DE LA RECHERCHE À L'INDUSTRIE

STATUS OF THE PU239 EVALUATION IN THE RESONANCE RANGE FOR JEFF

CONTRIBUTIONS FROM CEA/DEN CADARACHE

Gilles NOGUERE

CM-INDEN on the resonance parameters of actinides
IAEA, 8-11 may 2018

www.cea.fr

Evolution of the JEFF library for MOX fuel calculations

JEFF-3.1.1

- Good performances of the JEFF-3.1.1 library on PST benchmarks
- However, several physical problems still unsolved

JEFF-3.2

- Improved MOX calculations, mainly due to new Am241 evaluation
- Pu239 evaluation comes from WPEC/SG34
  - $\Rightarrow$ 3 resolved resonance ranges are merged
  - $\Rightarrow$ good performances on PST are preserved
  - $\Rightarrow$ Resonance Parameter Covariance Matrix is given

JEFF-3.3

- New Pu239 resonance parameters (to solve some missing interferences, …)
- Upper energy limit of the RRR is increased up to 4.5 keV

JEFF-x.x

- New PFNS
- New Thermal Neutron Constants
- New modeling of the fission process: Include (n,γf) reaction, add class II states …

Solve inconsisent RTC results with measurements performed in the EOLE reactor

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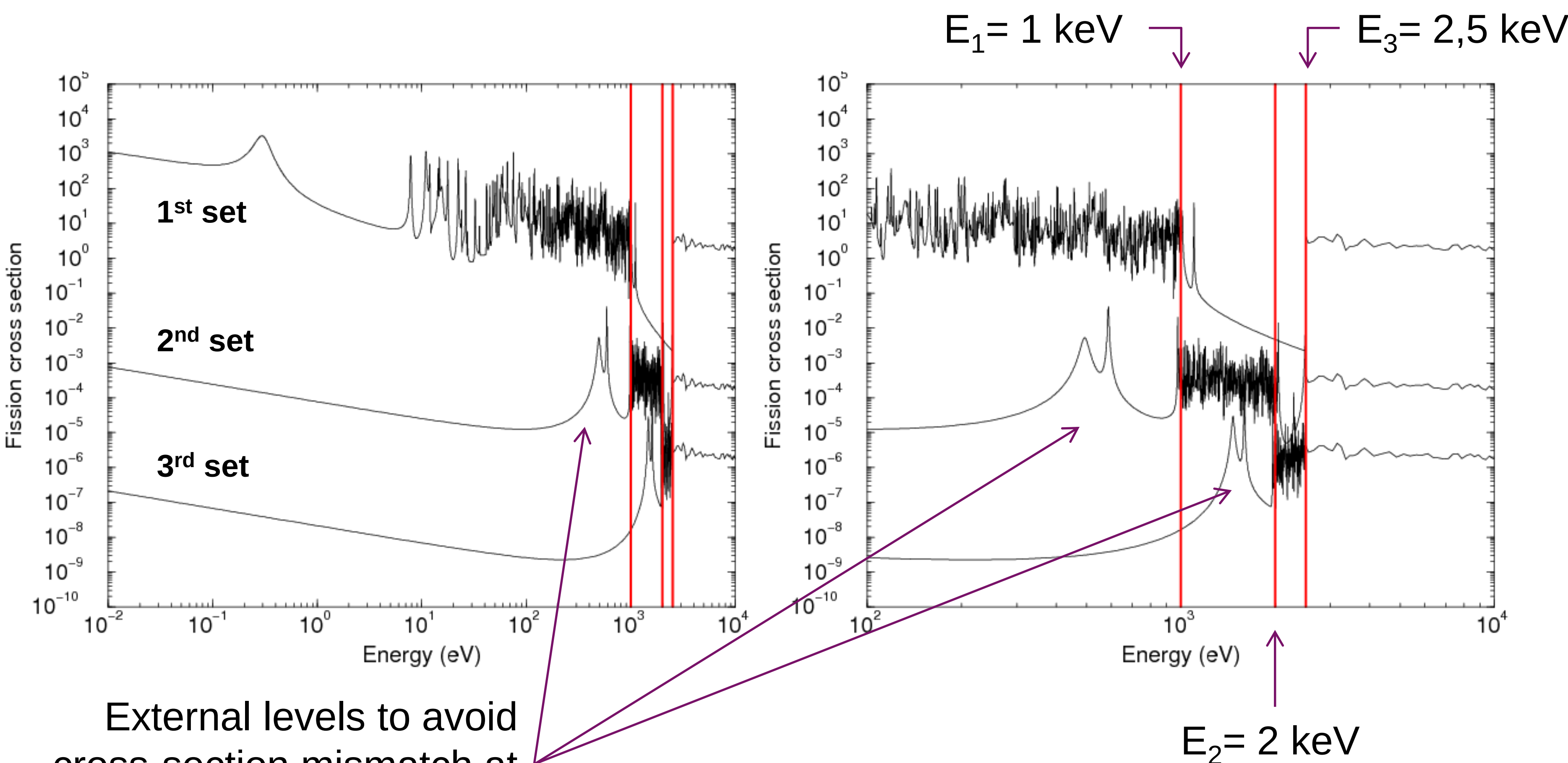
Pu239 evaluation in JEFF-3.1.1

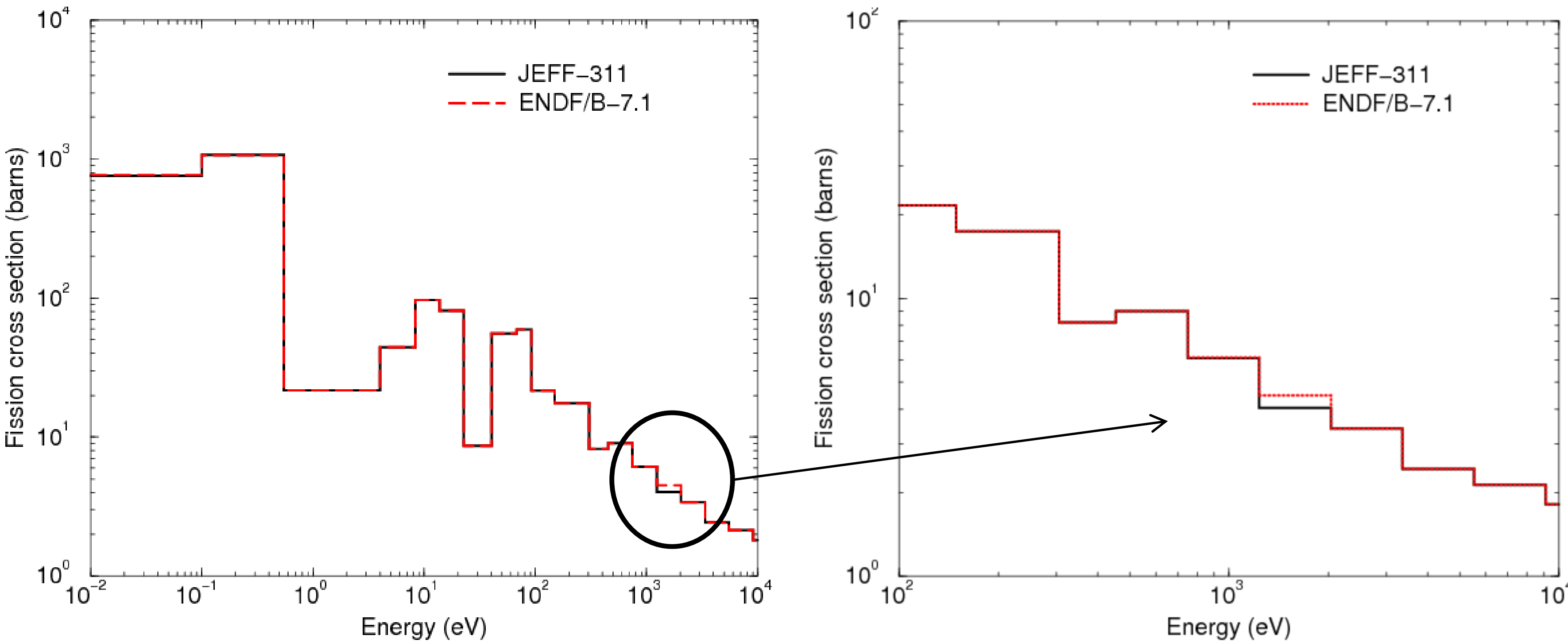
Resonance range divided into three resonance parameter sets (computer limitations)



