INDEN fissile actinide issues

https://www-nds.iaea.org/INDEN

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Nuclear Data Section, International Atomic Energy Agency

On behalf of the INDEN collaboration

Outlook

- General issues solved: TNC, PFNS
- Outstanding issues in fissile evaluations
- Comments on RPI quasi-diff. experiment
- Reaction rate testing of trial evaluations in fast assemblies

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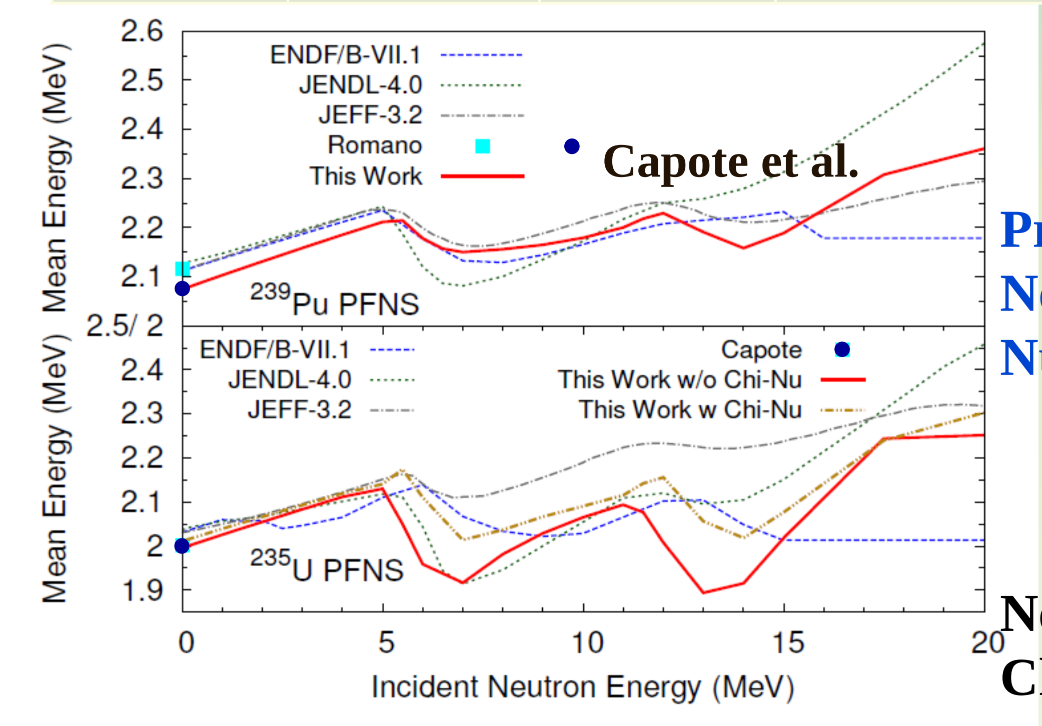
Thermal Neutron Constants

		Standards 2006 (+Maxwellian)	ENDF/B-VII.1	Standards 2017 (2200 m/s)	ENDF/B-VIII.0
$^{233}U(n_{th},f)$	σ_s	12.1±0.7	12.17	12.2±0.7	✓ 12.2
	σ_f	531.2±1.3	531.3	533.0±2.2	✓ 534.1
	σ_γ	45.6±0.7	45.3	44.9±0.9	✓ 42.3
	ν_t	2.4968±0.0035	2.4968	2.487±0.011	✓ 2.4852
$^{235}U(n_{th},f)$	σ_s	14.09±0.22	**15.11**	14.09±0.22	✓ 14.10
	σ_f	584.3±1.0	584.99	587.3±1.4	✓ 586.7
	σ_γ	99.4±0.7	98.69	99.5±1.3	✓ 99.4
	ν_t	2.4355(.0023)	2.4367(.0005)	2.425±0.011	✓ 2.4298
$^{239}Pu(n_{th},f)$	σ_s	7.8±1.0	7.99	7.8±1.0	✓ 8.1
	σ_f	750.0±1.8	**747.91**	752.4±2.2	**X 747.4**
	σ_γ	271.5±2.1	270.7	269.8±2.5	✓ 270.1
	ν_t	2.8836±0.0047	2.8807	2.878±0.013	✓ 2.8769
$^{241}Pu(n_{th},f)$	σ_s	12.1±2.6	11.2	11.9±2.6	✓ 11.3
	σ_f	1014±7	1012	1023.6±10.8	**X 1012**
	σ_γ	361.8±5.0	363.0	362.3±6.1	✓ 363.0
	ν_t	2.9479±0.0054	2.9453	2.940±0.013	✓ 2.9453
$^{252}Cf(sf)$	ν_t	3.7692±0.0047	3.7676	3.764±0.015	

n_{th}+X PFNS <E> (IAEA 2016, STD 2017)

^{233}U	^{235}U	^{239}Pu	evaluation	
2.074	2.03	2.112	ENDF/B-VII.1	
2.030	2.00	2.074	IAEA Standards 2017 **(target)**	E_n(eV)
2.032	2.00	2.074	Talou, Rising et al 2016	0.0253
2.074	✓ **2.00**	**2.112**	ENDF/B-VIII.0 2018	



Preliminary ChiNu data
Neudecker et al,
Nucl. Data Sheets 148 (2018) 293-311

New evaluation based on new data
ChiNu + CEA (Marini et al) on-going

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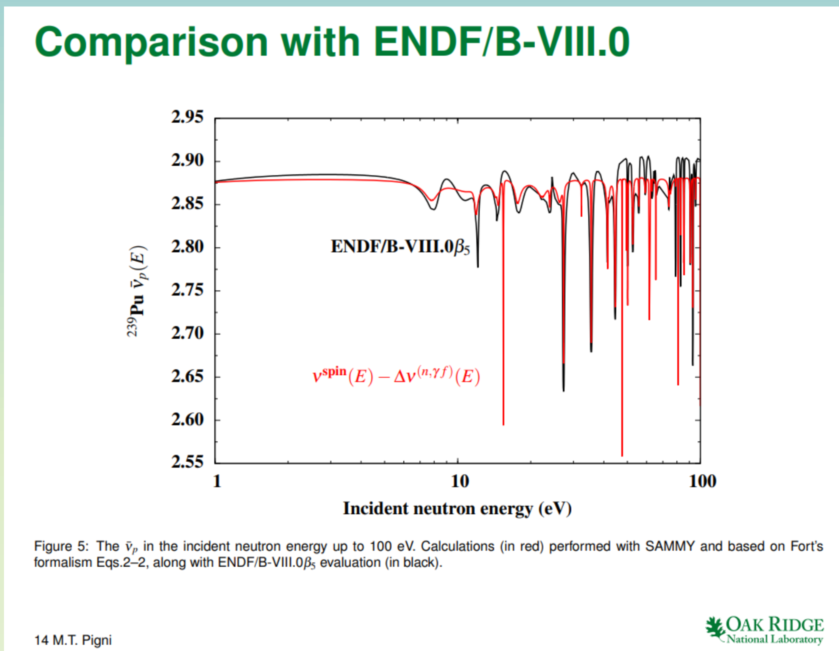
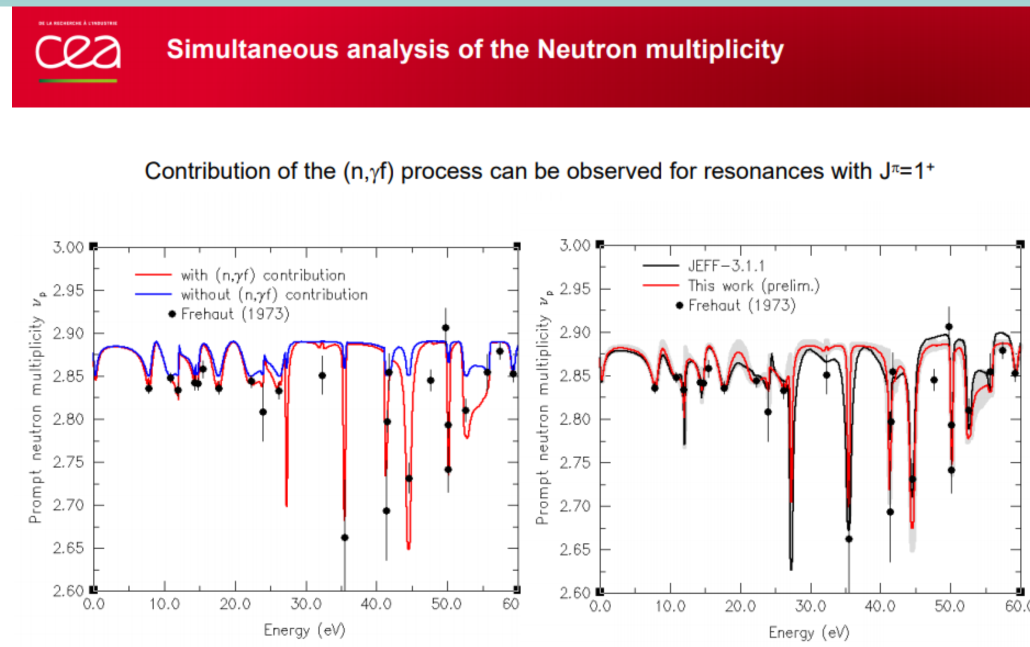
nubar fluctuations for resonances: reintroduced in ENDF/B-VIII.0 for n+^{235}U





U-235 nubar

M. Pigni, INDEN CM 2018

Pu-239 nubar

G. Noguere, INDEN CM 2018

U-233 nubar ??

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U-235 updated evaluation (u235…zt)

ORNL/IAEA, see also Pigni talk for the RRR

- Changes to the low-energy resonances (RRR) to improve the fit to measured capture data from RPI (capture reduced by 5% from 0.06-7.8 eV, by 7.7% from 7.8-11 eV)
- Small change to thermal nu-bar within uncertainties.
- Fluctuations in the fission cross section in the URR range were refined to represent measured data following Paradela *et al.* evaluation (*very small impact on criticality*)
- Discrete level data are stored in MF=6 (format requirement, no impact on calculations)
- Issues leading to negative eigenvalues in cross-covariances in the RR sorted out

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U-235 updated evaluation (u235…zt)

ORNL/IAEA, see also Pigni talk for the RRR

Refined resonance parameters from ORNL (better reproduction of RPI capture data, Danon et al).

