^{3}H – Comments on Evaluation by V.P. Chechev

The initial ^{3}H decay data evaluation was done by Chechev in 1998 (1999Be). This current (revised) evaluation was carried out in April 2006. The literature available by April 2006 was included.

1. DECAY SCHEME

^{3}H decays 100 % by β^--emission directly to the ground state of ^{3}He.

2. NUCLEAR DATA

Q^- value is from 2003Au03.

The evaluated ^{3}H half-life is based on the experimental data given in Table 1. This table has been taken from the paper of Lucas and Unterweger (2000Lu17) which contains a comprehensive review and critical evaluation of the half-life of tritium.

Table 1. Experimental values of the ^{3}H half-life (in years)

Reference	Author(s)	Measurement method	Half-life (years)	Stated uncertainty (years)	Meaning of the stated uncertainty	Comments
1936 McMillan	McMillan	Ionization current	>10	None	No uncertainty	Followed decay of radiation from irradiated beryllium for 4 months. OMITTED: limit only
1939 Alvarez	Alvarez and Cornog	Beta counting	0.41	0.11	Not given	One sample followed for 80 d. Chamber had diffusion losses. OMITTED: updated in 1940Alvarez
1940 Alvarez	Alvarez and Cornog	Beta counting	>10	None	No uncertainty	One sample followed for 5 months in new chamber. OMITTED: limit only
1940On01	O'Neal and Goldhaber	Beta counting	31	8	Not given	Counted tritium from irradiated lithium metal. OMITTED: outlier
1947Go08	Goldblatt *et al.*	Ionization current	10.7	2.0	Not given	Hydrogen + tritium in ionization chamber over 18 d. OMITTED: outlier
1947No01	Novick	Helium-3 collection	12.1	0.5	Not given	Two samples; accumulation times of 51 d and 197 d
1949Jenks	Jenks *et al.*	Helium-3 collection	12.46	0.20	Not given	Repeated measurements every two weeks until stable. OMITTED: updated in 1950Je60
1950Je60	Jenks *et al.*	Helium-3 collection	12.46	0.10	Probable error [a]	Four measurements over 206 d.
1951Jo15	Jones	Beta counting	12.41	0.05	Probable error [a]	Measurement of specific activity of tritium gas
1955Jo20	Jones	Helium-3 collection	12.262	0.004	Not given	Two samples; accumulation times of 578 d and 893 d
1958Po64	Popov *et al.*	Calorimetry	12.58	0.18	Not given	One sample; 21 measurements over 13 months
1963 Eichelberger	Eichelberger *et al.*	Calorimetry	12.355	0.010	Probable error [a]	Two samples measured over four years. OMITTED: updated in

						1967Jo09
1966Merritt	Merritt and Taylor	Beta counting	12.31	0.13	Not given	Five gas counting measurements over 13 years
1967Jo09	Jordan *et al.*	Calorimetry	12.346	0.002	Probable error [a]	Five samples; 266 measurements over 6 years. OMITTED: updated in 1977RuZZ
1967Jo10	Jones	Helium-3 collection	12.25 12.31	0.08 0.42	99.7 % confidence limits	Two samples; accumulation times of 450 d to 800 d. Only the first value is usually quoted
1977RuZZ	Rudy and Jordan	Calorimetry	12.3232	0.0043	95 % confidence limits	Eight samples; 1353 measurements over 16 years
1980Un01	Unterweger *et al.*	Beta counting	12.43	0.05	1 standard uncertainty	Two sets of gas counting measurements 18 years apart. OMITTED: updated in 2000Unterweger
1987Bu28	Budick *et al.*	Bremsstrahlung counting	12.29	0.10	Not given	Two samples of tritium + xenon gas measured over 320 d. OMITTED: updated in 1991Bu13
1987Ol04	Oliver *et al.*	Helium-3 collection	12.38	0.03	1 standard uncertainty	Fifteen samples, each with accumulation times of 1 year to 2 years
1987Si01	Simpson	Beta counting	12.32	0.03	1 standard uncertainty	Tritium implanted in Si(Li) detector measured over 5.5 years
1988 Akulov	Akulov *et al.*	Helium-3 collection	12.279	0.033	1 standard uncertainty	Five series of measurements over 846 d
1991Bu13	Budick et al.	Bremsstrahlung counting	12.31	0.03	1 standard uncertainty	Two samples of tritium + xenon gas measured over 5.5 years
2000 Unterweger	Unterweger and Lucas	Beta counting	12.33	0.03	1 standard uncertainty	Three sets of gas counting measurements over 38 years

[a] The probable error, PE , is the deviation from the population mean, μ , such that 50 % of the observations may be expected to lie between μ – PE and μ + PE . For a normal distribution, the probable error can be converted to the standard deviation by multiplying by 1.4826.

