^{147}Nd - Comments on evaluation of decay data by V. Chisté and M. M. Bé

This evaluation was completed in March 2011, including all publications by this date.

1 Decay Scheme

^{147}Nd disintegrates 100 % by beta minus emissions to excited levels of ^{147}Pm. If a transition to the ground state level exists, it is less than 0.15 % (1971Na11, 1966Be09).

A good agreement was found between the effective Q value (890 (60) keV) calculated from the decay scheme data and the adopted and recommended value from the mass adjustment of Audi (20012Au06), confirming the consistency of the adopted decay scheme.

2 Nuclear Data

The Q^- value is from the atomic mass evaluation of Audi *et al.* (2009AuZZ).

Experimental ^{147}Nd half-life values (in days) are given in Table 1:

Table 1: Experimental values of ^{147}Nd half-life.

Reference	Experimental value (d)	Comments
W. Bothe (1946Bo25)	11.1 (2)	
W. S. Emmerich (1951Em23)	11.1 (5)	
E. Kondaiah (1951Ko01)	11.6 (3)	
J. A. Marinsky (1951Ma**)	11.0 (3)	
W. C. Rutledge (1952Ru10)	11.9 (3)	Outlier
H. W. Wright (1957Wr37)	11.06 (4)	
R. G. Wille (1960Wi10)	11.5 (5)	
D. C. Hoffman (1963Ho15)	11.02 (5)	
S. Baba (1971Ba28)	10.98 (1)	
Recommended value	**10.987 (11)**	**χ^2 = 1.4**

A weighted average has been calculated using LWEIGHT computer program (version 3). The Rutledge value (1952Ru10) has been shown to be outlier, based on the Chauvenet's criterion and thus was omitted in the final calculation. The largest contribution to the weighted average comes from the value of S. Baba (1971Ba28), with a statistical weight of 90 %.

The adopted value is the weighted average of 10.987 d with an external uncertainty of 0.011 d. The reduced-χ^2 value is 1.4.

2.1 β- Transitions

The maximum energies of the β^- transitions in the decay of ^{147}Nd → ^{147}Pm have been obtained from the Q^- value (2009AuZZ) and the level energies given in Table 2 from N. Nica (2009Ni02).

Table 2: ^{147}Pm levels populated in the decay of ^{147}Nd and the adopted β^- transition probabilities.

Level Number	Level energy, (keV) [μ]	Spin and Parity [a]	Half-life [*]	Adopted P_{β^-} (%)
0	0	$7/2^+$		0 (5)
1	91.1049 (20)	$5/2^+$	2.50 (5) ns	81 (5)
2	408.54 (5)	$9/2^+$		
3	410.512 (13)	$3/2^+$	0.139 (14) ps	0.715 (34)
4	489.255 (16)	$7/2^+$		0.781 (15)
5	531.012 (15)	$5/2^+$	0.083 (15) ns	14.6 (9)
6	632.93 (7)	$1/2^+$		0.0190 (27)
7	641.27 (8) [μ]			
8	649.03 (4)	$11/2^-$	27 (3) ns	0.258 (19)
9	680.44 (4)	$7/2^+$		0.0897 (28)
10	685.890 (15)	$5/2^+$	0.25 (10) ns	2.184 (16)

* Given by N. Nica (2009Ni02).

[a] Given by N. Coursol et al. (1987Table).

[μ] Not used in this evaluation. No direct experimental evidences for this level, only speculative propositions: an unobservable weak β transition of ^{147}Nd decay (1997Sa53) or one 573-kev γ-ray transition (^{148}Nd(2p,nγ)^{147}Pm), 1977Ko24) that populated it.

The adopted β^- transition probabilities and the associated uncertainties (Table 2) were deduced from the γ transition probability balance at each level of the decay scheme.

For the ground state level, the adopted β^- transition probability of 0 (5) % is in agreement with the experimental values of < 0.15 % (1966Be09, 1971Na11) and < 0.25 % (1962Sh02).

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

2.2 γ Transitions

The γ-ray transition probabilities were calculated using the γ-ray emission intensities and the relevant internal conversion coefficients (see **5.2 γ Emissions**).

For all γ transitions, the internal conversion coefficients (ICC) and the associated uncertainties were interpolated from theoretical values of I. M. Band et al. (2002Ba85) using the BrIcc computer program (2008Ki07) for the "frozen orbital" approximation.

For multipolarities and mixing ratios, the evaluators used:

1) Multipolarities of γ-ray transitions listed in the Table 3 are from N. Nica (2009Ni02).

