with the transition multipolarities and conversion coefficients are given in Table VII [64, 89-99, 108-113].

^{144}Nd ground state

See description of ^{144}Pr decay scheme.

696 keV level

See description of ^{144}Pr decay scheme.

1314 keV level

Spin, parity - 4,+

$T_{\frac{1}{2}}$ = 21 (4) nsec [115]

A transition to the 696 keV level is observed. The level is populated by electron capture (^{144}Pm).

1510 keV level

See description of ^{144}Pr decay scheme.

In reference [116], where γ-γ correlations are studied, this level is given spin 2 and positive parity. This is the opposite of the 813.9 keV transition, with a mixture of E1 + M2 multipolarities, to the well established 696 keV level, with 2^+ characteristics.

In references [108-110, 113] a weak transition to the ground state is observed apart from the transition to the 696 keV level, but the authors give only the upper limit of the intensity.

1791 keV level

Spin, parity - 6,+

$T_{\frac{1}{2}}$ = ?

There is a transition to the 1314-keV level. Populated by electron capture (^{144}Pm).

2093 keV level

Spin, parity - 6,+

$T_{\frac{1}{2}}$ = ?

Transitions to the 1791, 1510 and 1314 keV levels are observed.

Population by electron capture (^{144}Pm).

2204 keV level

Spin, parity - (4,+).

$T_{\frac{1}{2}}$ = ?

Spin and parity are not reliably determined. There are transitions to the 1510 and 1314 keV levels.

TABLE I

ENERGIES AND INTENSITIES OF β-TRANSITIONS FROM ^{99}Mo DECAY

Transition number	E_{β}, keV		I_{β}, %	
I	I60	A)	0,002	A)
2	2I6	A)	0,II	A)
3	228	A)	0,002	A)
4	285	A)	0,00I	A)
5	354	A)	0,I3	A)
6	446 (3)	W)		
	437 (3)	A)	I5,6 (5)	A)
7	597	A)	0,0I6	A)
8	687	A)	0,04	A)
9	824	A)	0,00I	A)
I0	844 (9)	W)		
	849 (3)	A)	I,4 (I)	A)
II	I2I4,7 (I5)	W)		
	I2I5,4 (I5)	A)	83 (I)	A)

TABLE II

ENERGIES AND INTENSITIES OF γ-TRANSITIONS FROM ^{99}Mo DECAY

E_γ , keV			I_γ , (I)		E_i - E_j	Internal conversion coefficient		Multipolarity of transition
I			2		3	4		5
2,II (6)		A)	88,5 (5)	A)	I42 - I40	10^{10}	T)	
40,5844(I5)		W)	3,6 (2)	W)	I8I - I40	K 3,27(I7)	W)	M 1
I40,508 (2)		W)	92,I (4)	W)	I40 - 0	K 0,097 (3) TOT 0,II8 (3)	W)	M1+8% E2
I42,62 (6)		W)	0,78 (I5)	A)	I42 - 0	K 30,0(30)		M 4
I58,9 (3)	ж		0,0I2 (5)		920 - 76I			
I8I,086 (5)		W)	7,0 (2)	W)	I8I - 0	K 0,I25 (5)	W)	E 2 +I0% M 1
242,7 (4)	ж		0,0008 (3)		I004 - 76I			
249,I (2)	ж	W)	0,005 (I)	W)	920 - 67I			
344,0 (5)	ж	W)	0,00I0 (4)		?			
366,43 (2)		W)	I,4 (I)	W)	509 - I42	K 0,072 (I)		M I
380,7 (3)		W)	0,009 (I)	W)	II42 - 76I	K 0,009 (I)		
39I,7 (4)	ж		0,00I8 (5)		534 - I42			
408,5 (3)	ж	W)	0,00I3 (5)		?	K 0,0060 (8)		M 1
4II,32 (4)		W)	0,020 (2)	W)	920 - 509	K 0,0030 (5)		E 1
458,9 (5)		W)	0,007 (2)	W)	II29 - 67I	K 0,0054 (6)		E 2
470,I (5)	ж		0,0007 (2)		I004 - 534			
528,89 (8)		W)	0,052 (4)	W)	67I - I40	K 0,0050 (6)		E 2
538,6 (5)	ж		0,00II (3)		I072 -534			
[illegible] (4)	ж		0,003 (I)		76I - I8I			
620,6 (7)	ж	A)	0,003 (I)	W)	II29 - 509			

