Update and validation of INDEN evaluations: Impact on B81.beta2

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on behalf of the INDEN collaboration

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

Outlook

- Fe validation
- Si comments **(wrong b1, direct capture backg missed)**
- Cu validation and shortcomings
- F-19 validation
- U-238 validation and comments
- Pu-239 validation and needs
- O-16 comments
- INDEN Mn-55 capture gammas validated

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Fe validation
(and SS)

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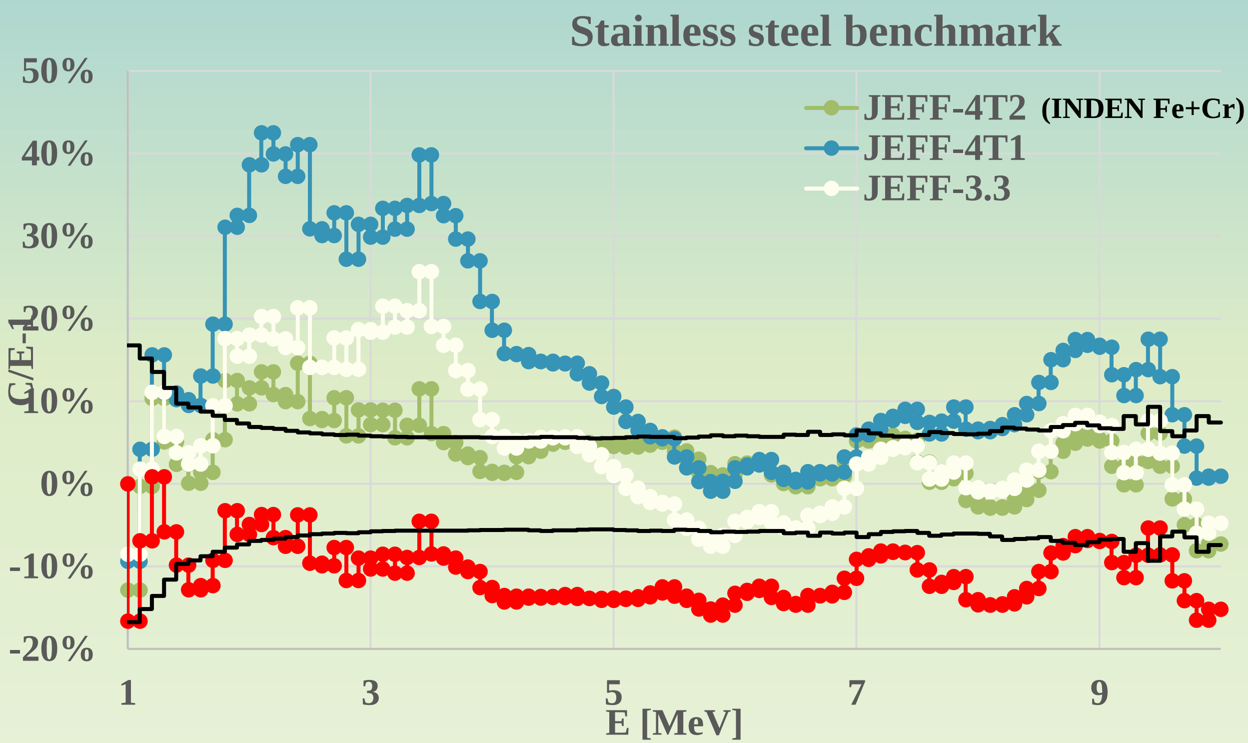
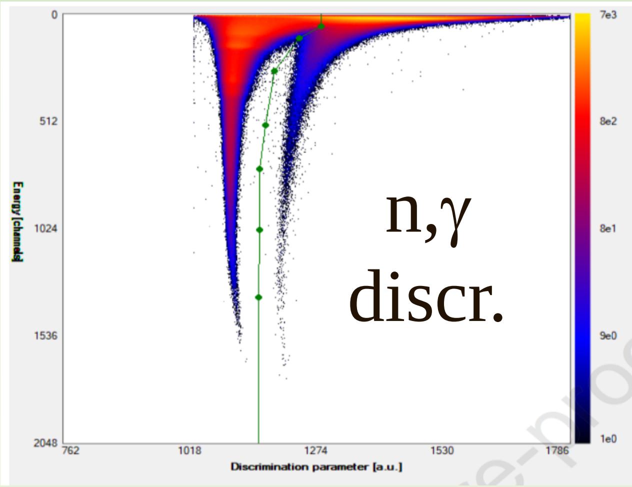
INDEN updated "structural" evaluations: see nds.iaea.org/INDEN/ - Validation

- ✓ Fe isotopes (IAEA/JSI), fe54e80o, fe56e80X29r41, fe54e80o
- ✓ Cr isotopes, BNL/ORNL/IAEA/JSI/CEA, v2.3.2



Kostal et al, priv. com. stilbene meas.



Stainless steel, neutron leakage (Rez, CZ, 11/2021)

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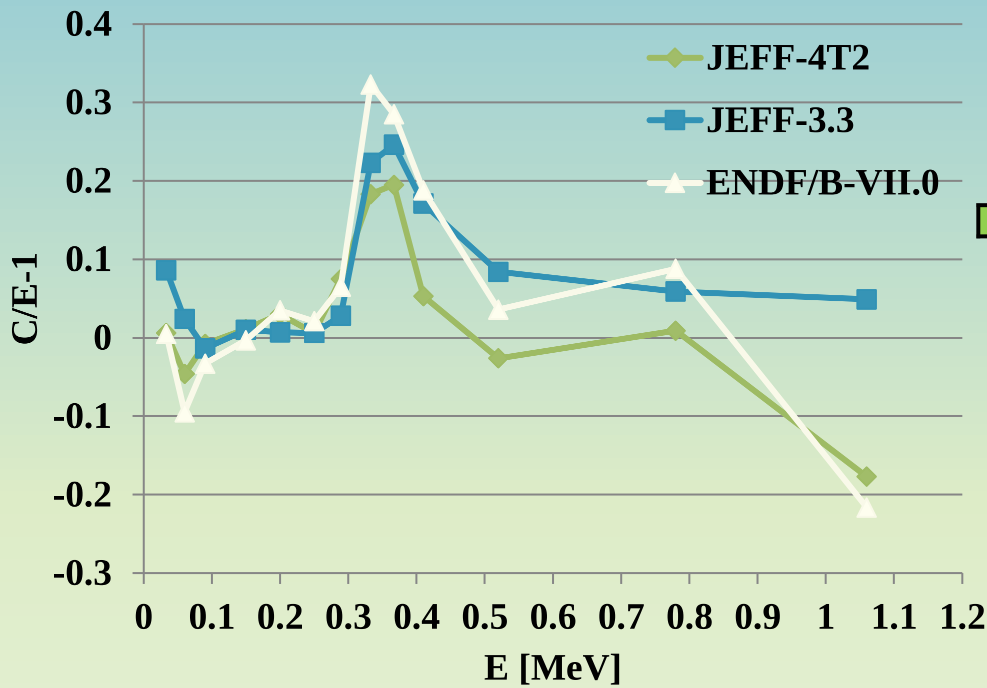
Iron sphere leakage, D=100 cm



	Assembly FE DIA100, R53; HPD measurements 200gpd						
	n-energy intervals for iron [MeV]				data library		
	From	To	EXP[1]	Statist. Unc. [%]	JEFF-4T2	JEFF-3.3	ENDF/B-VII.0
	0.020	1.290	1.01E+00	1.2	1.033	1.064	1.06
24 keV>>	0.020	0.033	1.21E-01	3.35	1.006	1.086	1.005
	0.033	0.060	2.99E-02	15.43	0.9537	1.024	0.905
	0.060	0.090	8.13E-02	5.88	0.9922	0.9864	0.967
	0.090	0.150	1.58E-01	3.84	1.011	1.01	0.9967
	0.150	0.200	1.05E-01	4.6	1.03	1.007	1.035
	0.200	0.250	6.49E-02	6.52	1.006	1.006	1.021
	0.250	0.289	7.80E-02	2.62	1.075	1.028	1.065
	0.289	0.333	9.45E-02	0.93	1.183	1.223	1.323
	0.333	0.367	5.19E-02	1.27	1.195	1.246	1.285
	0.367	0.410	3.00E-02	1.94	1.053	1.171	1.188
	0.410	0.520	5.09E-02	1.6	0.9738	1.084	1.036
	0.520	0.780	1.15E-01	0.63	1.009	1.059	1.088
	0.780	1.060	2.38E-02	1.45	0.8229	1.049	0.7835

Stainless steel, HPD detectors (Rez, CZ, 11/2021)

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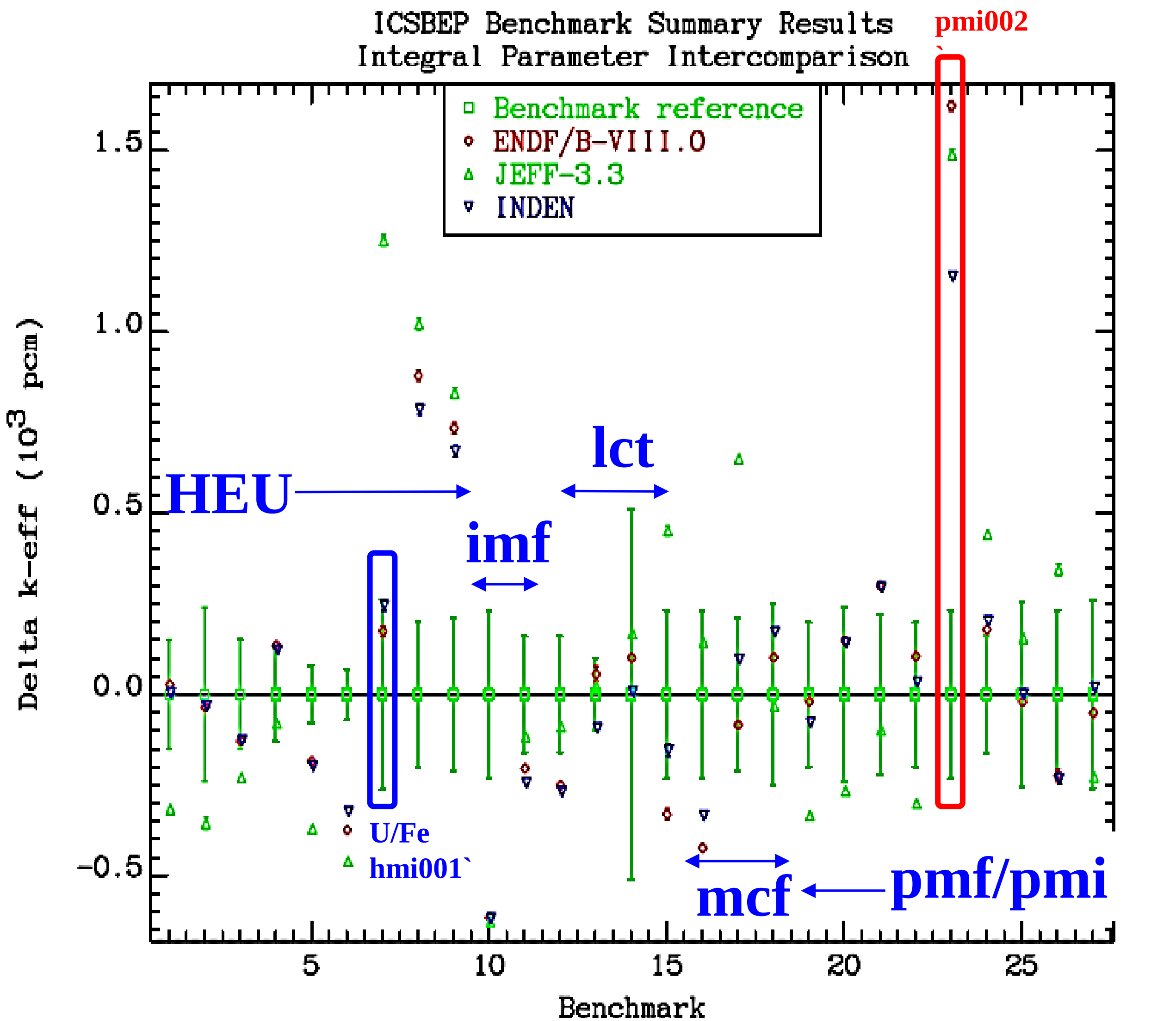
Iron (SS) CRITICALITY



No.	ICSBEP Label
1	HEU-MET-FAST-013
2	HEU-MET-FAST-021
3	HEU-MET-FAST-024
4	HEU-MET-FAST-087
5	HEU-MET-FAST-088
6	HEU-MET-FAST-088
7	HEU-MET-INTER-001
8	HEU-MET-THERM-013
9	HEU-MET-THERM-015
10	IEU-MET-FAST-005
11	IEU-MET-FAST-006
12	LEU-COMP-THERM-042
13	LEU-COMP-THERM-042
14	LEU-COMP-THERM-043
15	LEU-MET-THERM-015
16	MIX-COMP-FAST-001
17	MIX-COMP-FAST-005
18	MIX-COMP-FAST-006
19	PU-MET-FAST-015
20	PU-MET-FAST-025
21	PU-MET-FAST-026
22	PU-MET-FAST-028
23	PU-MET-FAST-032
24	PU-MET-INTER-002
25	PU-MET-INTER-003
26	PU-MET-INTER-004
27	IEU-COMP-INTER-005
28	PU-MET-FAST-015

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Keff as f(SS thickness)

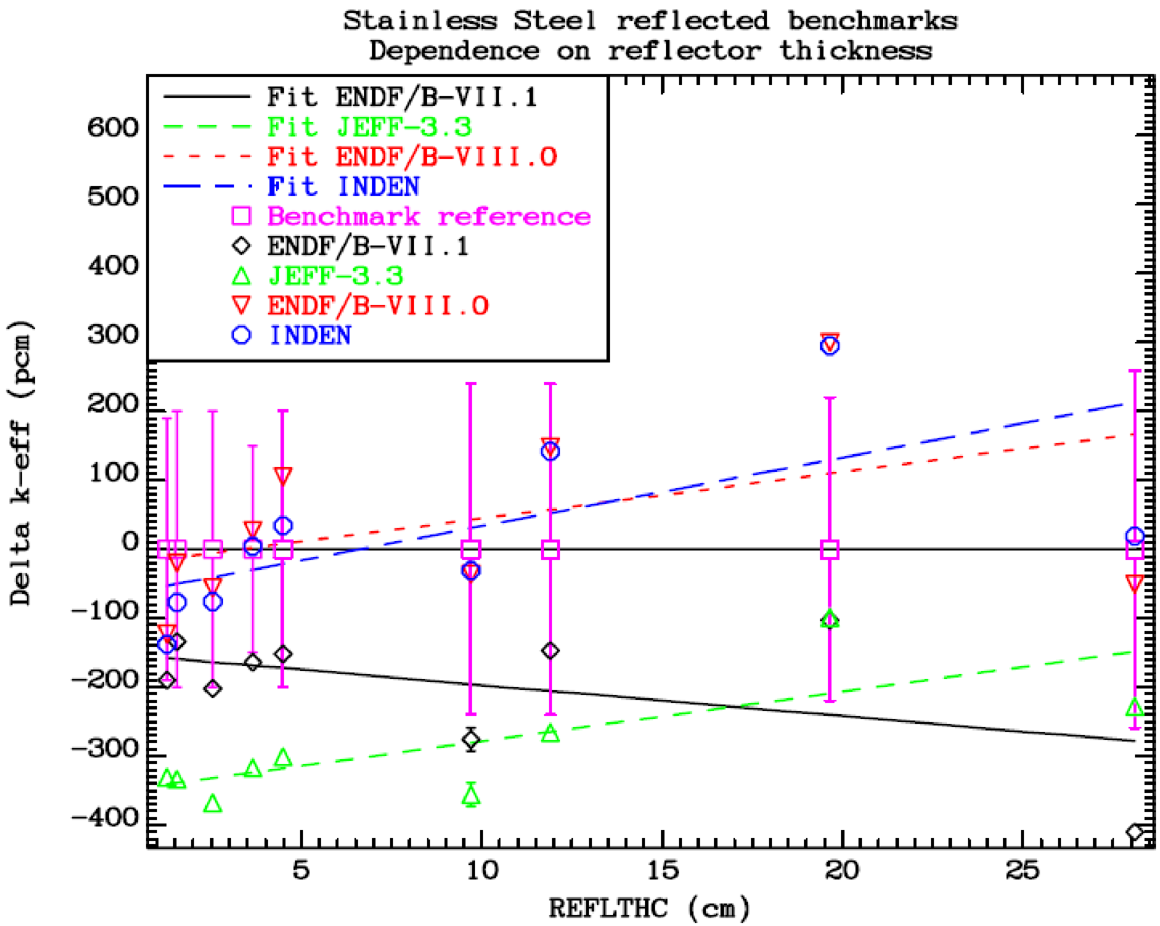

Table 2. Short list of ICSBEP criticality fast benchmarks with different thicknesses of stainless steel reflectors.

