$^{233}_{91}\mathrm{Pa}_{142}$

1 Decay Scheme

Pa-233 decays by beta minus emission to levels in U-233.
Le protactinium 233 se désintègre par émission bêta moins vers des niveaux excités de l'uranium 233.

2 Nuclear Data

$T_{1/2}(^{233}\mathrm{Pa})$	:	26,98	(2)	d
$T_{1/2}(^{233}\mathrm{U})$	:	159,2	(2)	10^3 a
$Q^-(^{233}\mathrm{Pa})$	:	570,1	(20)	keV

2.1 β^- Transitions

	Energy keV	Probability × 100	Nature	lg ft
$\beta^-_{0,11}$	114,1 (20)	0,0011 (2)	1st forbidden	10,6
$\beta^-_{0,10}$	154,3 (20)	25,4 (16)	1st forbidden	6,7
$\beta^-_{0,9}$	171,5 (20)	15,4 (8)	1st forbidden	7
$\beta^-_{0,8}$	189,8 (20)	0,020 (3)	1st forbidden unique	9,4
$\beta^-_{0,7}$	229,6 (20)	25,9 (32)	1st forbidden	7,2
$\beta^-_{0,6}$	249,4 (20)	0,020 (5)	2nd forbidden	10,4
$\beta^-_{0,5}$	258,2 (20)	26,6 (32)	1st forbidden	7,3
$\beta^-_{0,4}$	268,1 (20)	0,010 (2)	Allowed	11,8
$\beta^-_{0,3}$	271,3 (20)	0,12 (5)	Allowed	9,8
$\beta^-_{0,1}$	529,8 (20)	0,3 (19)	1st forbidden unique	10,2
$\beta^-_{0,0}$	570,1 (20)	6,3 (23)	1st forbidden	9,1

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M	α_T
$\gamma_{10,9}$(U)	17,262 (6)	2,07	M1+1,66%E2			374	503
$\gamma_{7,5}$(U)	28,559 (10)	22,3 (28)	M1+2,44%E2		233 (13)	60 (4)	313 (18)
$\gamma_{1,0}$(U)	40,349 (5)	13,9 (19)	M1+54%E2		430 (50)	117 (12)	580 (60)
$\gamma_{7,3}$(U)	41,663 (10)	0,032 (7)	[E1]		0,939 (19)	0,235 (5)	1,253 (25)
$\gamma_{2,1}$(U)	51,81 (4)	0,055	[M1+28%E2]		79	21	108
$\gamma_{10,7}$(U)	75,269 (10)	16,1 (16)	M1+2,2%E2		8,6 (9)	2,11 (24)	11,4 (12)
$\gamma_{9,5}$(U)	86,595 (5)	16,1 (9)	M1+0,31%E2		5,33 (11)	1,29 (3)	7,08 (14)
$\gamma_{2,0}$(U)	92,16 (4)	0,0492	[E2]		14,2	3,95	19,5
$\gamma_{10,5}$(U)	103,86 (1)	4,44 (18)	M1+(1%E2)		3,17 (15)	0,77 (5)	4,21 (21)
$\gamma_{6,2}$(U)	228,57 (5)	0,0042 (7)					
$\gamma_{7,2}$(U)	248,38 (4)	0,082 (2)	[E2]	0,1065 (21)	0,175 (4)	0,0479 (10)	0,346 (7)
$\gamma_{3,1}$(U)	258,45 (2)	0,0289 (6)	[E1]	0,0433 (9)	0,00857 (17)	0,00207 (4)	0,0547 (11)
$\gamma_{5,1}$(U)	271,555 (10)	0,406 (4)	E2	0,0904 (18)	0,1226 (25)	0,0334 (7)	0,258 (5)
$\gamma_{6,1}$(U)	280,61 (5)	0,011 (2)					
$\gamma_{8,2}$(U)	288,42 (10)	0,016 (3)					
$\gamma_{3,0}$(U)	298,81 (2)	0,12 (5)	[E1]	0,0315 (6)	0,00609 (12)	0,00147 (3)	0,0396 (8)
$\gamma_{7,1}$(U)	300,129 (5)	12,3 (4)	M1+0,6%E2	0,70 (2)	0,133 (4)	0,031 (1)	0,87 (2)
$\gamma_{4,0}$(U)	301,99 (10)	0,010 (2)					
$\gamma_{5,0}$(U)	311,904 (5)	68,9 (12)	M1+1%E2	0,64 (2)	0,126 (4)	0,031 (1)	0,80 (2)
$\gamma_{6,0}$(U)	320,73 (10)	0,0051 (4)					
$\gamma_{7,0}$(U)	340,476 (5)	7,24 (10)	M1+5%E2	0,50 (2)	0,103 (3)	0,022 (1)	0,62 (2)
$\gamma_{10,1}$(U)	375,404 (5)	0,751 (7)	E2	0,0491 (10)	0,0360 (7)	0,00962 (19)	0,0981 (20)
$\gamma_{8,0}$(U)	380,28 (10)	0,0037 (9)					
$\gamma_{9,0}$(U)	398,492 (5)	1,526 (15)	E2	0,0439 (9)	0,0291 (6)	0,00777 (16)	0,0835 (17)
$\gamma_{10,0}$(U)	415,764 (5)	1,97 (12)	M1+83%E2	0,09 (6)	0,032 (9)	0,0081 (21)	0,13 (8)
$\gamma_{11,0}$(U)	455,96 (10)	0,0011 (2)					