I	2	3	4	5
620,8I (I3) w)	0,023 (4) w)	76I - I40	K 0,0020 (4)	M I
689,6 (9) *	0,0004 (2)	II98 - 509		
739,57 (6) w)	II,4 (4) w)	920 - I8I	K 0,00I6 (4)	E 2 or M I
76I,08 (I4) w)	0,0022 (7)	76I - 0		
778,02 (I9) w)	4,2 (3) w)	920 - I42	K 0,0005 (I)	E I
822,98 (I3) w)	0,I32 (3) w)	I004 - I8I	K 0,0004 (I)	E I
86I,2 (9)	0,0007 (3)	I004 - I42		
96I,00 (5) w)	0,I0 (I) w)	II42 - I8I	K 0,0024(5)	M 2
988,4 (3) w)	0,00I6 (2) w)	II29 - I42		
I00I,64 (II) w)	0,004 (I) w)	II42 - I40	K 0,00I8 (3)	M 2
I0I7,0* (5) w)	0,0008 (4)	II98 - I8I		
I057,2 (8)	0,0009 (2)	II98 - I42		

* Transitions marked with an asterisk are not shown on the scheme and they are observed only in γ-γ coincidence experiments.

(1) Full intensity of the transition (gamma quanta + conversion electrons) per 100 disintegrations of the parent nucleus.

TABLE III

ENERGIES AND INTENSITIES OF β-TRANSITIONS
IN THE DECAY OF ^{144}Ce

№	E_β, keV		I_β, %	
I	I8I,5 (20)	W)		
	I82,I	A)	I9,4	A)
			I9,7 (5)	
2	2I5,6	A)	0,I	A)
3	238,2 (35)	W)		
	235,5	A)	4,3	A)
			4,6 (3)	
4	3I5,6	A)	76,2	A)
			75,7 (8)	

Q_β = 3I5,6 (I5)

TABLE IV

ENERGIES AND INTENSITIES OF γ-QUANTA AND CONVERSION ELECTRONS FROM β-DECAY OF ^{144}Ce

E_γ , keV		I_γ , quanta/100 dis.		I_{Ce}, n/I00 dis.			Conv. coeff.		Multipol.
33,58 (3)	W)	0,228 (I4)	W)	L	0,9 (I)	U)	L =4,5 (I2)		M 1
				M+N	0,I8 (5)		L =3,8	T)	
							MN/L =0,20 (3)		
40,93 (3)	W)	0,40 (3)	W)	L	0,90 (I5)	U)	L =I,8 (6)		M 1
				L	0,72 (I3)	A)	L =2,I3	T)	
				M+N	0,I7 (5)		MN/L =0,24 (3)		
53,42 (4)	W)	0,I24 (8)	W)	K	0,75 (I5)		K =6,0 (6)	W)	M 1
				L	0,I3 (2)		L =0,98 (I0)		
				M	0,03 (I)		L =0,95	T)	
							M/L=0,22		
59,04 (9)	W)	0,00I	A)	K	0,40 (8)		K =4I5	T)	M3
				L	0,60 (I)	U)	K/L=0,66	T)	
				M+N	0,I6 (4)		MN/L =0,26 (2)		
80,I3 (4)	W)	I,70 (I2)	W)	K	3,I (2)	J)	K =I,50 (23)		M 1
				L	0,43 (5)		K =2,I	T)	
				M+N	0,I2 (3)		K/L =7,3 (4)	W)	
							K/L =7,I	T)	

I	2	3	4	5
99,93 (5) W)	0,040 (2) W)	K 0,06 (I)	K = I,4 (5) K = I,22 T)	E2
133,54 (4) W)	I0,8 (4) W)	K 5,3 (2) W) L 0,74 (4) M+N 0,18 (3)	K = 0,57 (6) W) K = 0,48 T)	MI

TABLE V

ENERGIES AND INTENSITIES OF β-TRANSITIONS IN THE DECAY OF ^{144}Pr

№№	$E_β$, keV		$I_β$, %	
I	340	A)	~ 0,00016	A)
2	809,9 (40)	WA)	I,05	A)
3	909,3 (3)	U)	0,0066 (4)	U)
	909,9	A)	0,006	A)
4	I433,9 (I5)	U)		
	I434,3	A)	0,00I7	A)
5	2297,5 (20)	W)	I,24 (6)	U)
	2298,I	A)	I,2I	A)
6	2994,6 (32)	WA)	97,I (6)	U)
			97,7	A)