Table 3: Multipolarities of γ-ray transitions.

	Multipolarity	E_γ (keV)
^{147}Pm	[M2]	31.3 (2)
	[E2]	53.1 (2), 541.83 (7)
	[E3]	36.75 (10)
	[M1,E2]	80.82 (27), 149.3 (2), 154.7 (2), 191.0 (3), 589.35 (4), 680.52 (15)
	M2	159.7 (2), 649.04 (8)
	E1	240.5 (2)
	E2	410.48 (3)
	E3	117.95 (8)

	Multipolarity	E_γ (keV)
	M1 + E2	196.64 (4), $\|\delta\|$ = 0.20 (8) (1977Al34) 271.87 (6), $\|\delta\|$ = 0.10 (3) (1979Se05) 408.52 (6), $\|\delta\|$ = 0.57 (3)

2) For other γ-ray transitions, the adopted mixing ratios (δ) are the weighted means of the δ values found in the literature (given by 1977Kr13) and shown in Table 4. A good agreement has been found between the experimental values of K and L internal coefficients and the calculated ones obtained by using the evaluated δ values and the BrIcc program.

Table 4: Experimental and recommended conversion coefficients and mixing ratios for the γ-ray transitions.

E_γ (keV)	$\|\delta\|$ experimental (mixing ratio)	α experimental	α theoretical (given by BrIcc)
91.105 (2)	0.10 (9) (1957Bi86)* 0.229 (143) (1961Ar09) 0.089 (11) (1961Ew02)* 0.13 (2) (1961We07)μ 0.18 (6) (1963Ph02) 0.28 (9) (1967Ba06) 0.67 (15) (1967Ba22)@ 0.089 (5) (1969Ba32) 0.13 (2) (1970Bl12) 0.082 (10) (1977Al34)	α_K = 1.73 (6) (1997Sa53)	α_K = 1.714 (24)
Recommended value	$\|\delta\|$ = 0.090 (5)	Reduced χ^2 = 1.7	
120.48 (5)	0.12 (3) (1963Ph02) 0.158 (15) (1970Bl12) 0.050 (21) (1977Al34)	α_K = 0.79 (3) α_L = 0.113 (6) (1997Sa53)	α_K = 0.772 (11) α_L = 0.112 (4)
Recommended value	$\|\delta\|$ = 0.116 (42)	Reduced χ^2 = 8	
275.374 (15)	0.077 (14) (1960Bo17)* 0.13 (1) (1960Bo17)* 0.11 (11) (1961Ar09) 0.089 (11) (1961Ew02)* 0.14 (2) (1961We07)μ 0.05 (7) (1963Sp07)* 0.16 (4) (1966Go25)* 0.34 (12) (1967Ba06)@ 0.112 (6) (1969Ba32) 0.58 (25) (1970Bl12)@ 0.17 (4) (1974Bh02)* 0.16 (4) (1976Si08)* 0.14 (3) (1977Al34) 0.107 (7) (1979Se05)	α_K = 0.081 (3) α_L = 0.0109 (6) (1997Sa53)	α_K = 0.0792 (11) α_L = 0.01095 (16)
Recommended value	$\|\delta\|$ = 0.112 (5)	Reduced χ^2 = 1.8	
319.411 (18)	0.40 (2) (1957Li40)* 0.38 (1) (1960Bo17)* 0.27 (1) (1960Ma03)*@ 9.95 (11) (1961Ar09)@ 0.36 (2) (1961We07)μ 0.38 (6) (1963Ph02)* 0.39 (4) (1963Sp07)* 0.34 (2) (1966Go25)* 0.31 (10) (1967Ba06)@ 0.55 (5) (1969Ba32)@ 0.35 (4) (1970Bl12)	α_K = 0.052 (2) α_L = 0.0079 (4) (1997Sa53)	α_K = 0.0514 (8) α_L = 0.00734 (11)