ICSBEP Label	Short name	Common name	Reflector thickness [cm]
HEU-MET-FAST-084	hmf084-019	Comet-Fe	1.27
PU-MET-FAST-025	pmf025	pmf025	1.55
HEU-MET-FAST-084	hmf084-007	Comet-Fe	2.54
HEU-MET-FAST-013	hmf013	VNIITF-CTF-SS-13	3.65
PU-MET-FAST-032	pmf032	pmf032	4.49
HEU-MET-FAST-021	hmf021	VNIITF-CTF-SS-21	9.70
PU-MET-FAST-026	pmf026	pmf026	11.9
PU-MET-FAST-028	pmf028	pmf028	19.7
PU-MET-FAST-015	pmf015s	BR-1-3	28.1

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The Pool Critical Assembly (PCA) Pressure Vessel Simulator experiment was performed in the early 1980s as part of the NRC's LWR Pressure Vessel Surveillance Dosimetry Improvement Program (LWR-PV-SDIP)

Benchmark was recently re-analyzed with exact geometry by Dr. Kulesza (LANL/X-5), and MCNP inputs were published and available for use:
- NUCLEAR TECHNOLOGY · VOLUME 197 · 284–295 · MARCH 2017
- Paper: https://doi.org/10.1080/00295450.2016.1273711
- MCNP Inputs: https://doi.org/10.2172/1601379

Pool Critical Assembly Benchmarking

- C/E Results (ENDF/B-VIII.1b1):
  - MC uncertainty ~= 1%

Depends on U-235, water & SS

	al27a	ni48p	rh103n	in115n	u238f	np237f	**avg**	**std dev**
	0.97	0.96	1.04	1.00			**0.99**	**3.9%**
	1.02	0.98	1.08	1.01			**1.02**	**4.3%**
	1.05	1.01	1.07	1.06			**1.05**	**2.5%**
	1.03	0.96	1.00	1.01	0.98	1.03	**1.00**	**2.7%**
	1.03	0.96	0.95	1.00	0.98	1.05	**0.99**	**4.0%**
	1.04	1.02	0.93	1.03	0.98	1.03	**1.00**	**4.1%**
			0.96	0.99	0.99	1.13	**1.02**	**7.6%**
avg	**1.02**	**0.98**	**1.01**	**1.01**	**0.98**	**1.06**	**1.01**	
std dev	**2.8%**	**2.9%**	**6.4%**	**2.1%**	**0.1%**	**1.0%**		**4.2%**

Presented by Greg Fischer, Westinghouse @ miniCSWEG April 2023

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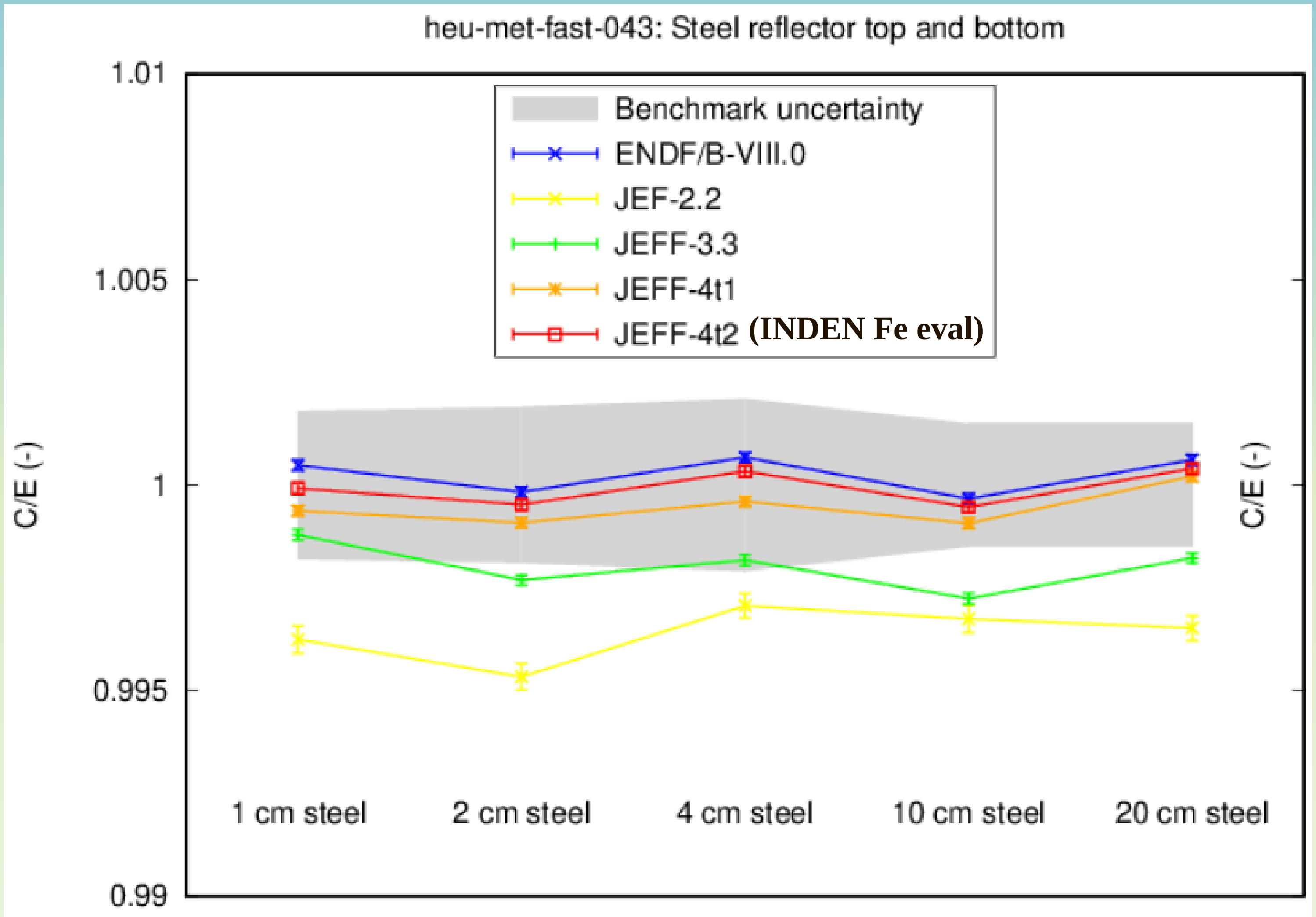
heu-met-fast-043 (steel reflector)



Courtesy of S. Vandermarck, @ JEFF meeting 24-27 April 2023

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F-19 validation
(Teflon, fluoride solutions)

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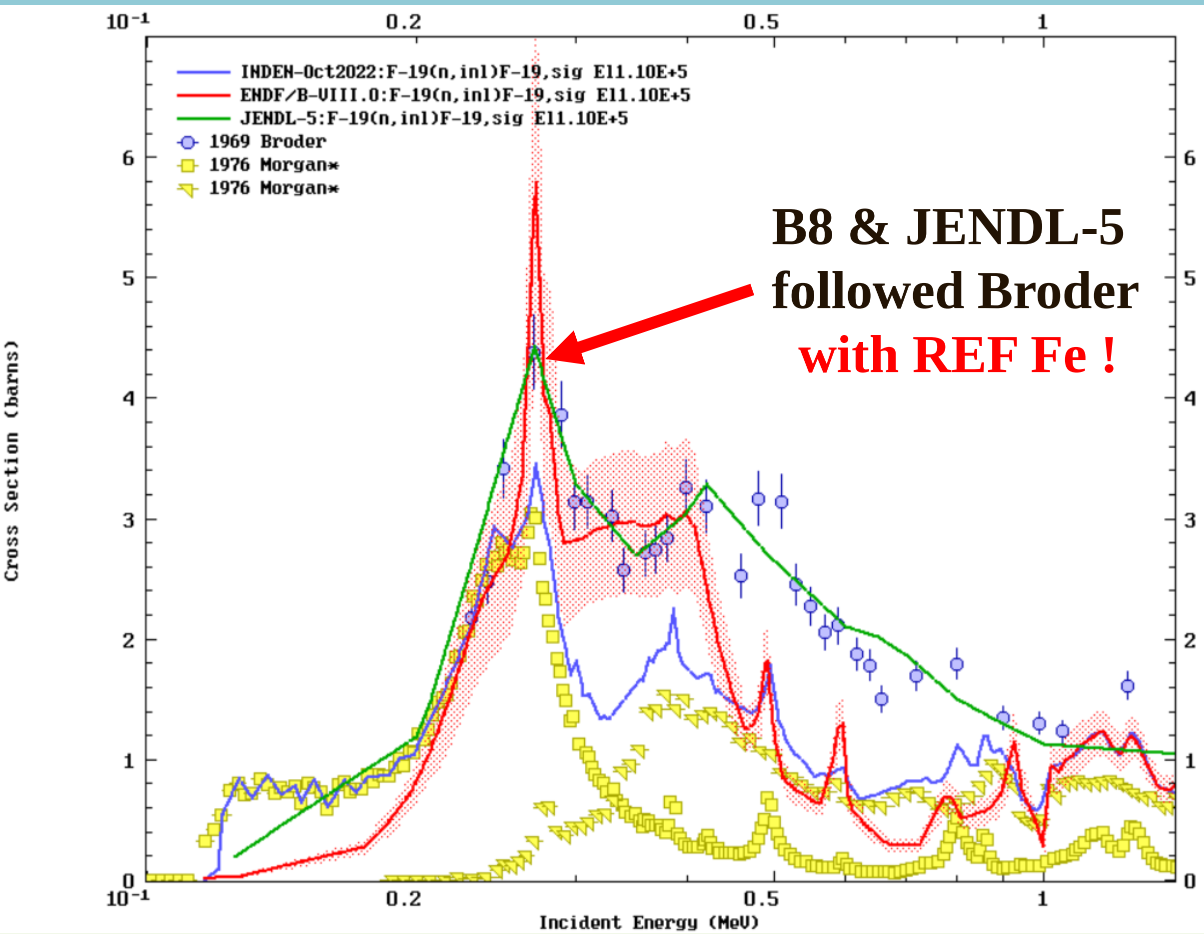
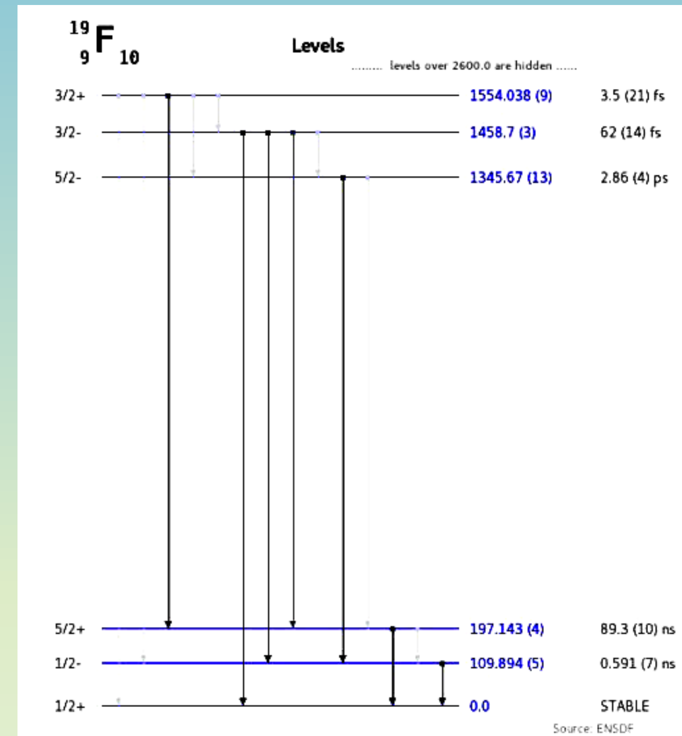
Morgan 76 data adopted << Broder data





By using Morgan derived INL data (nng x 4pi)
F-19(n,inl) reduced by ~40% from 300 keV

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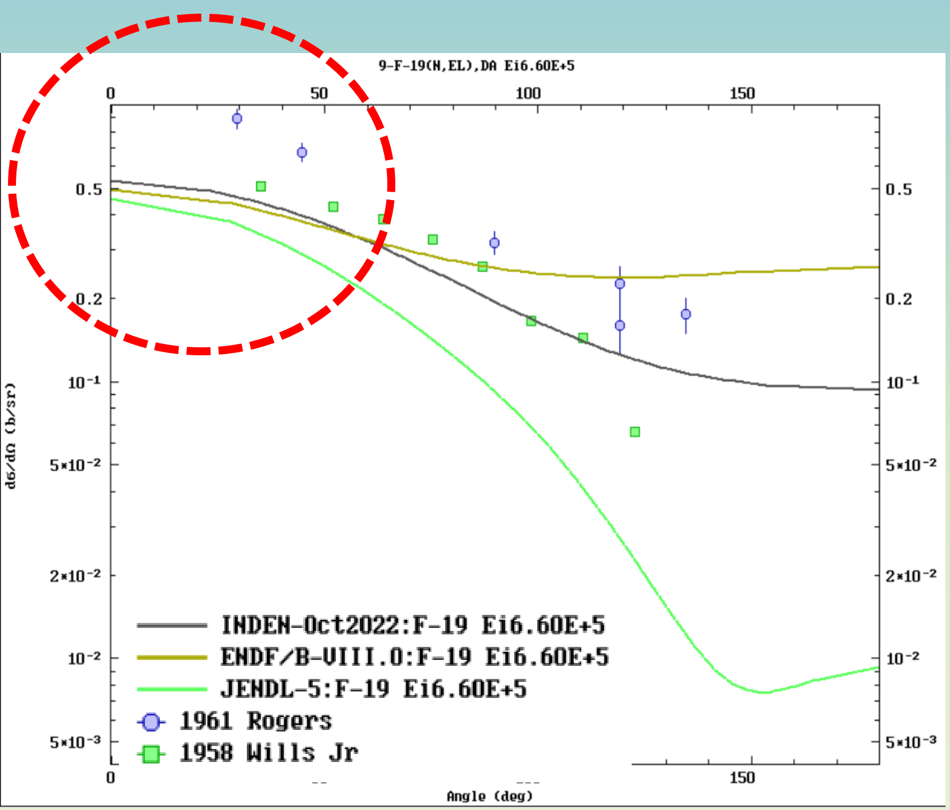
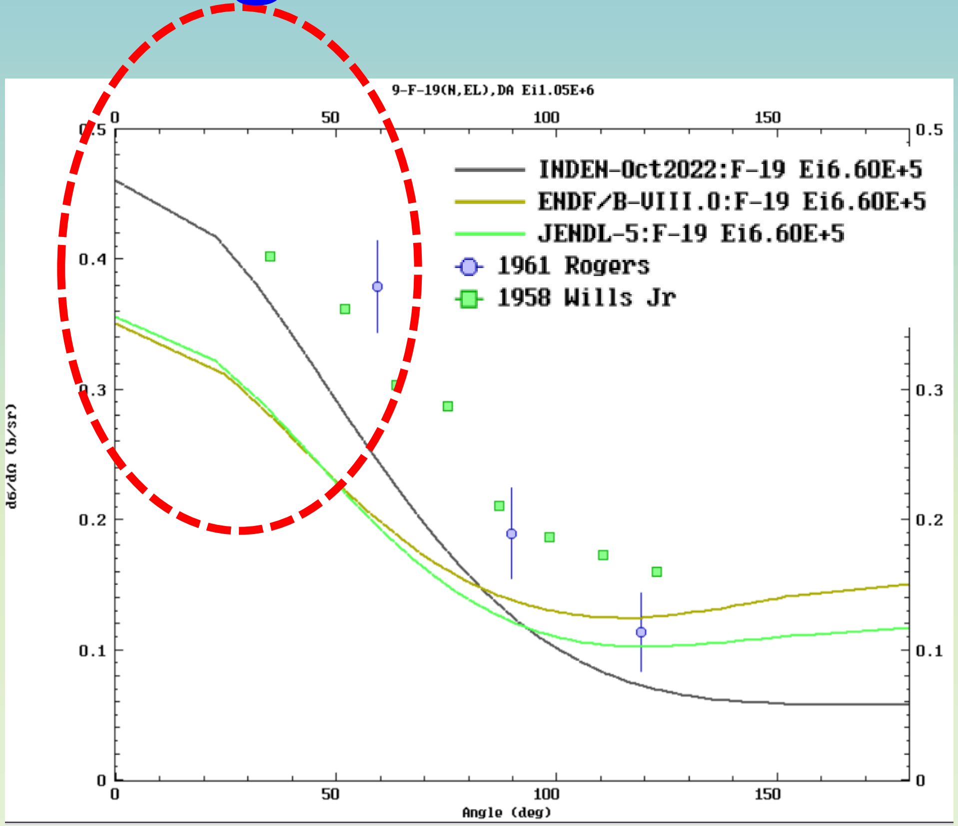
Issues in ^{19}F(n,el) AD below 1 MeV at forward angles