Danon et al, INDEN CM 2018

Energy [eV]		Fission C/E		Capture C/E	
From	To	ENDF 7.1	ENDF 8.0	ENDF 7.1	ENDF 8.0
0.0253	9.4	0.98	0.99	0.99	1.06
7.8	11	0.97	0.97	0.97	1.07
9.4	150	1.02	1.01	1.04	1.03
150	250	1.01	0.99	1.06	1.03
250	350	1.02	1.01	1.04	0.95
350	450	1.02	1.03	1.11	0.99
450	550	1.02	1.02	1.17	0.99
550	650	1.01	1.00	1.16	0.99
650	750	1.01	1.01	1.15	1.01
750	850	1.02	1.02	1.16	1.03
850	950	0.98	0.99	1.15	1.05
950	1500	1.01	0.98	1.23	1.00
1500	2500	1.02	1.01	1.47	1.03

Pigni et al, u235 "zt" ORNL/IAEA

Fission		ENDF/B-VIII.0	zt	Diff[%]	
0 ,	0.0206	1328.723838	1320.345144	-0.630	
0.0206,	0.0623	463.200002	461.189070	-0.434	!!!!
0.0623,	0.6	155.569447	153.743995	-1.173	
0.6 ,	7.8	23.550219	23.758391	0.883	
7.8 ,	11	77.176680	78.894845	2.226	!!!!
11 ,	17.5	41.586599	41.432797	-0.369	
17.5 ,	22	73.091506	73.028221	-0.086	
22 ,	30	35.852199	35.693548	-0.442	

Capture		ENDF/B-VIII.0	zt	Diff[%]	
0 ,	0.0206	241.900018	249.099064	2.976	
0.0206,	0.0623	76.875494	77.290171	0.539	
0.0623,	0.6	29.909777	28.366693	-5.159	<<<
0.6 ,	7.8	21.518358	20.626877	-4.142	<<<
7.8 ,	11	30.426102	28.068047	-7.750	<<<
11 ,	17.5	40.946615	40.994303	0.116	
17.5 ,	22	51.588576	51.557329	-0.060	
22 ,	30	18.093089	18.095457	0.013	

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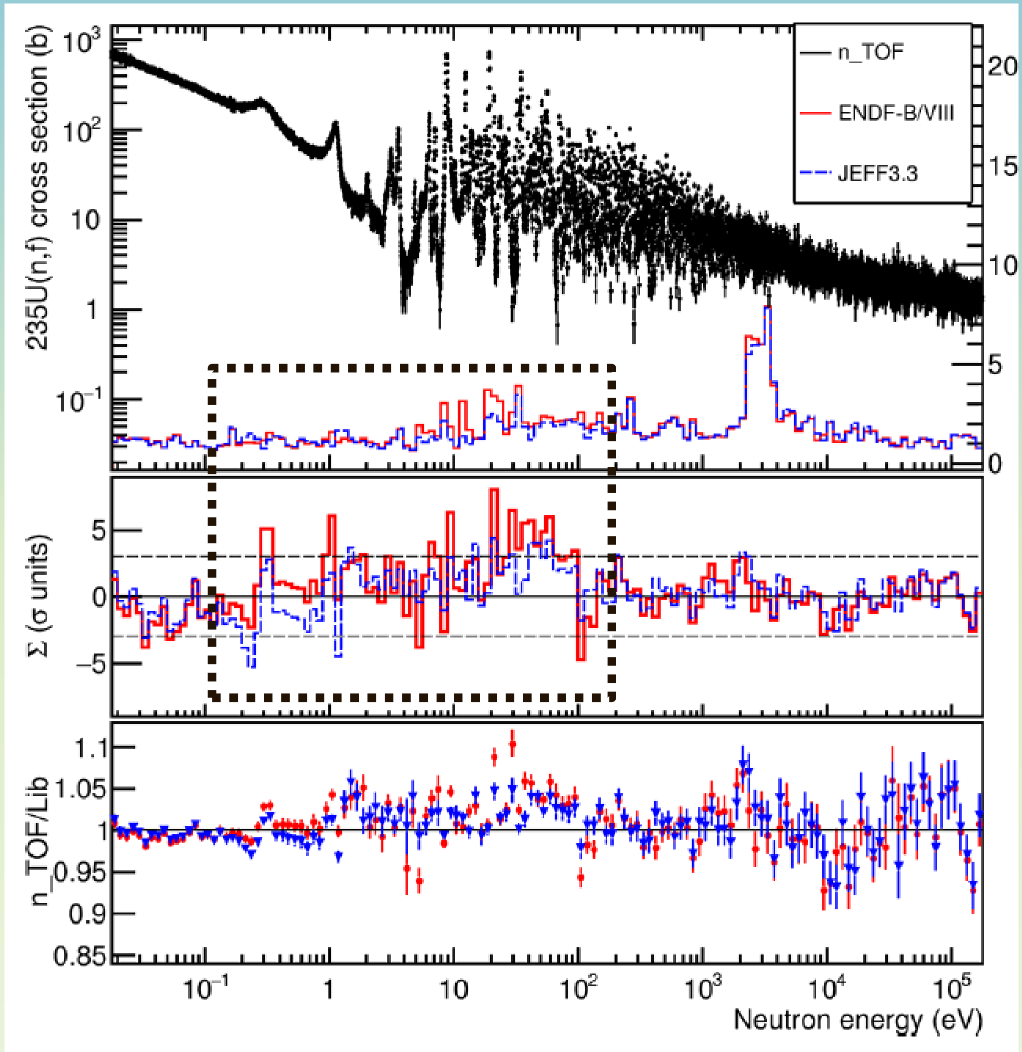
Remaining issue: ^{235}U+n RP



Slight overestimation of σ_f in ENDF/B-VIII.0

S. Amaducci et al., EPJ A55 (2019) 120

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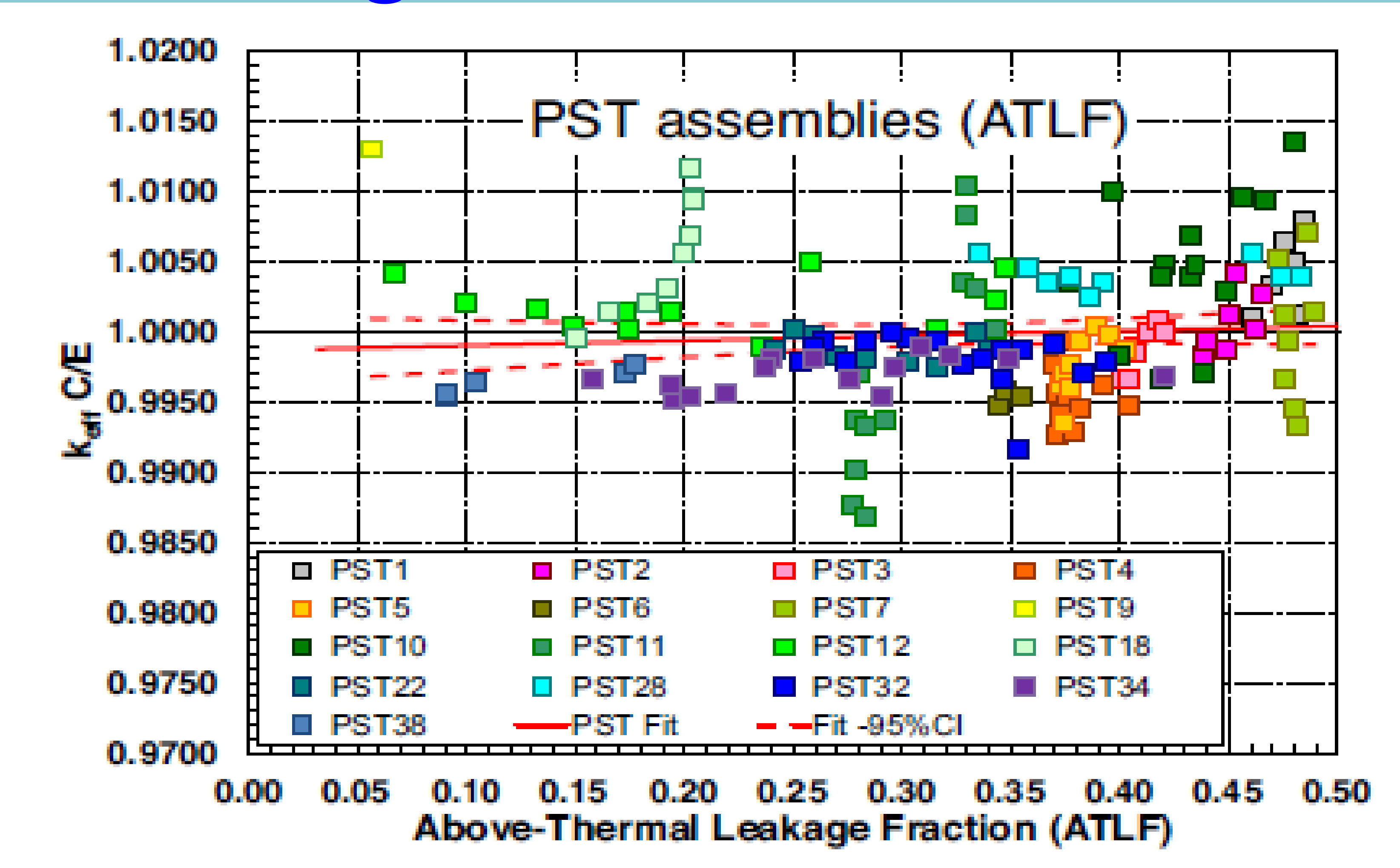
Challenges for a new $^{239}Pu+n$ RP



But wrong PFNS !

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Pu-239 trial evaluation pu239e80p17

ORNL/IAEA, see also Pigni talk for the RRR

- ❑ New resonance evaluation by M. Pigni (local designation “res-stan-00e”). Increased thermal fission to agree with Neutron Standards (Thermal Neutron Constants)
- ❑ Thermal PFNS evaluated with Standards 2017 + IAEA-CRP (Talou et al.) at higher energies (to be updated with LANL PFNS evaluation)
- → PFNS <En=th>=2.08 MeV (ENDF/B-VIII.0 =2.11 MeV), -30 keV.
- ❑ Prompt nu-bar increased by ~0.4% from 0.08 up to 1.4MeV to compensate the PFNS criticality reduction in fast assemblies
- ❑ EMPIRE calculation of fast-neutron cross sections reproducing ENDF/B-VIII.0 (n,f) and (n,γ) within 2-3%.

