^{57}Co - Comments on evaluation of decay data

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1. Decay Scheme

The 2nd forbidden electron capture (EC) transitions to the $3/2^-$ excited levels of 14,413 keV and 366,74 keV have not been observed, as well as the 2nd forbidden unique EC transition to the $1/2^-$ ground state of ^{57}Fe. From the log ft systematics the log ft of the 2nd forbidden transitions should be greater than 11,1 and 10,8, respectively, and for the 2nd forbidden unique transition, greater than 12,9. From these, the upper limits on the EC branch probabilities to the 14,413 keV level and ground state of ^{57}Fe are obtained as < 0,003 % and < 0,00035 %, and for the EC branch to the 366,74 keV level ≤ 0,002%. The calculations of the level probability balance in the decay scheme of ^{57}Co were made not taking into account the first two unobserved transitions. The EC branch probabilities to the levels of 136,47 keV, 366,74 keV and 706,42 keV were obtained from an probability balance of the gamma transitions.

2. Nuclear Data

Q value is from Audi and Wapstra (1995Au04).
There are available eight measurement results of the half-life of ^{57}Co (Table 1).

Table 1. Measurement results and evaluation of the half-life of ^{57}Co

Reference	Data set "1" χ^2 =39,2 $(\chi^2)_7^{0,05}$ =14,1	Data set "2" χ^2 =14,5 $(\chi^2)_6^{0,05}$ = 12,6	Data set "3" χ^2 =14,5 $(\chi^2)_6^{0,05}$ =12,6
1997Ma75	271,68(9)	271,68(9)	271,68(9)
1992Un01	272,11(26)	272,11(26)	272,11(26)
1983Wa26	271,84(4)	271,84(4)	271,84(4)
1981Va11	271,90(9)	271,90(9)	271,90(9)
1980Ho17	271,77(5)	271,77(5)	271,77(5)
1972La14	271,23(21)	271,23(21)	271,23(21)
1972Em01	269,8(4)	Omitted	Omitted
1965An07	271,65(13)	271,65(13)	271,65(13)
Evaluated value 271,80(5) d			

The value of 269,8(4) days from 1972Em01 was omitted on statistical considerations (because of a large contribution to χ^2 and also on the Chauvenet's criterion).This leads to the data set "2" of the seven values which coincides with the final data "3" as the LRSW method in statistical processing of the set "2" does not change the relative statistical weights.

The computer program EV1NEW 2000Ch01 has chosen the weighted mean of 271,80(5) days with the tS (or MBAYS) uncertainty as $(\chi^2)^{0,05}_{n-1}<\chi^2<10(\chi^2)^{0,05}_{n-1}$ (see evaluation technique in 2000Ch01). Other statistical procedures give, UWM-271,74(10), WM-271,80(3), CHV-271,83(7), UINF-271,80(4), PINF-271,80(4), BAYS-271,80(5), LWM-271,80(4), IEXW-271,75(8), NORM-271,80(4), RAJ-271,80(3). The computer program LWEIGHT leads to 271,80(3) days, the weighted mean with the internal uncertainty (the external uncertainty is 0,042). (The other evaluations of half-life of ^{57}Co see in 1990Ni03 and 1998Bh11).

The adopted value for the half-life of ^{57}Co is 271,80(5) days.

Half-life of excited levels in ^{57}Fe

The half-life of the excited levels (136 and 14 keV) have been evaluated being : **8,8(5)** ns [using 1989Ra17 and 1978AlZX] and **98,0(3)** ns [from 1961Cl11, 1965Ki03, 1967Ec05, 1969Ho28, 1978AlZX, 1995Ah04], respectively.

2.1. Electron Capture Transitions

The energies of the electron capture, ε, transitions have been calculated from the Q value and the level energies deduced from gamma transition energies.

The P_K, P_L and P_M values have been obtained from the tables of Schönfeld (1998Sc28). The experimental P_K values are available for $\varepsilon_{0,2}$ EC transitions to the level of 136,47 keV: 0,885(9) in 1968Ru04 ; 0,87(2) in 1969Bo49 ; 0,922(10) in 1973 Mukerji and 0,89(4) in 1990Si03.