$Q_β$ =2994,6 (32) W)

TABLE VI

ENERGIES AND INTENSITIES OF γ-QUANTA FROM ^{144}Pr DECAY

E_γ, keV		I_γ quanta/100 dis.		Conversion coeff.	Multi-pole
625,5 (7)	W)	0,0007 (3)	W)		
675,I0 (24)	W)	0,0026 (3)	W)		
696,45 (4)	W)	I,42 (4)	U)	K =0,0043	E2
		I,50	A)	L =0,00064(I0)	
8I3,7 (2)	W)	0,0035 (3)	W)	K =0,00I5 (2)	EI+M2
8I3,9	A)			L =0,000I7(7)	
863,8(3)	W)	0,0024(3)	W)	K =0,0038 (6)	MI+E2
				L =0,00042(I5)	
I388,2(3)	W)	0,0063 (6)	W)		
I489,I4 (7)	W)	0,280(7)	W)		
		0,282(I0)	U)		
2I85,7I(5)	W)	0,76 (4)	WA)		
		0,75 (2)			
2655(I)		~ 0,000I6(4)			

TABLE VII

ENERGIES AND INTENSITIES OF γ-QUANTA FROM DECAY OF ^{144}Pm

E_γ , keV		I_γ quanta/I00 dis.		Conv. coeff. multipolarity
302,6(6)	W)	0,I02 (I0)	W)	
476,79 (9)	W)	40,7 (5)	W)	
582,0 (5)	W)	0,20 (2)	W)	
6I7,96 (9)	W)	I00,0(9)	W)	E2
		99,5	A)	K =0,0052
				K =0,0072 T)
694,0 (7)	W)	0,45 (I5)		
		0,32	A)	
696,45 (4)	W)	I00	A)	E2
				K =0,0043
778,68 (I5)	W)	I,55 (6)	W)	
8I3,9 (2)	W)	0,52 (3)	W)	EI+M2
889,7 (5)		0,043 (7)		
I5I0		< 0,004		

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CAPTIONS TO FIGURES

Fig. 1 Scheme of ß-transitions for A = 99.

Fig. 2 Scheme of ß-transitions for A = 144.

Fig. 3 Decay scheme for ^{99}Mo. The energy is shown in keV and the transition intensity in % per disintegration.

Fig. 4 Decay scheme for ^{144}Ce. The energy is given in keV, and the transition intensity in % per disintegration.

Fig. 5 Decay scheme for ^{144}Pr and ^{144}Pm. The energy is given in keV, and the transition intensity in % per disintegration.