External levels to avoid cross-section mismatch at the energy boundaries

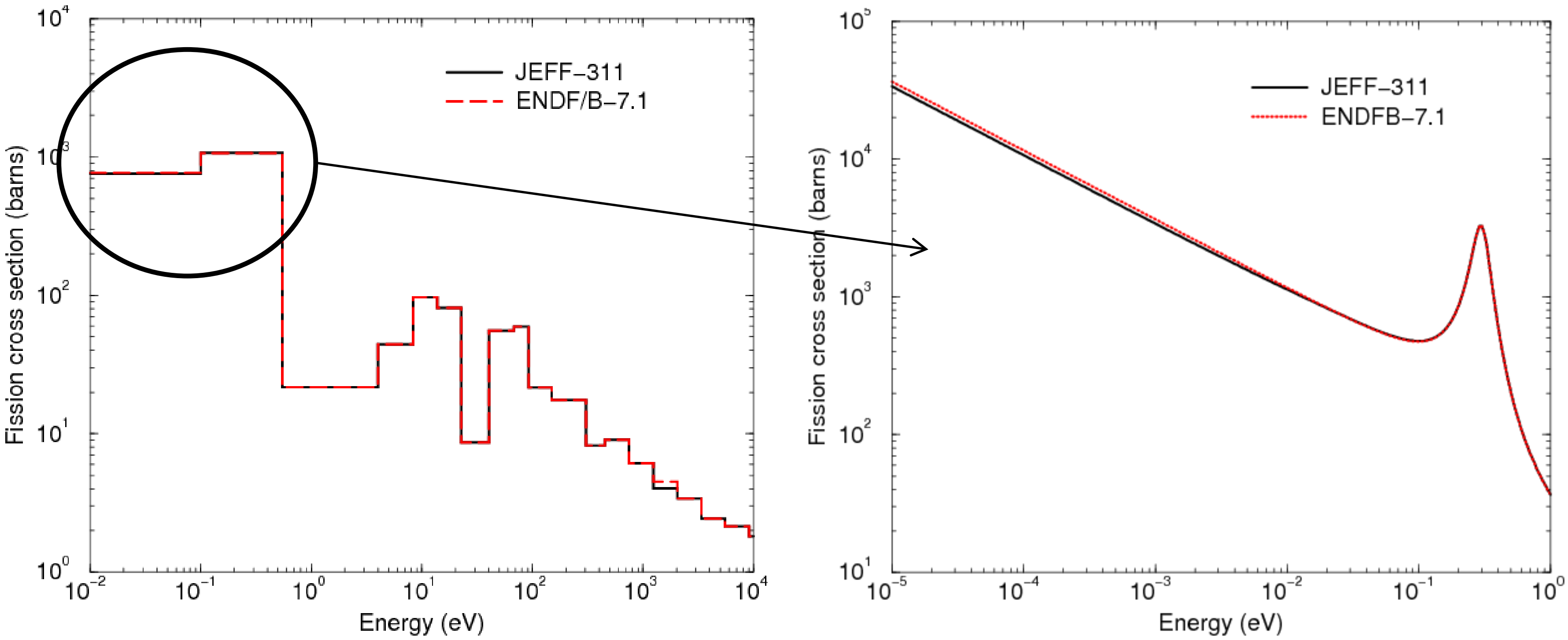
Pu239 evaluation in JEFF-3.1.1

Background cross section (for fission) not used in the resolved resonance range of JEFF-3.1.1



Pu239 evaluation in JEFF-3.1.1

Modification of α(Pu239) in JEFF-3;1;1 to improve the reactivity temperature coefficient (RTC) in EOLE experiments, cold conditions 20-80°C (JEF/DOC-1158)



Pu239 evaluation in JEFF-3.1.1

S. C. van der Marck
Nucl. Data Sheets 113 (2012) 2935

(average value over 368 PST)

TABLE XIX: The average values for $C/E - 1$ (in pcm) for ENDF/B-VII.1 per main ICSBEP benchmark category.

	COMP				MET				SOL	MIXED	
	therm	inter	fast	mixed	therm	inter	fast	mixed	therm	therm	fast
LEU	−80				553				133		
IEU	101	−253	−70				103		396		
HEU	746	2112		−892	130	−65	114	844	16		
MIX	402		16				418		−194	322	−845
PU		1119		1960		2950	164	921	462		
U233	23						−220		549		

TABLE XX: The average values for $C/E - 1$ (in pcm) for JENDL-4.0 per main ICSBEP benchmark category.

	COMP				MET				SOL	MIXED	
	therm	inter	fast	mixed	therm	inter	fast	mixed	therm	therm	fast
LEU	−29				736				−90		
IEU	87	−257	−209				−435		487		
HEU	985	2982		−497	397	209	31	948	197		
MIX	501		446				194		16	588	−591
PU		1376		2030		3529	0	970	633		
U233	25						−195		177		

TABLE XXI: The average values for $C/E - 1$ (in pcm) for JEFF-3.1.1 per main ICSBEP benchmark category.

	COMP				MET				SOL	MIXED	
	therm	inter	fast	mixed	therm	inter	fast	mixed	therm	therm	fast
LEU	−52				527				179		
IEU	−107	−468	258				−180		425		
HEU	381	1912		−1221	−45	145	−106	628	−56		
MIX	258		300				251		−274	87	−867
PU		692		1852		3275	95	478	203		
U233	−312						363		247		

good performances of the JEFF library on PST benchmarks

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Pu239 evaluation in JEFF-3.2

S. C. van der Marck
Nucl. Data Sheets 113 (2012) 2935

(average value over 368 PST)

WPEC/SG34 $\Rightarrow$ the **non-regression** of the Pu239 nuclear data was continuously monitored during the evaluation procedure with a selected set of ICSBEP benchmakrs

Crucial step to conserve the good performances of the JEFF library on PST benchmarks

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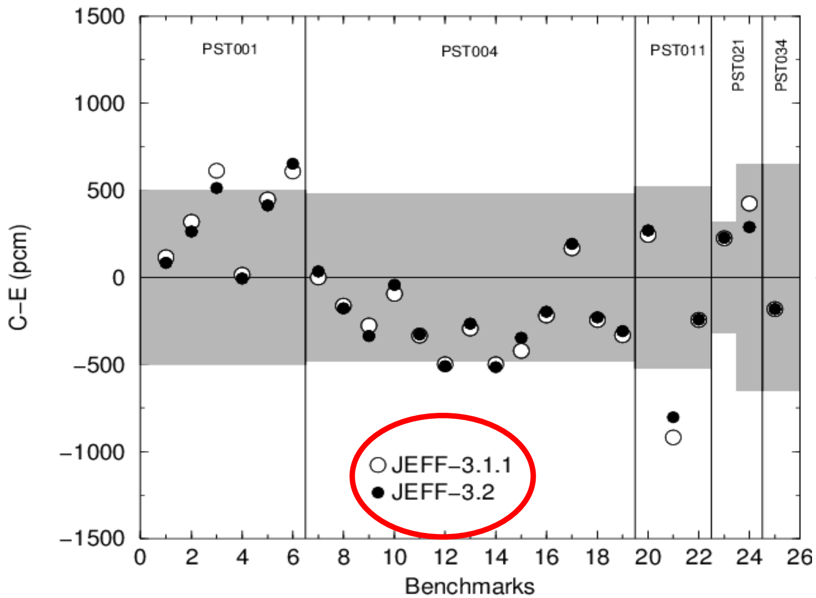


Y. Peneliau , JEFFDOC-1583, 2014
O. Caballos, JEFFDOC-1532, 2014

JEFF-311 and JEFF-32 ⇒ **Similar results for Plutonium in THERM spectrum**

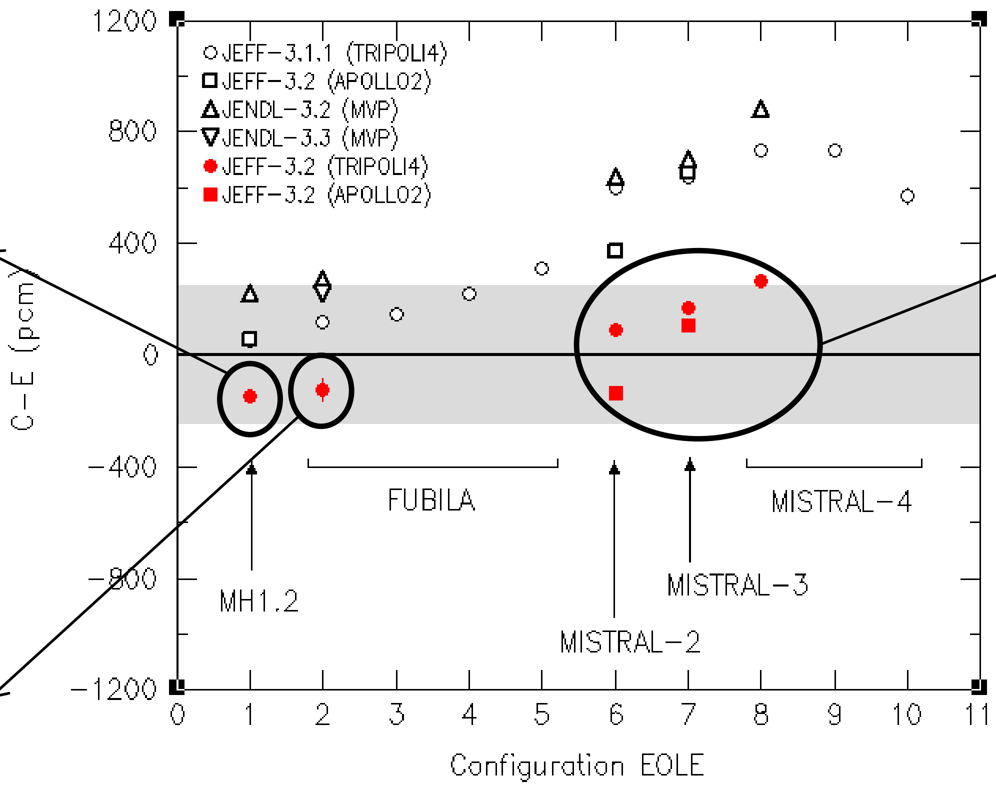
Pu239 evaluation in JEFF-3.2

Integral experiments carried out in the EOLE reactor of CEA Cadarache

Interpretation with the Monte-Carlo and deterministic codes TRIPOLI, MVP and APOLLO

PWR-MOX mixed core

BWR-MOX



PWR-MOX

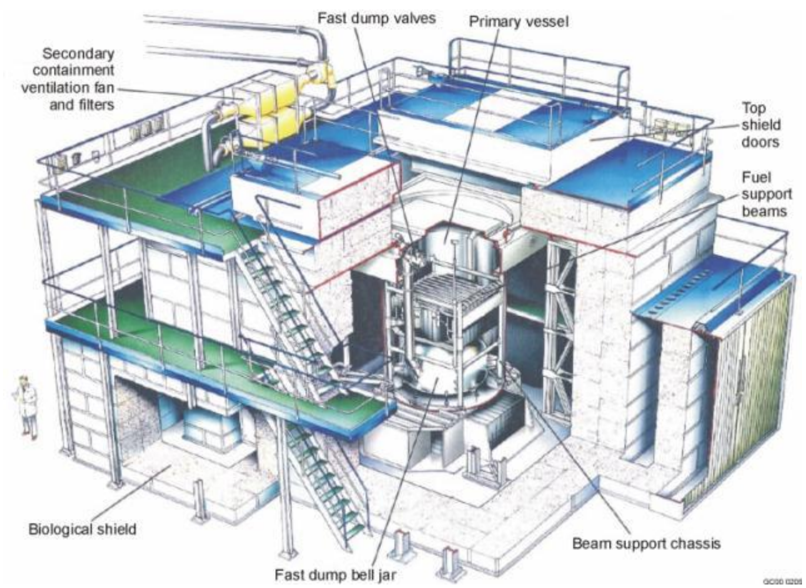
Several experimental programs were conducted by CEA to investigate the use of MOX fuel in commercial PWRs or innovative concepts for various moderation ratios

