Evaluation the decay data of ^{229}Th

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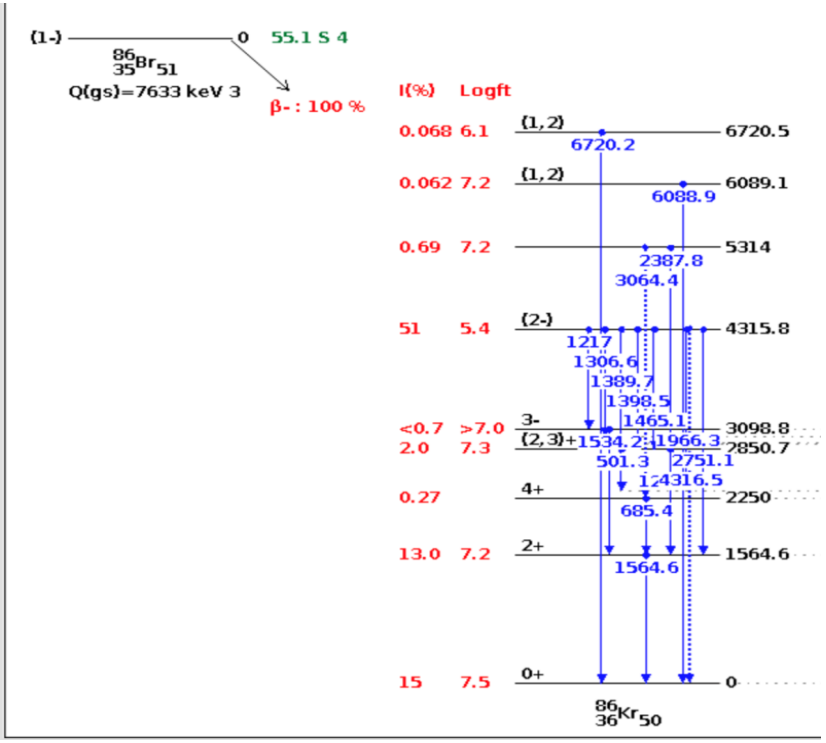
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1 General evaluation policy in DDEP

- Evaluated contents
- Evaluated method
- Data processing procedure
- Database

1 Evaluation policy in DDEP - Evaluated physical quantities

- Properties of the parent nucleus
- Gamma rays
- Decay scheme normalization
- Particles (Beta, Electron capture, Alpha)
- decay scheme
- Radiation data



1 Evaluation policy in DDEP - Evaluated physical quantities

1. Properties of the parent nucleus

- Level energy & Jπ: ENSDF
- Half-life(T1/2):
- Q-value (keV): 2021Wa16

2. Gamma rays

- **Energy:** LRSW average from radioactive decay or from level energy difference.
- **Relative intensity(Iγ):** LRSW average from radioactive decay
- **Multipolarity and mixing ratio(δ):** ENSDF
- **Internal conversion coefficients:** BRICC
- **Absolute intensities:** Calculation using Iγ and N or absolute measurements

3. Particles (β, ε, α)

- **Energy:** for β, ε, cal. by Betashape; for α, from exp. or level energy difference.
- **Absolute probability:** for β, ε, deduced from γ-ray transition intensity balance; for α, from exp. or deduced from γ-ray transition intensity balance.
- **Log*ft*:** cal. by Betashape
- **Hindrance factor (HF) :** cal. by ALPHAD

4. Radiation data

- Cal. by Emission code

1 Evaluation policy in DDEP - Evaluated method

- Find all available refs.
- All published values are examined and analysed
- Measured values may be rejected or the uncertainties adjusted
- Once this is done, data processing procedure by statistical analysis codes
- Construct the decay scheme

1 Evaluation policy in DDEP - Data processing procedure

- **Unweighted mean(UWM)**
- **Weighted mean(WM)**
- **Limitation of relative statistical weights (LRSW)**
- **Power-moderated mean(PMM mean)**

(Extend to deal with unrealistically or low uncertainty data)