  Focus on elastic/inelastic cross sections

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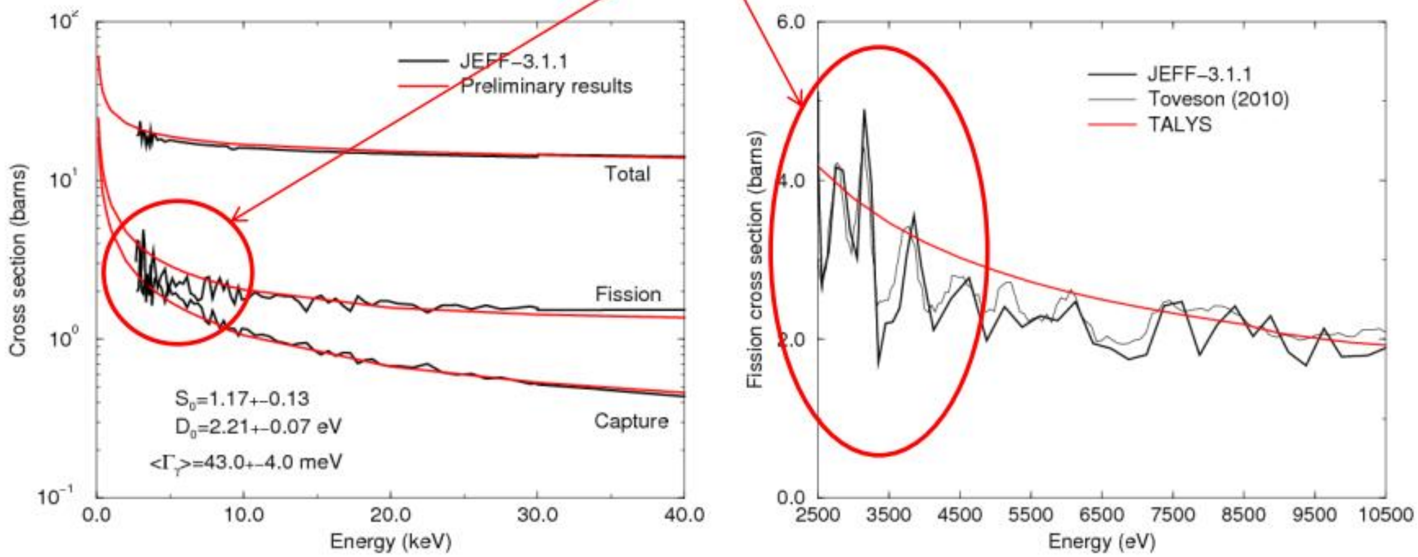
Remaining issue: extend the RRR in ^{239}Pu

Upper energy limit of the RRR ⇒ 5 keV

Fluctuations in the fission cross section between 2.5 keV – 5.0 keV not taken into account via statistical calculations



Fluctuations observed in JEFF-311 ⇒ **confirmed by Tovesson data (2010, LANL)**

Pu-239, G. Noguere, INDEN CM 2018

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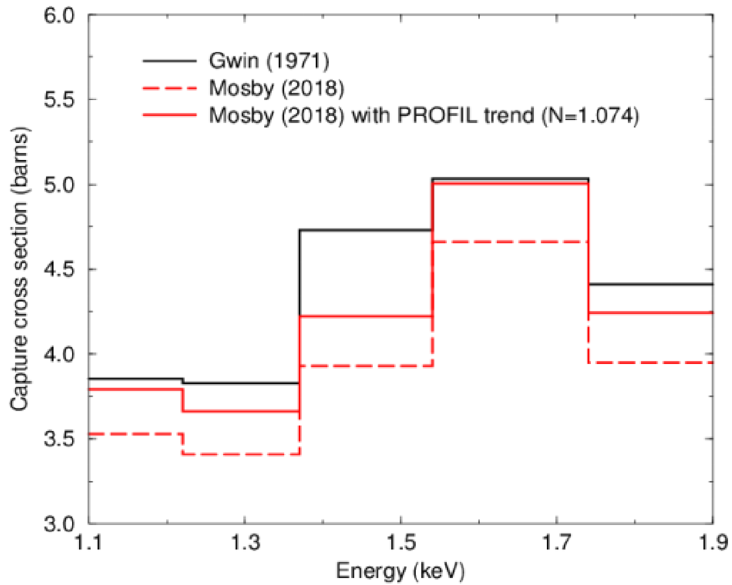
Remaining issue: Renormalize data?

Upper energy limit of the RRR ⇒ 5 keV

New capture data from Shea Mosby provide crucial trends to extend the RRR



Data from Mosby are shape data ⇒ A good agreement is obtained with the data from Gwin (normalisation with the PROFIL experiments carried out in the PHENIX reactor of CEA Marcoule)

Mosby et al, 2018 (n,g) normalization 37-100 eV to ENDF/B-VII.1

Noguere proposed renormalization factor of 1.074 based on integral PROFIL experiment

Pu-239, G. Noguere, INDEN CM 2018

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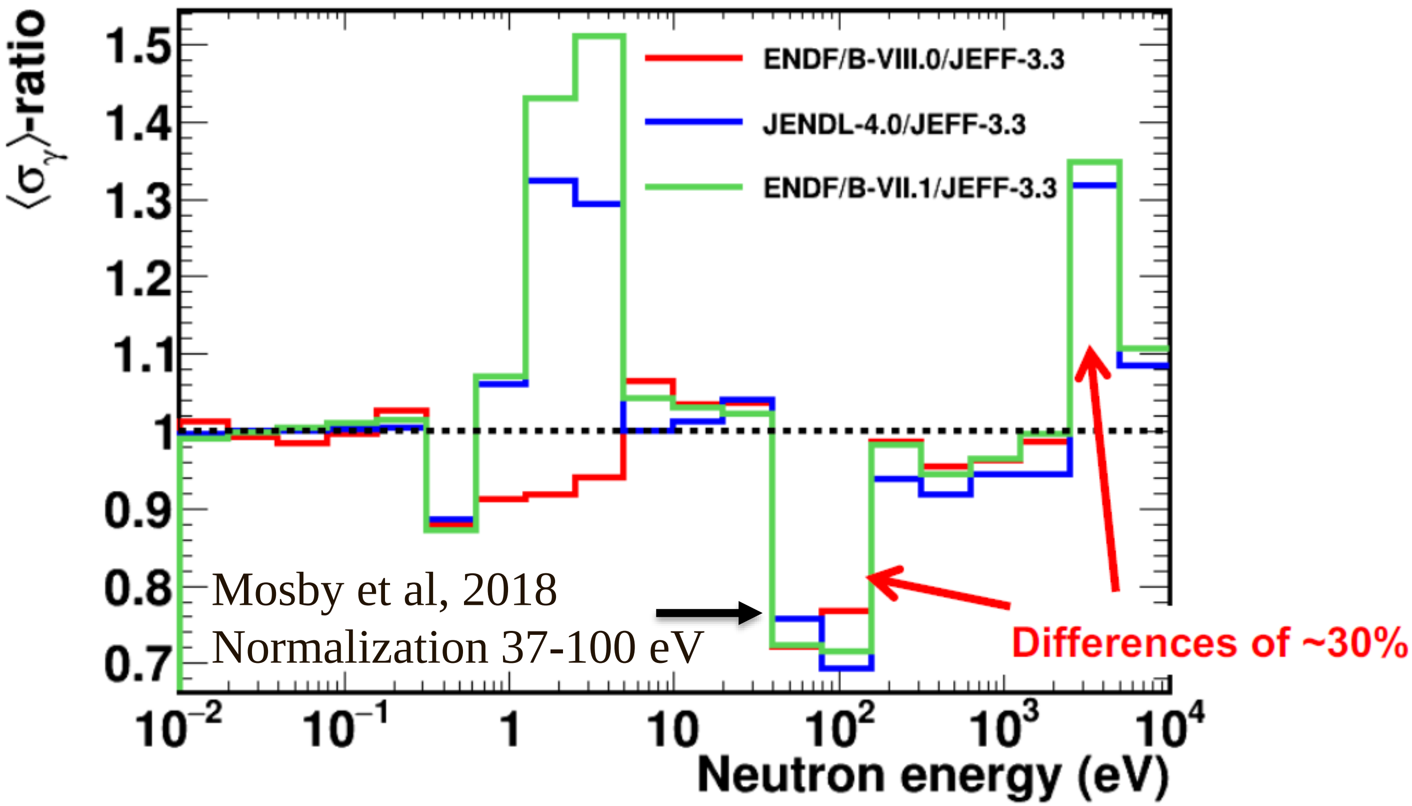
Status of the $^{239}Pu(n,\gamma)$ cross section



Ratio between the $^{239}Pu(n,\gamma)$ cross sections of ENDF/B-VIII.0, JENDL-4.0 and ENDF/B-VII.1 and JEFF-3.3.

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

IAEA INDEN meeting, November 16 – 19, 2020

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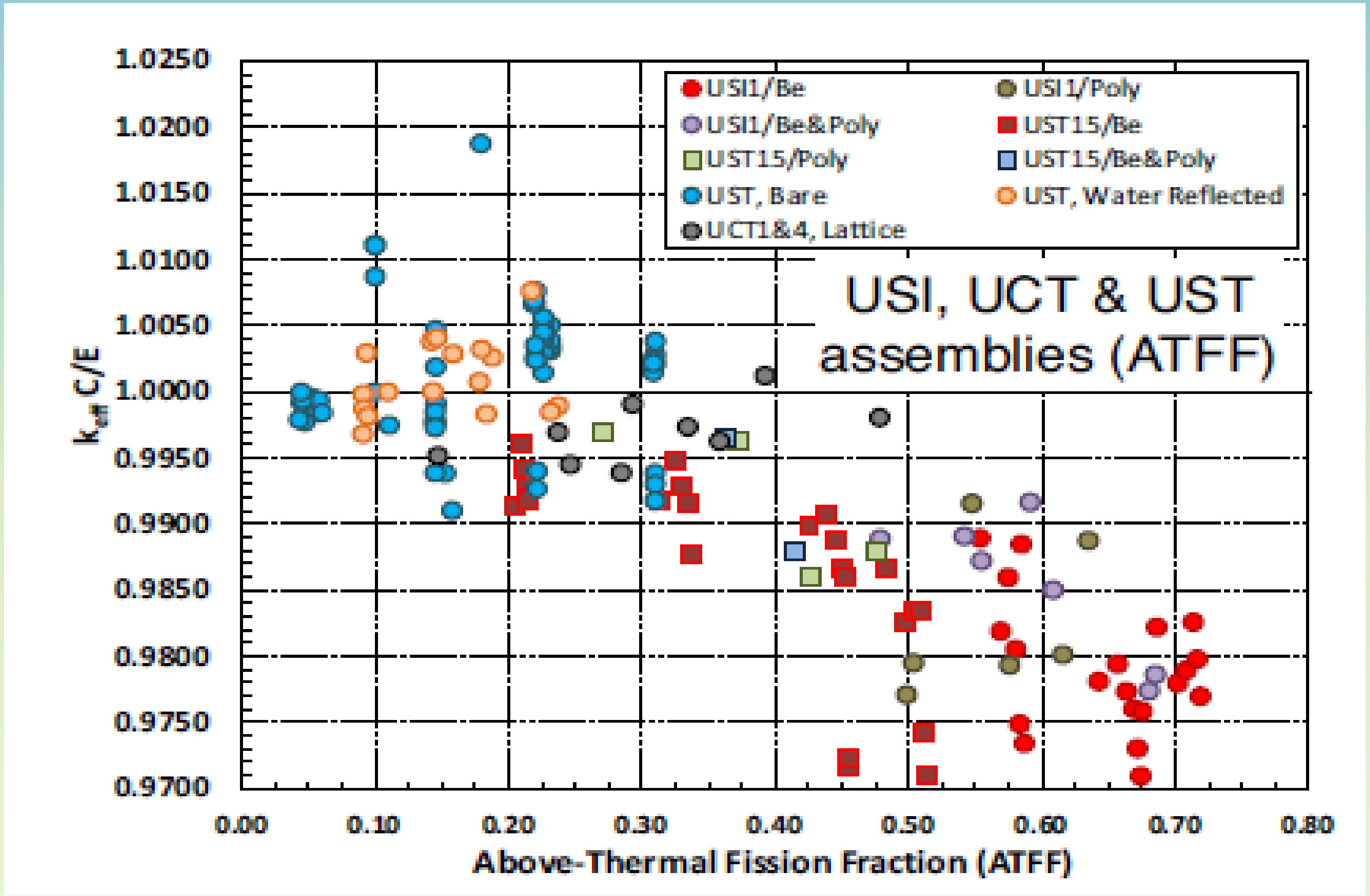
Challenges for a new ^{233}U+n RP