3 Atomic Data

3.1 U

ω_K : 0,970 (4)
$\bar{\omega}_L$: 0,500 (19)
n_{KL} : 0,794 (5)

3.1.1 X Radiations

		Energy keV		Relative probability
X_K				
	$K\alpha_2$	94,666		62,47
	$K\alpha_1$	98,44		100
	$K\beta_3$	110,421	}	
	$K\beta_1$	111,298	}	
	$K\beta_5''$	111,964	}	36,08
	$K\beta_2$	114,407	}	
	$K\beta_4$	115,012	}	12,34
	$KO_{2,3}$	115,377	}	
X_L				
	$L\ell$	11,619		
	$L\alpha$	13,438 – 13,615		
	$L\eta$	15,399		
	$L\beta$	15,727 – 18,206		
	$L\gamma$	19,507 – 20,714		

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	71,78 – 80,95	100
KLX	88,15 – 98,34	59,6
KXY	104,42 – 115,40	8,88
Auger L	5,9 – 21,6	

4 Electron Emissions

		Energy keV	Electrons per 100 disint.
e_{AL}	(U)	5,9 - 21,6	42,2 (13)
e_{AK}	(U)		0,95 (13)
	KLL	71,78 - 80,95	
	KLX	88,15 - 98,34	
	KXY	104,42 - 115,40	
$ec_{7,5\ L}$	(U)	6,80 - 11,39	16,5 (21)
$ec_{10,9\ M}$	(U)	11,714 - 13,710	1,53
$ec_{1,0\ L}$	(U)	18,59 - 23,18	10,3 (15)
$ec_{7,3\ L}$	(U)	19,9 - 24,5	0,013 (3)
$ec_{7,5\ M}$	(U)	23,01 - 25,01	4,3 (6)
$ec_{7,5\ N}$	(U)	27,118 - 28,180	1,14 (15)
$ec_{2,1\ L}$	(U)	30,05 - 34,64	0,04
$ec_{1,0\ M}$	(U)	34,8 - 36,8	2,8 (4)
$ec_{1,0\ N}$	(U)	38,908 - 39,970	0,77 (12)
$ec_{2,1\ M}$	(U)	46,26 - 48,26	0,011
$ec_{10,7\ L}$	(U)	53,51 - 58,10	11,2 (12)
$ec_{9,5\ L}$	(U)	64,84 - 69,43	10,6 (6)
$ec_{10,7\ M}$	(U)	69,72 - 71,72	2,7 (3)
$ec_{2,0\ L}$	(U)	70,40 - 74,99	0,034
$ec_{10,7\ N}$	(U)	73,828 - 74,890	0,74 (9)
$ec_{9,5\ M}$	(U)	81,05 - 83,04	2,57 (14)
$ec_{10,5\ L}$	(U)	82,10 - 86,69	2,70 (13)
$ec_{9,5\ N}$	(U)	85,154 - 86,216	0,695 (38)
$ec_{10,5\ M}$	(U)	98,31 - 100,31	0,66 (4)
$ec_{10,5\ N}$	(U)	102,42 - 103,48	0,18 (1)
$ec_{5,1\ K}$	(U)	155,95 (1)	0,0292 (6)
$ec_{7,1\ K}$	(U)	184,527 (5)	4,62 (20)
$ec_{7,1\ T}$	(U)	184,527 - 300,120	5,74 (23)
$ec_{5,0\ K}$	(U)	196,302 (5)	24,5 (8)
$ec_{5,0\ T}$	(U)	196,302 - 311,895	30,6 (9)
