^{235}U(n,Fγ),^{241}Pu(n,Fγ) 2012Mu08,2017Ur03,2017An15

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	Jun Chen, Balraj Singh	NDS 164, 1 (2020)	15-Feb-2020

Includes ^{232}Th(^{18}O,F), ^{238}U(^{7}Li,F), ^{238}U(n,F), ^{239}Pu(n,F). Most data are from ^{235}U(n,Fγ) in 2012Mu08.

2012Mu08: ^{235}U(n,Fγ) E=thermal neutrons from the CIRUS reactor facility at BARC. Target was ≈5.1 gm/cm^3 UAl_3 (17% enriched ^{235}U). γ rays were detected by two clover HPGe detectors equipped with anti-Compton shields, in coincidence mode. Measured Eγ, Iγ, $\gamma\gamma$-coin. Deduced levels, isotopic yield, angular momentum distribution.

2017Ur03: ^{235}U(n,Fγ): measured $\gamma\gamma(\theta)$ and $\gamma\gamma$(linear polarization) using PF1b cold-neutron facility at ILL-Grenoble reactor. For gamma detection, EXILL array containing eight large EXOGAM clover HPGe detectors were used. Deduced spins, parities, and multipolarities. Information about Eγ and Iγ values from this work is not available.

2017An15: ^{235}U(n,Fγ) and ^{241}Pu(n,Fγ): prompt-fission spectroscopy using incident neutrons from the PF1B cold neutron beam at the Institut Laue-Langevin (ILL) Grenoble. Measured Eγ, $\gamma\gamma$-coin, lifetimes of the first 2$^+$ and 4$^+$ levels by fast-timing technique using the EXILL-FATIMA array consisting of eight EXOGAM clovers and 16 $LaBr_3$(Ce) scintillators. Deduced B(E2) and compared with Interacting Boson model and Monte-Carlo shell-model calculations.

Others:

1998Ph04: ^{238}U(n,F) E=1.5-3.5 MeV. Measured yield.

1995GuZY: ^{239}Pu(n,F). Measured prompt γ.

1989AbZW, 1992PHZZ: ^{232}Th(^{18}O,F) and ^{238}U(^{7}Li,F). Measured $\gamma\gamma$-coin, $\gamma\gamma\gamma$-coin, yrast band observed up to 10$^+$.

1988FiZV: ^{235}U(n,F) and ^{238}U(n,F). Measured prompt γ rays.

1976Po11: ^{235}U(n,Fγ) E=thermal. Measured ce, ce(t).

1973Kh05: measured ce.

1971Fo21: measured ce, yields.

Yield data per 100 fissions: 2.3 *4* in ^{235}U(n,F) (1988FiZV), 0.8 in ^{235}U(n,F) (1971Fo21), 0.3 in ^{252}Cf(SF) (1970ChYJ).

^{98}Zr Levels

E(level)†	J$^{\pi}$#	T$_{1/2}$	Comments
0.0@	0$^+$		
854.0 *10*	0$^+$	65 ns *10*	T$_{1/2}$: from ce(t) (1976Po11).
1223.0@ *10*	2$^+$	≤4 ps	T$_{1/2}$: from fast-timing $\gamma\gamma$-coin technique, and analysis by generalized centroid difference method (GCDM) (2017An15); mean lifetime τ≤6 ps from τ≤10 ps in ^{241}Pu(n,Fγ), ≤6 ps in ^{235}U(n,Fγ). Due to the uncertainties in prompt response differences (PRD) and Compton background corrections in both the reactions, the lifetime of the first 2$^+$ state could not be determined precisely. This value can be compared with τ≤15 ps in 2010Be30.
1436.16‡ *7*	0$^+$		J$^{\pi}$: $\gamma\gamma(\theta)$ (2017Ur03).
1590.78‡ *6*	2$^+$		
1744.61‡ *6*	2$^+$		
1806.0 *13*	3$^-$		
1843.0& *15*	4$^+$	≤10 ps	T$_{1/2}$: from fast-timing $\gamma\gamma$-coin technique, and analysis by generalized centroid difference method (GCDM) (2017An15); mean lifetime τ≤15 ps from mean lifetime τ≤20 ps in ^{241}Pu(n,Fγ), and ≤15 ps in ^{235}U(n,Fγ). Due to the imprecise lifetime of the first 2$^+$ state, lifetime of the first 4$^+$ state could not be determined precisely. This value can be compared with τ=29 ps *8* in 2010Be30.
1859.37‡ *7*	0$^+$		J$^{\pi}$: $\gamma\gamma(\theta)$ (2017Ur03).
2048.0@ *13*	4$^+$		
2276.98‡ *9*	(4$^+$)		
2490.0& *18*	6$^+$		
3064.0 *18*	5$^{(-)}$		
3215.0& *20*	8$^+$		
3984.0& *23*	(10$^+$)		

