^{144}Pr – Comments on evaluation of decay data
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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, unless stated otherwise.

Decay Scheme

^{144}Pr ($T_{½}$ = 17.29 min) undergoes 100% β^- decay ($Q(\beta^-)$ = 2997.4 (24) keV) via various excited levels to the ground state of ^{144}Nd. A reasonably well-defined decay scheme was derived from the studies of 1954Kr40, 1958Gr99, 1959Po77, 1968Ra01, 1968Sa05, 1969Gu15, 1969Ma24, 1970Fa03, 1974Be09, 1975De17, 1976Ra22, 1977Ge12, 1979Pr11, 1981Ol04, 1985Da16 and 2000He14, and can be defined in terms of ten β^- transitions and seventeen gamma-ray emissions.

Nuclear Data

^{144}Pr constitutes a major feature of the ^{144}Ce-^{144}Pr-^{144}Nd decay chain. The high-energy gamma rays generated in the β^- decay of ^{144}Pr are important in decay heat assessments and the design of short- and medium-term shielding requirements for irradiated fuel facilities.

Half-life

Half-life measurements of 1957Pe09, 1963Ho15, 1968Ra01 and 1970Fa03 were adopted to give a weighted-mean value of 17.29 ± 0.04 minutes, based on the LWM-NRM-Rajeval analysis techniques.

Reference	Half-life (min)
1957Pe09	17.27 ± 0.04
1963Ho15	17.30 ± 0.05
1968Ra01	17.3 ± 0.1
1970Fa03	17.3 ± 0.1
Recommended value	17.29 ± 0.04*

* Recommended uncertainty adjusted from ± 0.03 to 0.04, in alignment with the smallest uncertainty of the values used to calculate the weighted-mean value.

Analytical method	Half-life (d)	$\chi^2/(N-1)$	$\chi^2/(N-1)_{critical}$
LWM	17.29 ± 0.03	0.09	3.78
NRM	17.29 ± 0.03	0.09	2.60
Rajeval	17.29 ± 0.03	0.09	–
Bootstrap	17.295 ± 0.008	0.14	–
Mandel-Paule	null result	–	–

A half-life of (17.29 ± 0.04) minutes is recommended, as quantified by the LWM-NRM-Rajeval analytical procedures.

Q value

Q_{β^-}-value of 2997.4 (24) keV was adopted from Wang *et al*. (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, and these data were adjusted to account for gamma recoil in the formulation of recommended gamma-ray emission energies and uncertainties. Greater confidence was placed in this approach because of the more wide-ranging origins of the level energies compared with the measured gamma-ray decay data, even though the energies of a significant number of gamma-ray

emissions have been directly measured by 1968Ra01, 1970Fa03, 1974Be09, 1976Ra22, 1979Pr11 and 1985Da16. Nevertheless, the recommended gamma-ray energy standards proposed by 2000He14 have been adopted in the form of the 696.505(4)-, 1489.148(3)- and 2185.645(5)-keV gamma rays. The long half-life for the α decay of the ^{144}Nd ground state was determined from the measurements of 1954Wa05, 1956Po16, 1961Ma05, 1965Is01 and 1987Al28, while other nuclear-level half-lives were adopted and calculated from the half-life and mean lifetime measurements of 1976CoZX, 1994Ro13 and 1998Hi09.

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

Nuclear level number*	Nuclear level energy (keV)	Spin and parity	
0	0.0	0 +	2.3 (3) × 10^{15} a
1	696.561 ± 0.010	2 +	–
2	1314.669 ± 0.013	4 +	7.4 (9) ps
3	1510.871 ± 0.021	3 −	0.56 (7) ps
4	1560.920 ± 0.013	2 +	–
(5)	2072.91 ± 0.03	2 +	59 (10) fs
(6)	2084.68 ± 0.03	0 +	0.12 (5) ps
(7)	2185.75 ± 0.03	1 −	15 (2) fs
(8)	2368.82 ± 0.04	2 +	39 (14) fs
(9)	2582.32 ± 0.06	(3 +)	–
(10)	2655.54 ± 0.03	1 +	9.9 (2) fs
(11)	2675.61 ± 0.08	0 +	0.2 (1) ps
(12)	2742.99 ± 0.07	0 +	64 (40) fs
(13)	2946.04 ± 0.10	(2, 3, 4) −	–

* Nuclear level numbers in parentheses have been defined only on the basis of their population by the β^- decay of ^{144}Pr and ^{144m}Pr – many other nuclear levels of ^{144}Nd are known, but have not been considered in this assignment process.