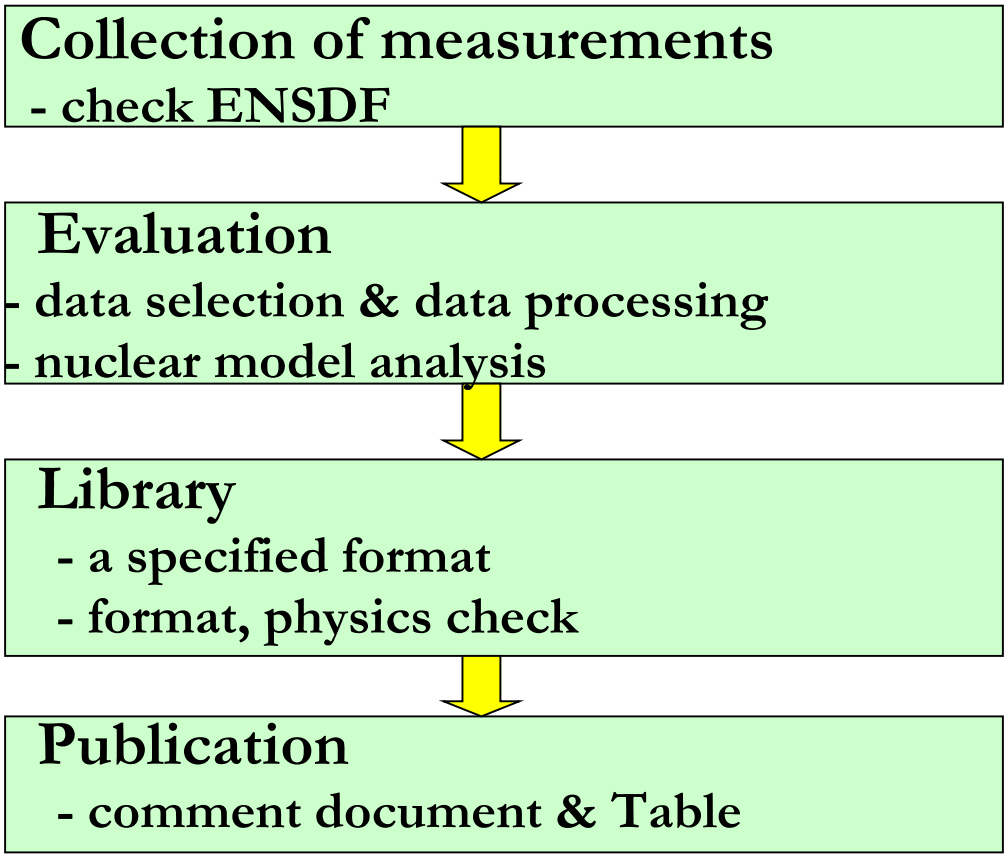
- **Avetools: combines different statistical methods to calculate averages of exp. data**

Statistical analysis codes

Estimators of mean

Estimator $x_{\mathrm{ref}} = \sum_{i=1}^{N} w_i x_i$	Normalised weight w_i	Mean x_{ref}	Associated standard uncertainty $u(x_{\mathrm{ref}})$
Arithmetic mean	$\frac{1}{N}$	$\frac{1}{N}\sum_{i=1}^{N} x_i$	$\left[\sum_{i=1}^{N} \frac{(x_i-\bar{x})^2}{N(N-1)}\right]^{1/2}$
Weighted mean	$\frac{u^2(x_{\mathrm{ref}})}{u_i^2}$	$u^2(x_{\mathrm{ref}})\sum_{i=1}^{N} \frac{x_i}{u_i^2}$	$\left[\sum_{i=1}^{N} \frac{1}{u_i^2}\right]^{-1/2}$
Mandel-Paule mean	$\frac{u^2(x_{\mathrm{ref}})}{u_i^2+s^2}$	$u^2(x_{\mathrm{ref}})\sum_{i=1}^{N} \frac{x_i}{u_i^2+s^2}$	$\left[\sum_{i=1}^{N} \frac{1}{u_i^2+s^2}\right]^{-1/2}$
PMM	$\frac{u^2(x_{\mathrm{ref}})}{\left(\sqrt{u_i^2+s^2}\right)^{\alpha} S^{2-\alpha}}$	$u^2(x_{\mathrm{ref}})\sum_{i=1}^{N} \frac{x_i}{\left(\sqrt{u_i^2+s^2}\right)^{\alpha} S^{2-\alpha}}$	$\left[\sum_{i=1}^{N} \left(\sqrt{u_i^2+s^2}\right)^{-\alpha} S^{\alpha-2}\right]^{-1/2}$

Flow of Data Evaluation



SAISINUC

2 ^{229}Th decay data evaluation – History eval.