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^{235}U(n,Fγ),^{241}Pu(n,Fγ) 2012Mu08,2017Ur03,2017An15 (continued)

^{98}Zr Levels (continued)

E(level)†	J$^\pi$#	Comments
4165.18‡ *6*	1$^-$	
4271.11‡ *6*	1$^-$	
4292.46‡ *11*	6$^+$	J$^\pi$: from $\gamma\gamma(\theta)$ (2017Ur03).
4452.58‡ *9*	1$^-$	
4821.0?& *25*	(12$^+$)	Level questioned by the evaluators due to misplacement of 837γ, and not listed in the Adopted dataset. J$^\pi$: from 2012Mu08.

† From least-squares fit to Eγ values, assuming 1 keV uncertainty for each γ ray.
‡ Population of this level implied from $\gamma\gamma(\theta)$ study by 2017Ur03 using ^{235}U(n,Fγ) reaction.
# From Adopted Levels, unless otherwise stated.
@ Seq.(B): γ cascade based on g.s.
& Band(A): Band based on 4$^+$.

γ(^{98}Zr)

E$_\gamma$†	I$_\gamma$†	E$_i$(level)	J$^\pi_i$	E$_f$	J$^\pi_f$	Mult.	δ	α‡	Comments
213.2 *1*		1436.16	0$^+$	1223.0	2$^+$	E2		0.0716	E$_\gamma$: from 2017Ur03 (in ^{98}Y decay). Mult.: from $\gamma\gamma(\theta)$ (2017Ur03) in ^{235}U(n,Fγ) reaction; (213.2γ)(1222.9γ)(θ): A$_2$=+0.356 *23*, A$_4$=+1.152 *48* consistent with 0 → 2 → 0 sequence.
242		2048.0	4$^+$	1806.0	3$^-$				
268.7 *1*		1859.37	0$^+$	1590.78	2$^+$	E2			Mult.: from (269γ)(1591γ)(θ): A$_2$=+0.340 *25*, A$_4$=+1.169 *48* (2017Ur03) consistent with 0 → 2 → 0 sequence.
521.6 *1*		1744.61	2$^+$	1223.0	2$^+$	(M1+E2)	+0.44 *4*		E$_\gamma$: from 2017Ur03 (in ^{98}Y decay). Mult.,δ: from (521.6γ)(1222.9γ)(θ): A$_2$=−0.073 *21*, A$_4$=+0.016 *43* (2017Ur03) consistent with 2 → 2 → 0 sequence.
583	65 *3*	1806.0	3$^-$	1223.0	2$^+$	(E1)			Mult.: from $\gamma\gamma(\theta)$ (2017Ur03). d(Q/D)=−0.01 *2* from (583.2γ)(1222.9γ)(θ): A$_2$=−0.076 *12*, A$_4$=−0.017 *27* for J(1806)=3. δ=−0.15 *1* for J(1806)=1, and no solution for δ for J(1806)=2 (2017Ur03).
620	100 *5*	1843.0	4$^+$	1223.0	2$^+$				(620.5γ)(1222.9γ)(θ): A$_2$=+0.102 *12*, A$_4$=−0.037 *28*, consistent with 4 → 2 → 0 sequence (2017Ur03).
647	70 *4*	2490.0	6$^+$	1843.0	4$^+$				(647.1γ)(1222.9γ)(θ): A$_2$=+0.105 *10*, A$_4$=−0.069 *22*, consistent with 6 → 4 → 2 sequence (2017Ur03).
686.2 *1*		2276.98	(4$^+$)	1590.78	2$^+$	Q			(686.2γ)(1590.9γ)(θ): A$_2$=+0.13 *4*, A$_4$=+0.01 *8*, consistent with 4 → 2 → 0 sequence (2017Ur03).
725	35 *5*	3215.0	8$^+$	2490.0	6$^+$				
769	23 *3*	3984.0	(10$^+$)	3215.0	8$^+$				Note that this γ is doubly placed in Adopted Levels, Gammas, the second component from 4756, (12$^+$) level, and 837γ in 2012Mu08 should be placed from a 5590, (14$^+$) level, above the 4756 level.