E_γ (keV)	$\|\delta\|$ experimental (mixing ratio)	α experimental	α theoretical (given by BrIcc)
	0.011 (16) (1974Bh02)*@ 0.38 (2) (1976Si08)* 0.41 (3) (1977Al34)		
Recommended value	$\|\delta\|$ = 0.378 (9)	Reduced χ^2 = 0.9	
398.155 (20)	0.31 (3) (1960Bo17)* 0.50 (7) (1966Go25)* 0.17 (7) (1970Bl12) 0.18 (6) (1974Bh02)* 0.30 (3) (1977Al34)	α_K = 0.0292 (11) (1997Sa53)	α_K = 0.0293 (5)
Recommended value	$\|\delta\|$ = 0.297 (37)	Reduced χ^2 = 3.9	
439.895 (22)	0.63 (5) (1960Bo17)* 0.70 (12) (1961Sa13)* 0.82 (65) (1961We07)μ 0.59 (7) (1963Sp07)* 0.56 (5) (1966Go25)* 0.62 (6) (1968Ra28)* 0.70 (9) (1969Ba32) 0.6 (1) (1970Bl12) 0.62 (7) (1974Bh02)* 0.59 (5) (1976Si08)* 0.77 (10) (1977Al34)@	α_K = 0.0212 (9) α_L = 0.0028 (2) (1997Sa53)	α_K = 0.0210 (4) α_L = 0.00300 (5)
Recommended value	$\|\delta\|$ = 0.609 (21)	Reduced χ^2 = 0.4	
489.24 (3)	0.79 (+23,-45) (1977Al34) 1.2 (+28,-8) (1961Sa13)*	α_K = 0.018 (1) (1997Sa53)	α_K = 0.0152 (16) α_K = 0.014 (4)
Recommended value	$\|\delta\|$ = 0.79 (+23,-45)		
531.016 (22)	0.75 (25) (1957Bi86)* 0.95 (30) (1961We07)μ 0.69 (32) (1969Ba32) 0.40 (3) (1977Al34)	α_K = 0.0133 (3) (1997Sa53)	α_K = 0.01374 (23)
Recommended value	$\|\delta\|$ = 0.407 (35)	Reduced χ^2 = 1.4	
594.80 (3)	0.66 (15) (1961Sa13)* 0.34 (16) (1963Sp07)* 0.66 (9) (1968Ra28)* 0.48 (8) (1974Bh02)*	α_K = 0.0071 (5) (1997Sa53)	α_K = 0.00995 (23)
Recommended value	$\|\delta\|$ = 0.55 (6)	Reduced χ^2 = 1.5	
685.90 (4)	0.95 (30) (1961We07)μ 0.87 (29) (1967Ba06) 1.05 (65) (1969Ba32) 0.95 (30) (1977Al34)	α_K = 0.0068 (4) (1997Sa53)	α_K = 0.0063 (4)
Recommended value	$\|\delta\|$ = 0.92 (20)	Reduced χ^2 = 0.04	

@ Value has been shown to be outlier, based on the Chauvenet's criterion and thus was omitted in the final calculation.
μ Not used: superseded by 1969Ba32.
* Given by 1977Kr13.

3 Atomic Data

Atomic values, ω_K, ϖ_L, ϖ_M and n_{KL} are from Schönfeld and Janβen (1996Sc06).
The X-ray and Auger electron emission probabilities are calculated from the data set values using the program EMISSION.

4 Electrons Emissions

The conversion electron emission probabilities were deduced from the ICC values and the γ-ray emission intensities.

5 Photon emissions

5.1 K x-rays

The X-ray absolute intensities were deduced from the decay data using the EMISSION computer code and are compared in Table 5 with measured values found in the literature. The experimental and calculated values are in agreement within the uncertainty limits, supporting the overall consistency of the decay scheme data.

Table 5: Experimental and recommended (calculated) values of X-ray absolute intensities (%).

	J. Goswamy (1995Go**)	Recommended values
$K\alpha_2$ x-ray	12.3 (5)	12.9 (9)
$K\alpha_1$ x-ray	21.6 (9)	23.5 (15)
K β_1 x-ray	6.4 (3)	7.3 (5)
K β_2 x-ray	1.64 (6)	1.87 (13)

5.2 Gamma emissions

The energies of the γ-rays given in section 5.2 are from N. Nica (2009Ni02).

The experimental relative γ-ray emission intensities from ^{147}Nd have been obtained from all the available relative values. The normalization factor to convert relative γ-ray emission probabilities to absolute values is calculated with the formula:

$$\text{Normalization} = \frac{100 - P_{\beta-}(g.s.)}{\sum(1 + \alpha_T)P_{rel}} = 0.127\ (9)$$

where the sum is to be done over all the gamma transitions to the ground state, and $P_{\beta-}$ (g.s.) = 0 (5) %, deduced from the probability balance at the ground state (g.s.) level (see Table 2, **2.1 β^- Transitions).** From the theoretical α_T and the evaluated relative emission intensities (Table 6), the calculated normalization factor is 0.127 (9).

The experimental γ-ray emission probabilities relative to 100 for the 531-keV γ-ray are given in Table 6.