- **ENSDF eval. in 2008 by A. K. Jain**

Decay scheme: 2000Ga52,

Eα,Pα : From 1970Ba20, 1976BaZZ and 1987He28

Eγ,Iγ : From 1970Tr04, 1987He28 and 2000Ga52

Normalization factor N: from 1986He06

- **New exp. :**

T1/2 : 2011Ki16,2014Va04,2018Es07

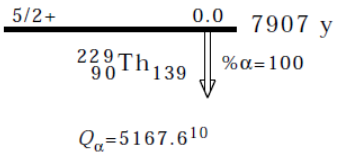
Pγ : 2020Go11,2010Fi10 for 3 γ-rays

2 ^{229}Th decay data evaluation

^{229}Th α Decay (continued)

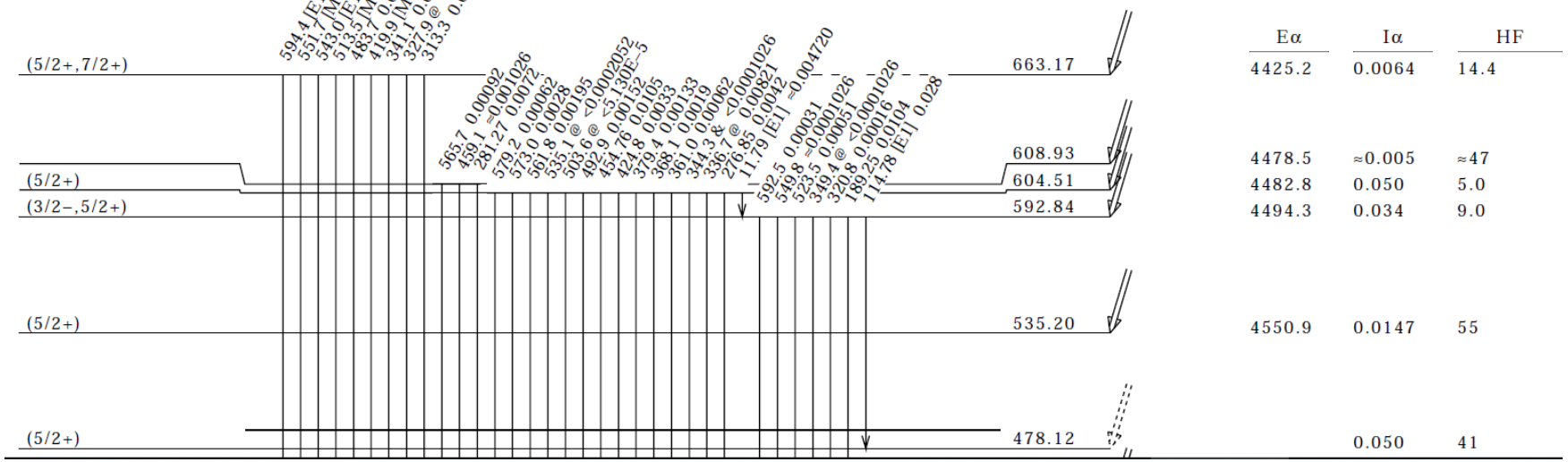
Decay Scheme

& Multiply placed; undivided intensity given
@ Multiply placed; intensity suitably divided
Intensities: I(γ+ce) per 100 parent decays



Decay scheme: based on 2000Ga52,1987He28

24 unplaced gamma rays



Eα	Iα	HF
4425.2	0.0064	14.4
4478.5	≈0.005	≈47
4482.8	0.050	5.0
4494.3	0.034	9.0
4550.9	0.0147	55
	0.050	41

2 ^{229}Th decay data evaluation

Half-life:

