^{144}Ce – Comments on evaluation of decay data by A. L. Nichols

Evaluated: May 2013 and March/April 2014

Evaluation Procedures

Limitation of Relative Statistical Weight Method (LWM) and other analytical techniques were applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Scheme

^{144}Ce ($T_{½}$ = 284.89 days) undergoes 100% β^- decay (Q(β^-) = 318.6 (8) keV) via various excited levels of ^{144}Pr to the metastable state of ^{144m}Pr (branching fraction of 0.0115 (20), and ^{144m}Pr half-life of 7.2 min) and to the ground state of ^{144}Pr (branching fraction of 0.9885 (20), and ^{144}Pr half-life of 17.29 min). A reasonably well-defined decay scheme was derived from the gamma-ray measurements of 1969Gu15, 1970An15, 1970Fa03, 1970Po09, 1975De17, 1976Ch33, 1977Ge12, 1981Ol04, 1982Yu02, 1983El14 and 1984Da13, coupled with comprehensive studies of conversion-electron spectra and extensive efforts to determine unambiguously the spin and parity of the ground state and the half-lives of the excited states of ^{144}Pr (1957Pa51, 1958Hi76, 1959Fr54, 1959Se57, 1960Ge05, 1961Ge09, 1962Bl05, 1962Bu09, 1962Bu22, 1962Fo04, 1963Co18, 1963Fu16, 1963Iw02, 1963Si10, 1963Cr11, 1963Kn05, 1963Bh11, 1964Az02, 1964Be36, 1964Mc22, 1965Re13, 1965Co19, 1966Be11, 1966Da04, 1967Gu17, 1968Da12, 1969Ge01, 1969Ma24, 1970An15, 1971Sa20 and 1975Ba32). While ^{144}Ce(β^-) ^{144m}Pr amounts to only 1.15 (20) % of the total decay, daughter ^{144m}Pr undergoes 99.94 (2) % isomeric-transition decay to ^{144}Pr by emission of a single 59.03(3)-keV gamma ray, and 0.06 (2) % β^- decay to ^{144}Nd. As a consequence of the short-lived decay of ^{144m}Pr the 59.03-keV M3 gamma transition has been included in both the ^{144}Ce and ^{144m}Pr decay-data files. Thus, the proposed decay scheme for ^{144}Ce consists of three β^- transitions and seven gamma-ray emissions, of which one gamma transition originates from ^{144m}Pr IT decay. Weighted-mean relative emission probabilities were calculated for some of the gamma rays, while equivalent data for other gamma transitions were primarily adopted from the comprehensive measurements of 1984Da13. All of these relative emission probabilities were defined in terms of the 133.515-keV gamma ray (100%).

Nuclear Data

^{144}Ce has been adopted as a burn-up monitor for irradiated fuel, and as a brachytherapy source in specific forms of cancer treatment. The β^- decay of daughter ^{144}Pr is important in decay heat assessments, design of irradiated fuel storage facilities, and other facets of radwaste management.

Half-life

The measurements of 1956Sc87, 1957Me47, 1965Fl02, 1968La10, 1968Re04, 1980Ho17, 1983Wa26, 1986Ol01, 1997Ma75 and 2014Un01 were analysed by means of the limitation of relative statistical weight method (LWM), normalised residual method (NRM), Rajeval technique, bootstrap method, and Mandel-Paule approach. χ^2/(N-1) obtained from the LWM, bootstrap and Mandel-Paule analyses are significantly higher than the values obtained from the equivalent data manipulation by means of the NRM and Rajeval techniques. While NRM resulted in adjustments to the half-life data measured by 1980Ho17 and 1997Ma75, the equivalent Rajeval analysis consisted of a small adjustment to the uncertainty of 1965Fl02, and more substantial changes to the uncertainties quoted by 1980Ho17, 1983Wa26 and 1997Ma75. Under these circumstances, a half-life value of (284.89 ± 0.06) days was preferred and recommended, as quantified by the Rajeval analytical procedure.

Reference	Half-life (d)
1956Sc87	284.5 ± 1.0
1957Me47	285 ± 2
1960Ea02	277 ± 4*
1965Fl02	283.8 ± 0.6
1968La10	284.8 ± 1.0
1968Re04	284.9 ± 0.8
1980Ho17	285.8 ± 0.1
1983Wa26	284.45 ± 0.14
1986Ol01	284.893 ± 0.008§
1992Un01	284.558 ± 0.038‡
1997Ma75	286.14 ± 0.09
2002Un02	284.534 ± 0.032‡
2012Fi12	284.35 ± 0.08Φ
2014Un01	284.35 ± 0.40
Recommended value	284.89 ± 0.06†

* Defined as an outlier, and therefore not adopted in the analytical procedures.
§ Uncertainty adjusted to ± 0.06 to reduce weighting to no more than 0.50.
‡ Superseded by study of 2012Fi12 after the discovery of problems in maintaining constant detector-source geometry within the NIST ionization chamber.
Φ Replaced by 2014Un01 − uncertainty increased from ± 0.08 to 0.40 in the most recent NIST paper.
† Recommended value adopted from Rajeval analysis, with uncertainty increased from ± 0.008 to 0.06 in alignment with the smallest uncertainty adopted to calculate the average value.

Analytical method	Half-life (d)	$\chi^2/(N-1)$	$\chi^2/(N-1)_{critical}$
UWM	284.86 ± 0.22	−	−
LWM − WM	284.91 ± 0.05	31.85	2.41
LWM – WM#	285.3 ± 0.4	23.22	2.41
NRM	284.64 ± 0.16	2.01	1.88
Rajeval	284.892 ± 0.008	1.56	−
Bootstrap	284.79 ± 0.21	57.74	−
Mandel-Paule	285.0 ± 0.6	46.43	−

Uncertainty of measurement by 1986Ol01 increased from ± 0.008 to 0.06 to reduce weighting to no more than 0.50.

Q values

The 59.03-keV IT gamma decay of ^{144m}Pr has been handled as part of the decay scheme of ^{144}Ce, with 100% β^- decay to ^{144}Pr and adoption of a Q^--value of 318.6 (8) keV (2012Wa38).

Gamma-ray energies and emission probabilities

Energies

The well-defined nuclear level energies of 2001So16 were used to calculate the gamma transition energies and their uncertainties. Greater confidence was placed on this approach because of the more wide-ranging origins of the gamma transition data even though the energies of the gamma-ray emissions have been measured by 1960Ge05, 1960Sa22, 1970An15, 1976Ch33, 1976Ra22, 1982Yu02, 1983El14 and 1984Da13. Daughter ^{144m}Pr undergoes 99.94 (2) % isomeric-transition decay to ^{144}Pr by means of a single 59.03(3)-keV gamma ray, and 0.06 (2) % β^- decay to ^{144}Nd − the 59.03-keV M3 gamma transition has been included in both the ^{144}Ce and ^{144m}Pr decay-data files.

