Adopted Levels, Gammas

History			
Type	Author	Citation	Literature Cutoff Date
Full Evaluation	Balraj Singh, Jagdish K. Tuli, and Edgardo Browne	NDS 185, 560 (2022)	31-Aug-2022

Q(β^-)=2454 *17*; S(n)=4371 *15*; S(p)=8559 *13*; Q(α)=2906 *18* 2021Wa16
S(2n)=10488 *19*, S(2p)=15724 *17* (2021Wa16).

1985Hi02: ^{231}Fr produced in spallation reaction of ^{238}U induced by 600 MeV protons from the CERN synchrocyclotron, followed by mass-separation using the ISOLDE II online separator. Measured Eγ and half-life of the decay of ^{231}Ra.

2001Fr05: ^{231}Fr was produced by spallation of 1 GeV proton beam on uranium targets. The activity was mass-separated at CERN ISOLDE on-line separator, deposited on a magnetic tape, and then radiations were counted at two stations.

2018Ly01: radioactive beams of Radium isotopes (A=222-233) produced by impinging 1.4-GeV protons onto a thick uranium carbide (UC_x) target at the ISOLDE-CERN facility. Radium atoms diffusing out of the target were ionized by a combination of surface ionization and multistep laser resonance ionization, using the resonance ionization laser ion source (RILIS), then accelerated to 30 keV and mass separated using the high resolution separator (HRS). Finally, the ions were cooled and bunched using the ISOLDE linear Paul trap ISOLDE cooler (ISCOOL), re-accelerated to 30 keV and directed to the Collinear Resonance Ionization Spectroscopy (CRIS) beam line. Measured high-resolution hyperfine-structure spectra of the $7s^2\ ^1S^0 \rightarrow 7s7p^3P_1$ atomic transition in the neutron-rich radium isotopes from A=222 to 232, changes in rms charge radii, isotope shifts, static magnetic dipole and electric quadrupole moments.

Atomic mass measurements: 2012Ch19 (also 2008ChZI), 2010Li02, 2005He26.

2013Fr09 cite 1983Ah03 for discovery of the ^{231}Ra isotope, but there is no mention of this isotope in 1983Ah03. Evaluators consider 1985Hi02 as the first article reporting discovery of this isotope.

1938Ha01 listed ^{231}Ra with half-life of 25 min followed by decay of ^{231}Ac with a half-life of 40 min. But with presently known half-lives, these activities must belong to other activities.

Theoretical nuclear structure calculations: consult the NSR database (www.nndc.bnl.gov/nsr/) for five primary references, also listed in this dataset under 'document' records, which can be accessed through on-line ENSDF database at www.nndc.bnl.gov/ensdf/.

Additional information 1.

^{231}Ra Levels

Cross Reference (XREF) Flags

A ^{231}Fr β^- decay (17.6 s)

E(level)†	J$^\pi$	$T_{1/2}$	XREF	Comments
0.0	(5/2$^+$)	103.9 s *14*	A	%β^-=100 μ=−0.3554 *11* (2018Ly01,2019StZV) Q=+3.282 *170* (2018Ly01) μ,Q: from hyperfine structure measurements using collinear resonance laser spectroscopy. Uncertainties in Q: 0.001 statistical and 0.170 systematic, combined in quadrature. Measured value of μ=−0.3572 *8* in 2018Ly01 is re-evaluated to −0.3554 *11* in 2019StZV evaluation. Spectroscopic quadrupole moment is not listed in 2021StZZ evaluation. Measured change in rms radius: $\delta\langle r^2\rangle(^{214}Ra,^{231}Ra)$=+2.0177 fm^2 *2*(stat) *1012*(syst) (2018Ly01). Measured isotope shifts: $\delta\nu(^{214}Ra,^{231}Ra)$=−56534 MHz *4*; $\delta\nu(^{226}Ra,^{231}Ra)$=−14790 MHz *3* (2018Ly01). J$^\pi$: Nilsson orbital assignment ν5/2[622] to this level is based on the energy of the ν5/2[622] orbital in ^{233}Th. Also on the retardation of the 66-keV E2 γ ray from the 1/2$^+$, ν1/2[631] state (at 66 keV) to the 5/2$^+$, ν5/2[622] (ground state) (2001Fr05). $T_{1/2}$: weighted average of 104.1 s *14* (2006Bo33,2008Bo29) and 103 s *3* (1985Hi02). Value given in 2006Bo33 is 104.1 s *8* from γ-decay curves, where the uncertainty does not include the dispersion in experimental values about the weighted average for the 17 γ rays used. 1985Hi02 followed the decay of Ac K x-rays as well as the

