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EVALUATION OF THE DECAY CHARACTERISTICS OF ^{3}H AND ^{36}CL

V.P. Chechev

V.G. Khlopin Radium Institute, St. Petersburg

DECAY DATA EVALUATIONS FOR ^{3}H AND ^{36}Cl. Decay data of the radionuclides ^{3}H and ^{36}Cl have been evaluated using the information published up to 1998.

1. Introduction

This article has been prepared as part of the workplan of the Radionuclide Data Centre at the V.G. Khlopin Radium Institute at the request of the Department for Nuclear Science and Engineering Research at the Ministry of the Russian Federation for Atomic Energy. The article presents the results of evaluation of the decay data of the radionuclides ^{3}H and ^{36}Cl, and of their atomic and nuclear characteristics, using the information published up to 1998. The work was carried out within the framework of the international project on decay data evaluation for widely used radionuclides: DDEP (Decay Data Evaluation Project)*. The number of such radionuclides is estimated to be approximately 300, and under the DDEP, it was agreed to distribute them among various groups participating in the project with subsequent expert assessment of the evaluations by all participants. At present, representatives of eight nuclear metrological laboratories from the United Kingdom, Germany, Spain, Russia and the United States of America are participating in the project. The project co-ordinator is Dr. Helmer from the Idaho National Engineering Laboratory (INEL). The Radionuclide Data Centre at the Radium Institute was given the task

* R.G. Helmer. International Decay Data Project. Proceedings of the International Symposium "Advances in α, β and γ-ray Spectrometry", Pushkin (St. Petersburg, Russia), September 1996. CIEMAT, Madrid, 1997, p. 71.

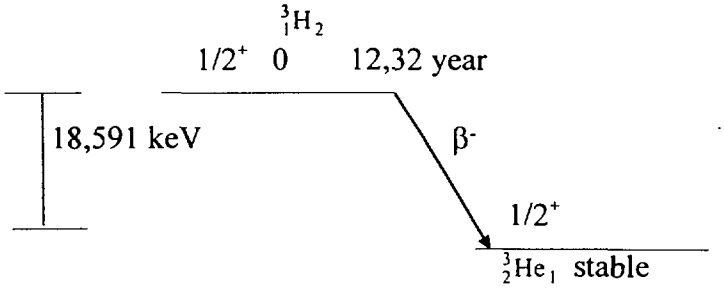
of evaluating the decay and radiation characteristics of the radionuclides ^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{36}Cl and ^{111}In in 1997-98. Accordingly, this article presents the results of the evaluation of the characteristics of two of the six above-mentioned radionuclides.

2. Evaluation of the data for ^{3}H

The results of the evaluation of the nuclear and atomic data for the radionuclide ^{3}H using information published up to 1998 are given below. The errors of these values are given in brackets in units of the last significant order of magnitude. The results of the evaluation are presented in the format adopted by the participants of the international co-operation project DDER.

2.1. Decay diagram

100% of ^{3}H is converted by the β-decay directly to the fundamental state of ^{3}He.



2.2. Nuclear data

$T_{½}$: 12.32 (2) years
$Q_{β^-}$: 18.591 (2) keV

2.2.1. β⁻-transition

	Energy, keV	Probability $P_{β^-}$	Nature	lg ft
$β^-$	18.591(2)	1	Allowed	3.05

2.3. Electron emission

	Boundary energy, keV	Average decay energy, keV	Number of electrons per 100 disintegrations
$β^-$	18.564(3)[*)]	5.68(1)	100

*) Calculated for a tritium atom: commentary, see Section 2.4.3.