Transition and gamma-ray energies for the β^- decay of ^{144}Pr (2001So16).

		Transition energy (keV)	Gamma-ray energy, E_γ (keV)
$\gamma_{(7,4)}$	(Nd)	624.83 (3)	624.83 ± 0.03
$\gamma_{(7,3)}$	(Nd)	674.88 (4)	674.88 ± 0.04
$\gamma_{1,0}$	(Nd)	696.561(10)	696.559 ± 0.010*
$\gamma_{3,1}$	(Nd)	814.310 (23)	814.308 ± 0.023
$\gamma_{4,1}$	(Nd)	864.359 (16)	864.356 ± 0.016
$\gamma_{(12,4)}$	(Nd)	1182.07 (7)	1182.06 ± 0.07
$\gamma_{(5,1)}$	(Nd)	1376.35 (3)	1376.34 ± 0.03
$\gamma_{(6,1)}$	(Nd)	1388.12 (4)	1388.11 ± 0.04
$\gamma_{(7,1)}$	(Nd)	1489.19 (3)	1489.18 ± 0.03*
$\gamma_{4,0}$	(Nd)	1560.920 (13)	1560.911 ± 0.013
$\gamma_{(8,1)}$	(Nd)	1672.26 (4)	1672.25 ± 0.04
$\gamma_{(11,1)}$	(Nd)	1979.05 (8)	1979.04 ± 0.08
$\gamma_{(12,1)}$	(Nd)	2046.43 (7)	2046.41 ± 0.07
$\gamma_{(5,0)}$	(Nd)	2072.91 (3)	2072.89 ± 0.03
$\gamma_{(7,0)}$	(Nd)	2185.75 (3)	2185.73 ± 0.03*
$\gamma_{(8,0)}$	(Nd)	2368.82 (4)	2368.80 ± 0.04
$\gamma_{(10,0)}$	(Nd)	2655.54 (3)	2655.51 ± 0.03

* Subsequently modified in line with the recommended energy standard of Helmer and van der Leun (2000He14).

Half-life of ^{144}Nd (α decay).

Reference	Half-life (years)
1954Wa05	(1.5 ± 0.8) × 10^{15}†
1956Po16	(2.2 ± 0.7) × 10^{15}‡
1961Ma05	(2.4 ± 0.3) × 10^{15}
1965Is01	(2.1 ± 0.4) × 10^{15}
1987Al28	(2.65 ± 0.37) × 10^{15}
Recommended value	(2.3 ± 0.3) × 10^{15}*

† Estimated uncertainty – defined by 1954Wa05 as uncertain by a factor of at least 2.
‡ Estimated uncertainty – defined by 1956Po16 as possessing a margin of error of approximately 30%.
* Recommended half-life and uncertainty have been adjusted from (2.33 ± 0.19) x 10^{15} to (2.3 ± 0.3) x 10^{15} years, in alignment with the smallest uncertainty of the values used to calculate the weighted-mean value.

Measured and recommended gamma-ray energies.