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Adopted Levels, Gammas (continued)

^{231}Ra Levels (continued)

E(level)†	Jπ	$T_{1/2}$	XREF	Comments
				growth of γ rays in ^{231}Th from the decay of ^{231}Ac.
46.23 *11*	(7/2+)		A	Jπ: From analogy to ^{233}Th, where the 7/2+ member of the ν5/2[622] state is at 44.3 keV.
66.21 *9*	(1/2+)	≈53 μs	A	%IT≈100 Jπ: 66.2γ E2 to (5/2+). Nilsson orbital assignment ν1/2[631] to this level is based on the expected energy of this orbital, and on the systematics of the B(E1) ratios between γ rays from the 1/2−, ν1/2[501] state to the 1/2+ and 3/2+ members of the ν1/2[631] rotational band in several odd-A nuclei near ^{231}Ra (2001Fr05). $T_{1/2}$: from 66.2γ(t) and $K_{\alpha 2}$ x-ray(t) in β− decay. 2001Fr05 mention that the half-life is an estimate only, and has significant systematic and statistical uncertainties.
87.64 *13*	(3/2+)		A	Jπ: 3/2+ member of configuration=ν1/2[631].
95.50 *9*	(5/2−)	4.72 ns *6*	A	Jπ: 49.3γ E1 to (7/2+); 95.5γ E1 to (5/2+). Nilsson orbital assignment ν5/2[572] to this level is based on the expected energy of this orbital, and on the similarity of B(E1) ratios between γ rays from the ν5/2[752] to the 5/2+ and 7/2+ members of the ν5/2[622] rotational band in ^{231}Th and ^{229}Ra (2001Fr05). $T_{1/2}$: from βγ(t) in β− decay. Other: 4.35 ns *44* from βγγ(t) in β− decay (2001Fr05).
285.62 *16*	(5/2+)		A	Jπ: 239.4γ (M1) to (7/2+); possible 285.7γ M1 to (5/2+). Nilsson orbital assignment ν5/2[533] to this level is based on the expected energy of this orbital, and on the similarity of B(M1) ratios between γ rays from the ν5/2[633] to the 5/2+ and 7/2+ members of the ν5/2[622] rotational band in ^{233}Th (2001Fr05).
397.33 *13*	(3/2+)		A	Jπ: 309.9γ M1 to (3/2+); 331.2γ M1 to (1/2+); 397.3γ (E2(+M1)) to (5/2+). Nilsson orbital assignment ν3/2[631] to this level is based on the expected energy of this orbital, and on the similarity of B(M1) ratios between γ rays to members of the ν1/2[631] and ν5/2[622] rotational bands (2001Fr05).
455.0 *4*	(1/2− to 9/2−)		A	Jπ: 359.5γ to (5/2−).
458.95 *16*	(1/2−,3/2−)	≤15 ps	A	Jπ: M1(+E2) γ to (5/2−); possible γ to (1/2+). $T_{1/2}$: from βγγ(t) in β− decay.
503.33 *21*	(1/2,3/2,5/2+)		A	Jπ: 415.6γ to (3/2+); possible 437.4γ to (1/2+).
511.36 *15*	(1/2+,3/2+)		A	Jπ: 445.1γ M1(+E2) to (1/2+).
520.29 *14*	(1/2−)	92 ps *5*	A	Jπ: 432.6γ E1 to (3/2+); 454.0γ E1 to (1/2+). Nilsson orbital assignment ν1/2[501] to this level is based on the characteristic β− decay pattern between the ν1/2[400] (ground state in ^{231}Fr) and ν1/2[501] orbitals in several odd-A nuclei near ^{231}Ra. See also arguments for Nilsson orbital assignment to ^{231}Fr ground state (2001Fr05). $T_{1/2}$: from βγγ(t) in β− decay.
605.4 *3*	(1/2−,3/2,5/2+)		A	Jπ: 510.3γ to (5/2−); 539.1γ to (1/2+).
620.59 *24*	(3/2,5/2,7/2)	≤12.5 ps	A	Jπ: 525.2γ to (5/2−); possible 620.2γ to (5/2+). $T_{1/2}$: from βγγ(t) in β− decay.
646.6 *4*	(1/2− to 7/2)		A	Jπ: 551.3γ to (5/2−); 1127.5γ from (1/2,3/2,5/2+).
740.72 *18*	(3/2+,5/2+)		A	Jπ: 674.6γ to (1/2+); 645.2γ to (5/2−); 740.5γ to (5/2+); possible 694.4γ to (7/2+).
750.86 *18*	(1/2,3/2,5/2+)		A	Jπ: 663.1γ to (3/2+); possible 684.6γ to (1/2+).
760.5 *4*	(1/2,3/2,5/2+)		A	Jπ: 672.8γ to (3/2+); possible 694.4γ to (1/2+).
772.80 *15*	(1/2+,3/2)		A	Jπ: 252.5γ to (1/2−); 706.5γ to (1/2+); 772.8γ to (5/2+).
796.2 *3*	(1/2,3/2,5/2+)		A	Jπ: 730.0γ to (1/2+); 708.6γ to (3/2+).
834.63 *18*	(1/2+,3/2,5/2−)		A	Jπ: 314.4γ to (1/2−); 834.5γ to (5/2+).
929.2 *4*	(1/2,3/2,5/2+)		A	Jπ: 862.9γ to (1/2+).
931.9 *3*	(1/2,3/2,5/2)		A	Jπ: 472.8γ to (1/2−,3/2−); 843.5γ to (3/2+).
944.31 *22*	(1/2+,3/2,5/2+)		A	Jπ: 877.9γ to (1/2+); 944.3γ to (5/2+).