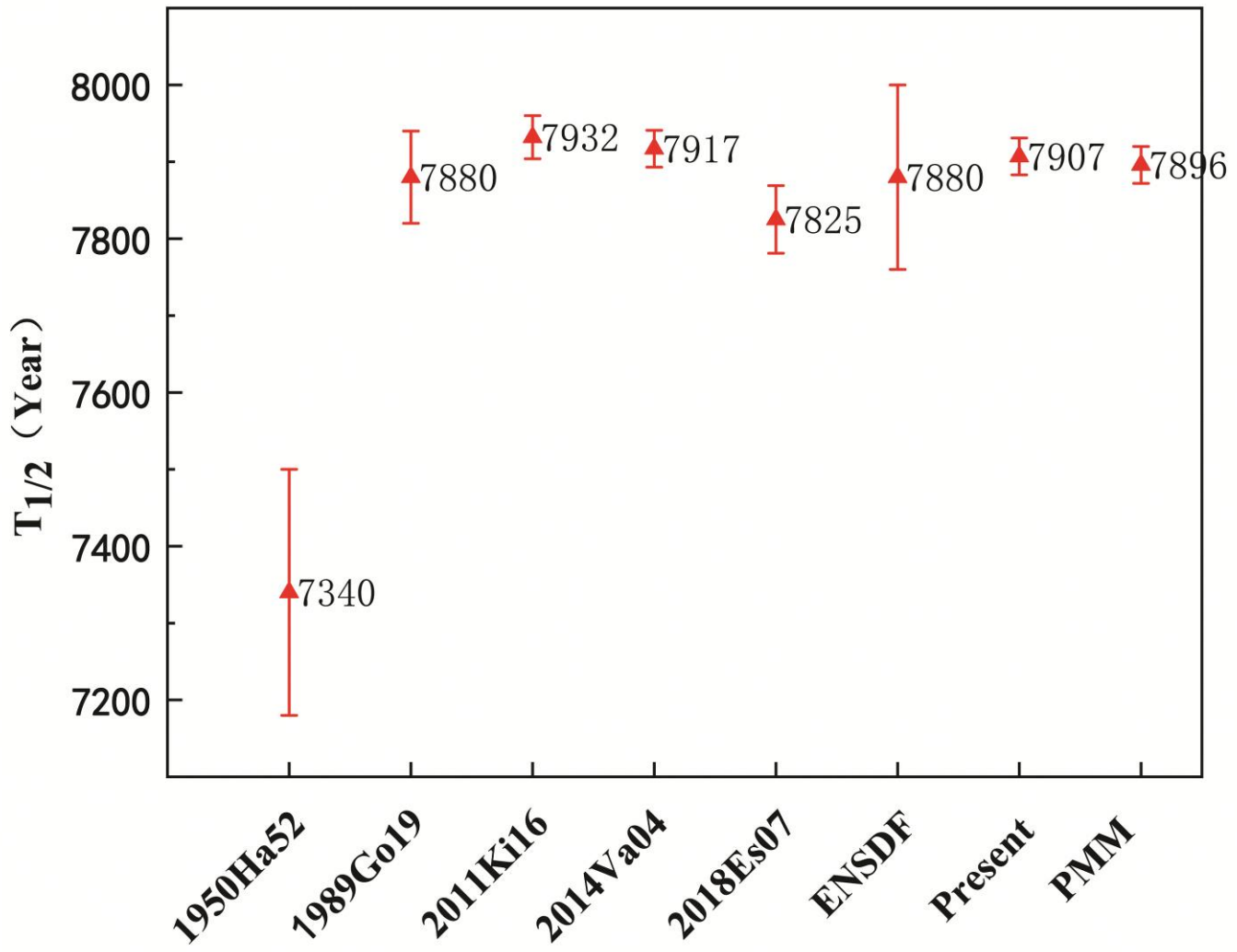
$T_{1/2}$(a)	Original	Ref.	Comments
7000		1947Ha02	no uncertainty,not used
5000		1947En03	no uncertainty,not used
7340 (160)		1950Ha52	Determined relative to $T_{1/2}$ (^{233}U), outlier
7880(60)	7880(120),k=2	1989Go19	Specific activity
7932 (28)	7932 (55),k=2	2011Ki16	Activity ratios
7917(24)	7917(48), k=2	2014Va04	Specific activity
7825(44)	7825(87), k=2	2018Es07	Specific activity
7889(24)	7889(24)		Unweighted av.
7907(int16) (ext20)		2024	LRSW av., χ2=1.55

LWM recommended weighted av. and external uncertainty:7907(20)

Adopted: 7907(24) compared NDS: 7880(120)

2 ^{229}Th decay data evaluation

Half-life:



2 ^{229}Th decay data evaluation

Eγ:

2000Ga52	1987He28	1983Ra01	1981Di14	LWM	Adopted
11.1(1)	11.1				11.1 (1)
11.79(20)					11.79 (20)
17.25(10)	17.36(3)			17.35(3)	17.35 (3)
19.08(20)					19.08 (20)×
21.60(10)	21.58(2)			21.59(2)	21.59 (2)×
	23.6				23.6
25.42(10)	25.39(2)			25.39(2)	25.39 (2)
	27.50(2)				27.50 (2)×
28.68(10)	30.3	28.50(14)		28.62(10)	28.62 (10)

Only 2000Ga52 observed γ-rays in the whole energy region. No uncertainty in 1981Di14. So recommended values are mainly from the LWM averages based on the measurements of 1983Ra01, 1987He28 and 2000Ga52 for Eγ<296keV, and from 2000Ga52 for Eγ>296keV

2 ^{229}Th decay data evaluation

Iγ:

