^{219}Rn – Comments on evaluation of decay data
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Evaluation Procedure

Limitation of Relative Statistical Weight Method (LWM) was 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

A reasonably comprehensive decay scheme has been derived from the alpha-particle studies of 1962Wa18, 1991Ry01 and 1999Li05, and the gamma-ray measurements of 1967Da20, 1968Br17, 1970Da09, 1970Kr08 and 1999Li05.

Nuclear Data

Part of the (4n + 3) decay chain, and of relevance in quantifying the environmental impact of ^{235}U and various decay-chain products. Specific radionuclides in this decay chain are noteworthy because of their distinctive and important decay characteristics (e.g. alpha decay of ^{215}Po, ^{211}Bi and ^{211}Po).

Half-life

The recommended half-life is the weighted mean of two measurements by 1961Ro14, and an additional independent study by 1966Hu20.

Reference	Half-life (s)
1961Ro14	4.01 (6)
	4.00 (5)
1966Hu20	3.96 (1)[#]
Recommended value	3.98 (3)

[#] Uncertainty adjusted to ± 0.04 to reduce weighting below 50 %.

Q value

Q_α of 6946.1 (3) keV was adopted from the evaluated tabulations of Audi *et al.* (2003Au03).

Alpha Particles

Energies

Alpha-particle energies were calculated from the structural details of the proposed decay scheme. While the energies of the alpha-particle emissions have been directly measured by 1962Wa18, 1971Gr07, 1991Ry01 and 1999Li05, the nuclear level energies of 2001Br31 and evaluated Q-value of 6946.1 (3) keV (2003Au03) were preferably used to determine the recommended energies and uncertainties of the alpha-particle transitions, taking into account the significant recoil.

Adopted nuclear levels of ^{215}Po: J^{π} and origins (2001Br31).

Nuclear level	Nuclear level energy (keV)	J^{π}	Origins
0	0.0	9/2 +	^{215}Bi β^- decay, **^{219}Rn α decay**
1	271.228 ± 0.010	7/2 +	^{215}Bi β^- decay, **^{219}Rn α decay**
2	293.56 ± 0.04	(11/2) +	^{215}Bi β^- decay, **^{219}Rn α decay**
3	401.812 ± 0.010	5/2 +	^{215}Bi β^- decay, **^{219}Rn α decay**
4	517.60 ± 0.06	7/2 +, 9/2 +	^{215}Bi β^- decay, **^{219}Rn α decay**
5	608.30 ± 0.07	(11/2 +, 13/2 +)	**^{219}Rn α decay**
6	676.66 ± 0.07		^{215}Bi β^- decay, **^{219}Rn α decay**
7	708.1 ± 0.5		**^{219}Rn α decay**
8	732.7 ± 0.4		**^{219}Rn α decay**
9	835.32 ± 0.22		^{215}Bi β^- decay, **^{219}Rn α decay**
10	877.2 ± 0.6		**^{219}Rn α decay**
11	891.1 ± 0.3		**^{219}Rn α decay**
12	930 ± 1		**^{219}Rn α decay**
13	1073.7 ± 0.4	(5/2 +)	**^{219}Rn α decay**
14	1094.2 ± 1.0		**^{219}Rn α decay**

Measured and recommended energies of the alpha-particle emissions of ^{219}Ra.