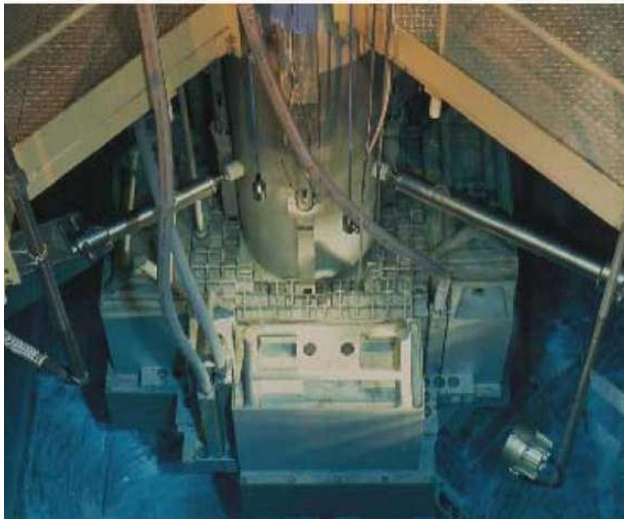
Average value obtained with JEFF-32 $\Rightarrow$ **⟨C-E⟩=+50 pcm** with a standard deviation of **180 pcm**

Pu239 evaluation in JEFF-3.2

CERES program (P. Leconte, PHYSOR 2014)

- Collaboration between Winfrith and Cadarache (1992-1995) as part of the CEA/UKAEA collaboration on LWRs
- Experiments conducted in the DIMPLE (AEA) and MINERVE (CEA) reactors on common samples, manufactured both at Cadarache and Winfrith
- Reactivity-worth measurements of fresh MOX fuel samples provided by CEA and AEA





Pu239 evaluation in JEFF-3.2

Integral results for $\nu\Sigma_f$ (SG-34)

@ P. Leconte

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	-9.0
	$\nu\Sigma_f$	**98.5**
^{240}Pu	Σ_a	-0.9
^{241}Pu	Σ_a	-1.0
	$\nu\Sigma_f$	12.3

Sample (Reference)	Full Monte Carlo Method C/E-1 (%)			
	Assembly-I	Assembly-II	Assembly-III	R1UO2
MOX1 (CEAU11)	**3.0 ± 4.9**	3.6 ± 9.3	10.9 ± 6.6	197 ± 9274
MOX2 (CEAU11)	**0.7 ± 3.2**	34.2 ± 22.8	5.7 ± 4.0	-59.2 ± 6.1
MOX3 (CEAU11)	**0.8 ± 1.7**	18.2 ± 4.8	2.9 ± 1.8	-79.6 ± 7.4
MOX4 (CEAU11)	**-0.7 ± 1.5**	9.6 ± 2.9	0.1 ± 1.3	-98 ± 8.7
MOX5 (CEAU11)	**-1.1 ± 1.3**	5.1 ± 1.5	-1.3 ± 1.1	97 ± 13.2
MOX6 (CEAU11)	**-1.5 ± 1.2**	1.4 ± 1.2		42 ± 7.8
Pu0403 (UO2nat)	**-2.4 ± 1.5**	-1.1 ± 4.0	-2.9 ± 2.4	-7.1 ± 4.5
Pu0413 (UO2nat)	**-2.9 ± 1.7**	-7.6 ± 6.8	-5.6 ± 2.6	-21.3 ± 10.2
Pu0426 (UO2nat)	**-6.6 ± 1.6**	-23 ± 5044	-8.1 ± 3.1	-93 ± 154
Pu2003 (UO2nat)	**1.1 ± 1.4**	0.1 ± 1.5	-0.7 ± 1.3	-7.7 ± 2.5
Pu2013 (UO2nat)	**0.4 ± 1.4**	3.0 ± 2.0	-0.8 ± 1.3	1.7 ± 3.9
Pu2026 (UO2nat)	**1.1 ± 1.4**	22.4 ± 5.1	2.1 ± 1.5	-140 ± 22

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	-17.8
	$\nu\Sigma_f$	**118.0**
^{240}Pu	Σ_a	-0.3
^{241}Pu	Σ_a	
	$\nu\Sigma_f$	0.1

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	-17.9
	$\nu\Sigma_f$	**118.7**
^{240}Pu	Σ_a	-2.1
^{241}Pu	Σ_a	-0.3
	$\nu\Sigma_f$	2.0

Mean value = -1.0 ± 0.5 %
(standard deviation : 2.5%)

SG34 seems to be Ok !

Pu239 evaluation in JEFF-3.2

Integral results for K1 (SG-34)

@ P. Leconte

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	**-88.2**
	$\nu\Sigma_f$	**185.5**
^{240}Pu	Σ_a	-7.9
^{241}Pu	Σ_a	-10.3
	$\nu\Sigma_f$	23.5

Sample (Reference)	Full Monte Carlo Method C/E-1 (%)			
	Assembly-I	Assembly-II	Assembly-III	R1UO2
MOX1 (CEAU11)	3.0 ± 4.9	3.6 ± 9.3	**10.9 ± 6.6**	197 ± 9274
MOX2 (CEAU11)	0.7 ± 3.2	34.2 ± 22.8	**5.7 ± 4.0**	-59.2 ± 6.1
MOX3 (CEAU11)	0.8 ± 1.7	18.2 ± 4.8	**2.9 ± 1.8**	-79.6 ± 7.4
MOX4 (CEAU11)	-0.7 ± 1.5	9.6 ± 2.9	**0.1 ± 1.3**	-98 ± 8.7
MOX5 (CEAU11)	-1.1 ± 1.3	5.1 ± 1.5	**-1.3 ± 1.1**	97 ± 13.2
MOX6 (CEAU11)	-1.5 ± 1.2	1.4 ± 1.2		42 ± 7.8
Pu0403 (UO2nat)	-2.4 ± 1.5	-1.1 ± 4.0	**-2.9 ± 2.4**	-7.1 ± 4.5
Pu0413 (UO2nat)	-2.9 ± 1.7	-7.6 ± 6.8	**-5.6 ± 2.6**	-21.3 ± 10.2
Pu0426 (UO2nat)	-6.6 ± 1.6	-23 ± 5044	**-8.1 ± 3.1**	-93 ± 154
Pu2003 (UO2nat)	1.1 ± 1.4	0.1 ± 1.5	**-0.7 ± 1.3**	-7.7 ± 2.5
Pu2013 (UO2nat)	0.4 ± 1.4	3.0 ± 2.0	**-0.8 ± 1.3**	1.7 ± 3.9
Pu2026 (UO2nat)	1.1 ± 1.4	22.4 ± 5.1	**2.1 ± 1.5**	-140 ± 22

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	**-100.8**
	$\nu\Sigma_f$	**202.4**
^{240}Pu	Σ_a	-1.6
^{241}Pu	Σ_a	
	$\nu\Sigma_f$	0.1

Reactivity breakdown (TOT=100)

^{239}Pu	Σ_a	**-113.6**
	$\nu\Sigma_f$	**228.2**
^{240}Pu	Σ_a	-13.9
^{241}Pu	Σ_a	-1.8
	$\nu\Sigma_f$	3.8

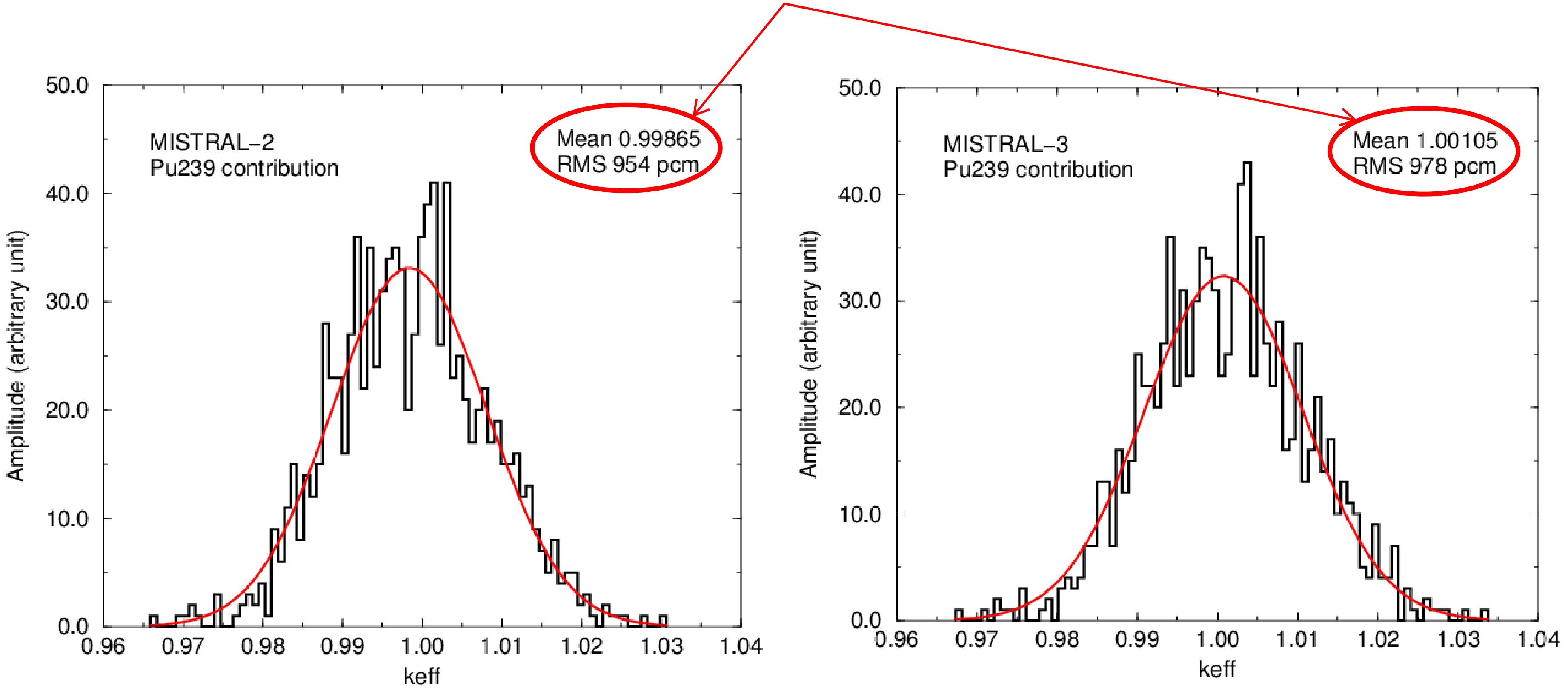
SG34 seems to be Ok !