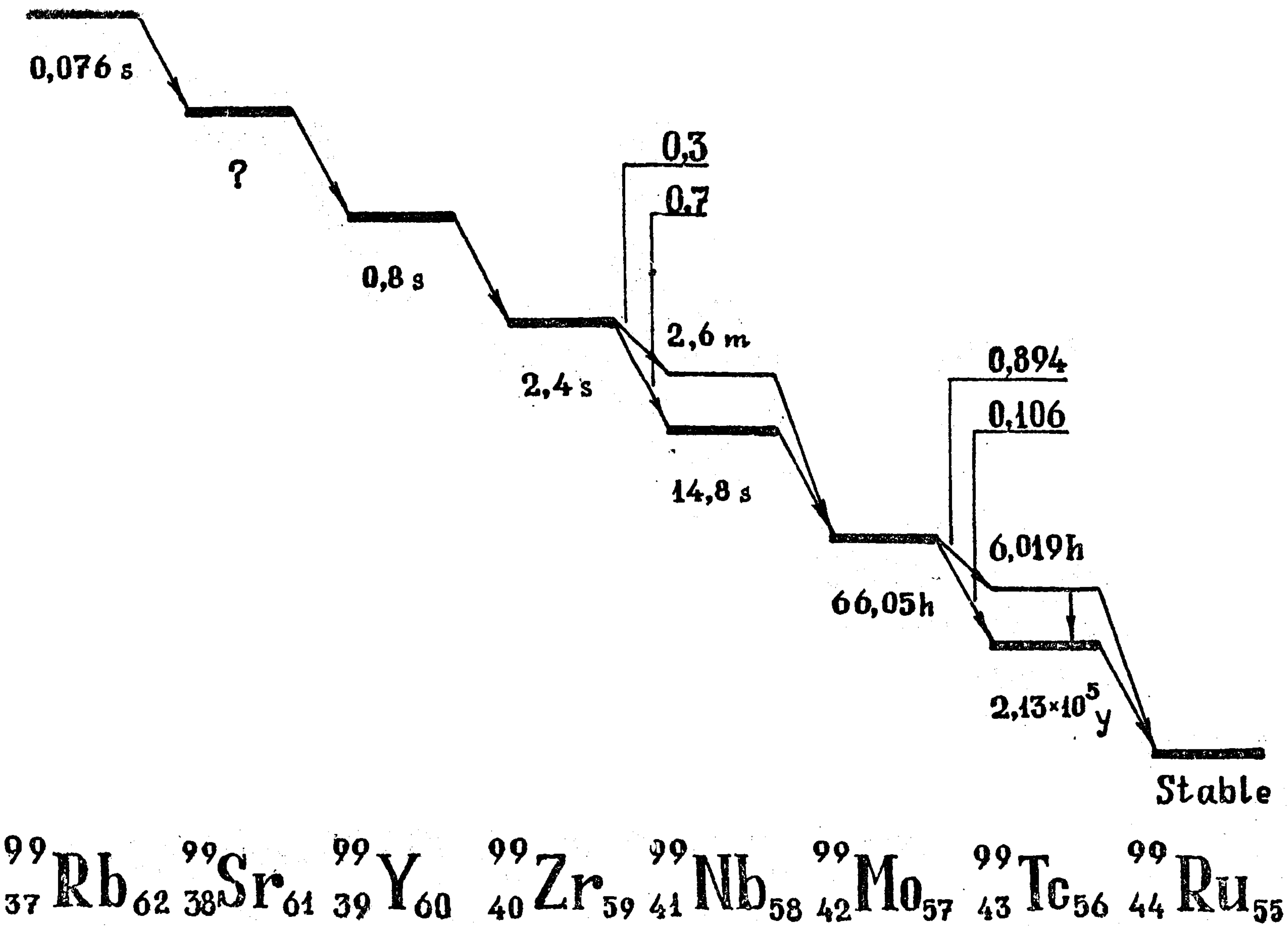

0,076 s
?
0,8 s
2,4 s
0,3
0,7
2,6 m
14,8 s
0,894
0,106
6,019h
66,05h
2,13×10⁵ y
Stable
99 37 Rb 62
99 38 Sr 61
99 39 Y 60
99 40 Zr 59
99 41 Nb 58
99 42 Mo 57
99 43 Tc 56
99 44 Ru 55