2.4. Substantiation of the evaluated values obtained for the decay characteristics of ^3H

2.4.1. Half-life

Many measurements of the half-life of tritium have been presented in the literature [1-17] (see Table 2.1). Three of these stand out for their high level of accuracy [6, 9, 11]. However, in their studies, the errors indicated for $T_{½}(^3H)$, do not include an evaluation of the possible systematic errors of the methods used. Today, with the benefit of later measurements and discussions of the half-life of tritium, it is possible to evaluate the "external" minimum error of the measurement method as a result of systematic effects (σ_{min}), which should be added to the errors given in Refs [6, 9, 11]. Such an addition to the weighting of all the existing results of the measurements of tritium half-life is necessary in view of the following:

(a) The result of the measurement $T_{½}(^3H)$ by accumulating ^3He [6] was obtained using only two points on each decay curve (for two samples). In a later study carried out using the same method [10], many experimental points were obtained on the decay curves (also for two samples) and the evaluated systematic error was 0.6% for a confidence level P = 99.7%, i.e. 0.2% for P = 0.68;

(b) Reference [11] was a continuation of the measurements of Ref. [9] using the calorimetric method for two solid tritides over an additional 12 years. The relative difference in the results was 0.2% (P = 0.68) - more than 5 σ_{exp} [11] and 10 σ_{exp} [9];

(c) A comparative analysis of measurements of the radioactive concentrations of solutions in some NBS tritiated water standards over an 18-year period 1961-1978 [12] showed that for agreement of the measurements (with a given tritium half-life), their evaluated standard errors (including those for the calorimetric method) should not be less than 0.2%.

Thus, we have sufficient grounds for adding to the errors given in Refs [6, 9, 11] the "external" systematic error $\sigma_{min} = 0.002 - T_{½}(^3H)$.

Table 3.2 shows a set of data "1" which was generated from set "0" by omitting the results of two earlier studies with large errors [1, 2] and increasing the errors of Refs [6, 9, 11] up to ±0.25 years.

In addition, the result of Ref. [13], which was refined later in Ref. [17], was omitted, and the weighted mean of measurements [14, 16], performed by the same authors by observing the growth of ^3He, was used for the statistical treatment.

The next step in the selection of data ("1" → "2") is linked to the use of the statistical value X^2 [18]. As none of the experimental results for set "1" lead to a significant increase in the value of X^2, the sets of data "1" and "2", as well as set "3", which is formed after verifying the relative statistical weights of the results (LWM, see [18, 19]), are in agreement.

Table 2.1.: Results of the measurements of tritium half-life (data "0" set)

Reference		Half-life $T_{1/2}(\sigma)$, years	Method	Comments assigned on the error[1]
No.	NSR-ref			
1	40On** [a]	31(8)	Beta count	
2	47Go08	10.7(20)	Decrease in the ionization current	
3	47No01	12.1(5)	^{3}He accumulation	Error of the mean of the results of measurements for two samples
4	50Je60	12.46(10)	^{3}He diffusion	σ_{syst} included [d]
5	51Jo15	12.41(7) [b]	Beta count	σ_{syst} included [d]
6	55Jo20	12.262(4)	^{3}He accumulation	Error of the measurement for each of the two samples
7	58Po64	12.58(18)	Calorimetry	σ_{syst} included
8	66Me** [a]	12.31(13)	Absolute count	See [20]
9	67Jo09	12.346(2)	Calorimetry	Probable error in the external agreement of the measurements of six samples
10	67Jo10	12.25(3) [c]	^{3}He accumulation	σ_{syst} included [d]
11	77RuZZ	12.3232(43)	Calorimetry	See text
12	80Un** [a]	12.43(5)	Comparison of tritium standards	σ_{syst} included [d]
13	87Bu** [a]	12.29(10)	Beta count	See [20]
14	87Ol04	12.38(3)	^{3}He accumulation	σ_{syst} included [d]
15	875i01	12.32(3)	Implantation of ^{3}H in Si(Li)	σ_{syst} included [d]
16	89Ol** [a]	12.38(3)	^{3}He accumulation	σ_{syst} included [d]
17	91Bu13	12.31(3)	Bremsstrahlung	σ_{syst} included [d]

a NSR reference not found.
b The limits +0.15 -0.25 are given in 50Jo15; σ is calculated in 87Si01.
c The error +0.08 is quoted in 67Jo10 for a confidence level 99.7%.
d This denotes allowance for the contribution of possible components of the systematic error in the total error stated by the authors.