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Adopted Levels, Gammas (continued)

^{231}Ra Levels (continued)

E(level)[†]	J^π	XREF	Comments
971.1 *6*	(1/2,3/2,5/2$^+$)	A	J^π: 904.6γ to (1/2$^+$).
1138.79 *24*	(1/2,3/2,5/2$^+$)	A	J^π: 1051.4γ to (3/2$^+$); possible 1072.5γ to (1/2$^+$).
1634.1 *4*	(1/2,3/2,5/2$^+$)	A	J^π: 1567.8γ to (1/2$^+$); 1546.4γ to (3/2$^+$).
1693.3 *3*	(1/2$^+$,3/2,5/2$^+$)	A	J^π: 1627.2γ to (1/2$^+$); 1693.7γ to (5/2$^+$).
1718.2 *3*	(1/2,3/2,5/2$^+$)	A	J^π: 1651.9γ to (1/2$^+$); 1630.6γ to (3/2$^+$).
1730.1 *4*	(1/2,3/2,5/2$^+$)	A	J^π: 1663.8γ to (1/2$^+$); 1642.5γ to (3/2$^+$).
1773.90 *25*	(1/2,3/2,5/2$^+$)	A	J^π: 1707.6γ to (1/2$^+$); 1686.1γ to (3/2$^+$).

[†] From ^{231}Fr β^- decay.

Adopted Levels, Gammas (continued)

γ(^{231}Ra)