	E_α (keV)				
	1962Wa18	**1971Gr07**	**1991Ry01**	**1999Li05**	**Recommended value***
$\alpha_{0,14}$	–	–	–	5744 (15)	5745.0 (10)
$\alpha_{0,13}$	–	–	–	5764 (8)	5765.1 (5)
$\alpha_{0,12}$	–	–	–	5900 (15)	5906.2 (10)
$\alpha_{0,11}$	–	–	–	5944 (6)	5944.4 (4)
$\alpha_{0,10}$	–	–	–	5958 (15)	5958.1 (7)
$\alpha_{0,9}$	5999.3	–	–	6000 (6)	5999.2 (4)
$\alpha_{0,8}$	6100.5	–	–	6100 (8)	6099.9 (5)
$\alpha_{0,7}$	~ 6146.2	–	–	6124 (8)	6124.1 (6)
$\alpha_{0,6}$	6157.1	–	–	6158 (4)	6154.9 (3)
$\alpha_{0,5}$	6222.1	–	–	6223 (6)	6222.0 (3)
$\alpha_{0,4}$	6310.3	–	–	6311 (3)	6311.1 (3)
$\alpha_{0,3}$	6423.2	–	6425.0 (10)	6425 (1)	6424.8 (3)
$\alpha_{0,2}$	6527.5	–	–	6530 (2)	6531.0 (3)
$\alpha_{0,1}$	6551.3	–	6552.6 (10)	6553 (1)	6553.0 (3)
$\alpha_{0,0}$	6817.5	6819.3 (3)	6819.1 (3)	6819.1 (3)	6819.2 (3)

* Determined from the nuclear level energies of 2001Br31 and evaluated Q-value of 6946.1 (3) keV (2003Au03).

Emission Probabilities

Alpha-particle emission probabilities were derived from the recommended relative emission probabilities of the gamma rays, a normalisation factor of 0.111 (5), and theoretical internal conversion coefficients (see below). The normalisation factor (F) was determined from the sum of the relative emission probabilities of the alpha particles calculated on the basis of α-γ population/depopulation balances of all the nuclear levels of ^{215}Po:

$$\sum[\text{calculated relative } P_\alpha \text{ to } ^{215}\text{Po excited states}]F + (\text{absolute } P_\alpha \text{ to } ^{215}\text{Po ground state}) = 100$$

An absolute P_α of 79.4 (10) % directly to the ^{215}Po ground state was adopted from 1991Ry01. Denoting F as the normalisation factor for the relative emission probabilities of both the gamma rays and alpha particles:

$$186.0626F + 79.4\ (10) = 100$$

$$F = 20.6\ (10) / 186.0626 = 0.1107\ (54) \rightarrow 0.111\ (5)$$

An unweighted mean value of 1.557 (2) was adopted for the radius parameter $r_0(^{215}Po)$ as derived from the equivalent data for neighbouring nuclei (1998Ak04), and used in the calculation of α-hindrance factors (HF):

$$r_0(^{215}Po) = [r_0(^{214}Po) + r_0(^{216}Po)] / 2$$

$$= [1.559(8) + 1.5555(2)] / 2 = 1.557\ (2)$$

Alpha-particle emission probabilities per 100 disintegrations of ^{219}Rn, and hindrance factors.

E_α(keV)	P_α				HF
	1962Wa18	1991Ry01	1999Li05	Recommended value*	
5745.0 (10)	–	–	< 0.0001	0.000 09 (5)	245
5765.1 (5)	–	–	0.001	0.000 94 (19)	33
5906.2 (10)	–	–	–	0.000 09 (5)	1590
5944.4 (4)	–	–	0.002	0.002 1 (3)	103
5958.1 (7)	–	–	0.0001	0.000 3 (1)	830
5999.2 (4)	0.0044	–	0.003	0.003 2 (5)	120
6099.9 (5)	0.003	–	0.001	0.001 23 (12)	880
6124.1 (6)	~ 0.0026	–	0.001	0.000 64 (12)	2170
6154.9 (3)	0.0174	–	0.018	0.018 4 (22)	103
6222.0 (3)	0.0026	–	0.004	0.004 3 (10)	860
6311.1 (3)	0.054	–	0.054	0.048 (3)	184
6424.8 (3)	7.5	7.5 (6)	7.5	7.85 (24)	3.31
6531.0 (3)	0.12	–	0.12	0.098 (5)	710
6553.0 (3)	11.5	12.9 (6)	13	12.6 (3)	6.75
6819.2 (3)	81	79.4 (10)	79.3	79.4 (10)	11.2
				Σ 100.02729 → 100.0 (11)	

* Recommended alpha-particle emission probabilities have been determined by calculating the populating alpha-particle balances of the daughter nuclear levels of ^{215}Po through individual consideration of their gamma population-depopulation, along with the adoption of a normalisation factor of 0.111 (5) for the relative emission probabilities of the observed gamma rays and derived alpha particles.

