^{214}Pb - Comments on evaluation of decay data
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This evaluation was completed in 2010. Literature available by Dec. 2010 was included, and the half-life value was updated in Dec. 2010 to include new publication.

1 Decay Scheme

^{214}Pb disintegrates by beta minus emission to the excited levels and to the ground state of ^{214}Bi. Spins and parities are from the mass-chain evaluation of Y. A. Akovali (1988Ak01 and 1995El07 for A = 214).
A good agreement was found between the recommended Q value of Audi and the effective Q value (1024 (11) keV) calculated from the decay scheme data.

2 Nuclear Data

The Q value is from the atomic mass evaluation of Audi *et al.* (2003Au03).

Experimental ^{214}Pb half-life values (in minutes) are given in Table 1:

Table 1: Experimental values of ^{214}Pb half-life

Reference	Experimental value (min)	Comments.
M. Curie (1931Cu01)	26.8 (9)	
D. E. Martz (1991Ma**)	26.89 (3)	Uncertainty increased to take into account systematic uncertainty.
M. Voltaggio (2011Vo**)	27.06 (7)	To be published in Appl. Rad. Isotop.
Recommended value	**26.916 (44)**	χ^2 = 2.5

The original uncertainty value given by D. E. Martz (1991Ma**) was multiplied by 2, in order to take into account the systematic uncertainties which were not considered by 1991Ma**. With the 3 values presented in Table 1, a weighted average was calculated using LWEIGHT computer code (version 3). The largest contribution to weighted average comes from the value of Martz (1991Ma**), amounting to 84 %.

The recommended value of ^{214}Pb half-life is the weighted average of 26.916 minutes with an external uncertainty of 0.044 minute. The reduced-χ^2 value is 2.5.

2.1 β^- Transitions and Emissions

The maximum energies of the β^- transitions in the decay of ^{214}Pb $\rightarrow$ ^{214}Bi were obtained from the Q^- value and the level energies given in Table 2 from Y. A. Akovali (1995El07).

Table 2: ^{214}Bi levels populated in the decay of ^{214}Pb.

Level number	Level energy, (keV)	Spin and parity	Half-life
0	0.0	1^-	19.9 (4) min
4	295.224 (2)	1^-	≤ 0.05 ns
5	351.932 (2)	0^-, 1^-	≤ 0.10 ns
7	533.67 (2)	(1^-)	
8	797.24 (9)		
9	839.00 (4)	1^+	

The adopted β^- transition probabilities were deduced from the P(γ + ce) balance at each level of the decay scheme. In the Table 3, the recommended values of β^- transition probabilities are compared with the experimental results found in the literature: E. E. Berlovich (1952Be78) and S. Kageyama (1953Ka40) observed only two β^- transitions 672-keV and 729-keV and H. Daniel (1956Da28) and K. O. Nielsen (1957Ni11) observed the1024-keV β^- transition. A fair agreement has been found between the results given by S. Kageyama and the recommended value for the 729-keV β^- transition.

Table 3: Recommended and experimental values of β^- transition probabilities

	672-keV β^- transition	729-keV β^- transition	1024-keV β^- transition
E. E. Berlovich (1952Be78)	25 %	75 %	
S. Kageyama (1953Ka40)	56 %	44 %	
H. Daniel (1956Da28)			6.3 (20) %
K. O. Nielsen (1957Ni11)			< 10 %
Recommended	**46.52 (37) %**	**41.09 (39) %**	**9.2 (7) %**

The values of lg *ft* and average β^- energies have been calculated with the program LOGFT for the β^- transitions.

2.2 γ Transitions

The γ-ray transition probabilities were deduced using the γ-ray emission intensities and the relevant internal conversion coefficients.

Multipolarities and δ (recommended by 1995El07) of these γ-ray transitions and the internal conversion coefficients (ICC's) are shown in Table 4.The internal conversion coefficients have been obtained using:

A - Icc99v3a computer program (GETICC dialog) which is based on the new tables of Band *et al.* (2002Ba85) (calculation for 'no hole') and Rösel (1978Ro22).

B - BrIcc computer program ("Frozen orbital approximation") which interpolated from theoretical values of Band *et al.* (2002Ba85).