Issues in ^{19}F(n,el) AD below 1 MeV pointed out by our Japanese colleagues

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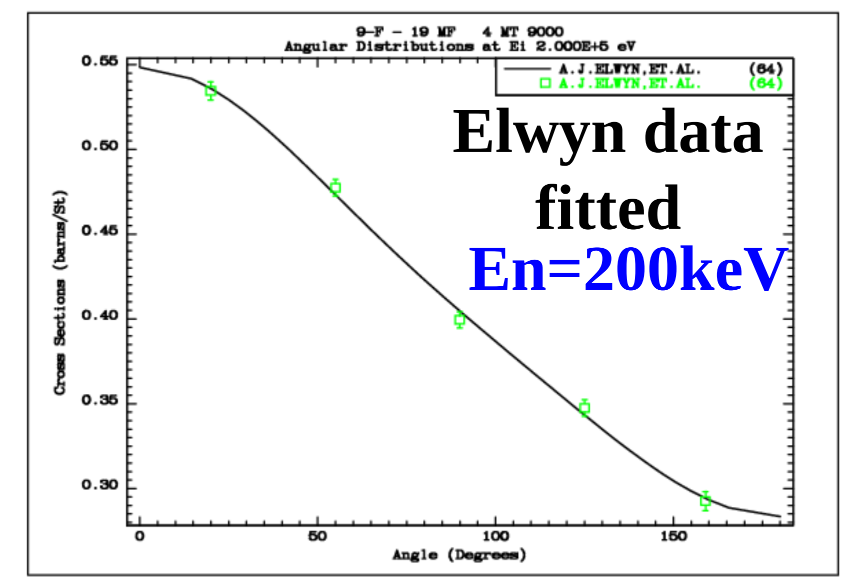
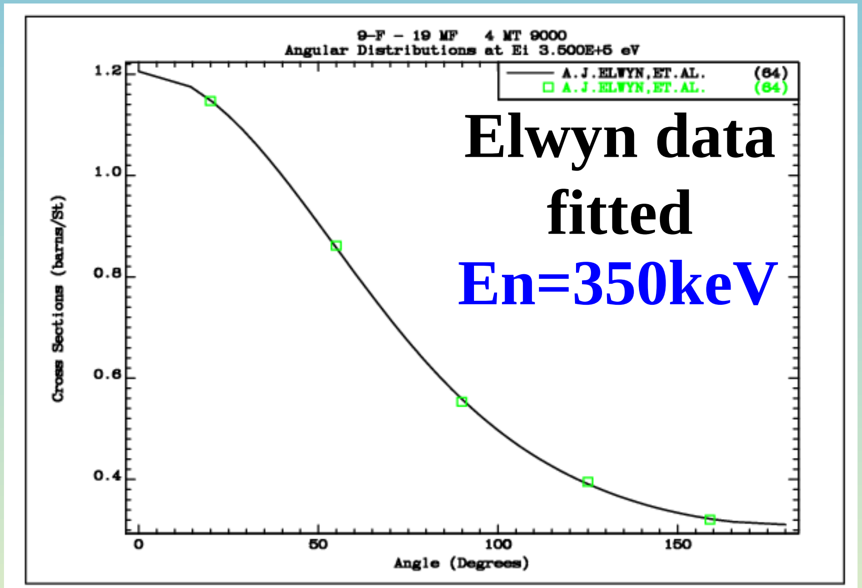
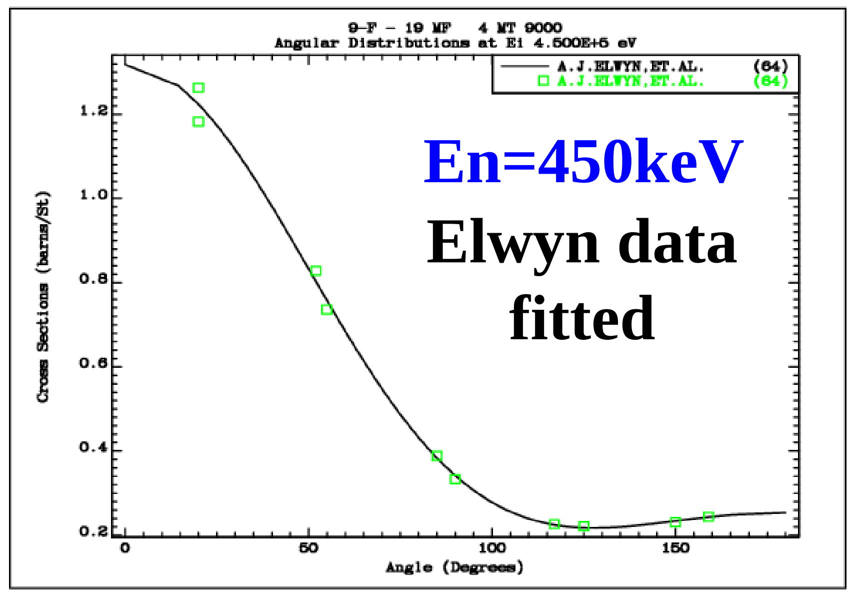
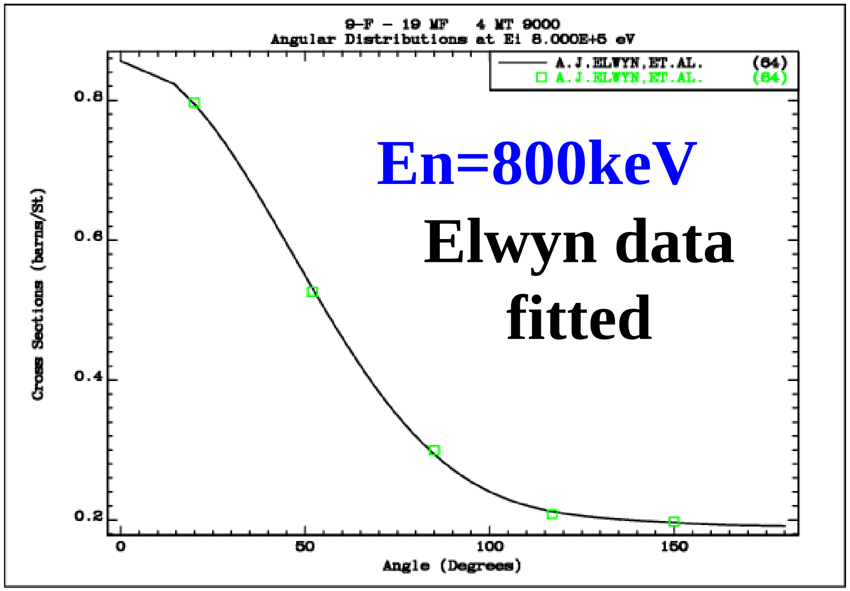
INDEN F-19 evaluation (f19e80_zt9)









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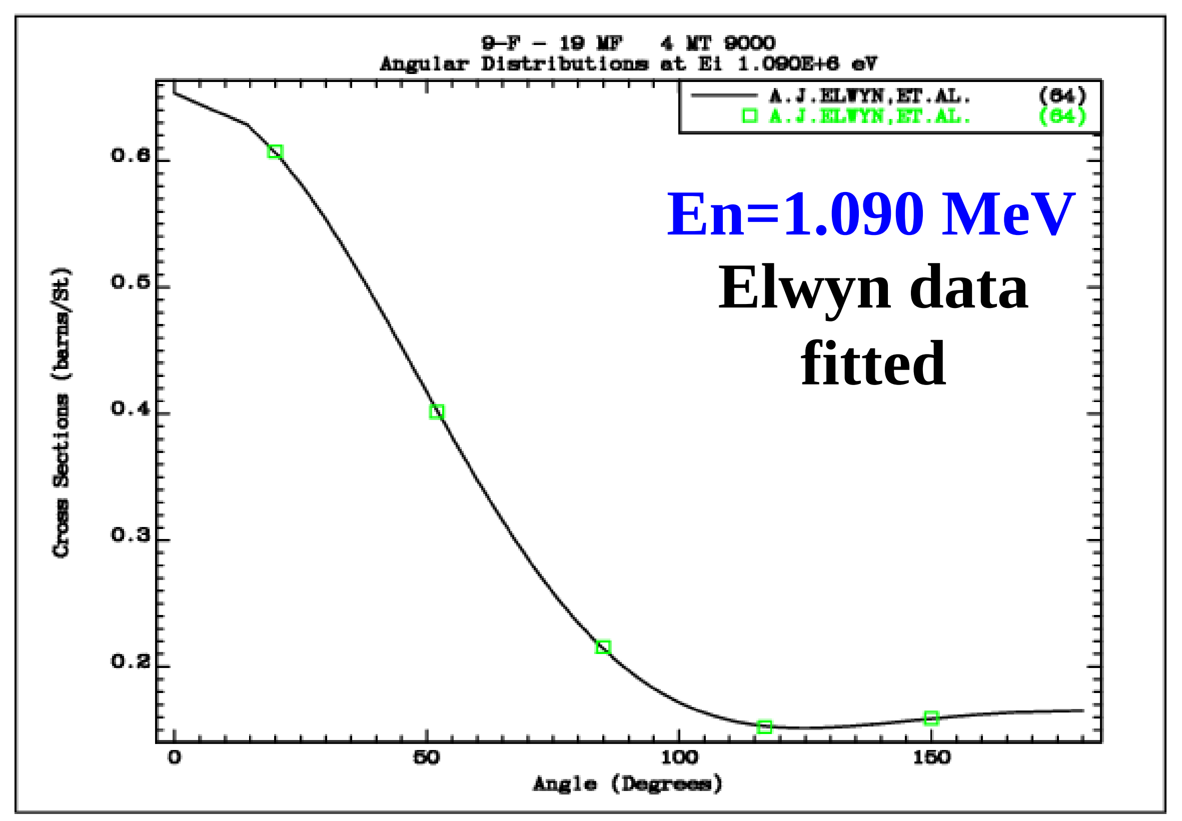
INDEN F-19 evaluation (f19e80_zt9)



Check updated INDEN F-19 evaluation

f19e80_zt9 vs f19j50_zq

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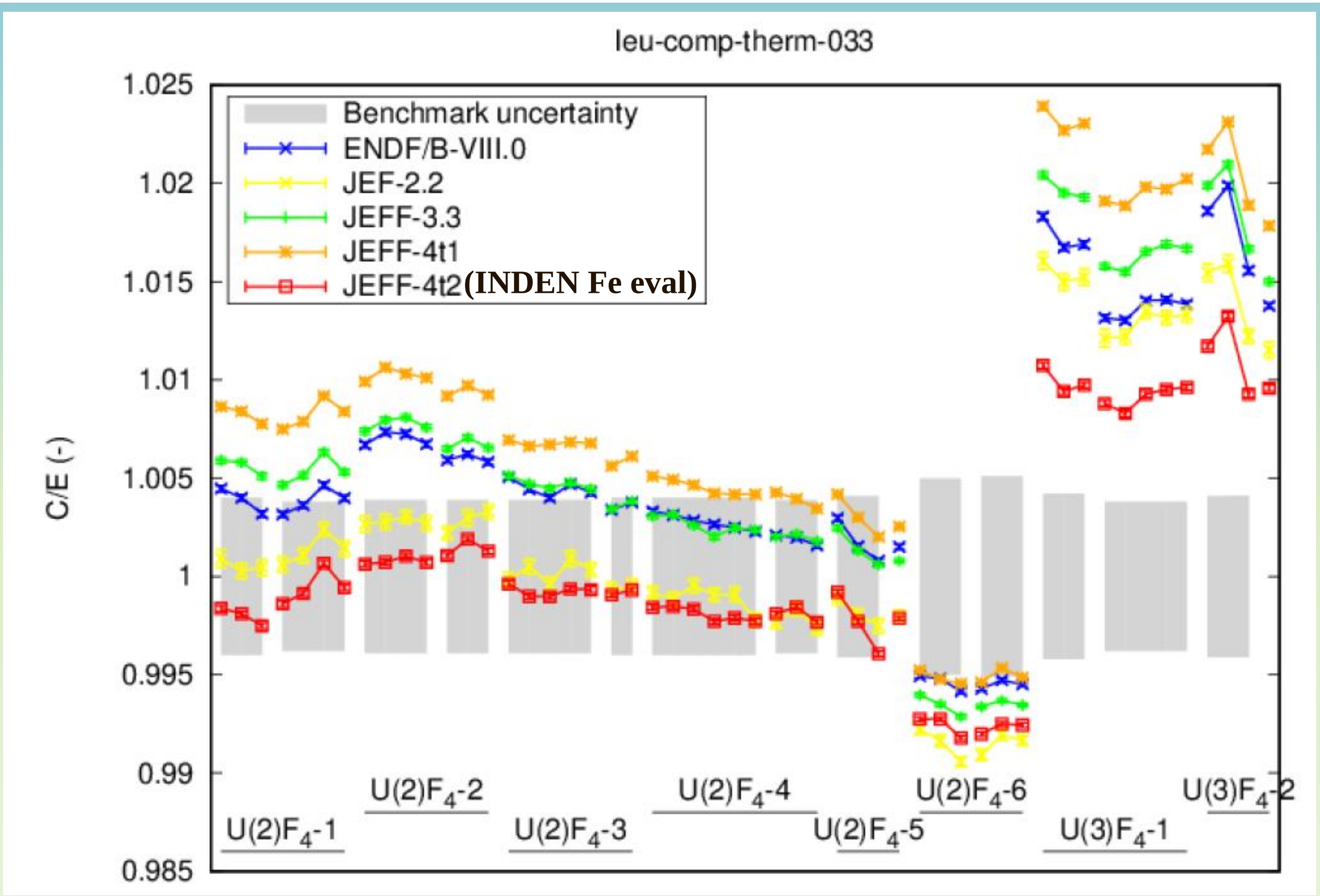
leu-comp-therm-033: UF_4 with paraffin