By comparing X^2=26.75 for the whole set of data (n=13) with the tabulated $(X^2)^{0.05}_{n-1}$ = 21.0, we can observe that there is only a small inconsistency in the data, and can use the WM, tS [18] or MBAYS [19] methods for the statistical treatment of data to obtain the recommended value, taking into account the independence of the measurements in Refs [3-17], performed using different methods. It should be noted that the UNIF, PINF, BAYS and NORM procedures give the same result for the recommended value for tritium half-life: $T_{1/2}$ =12.32(2) years (see Table 2.3). The recommended value is given to two decimal places, since the vast majority of processed experimental data do not have a third decimal place.

Table 2.2. Selected results of the Measurements of Tritium Half-life (set "1" = set "2" = set "3")

Year	Half-life $T_{½}(\sigma)$, years	Reference	
		No.	NSR-figure
1947	12.1(5)	3	47No01
1950	12.46(10)	4	50Je60
1951	12.41(7)	5	51Jo15
1955	12.262(25)[a]	6	55Jo20
1958	12.58(18)	7	58Po64
1966	12.31(13)	8	66Me**
1967	12.346(25)[a]	9	67Jo09
1967	12.25(3)	10	67Jo10
1977	12.323(25)[a]	11	77RuZZ
1980	12.43(5)	12	80Un**
1987, 1989	12.38(3)[b]	14,16	87Ol04, 89Ol**
1987	12.32(3)	15	87Si01
1991	12.31(3)	17	91Bu13

a Error taken as equal to 0.002 $T_{½}$, see text.

b Weighted mean of the results of the measurements 12.38(3) (87Ol04) and 12.38(4) (89Ol**).

Table 2.3.: Results of the Data Treatment using various Statistical Procedures, and Recommended Value of $T_{½}$ (^{3}H)

Procedure	Half-life (in years)	Error (in years)
UWM	0.12345E+02	0.32088E-01
WM	0.12321E+02	0.99788E-02
CHV	0.12346E+02	0.20309E-01
UINF	0.12321E+02	0.14899E-01
PINF	0.12321E+02	0.14899E-01
BAYS	0.12321E+02	0.16322E-01
MBAYS	0.12321E+02	0.15562E-01
LWM	0.12321E+02	0.14899E-01
LEXW	0.12333E+02	0.18600E-01
NORM	0.12321E+02	0.14899E-01
RAJ	0.12333E+02	0.10900E-01
WM, min	0.12322E+02	0.25000E-01
WM, tS	0.12322E+02	0.16320E-01
Recommended value	12.32 ± 0.02 years	

2.4.2. Tritium decay energy (Q_{β^-})

G. Audi and A.H. Wapstra [21] recommend a value of 18.591(1) keV for the difference in mass of ^{3}H-^{3}He () $Mc^2=Q_{\beta^-}$), using measurements performed with different methods between 1985 and 1993. Table 2.4 shows the results of the measurements of Q_{β^-} as they were given in Ref. [39], with the addition of 83De47 and new references [41-44] up to 1995.

Table 2.4.: Recent measurements of the difference in mass of ^{3}H-^{3}He

Mc^2 (eV)	Method	Year	Reference	
			No.	NSR-figure
18590(10)	Radio frequency mass spectrometry	1975	22	75Sm02
18579(12)	Radio frequency mass spectrometry	1981	23	81Sm02
18575(7)	Implantation in Si(Li)	1983	24	83De47
18584(4)	Ion cyclotron resonance doublet	1984	25	84Ni16
18599(2)	Ion cyclotron resonance doublet	1985	26	85L102
18582(3)	Ion cyclotron resonance doublet	1985	27	85Ta2K
18590(8)	Implantation in Si(Li)	1985	28	85Si07
18581(3)	Ion cyclotron resonance doublet	1986	29	86Go** [a]
18603(10)	Beta spectrometry	1986	30	86Fr09
18599(4)	Beta spectrometry	1987	31	87Bo07
18603(5)	Beta spectrometry	1987	32	87Ka** [a]
18586(6)	Implantation in Si (Li)	1988	33	88BrZN
18589.0(26)	Beta spectrometry	1989	34	89St05
18595(6)	Bremsstrahlung	1991	35	91Bu12
18590.6(20)	Beta spectrometry	1991	36	91Ro07
18590.9(30)	Beta spectrometry	1991	37	91Ka41
18591.0(20)	Beta spectrometry	1992	38	92Ho09
18590.1(17)	Penning trap MS	1993	39	93Va04
18591(3)	Beta spectrometry	1993	40	93Ba08
18597(5)	Beta spectrometry	1993	41	93Su32
18589(2)	Beta spectrometry	1995	42	95St26
18597(14)	Beta spectrometry	1995	43	95H114
18591(3) [b]	Beta spectrometry	1995	44	95Lo** [a]
Average weighting ± [tS or MBAYS]		18590.6+1.1 eV σ_{min}=1.7 eV		
Recommended value		18591(2) eV		