Adopted energies, spins and parities for the nuclear levels of ^{144}Pr (2001So16).

Nuclear level number	Nuclear level energy (keV)	Spin and parity		
0	0.0	0 −	17.29 (4) min	^{144}Pr
1	59.03 ± 0.03	3 −	7.2 (2) min	^{144m}Pr
2	80.120 ± 0.004	1 −	136 (11) ps*	
3	99.952 ± 0.009	2 −	0.67 (6) ns#	
4	133.5152 ± 0.0020	1 −	7 (4) ps†	

* Weighted mean of 125 (14) ps (1962Bu22 (same value also reported by 1962Bu09)) and 143 (11) ps (1964Mc22); uncertainty increased from ± 9 to 11, in alignment with the smallest measured uncertainty of the values used to calculate the weighted-mean value.
# Weighted mean of 0.69 (14) ns (1962Bu22 (same value also reported by 1962Bu09)) and 0.66 (6) ns (1964Be36).
† Determined by 1962Bu22 (same value also reported by 1962Bu09).

Measured and recommended gamma-ray energies.

E_γ (keV)													
1957Pa51[*]	**1959Fr54**	**1959Se57**	**1960Ge05[†]**	**1960Sa22**	**1970An15**	**1976Ch33**	**1976Ra22**	**1978Mo22**	**1979Bo26**	**1982Yu02**	**1983El14**	**1984Da13**	**Recommended[#]**
–	–	–	–	–	–	–	–	–	–	–	–	5.012 (50)	Pr X $L_{\alpha1} + L_{\alpha2}$
–	–	–	–	–	–	–	–	–	–	–	–	5.486 (50)	Pr X $L_{\beta1} + L_{\beta3} + L_{\beta4}$
–	–	–	–	–	–	–	–	–	–	–	–	5.851 (50)	Pr X $L_{\beta2,15}$
–	–	–	–	–	–	–	–	–	–	–	–	6.297 (50)	Pr X $L_{\gamma1}$
–	–	–	–	–	–	–	–	–	–	–	–	6.594 (50)	Pr X $L_{\gamma2,3}$
33.7	35 (X-ray)	36 (2)	33.57 (3)	34 (3)	33.6 (1)	33.622 (10)	33.6	–	–	33.552 (20)	33.56	33.568 (10)	33.563 ± 0.009
–	–	–	–	–	35.9 (1)	35.554 (10)	–	–	–	35.558 (20)	–	35.547 (10)	Pr X $K_{\alpha2}$
–	–	–	–	–	–	36.030 (10)	–	–	–	36.033 (20)	–	36.026 (10)	Pr X $K_{\alpha1}$
–	–	–	–	–	40.7	40.676 (10)	–	–	–	–	40.72	40.739 (20)	Pr X $K_{\beta1}$
41.0	–	–	40.93 (3)	–	41	40.892 (50)	40.8 (4)	–	–	–	–	40.98 (10)	40.92 ± 0.03
–	–	–	–	–	41.7 (1)	41.759 (10)	–	–	–	41.756 (15)	–	41.778 (10)	Pr X $K_{\beta2}$
53.0	–	–	53.41 (5)	54 (4)[*]	53.4 (1)	53.432 (10)	53.4 (1)	–	–	53.436 (10)	53.40	53.395 (5)	53.395 ± 0.005
–	–	–	59.03 (3)	–	59.0 (3)	–	58.5 (2)	–	–	–	58.96	58.98[‡]	59.03 ± 0.03 ^{144m}Pr IT decay
81.0	80	81 (4)	80.12 (3)	80 (3)	80.1 (1)	80.106 (5)	80.09 (8)	–	–	80.119 (10)	79.95	80.120 (5)	80.120 ± 0.004
100.6	–	–	99.95 (5)	101 (5)[*]	100.0 (1)	99.963 (20)	99.85 (8)	–	–	99.922 (15)	99.80	99.961 (15)	99.952 ± 0.009
134.1	133	134 (4)	133.53 (3)	134 (2)	133.5 (1)	133.544 (5)	133.51 (10)	133.515 (5)	133.528 (13)	133.514 (9)	133.29	133.515 (4)	133.5152 ± 0.0020

[#] Determined from the nuclear level energies of 2001So16.
[*] Gamma-ray energies derived from coincidence measurements.
[†] Gamma-ray energies determined from conversion-electron measurements.
[‡] Inadequate data arising from insufficient statistics for $P_\gamma^{rel} \leq 0.01$ (normalized with respect to a relative emission probability of 100% for the 133.515-keV gamma ray).

Emission Probabilities

Relative gamma-ray emission probabilities have been partially or fully determined or derived from the measurements of 1970An15, 1970Po09, 1976Ch33, 1977Ge12, 1982Yu02, 1983El14 and 1984Da13, and limited and complete studies of the absolute gamma-ray emission probabilities have been performed by 1960Ge05, 1969Gu15, 1970Fa03, 1975De17, 1976Ra22 and 1981Ol04. While considerable emphasis was placed on the comprehensive and well-defined measurements of 1984Da13, data from the studies of 1960Ge05, 1970An15, 1970Fa03, 1970Po09, 1976Ch33, 1977Ge12, 1982Yu02 and 1983El14 were also used in the weighted-mean analyses of the 33.563-, 40.92-, 53.395-, 80.120- and 99.952-keV gamma-ray emissions. All of the relative emission probabilities were suitably refined and quantified in terms of the emission probability of the 133.515-keV gamma ray (100.0%). Considerable difficulty has been experienced in resolving the 40.92-keV gamma-ray emission from Pr K_β X-rays (40.65 – 41.97 keV); hence, a speculative P_γ^{rel}(40.92 keV) weighted-mean value of 2.94 (50) was adopted to achieve a gamma population-depopulation balance in conjunction with an assumed zero β^- population of the 99.952-keV nuclear level of ^{144}Pr. A weighted-mean normalization factor (*F*) of 0.1083 ± 0.0012 was adopted for the relative gamma-ray emission probabilities, as determined from the conversion-electron and gamma spectroscopic studies of Geiger *et al.* (1960Ge05), Debertin *et al*. (1975De17) and Olomo and MacMahon (1981Ol04) by means of a well-characterised β spectrometer and Ge(Li) detector systems.

Absolute emission probability of 133.515-keV gamma ray (normalization factor).

Reference	$P_\gamma^{abs}(\mathbf{133.515\ keV})$
1960Ge05	0.108 (4)[#]
1975De17	0.1109 (16)
1981Ol04	0.1069 (12)
Recommended	0.1083 (12)[†]

[#] Calculated from theoretical internal conversion coefficients, measured conversion-electron and γ intensities, and (K(133.515 keV) / ^{144}Pr β spectrum) ratio of 0.053 (2), as specified in Table 2 and Section 6 of 1960Ge05.