Eγ/keV	2000Ga52	1987He28	1986He06	1983Ra01	1981Di14	LWM	Adopted
11.1 (1)		8(3)a					12.0(3)d
17.35 (3)	0.22(10)b						0.20(1)c
31.15 (7)	0.62(8)b	0.82(8)		1.02(10)	1.04(4)	0.79(11)	0.82(8)
31.52 (4)	1.86(20)	1.16(8)	2.39(6)	1.93(9)		1.65(25)f	1.65(25)f
31.57 (9)	0.022(10)b	0.066(10)					0.022(10)
75.12 (5)	0.52(5)	0.59(13)		0.48(5)		0.51(5)	0.42(5)b
136.990(4)	1.21(12)	1.15(3)	1.142(16)	1.031(21)	1.10(4)	1.09(4)	1.09(4)
193.510(5)	4.3	4.3	4.3	4.3	4.3		4.3
210.29 (5)	0.26(3)	0.19(4)	3.10(4)	0.240(38)		0.24(3)	0.24(3)
210.854(3)	2.77(12)	2.7(3)		2.815(72)	2.92(13)	2.80(8)	2.80(8)

Recommended values are mainly from the LWM averages based on the measurements of 1983Ra01, 1987He28 and 2000Ga52 for Eγ<296 keV, and from 2000Ga52 for Eγ>296 keV.

2 ^{229}Th decay data evaluation

P(γ193keV) : also normalization factor N

	2020Go11	2010Fi10	1986He06	1983Ra01	1981Di14	LWM
Pγ(%)	4.60(10)	4.62(12)	4.41(6)	3.77(8) (outlier)	5.89(30) (outlier)	4.49(7)

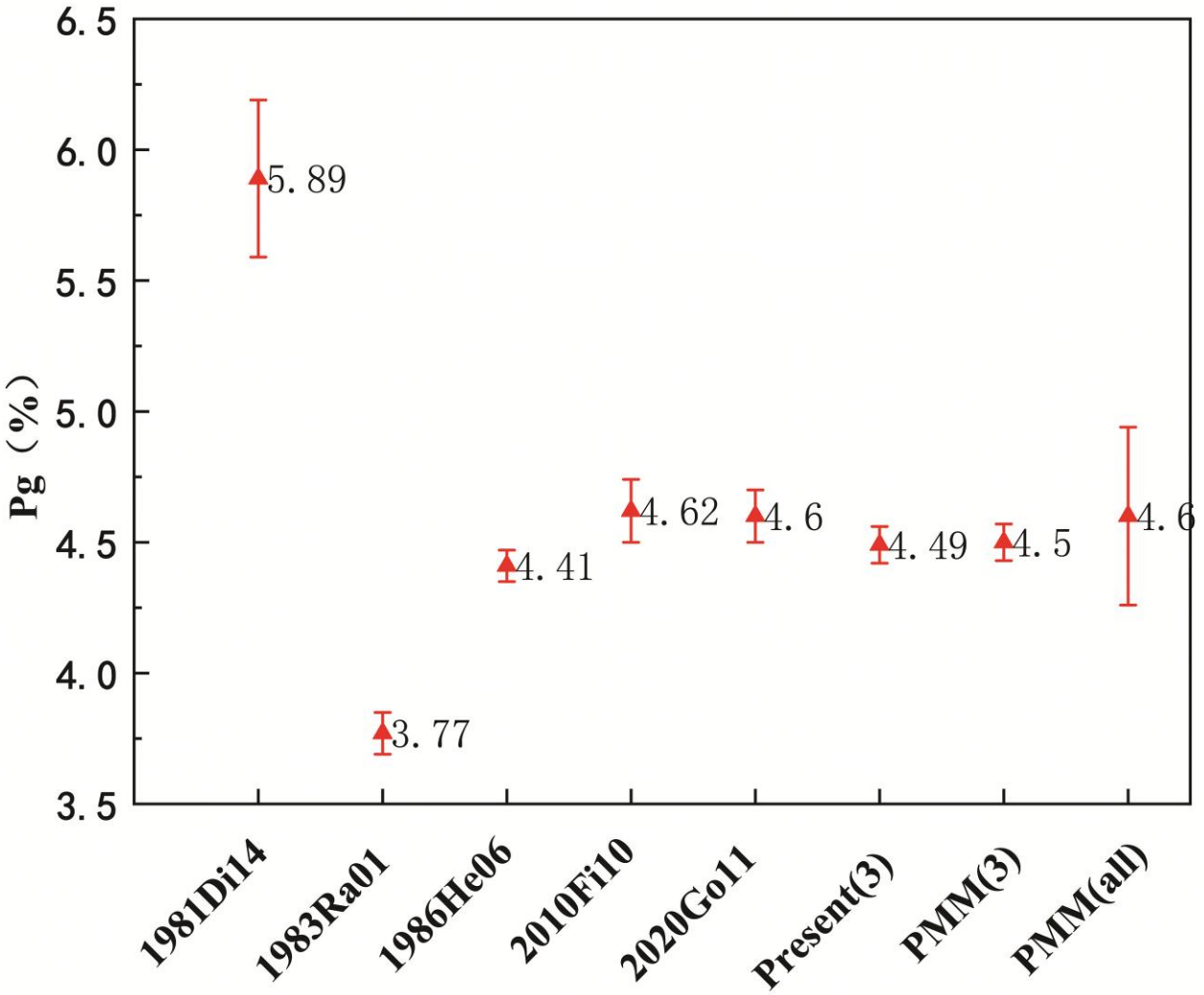
PMM (2020Go11, 2010Fi10, 1986He06): 4.50(7)
PMM(all exp.): 4.60(34)