E_i(level)	J_i^π	E_γ[†]	I_γ[†]	E_f	J_f^π	Mult.[†]	δ[†]	α[&]	Comments
46.23	(7/2$^+$)	46.3[b] *2*	100	0.0	(5/2$^+$)	[M1]		29.5 *6*	
66.21	(1/2$^+$)	66.2 *1*	100	0.0	(5/2$^+$)	E2		67.4 *10*	B(E2)(W.u.)≈0.0015 δ(E2/M1)>2 or 12.9 *12*; ΔJ^π consistent with pure E2.
87.64	(3/2$^+$)	(21.4)		66.21	(1/2$^+$)	[M1]		286 *4*	E_γ: γ ray was not observed. Iγ given in ^{231}Fr β^- decay is an upper limit.
95.50	(5/2$^-$)	49.3 *1*	5.1 *3*	46.23	(7/2$^+$)	E1		0.727 *10*	B(E1)(W.u.)=1.34×10^{-5} *13*
		95.5 *1*	100 *7*	0.0	(5/2$^+$)	E1		0.1247 *18*	B(E1)(W.u.)=3.60×10^{-5} *6*
285.62	(5/2$^+$)	239.4[a] *3*	<19[a]	46.23	(7/2$^+$)	(M1)		1.324 *19*	δ(E2/M1)<0.45 for a doubly placed γ ray.
		285.7[b] *2*	100 *9*	0.0	(5/2$^+$)	M1		0.811 *12*	δ(E2/M1)<0.4.
397.33	(3/2$^+$)	309.9 *2*	100 *10*	87.64	(3/2$^+$)	M1		0.648 *9*	δ(E2/M1)<0.35.
		331.2 *2*	88 *12*	66.21	(1/2$^+$)	M1		0.540 *8*	δ(E2/M1)<0.55.
		397.3 *3*	37 *4*	0.0	(5/2$^+$)	(E2(+M1))	>0.7	0.24 *18*	
455.0	(1/2$^-$ to 9/2$^-$)	359.5 *3*	100	95.50	(5/2$^-$)				
458.95	(1/2$^-$,3/2$^-$)	363.4 *2*	100 *10*	95.50	(5/2$^-$)	M1(+E2)	0.7 *7*	0.31 *11*	
		392.8[#b] *3*	26 *10*	66.21	(1/2$^+$)				
503.33	(1/2,3/2,5/2$^+$)	415.6 *3*	100 *12*	87.64	(3/2$^+$)				
		437.4[a] *3*	<43[a]	66.21	(1/2$^+$)				
511.36	(1/2$^+$,3/2$^+$)	423.8[‡b] *2*	18 *5*	87.64	(3/2$^+$)				
		445.1 *2*	100 *10*	66.21	(1/2$^+$)	M1+E2	0.45 *30*	0.21 *4*	
520.29	(1/2$^-$)	123.1 *2*	0.70 *10*	397.33	(3/2$^+$)	E1		0.291 *4*	B(E1)(W.u.)=4.1×10^{-6} *6*
		432.6 *2*	100 *5*	87.64	(3/2$^+$)	E1		0.01588 *22*	B(E1)(W.u.)=1.33×10^{-5} *9*
		454.0 *2*	78 *5*	66.21	(1/2$^+$)	E1		0.01437 *20*	B(E1)(W.u.)=9.0×10^{-6} *6*
605.4	(1/2$^-$,3/2,5/2$^+$)	510.3 *5*	33 *7*	95.50	(5/2$^-$)				
		539.1 *3*	100 *21*	66.21	(1/2$^+$)				
620.59	(3/2,5/2,7/2)	525.2 *3*	100 *10*	95.50	(5/2$^-$)				
		620.2[b] *5*	16.5 *22*	0.0	(5/2$^+$)				
646.6	(1/2$^-$ to 7/2)	551.3 *4*	100	95.50	(5/2$^-$)				
740.72	(3/2$^+$,5/2$^+$)	645.2 *3*	33 *17*	95.50	(5/2$^-$)				
		653.2 *3*	37 *10*	87.64	(3/2$^+$)				
		674.6[#] *5*	100 *10*	66.21	(1/2$^+$)				
		694.4[a] *4*	<43[a]	46.23	(7/2$^+$)				
		740.5 *5*	17 *5*	0.0	(5/2$^+$)				
750.86	(1/2,3/2,5/2,5/2$^+$)	239.4[ab] *3*	<18[a]	511.36	(1/2$^+$,3/2$^+$)	(M1)			δ(E2/M1)<0.45 for a doubly placed γ ray.
		353.6 *3*	13 *5*	397.33	(3/2$^+$)				
		663.1 *3*	100 *10*	87.64	(3/2$^+$)				
		684.6[a] *5*	<45[a]	66.21	(1/2$^+$)				
760.5	(1/2,3/2,5/2,5/2$^+$)	672.8[#] *5*	100 *24*	87.64	(3/2$^+$)				
		694.4[a] *4*	<164[a]	66.21	(1/2$^+$)				
772.80	(1/2$^+$,3/2)	252.5 *2*	38 *8*	520.29	(1/2$^-$)				

$^{231}_{88}Ra_{143}$-4

Adopted Levels, Gammas (continued)

γ(^{231}Ra) (continued)