Table 4: Multipolarities of γ-ray transitions

E_γ (keV)	Multipolarity	α_T (Band)[a]	α_T (Rösel)[a]	α_T (BrIcc)[b]
53.2275 (21)	M1 + E2, δ = 0.030 (10)	1.212 (36) E+01	1.288 (39) E+01	1.214 (19) E+01
241.997 (3)	M1 (+E2), δ = 0.00 (15)	8.37 (25) E-01	8.88 (27) E-01	8.38 (18) E-01
258.87 (3)	M1	6.95 (21) E-01	7.37 (22) E-01	6.96 (10) E-01
274.80 (5)	M1 + E2, δ = 1.0	3.73 (11) E-01	3.92 (12) E-01	3.74 (6) E-01
295.224 (2)	M1 + E2, δ = 0.30 (13)	4.54 (14) E-01	4.82 (14) E-01	4.6 (3) E-01
305.26 (3)	[E1]	2.91 (9) E-02	2.95 (9) E-02	2.92 (4) E-02
351.932 (2)	M1 (+ E2), δ = 0.00 (35)	3.00 (9) E-01	3.19 (10) E-01	3.00 (25) E-01
480.43 (2)	M1 (+E2), δ = 0.0 (10)	1.302 (39) E-01	1.384 (42) E-01	1.3 (5) E-03
487.09 (7)	(E1)	1.046 (31) E-02	1.058 (32) E-02	1.047 (15) E-03
533.66 (2)	[M1,E2]	6.24 (19) E-02	6.57 (20) E-02	6 (4) E-02
543.81 (7)	[E1]	8.34 (25) E-03	8.43 (25) E-03	8.34 (12) E-03
580.13 (3)	(E1)	7.32 (22) E-03	7.40 (22) E-03	7.32 (11) E-03
785.96 (9)	E1	4.07 (12) E-03	4.10 (12) E-03	4.06 (6) E-03
839.00 (4)	(E1)	3.60 (11) E-03	3.63 (11) E-03	3.59 (5) E-03

a: A fractional uncertainty of 3 % was adopted for all conversion coefficients.
b: Associated uncertainties are calculated by BrIcc.

The evaluators have adopted the internal conversion coefficients interpolated from the Rösel's tables, because these ICCs lead to a better decay scheme, where the sum of all the β transition probabilities is equal to 100.6 %. The others two ICC's set of values, Band and BrIcc, lead to an inconsistent decay scheme, where the sum of all β transitions probabilities would be of the order of 102 – 103 %. Moreover, the effective Q value, of 1024 (11) keV, calculated from the decay scheme data with Rösel's Icc, is closer to the recommended value of 1019 (11) keV than the 1029 (15) keV with the "No hole" approximation.

3 Atomic Data

Atomic values, ω_K, ϖ_L, ϖ_M, n_{KL} and ω_{LM} and the X-ray and Auger electrons relative probabilities are from Schönfeld and Janβen (1996Sc06).

4 Electron Emissions

The conversion electron emission probabilities have been calculated from γ-ray transition data.

5 Photon Emissions

5.1 X-ray Emissions

The X-ray absolute intensities were calculated from γ-ray data and Rösel's ICC using the EMISSION computer program and compared in Table 5 with the measured values of U. Schötzig (1983Sc13) and E. W. A. Lingeman (1969Li11). A good agreement was found between the experimental results given by 1969Li11 and 1983Sc13 and the recommended values deduced from the decay scheme balance. For the Kβ x-ray, a fair agreement was found between 1969Li11 and the recommended one.

Table 5: Experimental and recommended (calculated) values of X-ray

	U. Schötzig (1983Sc13)	E. W. A. Lingeman (1969Li10)	Recommended values
Kα x-ray (74.82 + 77.11 keV)	16.3 (4) %	17.3 (20) %	16.73 (23) %
Kβ x-ray		4.3 (8) %	4.69 (10) %

5.2 γ Emissions

The γ-ray energy emissions given are from Y. A. Akovali (1995El07).

The experimental relative γ emission intensities in ^{214}Bi are based on all available relative and absolute measurements of γ-rays for the ^{226}Ra decay chain. The normalization factor to convert the relative emission intensities to absolute intensities is the weighted average of the measured absolute γ-ray emission intensities (Table 6) of the most intense line in ^{226}Ra decay chain, presents in the ^{214}Bi disintegration namely the 609.3 keV line.

Table 6: The experimental absolute 609.3 keV gamma-ray emission intensity

References	Experimental values (%)	Comments
E. W. A. Lingeman (1969Li10)	42.8 (40)	
D. G. Olson (1983Ol01)	45.0 (7)	
U. Schötzig (1983Sc13)	44.6 (5)	
W. –J. Lin (1991Li11)	46.1 (5)	
J. Morel (1998Mo14)	44.8 (6)	Omitted (superseded in 2004Mo07)
J. Morel (2004Mo07)	45.57 (18)	
Recommended value	**45.49 (19)**	χ^2 = 1.45

The recommended normalization factor is the weighted average of the five experimental values: 45.49 with an external uncertainty of 0.19.

The experimental relative γ emission intensities given in Table 7 are relative to the ^{214}Bi 609-keV γ-ray.