$ec_{7,0\ K}$	(U)	224,874 (5)	2,24 (9)
$ec_{7,0\ T}$	(U)	224,874 - 340,468	2,77 (9)
$ec_{7,2\ L}$	(U)	226,62 - 231,21	0,0107 (3)
$ec_{5,1\ L}$	(U)	249,80 - 254,39	0,0396 (9)
$ec_{10,1\ K}$	(U)	259,802 (5)	0,0336 (8)
$ec_{5,1\ M}$	(U)	266,01 - 268,00	0,0108 (3)
$ec_{7,1\ L}$	(U)	278,37 - 282,96	0,88 (4)
$ec_{9,0\ K}$	(U)	282,890 (5)	0,0618 (12)
$ec_{5,0\ L}$	(U)	290,15 - 294,74	4,83 (17)
$ec_{7,1\ M}$	(U)	294,58 - 296,58	0,22 (1)
$ec_{7,1\ N}$	(U)	298,688 - 299,750	0,0659 (25)
$ec_{10,0\ K}$	(U)	300,162 (7)	0,16 (10)
$ec_{5,0\ M}$	(U)	306,36 - 308,35	1,19 (4)

		Energy keV		Electrons per 100 disint.
$ec_{5,0\ N}$	(U)	310,463 - 311,525		0,343 (6)
$ec_{7,0\ L}$	(U)	318,72 - 323,31		0,460 (14)
$ec_{7,0\ M}$	(U)	334,93 - 336,93		0,098 (5)
$ec_{7,0\ N}$	(U)	339,035 - 340,097		0,024 (8)
$ec_{10,1\ L}$	(U)	353,65 - 358,24		0,0246 (5)
$ec_{9,0\ L}$	(U)	376,73 - 381,32		0,0410 (9)
$ec_{9,0\ M}$	(U)	392,94 - 394,94		0,01094 (25)
$ec_{10,0\ L}$	(U)	394,01 - 398,60		0,056 (16)
$ec_{10,0\ M}$	(U)	410,22 - 412,21		0,014 (3)
$\beta^-_{0,11}$	max:	114,1	(20)	0,0011 (2)
$\beta^-_{0,11}$	avg:	29,8	(5)	
$\beta^-_{0,10}$	max:	154,3	(20)	25,4 (16)
$\beta^-_{0,10}$	avg:	40,9	(5)	
$\beta^-_{0,9}$	max:	171,5	(20)	15,4 (8)
$\beta^-_{0,9}$	avg:	45,7	(5)	
$\beta^-_{0,8}$	max:	189,8	(20)	0,020 (3)
$\beta^-_{0,8}$	avg:	50,9	(6)	
$\beta^-_{0,7}$	max:	229,6	(20)	25,9 (32)
$\beta^-_{0,7}$	avg:	62,4	(6)	
$\beta^-_{0,6}$	max:	249,4	(20)	0,020 (5)
$\beta^-_{0,6}$	avg:	68,2	(6)	
$\beta^-_{0,5}$	max:	258,2	(20)	26,6 (32)
$\beta^-_{0,5}$	avg:	70,8	(6)	
$\beta^-_{0,4}$	max:	268,1	(20)	0,010 (2)
$\beta^-_{0,4}$	avg:	73,7	(6)	
$\beta^-_{0,3}$	max:	271,3	(20)	0,12 (5)
$\beta^-_{0,3}$	avg:	74,6	(6)	
$\beta^-_{0,1}$	max:	529,8	(20)	0,3 (19)
$\beta^-_{0,1}$	avg:	156,1	(6)	
$\beta^-_{0,0}$	max:	570,1	(20)	6,3 (23)
$\beta^-_{0,0}$	avg:	169,6	(6)	