Gamma Rays

Energies

While the energies of the main gamma-ray emissions have been directly measured by 1967Da20, 1968Br17, 1970Da09, 1970Kr08, 1976Bl13 and 1999Li05, all of the recommended gamma-ray energies were calculated from the nuclear level energies of daughter ^{215}Po as adopted from 2001Br31.

Measured and recommended energies of the main gamma-ray emissions of ^{219}Ra.

	E_γ (keV)						
	1967Da20	1968Br17	1970Da09	1970Kr08	1976Bl13	1999Li05	Recommended value*
$\gamma_{3,1}(Po)$	130.9 (6)	130.5 (3)	130.7 (1)	130.6 (2)	130.588 (29)	130.6 (1)	130.58 (1)
$\gamma_{1,0}(Po)$	271.2 (5)	271.0 (2)	271.20 (5)	271.4 (1)	271.233 (10)	271.23 (5)	271.228 (10)
$\gamma_{2,0}(Po)$	293.2 (6)	293.4 (4)	294.0 (3)	293.8 (2)	293.538 (44)	293.6 (1)	293.56 (4)
$\gamma_{3,0}(Po)$	401.7 (5)	401.7 (1)	401.8 (2)	402.0 (3)	401.811 (10)	401.81 (5)	401.81 (1)
$\gamma_{4,0}(Po)$	517.1 (8)	517.4 (3)	516.5 (5)	–	517.639 (55)	517.5 (1)	517.60 (6)
$\gamma_{6,0}(Po)$	–	676.6 (3)	677.0 (10)	–	676.645 (70)	676.7 (1)	676.66 (7)

* Determined from the recommended nuclear level energies of 2001Br31.

Emission Probabilities

The emission probabilities were determined from measurements of 1967Da20, 1968Br17, 1970Da09, 1970Kr08, 1976Bl13 and 1999Li05. Weighted mean values were calculated for the relative emission probabilities of the 130.58-, 293.56-, 401.81-, 517.60-, 608.30-, 676.66- and 891.1-keV gamma rays, while all others were adopted from the more comprehensive set of data measured by 1999Li05.

Some of the reported gamma-ray emissions were of highly questionable validity, and were not considered for placement in the recommended decay scheme because of their nature and doubtful origins:

(a) 115.4-keV gamma ray was only observed by 1968Br17, and was furthermore labeled by these authors as ill-assigned – removed from consideration.
(b) 221.5-keV gamma ray was judged to be a major gamma emission from the alpha-decay mode of ^{223}Ra – removed from further consideration.
(c) 324.9-and 337.7-keV gamma-ray emission probabilities were expressed only in terms of their upper limits by 1967Da20, and not observed by 1999Li05 – removed from consideration.
(d) 370.9-keV gamma ray was observed by 1965Va10, an emission probability expressed only in terms of an upper limit by 1967Da20, and not observed by 1999Li05 – removed from consideration.
(e) 380-keV gamma ray was only observed by 1965Va10 without a quantified emission probability – removed from consideration.
(f) 438.2-keV gamma ray was judged to be a major gamma emission from the alpha-decay mode of ^{215}Po – removed from further consideration.
(g) 538.2-and 1005-keV gamma rays were observed by 1965Va10, emission probabilities quantified by 1967Da20, and not observed by 1999Li05 – removed from consideration.
(h) 665.5-keV gamma-ray emission probability was assigned an upper limit by 1967Da20 and identified as a possible doublet, and fully quantified as a singlet by 1999Li05 – retained as an unplaced gamma transition emitted in the decay of ^{219}Rn.