Mean value = -0.4 ± 0.5 %
(standard deviation : 5.2%)

Pu239 evaluation in JEFF-3.2

Propagation of the Pu239 resonance parameter uncertainties on EOLE benchmarks

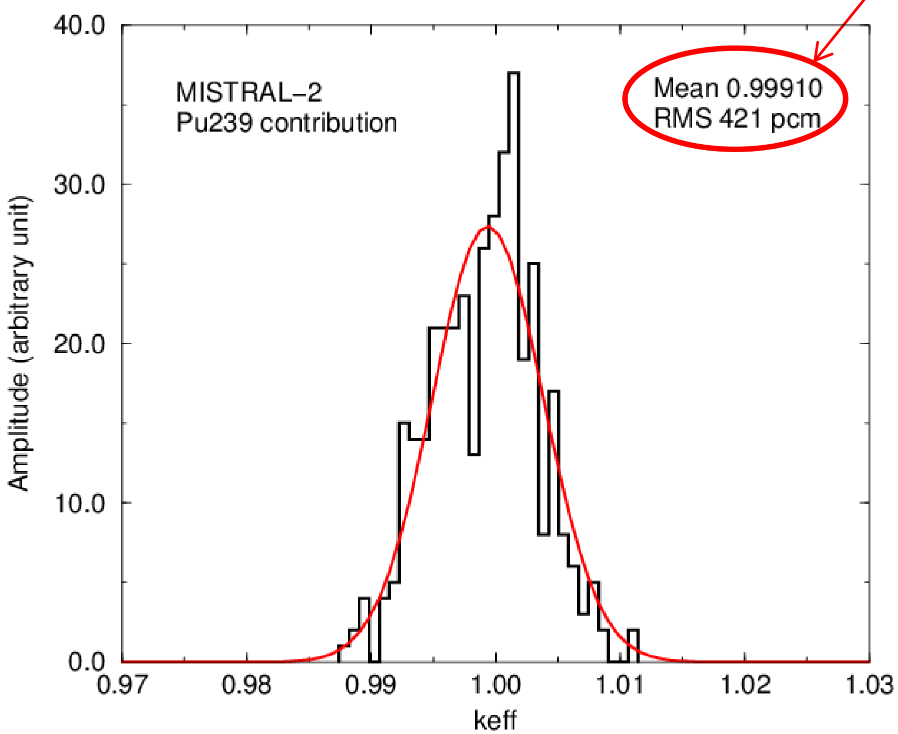
Final uncertainty (**≈1000 pcm**) ⇒ dominated by the capture cross section uncertainties

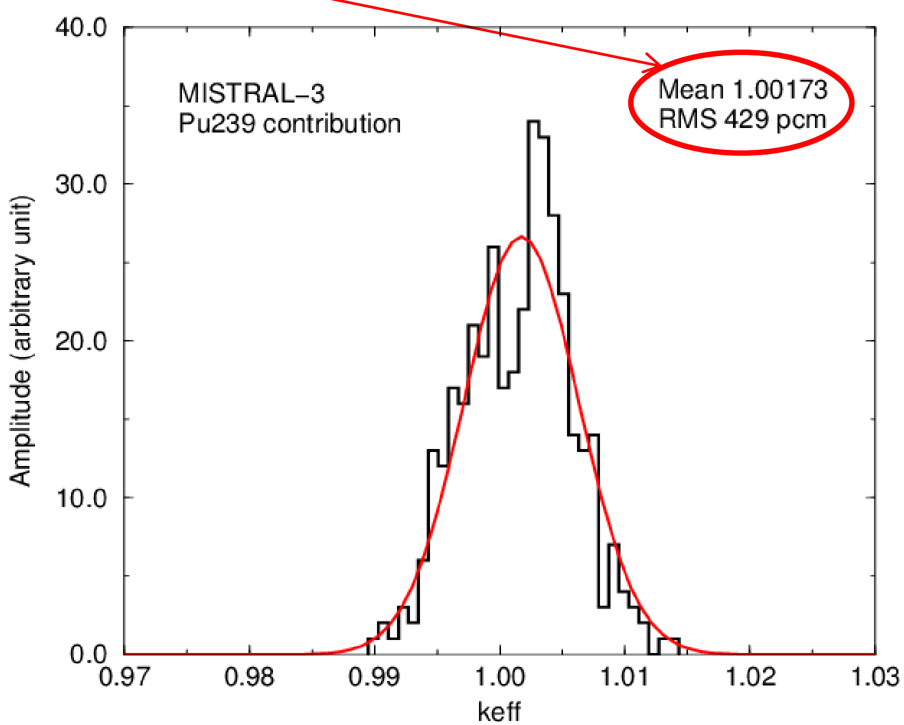


Pu239 evaluation in JEFF-3.2

Propagation of the Pu239 resonance parameter uncertainties on EOLE benchmarks

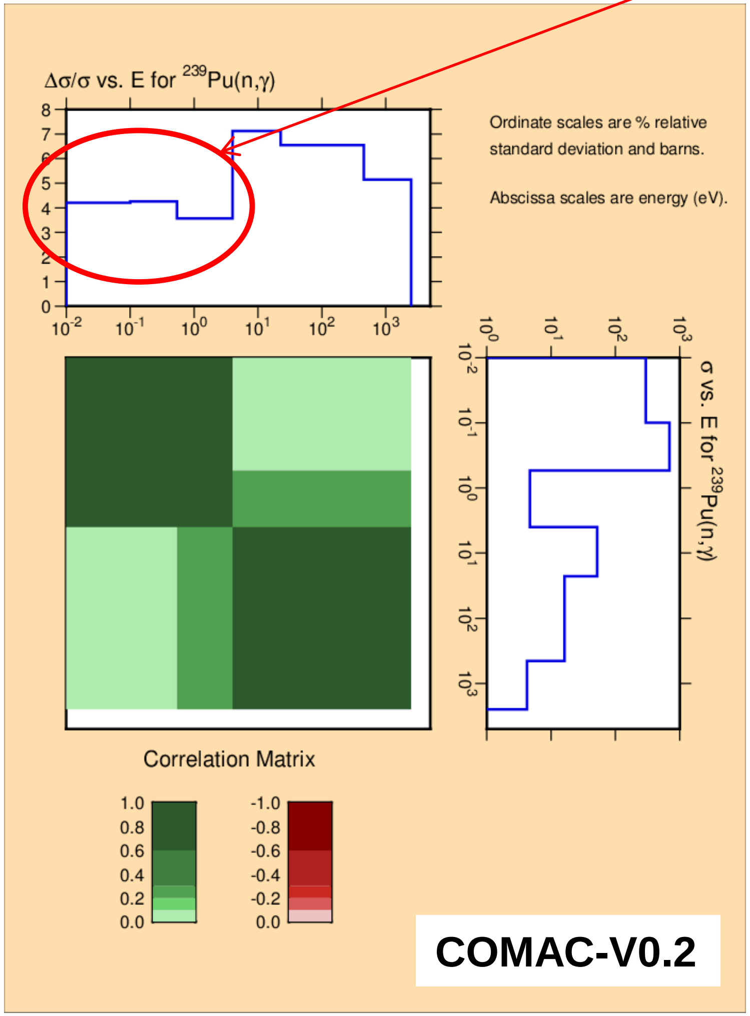
Final uncertainty (**≈400 pcm**) after the Integral Data Assimilation of CERES (P. Leconte)