FIG. 1

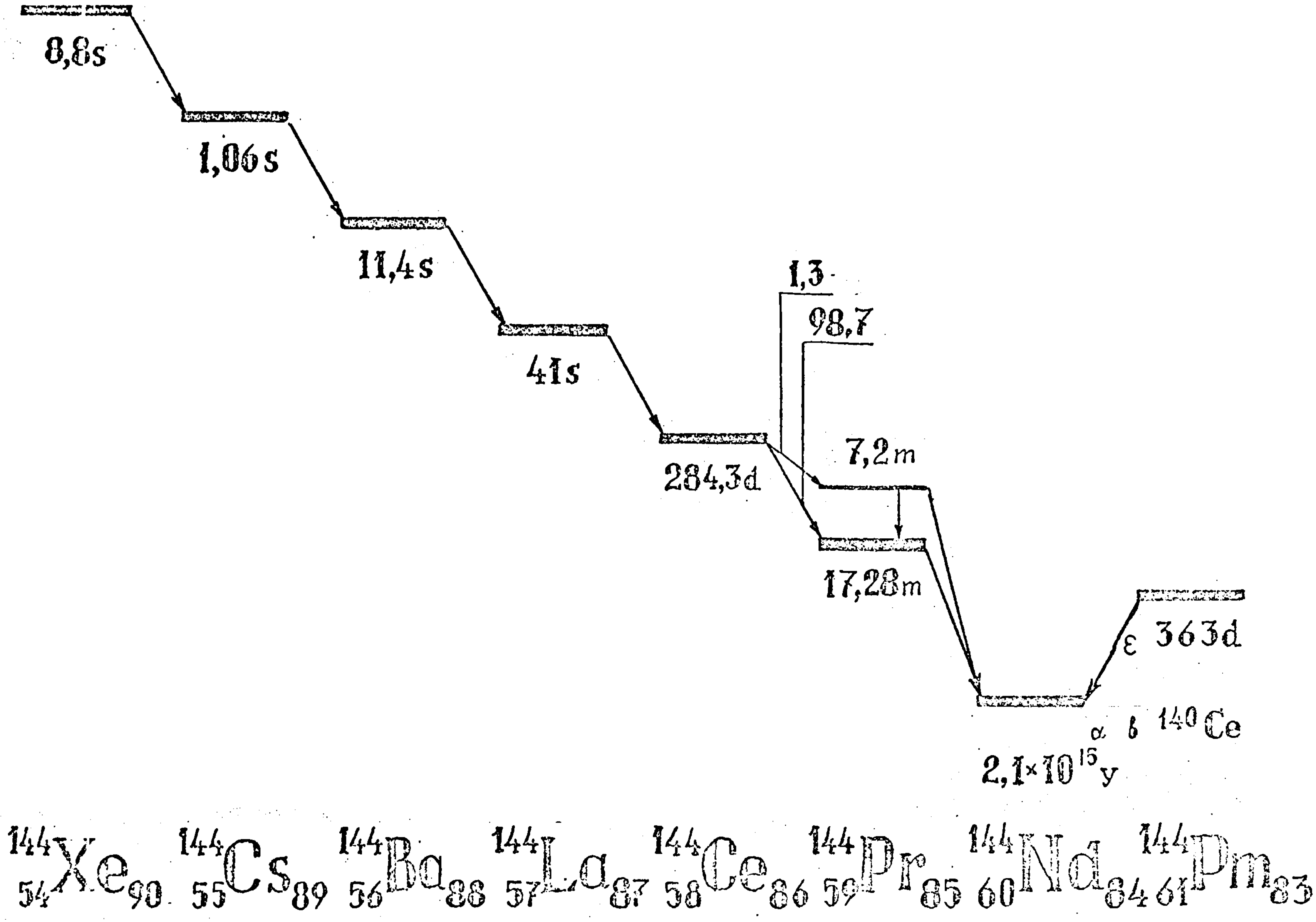