Adopted: P(γ193keV)=4.49(7), compared NDS:4.41(6)

Normalization factor N = 1.044(16)

2 ^{229}Th decay data evaluation

P(γ193keV) :



2 ^{229}Th decay data evaluation

P(γ136.99keV) : also test

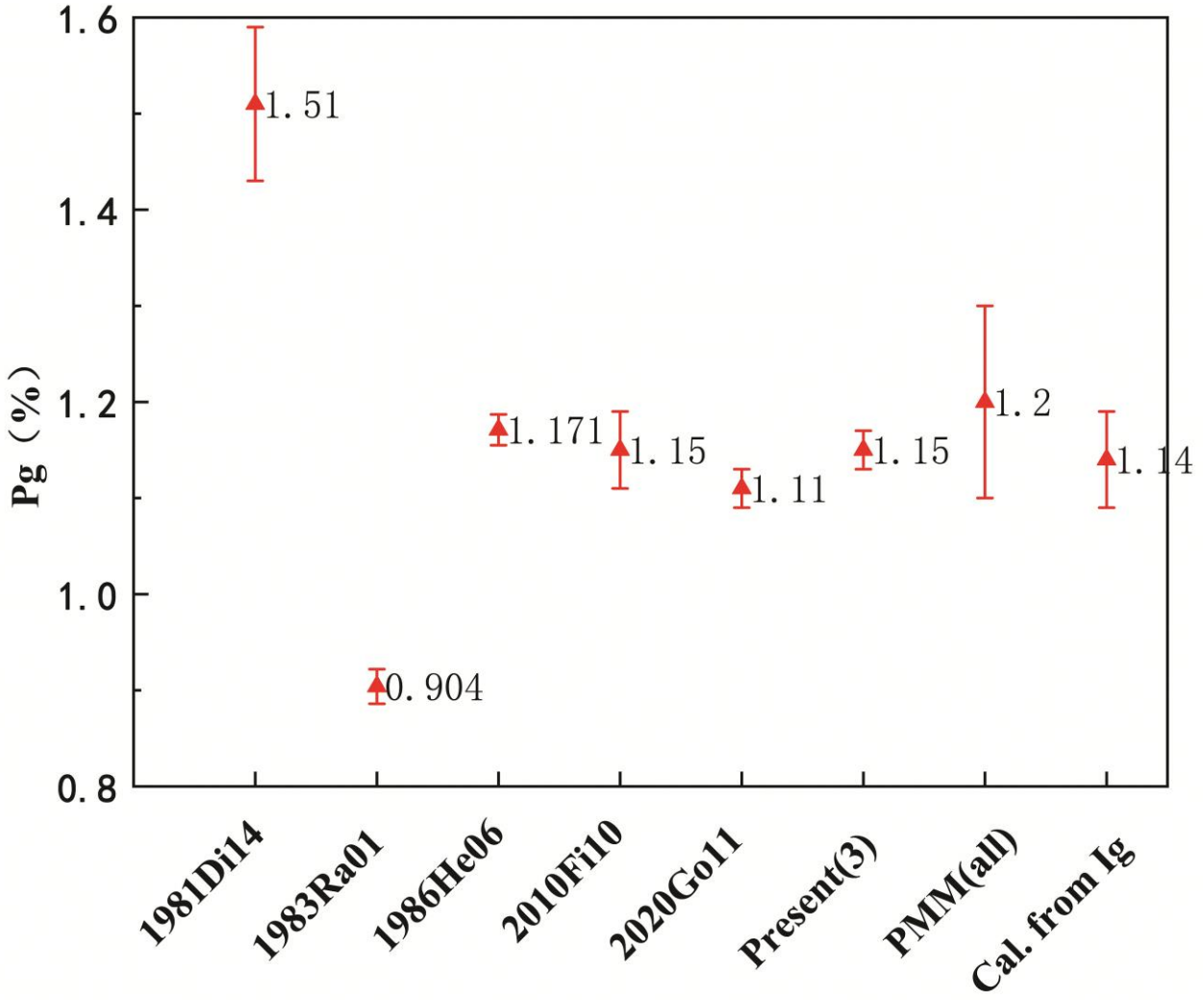
	2020Go11	2010Fi10	1986He06	1983Ra01	1981Di14	LWM	Cal. from Iγ
Pγ(%)	1.11(2)	1.15(4)	1.171(16)	0.904(18) (outlier)	1.51(8) (outlier)	1.15(2)	1.14(5)