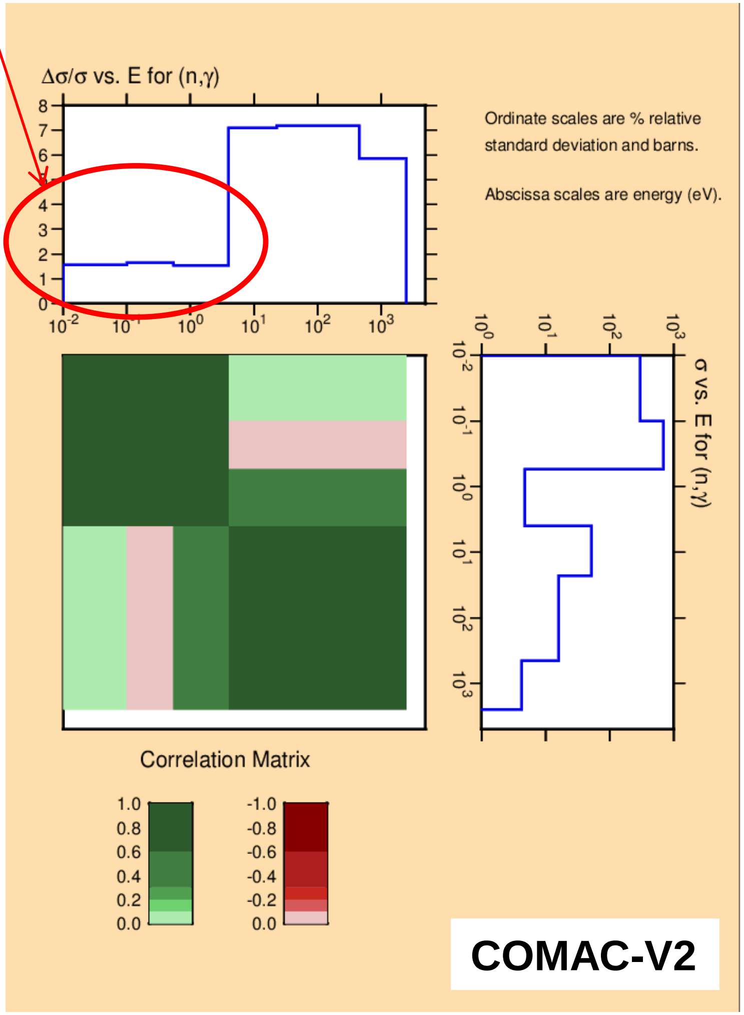




Pu239 evaluation in JEFF-3.2

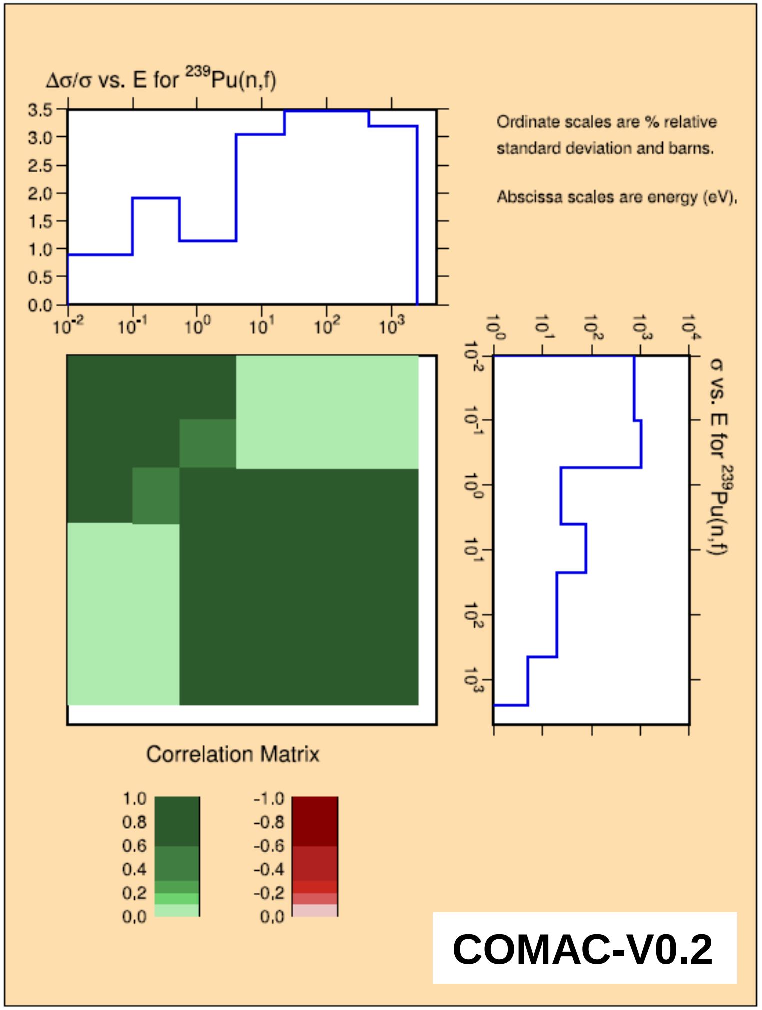
Significant reduction of the Pu239 capture cross section uncertainties at low neutron energy

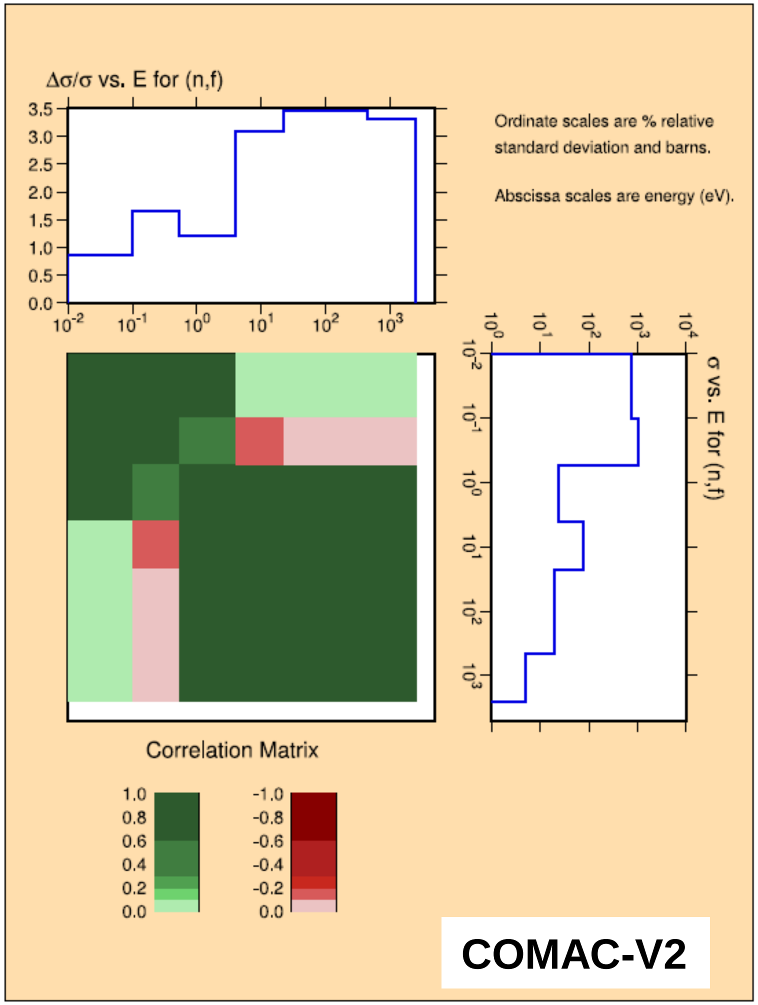




Pu239 evaluation in JEFF-3.2

No modification of the Pu239 fission cross section uncertainties





Pu239 evaluation in JEFF-3.2

Final uncertainties after the Integral Data Assimilation of the CERES program

	JEFF-3.2 (=SG34)	Relative uncertainty	
		JEFF-3.2	COMAC-V2
σ_f	747.2 barns	0.9%	0.7%
σ_γ	**270.1 barns**	**4.4%**	**1.6%**
I_f	308.8 barns	2.3%	2.3%
I_γ	180.1 barns	5.7%	5.7%
K1	1161.5 barns	1.7%	0.9%

Pu239 evaluation in JEFF-3.2

NUCLEAR SCIENCE AND ENGINEERING · VOLUME 182 · 135–150 · FEBRUARY 2016

ANS

Improved Mixed Oxide Fuel Calculations with the Evaluated Nuclear Data Library JEFF-3.2

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Received January 19, 2015
Accepted for Publication March 14, 2015
http://dx.doi.org/10.13182/NSE15-9

Abstract — *An overestimation of the k_{eff} values for mixed oxide (MOX) fuels was identified with Monte Carlo (TRIPOLI-4) and deterministic (APOLLO2) calculations based on the Joint Evaluated Fission and Fusion (JEFF) evaluated nuclear data library. The overestimation becomes sizeable with Pu aging, reaching a reactivity change of $\Delta\rho \simeq +700$ pcm for integral measurements carried out with MOX fuel containing a large amount of americium. This bias was observed for various critical configurations performed in the zero-power reactor EOLE of the Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Cadarache, France. The present work focuses on the improvements achieved with the new ^{239}Pu and ^{241}Am evaluated nuclear data files available in the latest version of the JEFF library (JEFF-3.2). The resolved resonance range of the plutonium evaluation was reevaluated at Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, with the SAMMY code in collaboration with CEA Cadarache. The resonance parameters of the americium evaluation were obtained with the REFIT code in collaboration with the research institutes Institute for Reference Materials and Measurements (IRMM), Geel, Belgium, and Institut de recherche sur les lois fondamentales de l'Univers (Irfu), Saclay, France.*

Keywords — *EOLE, MINERVE, TRIPOLI-4.*

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- **Upper energy limit of the RRR is increased up to 4.5 keV**

JEFF-x.x

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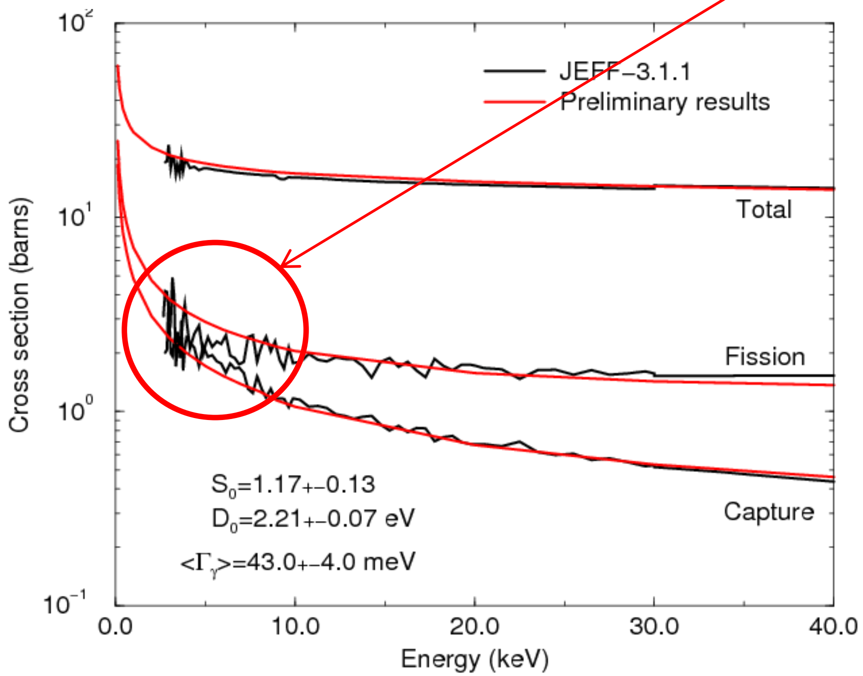
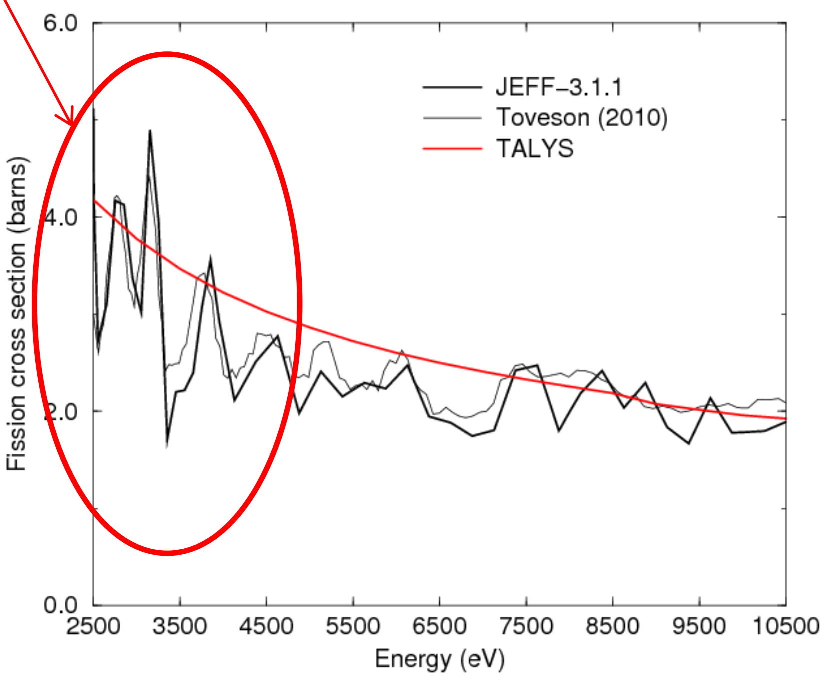
Solve inconsisent RTC results with measurements performed in the EOLE reactor