[†] Recommended uncertainty adjusted from ± 0.0009 to 0.0012 to align with the smallest uncertainty of the values used to calculate the weighted mean value.

Multipolarities, and Internal Conversion Coefficients

The nuclear level scheme specified by Sonzogni has been used to define the multipolarities of the gamma transitions on the basis of known spins and parities (2001So16). Extensive conversion-electron, e-γ, γ−γ coincidence and directional angular correlation studies throughout the 1960s/1970s focused on defining gamma multipolarities and spin-parity assignments for the nuclear levels of ^{144}Pr (particularly for the 0 − ground state). The detailed conversion-electron measurements of Geiger *et al.* are particularly noteworthy (1960Ge05, 1961Ge09, 1969Ge01), along with equivalent studies of 1959Se57, 1963Iw02, 1965Co19, 1966Be11, 1966Da04, 1969Ma24, 1970An15, 1971Sa20, 1975Ba32 and 1976Ch33. Adopted multipolarities are 100%M1 for the 33.563-, 40.92-, 53.395-, 80.120-, and 133.515-keV gamma rays, and E2 for the 99.952-keV gamma ray. More specifically, evidence of 100%M1 for the 40.92-keV gamma transition arises from measurements of the relative conversion-electron emission probabilities of 1960Ge05, and the α_L value of 1.8 (6) determined by 1970An15. Recommended internal conversion coefficients have been determined from the frozen orbital approximation of Kibédi *et al*. (2008Ki07), based on the theoretical model of Band *et al*. (2002Ba85, 2002Ra45).

The observation of a low-intensity, 59.03-keV gamma ray was identified with the subsequent IT decay of ^{144m}Pr (half-life of 7.2 (2) min. – defined as M3 transition).

Branching fractions for ^{144}Ce(β^-)^{144}Pr and ^{144}Ce(β^-)^{144m}Pr

^{144}Ce undergoes β^- decay predominantly to the ground state of ^{144}Pr via both β^- population of the ground state, 80.120- and 133.5152-keV nuclear levels of ^{144}Pr, and γ depopulation/population of the ground state, 80.120-, 99.952- and 133.5152-keV nuclear levels of ^{144}Pr. However, there is also evidence for the existence of a small branch that populates the 59.03-keV nuclear level of ^{144m}Pr by means of the 40.92-keV γ transition, which arises as part of the 33.563−40.92(−59.03) γ cascade embracing the 133.5152-, 99.952- and 59.03-keV nuclear levels.

Adopting a recommended relative γ-ray emission probability of 2.94 (50) % for the 40.92-keV γ ray, and a normalisation factor of 0.1083 (12):

BF(^{144}Ce(β^-)^{144m}Pr) = $[\,P_\gamma^{rel}\ x\ F\,]\ x\ (1+\ \alpha_{total})]$

where P_γ^{rel} is the relative γ-ray emission probability, F is the normalisation factor, and α_{total} is the total internal conversion coefficient.

Therefore, BF(^{144}Ce(β^-)^{144m}Pr) = [2.94 (50) x 0.1083 (12)] x 3.61 (4) = 1.149 (195) %.

BF(^{144}Ce(β^-)^{144m}Pr) = 0.0115 (20) when rounded-up and expressed as a fraction [i.e. 1.15 (20) %];

BF(^{144}Ce(β^-)^{144}Pr) = 0.9885 (20) when expressed as a fraction [i.e. 98.85 (20) %].

Published gamma-ray emission probabilities.

E_γ (keV)	P_γ (%)										
	1954Kr40*	**1959Fr54***	**1959Se57***	**1960Ge05▲**	**1960Sa22***	**1969Ma24***	**1969Gu15θ**	**1970An15***	**1970Fa03†**	**1970Po09***	**1975De17θ**
33.563 (9)	–	includes X-rays	144 (10)	0.23 (1)	95	80 (8)	–	2.0 (5)	0.15 (5)	2.3 (2)	–
40.92 (3)	–	–	–	0.36 (1)	–	–	–	4.4 (15)	0.50 (25)	5 (4)	–
53.395 (5)	–	–	–	0.127 (5)	–	–	–	1.2 (2)	0.09 (4)	1.1 (1)	–
59.03 (3) ^{144m}Pr IT decay	–	–	–	0.0011	–	–	–	~ 0.01	not observed	–	–
80.120 (4)	28.7 (43)	24 (5)	24 (5)	1.6 (1)	35	22 (2)	1.51 (15)	14.8 (10)	1.54 (15)	16 (1)	–
99.952 (9)	–	–	–	0.042 (2)	–	10 (2)	–	0.36 (5)	0.038 (4)	0.39 (4)	–
133.5152 (20)	100	100 (10)	100 (6)	10.8 (4)	100	100	11.0 (3)	100 (5)	(10.8)	100 (6)	11.09 (16)

E_γ (keV)	P_γ (%)						
	1976Ch33*	**1976Ra22‡**	**1977Ge12+**	**1981Ol04θ**	**1982Yu02***	**1983El14***	**1984Da13***
33.563 (9)	2.62 (15)	includes X-rays	–	–	2.14 (17)	1.77 (26)	1.8 (2)
40.92 (3)	3.59 (40)	0.72 (4)	–	–	3.76 (65)Δ	3.22 (230)#	1.38 (20)
53.395 (5)	0.86 (5)	0.07 (1)	7.8 (4)	–	1.05 (11)	0.84 (8)	0.90 (7)
59.03 (3) ^{144m}Pr IT decay	not observed	0.003 (2)	–	–	not observed	≈ 0.01	≤ 0.01
80.120 (4)	10.20 (100)	1.50 (4)	112 (6)	–	13.6 (10)	12.58 (100)	12.25 (49)
99.952 (9)	0.35 (3)	0.06 (1)	–	–	0.36 (4)	0.50 (7)	0.36 (4)
133.5152 (20)	100 (4)	10.0 (1)	836 (25)	10.69 (12)	100	100	100.0 (10)

* Emission probabilities expressed relative to P_γ(133.515 keV) of 100%.

▲ Absolute emission probabilities calculated from theoretical internal conversion coefficients, measured conversion-electron and γ intensities, and (K(133.515 keV) / ^{144}Pr β spectrum) ratio of 0.053 (2), as specified in Table 2 and Section 6 of 1960Ge05.

θ Measured absolute emission probability (and probabilities).

† Absolute emission probabilities expressed on the basis of an absolute emission probability of 10.8% for the 133.515-keV gamma ray.

‡ Emission probabilities expressed relative to an absolute emission probability of 10.0 (1) % for the 133.515-keV gamma ray.

+ Emission probabilities expressed relative to P_γ(696.5 keV) of 100% which is identified with the decay of daughter ^{144}Pr/^{144m}Pr.

Δ Authors state that relative emission probability obtained by subtracting theoretical relative emission probability of Pr X $K_{\alpha1}$ from measured composite peak.