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U-233 new trial evaluation u233a506c

ORNL/IAEA, see also Pigni talk for the RRR

- New resonance parameters by M. Pigni ("06c")
- Thermal constants agree with Standards 2017
- Thermal PFNS evaluated with Standards 2017, IAEA-CRP (Talou et al.) at higher energies
- Fluctuations in nu-bar(E) below 30 eV follow Reed (X4#10427002, 1973)
- As observed for U-235 and Pu-239, there is a need to compensate the PFNS criticality reduction in fast assemblies (not done yet).

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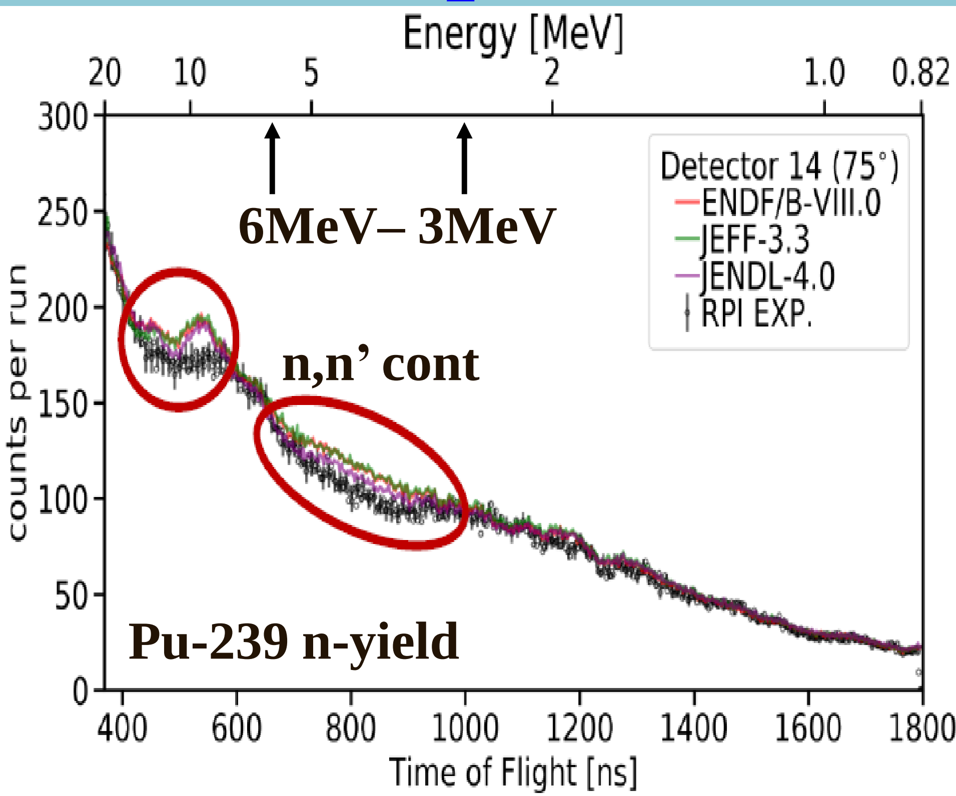
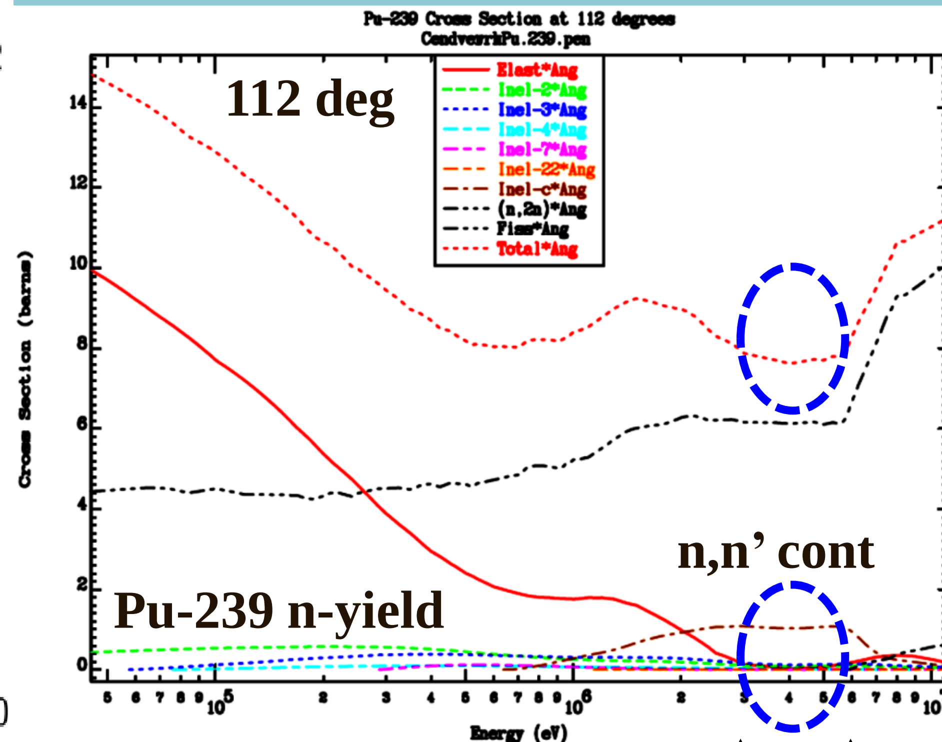
RPI quasi-differential ^{239}Pu data





3MeV– 6MeV

Sensitivity to n,n'

JENDL-4 better

(n,n' cont)?

Larger (n,n')= absorp => lower calc. yield

Y. Danon et al., EPJ WoC **239** (2020) 01004; Kumar Suni Mohindroo talk (yesterday)

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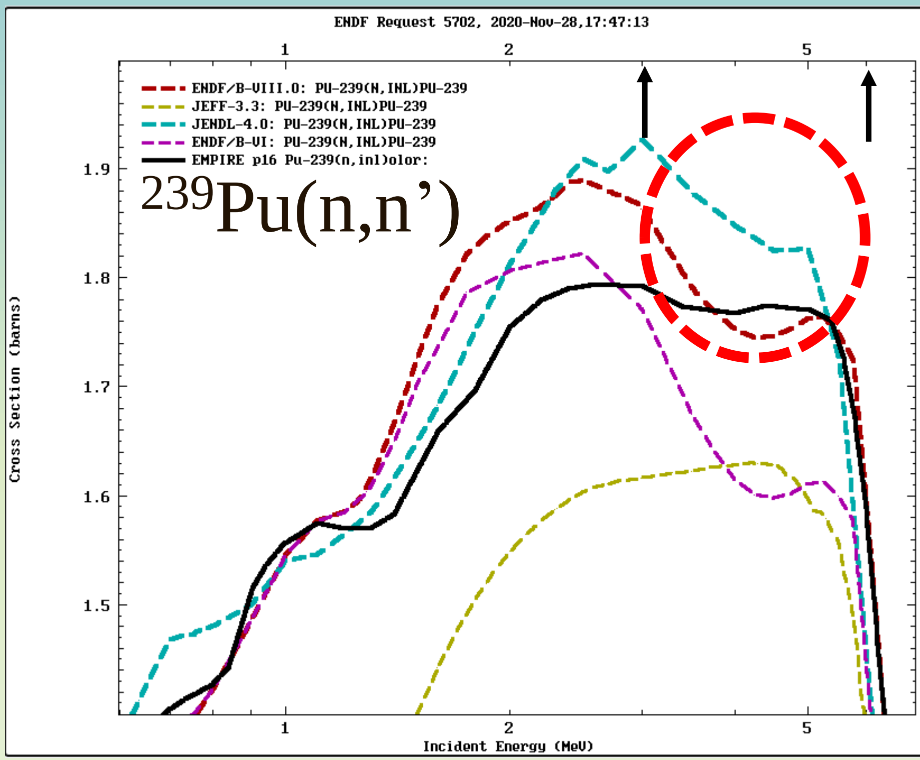
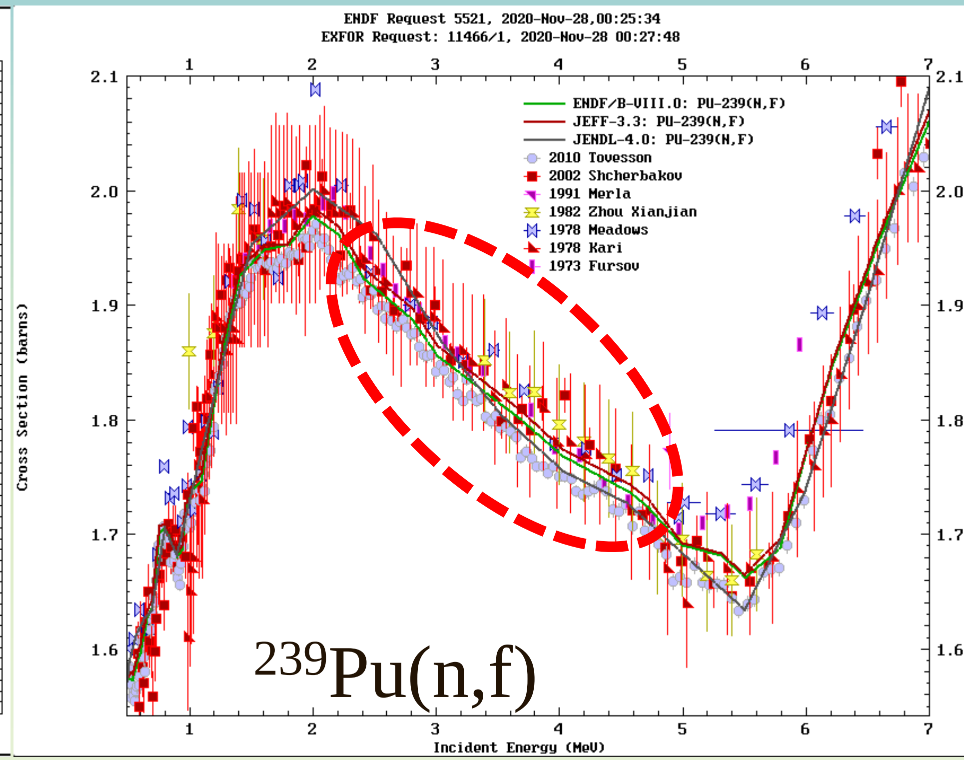
RPI quasi-differential ^{239}Pu data: Inelastic vs Fission from 2-5 MeV