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XL	(U)	11,619 — 20,714		40,6 (11)	
XKα_2	(U)	94,666		9,10 (26)	} Kα
XKα_1	(U)	98,44		14,6 (4)	}
XKβ_3	(U)	110,421	}		
XKβ_1	(U)	111,298	}	5,25 (18)	K$'\beta_1$
XKβ''_5	(U)	111,964	}		
XKβ_2	(U)	114,407	}		
XKβ_4	(U)	115,012	}	1,80 (7)	K$'\beta_2$
XKO$_{2,3}$	(U)	115,377	}		

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{10,9}$(U)	17,262 (6)	0,0041
$\gamma_{7,5}$(U)	28,559 (10)	0,071 (8)
$\gamma_{1,0}$(U)	40,349 (5)	0,024 (2)
$\gamma_{7,3}$(U)	41,663 (10)	0,014 (3)
$\gamma_{2,1}$(U)	51,81 (4)	0,0005
$\gamma_{10,7}$(U)	75,269 (10)	1,30 (3)
$\gamma_{9,5}$(U)	86,595 (5)	1,99 (10)
$\gamma_{2,0}$(U)	92,16 (4)	0,0024
$\gamma_{10,5}$(U)	103,86 (1)	0,853 (6)
$\gamma_{6,2}$(U)	228,57 (5)	0,0042 (7)
$\gamma_{7,2}$(U)	248,38 (4)	0,0609 (11)
$\gamma_{3,1}$(U)	258,45 (2)	0,0274 (6)
$\gamma_{5,1}$(U)	271,555 (10)	0,323 (3)
$\gamma_{6,1}$(U)	280,61 (5)	0,011 (2)
$\gamma_{8,2}$(U)	288,42 (10)	0,016 (3)
$\gamma_{3,0}$(U)	298,81 (2)	0,12 (5)
$\gamma_{7,1}$(U)	300,129 (5)	6,60 (21)
$\gamma_{4,0}$(U)	301,99 (10)	0,010 (2)
$\gamma_{5,0}$(U)	311,904 (5)	38,3 (5)
$\gamma_{6,0}$(U)	320,73 (10)	0,0051 (4)
$\gamma_{7,0}$(U)	340,476 (5)	4,47 (3)
$\gamma_{10,1}$(U)	375,404 (5)	0,684 (7)

	Energy keV	Photons per 100 disint.
$\gamma_{8,0}$(U)	380,28 (10)	0,0037 (9)
$\gamma_{9,0}$(U)	398,492 (5)	1,408 (14)
$\gamma_{10,0}$(U)	415,764 (5)	1,747 (7)
$\gamma_{11,0}$(U)	455,96 (10)	0,0011 (2)