Authors state that relative emission probability obtained by subtracting theoretical relative emission probabilities of Pr X $K_{\beta1}$ and $K_{\beta2}$ from measured composite peak.

Measured and recommended gamma-ray emission probabilities relative to P_γ(133.515 keV) of 100%.

E_γ (keV)	P_γ^{rel} (%)									
	1954Kr40	1959Fr54	1959Se57	1960Ge05*	1960Sa22	1969Ma24	1969Gu15*	1970An15	1970Fa03*	1970Po09
33.563 (9)	−	−	144 (10)#	2.1 (1)	95#	80 (8)#	−	2.0 (5)	1.4 (5)	2.3 (2)
40.92 (3)	−	−	−	3.3 (1)	−	−	−	4.4 (15)	4.6 (23)	5 (4)
53.395 (5)	−	−	−	1.18 (5)	−	−	−	1.2 (2)	0.8 (4)	1.1 (1)
59.03 (3) ^{144m}Pr IT decay	−	−	−	0.01	−	−	−	~ 0.01	not observed	−
80.120 (4)	28.7 (43)	24 (5)	24 (5)	14 (1)	35	22 (2)	13.7 (14)	14.8 (10)	14.3 (14)	16 (1)
99.952 (9)	−	−	−	0.39 (2)	−	10 (2)	−	0.36 (5)	0.35 (4)	0.39 (4)
133.5152 (20)	100	100 (10)	100 (6)	100 (4)	100	100	100	100 (5)	(100)	100 (6)

E_γ (keV)	P_γ^{rel} (%)						
	1976Ch33	1976Ra22*	1977Ge12*	1982Yu02	1983El14	1984Da13	Recommended†
33.563 (9)	2.62 (15)	−	−	2.14 (17)	1.77 (26)	1.8 (2)	2.08 (10)+
40.92 (3)	3.59 (40)	7.2 (4)	−	3.76 (65)‡	3.22 (230)θ	1.38 (20)	2.94 (50)▲
53.395 (5)	0.86 (5)	0.7 (1)	0.93 (6)	1.05 (11)	0.84 (8)	0.90 (7)	0.93 (5)Δ
59.03 (3) ^{144m}Pr IT decay	−	0.03 (2)	−	not observed	≈ 0.01	≤ 0.01	0.0087 (18)Φ
80.120 (4)	10.20 (100)	15.0 (4)	13.4 (8)	13.6 (10)	12.58 (100)	12.25 (49)	12.9 (5)×
99.952 (9)	0.35 (3)	0.6 (1)	−	0.36 (4)	0.50 (7)	0.36 (4)	0.38 (2)§
133.5152 (20)	100 (4)	(100 (1))	100	100	100	100.0 (10)	100

* Emission probabilities adjusted in order to be expressed relative to P_γ(133.515 keV) of 100%.

Unable to resolve 33.563-keV gamma transition from X-ray emissions – data not included in subsequent evaluation.

† LWM weighted-mean values adopted when judged appropriate.

‡ Stated as obtained by subtracting the theoretical Pr $K_{\alpha1}$ X-ray emission probability (36.033 keV) from the experimentally-measured composite peak.

θ Stated as obtained by subtracting the theoretical Pr $K_{\beta1}$ and $K_{\beta2}$ X-ray emission probabilities (40.739 and 41.778 keV) from the experimentally-measured composite peak.

+ Rajeval value adopted, with the recommended uncertainty adjusted from ± 0.07 to 0.10 to align with smallest uncertainty of the data used to calculate this weighted-mean value.

▲ Considerable difficulty has been experienced in resolving the 40.92-keV gamma-ray emission from Pr K_β X-ray emissions (40.65 – 41.97 keV) – hence, a speculative P_γ^{rel}(40.92 keV) weighted-mean value of 2.94 (50) was adopted to achieve a gamma population-depopulation balance in conjunction with an assumed zero β^- population of the 99.952-keV nuclear level of ^{144}Pr.

Δ Rajeval value adopted, with the recommended uncertainty adjusted from ± 0.03 to 0.05 to align with smallest uncertainty of the data used to calculate this weighted-mean value.

Φ Calculated from the recommended relative transition probability of 10.61 (215) % for the 40.92-keV γ ray which populates the 59.03-keV nuclear level of ^{144}Pr, and M3 total internal conversion coefficient of 1221 (18).

× Recommended uncertainty adjusted from ± 0.3 to 0.5 to align with smallest uncertainty of the data used to calculate the weighted-mean value.

§ Recommended uncertainty adjusted from ± 0.01 to 0.02 to align with smallest uncertainty of the data used to calculate the weighted-mean value.

Gamma-ray emissions: multipolarities, and theoretical internal-conversion coefficients (frozen orbital approximation).

E_γ(keV)		Multipolarity	α_K	α_L	α_{L1}	α_{L2}	α_{L3}	α_M	α_N	α_{O+}	α_{total}
33.563 (9)	(Pr)	M1	−	3.70 (6)	3.35 (5)	0.289 (4)	0.0603 (9)	0.780 (11)	0.1744 (25)	0.031	4.69 (7)
40.92 (3)	(Pr)	M1	−	2.06 (3)	1.87 (3)	0.1585 (23)	0.0329 (5)	0.434 (7)	0.0971 (14)	0.0168	2.61 (4)
53.395 (5)	(Pr)	M1	6.75 (10)	0.942 (14)	0.856 (12)	0.0710 (10)	0.01464 (21)	0.199 (3)	0.0444 (7)	0.0076	7.94 (12)
59.03 (3)	(Pr)	M3	408 (6)	618 (9)	233 (4)	34.9 (5)	351 (5)	155.0 (23)	34.7 (5)	5.20 (8)	1221 (18)
80.120 (4)	(Pr)	M1	2.08 (3)	0.288 (4)	0.263 (4)	0.0209 (3)	0.00427 (6)	0.0608 (9)	0.01359 (19)	0.0030	2.45 (4)
99.952 (9)	(Pr)	E2	1.214 (17)	0.710 (10)	0.1085 (16)	0.288 (4)	0.313 (5)	0.1599 (23)	0.0346 (5)	0.0049	2.12 (3)
133.5152 (20)	(Pr)	M1	0.486 (7)	0.0668 (10)	0.0613 (9)	0.00456 (7)	0.000919 (13)	0.01408 (20)	0.00315 (5)	0.00055	0.571 (8)

Recommended gamma-ray energies, relative and absolute emission probabilities, and transition probabilities, and conversion-electron probabilities.