Although some of the other observed gamma-ray emissions possess similar origins to the above, these transitions could be more comfortably placed in the proposed decay scheme, lending support to their acceptance and inclusion in the recommended data set.

Published gamma-ray emission probabilities.

E_γ (keV)	P_γ						
	1965Va10*	1967Da20†	1968Br17‡	1970Da09¶	1970Kr08	1976Bl13	1999Li05
115.4 (5)	–	–	0.033 (15)	–	–	–	–
130.58 (1)	observed	1.40 (14)	1.30 (25)	1.05 (25)	1.21 (10)	1.16 (12)	1.7 (2)
221.5 (3)	–	–	–	) 0.28 (7)	–	–	–
224.04 (7)	–	–	–	)	–	–	0.013 (2)
271.228 (10)	observed	100	110 (15)	100.00	100.0	105.5 (40)	100 (2)
293.56 (4)	–	0.64 (6)	0.77 (15)	0.59 (15)	0.51 (27)	0.76 (5)	0.68 (4)
322 (1)	–	–	–	–	–	–	0.0008 (4)
324.9 (10)	–	< 0.06	–	–	–	–	–
330.9 (4)	–	–	–	–	–	–	0.0090 (10)
337.7 (10)	–	< 0.08	–	–	–	–	–
370.9 (15)	observed	< 0.1	–	–	–	–	–
373.5 (3)	–	–	–	–	–	–	0.0023 (3)
~ 380	observed	–	–	–	–	–	–
383.1 (1)	–	–	–	–	–	–	0.0040 (6)
401.81 (1)	observed	58 (6)	67 (4)	65.2 (65)	69.0 (30)	61.6 (28)	59.0 (20)
405.4 (1)	–	–	–	–	–	–	0.0023 (4)
436.9 (5)	–	–	–	–	–	–	0.0028 (5)
438.2 (6)	–	0.54 (10)	–	–	–	–	–
461.5 (4)	–	–	–	–	–	–	0.0015 (3)
489.3 (3)	–	–	–	–	–	–	0.0058 (8)
517.60 (6)	observed	0.44 (10)	0.48 (4)	0.22 (5)	–	0.43 (3)	0.40 (2)
538.2 (15)	observed	0.06 (3)	–	–	–	–	–
556.1 (4)	–	–	–	–	–	–	0.0005 (3)
564.1 (2)	observed	< 0.03	–	–	–	–	0.014 (3)
576.6 (10)	–	–	–	–	–	–	0.0008 (4)
608.30 (7)	observed	0.04 (2)	–	–	–	–	0.040 (10)
619.9 (3)	–	–	–	–	–	–	0.003 (1)
665.5 (10)	–	< 0.08$^\Delta$	–	–	–	–	0.0008 (4)
671.9 (4)	observed	–	–	–	–	–	0.002 (1)
676.66 (7)	–	0.21 (3)	0.23 (2)$^\Delta$	0.06 (3)	–	0.16 (1)	0.16 (2)
708.1 (5)	–	–	–	–	–	–	0.003 (1)
732.7 (4)	–	–	–	–	–	–	0.0006 (3)
802.5 (4)	–	–	–	–	–	–	0.003 (1)
835.32 (22)	observed	–	–	–	–	–	0.015 (3)
877.2 (6)	–	–	–	–	–	–	0.003 (1)
891.1 (3)	observed	0.015 (7)	–	–	–	–	0.007 (2)
1055 (2)	observed	0.006 (3)	–	–	–	–	–
1073.7 (4)	–	–	–	–	–	–	0.003 (1)

* Quantified only in terms of percentage depopulation of a number of ill-defined nuclear levels of ^{215}Po – neither the gamma-ray energies nor this form of relative emission probability were adopted in the subsequent analyses.

† Quoted relative emission probabilities of 1967Da20 are based on Pγ(271.228 keV) of 1000, and have been adjusted to Pγ(271.228 keV) of 100.