Courtesy of S. Vandermarck, @ JEFF meeting 24-27 April 2023

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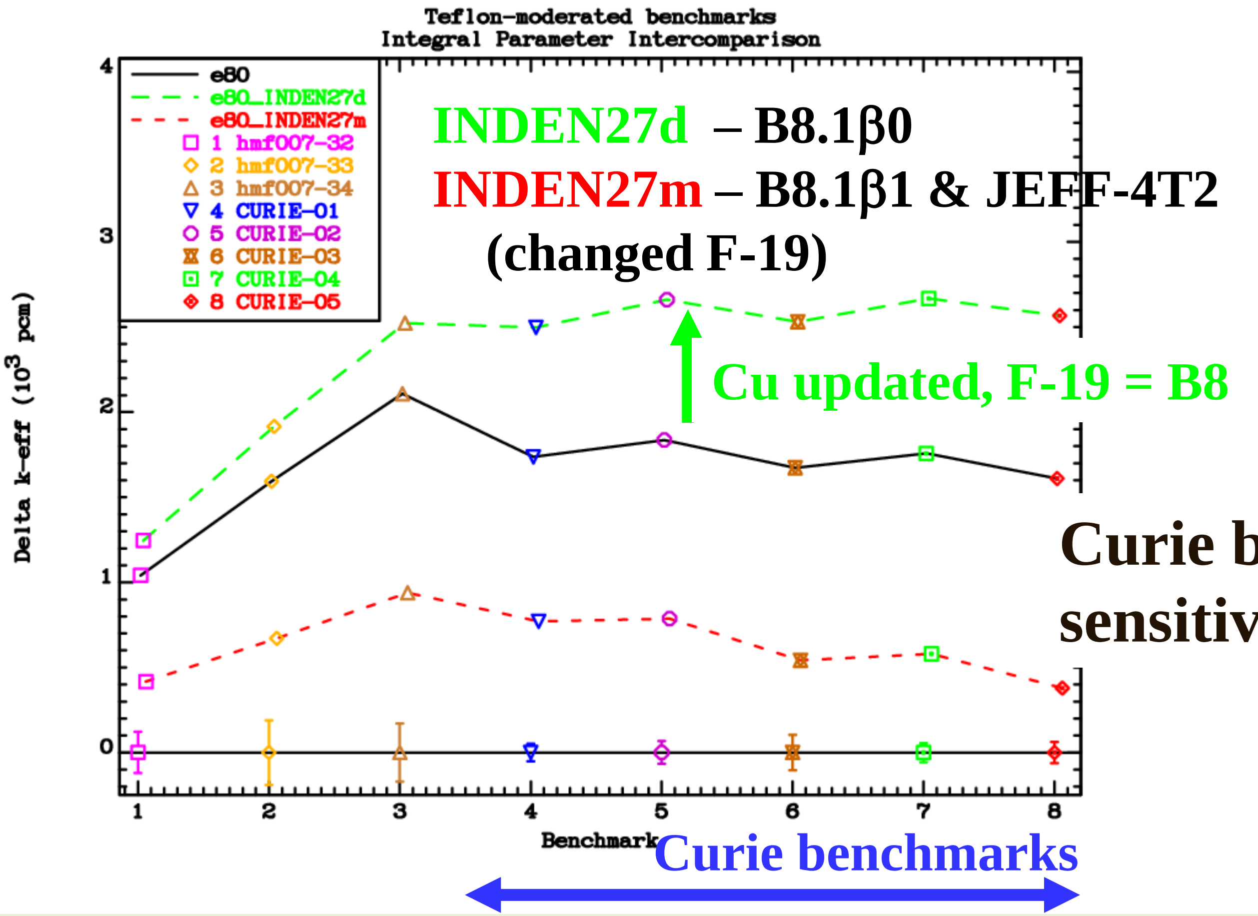
^{19}F: Teflon moderated Curie benchmarks



Curie benchmarks highly sensitive to Cu and F-19 !!

Check also HST039 !

Curie is in the latest ICBESP

See also LCT033 (UF4 with paraffin) performance shown by S. Vandermarck

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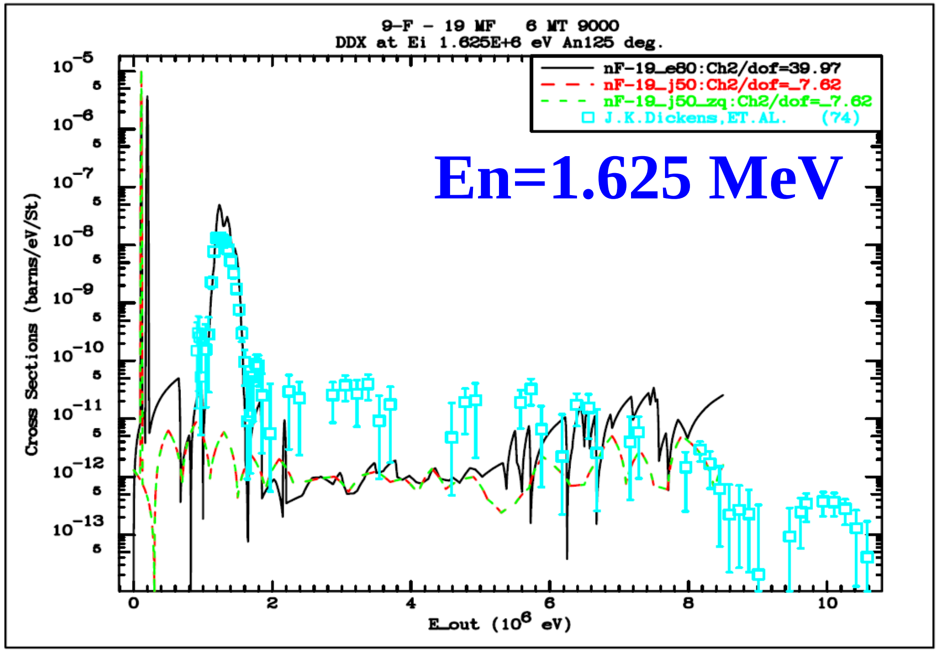
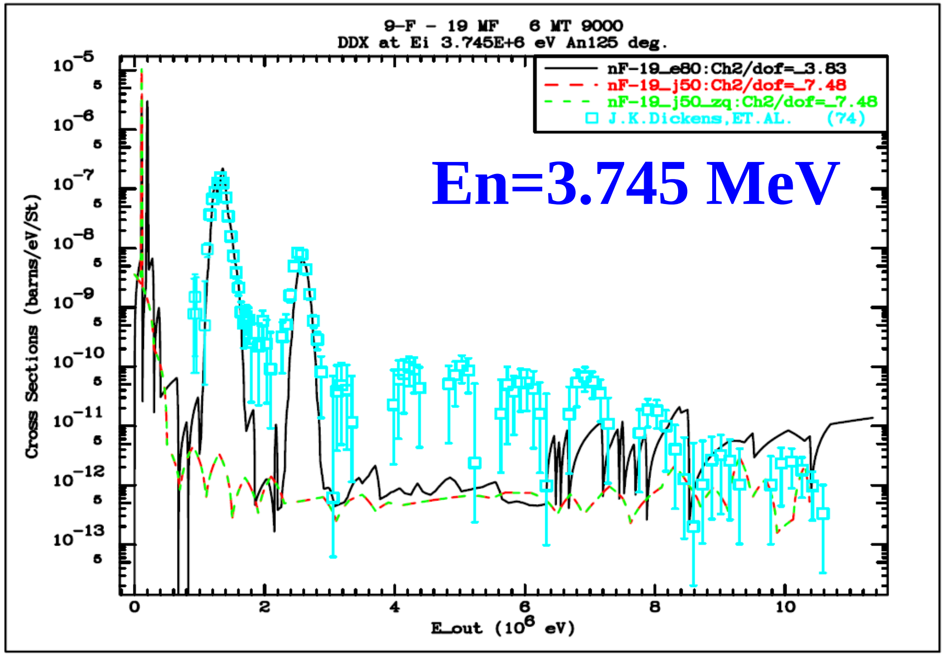
INDEN F-19 evaluation (f19e80_zt9)





Improved gamma emission in updated INDEN F-19 evaluation

f19e80_zt9

(vs f19j50_zq)

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Cu-63 & Cu-65 validation

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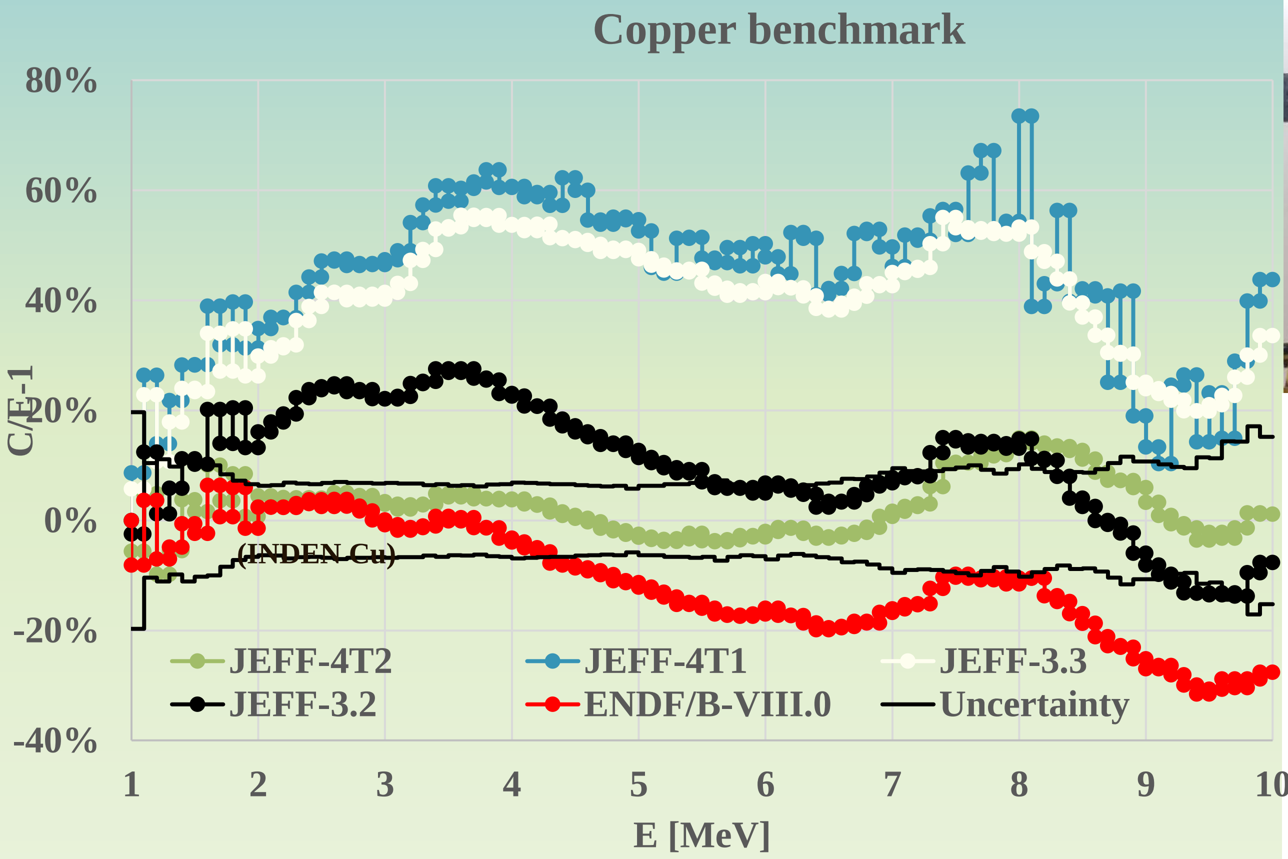
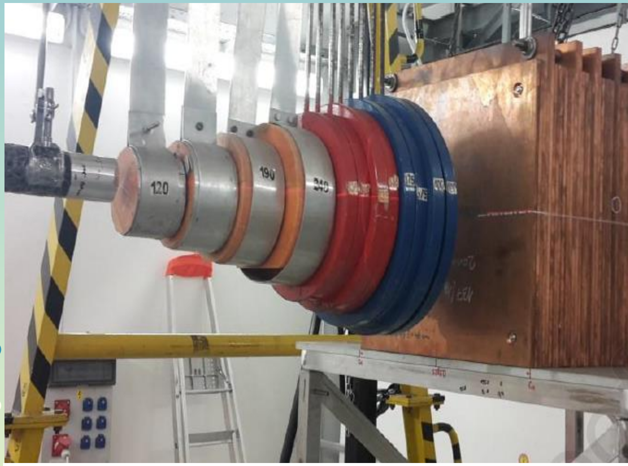
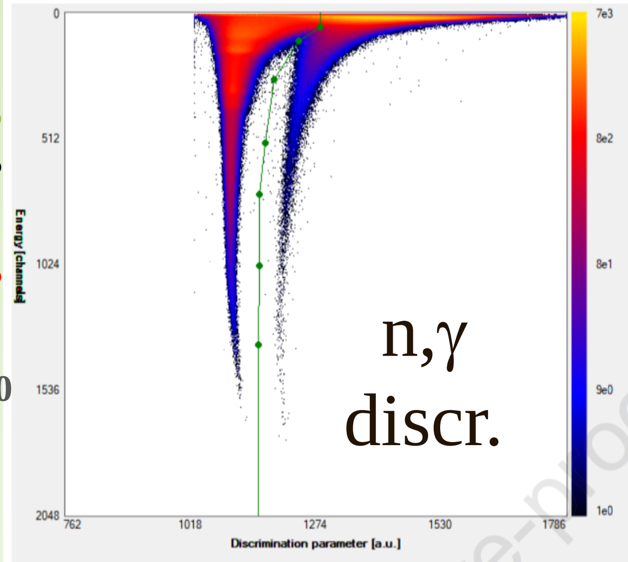
INDEN updated "structural" evaluations: see nds.iaea.org/INDEN/ - Validation

- ✓ Cu isotopes, ORNL/IAEA/JSI







Cu cube, neutron leakage (Rez, CZ) Schulc et al, Rad.Phys.Chem. 2021

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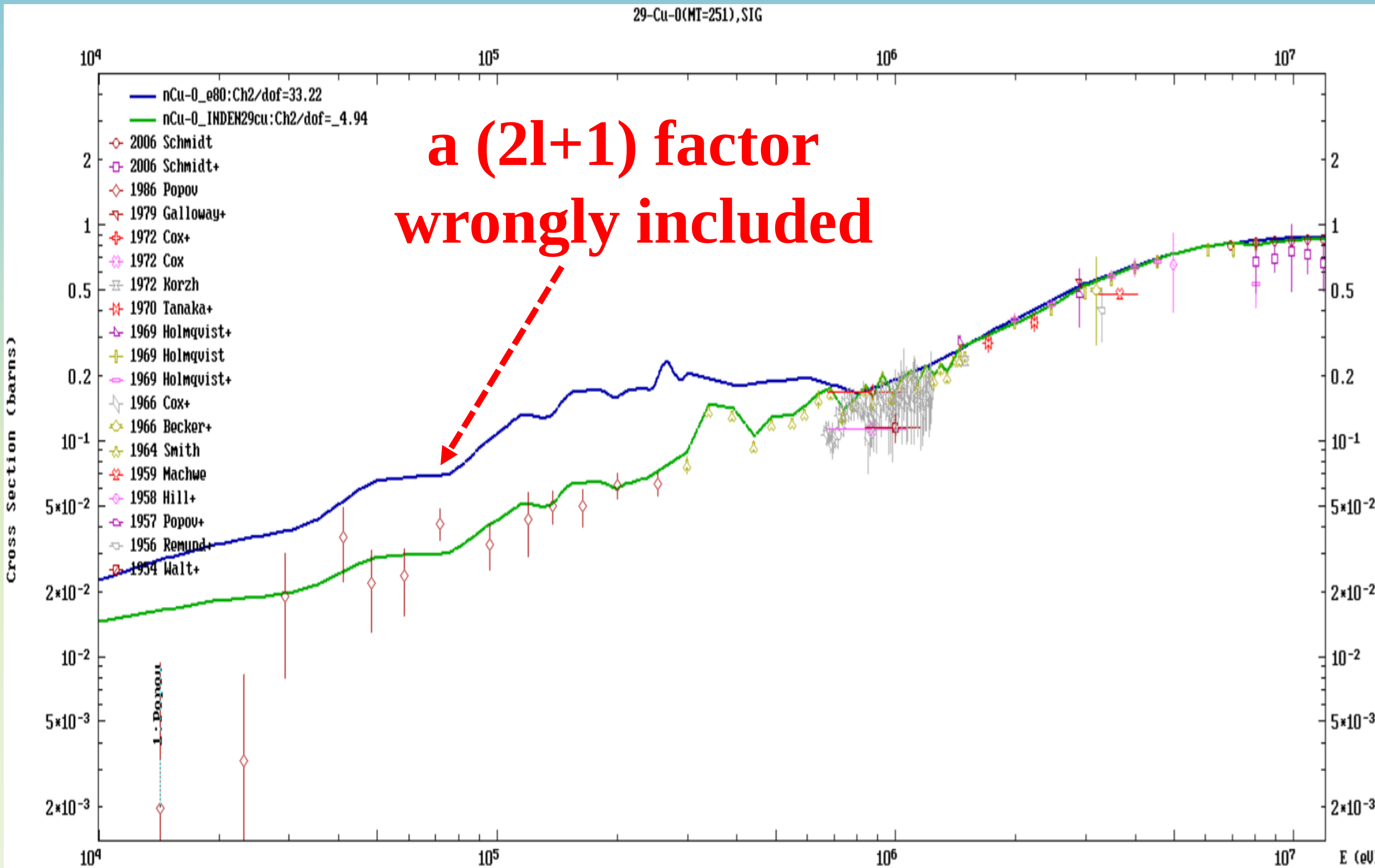
Problem in AD in the RRR: Popov data not reproduced!