	E_γ (keV)	P_γ^{rel}	P_γ^{abs} (%)	Transition probability (%)	P_{ce}^{abs} = (TP − P_γ^{abs}) (%)
$\gamma_{4,3}$	33.563 (9)	2.08 (10)	0.225 (11)	1.28 (6)	1.05 (6)
$\gamma_{3,1}$	40.92 (3)	2.94 (50)	0.32 (5)	1.16 (18)	0.84 (19)
$\gamma_{4,2}$	53.395 (5)	0.93 (5)	0.101 (5)	0.90 (4)	0.80 (4)
$\gamma_{1,0}$	59.03 (3)	0.0087 (18)	0.00094 (19)	1.15 (23)	1.149 (230)
$\gamma_{2,0}$	80.120 (4)	12.9 (5)	1.40 (5)	4.83 (17)	3.43 (18)
$\gamma_{3,0}$	99.952 (9)	0.38 (2)	0.041 (2)	0.128 (6)	0.087 (6)
$\gamma_{4,0}$	133.5152 (20)	100	10.83 (12)	17.01 (19)	6.18 (22)

β^- energies and emission probabilities

Energies

All β^- energies were derived from the structural details of the proposed decay scheme. The nuclear level energies of 2001So16 and evaluated Q-value of 318.6 (8) keV (2012Wa38) were used to determine the recommended energies and uncertainties of the β^- emissions.

Emission Probabilities

Emission probabilities were derived for the population-depopulation imbalances of the relative emission probabilities of the gamma rays, their theoretical internal-conversion coefficients, and the normalization factor of (0.1083 ± 0.0012) for the gamma-ray emissions, as noted above. β^- decay directly to the 99.952-keV nuclear level of ^{144}Pr and the 59.03-keV metastable state (^{144m}Pr) were both assumed to be zero on the basis of spin and parity considerations that would have resulted in first forbidden unique and third forbidden non-unique transitions, respectively. Log*ft* values and average $E_{\beta-}$ energies were determined by means of the LOGFT code.

Recommended energies and emission probabilities for the β^- decay of ^{144}Ce.

	E_β (keV)*	Av. $E_{\beta-}$ (keV)	P_β	^{144}Ce	^{144}Pr	transition type	log *ft*
$\beta^-_{0,4}$	185.1 (8)	50.29 (24)	19.2 (1)	0 +	1 −	first forbidden non-unique	7.27
$\beta^-_{0,2}$	238.5 (8)	66.24 (25)	3.9 (2)	0 +	1 −	first forbidden non-unique	8.31
$\beta^-_{0,0}$	318.6 (8)	91.3 (3)	76.9 (3)	0 +	0 −	first forbidden non-unique	7.424
			Σ 100				

* Determined from the nuclear level energies of 2001So16 and Q-value of 318.6(8) keV (2012Wa38).

Energies and emission probabilities of noteworthy internal-conversion electrons.

		Energy (keV)	Electrons per 100 disint.
$ec_{4,3\ T}$	(Pr)	26.728 – 33.563	1.05 (6)
$ec_{4,3\ L}$	(Pr)	26.728 – 27.599	0.83 (5)
$ec_{4,3\ M}$	(Pr)	32.052 – 32.632	0.175 (10)
$ec_{4,3\ N}$	(Pr)	32.259 – 33.561	0.039 (2)
$ec_{4,3\ O+}$	(Pr)	33.526 – 33.563	0.0069 (4)
$ec_{3,1\ T}$	(Pr)	34.09 – 40.90	0.84 (19)
$ec_{3,1\ L}$	(Pr)	34.09 – 34.96	0.66 (15)
$ec_{3,1\ M+}$	(Pr)	39.41 – 40.90	0.18 (4)
$ec_{4,2\ T}$	(Pr)	11.404 – 53.393	0.80 (4)
$ec_{4,2\ K}$	(Pr)	11.404 (5)	0.68 (3)
$ec_{4,2\ L}$	(Pr)	46.560 – 47.431	0.095 (5)
$ec_{4,2\ M+}$	(Pr)	51.884 – 53.393	0.025 (1)
$ec_{1,0\ T}$	(Pr)	17.04 – 59.03	1.15 (23)
$ec_{1,0\ K}$	(Pr)	17.04 (3)	0.38 (8)
$ec_{1,0\ L}$	(Pr)	52.20 – 53.07	0.58 (12)
$ec_{1,0\ M+}$	(Pr)	57.52 – 59.03	0.18 (4)
$ec_{2,0\ T}$	(Pr)	38.129 – 80.12	3.43 (18)
$ec_{2,0\ K}$	(Pr)	38.129 (4)	2.91 (15)
$ec_{2,0\ L}$	(Pr)	73.285 − 74.156	0.403 (21)
$ec_{2,0\ M}$	(Pr)	78.609 − 79.189	0.085 (4)
$ec_{2,0\ N}$	(Pr)	79.816 − 80.118	0.0190 (10)
$ec_{2,0\ O+}$	(Pr)	80.083 – 80.12	0.0042 (2)
$ec_{4,0\ T}$	(Pr)	91.524 – 133.515	6.18 (22)
$ec_{4,0\ K}$	(Pr)	91.524 (2)	5.26 (19)
$ec_{4,0\ L}$	(Pr)	126.680 – 127.551	0.723 (25)
$ec_{4,0\ M}$	(Pr)	132.004 – 132.584	0.152 (5)
$ec_{4,0\ N}$	(Pr)	133.211 – 133.513	0.0341 (12)
$ec_{4,0\ O+}$	(Pr)	133.478 – 133.515	0.00595 (21)

A consistent decay scheme was derived that contains three β^- transitions and seven gamma-ray emissions, of which one gamma transition originates from the IT decay of ^{144m}Pr. While the 59.03-keV gamma transition constitutes the major IT-decay mode of ^{144m}Pr, this emission has been adopted as part of the β^- decay scheme of ^{144}Ce, and can be found in the decay-data files of both ^{144}Ce and ^{144m}Pr.

Atomic Data

The X-ray and Auger-electron data have been calculated using the evaluated gamma-ray data, and atomic data from 1996Sc06, 1998ScZM and 1999ScZX. Both the X-ray and Auger-electron emission probabilities were determined by means of the EMISSION computer program (version 4.02, 28 February 2012), as described in 2000Sc47. This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray energies and emission probabilities of ^{144}Ce.

			Energy (keV)	Photons per 100 disint.	Relative probability
XL		(Pr)	4.453 – 6.617	1.54 (4)	35.0
	XL_l	(Pr)	4.453	0.0282 (9)	
	XL_α	(Pr)	5.013 – 5.033	0.711 (21)	
	XL_η	(Pr)	4.929	0.0107 (4)	
	XL_β	(Pr)	5.489 – 5.851	0.673 (15)	
	XL_γ	(Pr)	6.327 – 6.617	0.116 (3)	
XK_α	$XK_{\alpha2}$	(Pr)	35.5506 (2)	2.41 (5)	54.8
	$XK_{\alpha1}$	(Pr)	36.0267 (2)	4.40 (9)	100
$XK'_{\beta1}$	$XK_{\beta3}$	(Pr)	40.6533 (7)	}	
	$XK_{\beta1}$	(Pr)	40.7487 (5)	} 1.34 (3)	30.5
	$XK''_{\beta5}$	(Pr)	41.050	}	
$XK'_{\beta2}$	$XK_{\beta2}$	(Pr)	41.774 (2)	}	
	$XK_{\beta4}$	(Pr)	41.877	} 0.343 (10)	7.80
	$XKO_{2,3}$	(Pr)	41.968	}	

Auger-electron energies and emission probabilities of ^{144}Ce.