3 MeV – 6 MeV

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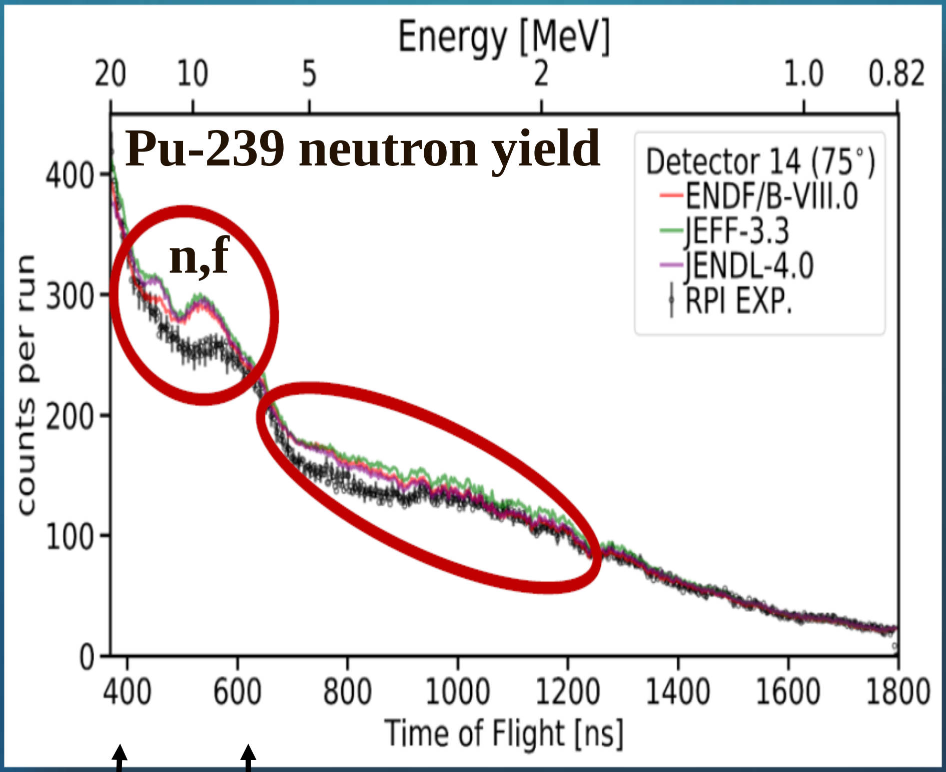
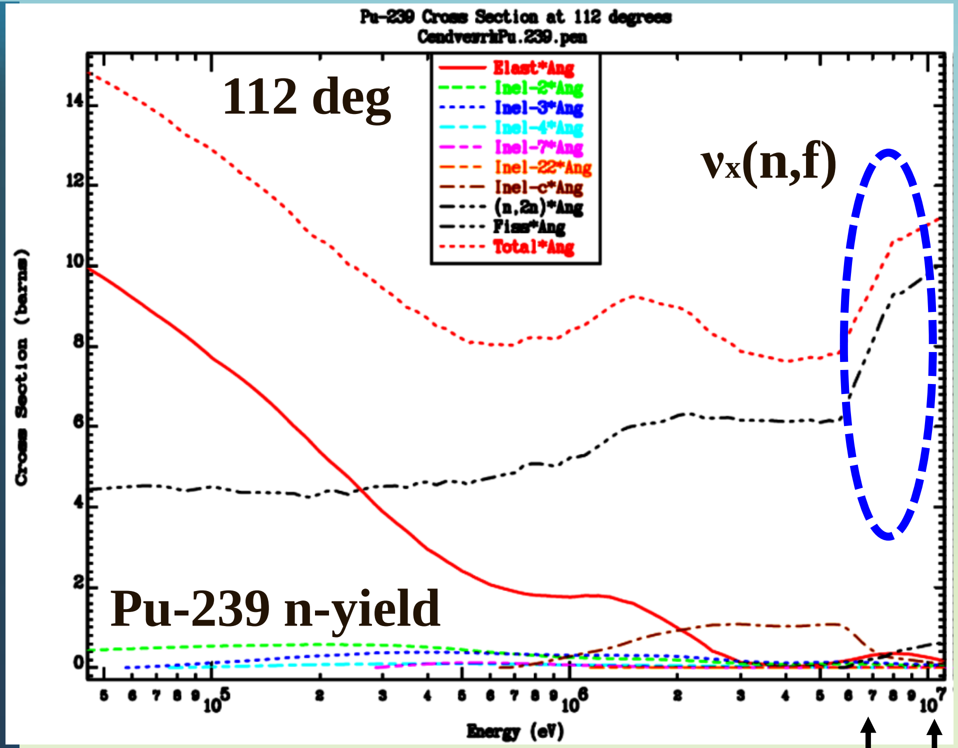
RPI quasi-differential ^{239}Pu data





15MeV–7MeV

7MeV–15MeV
Sensitivity to
ν_x(n,f)

Lower "ν" or (n,f) ?? PFNS impact, sensitivity studies needed
Check potential problems in (n,f) measurements

Y. Danon et al., EPJ WoC **239** (2020) 01004; Kumar Suni Mohindroo talk (yesterday)

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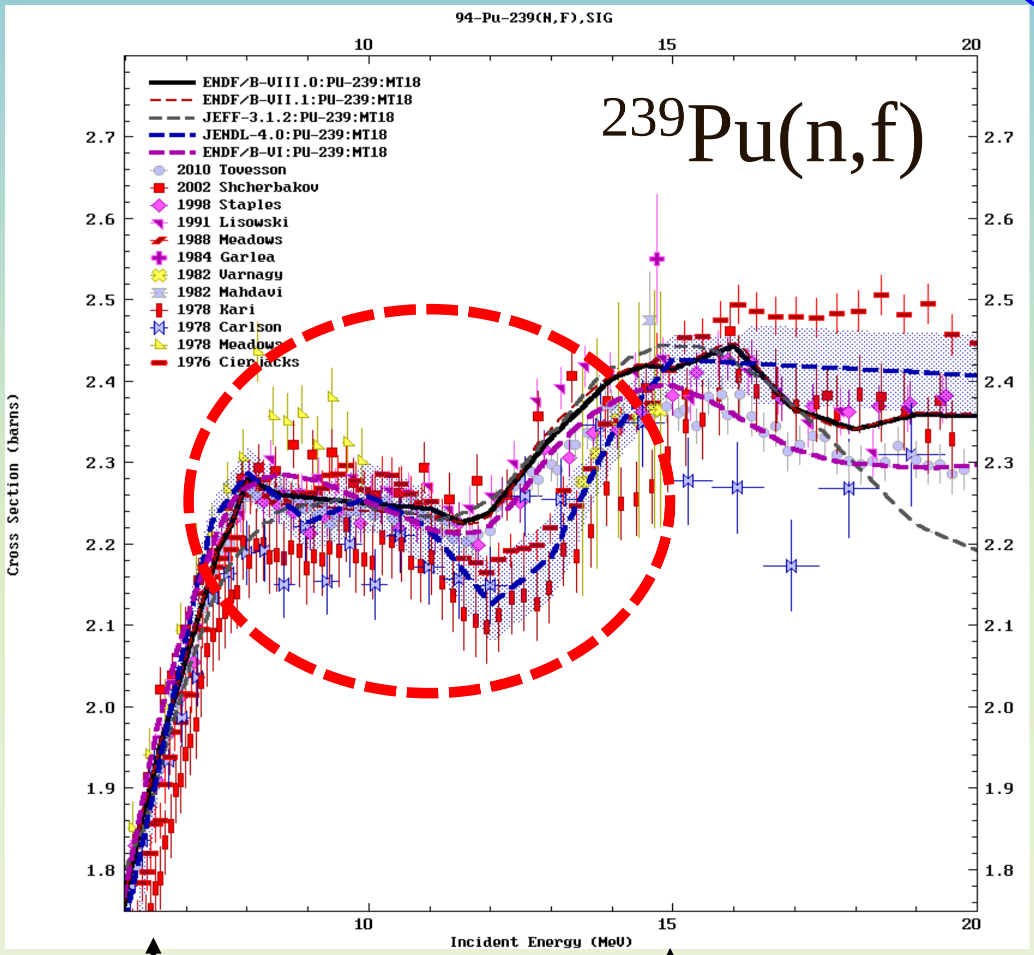
RPI quasi-differential ^{239}Pu data:

Fission from 6.5-15 MeV: (n,f) differential data



7MeV–15 MeV

All ratio measurements ^{239}Pu(n,f)/ ^{235}U(n,f) from EXFOR retrieved and ^{239}Pu(n,f) cross section is derived using the current ^{235}U(n,f) standard

All ratio measurements ^{239}Pu(n,f)/ ^{235}U(n,f) * STD ^{235}U

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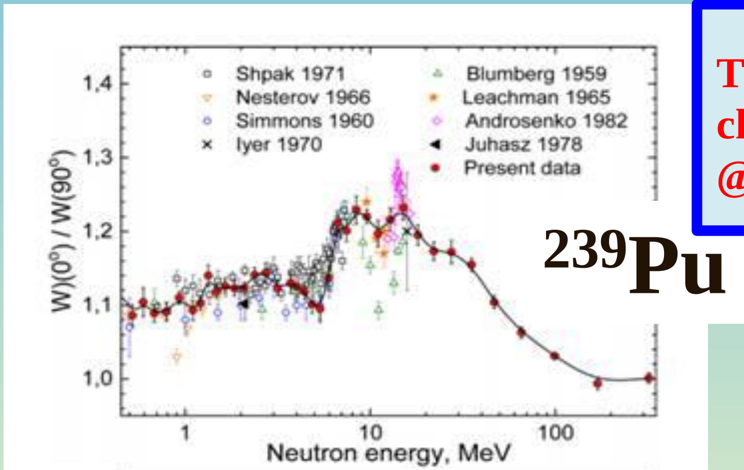
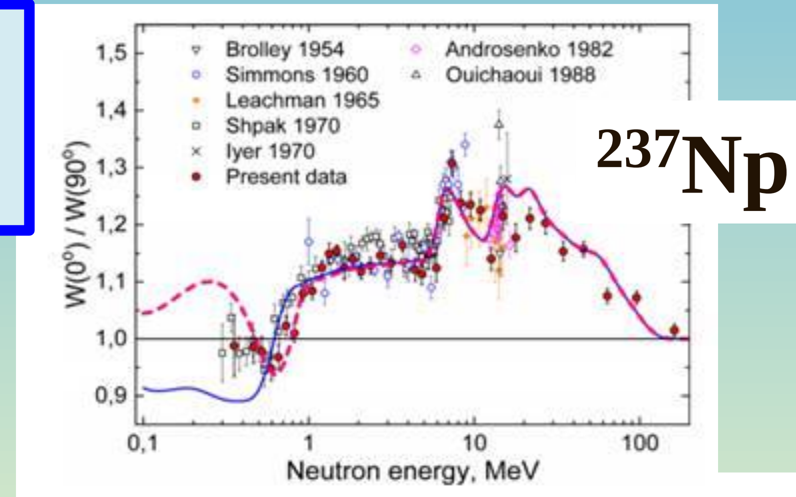
Re: (n,f) data, FF anisotropy @ 10 MeV