Eγ (keV)									
1968Ra01	**1968Sa05**	**1970Fa03**	**1974Be09**	**1976Ra22**	**1979Gr01**	**1979Pr11**	**1985Da16**	**2000He14**	**Recommended[#]**
–	–	–	–	609 (1)	–	–	–	–	not adopted
–	–	–	–	–	–	618.2 (5)	617.8 (2)	–	^{144m}Pr
626 (3)	–	625.0 (10)	624.66 (20)	625.8 (4)	–	624.89 (20)	624.7 (7)	–	624.83 ± 0.03
675.3 (6)	–	675.0 (3)	675.02 (20)	674.9 (2)	–	675.02 (10)	674.95 (10)	–	674.88 ± 0.04
696.3 (4)	696.48 (9)	696.43 (6)	696.49 (2)	696.4 (1)	696.510 (6)	696.50 (2)	696.50 (5)	696.505 (4)	696.505 ± 0.004[*]
813.7 (6)	–	813.8 (3)	814.15 (15)	813.6 (2)	–	814.03 (10)	814.10 (10)	–	814.308 ± 0.023
863.6 (6)	–	863.9 (3)	864.53 (15)	863.5 (5)	–	864.44 (10)	864.45 (10)	–	864.356 ± 0.016
–	–	–	–	–	–	–	1182.0 (3)	–	1182.06 ± 0.07
–	–	–	–	–	–	1376.31 (30)	1376.27 (10)	–	1376.34 ± 0.03
1388.6 (6)	–	1388.0 (4)	1388.00 (15)	1388.2 (4)	–	1388.20 (10)	1388.02 (10)	–	1388.11 ± 0.04
–	–	–	–	1421.0 (5)	–	–	–	–	not adopted
1489.5 (4)	1489.14 (7)	1489.2 (2)	1489.15 (5)	1489.3 (2)	1489.160 (8)	1489.16 (5)	1489.17 (5)	1489.148 (3)	1489.148 ± 0.003[*]
–	–	–	1562 (2)	1558.4 (8)	–	1561.0	1560.97 (10)	–	1560.911 ± 0.013
–	–	–	–	–	–	–	1631.36 (10)	–	^{144m}Pr
–	–	–	–	–	–	–	–	–	1672.25 ± 0.04
–	–	–	–	–	–	–	1885.3 (2)	–	^{144m}Pr
–	–	–	–	–	–	1978.67 (10)	1978.82 (10)	–	1979.04 ± 0.08
–	–	–	–	–	–	2046.6 (5)	2046.3 (2)	–	2046.41 ± 0.07
–	–	–	–	–	–	2072.7 (7)	2072.9 (2)	–	2072.89 ± 0.03
2114.0 (20)	–	–	–	2114.0 (20)	–	–	–	–	not adopted
2185.6 (4)	2185.72 (5)	2185.6 (2)	2185.70 (6)	2185.5 (4)	2185.662 (11)	2185.60 (5)	2185.65 (5)	2185.645 (5)	2185.645 ± 0.005[*]
–	–	–	–	–	–	2368.4 (10)	2368.3 (3)	–	2368.80 ± 0.04
–	–	–	2654.6 (7)	2656.4 (4)	–	2654.1 (5)	2654.9 (2)	–	2655.51 ± 0.03
–	–	–	–	2802 (2)	–	–	–	–	not adopted
–	–	–	–	–	–	2842.9 (10)	–	–	not adopted

[#] Determined from the nuclear level energies of 2001So16 unless stated otherwise.
[*] Gamma-ray energy adopted from the recommended energy standards published by Helmer and van der Leun (2000He14).

Emission Probabilities

Relative gamma-ray emission probabilities have been partially or fully determined in the measurements of 1954Kr40, 1958Gr99, 1968Ra01, 1968Sa05, 1969Ma24, 1970Fa03, 1974Be09, 1975De17, 1976Ra22, 1977Ge12, 1979Pr11, 1981Ol04 and 1985Da16, and limited studies of the absolute gamma-ray emission probabilities have been performed by 1959Po77, 1969Gu15, 1975De17 and 1981Ol04.

While considerable emphasis was placed on the well-defined measurements of the absolute gamma-ray emission probabilities by 1975De17 and 1981Ol04, data from studies of both the absolute and relative gamma-ray emission probabilities as reported by 1954Kr40, 1958Gr99, 1959Po77, 1968Ra01, 1968Sa05, 1969Gu15, 1969Ma24, 1970Fa03, 1974Be09, 1976Ra22, 1977Ge12, 1979Pr11 and 1985Da16 were also used in weighted-mean analyses of the various gamma-ray emissions. All of the relative emission probabilities were suitably quantified in terms of the emission probability of the 696.505-keV gamma ray (100.0%). Although 696.505- and 814.308-keV gamma rays are emitted in the β^- decay of both ^{144}Pr and ^{144m}Pr, the total β^- branch of ^{144m}Pr is only 0.0006 (2) (i.e. (0.06 (2) %), and therefore this additional complication has no significant impact when determining the emission probabilities of these particular gamma rays in the β^- decay of the ^{144}Pr ground state.

Unfortunately, there are significant discrepancies between the gamma-ray emission probabilities measured by Debertin *et al*. (1975De17) and Olomo and MacMahon (1981Ol04), both undertaken with well calibrated Ge(Li) detectors. Thus, the absolute emission probability of the main 696.505-keV gamma ray differs by ~ 10% with measured values of 1.342 (13) % (1975De17) and 1.484 (12) % (1981Ol04). The LWM weighted-mean value of these data is (1.41 ± 0.07) %, and compares with a value of (1.49 ± 0.09) % measured at a significantly earlier date by means of a NaI(Tl) detector (1959Po77).