‡ Quoted relative emission probabilities of 1968Br17 for ^{219}Rn decay are based on Pγ(271.228 keV) of 0.110 (15), and have been adjusted to Pγ(271.228 keV) of 110 (15).

¶ Uncertainties in the relative emission probabilities are not defined by 1970Da09, and have been derived from the quoted uncertainties of the absolute emission probabilities.

Δ Evidence for the existence of a doublet.

Relative gamma-ray emission probabilities: Relative to P_γ(271.228 keV) of 100 %.

	E_γ (keV)	P_γ						
		1967Da20	1968Br17	1970Da09	1970Kr08	1976Bl13	1999Li05	Recommended value
–	115.4 (5)*	–	0.030 (14)	–	–	–	–	–
$\gamma_{3,1}$	130.58 (1)	1.40 (14)	1.18 (23)	1.05 (25)	1.21 (10)	1.10 (11)	1.7 (2)	1.2 (1)
–	221.5 (3)#	–	–	) 0.28 (7)	–	–	–	–
$\gamma_{4,2}$	224.04 (7)	–	–	)	–	–	0.013 (2)	0.013 (2)
$\gamma_{1,0}$	271.228 (10)	100	100	100.00	100.0	100	100.0 (20)	100 (2)
$\gamma_{2,0}$	293.56 (4)	0.64 (6)	0.70 (14)	0.59 (15)	0.51 (27)	0.72 (5)	0.68 (4)	0.68 (3)
$\gamma_{12,5}$	322 (1)	–	–	–	–	–	0.0008 (4)	0.0008 (4)
–	324.9 (10)§	< 0.06	–	–	–	–	–	–
$\gamma_{8,3}$	330.9 (4)	–	–	–	–	–	0.0090 (10)	0.0090 (10)
–	337.7 (10)†	< 0.08	–	–	–	–	–	–
–	370.9 (15)†	< 0.1	–	–	–	–	–	–
$\gamma_{11,4}$	373.5 (3)	–	–	–	–	–	0.0023 (3)	0.0023 (3)
–	~ 380§	–	–	–	–	–	–	–
$\gamma_{6,2}$	383.1 (1)	–	–	–	–	–	0.0040 (6)	0.0040 (6)
$\gamma_{3,0}$	401.81 (1)	58 (6)	61 (4)	65.2 (65)	69 (3)	58.4 (27)	59.0 (20)	61 (2)
$\gamma_{6,1}$	405.4 (1)	–	–	–	–	–	0.0023 (4)	0.0023 (4)
$\gamma_{7,1}$	436.9 (5)	–	–	–	–	–	0.0028 (5)	0.0028 (5)
–	438.2 (6)‡	0.54 (10)	–	–	–	–	–	–
$\gamma_{8,1}$	461.5 (4)	–	–	–	–	–	0.0015 (3)	0.0015 (3)
$\gamma_{11,3}$	489.3 (3)	–	–	–	–	–	0.0058 (8)	0.0058 (8)
$\gamma_{4,0}$	517.60 (6)	0.44 (10)	0.44 (4)	0.22 (5)	–	0.41 (3)	0.40 (2)	0.39 (3)
–	538.2 (15)†	0.06 (3)	–	–	–	–	–	–
$\gamma_{13,4}$	556.1 (4)	–	–	–	–	–	0.0005 (3)	0.0005 (3)
$\gamma_{9,1}$	564.1 (2)	< 0.03	–	–	–	–	0.014 (3)	0.014 (3)
$\gamma_{14,4}$	576.6 (10)	–	–	–	–	–	0.0008 (4)	0.0008 (4)
$\gamma_{5,0}$	608.30 (7)	0.04 (2)	–	–	–	–	0.040 (10)	0.040 (9)
$\gamma_{11,1}$	619.9 (3)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{-1,1}$	665.5 (10)¶	< 0.08Δ	–	–	–	–	0.0008 (4)	0.0008 (4)
$\gamma_{13,3}$	671.9 (4)	–	–	–	–	–	0.002 (1)	0.002 (1)
$\gamma_{6,0}$	676.66 (7)	0.21 (3)	0.21 (2)	0.06 (3)	–	0.15 (1)	0.16 (2)	0.16 (2)
$\gamma_{7,0}$	708.1 (5)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{8,0}$	732.7 (4)	–	–	–	–	–	0.0006 (3)	0.0006 (3)
$\gamma_{13,1}$	802.5 (4)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{9,0}$	835.32 (22)	–	–	–	–	–	0.015 (3)	0.015 (3)
$\gamma_{10,0}$	877.2 (6)	–	–	–	–	–	0.003 (1)	0.003 (1)
$\gamma_{11,0}$	891.1 (3)	0.015 (7)	–	–	–	–	0.007 (2)	0.008 (2)
–	1055 (2)†	0.006 (3)	–	–	–	–	–	–
$\gamma_{13,0}$	1073.7 (4)	–	–	–	–	–	0.003 (1)	0.003 (1)