TPC may help to check the data @10-15 MeV



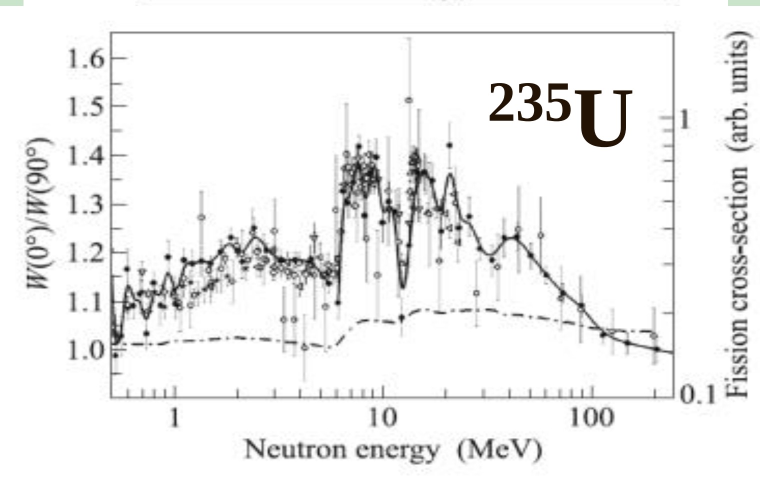


Fig. 4. Anisotropy of fission fragments of ^{235}U according to (▽) [12], (◁) [14], (△) [11], (◇) [15], (★) [10], (□) [13], (○) [8], (●) present data, and (–●–) fission cross section [9].

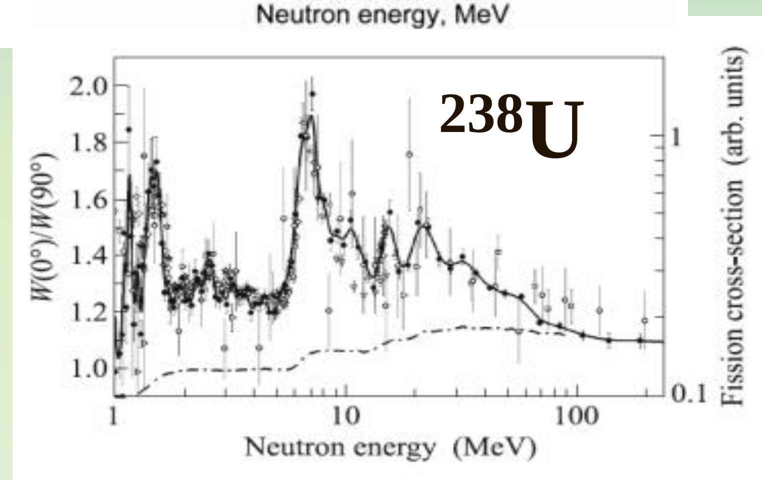


Fig. 5. Anisotropy of fission fragments of ^{238}U according to (▽) [12], (◁) [14], (▷) [16], (△) [11], (◇) [17], (★) [18], (□) [7], (○) [8], (●) present data, and (–●–) fission cross section [9].

A.S. Vorobyev et al., JETP Letters **102** (2015) 203-206; EPJ WoC **239** (2020) 05007

Jezebel and Flaptop-Pu Spectral indices

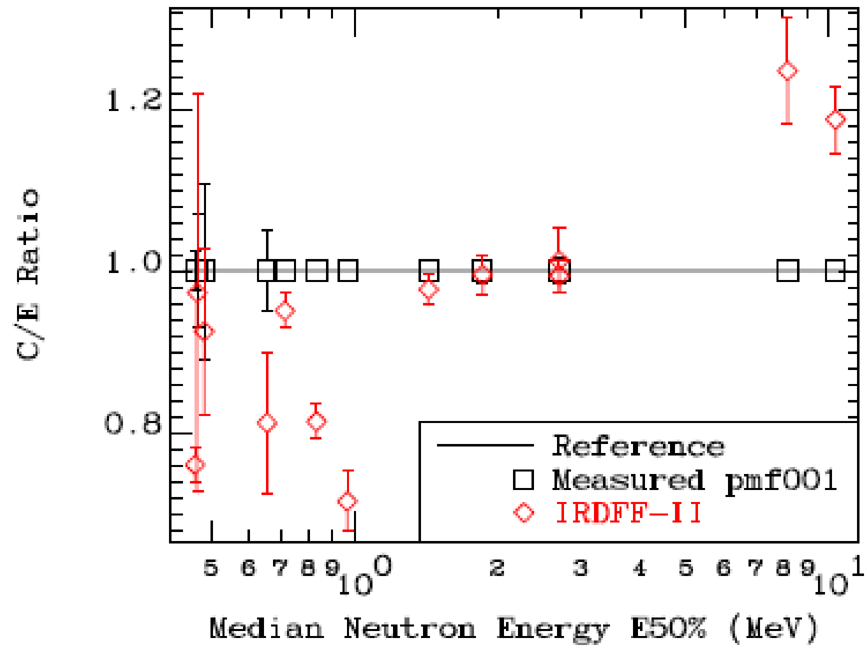


FIG. 109. (Color online) Ratio of Calculated and Measured SI in the central region of PMF001 (Jezebel) assembly.

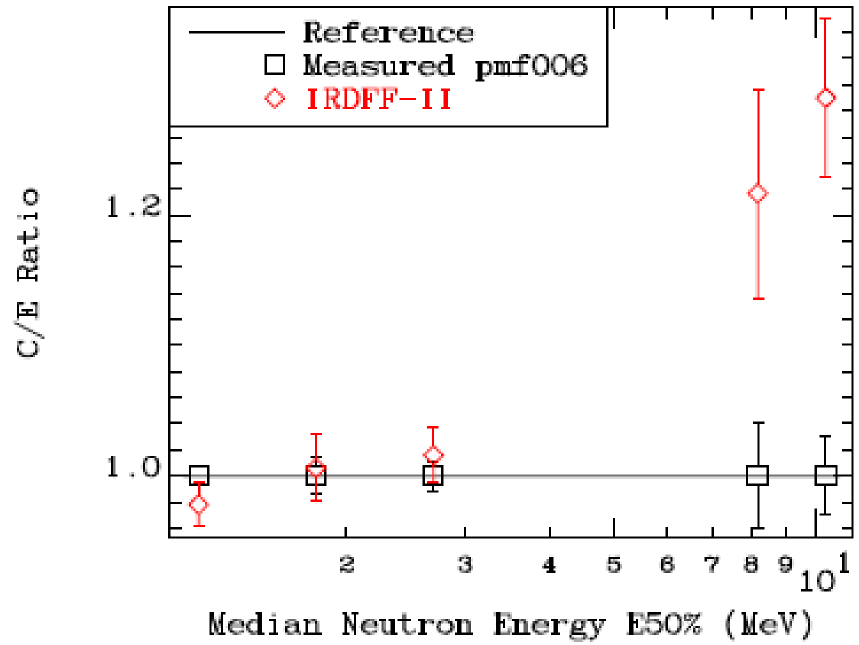


FIG. 110. (Color online) Ratio of Calculated and Measured SI in the central region of PMF006 (Flattop-Pu) assembly.

PMF assemblies, poor situation

More work needed for Pu data !!

IRDFF: A. Trkov et al, Nucl. Data Sheets **163** (2020) 1-108

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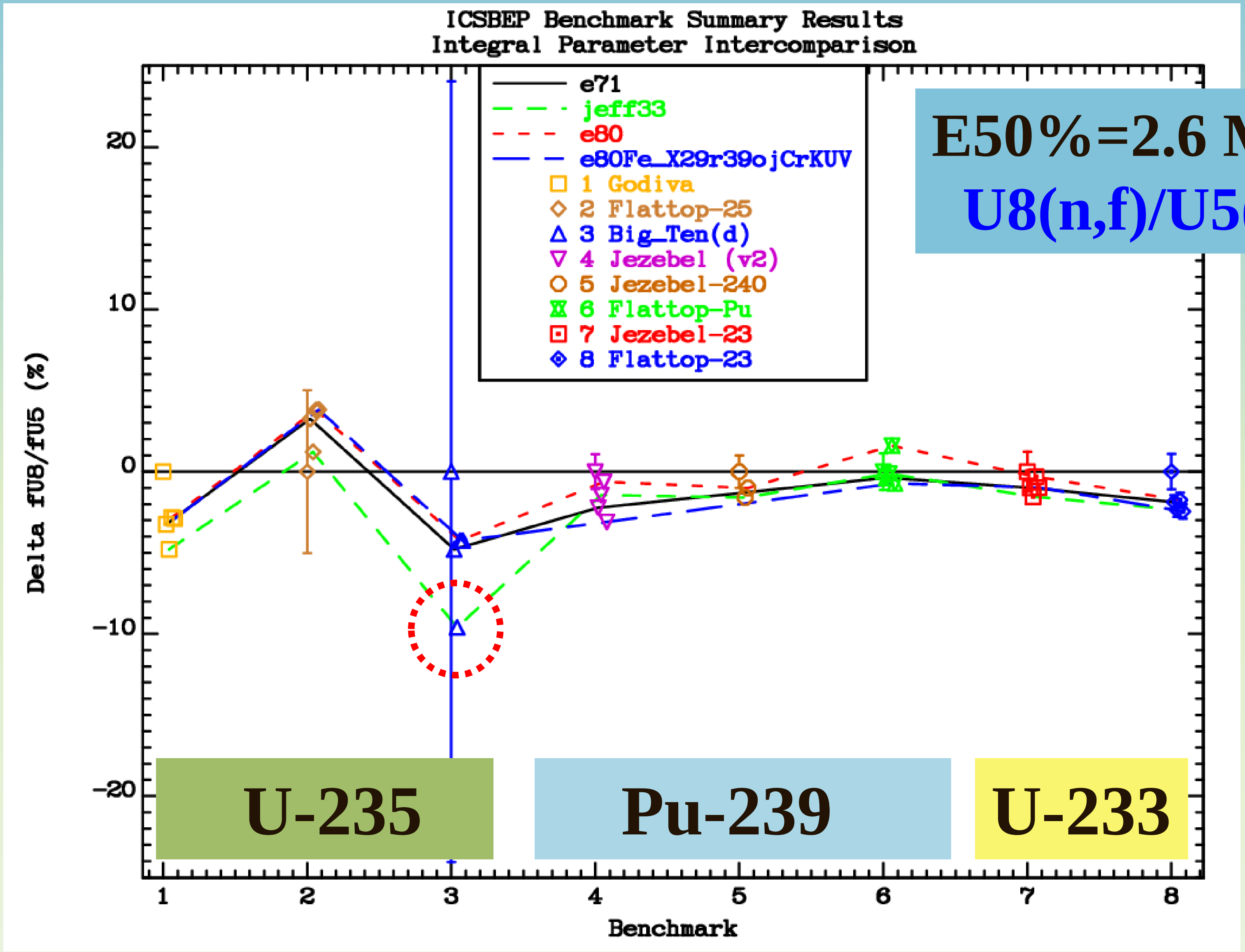
IRDFF Spectral indices: U5, Pu, U3 fast