PMM (2020Go11, 2010Fi10, 1986He06): 1.10(2)
PMM(all exp.): 1.20(10)

Adopted: P(γ136.99keV)=1.15(2), compared NDS:1.18(3)

2 ^{229}Th decay data evaluation

P(γ136.99keV)



2 ^{229}Th decay data evaluation

P(γ210.85keV) : also test

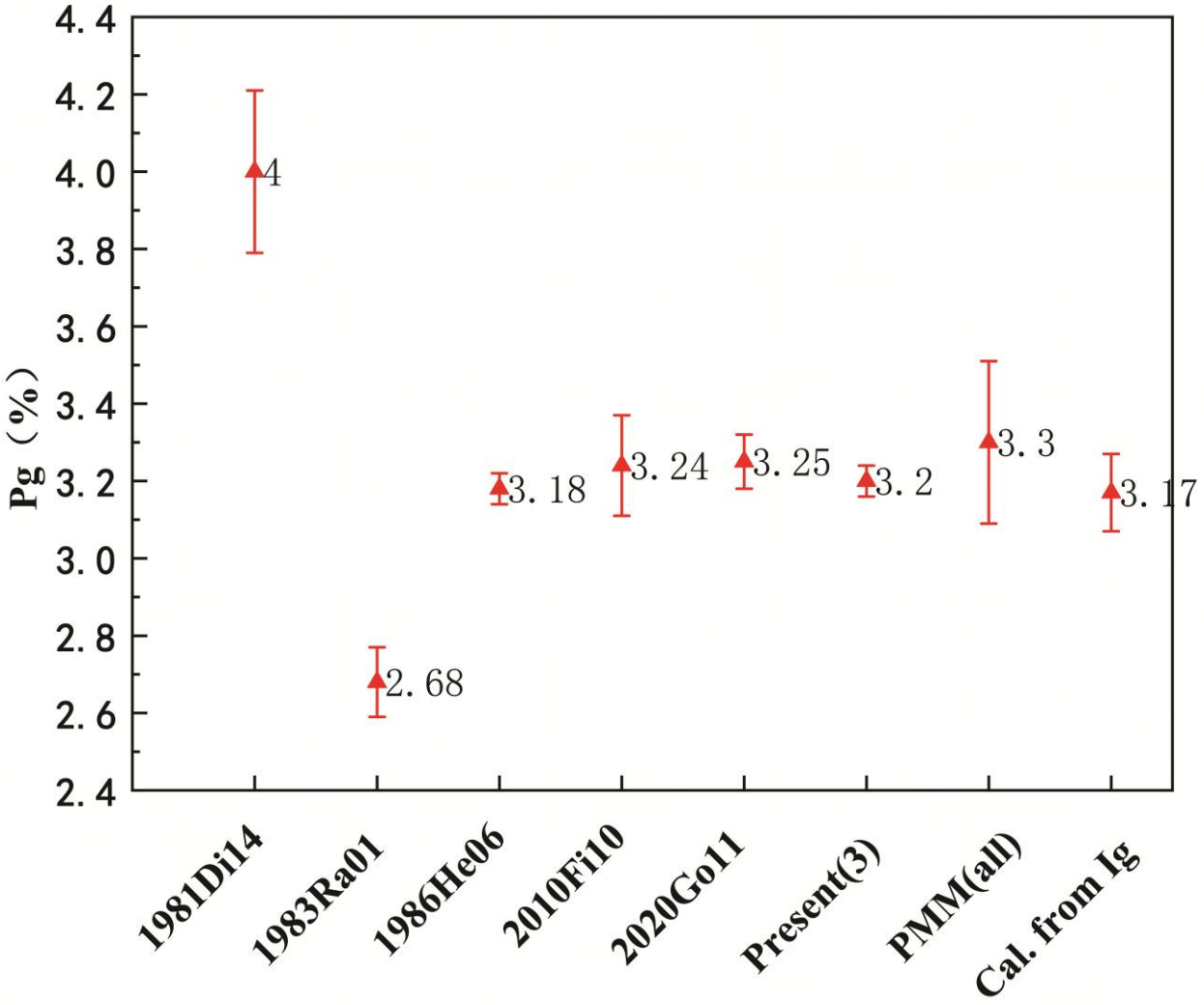
	2020Go11	2010Fi10	1986He06	1983Ra01	1981Di14	LWM	Cal. from Iγ
Pγ(%)	3.25(7)	3.24(13)	3.18(4)	2.68(9) (outlier)	4.00(21) (outlier)	3.20(4)	3.17(10)