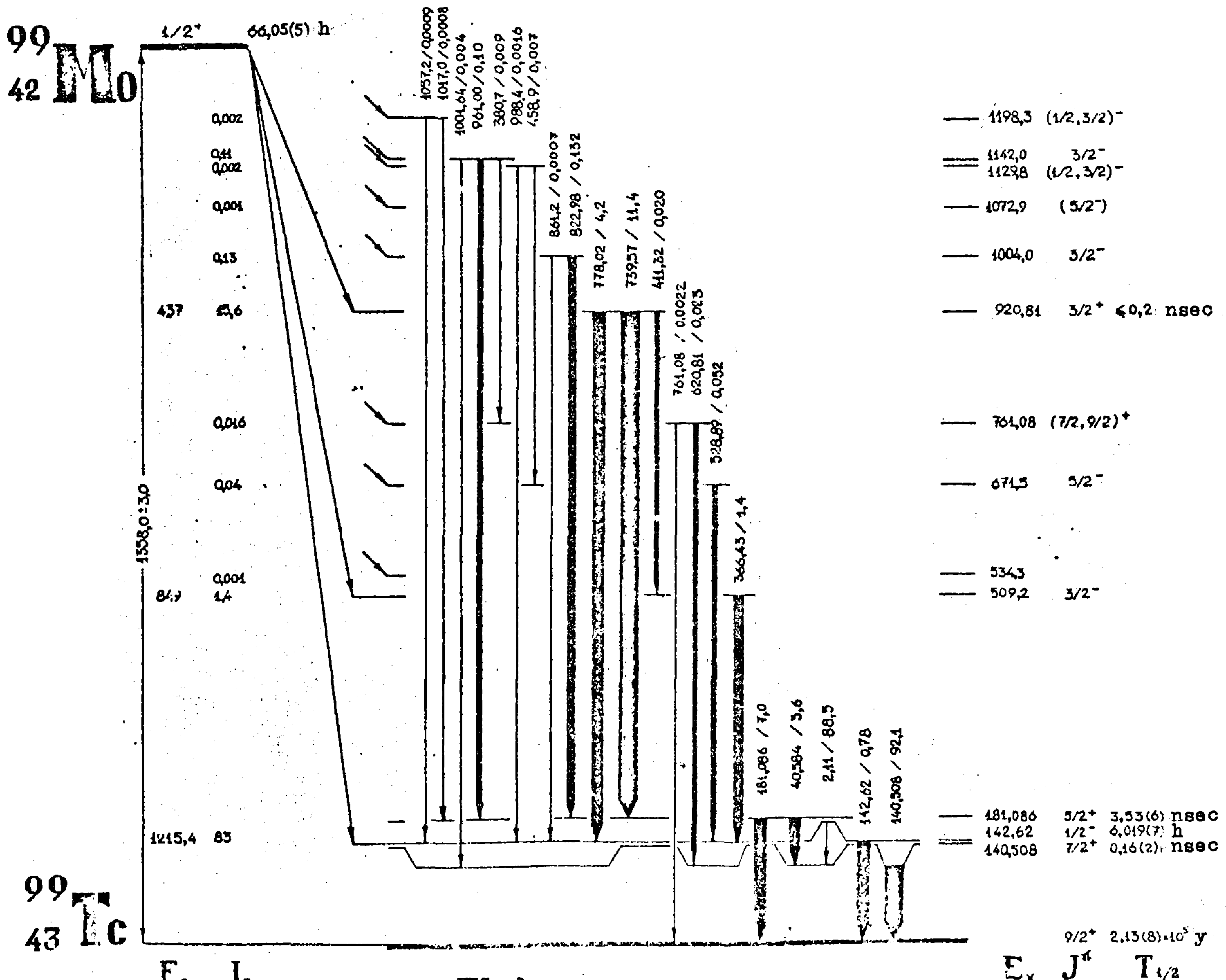
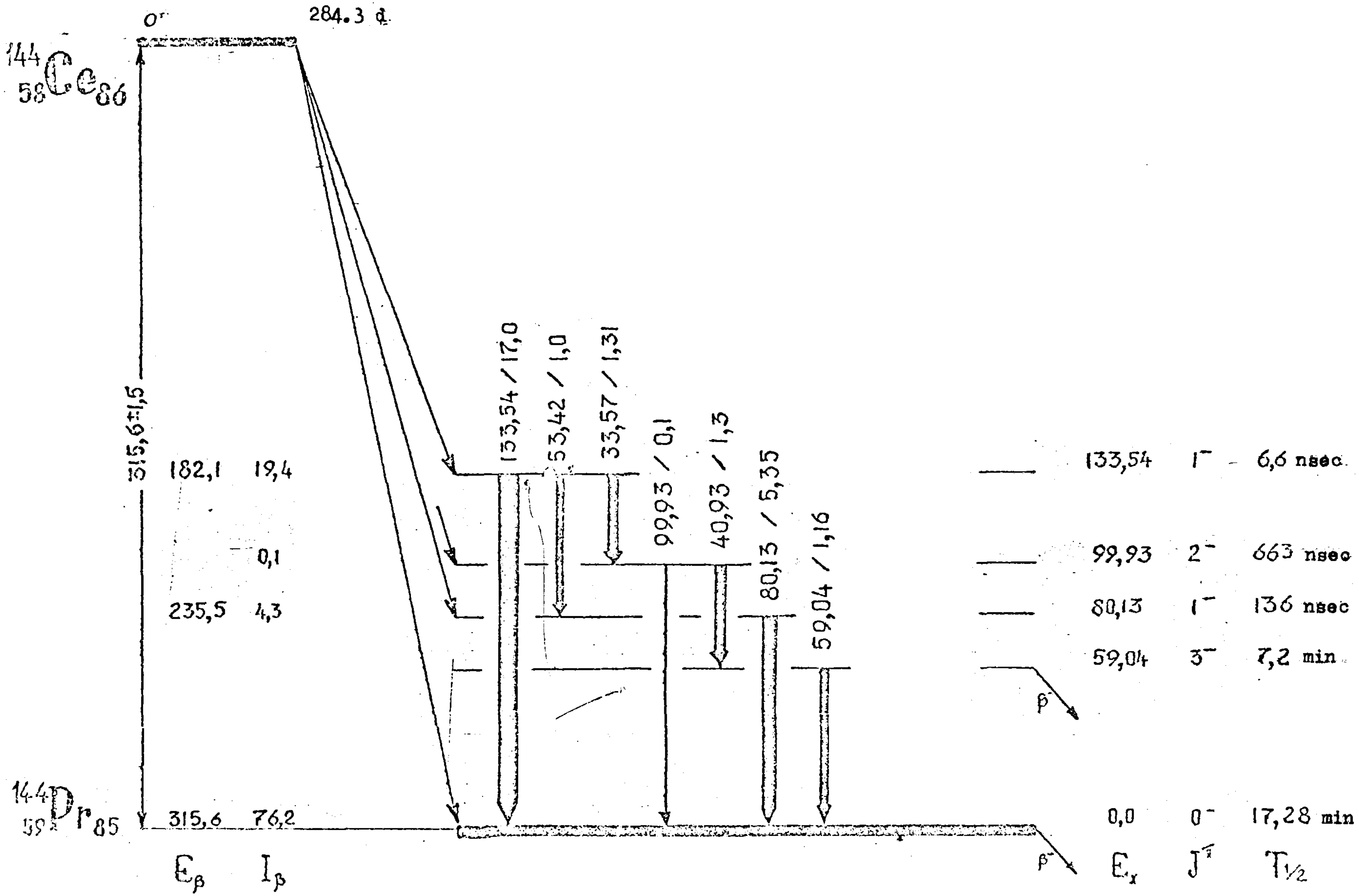