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

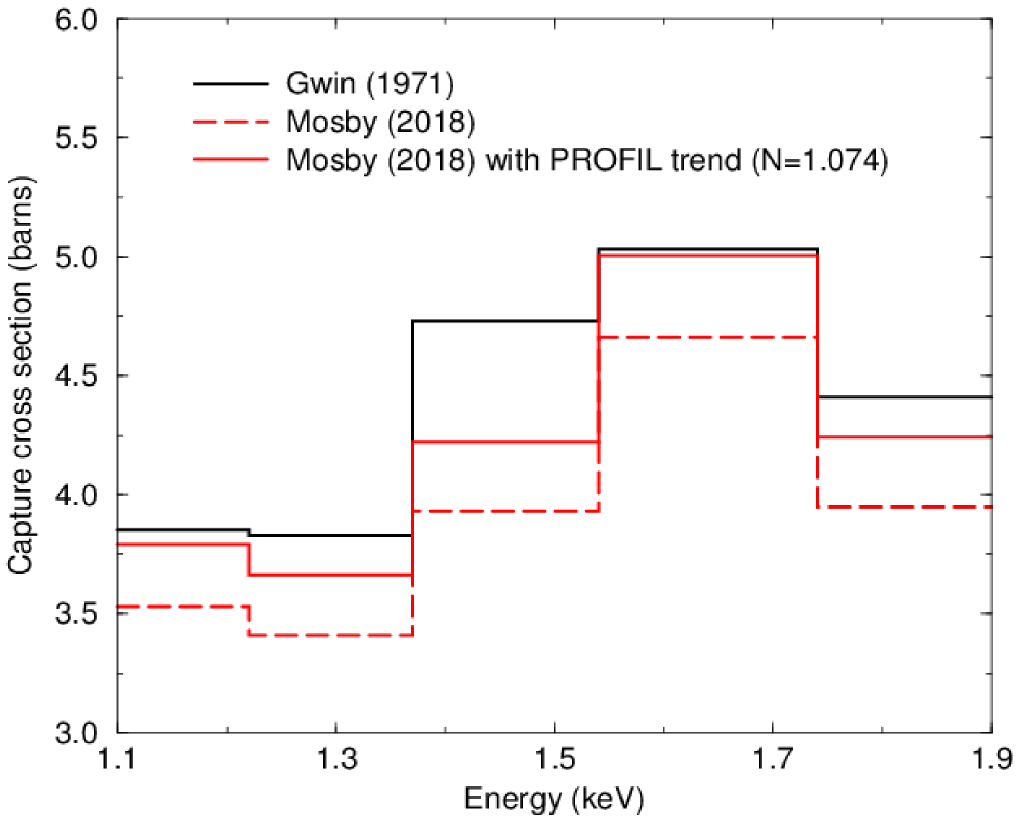




Fluctuations observed in JEFF-311 ⇒ **confirmed by Tovesson data (2010, LANL)**

Upper energy limit of the RRR ⇒ 5 keV

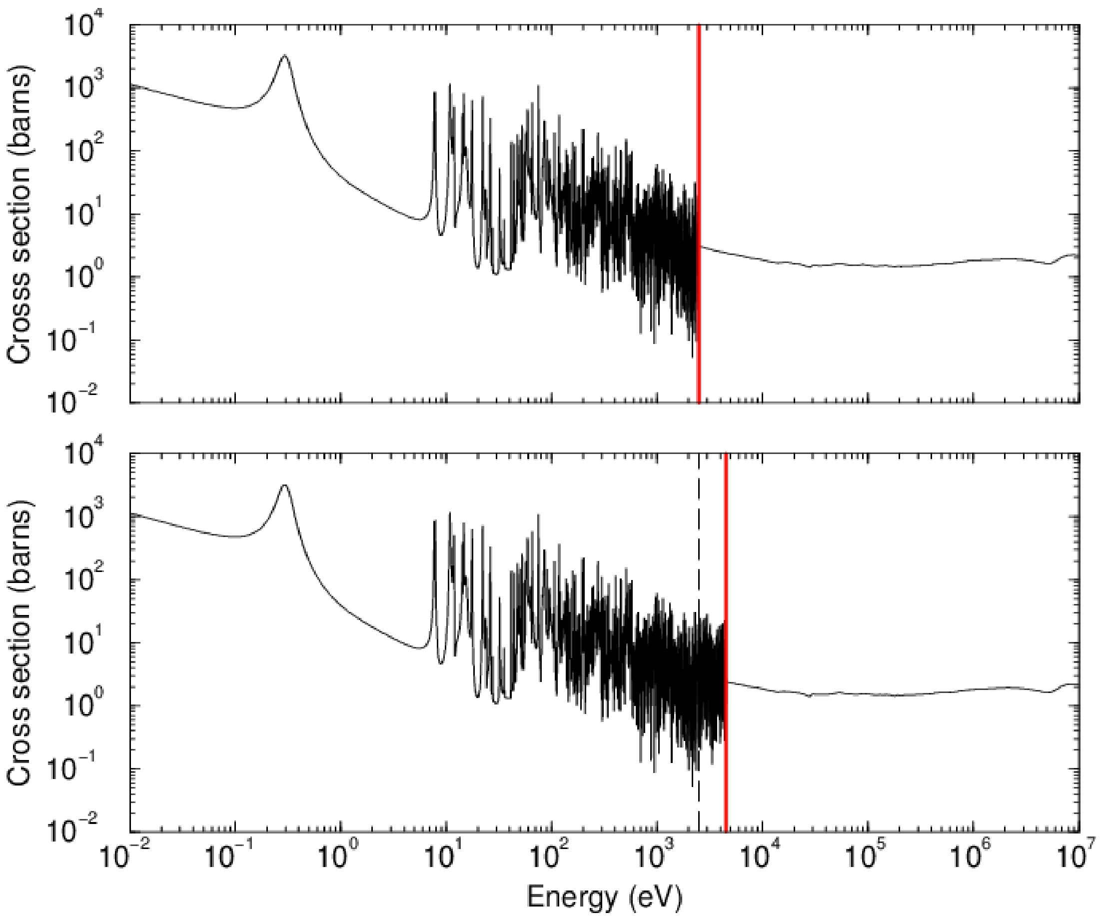
New capture data from Shea Mosby provide crucial trends to extend the RRR



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)

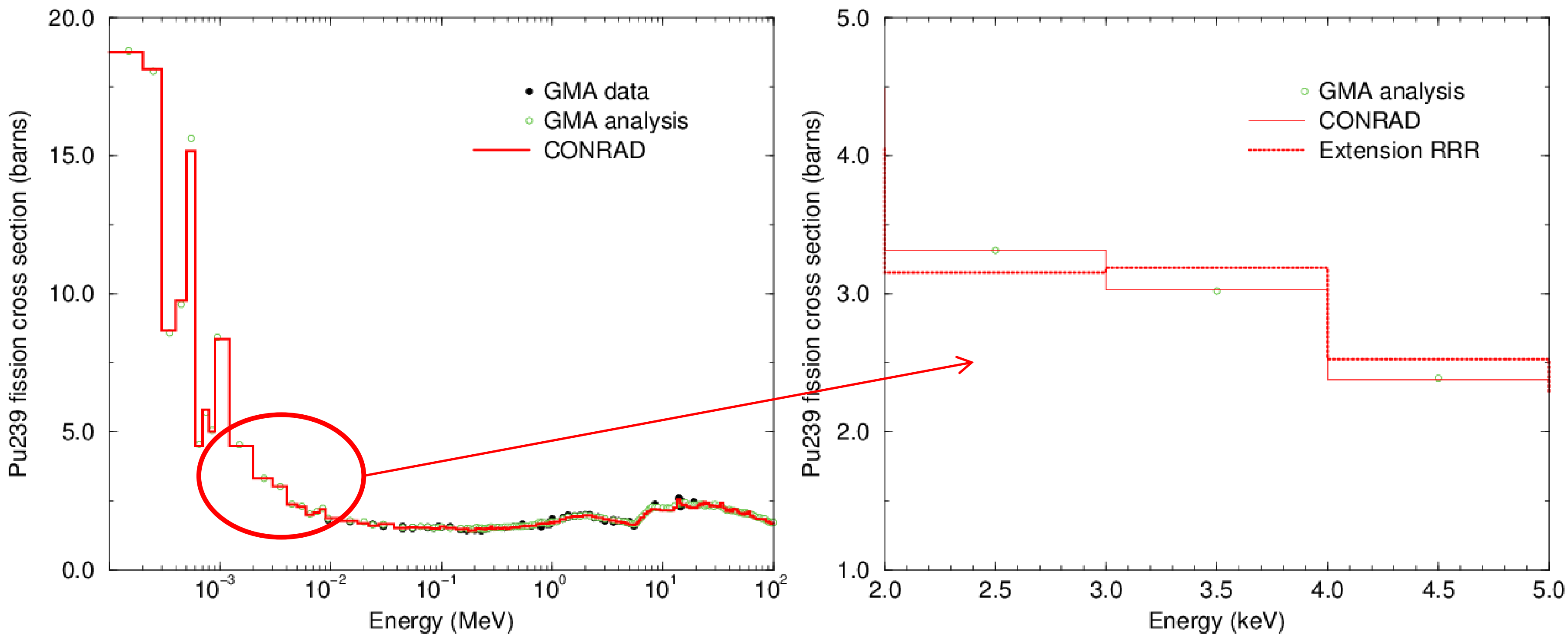
Upper energy limit of the RRR ⇒ 5 keV

Optimization of resonance ladders randomly generated by using URR parameters from JEFF-311