As seen from Table 1 there are a number of measurements of the tritium half-life. Three of them stand out by their high precision (1955Jo20, 1967Jo09, 1977RuZZ). However, the uncertainties stated for the half-life in these works do not include an estimation of possible systematic errors. There are available newer measurements and discussions of the tritium half-life, so it is possible to estimate an "external" minimum uncertainty due to systematic effects (σ_{min}) that should be added to the uncertainties stated in 1955Jo20, 1967Jo09 and 1977RuZZ. At that we can take into account the following circumstances:

a) The ^{3}He collection result of 1955Jo20 has been obtained using only two points on each decay curve (for two samples). In the later work by the same method (1967Jo09) many experimental points were obtained on the decay curves (also for two samples) and the estimated systematic uncertainty made up 0.8 % for a 99.7 % confidence level.

b) The result of 1977RuZZ is a continuation of the measurements of 1967Jo09 for two tritide solids by calorimetric method for an additional 12 years. The difference of results of 1967Jo09 and 1977RuZZ proved to be 0.2 %, more than 5σ_{exp} from 1977RuZZ and more than 10σ_{exp} from 1967Jo09.

c) The comparative analysis of measurements of the radioactivity concentrations in several NBS tritiated-water standards over an 18-year period 1961 - 1978 (1980Un01) showed that for agreement of measurements (at given tritium half-life) their estimated standard errors (including a calorimetric method) should not be less 0.2 %.

Thus we have sufficient grounds for adding the "external" systematic error $\sigma_{min} = 0.002 \cdot T_{1/2}$ (^{3}H) into the uncertainties quoted in 1955Jo20, 1967Jo09 and 1977RuZZ. Lucas and Unterweger (2000Lu17) estimated the standard uncertainty of 1955Jo20 as 0.030 yr and that of 1977RuZZ as 0.025 yr.

Table 2 shows the modified set of half-life values, which has been formed from the original set by omitting the ten measurement results (see Comments in Table 1) and adjusting the uncertainties of 1955Jo20, 1977RuZZ and 1966Merritt. Latter was re-estimated in 2000Lu17.

Table 2. Selected measurement results for tritium half-life (in years)

Reference	Half-life	Measurement method	Comments on uncertainty
1947No01	12.1(5)	^{3}He collection	Author's stated uncertainty (ASU)
1950Je60	12.46(15)	^{3}He collection	ASU multiplied by 1.4826
1951Jo15	12.41(7)	Beta counting	Author's stated uncertainty
1955Jo20	12.262(30)	^{3}He collection	Uncertainty re-estimated in 2000Lu17
1958Po64	12.58(18)	Calorimetry	Author's stated uncertainty
1966Merritt	12.31(4)	Beta counting	Uncertainty re-estimated in 2000Lu17
1967Jo10	12.25(3)	^{3}He collection	Author's stated uncertainty
1977RuZZ	12.323(25)	Calorimetry	See text
1987Ol04	12.38(3)	^{3}He collection	Author's stated uncertainty
1987Si01	12.32(3)	^{3}H implanted into Si(Li)	Author's stated uncertainty
1988Akulov	12.279(33)	^{3}He collection	Author's stated uncertainty
1991Bu13	12.31(3)	Bremsstrahlung	Author's stated uncertainty
2000Unterweger	12.33(3)	Three sets of gas counting measurements over 38 years	Author's stated uncertainty

A weighted average for the final data set is 12.312 with an internal uncertainty of 0.010 and an external uncertainty of 0.013 and a reduced χ^2/ν = 1.6. An unweighted average is 12.33(3).
Different statistical procedures from 1994Ka08 give the similar results: UINF, LWM, NORM – 12.312(10), PINF, BAYS and MBAYS – 12.312(13), IEXW – 12.314(14), RAJ – 12.311(10), CHV – 12.317(16). Lucas and Unterweger (2000Lu17) used three other statistical procedures including the method of determining the median and the estimated standard deviation of the median and adopted the value of 12.318(25).