Difficulties have been experienced in determining the emission probability of the 1672.25-keV gamma ray, and a somewhat speculative P_γ^{rel}(1672.25 keV) value of 0.015 (4) was adopted from measurements of the relative gamma-ray emission probabilities of the 1672.25- and 2368.80-keV gamma transitions that depopulate the 2368.82-keV nuclear level following neutron capture by ^{144}Nd (1983Sn04, 1998Hi09):

Reference	E_γ (keV)	Relative intensity (I_γ^{rel})	Ratio [I_γ^{rel}(1672.25 keV) / I_γ^{rel}(2368.80 keV)]
1983Sn04	1672.25 2368.80	28.4 (2) 6.9 (1)	4.12 (7)
1998Hi09	1672.25 2368.80	84 (1) 16 (1)	5.25 (33)
Mean			4.17 (23)
Evaluation	1672.25 2368.80	0.015 (4) calculated 0.0036 (10)	4.17

Despite the detection of a low-intensity 2114.0-keV gamma emission by Raman (1968Ra01) and 609-, 1421.0-, 2114.0- and 2802-keV gamma emissions by Rao and Rao (1976Ra22), the spectral observations are unconvincing, and therefore these particular gamma transitions have not be included in the evaluation of the decay scheme. Furthermore, Dalmasso *et al*. (1985Da16) searched unsuccessfully for the 2842.9-keV gamma emission observed by Pravikoff *et al*. (1979Pr11), and hence this high-energy gamma transition was also discarded.

Multipolarities, and Internal-Conversion and Internal-Pair Formation Coefficients

The nuclear level scheme specified by Sonzogni has been used to define the multipolarities of the gamma transitions on the basis of the known spins and parities (2001So16). Adopted multipolarities are 100%E1 for the 624.83-, 814.308-, 1489.148- and 2185.645-keV gamma rays, and 100%E2 for the 674.88-, 696.505-, 1182.06-, 1388.11-, 1560.911-, 1979.04-, 2046.41-, 2072.89- and 2368.80-keV gamma rays. Evidence for the mixing ratios and multipolarities of the 864.356-keV (51.5%M1 + 48.5%E2), 1376.34-keV (89.6%M1 + 10.4%E2) and 1672.25-keV (97.5%M1 + 2.5%E2) gamma transitions arise from γ-γ correlation studies by 1983Kr09, 1983Sn04 and 1998Hi09.

Extensive conversion-electron, e-γ, γ-γ coincidence and directional angular correlation studies throughout the 1960s focused on defining the spin-parity for the 0 − ground state of ^{144}Pr (1963Co18, 1963Cr11, 1963Iw02, 1963Kn05, 1963Si10, 1965Co19, 1965Re13, 1966Be11, 1967Gu17, 1968Da12, 1969Ge01 and 1969Ma24).

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). A significant number of gamma transitions undergo decay via internal-pair formation, and the coefficient for this process has also been quantified from the tabulations of 2008Ki07.

Published gamma-ray emission probabilities - measured and recommended gamma-ray emission probabilities relative to P_γ(696.505 keV) of 100%.

E_γ (keV)	P_γ (%)									
	1954Kr40^{+}	**1958Gr99***	**1959Po77^{0}**	**1968Ra01***	**1968Sa05***	**1969Gu15^{0}**	**1969Ma24***	**1970Fa03***	**1974Be09***	**1975De17^{0}**
[609 (1)]	–	–	–	–	–	–	–	–	–	–
624.83 (3)	–	–	–	0.15 (4)	–	–	–	0.045 (20)	**0.085 (15)**	–
674.88 (4)	–	**–**	–	**0.23 (6)**	–	–	–	**0.172 (17)**	**0.207 (15)**	–
696.505 (4)	0.116 (9) → 100	100	1.49 (9) → 100	100	100	1.51 (15) → 100	100	100	100	1.342 (13) → 100
814.308 (23)	–	–	–	0.29 (7)	–	–	–	**0.228 (22)**	**0.245 (13)**	–
864.356 (16)	–	–	–	0.26 (7)	–	–	–	0.156 (15)	**0.193 (12)**	–
1182.06 (7)	–	–	–	–	–	–	–	–	–	–
1376.34 (3)	–	–	–	–	–	–	–	–	–	–
1388.11 (4)	–	–	–	0.45 (11)	–	–	–	0.420 (42)	0.445 (16)	–
[1421.0 (5)]	–	–	–	–	–	–	–	–	–	–
1489.148 (3)	0.0226 (18) → **19.5 (16)**	17 (2)	0.29 (3) → **19.5 (20)**	**20.2 (20)**	17.7 (5)	0.35 (7) → **23 (5)**	**22 (2)**	**19.5 (14)**	**20.3 (7)**	0.279 (3) → **20.7 (3)**
1560.911 (13)	–	–	–	–	–	–	–	–	~ 0.017	–
1672.25 (4)	–	–	–	–	–	–	–	–	–	–
1979.04 (8)	–	–	–	–	–	–	–	–	–	–
2046.41 (7)	–	–	–	–	–	–	–	–	–	–
2072.89 (3)	–	–	–	–	–	–	–	–	–	–
[2114.0 (20)]	–	–	–	0.03 (1)	–	–	–	< 0.016	–	–
2185.645 (5)	0.059 (5) → **51 (4)**	**50 (5)**	0.68 (10) → **46 (7)**	**49.5 (50)**	**48 (9)**	0.86 (17) → **57 (11)**	64 (6)	**49.5 (35)**	**52.2 (20)**	0.700 (10) → **51.7 (10)**
2368.80 (4)	–	–	–	–	–	–	–	–	–	–
2655.51 (3)	–	–	–	–	–	–	–	**0.011 (3)**	**0.014 (2)**	–
[2802 (2)]	–	–	–	–	–	–	–	–	–	–
[2842.9 (10)]	–	–	–	–	–	–	–	–	–	–