E50%=2.6 MeV

U8(n,f)/U5(n,f)

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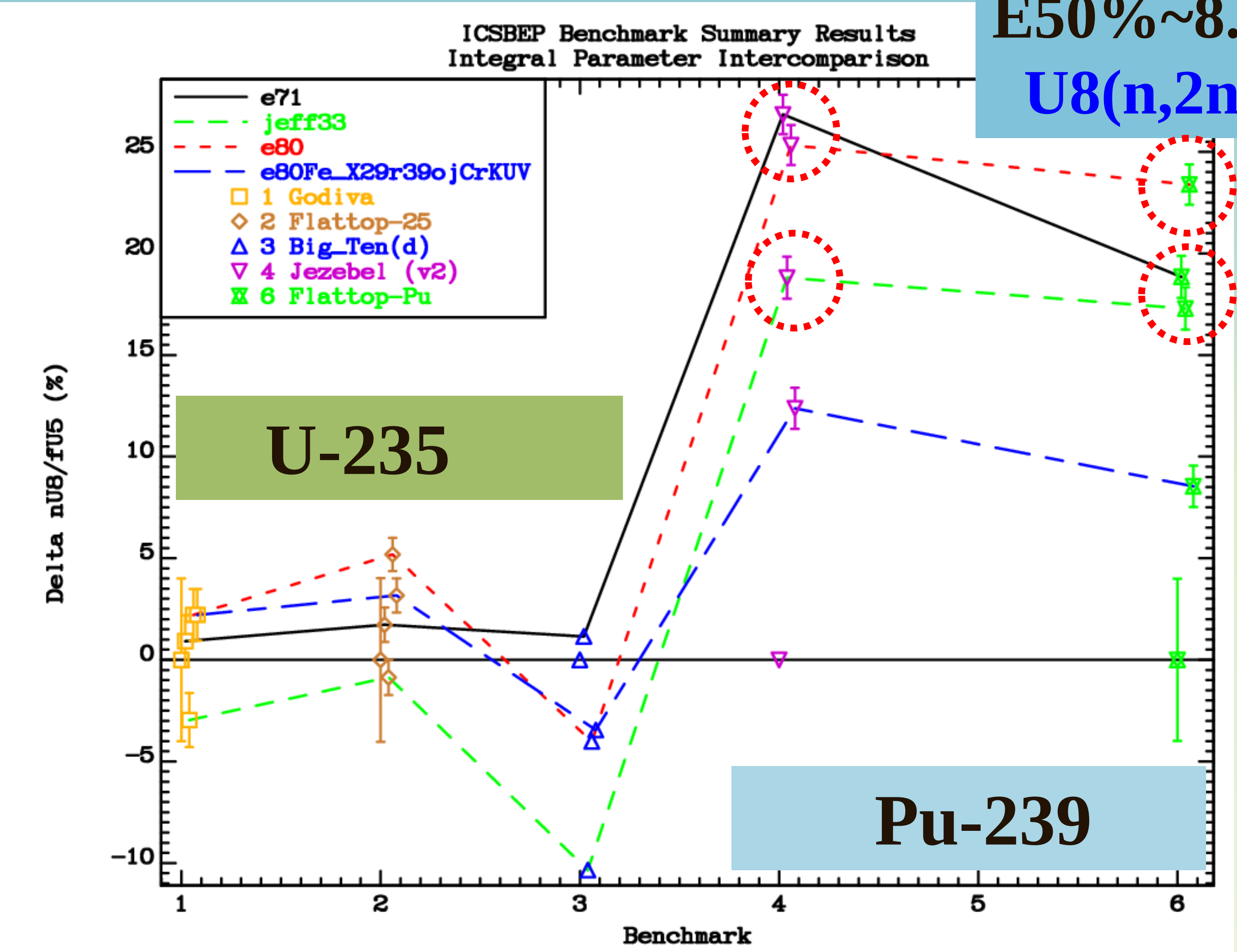

E50%~8.1 MeV
U8(n,2n)/U5(n,f)

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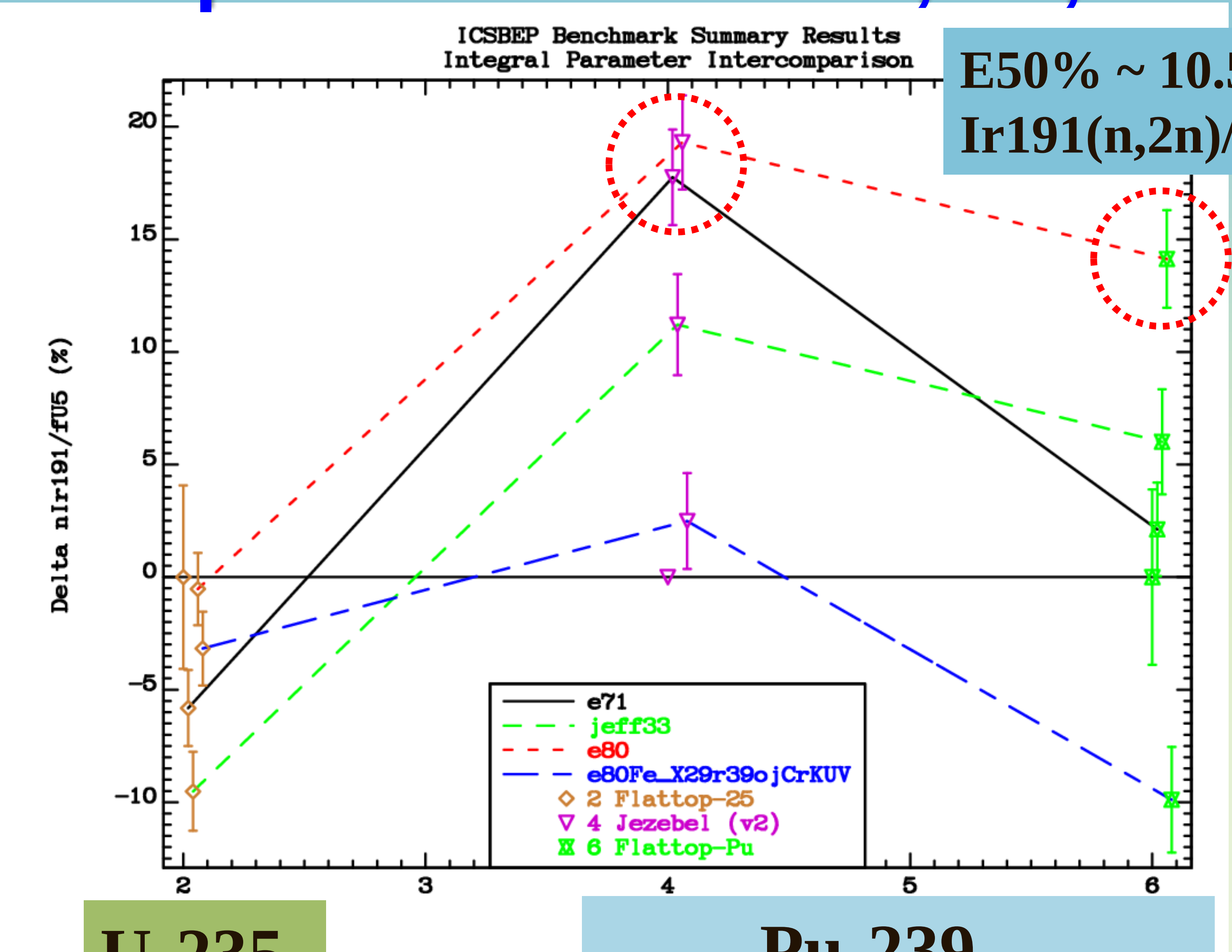
IRDFF Spectral indices: U5, Pu, U3 fast



E50% ~ 10.5MeV
Ir191(n,2n)/U5(n,2n)