E_i(level)	J_i^π	E_γ[†]	I_γ[†]	E_f	J_f^π
772.80	(1/2$^+$,3/2)	261.6 *3*	29 *6*	511.36	(1/2$^+$,3/2$^+$)
		375.7[a] *3*	<40[a]	397.33	(3/2$^+$)
		684.6[a] *5*	<135[a]	87.64	(3/2$^+$)
		706.5[@] *5*	100 *10*	66.21	(1/2$^+$)
		772.8[#] *3*	90 *10*	0.0	(5/2$^+$)
796.2	(1/2,3/2,5/2$^+$)	708.6[@] *5*	42 *6*	87.64	(3/2$^+$)
		730.0[#] *3*	100 *19*	66.21	(1/2$^+$)
834.63	(1/2$^+$,3/2,5/2$^-$)	314.4 *3*	24 *8*	520.29	(1/2$^-$)
		375.7[a] *3*	<40[a]	458.95	(1/2$^-$,3/2$^-$)
		437.4[a] *3*	<56[a]	397.33	(3/2$^+$)
		746.9 *4*	100 *20*	87.64	(3/2$^+$)
		834.5 *6*	65 *10*	0.0	(5/2$^+$)
929.2	(1/2,3/2,5/2$^+$)	841.4[a] *6*	<64[a]	87.64	(3/2$^+$)
		862.9 *6*	100 *14*	66.21	(1/2$^+$)
931.9	(1/2,3/2,5/2)	428.8[‡b] *3*	42 *17*	503.33	(1/2,3/2,5/2$^+$)
		472.8 *5*	100 *25*	458.95	(1/2$^-$,3/2$^-$)
		843.5[#] *5*	67 *17*	87.64	(3/2$^+$)
944.31	(1/2$^+$,3/2,5/2$^+$)	659.0[b] *5*	53 *11*	285.62	(5/2$^+$)
		877.9 *4*	37 *16*	66.21	(1/2$^+$)
		944.3 *3*	100 *16*	0.0	(5/2$^+$)
971.1	(1/2,3/2,5/2$^+$)	883.6[a] *6*	<102[a]	87.64	(3/2$^+$)
		904.6 *10*	100 *25*	66.21	(1/2$^+$)
1138.79	(1/2,3/2,5/2$^+$)	387.7 *3*	42 *9*	750.86	(1/2,3/2,5/2$^+$)
		1051.4 *3*	100 *23*	87.64	(3/2$^+$)
		1072.5[a] *6*	<77[a]	66.21	(1/2$^+$)
1634.1	(1/2,3/2,5/2$^+$)	704.8[@] *5*	100 *13*	929.2	(1/2,3/2,5/2$^+$)
		883.6[a] *6*	<37[a]	750.86	(1/2,3/2,5/2$^+$)
		1546.4 *6*	73 *27*	87.64	(3/2$^+$)
		1567.8 *6*	53 *20*	66.21	(1/2$^+$)
1693.3	(1/2$^+$,3/2,5/2$^+$)	1072.5[a] *6*	<30[a]	620.59	(3/2,5/2,7/2)
		1408.0[#b] *6*	30 *6*	285.62	(5/2$^+$)
		1605.5 *4*	100 *12*	87.64	(3/2$^+$)
		1627.2 *6*	33 *9*	66.21	(1/2$^+$)
		1693.7 *8*	52 *15*	0.0	(5/2$^+$)
1718.2	(1/2,3/2,5/2$^+$)	883.6[a] *6*	<29[a]	834.63	(1/2$^+$,3/2,5/2$^-$)
		1097.8 *6*	37 *11*	620.59	(3/2,5/2,7/2)
		1630.6 *5*	100 *16*	87.64	(3/2$^+$)
		1651.9[#] *6*	26 *11*	66.21	(1/2$^+$)
1730.1	(1/2,3/2,5/2$^+$)	1642.5 *5*	100 *10*	87.64	(3/2$^+$)
		1663.8 *5*	41 *8*	66.21	(1/2$^+$)

$^{231}_{88}Ra_{143}$-5

Adopted Levels, Gammas (continued)

$\gamma(^{231}Ra)$ (continued)

E_i(level)	J_i^π	E_γ †	I_γ †	E_f	J_f^π
1773.90	(1/2,3/2,5/2$^+$)	841.4[a] *6*	<24[a]	931.9	(1/2,3/2,5/2)
		939.8 *7*	19 *4*	834.63	(1/2$^+$,3/2,5/2$^-$)
		1001.7 *6*	32 *26*	772.80	(1/2$^+$,3/2)
		1127.5# *5*	24 *5*	646.6	(1/2$^-$ to 7/2)
1773.90	(1/2,3/2,5/2$^+$)	1376.1 *6*	24 *5*	397.33	(3/2$^+$)
		1686.1# *5*	100 *13*	87.64	(3/2$^+$)
		1707.6 *7*	26 *11*	66.21	(1/2$^+$)

† From ^{231}Fr β^- decay (2001Fr05).
‡ Tentatively assigned to ^{231}Ra.
# Possible doublet.
@ Possible multiplet.
& Total theoretical internal conversion coefficients, calculated using the BrIcc code (2008Ki07) with Frozen orbital approximation based on γ-ray energies, assigned multipolarities, and mixing ratios, unless otherwise specified.
[a] Multiply placed with undivided intensity.
[b] Placement of transition in the level scheme is uncertain.