8,8s
1,06s
11,4s
41s
1,3
98,7
284,3d
7,2m
17,28m
ε 363d
α
140Ce
2,1×10^15 y
144 54 Xe 90
144 55 Cs 89
144 56 Ba 88
144 57 La 87
144 58 Ce 86
144 59 Pr 85
144 60 Nd 84
144 61 Pm 83

FIG. 2



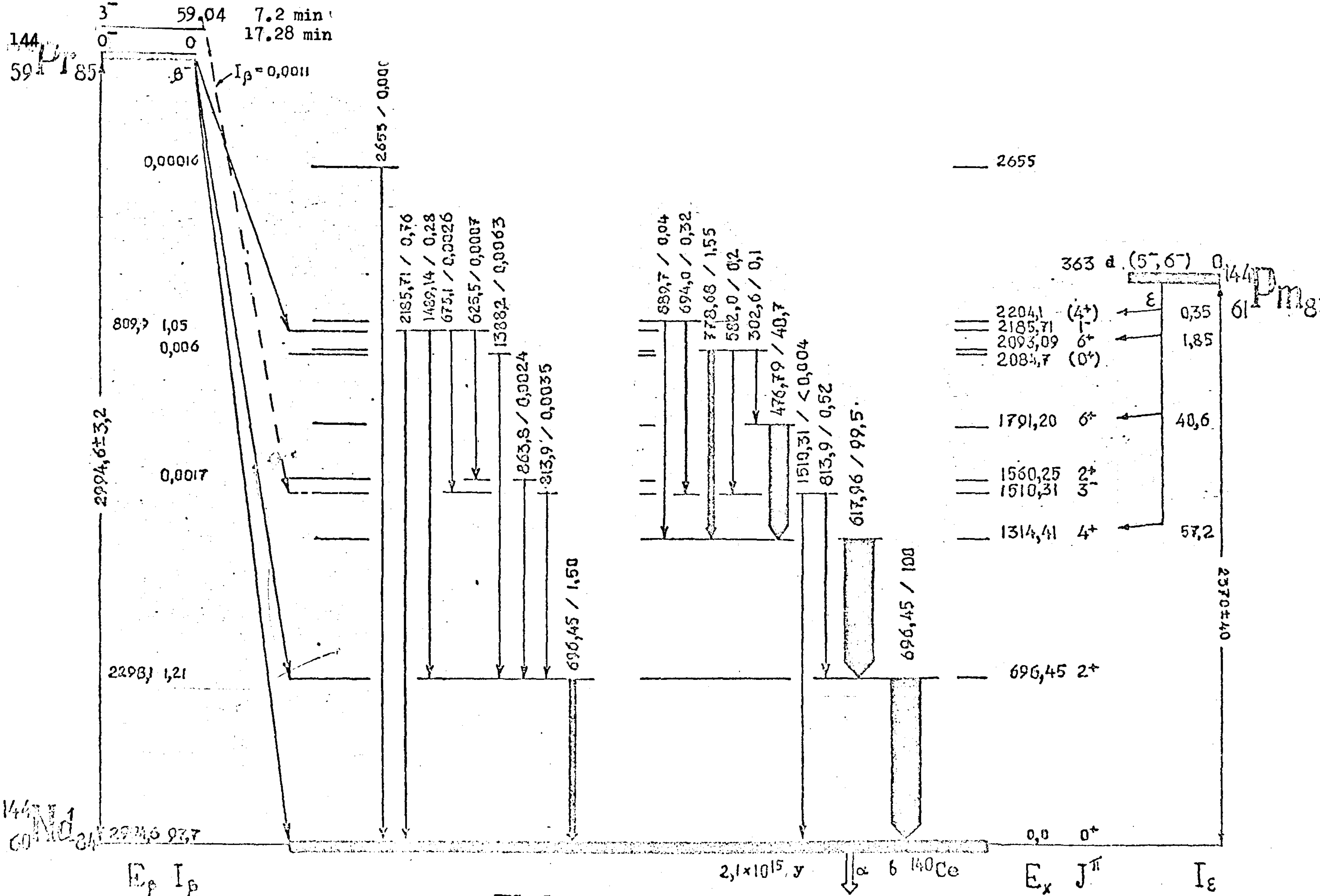
99 42 Mo
1/2+
66,05(5) h
99 43 Tc
1358,0±3,0
1198,3 (1/2,3/2)−
1142,0 3/2−
1129,8 (1/2,3/2)−
1072,9 (5/2−)
1004,0 3/2−
920,81 3/2+ ≤0,2 nsec
761,08 (7/2,9/2)+
671,5 5/2−
534,3
509,2 3/2−
181,086 5/2+ 3,53(6) nsec
142,62 1/2− 6,019(7) h
140,508 7/2+ 0,16(2) nsec
9/2+ 2,13(8)×10^5 y
437 15,6
849 1,4
1215,4 83
0,002
0,11
0,002
0,001
0,13
0,016
0,04
0,001
1057,2 / 0,0009
1017,0 / 0,0008
1001,64 / 0,004
961,00 / 0,10
380,7 / 0,009
988,4 / 0,0016
458,9 / 0,007
861,2 / 0,0007
822,98 / 0,132
778,02 / 4,2
739,57 / 11,4
411,32 / 0,020
761,08 / 0,0022
620,81 / 0,023
528,89 / 0,032
366,43 / 1,4
181,086 / 7,0
40,584 / 3,6
2,11 / 88,5
142,62 / 0,78
140,508 / 92,1
Eβ
Iβ
Ex
Jπ
T1/2