a NSR figure not found.
b Calculated by the evaluator.

The original results in Table 2.4 for measurements using beta spectrometry have been corrected for the spectra of final states, using the analysis by Kaplan, et al. [45]. The Si(Li) measurements have been corrected for the chemical shift +10(3) eV, evaluated by Redondo and Robertson [46].

The weighted mean of all 23 results is equal to 18590.6(7) eV with X^2=61 (reduced $X^2/(n-1)$=2.8). This is not too great a deviation in the results, as the tabulated $(X^2)^{0.05}_{22}$ is equal to 34. In order to obtain the total error of the evaluated value taking into account the independence of the measurements [22-44], it is possible to use the [WM, tS] [18] or [MBAYS] [19] methods of statistical data treatment: Q'_β=18590.6+1.1 eV (σ_{min}=1.7 eV). However, considering the uncertainty of the error associated with correction for the spectra of final states [45], and the absence in the vast majority of cited results of measurements of decimal fractions of eV, we give the recommended value of Q_β- as 18591(2) eV.

2.4.3. Beta spectrum boundary energy of tritium (E^0)

The beta spectrum boundary energy of tritium depends on the chemical composition of the tritium in the experiment. The expression for E^0_β of molecular tritium differs from E^0_β of a "bare" nucleus by the energy of the chemical shift ΔE=B(RHe+)-B(RT) [45, 46] which is calculated taking into account the spectrum of final states (SFS). (Here, the quantities B denote the electron binding energy for an He^+ ion and a tritium atom, and R denotes the chemical composition.)

For the known difference in the atomic mass of ^{3}He-^{3}H (ΔMc^2), the beta spectrum boundary energy of tritium, measured in a certain experiment, is equal to:

$$E'^0_\beta = \Delta Mc^2 \; E_{rec} - [B(He)-B(T)] + [B(RHe^+)-B(RT)],$$

where E_{rec} is the recoil energy of a helium ion.

For a tritium atom

$$E^0_\beta = \Delta Mc^2 - 3.4 \text{ eV} - 64.3 \text{ eV}$$

where ΔE=40.82 eV. Using the recommended value for Mc^2, the beta spectrum boundary energy of the tritium nuclide is obtained in this way as 18564 eV. It is difficult to evaluate the error in the calculation of ΔE [45]. Assuming that it is approximately equal to the evaluated error for ΔMc^2, we obtain E^0_β(^{3}H-nuclide)=18.564(3) eV.

For the real chemical forms of tritium sources in beta spectrometry, the boundary energies of beta particles of ^{3}H differ from the atomic value. For the molecular forms of HT, CH_3T and valine, the calculated value of E^0_β amounts to 18572(3) eV, on the assumption that Q_β=18591(2) eV. The boundary energies E^0_β measured in recent experiments are given below:

87Bo07	valine	18579.4±4 eV
93Ba08	molecular tritium	18574.8±0.6 eV
95Su32	$C_{14}H_{16}TeO_2N_3$	18578.3±5.1 eV
95St26	gaseous tritium	18568.5±2.0 eV
95Lo**	gaseous tritium	18570.5 eV

2.4.4. Average energy of the beta particles of tritium per disintegration (<E_β>)

Table 2.5 shows the available data concerning <E_β>. The recommended value of <E_β> was obtained as a weighted mean after corrections had been made to the original results of experiments and calculations. The calculation of <E_β> for the recommended value Q_β=18.591(2) keV with the LOGFT program used in ENSDF evaluations, results in a value of 5.68(10) keV [55].