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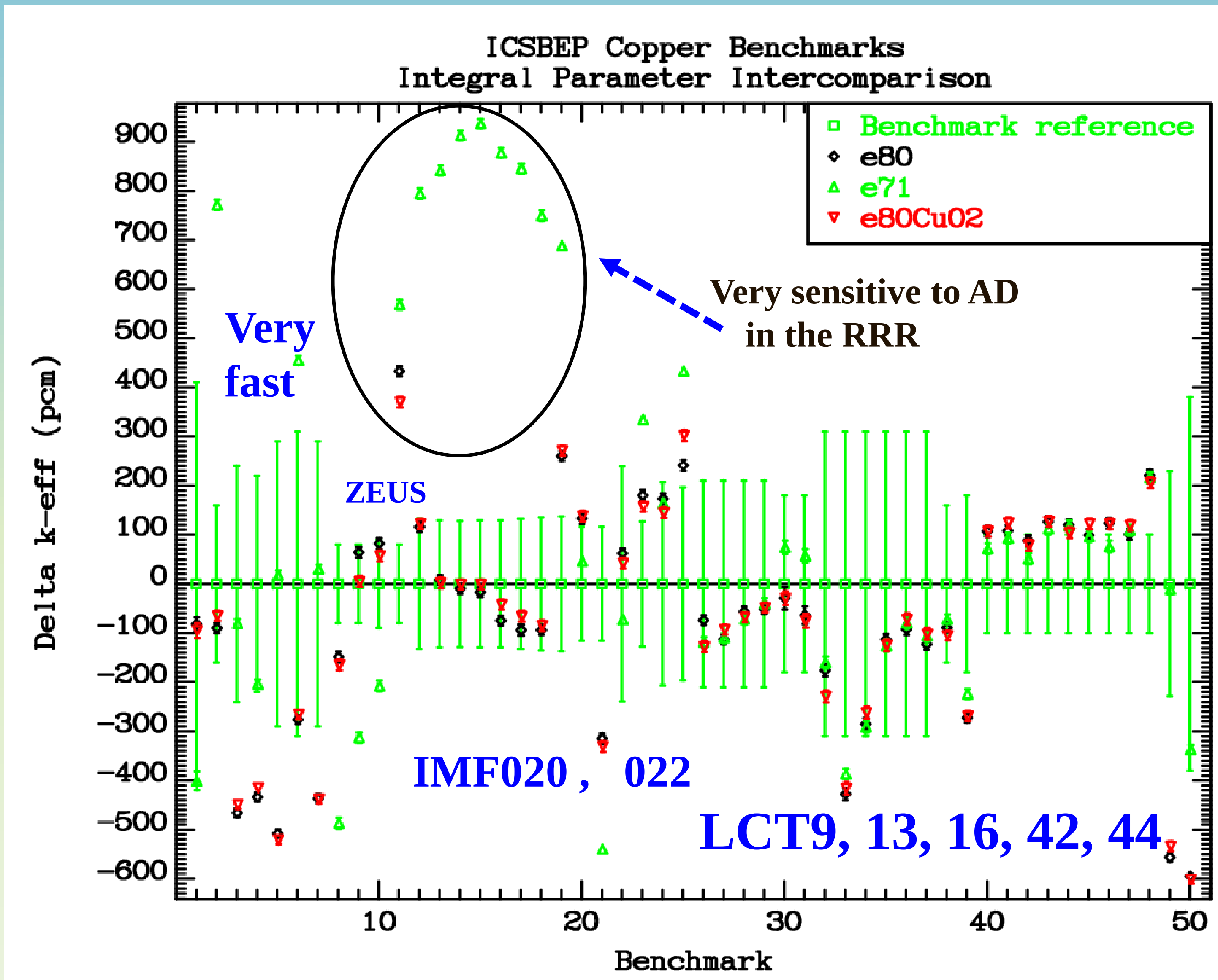
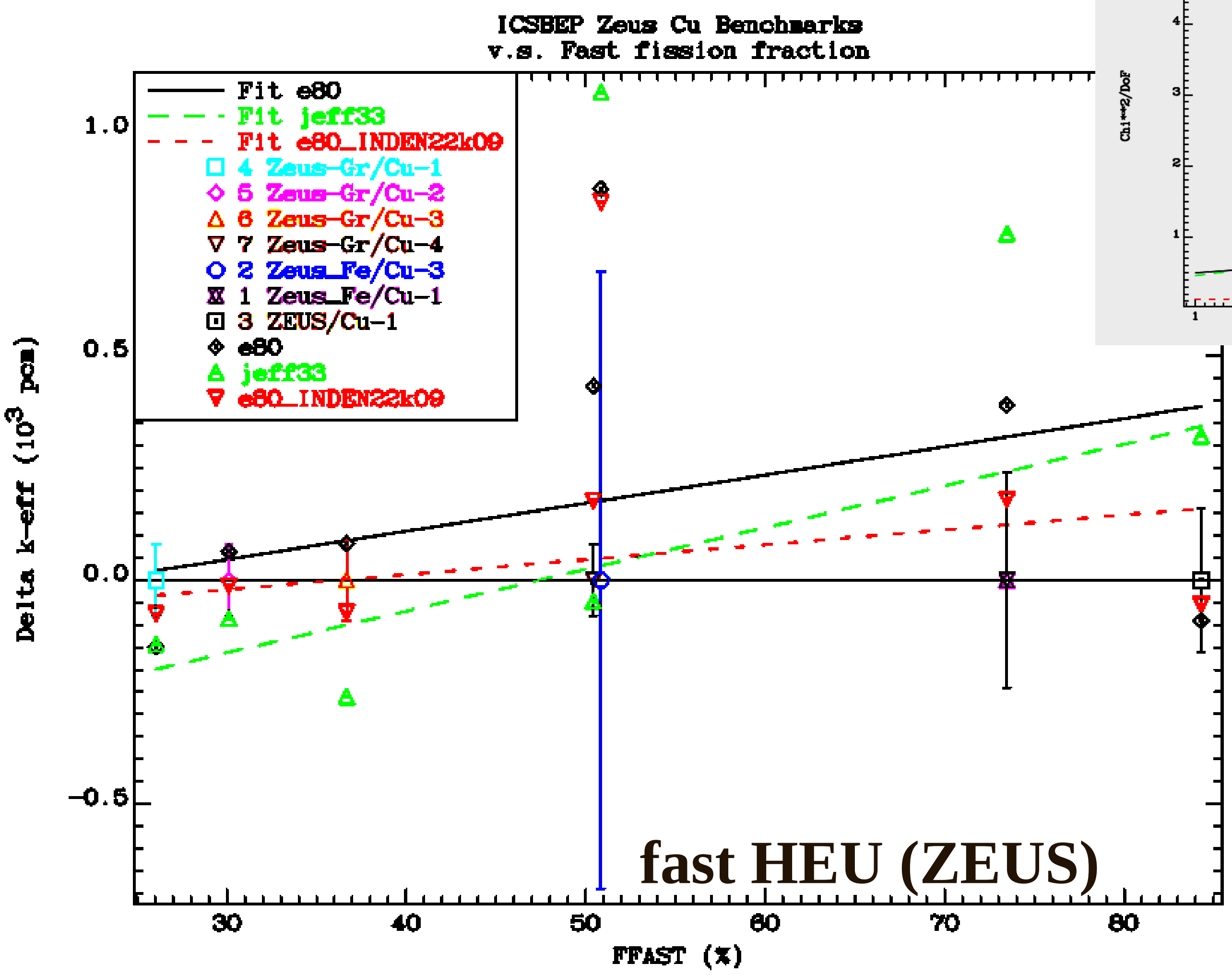
Criticality validation of INDEN Cu adopted in B81b1

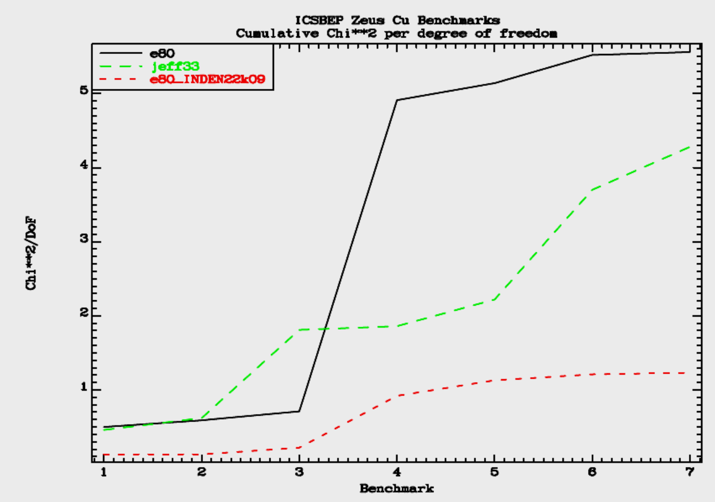


1	hct007-002	RRCt-2
2	hmf073	Zeus/Cu
3	hmf084-006	Comet-Cu_1.0in
4	hmf084-018	Comet-Cu_0.5in
5	hmf085-001	Comet-Cu_2in
6	hmf085-002	Comet-Cu_4in
7	hmf085-004	Comet-SS_4in
8	hmi006-001	Zeus-Gr/Cu-1
9	hmi006-002	Zeus-Gr/Cu-2
10	hmi006-003	Zeus-Gr/Cu-3
11	hmi006-004	Zeus-Gr/Cu-4
12	imf020-001s	FRO_T0/1E-S
13	imf020-002s	FRO_T1-S
14	imf020-003s	FRO_T2-S
15	imf020-004s	FRO_T3-S
16	imf020-005s	FRO_T4a-S
17	imf020-006s	FRO_T5-S
18	imf020-007s	FRO_T6a-S
19	imf022-001	FRO_3X-S
20	imf022-002	FRO_5-S
21	imf022-003	FRO_6A-S
22	imf022-004	FRO_7-S
23	imf022-005	FRO_8-S
24	imf022-006	FRO_9-S
25	imf022-007	FRO_10-S
26	lct009-010	PNL_2.54p_CuNoCd
27	lct009-011	PNL_2.54p_CuNoCd
28	lct009-013	PNL_2.54p_CuNoCd
29	lct009-015	PNL_2.54p_Cu1.0Cd
30	lct013-006	PNL_1.892p_Cu
31	lct013-007	PNL_1.892p_CuCd
32	lct016-015	PNL_2.032p_t11Cu
33	lct016-016	PNL_2.032p_t22Cu
34	lct016-017	PNL_2.032p_t33Cu
35	lct016-018	PNL_2.032p_t14Cu
36	lct016-019	PNL_2.032p_t25Cu
37	lct016-020	PNL_2.032p_Cdt16Cu
38	lct042-006	PNL_1.68p-6
39	lct042-007	PNL_1.68p-7
40	lct044-002	IPEN/MB-01_D02
41	lct044-003	IPEN/MB-01_D03
42	lct044-004	IPEN/MB-01_D04
43	lct044-005	IPEN/MB-01_D05
44	lct044-006	IPEN/MB-01_D06
45	lct044-007	IPEN/MB-01_D07
46	lct044-008	IPEN/MB-01_D08
47	lct044-009	IPEN/MB-01_D09
48	lct044-010	IPEN/MB-01_D10
49	pmf013	BR-1-2/Cu
50	pmf040	VNIIEF/Cu

ENDF/B-VIII.0 good criticality preserved (blue vs black)

INDEN Cu evaluation: Zeus benchmarks





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U-238 new evaluation
post-b1 evaluation

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Summary: INDEN e80V03i4 evaluation

Update of the ENDF/B-VIII.0 evaluation (IAEA CIELO)

INDEN e80V03i4 @ https://www-nds.iaea.org/INDEN/data/u238e80u8V03i4_ENDF.zip

- ✓ The ENDF/B-VIII.0 RRR is replaced by JENDL-5 RRR evaluation
- ✓ This update preserves the ENDF/B-VIII.0 BOC criticality but eliminates the depletion trend at high burnup (due to higher Pu239 accumulation).
- ✓ A new nubar evaluation was produced by LANL colleagues (Neudecker et al). Nubar was tweaked to better reproduce Jemima trend.