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^{235}U(n,Fγ),^{241}Pu(n,Fγ) 2012Mu08,2017Ur03,2017An15 (continued)

γ(^{98}Zr) (continued)

Eγ†	Iγ†	Ei(level)	J^π_i	Ef	J^π_f	Mult.	δ	Comments
825	55 *3*	2048.0	4+	1223.0	2+			(824.8γ)(1222.9γ)(θ): A_2=+0.15 *5*, A_4=−0.11 *12*, consistent with 4 → 2 → 0 sequence (2017Ur03).
837		4821.0?	(12+)	3984.0	(10+)			Eγ: this γ should be placed from a 5590, (14+) level, as in 2006Si36, and in the Adopted dataset. See also comment for 769γ.
854		854.0	0+	0.0	0+	E0		Eγ: from 1973Kh05. Mult.: from ce data (1976Po11).
1016#		3064.0	5(−)	2048.0	4+			
1221	23 *3*	3064.0	5(−)	1843.0	4+			
1223	>220	1223.0	2+	0.0	0+	E2		
1590.9 *1*		1590.78	2+	0.0	0+	Q		Eγ: from 2017Ur03 (in ^{98}Y decay).
1801.6 *1*		4292.46	6+	2490.0	6+	M1+E2	−0.77 *12*	Mult.,δ: from γγ(θ) and linear polarization data in 2017Ur03. Preferred δ(E2/M1) value in 2017Ur03 from three possible values for J(4292)=6: −0.77 *12*, +0.17 *8* or −0.80 *14*. Mult.,δ: from (1801.6γ)(1222.9γ+620.5γ+647.1γ)(θ) and polarization data (2017Ur03); A_2=+0.160 *16*, A_4=+0.065 *36* for J(4292)=6. No solution for δ(Q/D) for J(1802)=7. But δ(E2/M1)=+0.17 *8* from γγ(θ) in SF decay preferred by 2017Ur03. POL(1801.6γ)=+0.4 *15* from (1801.6γ)(1222.9γ+620.5γ+647.1γ). δ(E2/M1)=−0.78 *9* or +0.17 *8* for J(4292)=6, δ(E2/M1)=+0.38 *6* or +2.3 *3* for J(4292)=7 (2017Ur03).
2574.4 *1*		4165.18	1−	1590.78	2+	(E1)		Mult.: from γγ(θ) and linear polarization data (2017Ur03); δ(Q/D)=−0.03 *3* from (2574.4γ)(1590.9γ)(θ): A_2=−0.213 *28*, A_4=+0.051 *56* for J(4165)=1; δ(Q/D)=+0.71 *8* for unlikely J(4165)=2, and −0.18 *4* for J(4165)=3.
2680.3 *1*		4271.11	1−	1590.78	2+	(E1)		Mult.: from γγ(θ) (2017Ur03); δ(Q/D)=−0.03 *7* from (2680.3γ)(1590.9γ)(θ): A_2=−0.28 *7*, A_4=0.00 *13*.
2942.3 *1*		4165.18	1−	1223.0	2+	E1		Mult.: from γγ(θ) and linear polarization data (2017Ur03); δ(Q/D)=−0.01 *1* from (2942.3γ)(1222.9γ)(θ): A_2=−0.24 *1*, A_4=+0.01 *1* for J(4165)=1; δ(Q/D)=−0.21 *15* for unlikely J(4165)=3, and no solution for δ for J(4165)=0, 2 and 4. POL(2942.3γ)=+0.2 *1* from (2942.3γ)(1222.9γ), δ=−0.01 *1*. (2017Ur03).
3229.8 *2*		4452.58	1−	1223.0	2+	E1		Mult.: from γγ(θ) and linear pol data (2017Ur03); δ(Q/D)=+0.03 *2* from (3229.8γ)(1222.9γ)(θ), A_2=−0.29 *2*, A_4=0.00 *5* for J(4452)=1; δ(Q/D)=−0.29 *4* for unlikely J(4452)=3. POL(3229.8γ)=+0.5 *2* from (3229.8γ)(1222.9γ), δ=+0.03 *2* for J(4452)=1, and δ=−0.29 *4* for unlikely J(4452)=3 (2017Ur03).