Table 2.5.: Available data on the average energy of beta particles of tritium per disintegration

Reference		Method	Published value (keV)	Corrected value (keV)	Adopted value (keV)
No.	NSR figure				
4	50Je60	Calorimetry	5.69(4)	1 5.69(4)[a]	5.68(4)
47	58Gr93	Calorimetry	5.57(1)	5.68(2)[c]	5.68(2)
48	61Ói01	Calorimetry	5.73(3)	5.68(3)[b]	5.68(3)
49	72Ma72	Calculation	5.		5.7(1)[e]
50	85Ma**	Calculation	5.684(5)	5.680(5)[d]	5.68(1)
51	85Ga**	TDCR*)	5.70		5.70(2)[e]
52	87La**	Calculation	5.71(3)	5.70(3)[d]	5.70(3)
Recommended value				5.68(1) keV	

a Corrected for the adopted $T_{1/2}(^3H)$=12.32(2) years and a thermal output of 0.324(1) W/year.
b Corrected for the adopted $T_{1/2}(^3H)$=12.32(2) years.
c Corrected for the adopted $T_{1/2}(^3H)$=12.32(2) years and a thermal output 0.324(1) W/year.
d Corrected for the recommended value of the decay energy (Q_β = 18.5906 keV).
e Error adopted by the evaluator.
*) See also 94Si21 [53].

2.5. REFERENCES

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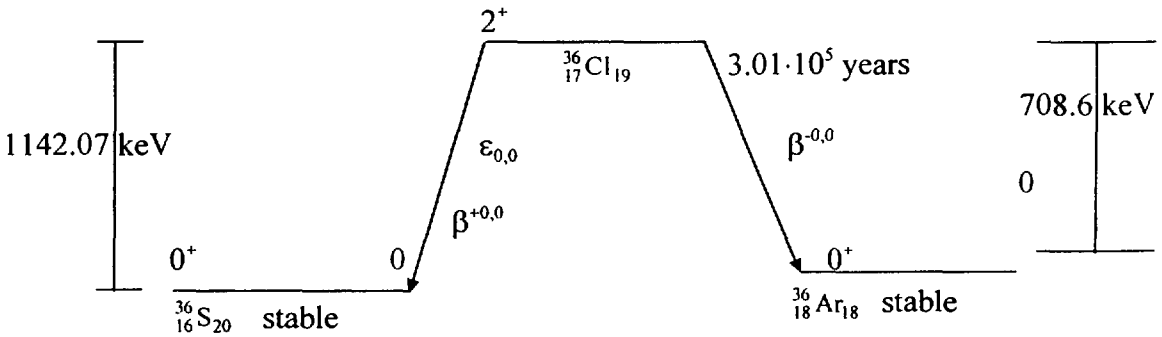
3. Evaluation of the data for ^{36}Cl

The results of the evaluation of nuclear and atomic data for the radionuclide ^{36}Cl using information published up to 1998 are given below. In contrast to ^{3}H, the amount of new published data for ^{36}Cl is quite small and the evaluated values of the characteristics have changed little in comparison with the reference data of 1980 and 1990.*

3.1. Decay scheme

98.1% of ^{36}Cl is converted by β^- decay to the ground state of ^{36}Ar, 1.9% is converted by electron capture, and 0.0017% is converted by β^+ decay to the fundamental state of ^{36}S.