$^{231}_{88}Ra_{143}$-6

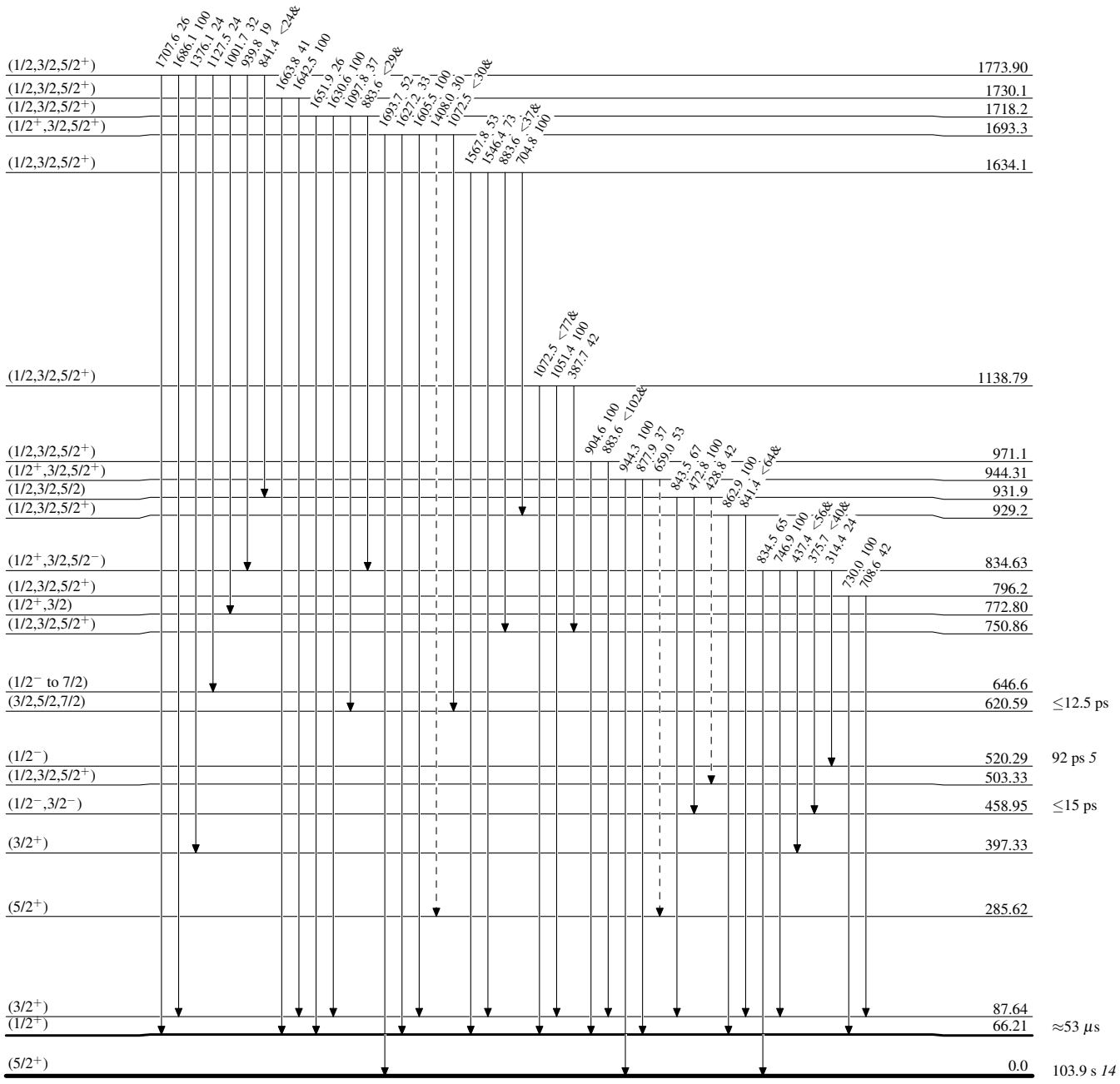
Adopted Levels, Gammas

Legend

Level Scheme

Intensities: Relative photon branching from each level
& Multiply placed: undivided intensity given