* Only observed by 1968Br17, and of doubtful origin – discarded.
# Determined from the measurements of 1970Da09, but identified as a gamma-ray emission within the alpha-decay mode of ^{223}Ra – discarded.
§ Only observed in a qualitative manner by 1965Va10 and 1967Da20, and of doubtful origin – discarded.
† Derived only from the measurements of 1967Da20, and of doubtful origin – discarded.
‡ Determined from the measurements of 1967Da20, but identified as a gamma-ray emission within the alpha-decay mode of ^{215}Po – discarded.
¶ Derived only from the measurements of 1967Da20 and 1999Li05, and of doubtful origin – unplaced within the proposed ^{219}Rn decay scheme.
Δ Evidence for the existence of a doublet.

Multipolarity and Internal Conversion Coefficients

The decay scheme specified by 2001Br31 has been used to define the multipolarity of specific gamma transitions on the basis of the known spins and parities of the nuclear levels. Thus, the 224.04-, 401.81 and 1073.7-keV gamma-ray emissions are adjudged to be E2 transitions. Multipolarity mixing ratios for the 130.58- and 271.228-keV gamma transitions of 0.60 (6) and 4.0 (4), respectively, were derived from the K/L and L sub-shell conversion-electron intensities determined by Davidson and Connor (1970Da09), while the 293.56-, 517.60- and 556.1-keV gamma-ray emissions were arbitrarily assigned mixing ratios of 1.0 (2) (i.e. 50%M1 + 50%E2). 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).