U-235

Pu-239

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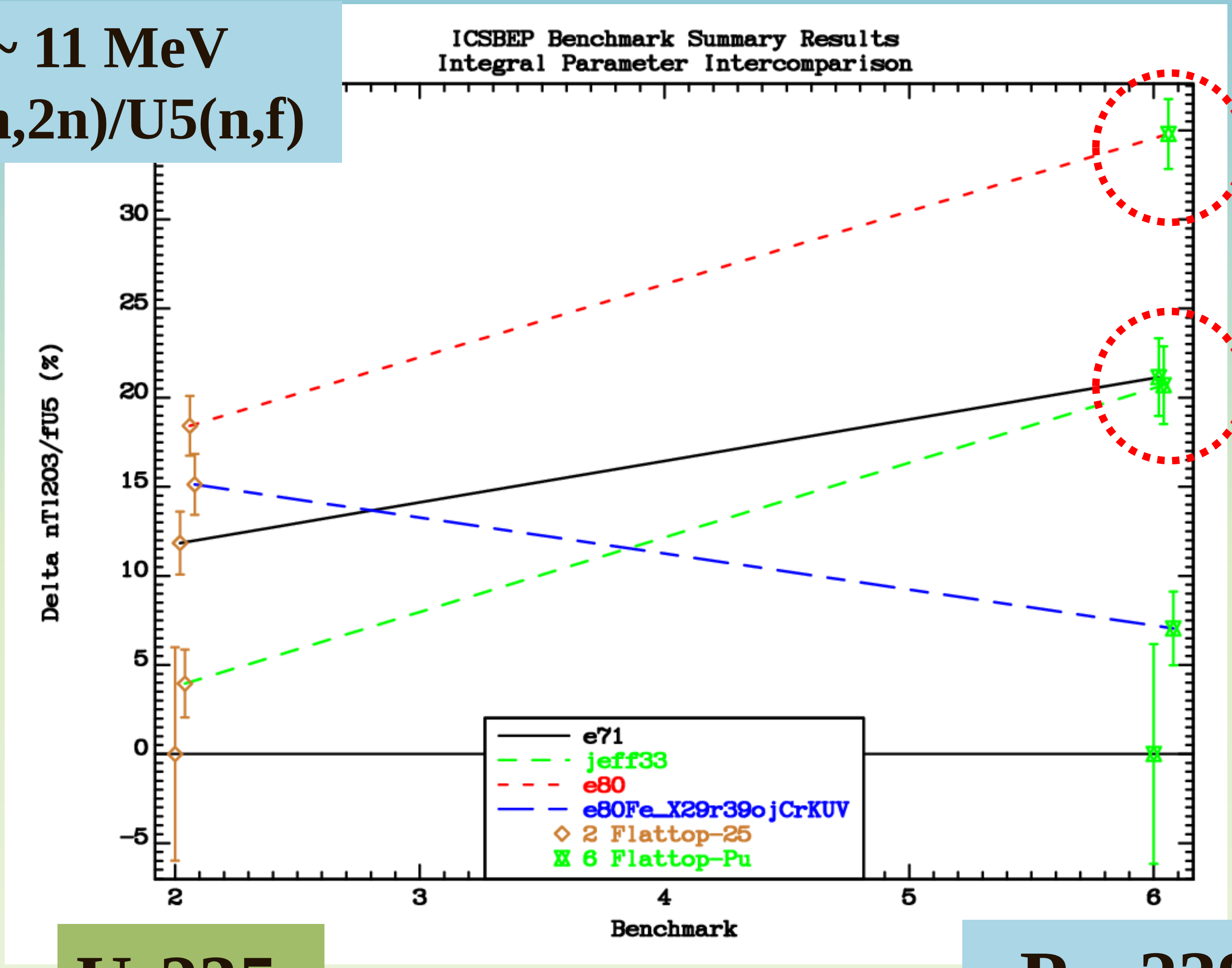
IRDFF Spectral indices: U5, Pu, U3 fast

E50% ~ 11 MeV
Tl203(n,2n)/U5(n,f)



U-235

Pu-239

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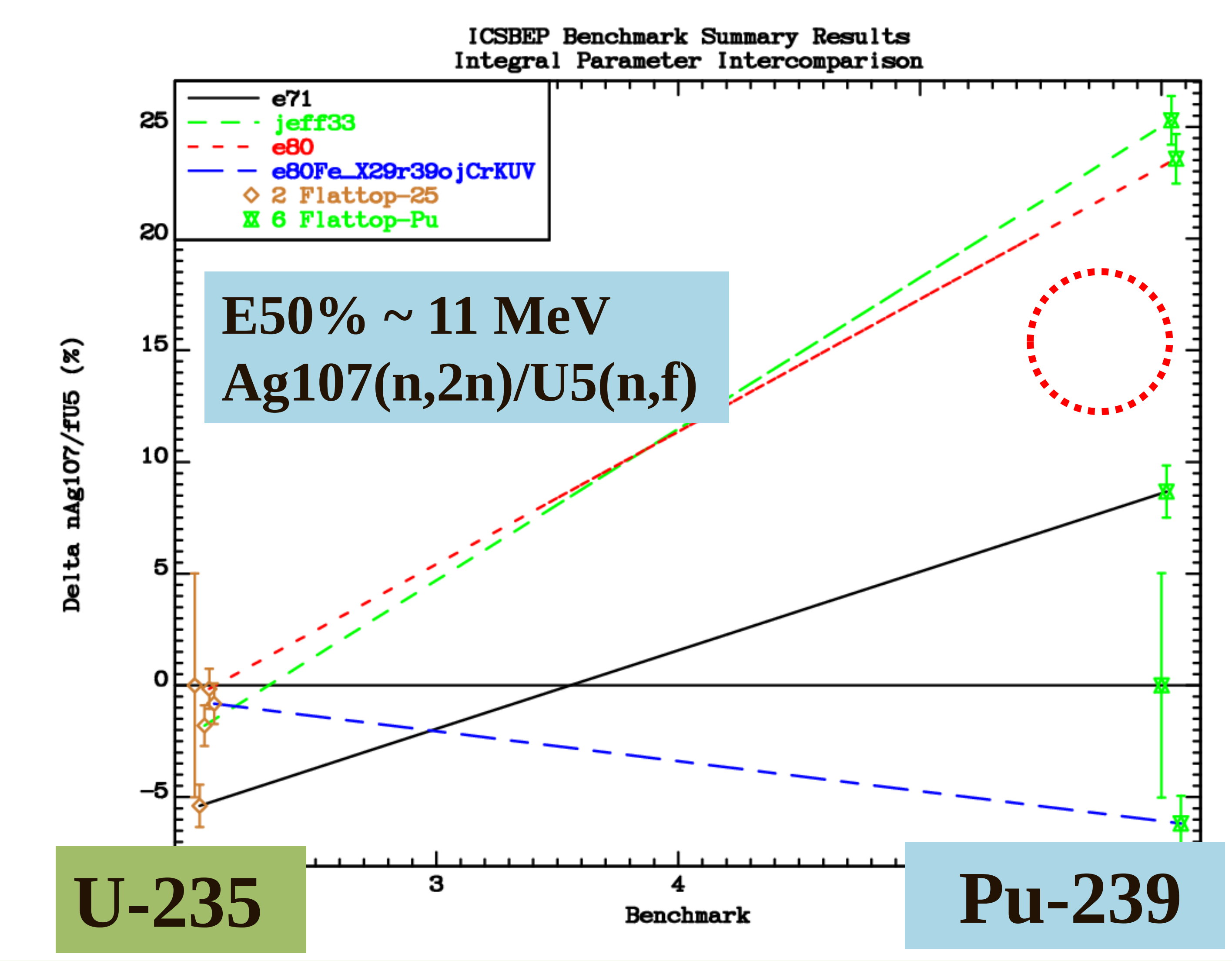
IRDFF Spectral indices: U5, Pu, U3 fast



E50% ~ 11 MeV
Ag107(n,2n)/U5(n,f)

U-235

Pu-239

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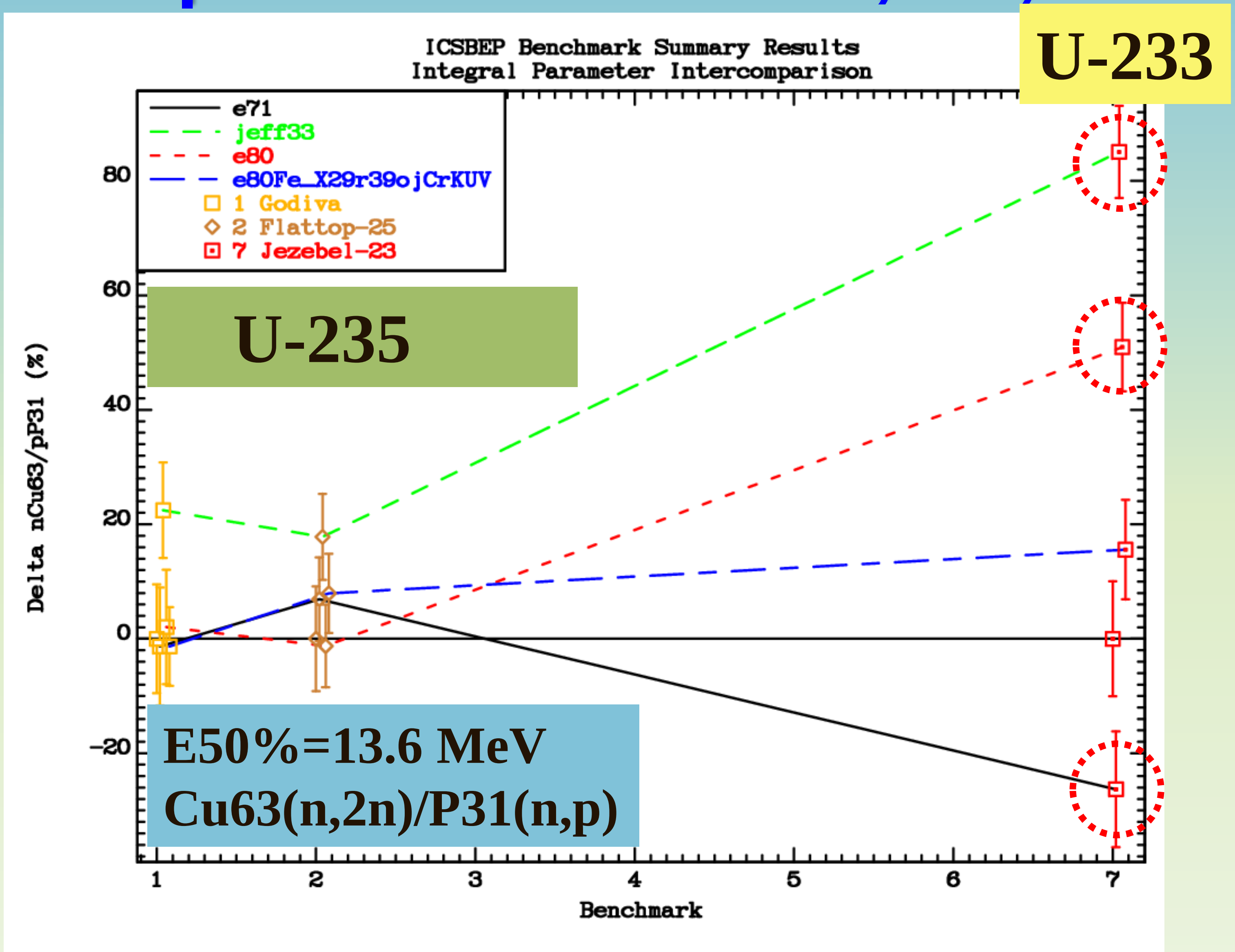
IRDFF Spectral indices: U5, Pu, U3 fast



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Conclusions

- INDEN interactions strongly helped to find deficiencies in existing evaluations and highlight potential solutions to existing challenges: https://www-nds.iaea.org/INDEN/
- Updated trial evaluations for U-235, U-233, Pu-239 are available for testing.

Further work is expected on U-235, Pu-239, and U-233.

- Performance was tested on the ICSBEP and/or SINBAD benchmarks. Significant improvement was demonstrated

  (see Trkov presentation tomorrow), see also RR in Pu and U3.
- The **INDEN** scheme of international collaboration on nuclear data evaluation **is working well**.

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