	Energy (keV)	Electrons per 100 disint.	Relative probability
e_{AK} (Pr)		0.80 (4)	
KLL	28.162 – 29.890	0.514 (26)	100
KLX	33.576 – 36.004	0.254 (13)	49.4
KXY	38.97 – 41.95	0.0313 (17)	6.1
e_{AL} (Pr)	2.90 – 4.91	9.88 (10)	1922

Pr: ω_K = 0.914 (4); ϖ_L = 0.132 (5); n_{KL} = 0.871 (4) were taken from 1996Sc06.

Electron energies were determined from electron binding energies tabulated by Larkins (1977La19) and the evaluated gamma-ray energies. Absolute electron emission probabilities were calculated from the evaluated absolute gamma-ray emission probabilities and associated internal conversion coefficients.

Data Consistency

An effective Q_β-value of 318.6 (8) keV has been adopted from Wang *et al*. (2012Wa38), and compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{144}Ce β^--decay process (i.e. β^-, conversion electrons, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 318.5\ (13)\ \text{keV}$$

The percentage deviation of the calculated Q-value from the effective Q-value is (0.0 ± 0.5) %, which supports the derivation of an extremely consistent decay scheme with a relatively modest variant.

References

1954Co60 J.M. Cork, M.K. Brick, L.C. Schmid, Energies of the Radiations from Ce^{144} and Pr^{144}, Phys. Rev. 96 (1954) 1295-1297. [E_γ, E_e]

1954Em09 W.S. Emmerich, W.J. Auth, J.D. Kurbatov, The Nuclear Spectra of Ce^{144} and Pr^{144}, Phys. Rev. 94 (1954) 110-112. [E_β, E_γ]

1954Kr40 W.E. Kreger, C.S. Cook, Gamma Radiation from Ce^{144} and Pr^{144}, Phys. Rev. 96 (1954) 1276-1278. [P_γ]

1956Pu24 I. Pullman, P. Axel, Decay of Ce^{144}, Phys. Rev. 102 (1956) 1366-1372. [E_β, E_γ, E_e]

1956Sc87 R.P. Schuman, M.E. Jones, A.C. Mewherter, Half-lives of Ce^{144}, Co^{58}, Cr^{51}, Fe^{55}, Mn^{54}, Pm^{147}, Ru^{106} and Sc^{46}, J. Inorg. Nucl. Chem. 3 (1956) 160-163. [Half-life]

1957Me47 W.F. Merritt, P.J. Campion, R.C. Hawkings, Half-life Determination of Some Radionuclides, Can. J. Phys. 35 (1957) 16-20. [Half-life]

1957Pa51 V. Parfenova, N.V. Forafontov, V.S. Shpinel, Investigation of the Ce^{144} Decay Using the β-γ Coincidence Method, Izvest. Akad. Nauk SSSR, Ser. Fiz. 21 (1957) 1601-1606.[E_β, P_β, E_γ]

1958Hi76 R.L. Hickok, W.A. McKinley, S.C. Fultz, Decay of Ce^{144} and Pr^{144}, Phys. Rev. 109 (1958) 113-116. [E_β, P_β, α_K]

1959Fr54 N.J. Freeman, The Decay of ^{144}Ce, Proc. Phys. Soc. 74 (1959) 449-456. [E_β, P_β, transition type, E_γ, α_K, α_L, E_{ce}]

1959Se57 A.K. Sengupta, R. Bhattacharyya, J. Lahiri, P.N. Mukherjee, Level Scheme of Pr^{144}, Indian J. Phys. 33 (1959) 388-394. [E_β, P_β, E_γ, P_γ, $\alpha_K/\alpha_{(L+M)}$]

1960Ea02 H.T. Easterday, R.L. Smith, Balanced Ion Chamber Measurement of Half-lives of Several Radioisotopes, Nucl. Phys. 20 (1960) 155-158. [Half-life]

1960Ge05 J.S. Geiger, R.L. Graham, G.T. Ewan, Conversion Electron Spectrum from Ce^{144} Decay, Nucl. Phys. 16 (1960) 1-26. [E_{ce}, P_{ce}, multipolarity]

1960Sa22 H.J. Sathoff, T. Azuma, Decay of Cerium-144, Ohio State University Research Report R-35051, TID-6080, Appendix 8 (1960). [E_γ, P_γ]

1961Ge09 J.S. Geiger, R.L. Graham, G.T. Ewan, The Decay of Ce^{144}, Nucl. Phys. 28 (1961) 387-406. [E_{ce}, P_{ce}, e-γ, γ-γ coincidence]

1962Bl05 B. Blake, R. Bobone, H. Frauenfelder, H.J. Lipkin, Transverse Polarization of Conversion Electrons Following β-decay, Nuovo Cimento 25 (1962) 942-945. [133.5-keV conversion-electron process]

1962Bu09 J. Burde, M. Rakavy, G. Engler, Lifetime Determination of Three Excited Levels in the Odd-odd Nucleus Pr^{144}, Phys. Lett. 1 (1962) 147-149. [Nuclear-level lifetime]

1962Bu22 J. Burde, M. Rakavy, G. Engler, Absolute Transition Probabilities in the Odd-odd Nucleus Pr^{144}, Phys. Rev. 128 (1962) 325-332. [Nuclear-level lifetime]

1962Fo04 N.V. Forafontov V.S. Shpinel, Ts. Vasilev, Study of Ce^{144} Decay by Coincidence Method, Nucl. Phys. 35 (1962) 260-272. [E_{ce}, E_{Ae}, P_{ce} summed subshell ratios]

1963Bh11 R. Bhattacharyya, S. Shastry, E2-M1 Mixing in the 100 keV Transition of Pr^{144}, Indian J. Phys. 37 (1963) 357-358. [γ-γ directional angular correlation, multipolarity]

1963Co18 W. Collin, H. Daniel, S. Margulies, O. Mehling, P. Schmidlin, H. Schmitt, K.S. Sibudhi, The Spins of Pr^{144} from β-γ Correlation Measurements, Phys. Lett. 5 (1963) 329-331. [Spin]

1963Cr11 E. Creutz, J. de Raedt, J.P. Deutsch, L. Grenacs, D. Siddique, Spin of the Pr^{144} Ground State Beta-decay Measurements on Ce^{144} and Pr^{144}, Phys. Lett. 6 (1963) 329-331. [Ground-state spin]