The adopted relative γ-ray intensity values are the weighted means calculated by the LWEIGHT program (version 3).

It should be noted that in the 50-150 keV region, only a few points of calibration exist to establish an efficiency curve for γ-ray detectors. Then the γ-ray intensity measurements in this region cannot lead to results with uncertainties better than 2-4 %. For this reason, the values of γ-ray intensities relative to the 91-keV γ-ray (Table 7) were omitted from averaging. The use of these values renormalized to the 531-keV γ-ray would introduce an increase of the uncertainties.

Our recommended relative and absolute γ-ray emission probabilities are given in Table 8.

Table 6: Experimental data sets of the relative γ-ray emission intensities (%).

Reference Energy (keV)	1966Ar16	1967Ca18	1967Do07	1967Hi04	1967Ja05	1974Ra30	1979Vo09	1997Sa53	1998Po**	Evaluated	Reduced χ^2
31.3 (2)											
36.75 (10)											
53.1 (2)											
80.82 (27)								0.0068 (9)		0.0068 (9)	
91.105 (2)	275 (50)$^{\mu}$	211 (42)	248 (13)	227 (35)	300 (100)$^{\mu}$	220 (14)	239 (5)	210.0 (43)		224 (14)	4.6
117.98 (5)								0.120 (10)		0.120 (10)	
120.48 (5)	2.6 (4)	2.5 (5)	2.1 (2)	3.3 (5)	8 (1)$^{\mu}$	3.3 (5)	3.05 (10)	2.810 (46)		2.84 (11)	3.5
149.3 (2)								0.0290 (30)		0.0290 (30)	
154.7 (2)					< 0.5			0.0310 (30)		0.0310 (30)	
159.7 (2)								0.0400 (30)		0.0400 (30)	
191.0 (3)								0.0280 (30)		0.0280 (30)	
196.64 (4)	1.3 (2)	1.30 (13)	1.0 (1)$^{\mu}$	1.5 (6)	2 (1)$^{\mu}$	1.4 (4)	1.38 (6)	1.420 (15)		1.416 (14)	0.3
230.77 (8)											
240.5 (2)								0.320 (20)		0.320 (20)	
271.87 (6)								0.099 (7)		0.099 (7)	
275.374 (15)	6.6 (7)	6.5 (6)	6.1 (5)	6.8 (14)	7 (2)	6.7 (7)	6.05 (10)	6.81 (8)	6 (1)	6.10 (9)	0.4
310							< 0.1				
319.411 (18)	15.0 (15)	14.2 (14)	15.8 (10)	16.3 (24)	15 (5)	16.5 (10)	15.0 (3)	15.91 (17)	15 (2)	15.68 (15)	1.2
398.155 (20)	7.0 (7)	6.4 (6)	6.7 (5)	6.8 (11)	5 (2)μ	6.5 (7)	6.59 (10)	6.82 (8)		6.73 (6)	0.6
408.52 (6)								0.140 (10)		0.140 (10)	
410.48 (3)	1.3 (1)	1.30 (13)	0.9 (2)	1.2 (5)	1.0 (6)	1.2 (3)	0.93 (5)	1.120 (13)		1.077 (47)	2.7
439.895 (22)	8.8 (9)	9.2 (9)	9.7 (6)	9.3 (11)	8 (2)$^{\mu}$	9.8 (2)	9.19 (14)	9.54 (10)		9.47 (9)	1.3
489.24 (3)	0.70 (8)	1.5 (8)	1.2 (3)	1.1 (5)	1.0 (5)	1.4 (4)	1.12 (6)	1.160 (14)		1.07 (9)	3.9
531.016 (22)	100	100	100	100	100	100	100	100	100	100	
541.83 (7)	0.20 (5)							0.140 (20)		0.148 (21)	1.2
589.35 (4)	0.40 (6)$^{\mu}$		0.26 (6)	0.31 (14)		0.29 (8)	0.30 (3)	0.290 (20)		0.291 (16)	0.09
594.80 (3)	2.2 (2)	2.20 (22)	1.6 (2)$^{\mu}$	1.9 (4)	2 (1)	2.0 (3)	1.92 (6)	2.120 (26)	2.0 (3)	2.089 (28)	1.5
649.04 (8)								0.0390 (30)		0.0390 (30)	
680.52 (15)			< 0.05	0.23 (16)		0.06	0.30 (5)	0.220 (10)		0.223 (11)	1.2
685.90 (4)	7.0 (7)	6.6 (7)	5.0 (4)$^{\mu}$	5.9 (10)	6 (1)	6.7 (6)	6.1 (2)	6.63 (7)		6.57 (7)	1.2

μ: the experimental value has been shown to be an outlier value by the Lweight program.