E_γ (keV)	P_γ (%)					
	1976Ra22[*]	**1977Ge12**[*]	**1979Pr11**[*]	**1981Ol04**[#]	**1985Da16**[*]	**Recommended**[†]
[609 (1)]	0.06 (2)	–	–	–	–	not adopted
624.83 (3)	**0.09 (2)**	–	**0.092 (9)**	–	**0.084 (2)**	0.084 (2)
674.88 (4)	**0.23 (1)**	–	**0.195 (20)**	–	**0.22 (2)**	0.212 (10)[‡]
696.505 (4)	100	100 (1)	100	1.484 (12) → 100 (1)	100	100
814.308 (23)	**0.23 (1)**	–	**0.231 (25)**	–	**0.24 (2)**	0.235 (10)[‡]
864.356 (16)	**0.19 (1)**	–	**0.197 (20)**	–	**0.18 (2)**	0.191 (10)[‡]
1182.06 (7)	–	–	–	–	0.004	0.004 (2)[§]
1376.34 (3)	–	–	**0.029 (3)**	–	**0.029 (3)**	0.029 (3)
1388.11 (4)	0.39 (3)	–	**0.506 (20)**	–	**0.501 (4)**	0.501 (4)
[1421.0 (5)]	0.03 (1)	–	–	–	–	not adopted
1489.148 (3)	**20.0 (4)**	**20.27 (21)**	**21.8 (9)**	0.277 (3) → **18.7 (3)**	**22.0 (12)**	20.3 (2)[¶]
1560.911 (13)	0.11 (1)	–	**0.016 (5)**	–	**0.015 (2)**	0.015 (2)
1672.25 (4)	–	–	–	–	–	0.015 (4)[Δ]
1979.04 (8)	–	–	**0.071 (7)**	–	**0.065 (6)**	0.068 (6)[‡]
2046.41 (7)	–	–	**0.021 (4)**	–	**0.020 (4)**	0.021 (4)[‡]
2072.89 (3)	–	–	**0.016 (4)**	–	**0.017 (2)**	0.017 (2)[‡]
[2114.0 (20)]	0.03 (1)	–	–	–	–	not adopted
2185.645 (5)	**49.9 (10)**	**52.3 (7)**	**55.7 (22)**	0.768 (9) → **51.8 (7)**	**56.1 (25)**	51.8 (7)[‡]
2368.80 (4)		–	**0.0031 (10)**	–	**0.004 (1)**	0.0036 (10)[‡]
2655.51 (3)	**0.011 (2)**	–	**0.016 (2)**	–	**0.011 (2)**	0.013 (2)[‡]
[2802 (2)]	0.004 (2)	–	–	–	–	not adopted
[2842.9 (10)]	–	–	0.008 (2)	–	–	not adopted

[+] Measured emission probabilities expressed relative to P_γ(133.515 keV) of 100% from β^- decay of parent ^{144}Ce; data have subsequently been adjusted to emission probabilities expressed relative to P_γ(696.505 keV) of 100% from β^- decay of ^{144}Pr .

[*] Emission probabilities expressed relative to P_γ(696.505 keV) of 100%.

[θ] Measured absolute emission probabilities; data have subsequently been converted to relative emission probabilities (P_γ(696.505 keV) of 100%).

[#] Measured absolute emission probabilities; authors also converted these data to relative emission probabilities (P_γ(696.505 keV) of 100%) – errors in Table 3 of 1981Ol04 have been noted (e-mail communications with T.D. MacMahon, 19/24 November 2013) and corrected.

[†] Weighted-mean values adopted when judged appropriate.