1963Fu16 M. Fujishiro, T. Azuma, Beta-spectra of Ce-144, Annu. Report Radiation Center of Osaka Prefect. 4 (1963) 86-89. [E_β, P_β, E_γ, P_γ]

1963Iw02 T. Iwashita, T. Inamura, Y. Ikemoto, S. Kageyama, Decay of ^{144}Ce, J. Phys. Soc. Japan 18 (1963) 1358-1365. [γ-γ coincidence, γ-γ directional angular correlation, level structure, spin]

1963Kn05 U. Kneissel, H. Schneider, Bestimmung der Spins des Grundzustandes und des 134 keV Niveaus von ^{144}Pr durch Messung der β-γ-Zirkularpolarisation am β-Zerfall des $^{144}_{58}Ce$ und $^{144}_{59}Pr$, Physik Verhandl 14 (1963) 125, 13. [Spin]

1963Si10 R.M. Singru, R.S. Raghavan, R.M. Steffen, Unique Spin Assignment to the Pr^{144} Ground State, Phys. Lett. 6 (1963) 319-320. [Ground state spin, multipolarity]

1964Az02 T. Azuma, Y. Sato, β-γ Directional Angular Correlation of Pr-144, Annu. Report Radiation Center of Osaka Prefect. 5 (1964) 43-47. [γ-γ directional angular correlation, β transition type]

1964Be36 E.E. Berlovich, Yu.K. Gusev, D.M. Khai, I. Shenaikh, Lifetimes of Excited States of W^{182}, Pr^{144} and Eu^{151}, Bull. Acad. Sci. USSR, Phys. Ser. 28 (1965) 77-84. [Nuclear-level lifetime]

1964Mc22 R.E. McAdams, E.N. Hatch, Some Lifetime Measurements of Isomeric States in the Rare Earth Region with Magnetic Coincidence Beta-ray Spectrometers, USAEC Research and Development Report IS-1071, TID-4500 (1964) 127-135. [Nuclear-level lifetime]

1965Co19 W. Collin, H. Daniel, B. Martin, P. Schmidlin, H. Schmitt, β-γ-Richtungskorrelationen und β-γ-Zirkularpolarisations-Korrelationen beim Einfach Verbotenen β-Zerfall von Ce^{144}, Pr^{144}, Tm^{170} und Hg^{203}, Kolloquium über Beta-Zerfall und Schwache Wechselwirkungen, Heidelberg (1965) 213-220. [β-γ correlation, nuclear-level structure]

1965Fl02 K.F. Flynn, L.E. Glendenin, E.P. Steinberg, Half-life Determinations by Direct Decay, Nucl. Sci. Eng. 22 (1965) 416-419. [Half-life]

1965Re13 W. Reiser, Spinbestimmung bei Praseodym 144 durch Winkelkorrelationsmessungen, Atomkernenergie 10 (1965) 307-310. [Spin]

1966Be11 H. Beer, H. Schneider, (54 – 80) keV-γ-γ-Winkelkorrelation von Pr^{144}, Z. Naturforsch. 21A (1966) 174-175. [Ground-state spin, δ(53.4 keV)]

1966Da04 H. Daniel, G.Th. Kaschl, Spektralformen von (0 → 0)-β-Übergängen mit Paritätswechsel: ^{144}Ce, ^{144}Pr und ^{166}Ho, Nucl. Phys. 76 (1966) 97-117. [E_β, P_β]

1967Gu17 S.L. Gupta, N.K. Saha, Gamma-Gamma Directional Correlations in Pr^{144}, Indian J. Phys. 41 (1967) 48-54. [γ-γ coincidence, γ-γ directional correlation, ground-state spin]

1968Da12 H. Daniel, W. Collin, M. Kuntze, S. Margulies, B. Martin, O. Mehling, P. Schmidlin, H. Schmitt, Kernspektroskopische Untersuchungen an ^{8}Li, ^{42}K, ^{86}Rb, ^{141}Ce, ^{144}Ce, ^{144}Pr und ^{203}Hg, Nucl. Phys. A118 (1968) 689-697. [β-γ directional correlation, ground-state spin]

1968La10 F. Lagoutine, Y. le Gallic, J. Legrand, Determination Précise de Quelques Périodes Radioactives, Int. J. Appl. Radiat. Isot. 19 (1968) 475-482. [Half-life]

1968Re04 S.A. Reynolds, J.F. Emery, E.I. Wyatt, Half-lives of Radionuclides III, Nucl. Sci. Eng. 32 (1968) 46-48. [Half-life]

1969Ge01 W. Gelletly, J.S. Geiger, L-subshell Conversion Line Intensity Ratios for Pure M1(1 ↔ 0) Transitions, Nucl. Phys. A123 (1969) 369-385. [L-subshell ratios]

1969Gu15 R. Gunnink, J.B. Niday, R.P. Anderson, R.A. Meyer, Gamma-ray Energies and Intensities, Lawrence Radiation Laboratory Report UCID-15439 (1969). [E_γ, Pγ]

1969Ma24 P.C. Mangal, P.N. Trehan, The Decay of ^{144}Ce, J. Phys. Soc. Japan 27 (1969) 1-7. [γ-γ coincidence, γ-γ angular correlation, nuclear structure, P_γ]

1970An15 A. Anttila, M. Piiparinen, The Levels of ^{144}Pr from the Decay of ^{144}Ce, Z. Phys. 237 (1970) 126-130. [E_γ, P_γ, α_K, α_L]

1970Fa03 J.L. Fasching, W.B. Walters, C.D. Coryell, Decay of 284-day ^{144}Ce, 17.3-min ^{144}Pr, and a New Isomer 7.2-min ^{144m}Pr, Phys. Rev. C1 (1970) 1126-1131. [E_γ, P_γ]

1970Po09 V.R. Potnis, G.P. Agin, C.E. Mandeville, The Decay of ^{144}Ce, J. Phys. Soc. Japan 29 (1970) 539-542. [P_γ]

1971Sa20 H.S. Sahota, Experimental Measurement of the K Conversion Coefficient of 80-keV Transition in ^{144}Pr, Curr. Sci., India 40 (1971) 289-290. [80-keV α_K]

1975Ba32 Chr. Bargholtz, S. Beshai, L. Eriksson, L.-E. Fröberg, L. Gidefeidt, The g-factor of the 80.1-keV Level in ^{144}Pr, Physica Scripta 11 (1975) 363-365. [δ(53 keV)]

1975De17 K. Debertin, U. Schötzig, K.F. Walz, H.M. Weiss, Gamma-ray Emission Probabilities of the Fission Products ^{144}Ce-^{144}Pr, ^{106}Rh, ^{95}Zr, Ann. Nucl. Energy 2 (1975) 37-43.[134-keV P_γ]