The LWEIGHT computer program using the LWM procedure has led to the recommended value of 12.312(10).

The EV1NEW computer program (2000Ch01) has chosen the weighted average of 12.312 and recommended the smallest experimental uncertainty of 0.025 as a final uncertainty.

The adopted value of the ^{3}H half-life is 12.312(25) years, or 4497(9) days.

It should be noted this half-life value has been evaluated for molecular tritium. The half-life of atomic tritium is less by ~0.26% (2004Ak16). See also 2005Ak04 for a bare triton half-life.

2.1. Tritium Beta End-Point Energy (E_b^0)

The tritium beta end-point energy depends upon the chemical state of the tritium in an experiment. The expression for E_β^0 of molecular tritium differs from that of a "bare" nucleus by the "chemical shift" ΔE= B(RHe+) – B(RT) (1985Ka21, 1989Re04) which is calculated taking into account the spectrum of final states (SFS). (Here the B values indicate electron binding energies for He+ ion and tritium atom, R indicates a chemical state).

For known ^{3}He-^{3}H atom mass difference (ΔMc^2) the tritium beta "end-point" energy measured in some experiment is :

$E_\beta^0 = \Delta Mc^2 - E_{rec} - [B(He) - B(T)] + [B(RHe+) - B(RT)]$

where E_{rec} is the helium recoil energy.

For tritium atom (nuclide) $E_\beta^0 = \Delta Mc^2 - 3.4$ eV $- 64.3$ eV $+ \Delta E$ where $\Delta E = 40.82$ eV.

With the recommended value of ΔMc^2, the beta end-point energy for tritium nuclide is obtained by this way as 18563.6 eV. It is difficult to estimate the uncertainty of the ΔE calculation in1985Ka21. Supposing it about the evaluated uncertainty of ΔMc^2 (Q value), we have E_β^0 (^{3}H nuclide) = 18.564(2) keV.

For real forms of tritium sources in beta-spectrometry experiments the ^{3}H end-point energies differ from the atomic value. For a molecular forms HT, CH_3T, valine the calculated E_β^0 makes 18572(2) eV. Below the measured end-point energies in some experiments are shown.

1987Bo07	Valine	18.579.4 ± 4 eV
1993Ba08	Molecular tritium	18.574.8 ± 0.6 eV
1993Su32	$C_{14}H_{15}T_6O_2N_3$	18.578.3 ± 5.1 eV
1995St26	Gaseous tritium	18.568.5 ± 2.0 eV
2003Kr17	Gaseous tritium	18.570.5 eV

It should be noted that many works devoted to study of tritium beta-spectrum as it provided the most precise data of neutrino mass upper limit (see, for example, 2005Kr03, 2003Lo10, 2002Bo31 and references therein).

2.2. Average energy of beta particles of tritium per disintegration ($<E_b>$)

In Table 3 the available data of the $<E_\beta>$ have been presented. The recommended value $<E_\beta>$ has been obtained as the weighted average after corrections into the original results of the experiments and calculations. The calculation of the $<E_\beta>$ with the LOGFT computer program using the adopted value $Q^- =$ 18.591(1) keV gives 5.68 (±0.0011) keV.

Table 3. The available data of the tritium average beta energy (per disintegration, keV)

Reference	Method	Original	Re-estimated	Adopted
1950Je60	Calorimetry	5.69(4)	5.68(4) [a]	5.68(4)
1958Gr93	Calorimetry	5.57(1)	5.68(2) [a]	5.68(2)
1961Pi01	Calorimetry	5.73(3)	5.68(3) [b]	5.68(3)
1972Ma72	Calculation	5.7		5.7(1) [d]
1985Martin	Calculation	5.684(5)	5.680(5) [c]	5.68(1) [d]
1985Garcia	TDCR	5.70		5.70(2) [d]
1987Lagoutine, 1994Si21	Calculation	5.71(3)	5.70(3) [c]	5.70(3)
Recommended value 5.68(1) keV				

[a] Corrected for the adopted tritium half-life of 12.312 y and heat output of 0.324(1) W/g

[b] Corrected for the adopted tritium half-life of 12.312 y

[c] Corrected for the adopted decay energy ($Q^- = 18.591$ keV)

[d] Uncertainty attributed by the evaluator

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