Upper energy limit of the RRR ⇒ 5 keV

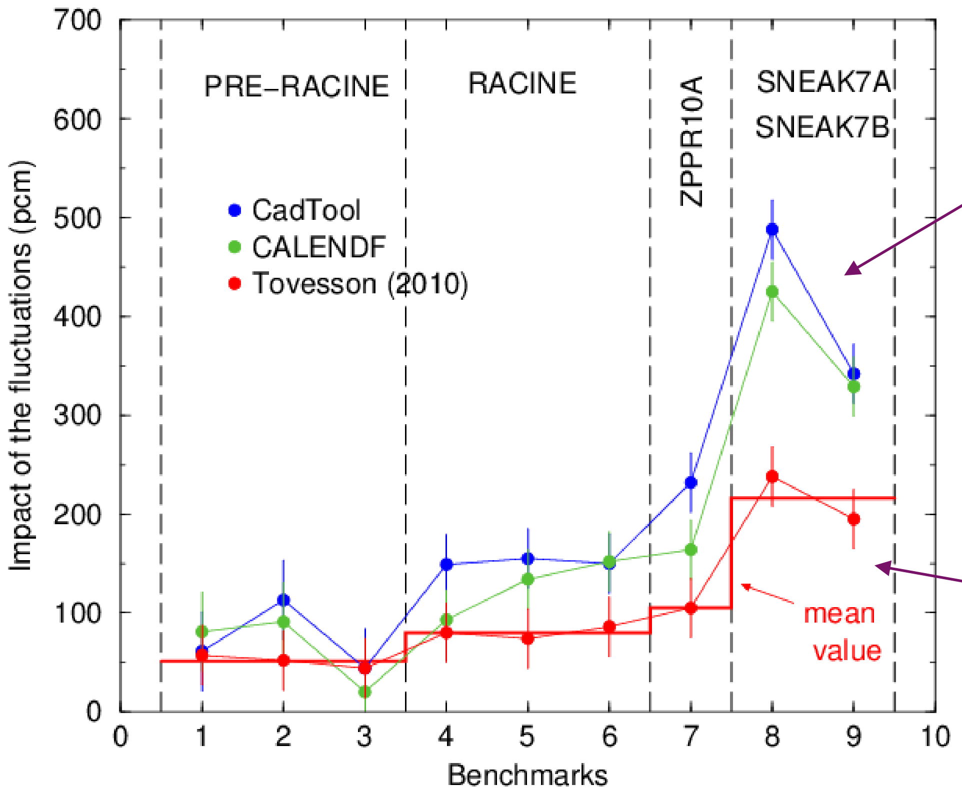
Comparison with GMA/CONRAD results



Extension of the RRR from 2.5 keV to 5 keV in good agreement with the GMA analysis (differences of 4%)

Upper energy limit of the RRR ⇒ 5 keV

Impact of the extension of the RRR up to 5 keV



Two sets of resonance ladders (CadTool and CALENDF) were generated and included in the ENDF file (MF=2, MT=151)

Tovesson data included in the Pu239 evaluation (MF=3, MT=18)

Significant impact (≈ 200 pcm) on SNEAK7A and SNEAK7B ⇒ **sodium free configurations**

Evolution of the JEFF library for MOX fuel calculations

JEFF-3.1.1

- Good performances of the JEFF-3.1.1 library on PST benchmarks
- However, several physical problems still unsolved

JEFF-3.2

- Improved MOX calculations, mainly due to new Am241 evaluation
- Pu239 evaluation comes from WPEC/SG34
  - ⇒ 3 resolved resonance ranges are merged
  - ⇒ good performances on PST are preserved
  - ⇒ Resonance Parameter Covariance Matrix is given

JEFF-3.3

- New Pu239 resonance parameters (to solve some missing interferences, …)
- Upper energy limit of the RRR is increased up to 4.5 keV

JEFF-x.x

- New PFNS
- New Thermal Neutron Constants
- New modeling of the fission process: Include (n,γf) reaction, add class II states …

Solve inconsisent RTC results with measurements performed in the EOLE reactor

New PFNS

Impact of the mean neutron energy uncertainty on PST calculations

Y. Peneliau et al., Pu239 Prompt Fission Neutron Spectra Impact on a Set of Criticality and Experimental Reactor Benchmarks, ND2013 (2013)

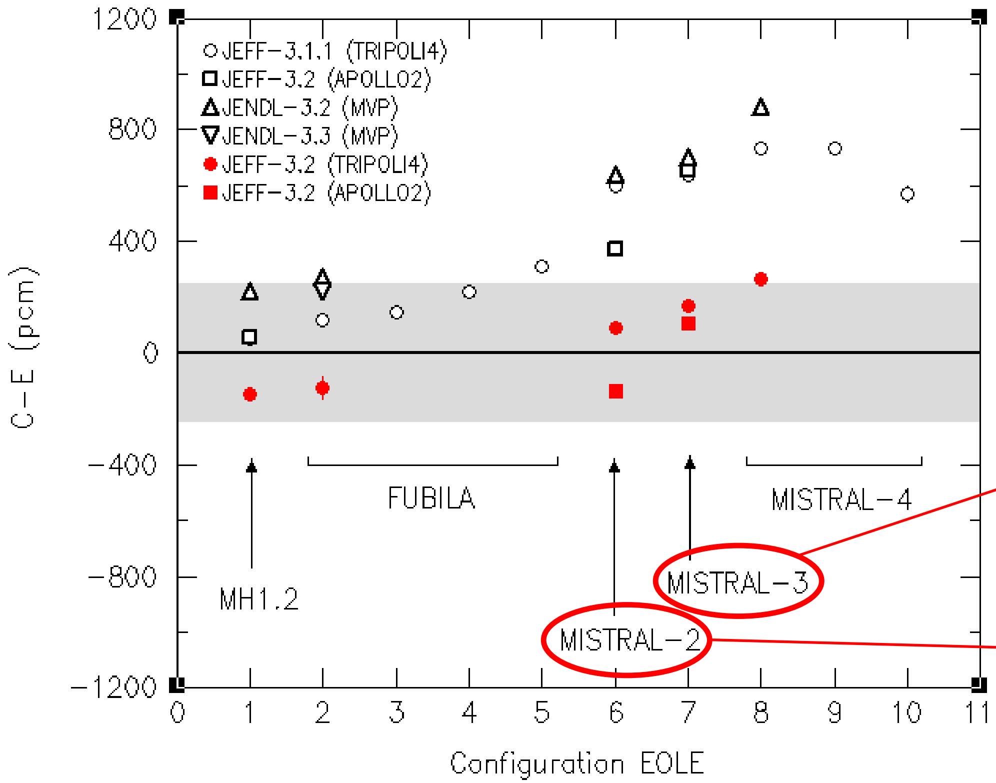
Authors	years	⟨E⟩	Δ[⟨E(PFNS)⟩,⟨E(JEFF-32)⟩]	Δ[keff(PFNS),keff(JEFF-32)
N. Kornilov	2008	2,055	-2,8%	+680 pcm
L. Berge	2014	2,087	-1,2%	+316 pcm
V. Maslov	2008	2,092	-1,0%	+250 pcm
JEFF-32	**2013**	**2,113**	**0%**	**0 pcm**
P. Romano	2014	2,122	+0,4%	-90 pcm
O. Serot	2013	2,140	+1,3%	-290 pcm
D. Rochman	2014	2,195	+3,9%	-890 pcm

Uncertainty suggested by R. capote ⇒**Δ⟨E⟩ = ± 1.5% ⇒ Δkeff(PST) ≈ ± 300 pcm**

New PFNS

@ A. Chebbouboi

Impact of the mean neutron energy uncertainty on MOX fuel calculations



Δ⟨E⟩= ± 1.5% ⇒ **± 109 pcm**

Δ⟨E⟩= ± 1.5% ⇒ **± 87 pcm**

mean neutron energy uncertainty ⇒ **low impact on EOLE benchmarks**

New Thermal Neutron Constant

Determination of the TNC with the CONRAD code by using “mic” data from Axton

Thermal constants		AGS			Monte-Carlo (N=1000)			STD2018		
		Values and fitting uncertainties		Final unc.	Values and fitting uncertainties		Final unc.	Values	Final Unc.	
Pu239	σ_s	7.99	(12.40%)	12.40%	7.99	(12.40%)	12.38%	7.8	12.82%	✓
	σ_f	749.10	(0.35%)	0.45%	749.50	(0.27%)	**0.49%**	752.4	**0.29%**	×
	σ_γ	270.60	(1.02%)	1.07%	270.10	(0.91%)	1.15%	269.8	0.93%	✓
	υ_t	2.882	(0.19%)	0.20%	2.881	(0.13%)	**0.23%**	2.878	**0.45%**	×

⇒ CONRAD and GMA analysis provide similar results

Fission cross section uncertainty seems to be underestimated

υ_t uncertainty seems to be overerestimated

New Thermal Neutron Constant

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	υ_t	2.882	(0.19%)	0.20%	2.881	(0.13%)	0.23%	2.878	0.45%	×

	JEFF-3.2 (=SG34)	Relative uncertainty	
		JEFF-3.2	COMAC-V2
σ_f	747.2 barns	0.9%	0.7%
σ_γ	270.1 barns	4.4%	1.6%
υ_t	2.875	-	0.1%

Two problems in JEFF3.2 and COMAC-V2

- Fission cross section
- υ_t Uncertainty

New Thermal Neutron Constant

Determination of the Westcott factors by using the “mac” data

Westcott factors were extracted from the macroscopic data of Axton by considering the TNC as fixed parameters with known uncertainties. Their uncertainties were propagated via the marginalization technique implemented in the CONRAD code.