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

E_γ (keV)	P_γ^{abs} × 100	Multipolarity	α_K	α_L	α_{M+}	α_{total}
130.58 (1)	0.133 (11)	73.5%M1 + 26.5%E2 δ = 0.60 (6)	3.19 (16)	0.94 (4)	0.31	4.44 (13)
224.04 (7)	0.001 4 (2)	(E2)	0.129 6 (19)	0.140 7 (20)	0.048 7	0.319 (5)
271.228 (10)	11.07 (22)	(6%M1 + 94%E2) δ = 4.0 (4)	0.111 (6)	0.066 8 (11)	0.023 2	0.201 (7)
293.56 (4)	0.075 (3)	(50%M1 + 50%E2) δ = 1.0 (2)	0.25 (4)	0.062 (4)	0.028	0.34 (5)
322 (1)	0.000 09 (5)	–	–	–	–	–
330.9 (4)	0.001 00 (11)	–	–	–	–	–
373.5 (3)	0.000 25 (3)	–	–	–	–	–
383.1 (1)	0.000 44 (7)	–	–	–	–	–
401.81 (1)	6.75 (22)	E2	0.0351 (5)	0.015 28 (22)	0.005 12	0.055 5 (8)
405.4 (1)	0.000 25 (4)	–	–	–	–	–
436.9 (5)	0.000 31 (6)	–	–	–	–	–
461.5 (4)	0.000 17 (3)	–	–	–	–	–
489.3 (3)	0.000 64 (9)	–	–	–	–	–
517.60 (6)	0.043 (3)	(50%M1 + 50%E2) δ = 1.0 (2)	0.058 (9)	0.011 5 (11)	0.003 5	0.073 (10)
556.1 (4)	0.000 06 (4)	(50%M1 + 50%E2) δ = 1.0 (2)	0.048 (7)	0.009 5 (9)	0.003 5	0.061 (8)
564.1 (2)	0.001 5 (3)	–	–	–	–	–
576.6 (10)	0.000 09 (5)	–	–	–	–	–
608.30 (7)	0.004 4 (10)	(M1 + E2)	–	–	–	–
619.9 (3)	0.000 33 (11)	–	–	–	–	–
665.5 (10)	0.000 09 (5)	–	–	–	–	–
671.9 (4)	0.000 22 (11)	M1 + E2	–	–	–	–
676.66 (7)	0.018 (2)	–	–	–	–	–
708.1 (5)	0.000 33 (11)	–	–	–	–	–
732.7 (4)	0.000 07 (4)	–	–	–	–	–
802.5 (4)	0.000 33 (11)	M1 + E2	–	–	–	–
835.32 (22)	0.001 7 (3)	–	–	–	–	–
877.2 (6)	0.000 33 (11)	–	–	–	–	–
891.1 (3)	0.000 9 (2)	–	–	–	–	–
1073.7 (4)	0.000 33 (11)	E2	0.005 10 (8)	0.001 002 (14)	0.000 308	0.006 41 (9)

Atomic Data

The x-ray data have been calculated using the evaluated gamma-ray data, and the 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 4.01, 28 January 2003). This program incorporates atomic data from 1996Sc06 and the evaluated gamma-ray data.

K and L X-ray emission probabilities per 100 disintegrations of ^{219}Rn.

			Energy (keV)		Photons per 100 disint.
XL		(Po)	9.658 – 16.213		1.01 (5)
	XL_l	(Po)	9.658		0.0229 (9)
	XL_α	(Po)	11.016 – 11.130		0.420 (15)
	XL_η	(Po)	12.085		0.0095 (4)
	XL_β	(Po)	12.823 – 13.778		0.475 (13)
	XL_γ	(Po)	15.742 – 16.213		0.098 (3)
XK_α	$XK_{\alpha2}$	(Po)	76.864		0.540 (24)
	$XK_{\alpha1}$	(Po)	79.293		0.90 (4)
$XK'_{\beta1}$	$XK_{\beta3}$	(Po)	89.256	)	
	$XK_{\beta1}$"	(Po)	89.807	)	0.309 (15)
	$XK_{\beta5}$"	(Po)	90.363	)	
$XK'_{\beta2}$	$XK_{\beta2}$	(Po)	92.263	)	
	$XK_{\beta4}$	(Po)	92.618	)	0.096 (5)
	$XKO_{2,3}$	(Po)	92.983	)	

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

A Q_α-value of 6946.1 (3) keV has been adopted from the atomic mass evaluation of Audi *et al.* (2003Au03) while in the course of formulating the decay scheme of ^{219}Rn. This value has subsequently been compared with the Q-value calculated by summing the contributions of the individual emissions to the ^{219}Rn alpha-decay process (i.e. α, electron, γ, etc.):

$$\text{calculated Q-value} = \sum (E_i \times P_i) = 6945\ (70)\ \text{keV}$$

Percentage deviation from the Q-value of Audi *et al.* is (0.0 ± 1.0) %, which supports the derivation of a highly consistent decay scheme with a rather significant variant.