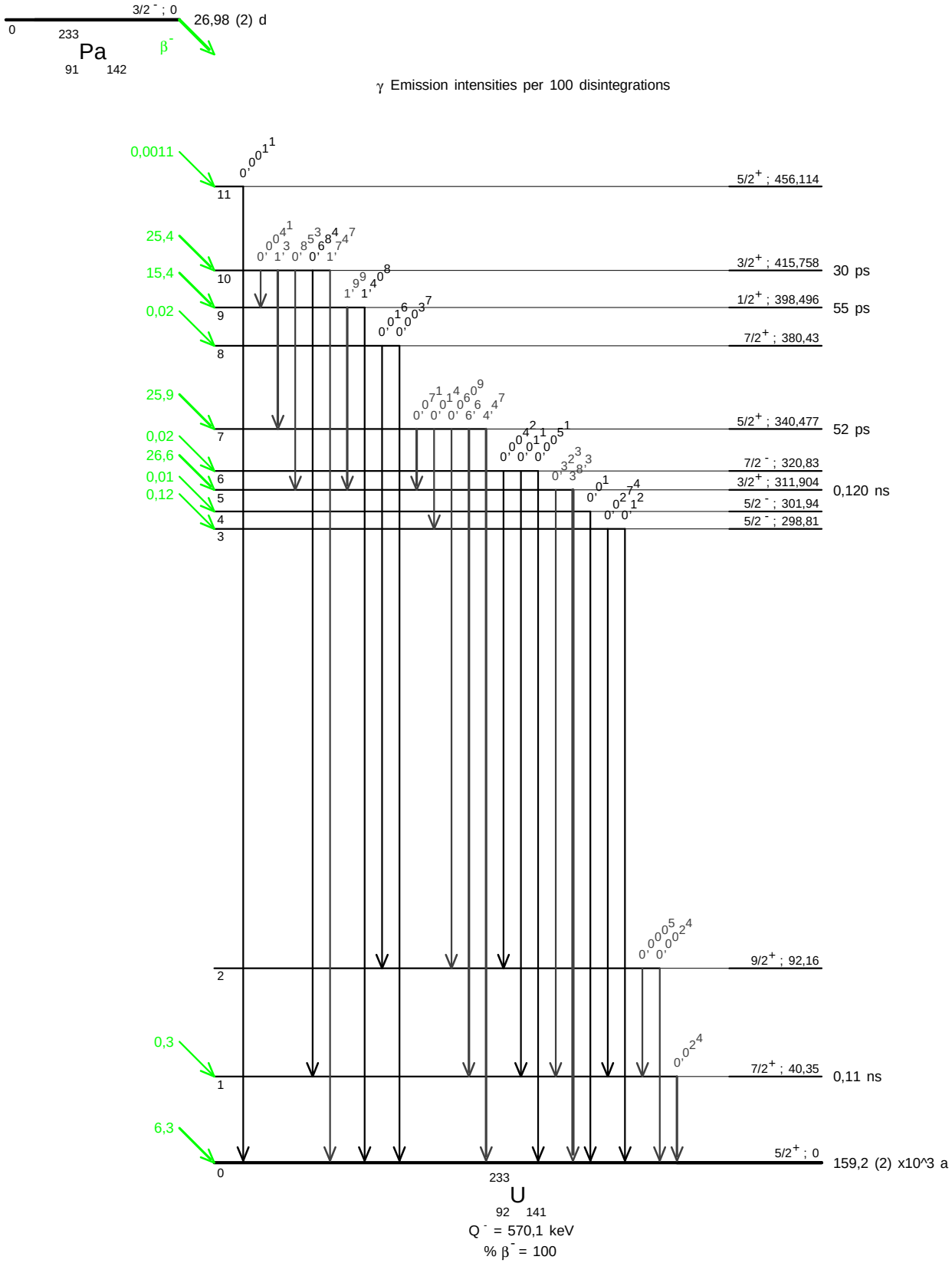
6 Main Production Modes

$\mathrm{Th-232(n,\gamma)Th-233}$
$\mathrm{Th-233}(\beta^-)\mathrm{Pa-233}$

7 References

- A. V. Grosse, E. T. Booth, J .R. Dunning. Phys. Rev. 59 (1941) 322
  (Half-life.)
- C. I. Browne Jr.. Thesis, Univ. California (1952)
  (Gamma-ray energies.)
- W. D. BRODIE. Proc. Phys. Soc. (London) 67A (1954) 397
  (Measured energies and probabilities of beta-transitions.)
- Ong Ping Hok, P. Kramer. Physica 21 (1955) 676
  (Measured energies and probabilities of beta-transitions.)
- L. D. Mc Isaac, E. C. Freiling. Nucleonics 14 (1956) 65
  (Half-life.)
- H. W. Wright, E. T. Wyatt, S. A. Reynolds, W. S. Lyon, T. H. Handley. Nucl. Sci. Eng. 2 (1957) 427
  (Half-life.)
- J. P. Unik. Thesis, Univ. California ,UCRL-9105 (1960) (1960)
  (Measured energies and probabilities of beta-transitions.)
- R. G. ALBRIDGE, J. M. Hollander, C. J. Gallagher, J .H. Hamilton. Nucl. Phys. 27 (1961) 529