† From 2012Mu08. Authors mention Iγ uncertainties of 5% to 25% depending on γ-ray intensity. Evaluators assign 5% for γ rays

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^{235}U(n,Fγ),^{241}Pu(n,Fγ) 2012Mu08,2017Ur03,2017An15 (continued)

γ(^{98}Zr) (continued)

with I$\gamma \geq$50, 15% for Iγ=20-50 and 25% for Iγ<20.

‡ 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.

Placement of transition in the level scheme is uncertain.

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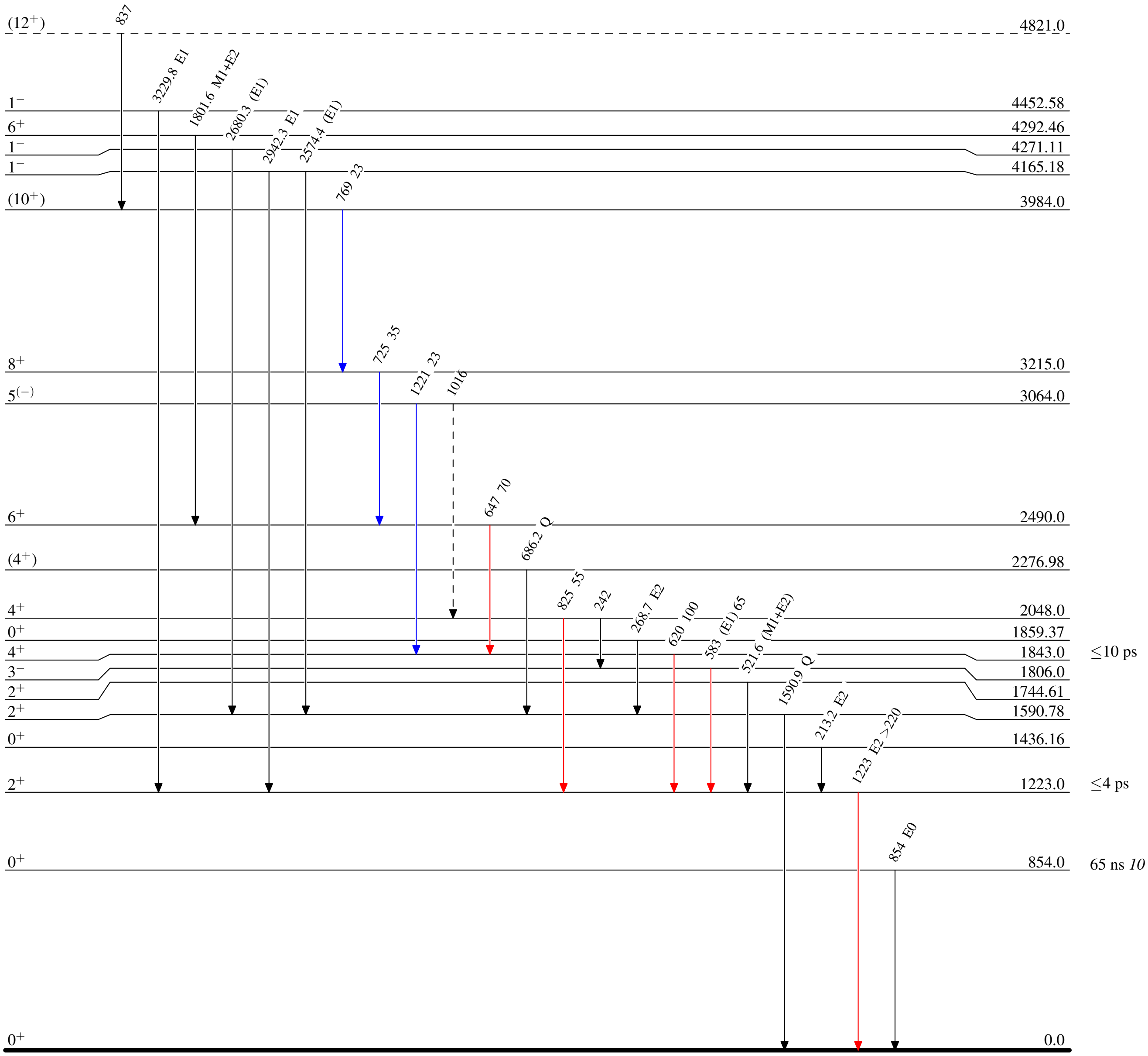
Level Scheme