References

1961Ro14 H. RODENBUSCH, G. HERRMANN, Ein Verfahren zur Bestimmung von Halbwertszeiten kurzlebiger gasförmiger Radioisotope. Die Halbwertszeiten des Thorons (^{220}Rn) und Actinons (^{219}Rn), Z. Naturforsch. 16a (1961) 577-582. [Half-life]

1962Wa18 R.J. WALEN, V. NEDOVESSOV, G. BASTIN-SCOFFIER, Spectrographie α de ^{223}Ra (AcX) et de ses Dérivés, Nucl. Phys. 35 (1962) 232-252. [E_α, P_α]

1965Va10 K. VALLI, J. AALTONEN, G. GRAEFFE, M. NURMIA, An Alpha-Gamma and Alpha-Conversion Electron Coincidence Study of Rn-219, Po-215, and Bi-211, Ann. Acad. Sci. Fenn., Ser. A VI, No. 184 (1965). [E_γ, P_γ]

1966Hu20 J.B. HURSH, Thoron Half-life, J. Inorg. Nucl. Chem. 28 (1966) 2771-2776. [Half-life]

1967Da20 J. DALMASSO, H. MARIA, Sur le Rayonnement γ du Radon 219, du Polonium 215 et du Plomb 211, C. R. Acad. Sci. Paris 265B (1967) 822-825. [E_γ, P_γ]

1968Br17 C. BRIANÇON, CHIN FAN LEANG, R. WALEN, Étude du Spectre γ Émis par le Radium-223 et ses Dérivés, C. R. Acad. Sci. Paris 266B (1968) 1533-1536. [E_γ, P_γ]

1970Da09 W.F. DAVIDSON, R.D. CONNOR, The Decay of ^{223}Ra and its Daughter Products (II). The Decay of ^{219}Rn and ^{215}Po, Nucl. Phys. A149 (1970) 385-391. [E_γ, P_γ, P_{ce}, K/L and L sub-shell ratios, ICC]

1971Gr07 B. GRENNBERG, A. RYTZ, Absolute Measurements of α-ray Energies, Metrologia 7 (1971) 65-77 [E_α]

1970Kr08 K. KRIEN, M.J. CANTY, P. HERZOG, Determination of Spins in the Decay of ^{219}Rn → ^{215}Po by Alpha-Gamma Linear Polarization Measurements, Nucl. Phys. A157 (1970) 456-470. [E_γ, P_γ, P_{ce}, L sub-shell ratios, ICC]

1976Bl13 K. BLATON-ALBICKA, B. KOTLIŃSKA-FILIPEK, M. MATUL, K. STRYCZNIEWICZ, M. NOWICKI, E. RUCHOWSKA-ŁUKASIAK, Precision Gamma-ray Spectroscopy of the Decay of ^{223}Ra and its Daughter Products, Nukleonika 21 (1976) 935-947. [E_γ, P_γ]

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

1991Ry01 A. RYTZ, Recommended Energy and Intensity Values of Alpha Particles from Radioactive Decay, At. Data Nucl. Data Tables 47 (1991) 205-239. [E_α, P_α]

1996Sc06 E. SCHÖNFELD, H. JANβEN, Evaluation of Atomic Shell Data, Nucl. Instrum. Methods Phys. Res. A369 (1996) 527-533. [X_K, X_L, Auger electrons]

1998Ak04 Y.A. AKOVALI, Review of Alpha-decay Data from Doubly-even Nuclei, Nucl. Data Sheets 84 (1998) 1-114. [alpha decay, r_0 parameters]

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]

1999Li05 C.F. LIANG, P. PARIS, R.K. SHELINE, Configurations and Level Structure of ^{215}Po, Phys. Rev. C59 (1999) 648-654. [E_α, P_α, E_γ, P_γ]

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]

2001Br31 E. BROWNE, Nuclear Data Sheets for A = 215, 219, 223, 227, 231, Nucl. Data Sheets 93 (2001) 763-1061. [Nuclear structure, level energies]

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]

2003Au03 G. AUDI, A.H. WAPSTRA, C. THIBAULT, The AME2003 Atomic Mass Evaluation (II). Tables, Graphs and References, Nucl. Phys. A729 (2003) 337-676. [Q-value]

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]