  (Gamma-ray energies and multipolarities, E2 admixtures.)
- G. SCHULTZE, J. Ahlf. Nucl. Phys. 30 (1962) 163
  (Multipolarities, E2 admixtures.)
- S. Bjørnholm, M. Lederer, F. Asaro, I. Perlman. Phys. Rev. 130 (1963) 2000
  (Energies and probabilities of beta-transitions.)
- K. M. Bisgard, P. Dahl, P. Hornshoj, A. B. Knutsen. Nucl. Phys. 41 (1963) 21
  (Multipolarities, E2 admixtures.)
- M. J. ZENDER. Thesis, Vanderbilt Univ. (1966)
  (Multipolarities, E2 admixtures.)
- C. BRIANCON, C.- F. Leang, P. Paris. Compt. Rend. 264B (1967) 1522
  (Gamma-ray energies.)
- S. G. Malmskog, M. Hojeberg. Ark. Fys. 35 (1968) 197
  (Gamma-ray energies.)
- Z. T. von Egidy, O. W. B. Schult, W. Kallinger, D. Breitig, R. P. Sharma, H. R. Koch, H. A. Baader. Naturforsch. 26a (1971) 1092
  (Gamma-ray energies.)
- M. de Bruin, P. J. M. Korthoven. J. Radioanal. Chem. 10 (1972) 125
  (Gamma-ray energies.)
- T. Valkeapaa, A. Siivola, G. Graeffe. Phys. Fenn. 9 (1973) 43
  (Gamma-ray energies and emission probabilities.)