The electron capture probabilities of $\varepsilon_{0,2}$, $\varepsilon_{0,3}$ and $\varepsilon_{0,4}$ have been calculated from the balance of the evaluated Pγ+ce values for the136,47 keV, 366,74 keV and 706,42 keV levels, respectively, assuming negligible EC transitions to the 14,4 keV level and the ground state of ^{57}Fe.

The calculated value of the sum of $P_{\gamma+ce}$ for the 4 gamma transitions to the ground state of ^{57}Fe is 99,996 (19) %.

2.2. Gamma Transitions and Internal Conversion Coefficients

The evaluated energies of gamma transitions are the energies of the gamma rays plus the recoil energy.

The probabilities of gamma transitions $P_{\gamma+ce}$ have been computed using the evaluated absolute gamma ray emission intensities and the total internal conversion coefficients (ICC). The ICC have been evaluated using the experimental information on the multipolarity admixture coefficients (see below) and the theoretical values from 1976Ba63.

The values of δ(E2/M1) have been adopted from the analysis of 1978Kr19 except for $\gamma_{2,1}$ which is obtained by weighting the 4 values of +0,120 from 1972Fo05, +0,116(1) from 1973Sc15, +0,1195(10) from 1975Co22 and +0,120(4) from 1972Kr15 (see also the evaluation of 1998Bh11). The weighted average of δ(E2/M1) for $\gamma_{2,1}$ is +0,1180(12).

The adopted values of δ(E2/M1) for other gamma transitions are 0,00223(18) for $\gamma_{1,0}$, +0,02 for $\gamma_{3,2}$, +0,083(5) for $\gamma_{4,3}$, +0,025(9) for $\gamma_{3,1}$,-0,45(5) for $\gamma_{3,0}$,+0,097(8) for $\gamma_{4,2}$ and -0,465(8) for $\gamma_{4,1}$.

There are many experimental values of ICC and the ratios of the fractional intensities of conversion electrons for $\gamma_{1,0}$, $\gamma_{2,1}$ and $\gamma_{3,0}$ which, with the exception of 1996Me11, support the adopted values of ICC:

$\gamma_{1,0}$ α_K=7,76(23), α_L=0,804 (24) from 1976Ba63
α_K=7,35(19) from 1985HaZA
K:L:M+=100:9,59(13):1,48(15) from 1971Po05

$\gamma_{2,1}$ α_K=0,0214(12), K/L+ =8,2(6) from 1967Ha06
K:L:M+ =100:9,0:1,5 from 1955Co31

$\gamma_{3,0}$ α_K=0,122(13), K/L+ =8,6(5), α_T/α_K =1,118(5) from 1967Ha06

There are 6 experimental values for the total ICC (α_T) of the low-energy gamma transition $\gamma_{1,0}$(14,413 keV): 9,0(5) and 8,9(6) from 1965Ki03 ; 8,26(22) from 1965Mo22 ; 8,25(46) from 1966Sp06 ; 8,26(22) from 1968Ru04 and 8,19(18) from 1970Jo30. They can be compared to the adopted value of α_T=8,58(18).

3. Atomic Data

3.1. Fluorescence yields

The fluorescence yields are taken from 1996Sc06 (Schönfeld and Janβen).

3.2. X Radiations

The X-ray energies are based on the wavelengths in the compilation of 1967Be65 (Bearden).

The relative Kβ/Kα emission probability is taken from 1998Be and 1997Lepy. They have shown that taking into account double-electron transitions with a simultaneous emission of a photon and Auger electron (the radiative Auger effect RAE) increases the value of Kβ/Kα = from 0,1368(14) (1996Sc06) to 0,1419(19) (1998Be) or 0,1423(17) (1997Lepy). From these we have adopted Kβ/Kα = 0,142(2).

The ratio $K\alpha_2/K\alpha_1$ is from 1996Sc06

3.3. Auger Electrons

The energies of Auger electrons are from 1977La19 (Larkins).

The ratios P(KLX)/P(KLL) and P(KXY)/P(KLL) are taken from 1996Sc06.

4.Photon Emissions

4.1 X-Ray Emissions

The total absolute emission intensity of KX-rays (P_{XK}) has been computed using the adopted value of ω_K, the evaluated total absolute emission probabilities (sums) of K conversion electrons (Pce_K) and K electron capture ($P\varepsilon_K$).

The absolute emission intensities of the KX-ray components have been computed from the total P_{XK} using the relative probabilities from sect. 3.2.