PMM (2020Go11, 2010Fi10, 1986He06): 3.20(4)
PMM(all exp.): 3.30(21)

Adopted: P(γ210.85keV)=3.20(4), compared NDS:3.0(4)

2 ^{229}Th decay data evaluation

P(γ210.85keV) :



2 ^{229}Th decay data evaluation

Eα:

Level Energy	1970Ba20	1987He28	Cal. from level	Adopted
0.0	5077	5077 (2)	5077.2(10)	5077.2(10)
25.401(6)	5052	5053 (2)	5052.2(10)	5052.2(10)
42.754(6)	5033	5036 (2)	5035.2(10)	5035.2(10)
100.553(9)	4977.9(12)	4979 (2)	4978.4(10)	4978.4(10)
111.583(9)	4966.9(12)	4968 (2)	4967.5(10)	4967.5(10)
179.740(5)	4900.4(12)	4901 (2)	4900.6(10)	4900.6(10)
220.971(23)	~4861	4860 (2)	4860.1(10)	4860.1(10)
236.261(5)	4844.7(12)	4845 (2)	4845.0(10)	4845.0(10)
243.515(9)	~4837	4838 (2)	4837.9(10)	4837.9(10)
267.959(11)	4814.0(12)	4815 (2)	4813.9(10)	4813.9(10)

Recommended energies of alpha particles were taken the calculation from level and Q

2 ^{229}Th decay data evaluation

Pα:

Eα(keV)	1970Ba20	1987He28	Deduced from Iγ	Adopted
5077.2(10)	0.01	0.05(1)	-2(5)	0.05(1)
5052.2(10)	1.6	6.6(1)	7(4)	6.6(1)
5035.2(10)	0.24	0.24(2)	0(5)	0.24(2)
4978.4(10)	3.2	3.4(1)	3.3(21)	3.4(1)
4967.5(10)	6.4	7.0(1)	7(3)	7.0(1)
4900.6(10)	10.8	10.6(2)	10.5(15)	10.6(2)
4860.1(10)	0.18	0.38(4)	0.47(22)	0.38(4)
4845.0(10)	56.2	53.0	53.0(24)	53.0(24)
4837.9(10)	4.8	5.2	5.54(22)	5.54(22)
4813.9(10)	8.4	9.6(2)	9.2(11)	9.2(11)

Recommended α-particle emission probabilities are from measurements of 1987He28 for the prominent α transitions, others are from the calculated results

2 ^{229}Th decay data evaluation

X-ray Emission:

The absolute emission probabilities of KX- and LX- rays have been calculated using the EMISSION computer program.

	1983Ra01	1987He28	Deduced
XL	93.9(21)		79.3(41)
XK	40.6(33)	51.5(21)	48.9(12)

Electron Emission:

The energies of the conversion electrons have been obtained from the γ-ray transition energies and the electron binding energies. The absolute emission probabilities of the conversion electrons have been deduced using recommended Pγ and ICC values.

The absolute emission probabilities of K and L Auger electrons have been calculated using the EMISSION computer program.

2 ^{229}Th decay data evaluation

Consistency:

Consistency of the recommended data has been checked by calculating the total average emission energy per decay for all emissions involved in the ^{229}Th α decay with Saisinuc (2008DuZX).

The total decay energy of 5163.8(23) keV, deduced from the current evaluated data and decay scheme is in agreement with the adopted value of 5167.6(10) keV by 2021Wa16, indicate that decay scheme is complete and confirm the reliability of the current evaluation.

3. Summary

➢Half-life:

The recommended value may be overstimated and its uncertainty may be underestimated. K=2？

T1/2= 7907 →7896(PMM)

$\triangle_{T1/2}$ =24 →48(k=2)

➢The relative intensities for some low energy γ-ray need more precise measurements, for example:

γ 11.1 keV:

γ 11.1 keV is an unobserved transition. Multipolarity is M1+E2 from decay scheme. The mixing ratio is unknown. Present evaluation adopt P(ce+γ) and deduced from intensity balance at level.

3. Summary

➢Some measured α-particle emission probabilities are disagreed:

Eα(keV)	1970Ba20	1987He28	Deduced from Iγ	Adopted
5052.2(10)	1.6	6.6(1)	7(4)	6.6(1)
5046.2(10)	5.2		0.0(10)	<0.2a

$\Sigma I\alpha = 101.6(27)$

➢The calculated emission probabilities of KX- and LX- rays are not consistent with the measurements.



Thank you for your attention !
Comments and suggestion welcome !