- W. P. Poenitz, D. I. Smith. United States Dept. of Energy, Washington D. C., Rep. ANL/NDM-42 (March 1978) (1978)
  (Gamma-ray emission probabilities.)
- R. J. Gehrke, R. G. Helmer, C. W. Reich. Nucl. Sci. Eng. 70 (1979) 298
  (X- and gamma-ray emission probabilities.)
- R. Vaninbroukx, G. Bortels, B. Denecke. Int.J.Appl.Radiat.Isotop. 35 (1984) 905
  (X- and gamma-ray emission probabilities.)
- M. J. de Bettencourt. Thesis, Univ. Paris-Sud (Orsay) (1985)
  (Tentative gamma-rays.)
- K. S. Krane. Nucl. Phys. A459 (1986) 1
  (Multipolarities, E2 admixtures.)
- R. T. Jones, J. S. Merritt, A. Okazaki. Nucl. Sci. Eng. 93 (1986) 171
  (Half-life.)
- S. A. Woods, P. Christmas, P. Cross, S. M. Judge, W. Gelletly. Nucl. Instrum. Meth. Phys. Res. A264 (1988) 333
  (Gamma-ray energies.)
- E. Browne, B. Sur, E. B. Norman. Nucl. Phys. A501 (1989) 477
  (Experimental ICC, gamma multipolarities, beta transition probabilities.)
- Y. A. Akovali. Nucl. Data Sheets 59 (1990) 263
  (A=233 NDS evaluation, gamma-ray multipolarities, E2 admixtures.)
- M. C. Kouassi, C. Ardisson-Marsol, G. Ardisson. J. Phys. (London) G16 (1990) 1881
  (Level scheme, multipolarities, absolute KX-ray emission probability and gamma-ray energies.)
- J. Pearcey, S. A. Woods, P. Christmas. Nucl. Instrum. Meth. Phys. Res. A294 (1990) 516
  (E2 gamma-ray admixtures.)
- M. U. Rajput, T. D. Mac Mahon. Nucl. Instrum. Meth. Phys. Res. A312 (1992) 298
  (Evaluation technique.)
- Yu. S. Popov, G. A. Timofeev. Radiokhimiya (in Russian) 41 (1999) 27
  (Half-life.)
- K. Usman, T. D. MacMahon. Appl. Radiat. Isot. 52 (2000) 475
  (Half-life.)
- S. A. Woods, D. H. Woods, P. de Lavison, S. M. Jerome, J. L. Makepeace, M. J. Woods, L. J. Husband, S. Lineham. Appl. Radiat. Isot. 52 (2000) 475
  (Gamma-ray emission probabilities.)
- V. P. Chechev, A. G. Egorov. Appl. Radiat. Isot. 52 (2000) 601
  (Evaluation technique.)
- D. Smith, M. I. Woods, D. H. Woods. Preliminary Report, NPL, Teddington, 2000 (2000)
  (Gamma-ray and X-ray emission probabilities.)
- U. SCHöTZIG, E. Schönfeld, H.Janssen. Appl. Radiat. Isot. 52 (2000) 883
  (Gamma-ray and X-ray emission probabilities.)
- A. Luca, M. Etcheverry, J. Morel. Appl. Radiat. Isot. 52 (2000) 481
  (Gamma-ray emission probabilities.)
- A. Luca, S. Sepman, K. Iakovlev, G. Shchukin, M. Etcheverry, J. Morel. Appl. Radiat. Isot. 56 (2002) 173
  (Gamma-ray and X-ray emission probabilities.)
- G. Audi, A. H. Wapstra, C. Thibault. Nucl. Phys. A729 (2003) 337
  (Q value.)
- G. Shchukin, K. Iakovlev, J. Morel. Appl. Radiat. Isot. 60 (2004) 239
  (Gamma-ray emission probabilities.)
- X. Huang, P. Liu, B. Wang. Appl. Radiat. Isot. 62 (2005) 797
  (Evaluation of 233Pa Decay Data.)
- B. Singh, J. K. Tuli. Nucl. Data Sheets 105 (2005) 109
  (A=233 NDS evaluation, 233U level energies, gamma-ray energies and multipolarities.)
- V. P. CHECHEV, N. K. Kuzmenko. Appl. Radiat. Isot. 64 (2006) 1403
  (233Pa decay data evaluation.)
- H. Harada, S. Nakamura, M. Ohta, T. Fujii, H. Yamana. J. Nucl. Sci. Technol. (Tokyo) 43 (2006) 1289
  (Gamma-ray emission probabilities.)
- T. Kibédi, T. W. Burrows, M. B. Trzhaskovskaya, P. M. Davidson, and C. W. Nestor Jr.. Nucl. Instrum. Meth. Phys. Res. A589 (2008) 202
  (Theoretical ICC.)
- D. J. DeVries, H. C. Griffin. Appl. Radiat. Isotop. 66 (2008) 1999
  (Uncertainties of LX-ray absolute emission probabilities.)


3/2 - ; 0
26,98 (2) d
0
233
Pa
91 142
β -
γ Emission intensities per 100 disintegrations
0,0011
5/2+ ; 456,114
11
25,4
15,4
3/2+ ; 415,758
30 ps
10
0,02
1/2+ ; 398,496
55 ps
9
7/2+ ; 380,43
8
25,9
5/2+ ; 340,477
52 ps
7
0,02
26,6
7/2 - ; 320,83
6
0,01
3/2+ ; 311,904
0,120 ns
5
0,12
5/2 - ; 301,94
4
5/2 - ; 298,81
3
9/2+ ; 92,16
2
0,3
7/2+ ; 40,35
0,11 ns
1
6,3
5/2+ ; 0
159,2 (2) x10^3 a
0
233
U
92 141
Q - = 570,1 keV
% β - = 100