Table 7: The experimental data set of the relative γ emission intensities (see next page)

Reference	53-keV γ-ray	107-keV γ-ray	137-keV γ-ray	141-keV γ-ray	170-keV γ-ray	196-keV γ-ray	205-keV γ-ray	216-keV γ-ray	241-keV γ-ray
1964Ew04									16.0 (16)
1969Li10									17.1 (18)[b]
1969Wa27									19.33 (30)[a]
1969Gr33	3.15 (34)[a]								16.2 (17)[a]
1970Mo28									16.10(21)
1975Ha31						0.16 (7)[a]			17.5 (17)[a]
1977Zo01									16.06 (19)[a]
1982Ak03						0.14 (2)[a]			16.1 (24)[a]
1982Fa10					0.020 (8)[a]				16.53 (31)[a]
1983Ol01									16.49 (29)
1983Sc13	2.44 (11)								15.65 (25)
1990Mouze		0.015 (3)			0.032 (6)	0.15 (2)	0.025 (6)	0.022 (5)	16.23 (10)
1991Li11									16.33 (25)
2000Sa32						0.16 (8)	0.026 (12)		16.1 (10)
2002De03	2.329 (23)		0.10 (4)	0.06 (3)					15.896 (48)
2002MoZP	2.329 (23)								15.98 (6)
2004Mo07	2.329 (23)[a]								15.880 (48)[a]
Recommended	2.331 (16)	0.015 (3)			0.032 (6)	0.151 (9)	0.025 (5)	0.022 (5)	15.977 (48)
χ^2	0.5					0.015	0.005		2.0

Reference	258-keV γ-ray	274-keV γ-ray	295-keV γ-ray	305-keV γ-ray	314-keV γ-ray	323-keV γ-ray	351-keV γ-ray	462-keV γ-ray	480-keV γ-ray
1964Ew04			40.46 (40)				77 (8)		
1969Li10	1.32 (22)	1.10 (22)[b]	42.6 (44)[b]		0.220 (44)	0.066 (22)	80 (9)	0.46 (11)	0.66 (15)
1969Wa27			47.87 (91)[a]				87.2 (19)[a]		
1969Gr33	1.16 (7)[a]	1.01 (10)[a]	40.2 (40)[a]		0.137 (23)[a]		79 (7)[a]	0.444 (46)[a]	
1970Mo28			41.45 (56)[b]				79.7 (11)		
1975Ha31	1.24 (12)[a]	0.71 (7)[a]	40.2 (40)[a]	0.050 (25)[a]	0.198 (50)[a]	0.062 (25)[a]	86 (9)[a]	0.446 (50)[a]	0.73 (7)[a]
1977Zo01			42.01 (53)[a]				80.42 (81)[a]		
1982Ak03	1.17 (15)[a]	0.86 (16)[a]	42.2 (54)[a]	0.075 (16)[a]	0.185 (28)[a]	0.072 (40)[a]	82 (11)[a]	0.44 (7)[a]	0.75 (10)[a]
1982Fa10	1.72 (4)[a]		42.52 (59)[a]				81.3 (8)[a]		0.68 (2)[a]
1983Ol01			40.8 (6)				78.7 (11)		
1983Sc13			40.0 (7)				77.2 (9)		
1990Mouze	1.23 (6)	0.84 (6)	41.85 (26)[a]	0.068 (10)	0.17 (2)	0.06 (1)	81.48 (48)[a]	0.40 (4)	0.71 (5)
1991Li11	1.152 (25)	1.042 (25)[b]	42.43 (47)[a]				82.7 (9)[a]	0.486 (20)	0.703 (24)
2000Sa32	1.15 (4)	0.83 (8)	40.8 (12)	0.080 (15)	0.158 (20)	0.084 (20)	78.5 (24)	0.470 (14)	0.74 (3)
2002De03	1.171(9)	0.787 (23)	40.36 (12)				78.16 (23)		0.749 (10)
2002MoZP			40.61 (13)				78.34 (23)		
2004Mo07	1.171(9)[a]	0.760(27)[a]	40.32 (12)[a]				78.10 (23)[a]		0.75 (1)[a]
Recommended	1.169 (8)	0.796 (21)	40.48 (31)	0.0692 (47)	0.169 (13)	0.063 (7)	78.26 (16)	0.469 (12)	0.741 (9)
χ^2	0.56	0.43	0.57	0.56	0.82	0.65	0.52	1.24	0.95