3.2. Nuclear data

$T_{½}$: 3.01(3)·10^5 years
Q_{β^-}: 708.6(3) keV
Q_{ε}: 1142.07(25) keV

3.2.1. β^--transition

	Energy, keV	Probability P^-	Nature	lg ft.
$\beta^{-0,0}$	708.6(3)	0.981(1)	Non-unique second-order forbidden	3.05

* Khol'nov, Yu.V., Chechev, V.P., Kamynov, Sh.V., Kuz'menko, N.K., Nedovesov, V.G., Characteristics of the radiation of radionuclides used in the national economy. Evaluated data. Handbook. Moscow, Atomizdat, 1980;

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3.2.2. Electron capture transition

	Energy keV	Probability P_{ec}	Nature	lg ft	P_k	P_L	P_M^+
$\varepsilon_{0,0}$	1142.07(25)	0.019(1)	Non-unique second- order forbidden	13.5	0.901(7)	0.089(7)	0,010(1)

3.2.3. β^+-transition

	Energy, keV	Probability P_β^+	Nature	lg ft
$\beta^{+0,0}$	120.07(25)	$1.5(3)\cdot10^{-5}$	Non-unique second-order forbidden	14,5

3.3. Atomic data

S, Z = 16 ω_K 0.0804(19)
nKL 1.807(5)
Ar, Z = 18 ω_K 0.120(3)
nKL 1.697(6)

3.3.1. X-radiation

		Energy, keV	Relative probability
S	XK	2.3066-2.464	
	$K\alpha_2$	2.3066	0.505(3)
	$K\alpha_1$	2.3078	1
	$K\beta$	2.457-2.464	0.093(6)
Ar	X_K	2.9453-3.190	
	$K\alpha_2$	2.9453	0.505(3)
	$K\alpha_1$	2.9574	1
	$K\beta$	3.177-3.190	0.162(5)

3.3.2. Auger electrons

		Energy, keV	Relative probability
S	eAK	1.98-2.46	
	KLL	1.98-2.12	1
	KLX	2.22-2.30	0.124(8)
	KXY	2.44-2.46	0.0039(5)
Ar	eAK	2.51-3.17	
	KLL	2.51-2.60	1
	KLX	2.83-2.93	0.216(7)
	KXY	3.14-3.17	0.0116(7)

3.4. Radiation emission

3.4.1. Electron radiation

		Energy, keV	Number of electrons per 100 disintegrations
	β^-	0-1142	98.1(1)
S	eAK	1.98-2.46	1.57(10)
	KLL	1.98-2.12	1.40(9)
	KLX	2.22-2.30	0.17(2)
	KXY	2.44-2.46	0.005(1)
Ar	eAK *)	2.51-3.17	0.130(19)
	KLL	2.51-2.60	0.106(16)
	KLX	2.83-2.93	0.023(4)
	KXY	3.14-3.17	0.0012(2)

*) Emission of Auger electrons of Ar is associated with the autoionization of the K-shell accompanying the β^- decay of ^{36}Cl.

3.4.2. Photon radiation

		Energy, keV	Number of photons per 100 disintegrations
S	XK	2.3066-2.464	0.38(8)
	$K\alpha_2$	2.3066	0.044(3)
	$K\alpha_1$	2.3078	0.086(5)
	$K\beta$	2.457-2.464	0.0080(7)
Ar	XK *)	2.9453-3.190	0.0205(30)
	$K\alpha_2$	2.9453	0.0062(10)
	$K\alpha_1$	2.9574	0.0123(19)
	$K\beta$	3.177-3.190	0.0020(3)
	γ_a **)	511.00	0.0030(6)

*) *Emission of KX radiation of Ar is associated with autoionization of the K-shell accompanying β^- decay of ^{36}Cl.*

**) *Annihilation γ_a radiation occurs in the source from positrons of β^+* decay.

3.4.3. β^--particles

	Boundary energy, keV	Average energy, keV	Average energy per disintegration, keV $<E_{\beta^-}>$	Number of electrons per 100 disintegrations
β^-	708.6(3)	251.20(11)*)	246.4(4)*)	96.1(1)

*) Calculated for the allowed form of the β^- spectrum; see Section 3.6.7.

3.4.4. β^+- particles

	Boundary energy, keV	Average energy, keV	Average energy per disintegration, keV $<E_{\beta^+}>$	Number of electrons per 100 disintegrations
β^+	120.07(25)	50.24(10)*)	0.075(15)*)	0.0015(3)

*) Calculated for the allowed form of the β^+ spectrum; see Section 3.6.7.