[‡] Uncertainty adjusted upwards to align with smallest uncertainty of the values used to calculate the weighted-mean value.

[§] Arbitrary uncertainty assigned of ± 0.002 (50%).

[¶] Limitation of relative statistical weight method (LWM) produces a value of 20.07 (23) and χ^2/(N-1) of 2.85, while the normalized residual method (NRM) defines a value of 20.31 (14) and χ^2/(N-1) of 1.31; under these circumstances, a value of 20.3 (2) has been adopted, in good agreement with the well-defined measurement of 1975De17.

[Δ] Considerable difficulty has been experienced in resolving the 1672.25-keV gamma-ray emission, and therefore a speculative P_γ^{rel}(1672.25 keV) value of 0.015 (4) was adopted on the basis of the assumed relative probabilities of the 1672.25- and 2368.80-keV gamma transitions that depopulate the 2368.82-keV nuclear level of ^{144}Nd. A weighted mean for the $P_\gamma^{rel}(1672.25\ keV)/P_\gamma^{rel}(2368.80\ keV)$ ratio of 4.17 (23) and a recommended $P_\gamma^{rel}(2368.80\ keV)$ of 0.0036(10) define $P_\gamma^{rel}(1672.25\ keV)$ of 0.015 (4).

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

E_γ(keV)	Multipolarity	α_K	α_L	α_{L1}	α_{L2}	α_{L3}	α_{M+}	$\alpha_{totalICC}$	α_{IPF}	α_{total}
624.83 (3)	E1	0.002 07 (3)	0.000 267 (4)	0.000 242 (4)	0.000 011 55 (17)	0.000 0135 5 (19)	0.000 073	0.002 41 (4)	−	0.002 41 (4)
674.88 (4)	E2	0.004 60 (7)	0.000 686 (10)	0.000 547 (8)	0.000 088 3 (13)	0.000 051 1 (8)	0.000 184	0.005 47 (8)	−	0.005 47 (8)
696.505 (4)	E2	0.004 27 (6)	0.000 631 (9)	0.000 508 (8)	0.000 078 5 (11)	0.000 045 1 (7)	0.000 169	0.005 07 (7)	−	0.005 07 (7)
814.308 (23)	E1	0.001 198 (17)	0.000 152 8 (22)	0.000 140 7 (20)	0.000 005 46 (8)	0.000 006 56 (10)	0.000 040 2	0.001 391 (20)	−	0.001 391 (20)
864.356 (16)	51.5%M1 + 48.5%E2 δ = - 0.97 (15) (1983Kr09, 1983Sn04, 1998Hi09)	0.003 38 (14)	0.000 456 (16)	0.000 414 (18)	0.000 029 0 (12)	0.000 012 3 (13)	0.000 122	0.003 96 (16)	−	0.003 96 (16)
1182.06 (7)	E2	0.001 353 (19)	0.000 182 (3)	0.000 162 8 (23)	0.000 012 15 (17)	0.000 006 62 (10)	0.000 048	0.001 583 (19)	0.000 004 10 (6)	0.001 587 (23)
1376.34 (3)	89.6%M1 + 10.4%E2 δ = 0.34 (10) (1983Sn04, 1998Hi09)	0.001 35 (3)	0.000 175 (4)	0.000 166 (4)	0.000 006 30 (12)	0.000 002 00 (14)	0.000 046	0.001 57 (3)	0.000 039 8 (6)	0.001 61 (4)
1388.11 (4)	E2	0.000 984 (14)	0.000 129 7 (19)	0.000 118 6 (17)	0.000 007 18 (10)	0.000 003 96 (6)	0.000 035	0.001 149 (14)	0.000 041 6 (6)	0.001 190 (17)
1489.148 (3)	E1	0.000 397 (6)	0.000 049 5 (7)	0.000 046 9 (7)	0.000 001 109 (16)	0.000 001 529 (22)	0.000 012 5	0.000 459 (6)	0.000 204 (3)	0.000 663 (10)
1560.911 (13)	E2	0.000 786 (11)	0.000 102 4 (15)	0.000 094 7 (14)	0.000 004 95 (7)	0.000 002 78 (4)	0.000 027 5	0.000 916 (11)	0.000 098 1 (14)	0.001 014 (15)
1672.25 (4)	97.5%M1 + 2.5%E2 δ = 0.16 (7) (1983Sn04, 1998Hi09)	0.000 892 (14)	0.000 114 6 (18)	0.000 109 8 (17)	0.000 003 61 (6)	0.000 001 19 (4)	0.000 030 4	0.001 037 (14)	0.000 151 9 (22)	0.001 189 (18)
1979.04 (8)	E2	0.000 505 (7)	0.000 064 7 (9)	0.000 060 9 (9)	0.000 002 40 (4)	0.000 001 434 (20)	0.000 017 3	0.000 587 (8)	0.000 281 (4)	0.000 868 (13)
2046.41 (7)	E2	0.000 475 (7)	0.000 060 7 (9)	0.000 057 3 (8)	0.000 002 17 (3)	0.000 001 314 (19)	0.000 016 3	0.000 552 (7)	0.000 313 (5)	0.000 865 (13)
2072.89 (3)	E2	0.000 465 (7)	0.000 059 3 (9)	0.000 055 9 (8)	0.000 002 09 (3)	0.000 001 271 (18)	0.000 015 7	0.000 540 (7)	0.000 326 (5)	0.000 865 (13)
2185.645 (5)	E1	0.000 213 (3)	0.000 026 4 (4)	0.000 025 2 (4)	0.000 000 437 (7)	0.000 000 702 (10)	0.000 007 6	0.000 246 (3)	0.000 712 (10)	0.000 959 (14)
2368.80 (4)	E2	0.000 365 (6)	0.000 046 3 (7)	0.000 044 0 (7)	0.000 001 420 (20)	0.000 000 911 (13)	0.000 012 7	0.000 424 (6)	0.000 467 (7)	0.000 891 (13)
2655.51 (3)	M1+E2	−	−	−	−	−	−	−	−	−