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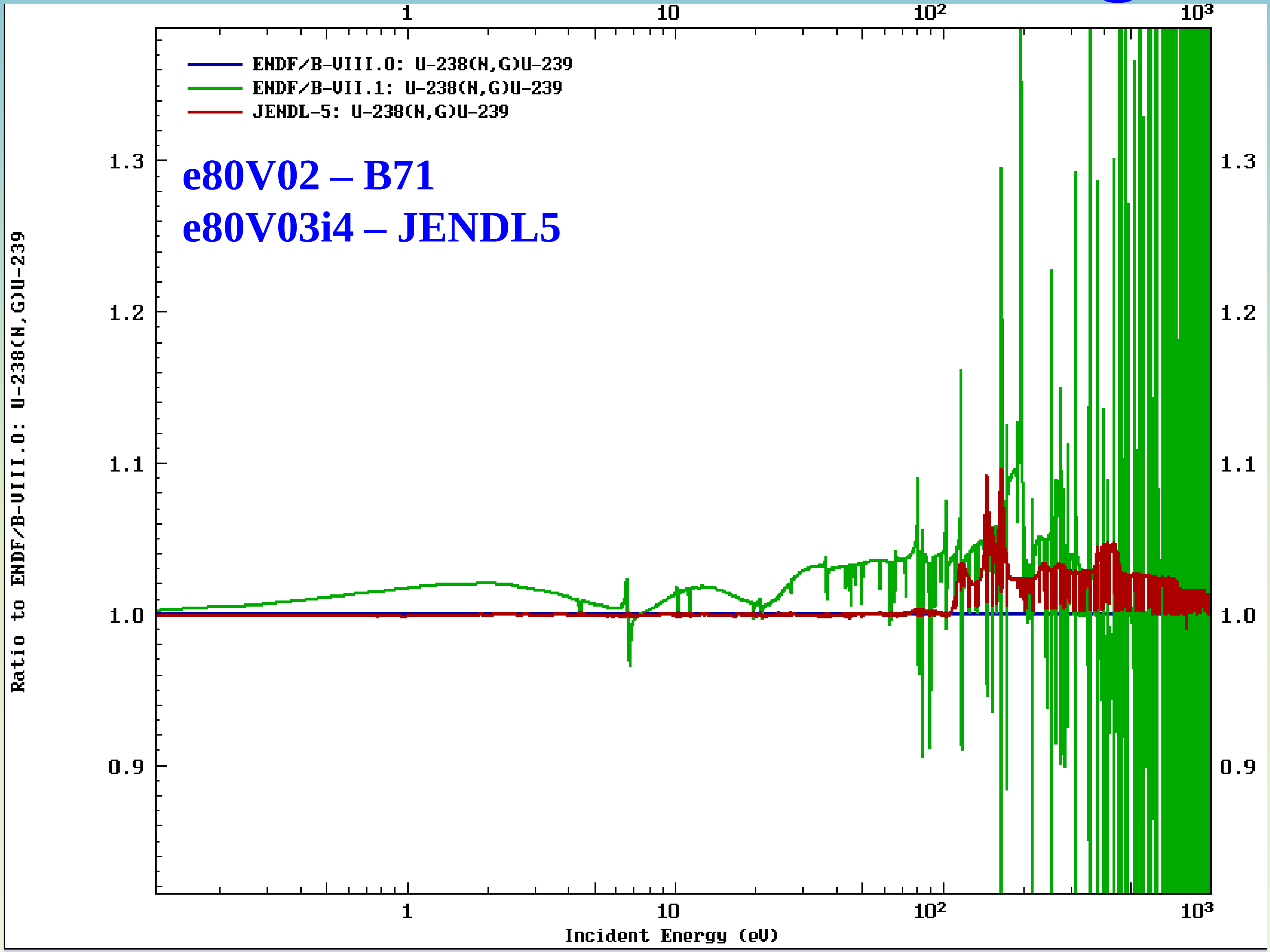
INDEN e80V03i4 RRR changes



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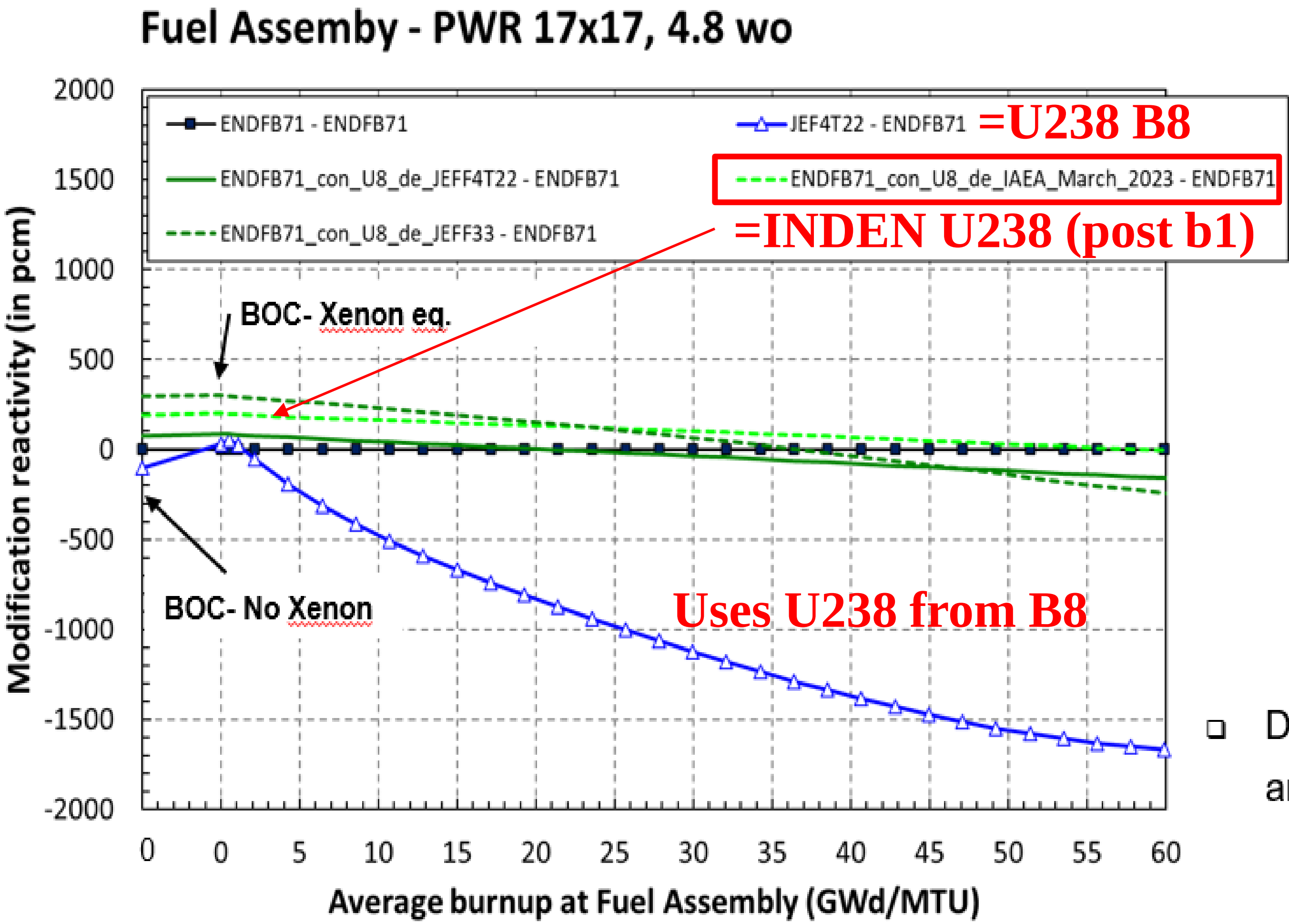
Depletion studies



Nuclear Data:

- JEFF-4T2.2 – XS + TSL
- JEFF-3.3 DD and FYs

- Different 238U evaluations are tested

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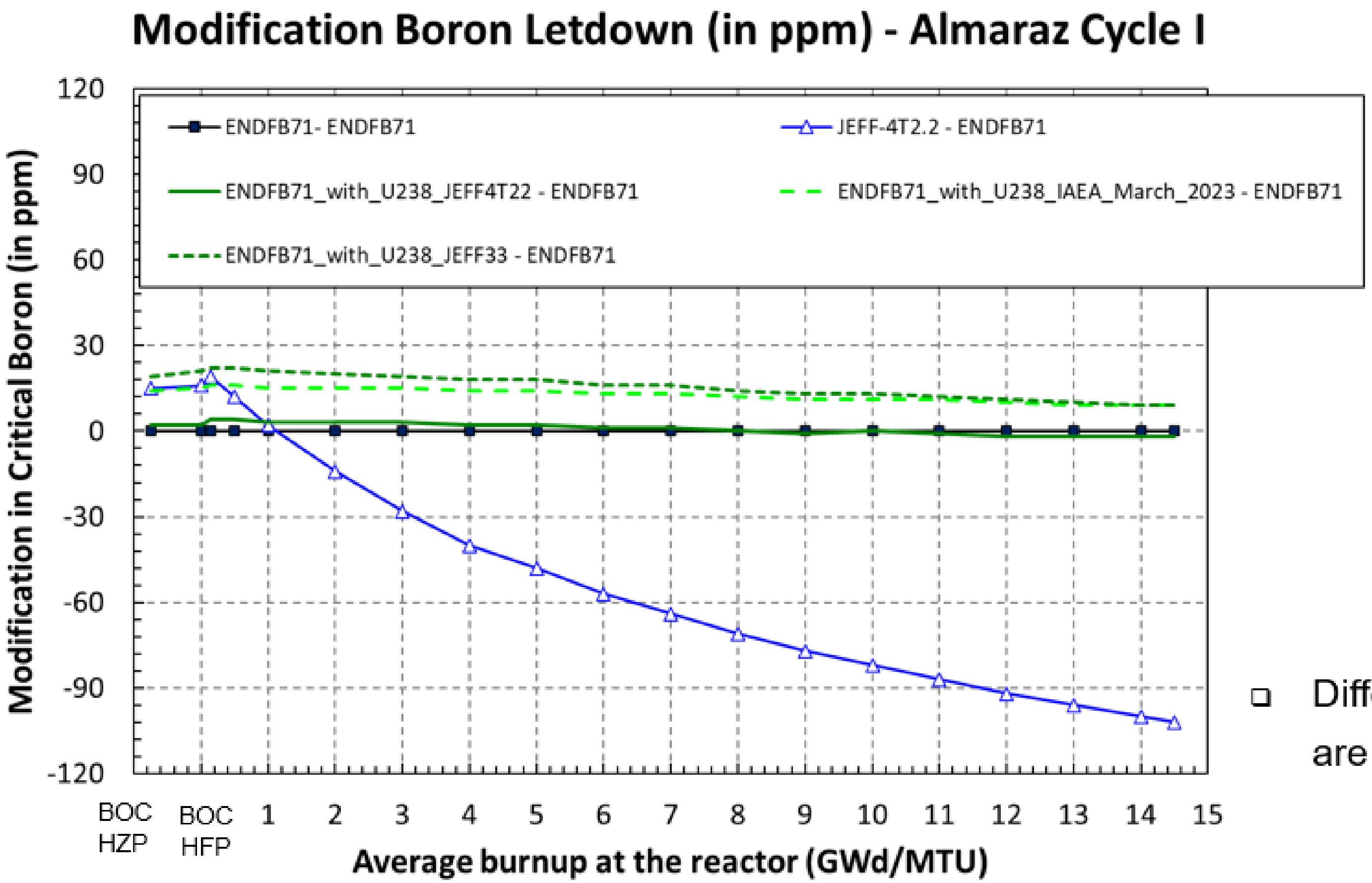
Depletion studies



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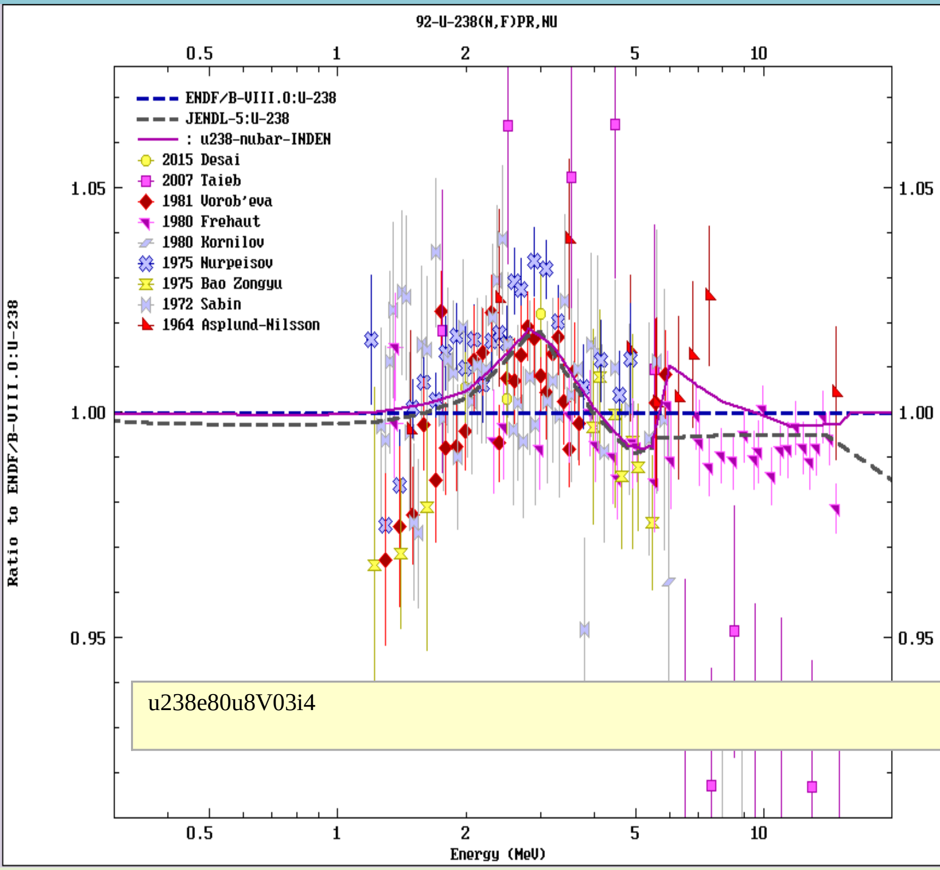
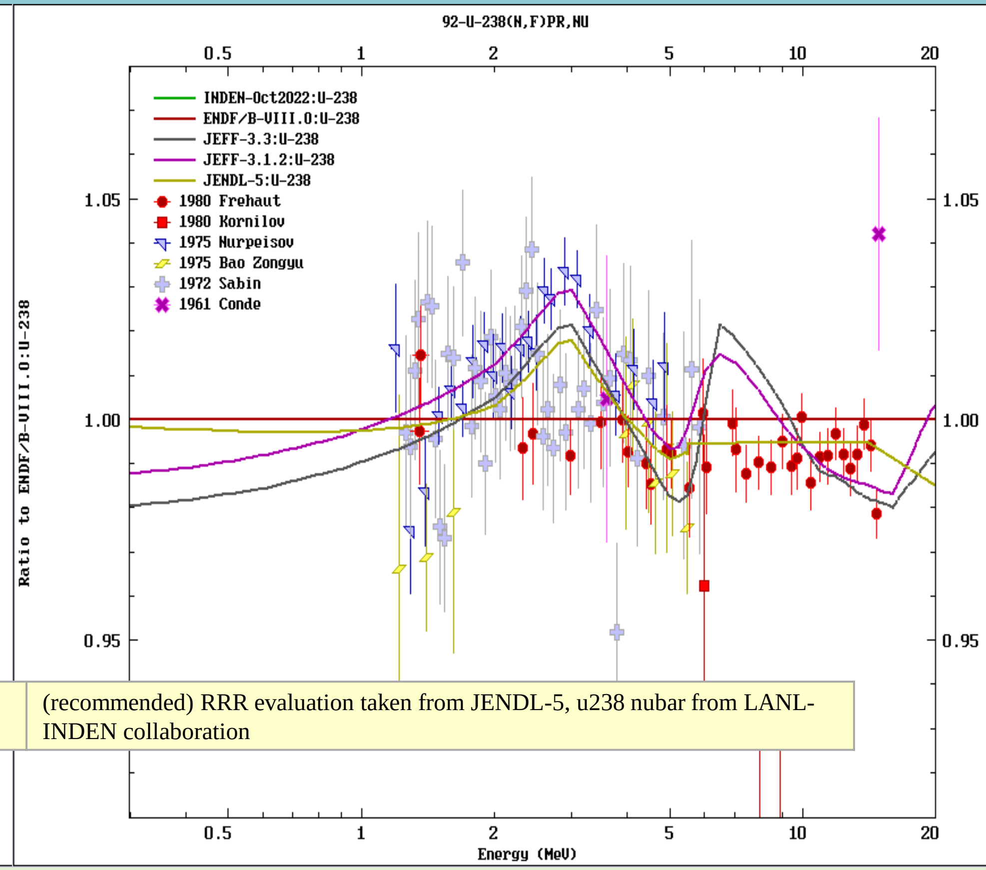
U-238 nubar dependence





u238e80u8V03i4	(recommended) RRR evaluation taken from JENDL-5, u238 nubar from LANL-INDEN collaboration

Convergence between JEFF & INDEN evaluations observed

INDEN latest : u238e80u8V03i4

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Pu-239 evaluations

JEFF-4T2 – Noguere et al
INDEN – ORNL/IAEA collaboration

Similar approaches, underlying data discussed at INDEN meetings

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Depletion studies

Burnup dependence (Pu-239)

OpenMC calculations by J. Malec & A. Trkov

endfb8_orig(average)	Original OpenMC library based on ENDF/B-VIII.0 data
endfb8+P9(run 6)	**Original endfb8+ INDEN Pu239**
endfb8+U8e71(run 7)	Original endfb8+U238 from ENDF/B-VII.1
endfb71(run8)	Pure endfb71

	Bu[GWd/tU]	0	0.925	5.3	30.3	60.3
	Case	Delta_Rho				
endfb8_orig(average)	Case 14-5	42	-1	-14	97	41
endfb8+P9(run 6)	**Case 15-14**	**0**	**-26**	**-33**	**-476**	**-688**
endfb8+U8e71(run 7)	Case 16-14	-181	-149	-84	-184	1
endfb71(run8)	Case 17-14	79	115	158	-35	318

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New integral constraints for RP fit fissile targets

All measured ToF high-resolution data (1955-2019)

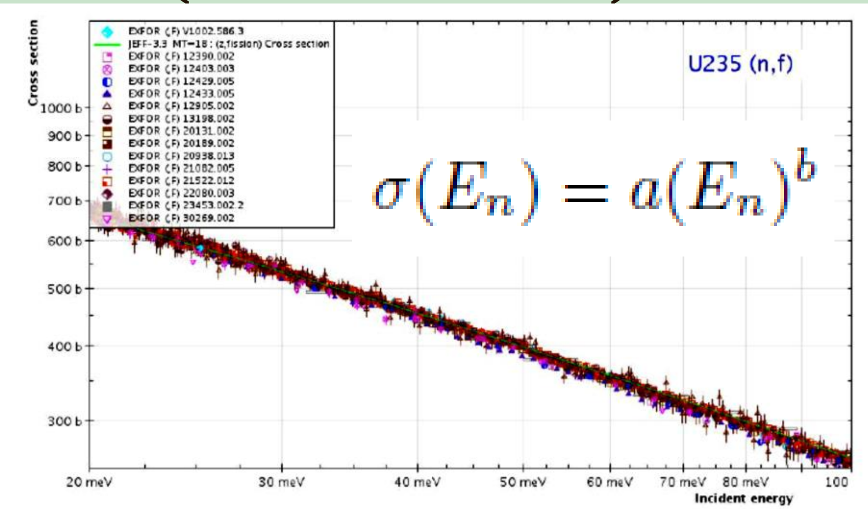

FIG. 1. (Color online) High-resolution datafiles in the 0.02 eV to 0.1 eV energy region for the ^{235}U(n,f) reaction, as retrieved from EXFOR.