Below the measured values of $P_{K\alpha}$ and P_{XK} are compared to our calculated (evaluated) values:

	Measured		*Calculated*
	1989 Debertin	1994Ar22	(evaluated)
$\mathbf{P_{K\alpha}}$**, %**	50,6(9)	50,1(5)	50,0(6)

	Measured				*Calculated*
	1968Ru04	1973 Mukerji	1978 Vylov	1989 Debertin	(evaluated)
$\mathbf{P_{XK}}$**, %**	56,9(8)	58,4(17)	55,3(15)	56,0(11)	57,1(9)

The total absolute emission intensity of LX-rays has been computed using absolute sums Pce_L, Pce_K, $P\varepsilon_K$, $P\varepsilon_L$ and atomic data of section 3.1 (ω_K, ϖ_K, n_{KL}).

4.2. Gamma Emissions

The energies of the gamma rays $\gamma_{2,1}$ and $\gamma_{3,0}$ have been adopted from 1976Bo16 and 2000He14. The energies of other gamma rays have been obtained as the weighted means of measurement results listed in Table 2 or calculated from the decay scheme of ^{57}Co. The corrections to the revised energetic scale in 2000He14 (lowering the values by 5,80 ppm) do not change these values.

The evaluator has assumed no EC feeding to the ground and first excited states and used the total gamma-ray transition probabilities to these two states (except that for the 14,4-keV transition) to normalize the decay scheme (using adopted relative photon intensities from Table 3, conversion coefficients from Section 2.2). This procedure has produced a normalization factor of 0,8551(6).

The absolute gamma ray emission intensity for $\gamma_{1,0}$ (14,413 keV) has been computed as follows: $P'_{\gamma}(\gamma_{1,0}) = P'_{\gamma+ce}(\gamma_{1,0})/(1+\alpha_T(\gamma_{1,0}))$, where $P'_{\gamma+ce}(\gamma_{1,0})$ = 87,57(16) comes from decay-scheme probability balance at the 14,4-keV level, and $\alpha_T(\gamma_{1,0})$=8,58. The deduced value of $P_{\gamma}(\gamma_{1,0})$=9,15(17) % can be compared with the experimental values, such as 9,5(2) % (1978Vylov), 9,54(12) % (1992ScZZ) and 9,16(15) % (1989Debertin). It agrees extremely well with the CRP experimental result from 1989 Debertin.
It should be noted also that the evaluated sum $P_{\gamma}(\gamma_{2,0})+P_{\gamma}(\gamma_{1,0})$==19,86(23) % agrees well with the measured value of 19,84(17)% in 1971Ko19.

Table 2 - Measured and adopted energies of gamma-rays in the decays of $^{57}Co \rightarrow {}^{57}Fe$ and $^{57}Mn \rightarrow {}^{57}Fe$

	1965Ki03	1965Sp06	1970Gr13	1971Ko19	1972He42	1974Ti01[a]	1976Bo16	1980Ve05	WM	Adopted
$\gamma_{1,0}$			14,408(5)		14,41247(29)	14,410(6)			-	14,41295(31)[b]
$\gamma_{2,1}$			122,07(3)	122,06(2)		122,063(4)	122,06065(12)		-	122,06065(12)
$\gamma_{2,0}$			136,473(4)	136,47(3)		136,473(4)	136,47356(29)		-	136,47356(29)
$\gamma_{3,2}$	229,8(10)	230,6(6)	230,4(5)	230,4(6)		230,25(4)		230,29(2)	230,27(3)	230,27(3)
$\gamma_{4,3}$	339,7(4)	339,7(5)	339,7(3)	339,68(28)		339,60(6)		339,54(18)	339,61(9)	339,67(3) [b]
$\gamma_{3,1}$	352,5(4)	352,4(5)	352,5(3)	352,23(27)		352,32(3)		352,36(1)	352,34(2)	352,34(2)
$\gamma_{3,0}$	366,8(5)	366,7(5)	336,8(4)	367,0(5)		366,73(4)		366,75(1)	366,74(3)	366,74(3) [b]
$\gamma_{4,2}$	570,0(4)	570,3(4)	570,1(3)	570,04(28)		569,93(5)		569,92(4)	569,94(4)	569,94(4)
$\gamma_{4,1}$	692,1(3)	692,1(3)	692,1(2)	692,44(6)		692,00(3)		692,03(2)	692,02(2)	692,01(2)[b]
$\gamma_{4,0}$	706,4(4)	706,8(4)	706,6(3)	706,46(34)		706,54(22)		706,40(20)	706,50(20)	706,42(2)[b]

a Experimental values from the decay of ^{57}Mn

b Calculated from decay scheme using the energies of $\gamma_{2,1}$, $\gamma_{2,0}$, $\gamma_{3,2}$, $\gamma_{3,2}$, $\gamma_{4,2}$