FIG. 3



0⁻
284.3 d
144 58 Ce 86
315,6±1,5
182,1 19,4
0,1
235,5 4,3
144 59 Pr 85
315,6 76,2
Eβ Iβ
133,54 / 17,0
53,42 / 1,0
33,57 / 1,31
99,93 / 0,1
40,93 / 1,3
80,13 / 5,35
59,04 / 1,16
133,54 1⁻ 6,6 nsec
99,93 2⁻ 663 nsec
80,13 1⁻ 136 nsec
59,04 3⁻ 7,2 min
0,0 0⁻ 17,28 min
β⁻
β⁻
Ex Jπ T1/2

FIG. 4



3⁻ 59,04 7.2 min
17.28 min
0⁻ 0
$^{144}_{59}Pr_{85}$
β⁻
I_β = 0,0011
2655 / 0,000
0,00016
2655
2185,71 / 0,76
1489,14 / 0,28
675,1 / 0,0026
625,5 / 0,0007
1388,2 / 0,0063
889,7 / 0,04
694,0 / 0,32
778,68 / 1,55
582,0 / 0,2
302,6 / 0,1
476,79 / 40,7
363 d (5⁻,6⁻) 0 $^{144}_{61}Pm_{83}$
ε
809,7 1,05
0,006
2204,1 (4⁺) 0,35
2185,71 1⁻
2093,09 6⁺ 1,85
2084,7 (0⁺)
863,8 / 0,0024
813,9 / 0,0035
1519,31 / < 0,004
813,9 / 0,52
617,96 / 99,5
1791,20 6⁺ 40,6
2994,6±3,2
0,0017
1560,25 2⁺
1510,31 3⁻
1314,41 4⁺ 57,2
696,45 / 1,50
696,45 / 100
2370±40
2298,1 1,21
696,45 2⁺
$^{144}_{60}Nd_{84}$ 2994,6 97,7
0,0 0⁺
2,1×10¹⁵ y
α 6 ^{140}Ce
E_β I_β
E_x J^π
I_ε

FIG. 5

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