The recommended normalization factor for the relative gamma-ray emission probabilities is based on the somewhat discrepant yet well-defined gamma-ray spectroscopy studies of 1975De17 and 1981Ol04. Measured absolute emission probabilities for the main 696.505-keV gamma ray differ by ~ 10%, with values of 1.342 (13) % (1975De17) and 1.484 (12) % (1981Ol04), to give (a) LWM weighted-mean value of (1.41 ± 0.07) % and χ^2/(N-1) of 59.7 and (b) NRM weighted-mean value of (1.41 ± 0.05) % and χ^2/(N-1) of 1.98 (NRM). Under these unsatisfactory circumstances, a normalization factor of (0.0141 ± 0.0007) has been adopted.

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

E_γ (keV)	P_γ^{rel}	P_γ^{abs} (%)	Transition probability (%)
624.83 (3)	0.084 (2)	0.001 18 (3)	0.001 18 (3)
674.88 (4)	0.212 (10)	0.002 99 (14)	0.003 01 (14)
696.505 (4)	100	1.41 (7)	1.42 (7)
814.308 (23)	0.235 (10)	0.003 31 (14)	0.003 31 (14)
864.356 (16)	0.191 (10)	0.002 69 (14)	0.002 70 (14)
1182.06 (7)	0.004 (2)	0.000 06 (3)	0.000 06 (3)
1376.34 (3)	0.029 (3)	0.000 41 (4)	0.000 41 (4)
1388.11 (4)	0.501 (4)	0.007 06 (6)	0.007 07 (6)
1489.148 (3)	20.3 (2)	0.286 (3)	0.286 (3)
1560.911 (13)	0.015 (2)	0.000 21 (3)	0.000 21 (3)
1672.25 (4)	0.015 (4)	0.000 21 (6)	0.000 21 (6)
1979.04 (8)	0.068 (6)	0.000 96 (8)	0.000 96 (8)
2046.41 (7)	0.021 (4)	0.000 30 (6)	0.000 30 (6)
2072.89 (3)	0.017 (2)	0.000 24 (3)	0.000 24 (3)
2185.645 (5)	51.8 (7)	0.730 (10)	0.731 (10)
2368.80 (4)	0.003 6 (10)	0.000 051 (14)	0.000 051 (14)
2655.51 (3)	0.013 (2)	0.000 18 (3)	0.000 18 (3)

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 2997.4 (24) keV (2012Wa38) were used to determine the recommended energies and uncertainties of the β^- emissions.

Emission Probabilities

Emission probabilities were derived from the population-depopulation imbalances of the relative emission probabilities of the gamma rays, their theoretical internal-conversion coefficients, and a normalization factor of (0.0141 ± 0.0007) for the gamma-ray emissions, as noted above. The dominant first forbidden β^- transition directly to the ground state of ^{144}Nd ($0^- \rightarrow 0^+$) and resulting shape factor have been studied in detail to confirm the nature of the transition and parity of the ^{144}Pr ground state (1959Po77, 1971Na12, 1973Bo43). β^- decay to the 1510.871-keV nuclear level of ^{144}Nd was assumed to be zero on the basis of spin and parity considerations that would have resulted in a second forbidden unique transition. Log*ft* values and average E_{β^-} energies were determined by means of the LOGFT code.