Intensities: Relative I_γ

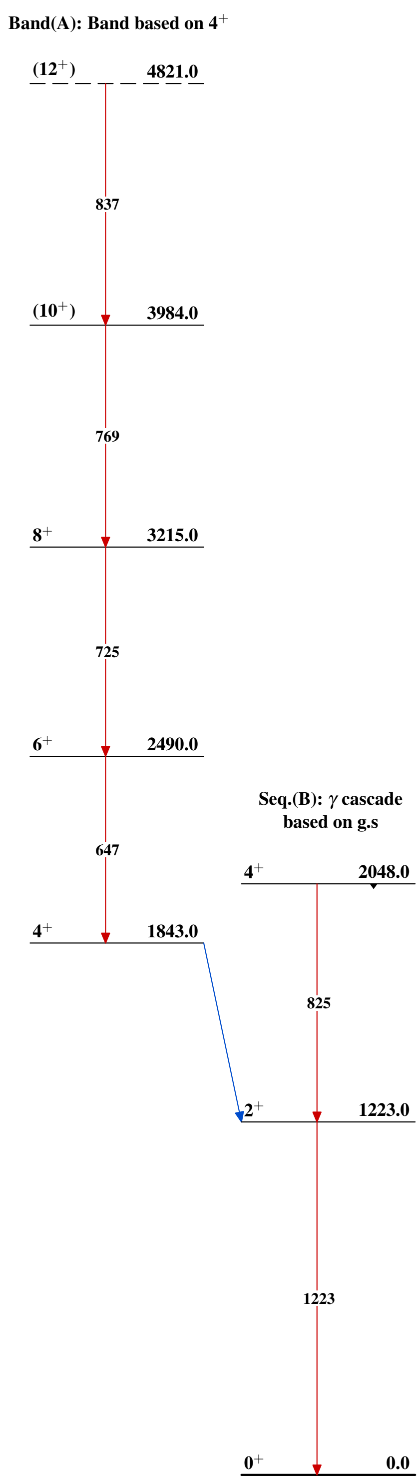
Legend

- $I_\gamma < 2\% \times I_\gamma^{max}$
- $I_\gamma < 10\% \times I_\gamma^{max}$
- $I_\gamma > 10\% \times I_\gamma^{max}$
- γ Decay (Uncertain)



$^{98}_{40}Zr_{58}$

$^{235}U(n,F\gamma)$,$^{241}Pu(n,F\gamma)$ 2012Mu08,2017Ur03,2017An15



$^{98}_{40}Zr_{58}$