1976Ch33 J.M. Chatterjee-Das, R.K. Chattopadhyay, P. Bhattacharya, B. Sethi, S.K. Mukherjee, The Decay Scheme of the 284.3 d ^{144}Ce and Energy Levels and Transitions in ^{144}Pr, Radiochem. Radioanal. Lett. 27 (1976) 119-128. [E_γ, P_γ]

1976Ra22 B.V.N. Rao, G.N. Rao, Decay of ^{144}Ce to Levels in ^{144}Pr and ^{144}Nd, J. Phys. Soc. Japan 40 (1976) 1-5. [E_γ, P_γ]

1977Ge12 R.J. Gehrke, R.G. Helmer, R.C. Greenwood, Precise Relative γ-ray Intensities for Calibration of Ge Semiconductor Detectors, Nucl. Instrum. Methods 147 (1977) 405-423. [P_γ]

1977La19 F.P. Larkins, Semiempirical Auger-electron Energies for Elements 10 ≤ Z ≤ 100, At. Data Nucl. Data Tables 20 (1977) 311-387. [Auger-electron energies]

1978Mo22 T. Morii, Precision Energy Measurement of Gamma Rays of ^{51}Cr, ^{103}Ru, ^{109}Cd, ^{144}Ce and ^{203}Hg, Nucl. Instrum. Methods 151 (1978) 489-491. [133.5-keV E_γ]

1979Bo26 H.G. Borner, W.F. Davidson, J. Almeida, J. Blachot, J.A. Pinston, P.H.M. Van Assche, High Precision Gamma-ray Energy Measurements of Fission Products, Nucl. Instrum. Methods 164 (1979) 579-586. [133.5-keV E_γ]

1980Ho17 H. Houtermans, O. Milosevic, F. Reichel, Half-lives of 35 Radionuclides, Int. J. Appl. Radiat. Isot. 31 (1980) 153-154. [Half-life]

1981Ol04 J.B. Olomo, T.D. MacMahon, Gamma-ray Emission Probabilities in the Decay of ^{144}Ce and ^{144}Pr, Nucl. Energy 20 (1981) 237-240. [P_γ]

1982Yu02 B. Yu, F. Liu, X. Lu, S. Li, C. Yang, The Decay of ^{144}Ce, Radiochem. Radioanal. Lett. 53 (1982) 351-358. [E_γ, P_γ, P_X, P_X]

1983El14 M.R. El-Aasser, A. Abdel-Haliem, P. Asfour, M.N.H. Comsan, On the Decay of ^{144}Ce, Arab J. Nucl. Sci. Appl. 16-2 (1983) 283-292. [E_γ, P_γ]

1983Wa26 K.F. Walz, K. Debertin, H. Schrader, Half-life Measurements at the PTB, Int. J. Appl. Radiat. Isot. 34 (1983) 1191-1199. [Half-life]

1984Da13 J. Dalmasso, H. Maria, A. Hachem, G. Ardisson, Energie et Intensité des Photons X et de ^{144}Ce, Nucl. Instrum. Methods Phys. Res. 221 (1984) 564-565. [E_γ, P_γ]

1986Ol01 J.B. Olomo, Half-life of Radiotherapeutic ^{144}Ce Used as Beta-ray Applicator, Radiation Effects 94 (1986) 109-112. [Half-life]

1992Un01 M.P. Unterweger, D.D. Hoppes, F.J. Schima, New and Revised Half-life Measurements Results, Nucl. Instrum. Methods Phys. Res. A312 (1992) 349-352. [Half-life]

1996Sc06 E. Schönfeld, H. Janβen, Evaluation of Atomic Shell Data, Nucl. Instrum. Methods Phys. Res. A369 (1996) 527-533. [ω_K, ϖ_L, K_β/K_α, $K_{\alpha2}/K_{\alpha1}$, KLX/KLL, KXY/KLL]

1997Ma75 R.H. Martin, K.I.W. Burns, J.G.V. Taylor, A Measurement of the Half-lives of ^{54}Mn, ^{57}Co, ^{59}Fe, ^{88}Y, ^{95}Nb, ^{109}Cd, ^{133}Ba, ^{134}Cs, ^{144}Ce, ^{152}Eu, Nucl. Instrum. Methods Phys. Res. A390 (1997) 267-273. [Half-life]

1998ScZM E. Schönfeld, G. Rodloff, Tables of the Energies of K-Auger Electrons for Elements with Atomic Numbers in the Range from Z = 11 to Z = 100, PTB Report PTB-6.11-98-1, October 1998. [Auger electrons]

1999ScZX E. Schönfeld, G. Rodloff, Energies and Relative Emission Probabilities of K X-rays for Elements with Atomic Numbers in the Range from Z = 5 to Z = 100, PTB Report PTB-6.11-1999-1, February 1999. [X_K]

2000Sc47 E. Schönfeld, H. Janβen, Calculation of Emission Probabilities of X-rays and Auger Electrons Emitted in Radioactive Disintegration Processes, Appl. Radiat. Isot. 52 (2000) 595-600. [P_X, P_{Ae}]

2001So16 A.A. Sonzogni, Nuclear Data Sheets for A = 144, Nucl. Data Sheets 93 (2001) 599-762. [Nuclear levels]

2002Ba85 I.M. Band, M.B. Trzhaskovskaya, C.W. Nestor, Jr., P.O. Tikkanen, S. Raman, Dirac–Fock Internal Conversion Coefficients, At. Data Nucl. Data Tables 81 (2002) 1-334. [ICC]

2002Ra45 S. Raman, C.W. Nestor, Jr., A. Ichihara, M.B. Trzhaskovskaya, How Good are the Internal Conversion Coefficients Now? Phys. Rev. C66 (2002) 044312, 1-23. [ICC]

2002Un02 M.P. Unterweger, Half-life Measurements at the National Institute of Standards and Technology, Appl. Radiat. Isot. 56 (2002) 125-130. [Half-life]

2008Ki07 T. Kibédi, T.W. Burrows, M.B. Trzhaskovskaya, P.M. Davidson, C.W. Nestor, Jr., Evaluation of Theoretical Conversion Coefficients using BrIcc, Nucl. Instrum. Methods Phys. Res. A589 (2008) 202-229. [ICC]

2012Fi12 R. Fitzgerald, NIST Ionization Chamber "A" Sample-Height Corrections, J. Res. Natl. Inst. Stand. Technol. 117 (2012) 80-95. [Half-life]

2012Wa38 M. Wang, G. Audi, A.H. Wapstra, F.G. Kondev, M. MacCormick, X. Xu, B. Pfeiffer, The AME2012 Atomic Mass Evaluation, (I). Tables, Graphs and References, Chin. Phys. C36 (2012) 1603-2014. [Q-value]

2014Un01 M.P. Unterweger, R. Fitzgerald, Update of NIST Half-life Results Corrected for Ionization Chamber Source-Holder Instability, Appl. Radiat. Isot. 87 (2014) 92-94. [Half-life]