3.5. Basic mode of production $^{35}Cl(n,\gamma)^{36}Cl$

3.6. Substantiation of the evaluated data obtained for the decay characteristics of ^{36}Cl

3.6.1. Decay scheme and decay energies

The decay scheme for ^{36}Cl is based on the measurements in Refs [1, 2]. The decay energies (Q_{β^-},Q_{ε}) are taken from Ref. [5]. They are based on many measurements. The references to earlier measurement results (up to 1980) can be found in the handbook [19].

3.6.2. Half-life

Measured values of the partial half-life of ^{36}Cl for β^- decay and also $^{36}Ar(T_{1/2}\beta^-)$ are presented in Table 3.1.

Table 3.1.: Results of the measurements of the half-life of ^{36}Cl for decay of $^{36}Cl \rightarrow {}^{36}Ar$

Reference		$T_{1/2}\ \beta^-$ in 10^5 years	Method
No.	NSR figure		
14	47Hu**	20	
15	470v**	10	
16	49Re**	2	
10	49Wu15	4,4(5)	Specific activity β(GM)
11	55Ba93	3,08(3)	Specific activity 4πβ(pc)
12	57Wr37 [a]	2,6(4)	Cl(n,γ)-yield, β(GM)
12	57Wr37 [b]	2,5(4)	Specific activity, β(GM)
13	66Go07 [a]	3,10(4)	Specific activity, 4πβ(pc)
13	66Go07 [b]	3,06(2)	Specific activity, liquid scint.

Six results of measurements with stated error [10-13] were selected for statistical data treatment (set "1" = set "2", see description of the evaluation technique in Ref. [17]). In set "2" among the six results the weight of the measurement 66Go07[b] exceeds 0.50 (58.5%). Taking this into account and using the LWM procedure [18], the data set "3" was formed. The final results of the data treatment are shown below.

Table 3.2.: The results of treatment of data for $T_{½}$ β^- ^{36}Cl, obtained using various statistical procedures

Procedure	Half-life (period) (β^-), in 10^5 years	Error, in 10^5 years
UWM	0.31233E+01	0.27681E+00
WM	0.30732E+01	0.16890E-01
CHV	0.23630E+01	0.13094E+00
UINF	0.30732E+01	0.25392E-01
PINF	0.30732E+01	0.25392E-01
BAYS	0.30732E+01	0.32781E-01
MBAY8	0.30732E+01	0.28389E-01
LWM	0.30732E+01	0.25392E-01
IEXW	0.30647E+01	0.24180E+00
NORM	0.30729E+01	0.18892E-01
RAJ	0.30722E+01	0.18897E-01
WM, tS	0.30732E+01	0.27931E-01
Recommended value	$3.07(3)\cdot10^5$ years	

The weighted mean with error tS was chosen as the recommended value:

$$T_{1/2\beta^-}(^{36}Cl) = (3.07\pm0.03)\cdot10^5 \text{ years}$$

Hence, the **total** half-life of ^{36}Cl is obtained as

$$T_{1/2\beta^-} \times 0.981(1) = 3.01(3)\cdot10^5 \text{ years}$$

3.6.3. Electron capture

The recommended values of P_K, P_L and P_M were calculated using the ratio $P_L/P_K=0.099(8)$, which was obtained as the weighted mean of the theoretical value $(P_L/P_K)_T=0.094(5)$ and the experimental value $(P_L/P_K)_{exp}=0.112(8)$, measured in Ref. [8]. The theoretical value $(P_L/P_K)_T$ was obtained from the tables in Ref. [6] and with the aid of the LOGFT program on the assumption of an allowed transition, using the Q_ε value and taking into account the error of using P_K and P_L for the allowed transition instead of the unknown P_K and P_L for the non-unique second-order forbidden transition of $^{36}Cl \rightarrow ^{36}S$ (0.0). According to Ref. [20] the error from using P_K and P_L tabulated in Ref. [20] is no more than 3% for such transitions, if Q is much greater than the electron binding energy on the K-shell and the nuclear charge is small. For the purposes of comparison, note that calculation of P_L/P_K for the allowed transition with the LOGFT program gives 0.0944 in agreement with the tables of Ref. [6]. For the relative error $(P_L/P_K)_T$, we have taken a conservative estimate of 5%, considering the nature of the transition $\varepsilon_{0.0}$ (second-order forbidden). The error of the