Table 7: Omitted experimental data sets of the relative γ-ray emission intensities (%).

Reference Energy (keV)	1963Ph02	1967Ba21	1971Si20	1974HeYW	1995Go**	2010Gh**
31.3 (2)						
36.75 (10)	106 (16)					
53.1 (2)	7.5 (10)					
80.82 (27)	8 (1)					
91.105 (2)	100	100	100	100	100	100
117.98 (5)						
120.48 (5)	2.0 (2)	1.4 (1)	1.42 (18)	1.42 (15)	1.64 (5)	1.540 (3)
149.3 (2)						
154.7 (2)					0.0250 (10)	< 0.034
159.7 (2)	1.5 (2)					
191.0 (3)						
196.64 (4)	1.6 (2)	0.72 (7)	0.73 (12)	0.73 (6)	0.610 (12)	1.012 (27)
230.77 (8)						
240.5 (2)						
271.87 (6)						
275.374 (15)	2.5 (2)	3.0 (2)	3.05 (20)	2.87 (18)	2.720 (40)	3.320 (5)
310	< 2	< 0.2	0.13 (5)			
319.411 (18)	7.0 (6)	6.8 (5)	7.60 (70)	7.0 (4)	6.80 (12)	8.010 (12)
398.155 (20)	< 2.5	3.1 (3)	3.35 (25)	3.12 (30)	3.050 (43)	3.680 (7)
408.52 (6)						
410.48 (3)	3.7 (3)	0.8 (1)	0.55 (15)	0.50 (3)	0.360 (20)	0.790 (2)
439.895 (22)	4.5 (4)	4.2 (3)	5.1 (3)	4.3 (3)	4.20 (9)	5.200 (7)
489.24 (3)	< 0.2	0.7 (1)	0.6 (1)	0.55 (3)	0.49 (11)	0.530 (7)
531.016 (22)	58 (2)	47 (3)	53.5 (15)	46.9 (26)	45.9 (10)	47.20 (24)
541.83 (7)						
589.35 (4)		0.13 (2)	0.20 (2)	0.164 (16)	0.1580 (25)	0.224 (6)
594.80 (3)	1.6 (1)	0.9 (1)	1.1 (1)	0.95 (6)	0.850 (13)	0.586 (14)
649.04 (8)						
680.52 (15)			0.17 (8)	0.070 (15)	0.0560 (31)	0.072 (5)
685.90 (4)	4.7 (1)	3.3 (2)	3.5 (2)	2.91 (18)	2.850 (41)	2.430 (5)

Table 8: Recommended relative and absolute γ-ray intensities (%).

Eγ (keV)	Relative γ-ray intensity (%)	Absolute γ-ray intensity (%)
31.3 (2)		
36.75 (10)		
53.1 (2)		
80.82 (27)	0.006 8 (9)	0.000 86 (11)
91.105 (2)	224 (14)	28.4 (18)
117.98 (5)	0.120 (10)	0.015 2 (13)
120.48 (5)	2.84 (11)	0.361 (14)
149.3 (2)	0.029 0 (30)	0.003 68 (38)
154.7 (2)	0.031 0 (30)	0.003 94 (38)
159.7 (2)	0.040 0 (30)	0.005 08 (38)
191.0 (3)	0.028 0 (30)	0.003 56 (38)
196.64 (4)	1.416 (14)	0.179 8 (18)
230.77 (8)		
240.5 (2)	0.320 (20)	0.040 6 (25)
271.87 (6)	0.099 (7)	0.012 6 (9)
275.374 (15)	6.10 (9)	0.775 (11)
310		
319.411 (18)	15.68 (15)	1.991 (19)
398.155 (20)	6.73 (6)	0.855 (8)
408.52 (6)	0.140 (10)	0.017 8 (13)
410.48 (3)	1.077 (47)	0.137 (6)
439.895 (22)	9.47 (9)	1.203 (11)
489.24 (3)	1.07 (9)	0.136 (11)
531.016 (22)	100	12.7 (9)
541.83 (7)	0.148 (21)	0.018 8 (27)
589.35 (4)	0.291 (16)	0.037 0 (20)
594.80 (3)	2.089 (28)	0.265 3 (36)
649.04 (8)	0.039 0 (30)	0.004 95 (38)
680.52 (15)	0.223 (11)	0.028 3 (14)
685.90 (4)	6.57 (7)	0.834 (9)

6 References

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