Table 3 - Relative emission probabilities of gamma rays in the decay of ^{57}Co

γ	E_γ	1965Ki03	1965Ma38	1971Ko19	1974 HeYW	1980Sc07 [a]	1982Gr10	Average	Adopted
$\gamma_{1,0}$	14			$1,14(5)\cdot 10^4$					10,70(20) [b]
$\gamma_{2,1}$	122	10^5	10^5	10^5	10^5	10^5	10^5	10^5	100
$\gamma_{2,0}$	136	$1,25(8)\ 10^4$	$1,20(1)\ 10^4$	$1,30(4)\ 10^4$	$1,29(7)\ 10^4$	$1,236(9)\ 10^4$	$1,245(30)\ 10^4$	$1,253(18)\ 10^4$ [c]	12,53(18)
$\gamma_{3,2}$	230		0,2(2)	0,5(5)					$4(4)\ 10^{-4}$
$\gamma_{4,3}$	340		2,9(3)	4,5(4)					0,0045(4) [d]
$\gamma_{3,1}$	352		2,0(2)	3,7(4)					0,0037(4) [d]
$\gamma_{3,0}$	367		0,7(1)	1,5(4)					0,0015(4) [d]
$\gamma_{4,2}$	570		16(1)	19,4(11)	10(10)			18(2) [e]	0,018(2)
$\gamma_{4,1}$	692		188(5)	183(11)	190(30)			186(7) [f]	0,186(7)
$\gamma_{4,0}$	706		5,5(6)	6,2(6)				5,8(6) [g]	0,0058(6)

[a] In 1980Sc07 the absolute gamma-ray emission probabilities are reported: $P\gamma_{2,0}(136)$=10,58(8)% and $P\gamma_{2,1}(122)$=85,59(19)%. Their ratio is 0,1236(9).

[b] Calculated as described in the text

[c] The LWEIGHT program (version 1.2) has used an unweighted average and expanded the uncertainty so range includes the most precise value of 1980Sc07 . It is reasonable choice because of disagreement of the experimental values some uncertainties of which are only statistical.

[d] Adopted from 1971Ko19.

[e] LWEIGHT has used a weighted average and expanded the uncertainty so range includes the most precise value of 1965Ma38.

[f] The method of Limitation of Relative Statistical Weights (LRSW) increased the uncertainty of 1965Ma38 to 10,3.

[g] The experimental uncertainty is adopted as the uncertainty of the evaluated value.

5. Electron emissions

The energies of the conversion electrons have been calculated from the gamma transition energies given in sect. 2.2 and the electron binding energies.

The emission intensities of the conversion electrons have been calculated using the transition probabilities given in sect. 2.1and 2.2, the atomic data given in sect. 3, and the internal conversion coefficients given in sect. 2.2.

The low energy electron spectrum from the decay of ^{57}Co has been analysed in 1997KoZJ using a combined electrostatic spectrometers. They obtained the following intensity ratios for the main spectrum components: (LMM+LXY) / KLL / KLX / KMX / K-14,4 / L-14,4 / (M+N)-14,4 = 49,3(38): 59,6(23): 15,2(6): 1,2(2): 49,9(18): 5,1(3): 0,80(4). These values agree mainly with our evaluated data on electron emissions apart from the intensity of L Auger electrons. Perhaps, the latter is connected with difficulties of the electron spectrum measurement in the energy region of 0,6-0,7 keV. The discrepancy takes place also for the L/(M+N) and K/(M+N) ratios.

Also in 1997KoZJ L_1/L_2 = 15,7(5), L_1/L_3=39,3(16), $M_{2,3}/M_1$=0,076(4) have been measured for the gamma transition $\gamma_{1,0}$ (14,4 keV).

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