recommended (weighted mean) value P_L/P_K=0.099(8) was obtained in accordance with the evaluation procedure in Ref. [17] as the scattering error S=0.008.

The ratio P_{M+}/P_K=0.0115(12) was taken from the tabular values of P_{M+}, P_K for allowed transitions with an error of 10%.

The probability of electron capture P_{EC}=0.019(1) was calculated, using the measured ratio $P\varepsilon_K/P_{\beta^-}$=0.017(1) [1].

3.6.4. β^+-transitions

The probability $P_{\beta+}=1.5(3)\cdot10^{-5}$ as obtained by averaging the experimental data presented in Table 3.3.

The recommended value was obtained as the weighted mean using the LWM-procedure (see [17, 18]), which involved reducing the weight of the result of the measurement 67Pi03 up to 50% prior to the final averaging.

3.6.5. β^--transition

The probability P_{β^-}=0.981(1) was calculated using the balance equation $P_{\beta^-}=1-P_{EC}-P_{\beta+}$.

3.6.6. Atomic data

The atomic constants ω_K, n_{KL} were taken from Ref. [7]. The X-radiation energies were calculated from the wavelengths (in Å) given in Ref. [9]. The Auger electron energies were taken from Ref. [4].

The relative probabilities of the emission of components of KX-radiation and K-Auger electrons were taken from the tables in Ref. [7].

3.6.7. Radiation characteristics

The probabilities of emission of K-Auger electrons and components of KX-radiation from sulphur were calculated from the probability of electron capture P_{EC} and the adopted values of P_K and ω_K.

The probabilities of emission of K-Auger electrons and components of KX-radiation from argon were calculated from the ratio $P_{XK}(Ar)/P_{XK}(S)$=0.149(22) found in Ref. [3], and the atomic data in Section 3.3.

The number of photons per 100 disintegrations for annihilation radiation was calculated as $2I_{\beta+}$ where $I_{\beta+}$ is the number of β^+ decay positrons per 100 disintegrations.

The β^-spectrum boundary energy for ^{36}Cl was obtained from the relation $E_{\beta^-} = Q_{\beta^-} - E_m$, where E_m is the recoil nucleus energy. The β^+-spectrum boundary energy for ^{36}Cl was calculated as $E_{\beta+} = Q_\varepsilon - E_m - 1022.00$ keV. The average energies of the $\beta^\pm$-spectra, calculated using the data in the tables of Ref. [20] and the LOGFT program on the assumption of an

allowed form are not the actual average $\beta^{\pm}$-particle energies, since $\beta^{\pm}$-transitions of ^{36}Cl are related to non-unique forbidden transitions with the spin variation 4I=2. The nuclear matrix elements for the probabilities of these transitions are not known. Mantel has [23] calculated the average energy of the β^{-}-spectrum for ^{36}Cl as 320 keV, assuming the spectrum to be close to the unique first-order forbidden form. This value is significantly higher than the one given in Section 3.4.3 for the allowed form of the beta-spectrum.

Table 3.3.:Results of the measurement of the probability of β^{+} decay of ^{36}Cl ($P_{\beta}+$)

Reference		P^{+} (x 10^{5}) (Set "1" = "2")	P^{+} (x 10^{5}) (Set "3")
No.	NSR figure		
8	62Do07	1.2(5)	1.2(5)
21	62Be29, 63Be38	2.3(9)	2.3(9)
22	65To**	1(1)*)	1(1)
2	67Pi03	1.06(11)	1.60(40)
Recommended value		1,5(3)	

*) Error assigned by the evaluator.

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