- - - - - - ► γ Decay (Uncertain)



$^{231}_{88}Ra_{143}$

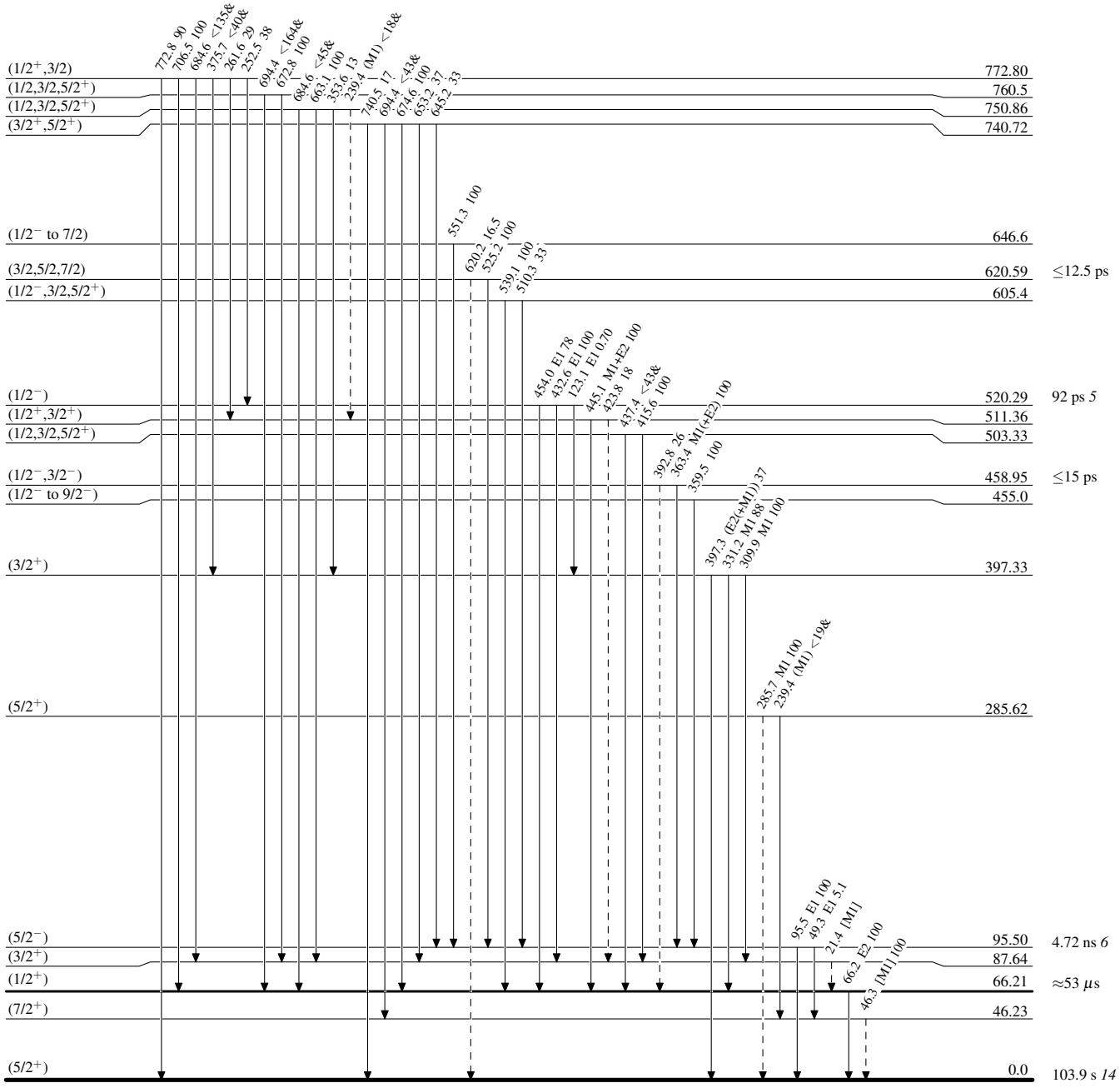
Adopted Levels, Gammas

Legend

Level Scheme (continued)

Intensities: Relative photon branching from each level
& Multiply placed: undivided intensity given

- - - - - - ► γ Decay (Uncertain)



$^{231}_{88}Ra_{143}$