Duran et al, 2021 (submitted to NDS)
Discussed at INDEN CM November 2021

Derived σ_f(th)

Duran et al	TNC
533.0(0.7)	533.0(2.2)
586.1(2.6)	587.3(1.4)
751.0(1.9)	752.4(2.2)
1019(3)	1024(11)

Good consistency with TNC (slightly lower)
Similar to libraries !!

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New integral constraints for RP fit fissile targets

TABLE III. Recommended (n,f) (reference) data I_1, I_3, σ_0^f/I_1, and I_3/I_1 for ^{233}U, ^{235}U, ^{239}Pu, and ^{241}Pu fissile targets. A reference integral I_1=127(1) b·eV of the $^{10}B(n,\alpha)$ cross sections from 0.02 eV up to 0.06 eV is also recommended. These data are consistent with the Thermal Neutron Constants recommended by the IAEA Standards 2017 [3].

Cross-sect. Integrals	^{233}U	^{235}U	^{239}Pu	^{241}Pu
I_1 interval(eV)	0.02–0.06			
I_1 integral(b·eV)	17.53	18.78	25.42	34.05
Absol.std.dev.(b·eV)	0.10	0.08	0.05	0.47
Relat.std.dev.	0.6%	0.4%	0.2%	1.4%
I_3 interval (eV)	8.1–14.7	7.8–11	9–20	11.7–19.5
I_3 integral (b·eV)	689.0	245.7	1059	1378
Absol.std.dev.(b·eV)	10.8	4.1	6	33
Relat.std.dev.	1.6%	1.7%	0.6%	2.4%
Integral ratios				
σ_0^f/I_1 (1/eV)	30.40	31.22	29.58	29.95
Absol.std.dev.(b·eV)	0.18	0.12	0.07	0.35
Relat.std.dev.	0.6%	0.4%	0.2%	1.2%
I_3/I_1	39.31	13.08	41.65	40.46
Absol.std.dev.(b·eV)	0.54	0.20	0.22	0.85
Relat.std.dev.	1.4%	1.5%	0.5%	2.1%

Duran et al, 2021 (submitted to NDS)
Discussed at INDEN CM November 2021

All measured ToF high-resolution data (1955-2019) used to derive:

I_1, I_3, I_3/I_1, σ_f(th)/I_1

May require small revision of RP fits for all fissiles

Derived σ_f(th) consistent with TNC

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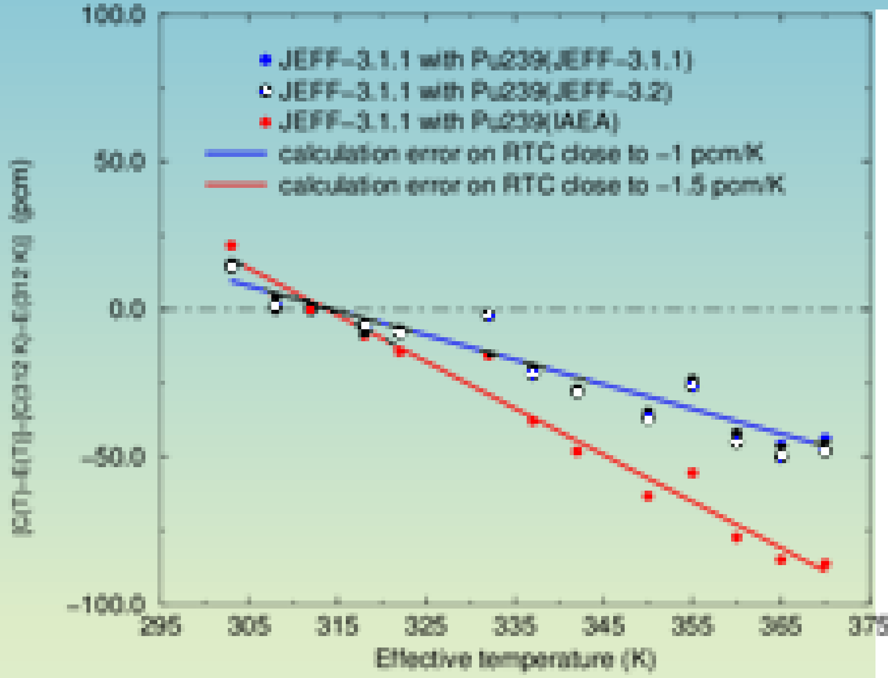
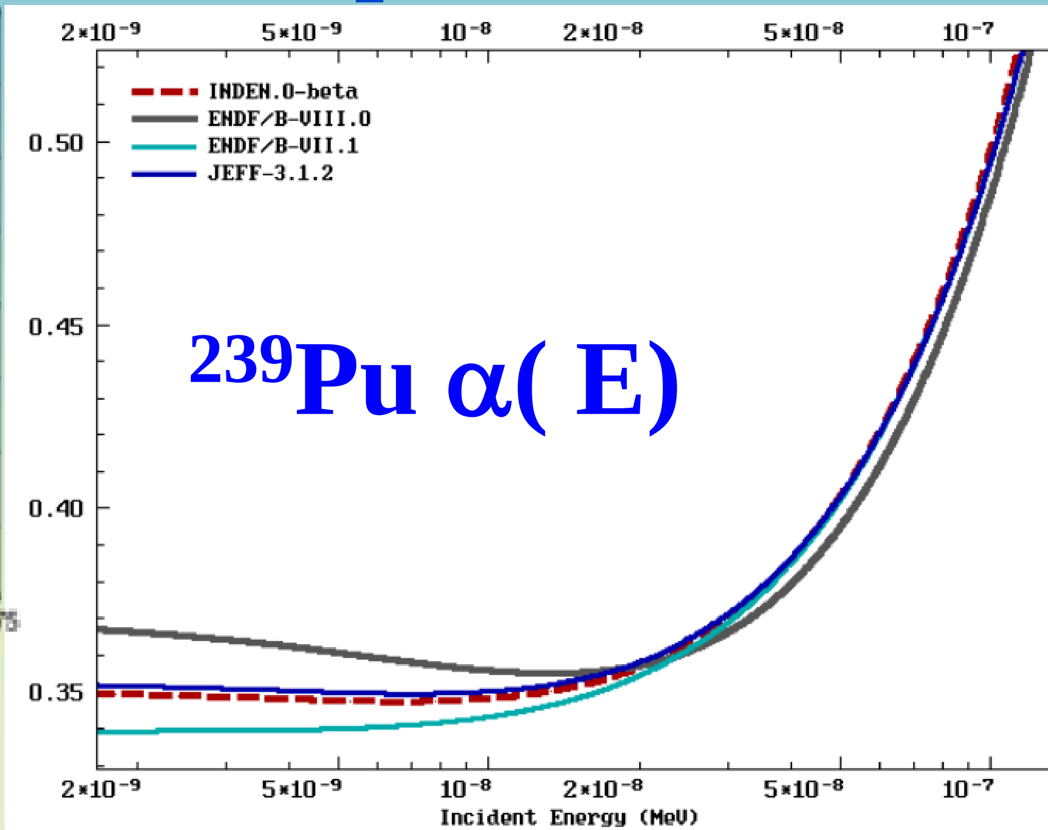
^{239}Pu RTC-MISTRAL2 experiment, CEA



Presented by G. Noguere @ INDEN meet.



Modifications to the RR fit required:

- ↑subthermal α, ↓ α till 1eV (closer to B8)

⇒ To improve RTC and ↑ crit. @ high burnup

NOTE: In the light of latest U-238, we have to solve Pu239!

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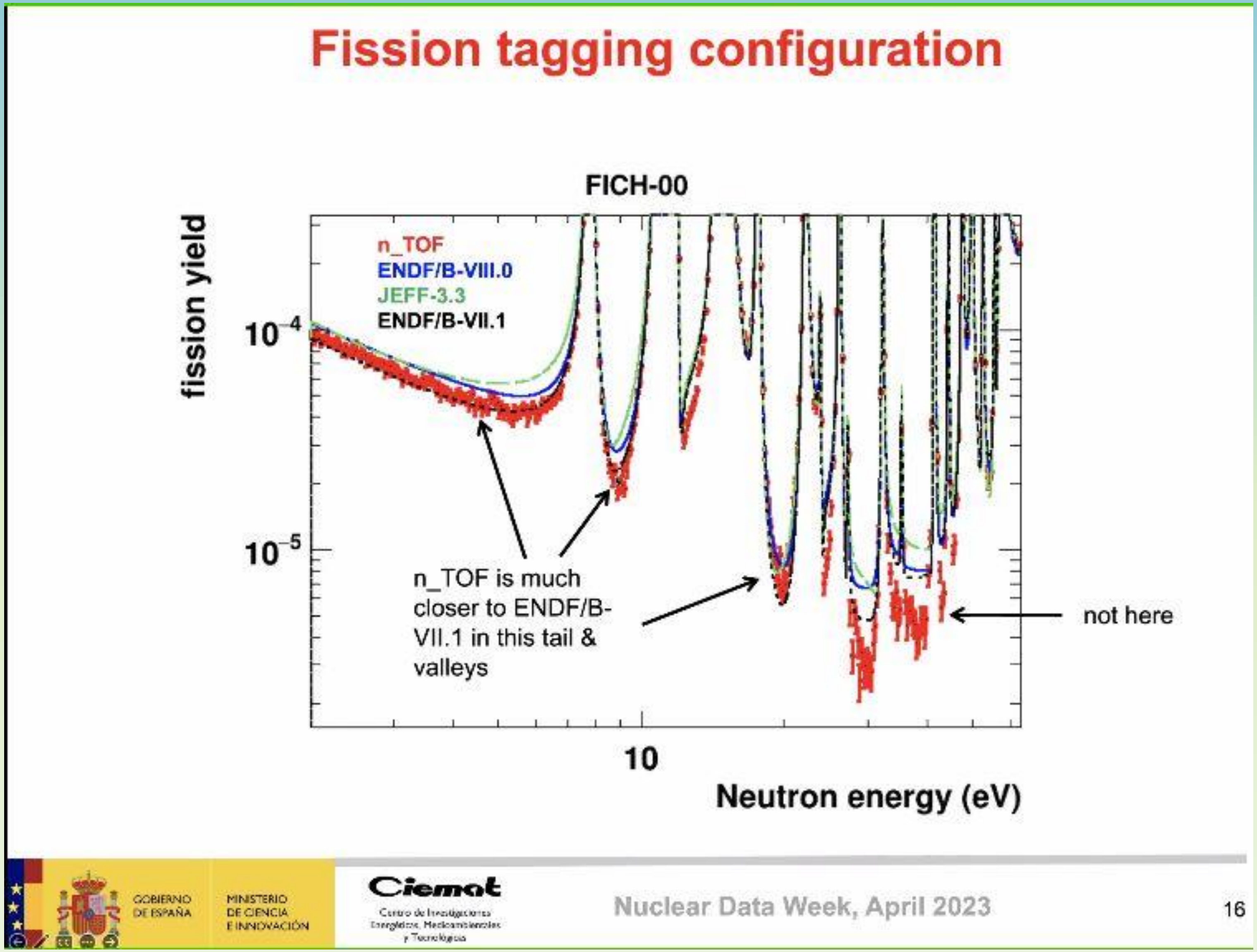
Pu-239 new n_TOF experiment (fiss & capt)



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O-16 observations

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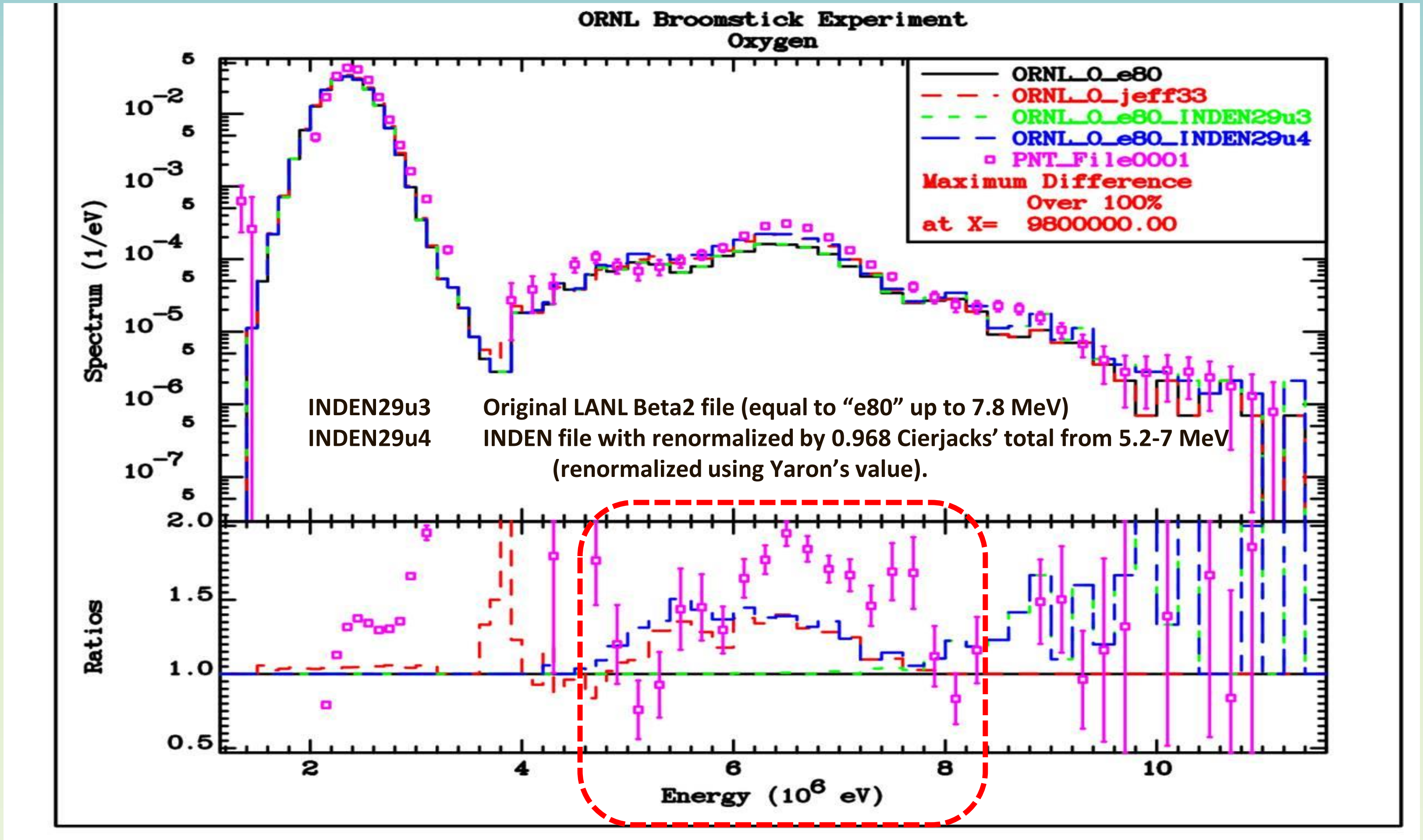
O-16: ORNL Broomstick experiment