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

	E_β (keV)*	Av. E_{β^-} (keV)	P_β	^{144}Pr	^{144}Nd	transition type	log *ft*
$\beta^-_{(0,12)}$	254.4 (24)	71.05 (8)	0.000 35 (6)	0 −	0 +	first forbidden non-unique	8.1
$\beta^-_{(0,11)}$	321.8 (24)	92.21 (8)	0.000 96 (8)	0 −	0 +	first forbidden non-unique	8.0
$\beta^-_{(0,10)}$	341.9 (24)	98.68 (8)	0.000 18 (3)	0 −	1 +	first forbidden non-unique	8.8
$\beta^-_{(0,8)}$	628.6 (24)	213.04 (9)	0.000 27 (6)	0 −	2 +	first forbidden unique	9.7^{1u}
$\beta^-_{(0,7)}$	811.7 (24)	267.12 (9)	1.021 (10)	0 −	1 −	allowed	6.32
$\beta^-_{(0,6)}$	912.7 (24)	306.67 (10)	0.007 08 (6)	0 −	0 +	first forbidden non-unique	8.7
$\beta^-_{(0,5)}$	924.5 (24)	322.77 (9)	0.000 65 (6)	0 −	2 +	first forbidden unique	10.2^{1u}
$\beta^-_{0,4}$	1436.5 (24)	526.25 (10)	0.001 7 (3)	0 −	2 +	first forbidden unique	10.8^{1u}
$\beta^-_{0,1}$	2300.8 (24)	894.90 (11)	1.116 (3)	0 −	2 +	first forbidden unique	9.17^{1u}
$\beta^-_{0,0}$	2997.4 (24)	1221.990 (1)	97.852 (10)	0 −	0 +	first forbidden non-unique	6.530
			Σ 100.000 19				

* Determined from the nuclear level energies of 2001So16 and Q-value of 2997.4 (24) keV (2012Wa38).

A consistent decay scheme was derived that contains ten β^- transitions and seventeen gamma-ray emissions.

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}Pr.

			Energy (keV)	Photons per 100 disint.	Relative probability
XL		(Nd)	4.633 – 6.901	0.000 92 (3)	
	XL_l	(Nd)	4.633	0.000 017 9 (9)	
	XL_α	(Nd)	5.208 – 5.230	0.000 449 (20)	
	XL_η	(Nd)	5.146	0.000 006 9 (4)	
	XL_β	(Nd)	5.722 – 6.090	0.000 384 (14)	
	XL_γ	(Nd)	6.604 – 6.901	0.000 061 5 (23)	
XK_α	$XK_{\alpha2}$	(Nd)	36.8478 (3)	0.001 65 (9)	55
	$XK_{\alpha1}$	(Nd)	37.3614 (2)	0.003 00 (15)	100
$XK'_{\beta1}$	$XK_{\beta3}$	(Nd)	42.1670 (4)	)	
	$XK_{\beta1}$	(Nd)	42.2717 (3)	) 0.000 92 (5)	30.7
	$XK_{\beta5}''$	(Nd)	42.580	)	
$XK'_{\beta2}$	$XK_{\beta2}$	(Nd)	43.335 (3)	)	
	$XK_{\beta4}$	(Nd)	43.451	) 0.000 237 (13)	7.9
	$XKO_{2,3}$	(Nd)	43.548	)	

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

		Energy (keV)	Electrons per 100 disint.	Relative probability
e_{AK}	(Nd)		0.000 52 (4)	
	KLL	29.154 – 30.978	0.000 333 (23)	100
	KLX	34.798 – 37.340	0.000 166 (12)	50
	KXY	40.42 – 43.53	0.000 020 7 (15)	6.2
e_{AL}	(Nd)	3.01 – 5.10	0.005 51 (18)	1655

Nd: ω_K = 0.918 (4); ϖ_L = 0.140 (6); n_{KL} = 0.866 (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

Q_β-value of 2997.4 (24) keV has been adopted from the atomic mass evaluation of Wang *et al.* (2012Wa38) while in the course of formulating the decay scheme of ^{144}Pr. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions of the ^{144}Pr decay processes (i.e. β^-, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 2997.3\ (25)\ \text{keV}$$

Percentage deviation from the Q-value of Wang *et al*. is (0.00 ± 0.12) %, which supports the derivation of an extremely consistent decay scheme with a modest variant.

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