Reference	487-keV γ-ray	533-keV γ-ray	538-keV γ-ray	543-keV γ-ray	580-keV γ-ray	765-keV γ-ray	785-keV γ-ray	839-keV γ-ray
1964Ew04								
1969Li10	0.77 (18)	0.37 (9)			0.70 (13)		2.31 (33)	1.30 (18)
1969Wa27								
1969Gr33	0.91 (23)[a]	0.501 (46)[a]			0.89 (9)[a]		2.41 (23)[a]	1.41 (14)[a]
1970Mo28								
1975Ha31	0.88 (10)[a]	0.408 (50)[a]		0.050 (16)[a]	0.80 (7)[a]		2.48 (25)[a]	1.42 (14)[a]
1977Zo01								
1982Ak03	0.88 (11)[a]	0.42 (5)[a]		0.14 (2)[a]	0.79 (11)[a]		2.32 (32)[a]	1.33 (19)[a]
1982Fa10	0.83 (3)[a]							1.30 (3)[a]
1983Ol01								
1983Sc13							2.286 (45)	
1990Mouze	0.83 (7)	0.39 (3)	0.044 (6)	0.15 (2)	0.76 (6)	0.17 (3)	2.33 (17)	1.29 (10)
1991Li11	0.928 (35)	0.409 (20)			0.774 (31)		2.396 (45)	1.290 (20)
2000Sa32	0.90 (5)	0.39 (3)	0.037 (20)	0.100 (10)	0.74 (4)	0.11 (1)	2.33 (7)	1.29 (4)
2002De03	0.961 (12)				0.823 (11)			
2002MoZP								
2004Mo07	0.961 (12)[a]				0.824 (10)[a]			
Recommended	0.951 (14)	0.399 (14)	0.043 (6)	0.11 (2)	0.811 (13)	0.116 (18)	2.339 (28)	1.290(18)
χ^2	1.54	0.18	0.11	5	1.80	3.6	0.75	0.001

a: Not used by the evaluators (see below).
b: the experimental value has been shown to be outlier value by the Lweight program.

There were omitted from analysis:

a) four sets of values, A. Hachem (1975Ha31), G. Mouze (1981Mo28), H. Akcay (1982Ak03), G. Mouze (1990Mo08) and O. Diallo (1993Di09), because these values comes from the same laboratory of G. Mouze (1990Mo**).

b) the sets of values from K. Ya. Gromov (1969Gr33), G. Wallace (1969Wa27) and M. A. Farouk (1982Fa10), because a lack of information in the articles describing their experimental measurements.

c) the set of values from V. Zobel (1977Zo01), because these values changed the consistency of the data set when introduced in the preliminary calculation with Lweight program, and produced inconsistent set of data for gamma emission intensities. Therefore, in the case of 295-keV and 351-keV γ-rays, the values of G. Mouze (1990Mouze) and W.-J. Lin (1991Li11), consistent with Zobel values, were not used by the evaluators for the weighted mean calculations.

d) the relative γ emission intensity values given by 2004Mo07, because they are those measured by J. U. Delgado (2002De03). In 2004Mo07 article, the author measured the 609.3 keV absolute emission probability (Table 2) and normalized the 2002De03 data set with this value of 45.57 (18).

The adopted values are the weighted means calculated by the Lweight program (version 3).

The evaluated relative and absolute γ-ray emission intensities are given in Table 8.

Table 8: Evaluated relative and absolute γ-ray emission intensities

Energy (keV)	Relative emission intensity	Absolute emission intensity (%)
53.2275 (21)	2.331 (16)	1.060 (9)
107.22 (9)	0.015 (3)	0.0068 (14)
137.45 (30)	0.10 (4)	0.045 (18)
141.3 (6)	0.06 (3)	0.027 (14)
170.07 (6)	0.032 (6)	0.0146 (27)
196.20 (5)	0.151 (9)	0.069 (9)
205.68 (9)	0.025 (5)	0.0114 (23)
216.47 (7)	0.022 (5)	0.0100 (23)
241.997 (3)	15.977 (48)	7.268 (22)
258.87 (3)	1.169 (8)	0.5318 (43)
274.80 (5)	0.796 (21)	0.362 (10)
295.224 (2)	40.48 (8)	18.414 (36)
305.26 (3)	0.0692 (47)	0.0315 (21)

Energy (keV)	Relative emission intensity	Absolute emission intensity (%)
314.32 (7)	0.169 (13)	0.077 (6)
323.83 (4)	0.063 (7)	0.0287 (32)
351.932 (2)	78.26 (16)	35.60 (7)
462.00 (7)	0.469 (12)	0.213 (6)
480.43 (2)	0.741 (9)	0.3371 (43)
487.09 (7)	0.951 (14)	0.433 (7)
533.66 (2)	0.399 (14)	0.182 (6)
538.41 (8)	0.043 (6)	0.0196 (27)
543.81 (7)	0.11 (2)	0.050 (9)
580.13 (3)	0.811 (13)	0.369 (6)
765.96 (9)	0.116 (18)	0.053(8)
785.96 (9)	2.339 (28)	1.064 (13)
839.04 (9)	1.290 (18)	0.587 (8)

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