Need to decrease σ_{tot} from 5 to 7 MeV



Broomstick experiment C/E problem 5-7MeV

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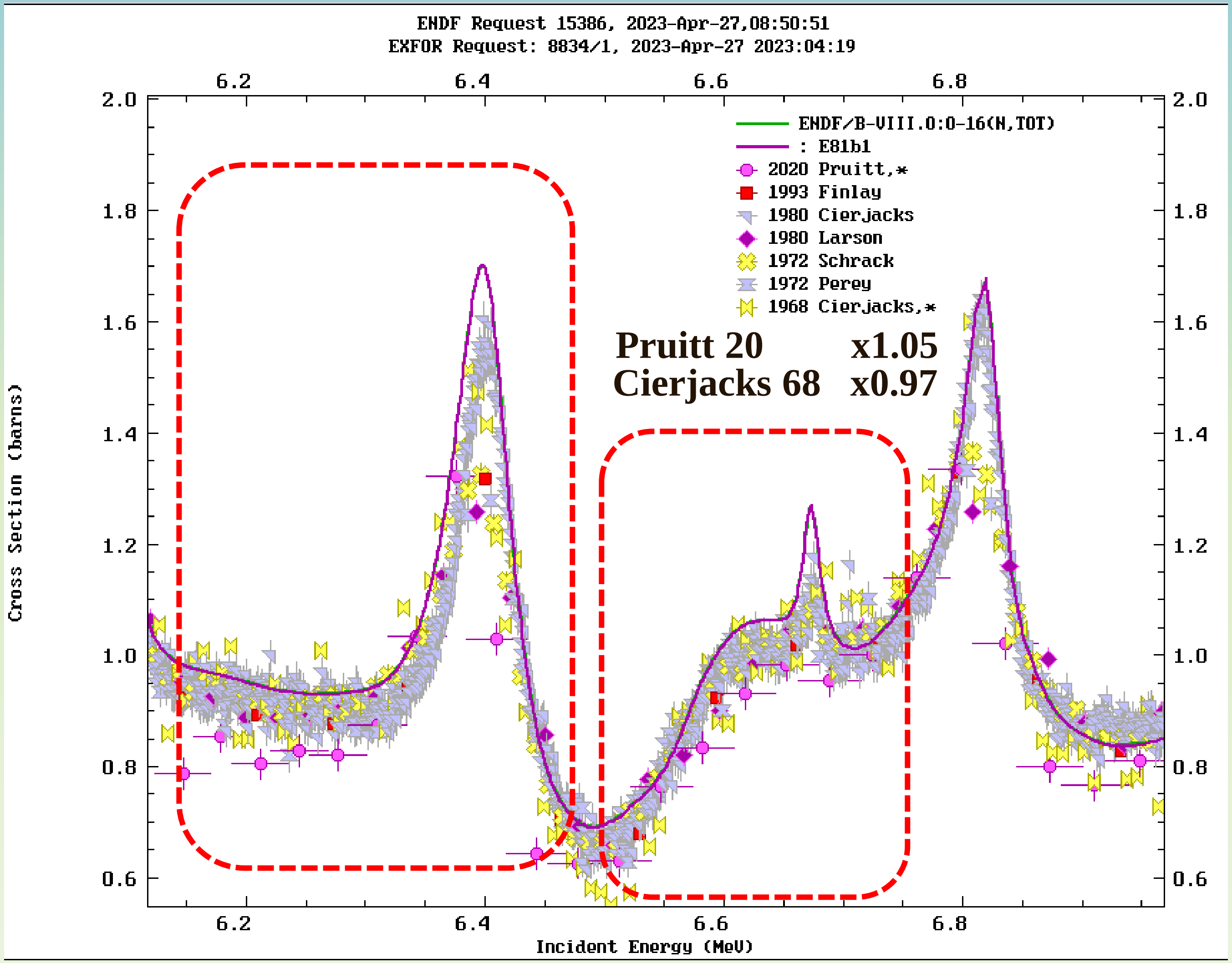
O-16 E81b1 total XS =B8

Overestimation of normalized σ_{tot} data Need to from 5 to 7 MeV



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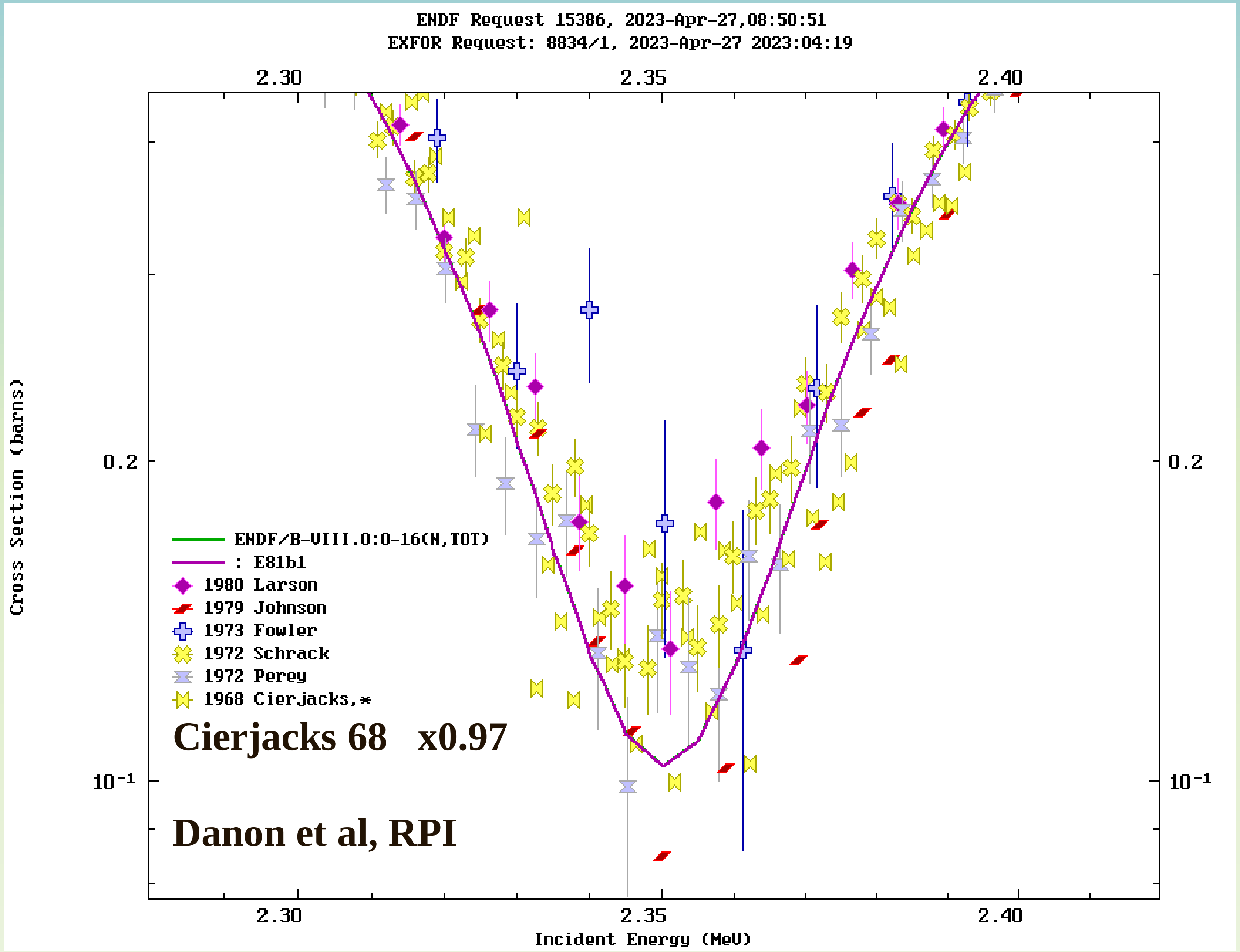
O-16 E81b1 total XS =B8 normalization

Evaluation seems ok vs normalized data @ XS minima (2.35)



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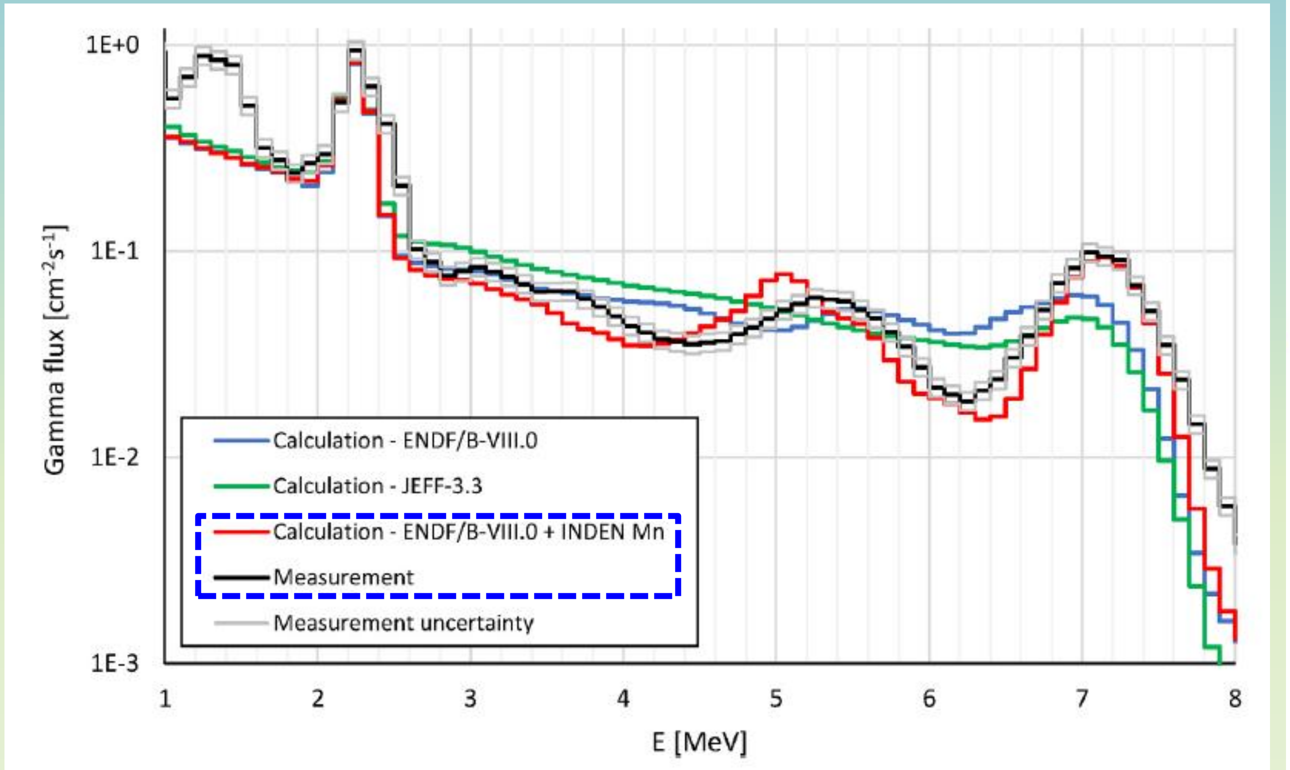
Mn-55 improvement of capture gammas



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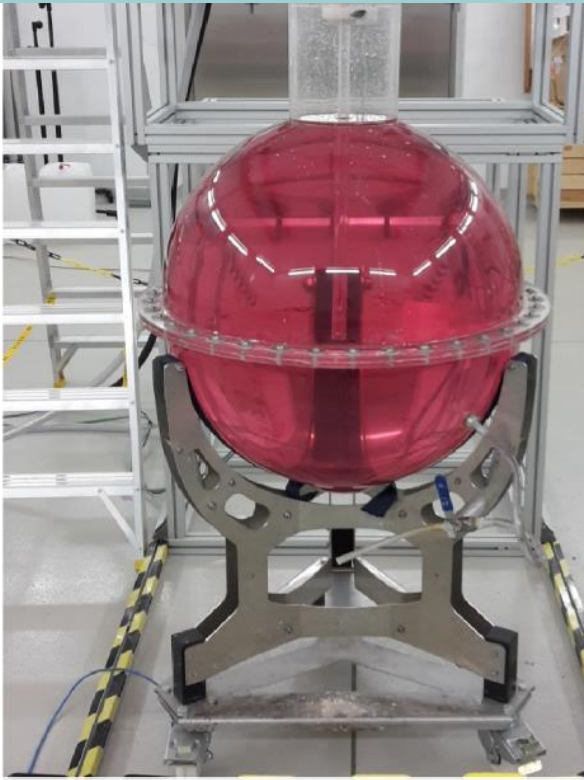

Fig. 1. Photography of manganese bath in lab.

Cf-252(sf) source, gamma leakage

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INDEN Summary @nds.iaea.org/INDEN/

- Fe files from INDEN validated independently by Westinghouse, and Rez (CZ) Cf neutron leakage experiments
  Minor glitches to be fixed (negative angular distributions). Criticality performance is also very good.

- Si files from INDEN were missing capture background (affected B81b1).
  Updated files dated 26/4/2020 available: https://www-nds.iaea.org/INDEN/data/si_iaea_E_ENDF.zip
  Recommended to be updated for B81b2 (INDEN was updated on April 26/2023)

- Cu files from INDEN validated in shielding and criticality. Minor updates carried out.
  Updated files available: https://www-nds.iaea.org/INDEN/data/cu63ane6k09aRR_ENDF.zip
  https://www-nds.iaea.org/INDEN/data/cu65ane5k05_ENDF.zip
  There is an inconsistency in angular distributions in the RRR (with Popov data), to be addressed post-E81

- F-19 files from INDEN extensively validated in criticality (LCT033,HST039,HMF007,Curie)
  E81b1 files include better gamma emission.
  Updated files available: https://www-nds.iaea.org/INDEN/data/f19e80_zt9_ENDF.zip

- **Pu-239 INDEN evaluation is shown to decrease criticality at 60GWD/tU by ~ -600pcm.**
  A similar effect is seen in JEFF-4T2. More work needed. A solution closer to B/VII.1 desirable. To be done for B81b2

- U-238 (https://www-nds.iaea.org/INDEN/data/u238e80u8V03i4_ENDF.zip)
  Latest U-238 iteration with modified nubar and JENDL-5 RRR. (loss of criticality at high burnup solved).
  Recommended to be updated in B81b2.

- **U-233 INDEN evaluation still to be sorted out. More work needed. To be done for E8B2.**
- **O-16: improvement in the evaluated total XS needed to improve description of diff. & integral data**
- **Mn-55 modification of the capture gammas validated by direct measurement at Rez (CZ)**

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