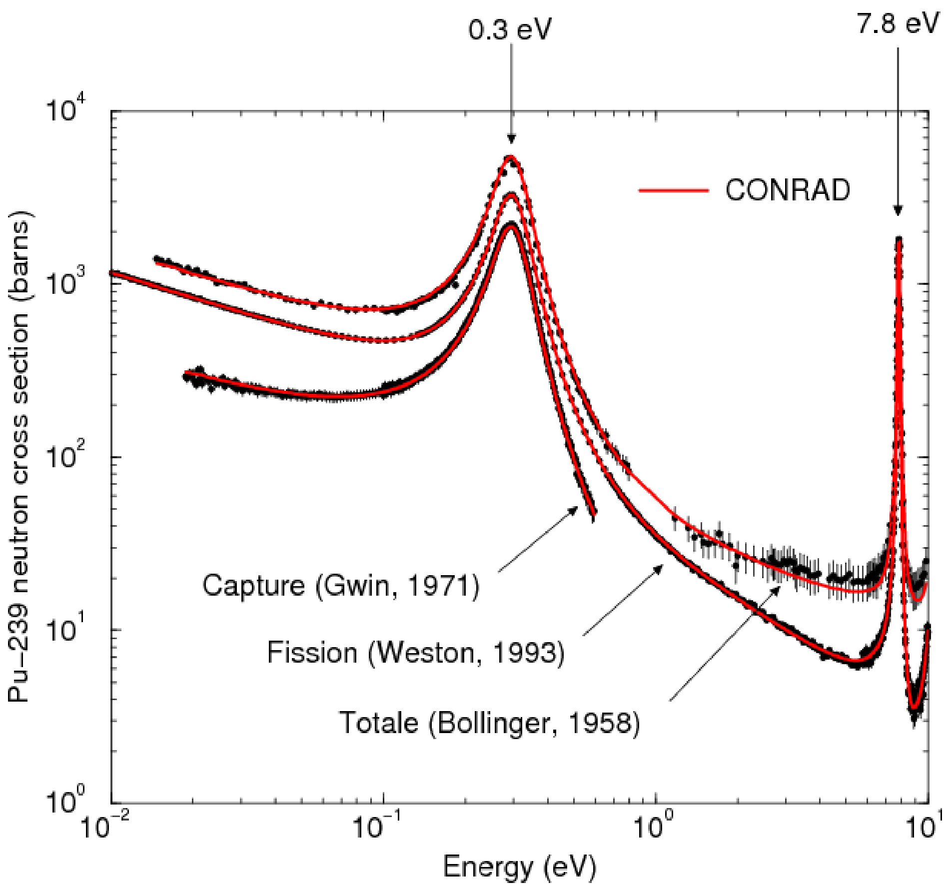
Thermal constants		AGS			Monte-Carlo (N=1000)			[car09]		
		Values and fitting uncertainties		Final unc.	Values and fitting uncertainties		Final unc.	Values	Final Unc.	
Pu239	g_a	1.079	(0.51%)	0.71%	1.081	(0.44%)	0.75%	1.078	**0.22%**	✓
	g_f	1.053	(0.44%)	0.64%	1.053	(0.35%)	0.64%	1.055	**0.21%**	✓

	JEFF-3.2 (=SG34)
g_a	1,077
g_f	1,052

Westcott factors in JEFF-3.2 ⇒ Ok

New resonance parameters

Reich-Moore analysis with the CONRAD code



- **New transmission of the 1st resonance is needed ⇒ Bollinger 1958 !!!**
- Fission cross section ⇒ problems to normalize the 3 data sets from Weston
- Capture cross section ⇒ problems to normalize the capture data from Brooks (1966) and the 2 data sets from Gwin (1971)
- Mosby data not yet available
- Comparison with the Pu239 evaluation study of M. Alrwashdeh (ANE 118, 313, 2018)

New model for the fission process

"The R-Matrix formalism"

@ E. Leal Cidoncha

Total cross section:

$$\sigma^{total} = \frac{2\pi}{k_\alpha^2} \sum_J g_J \sum_c \left[1 - \mathrm{Re}\left(U_{cc'}\right)\right]$$

Scattering matrix:

$$U_{cc'} = e^{-i(\phi_c - \phi_{c'})} \left\{ \delta_{cc'} + 2iP_c^{1/2} \left[\left(1 - R(L-B)\right)^{-1} R \right]_{cc'} P_{c'}^{1/2} \right\}$$

L is a diagonal matrix with elements $L_c = S_c + iP_c$, being S_c the phase factor.
B is a diagonal matrix which elements B_c represents the boundary conditions.

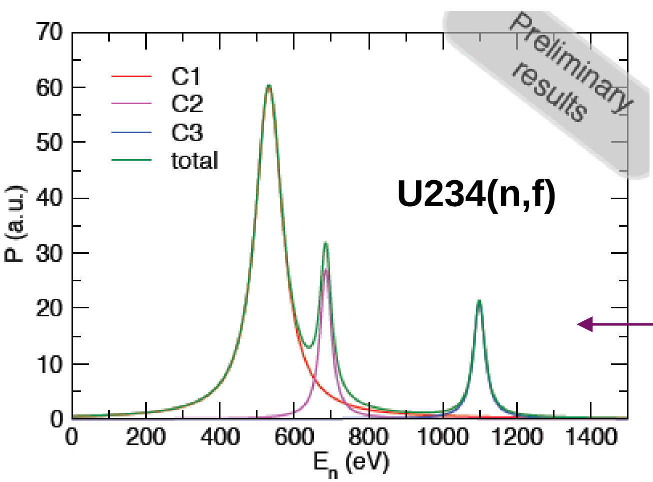
R-matrix:

$$R_{cc'}(E) = \sum_\lambda \frac{\gamma_{\lambda c} \gamma_{\lambda c'}}{E_\lambda - E}$$

Reduced width amplitude:

$$\gamma_{\lambda c} = \sqrt{\Gamma_{\lambda c} / 2P_c}$$

Penetration factor



P_c=1 for the fission reaction ⇒ $P_c(E)$

New resonance analysis by including the (n,γf) process

The observed fission is the sum of the « direct » fission and of the two-step (n,γf) reaction:

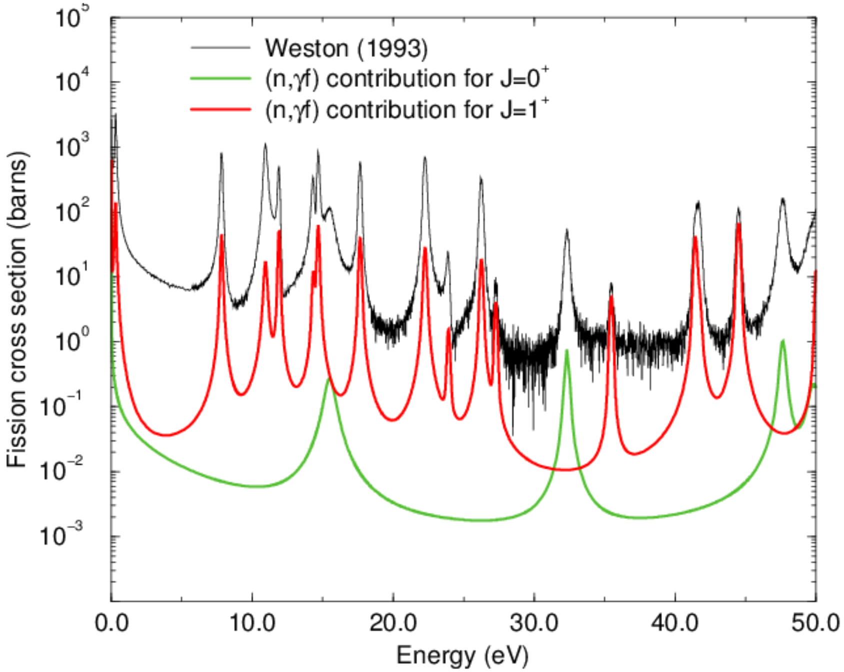
$$\sigma_{f,obs}(E)=\sigma_{(n,f)}(E)+\sigma_{(n,\gamma f)}(E)$$

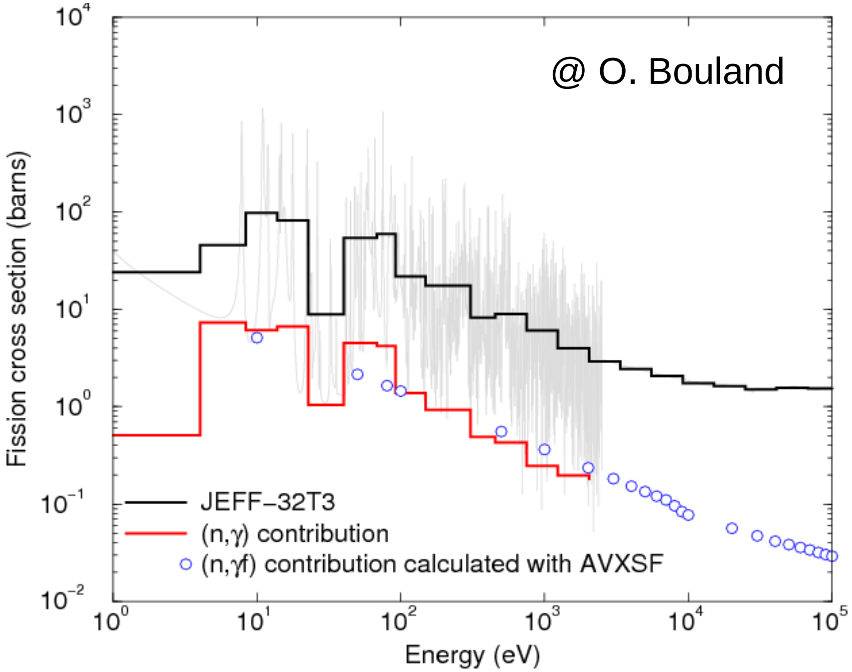
Channel widths for the direct fission (n,f) and for the two-step (n,γf) reaction

- Two openened fission channels for $J^{\pi}=0^{+} \Rightarrow \Gamma_{f1}(0^{+})$ and $\Gamma_{f2}(0^{+})$
- One openened fission channels for $J^{\pi}=1^{+} \Rightarrow \Gamma_{f}(1^{+})$
- Two J-dependent widths for the (n,γf) reaction $\Rightarrow \Gamma_{\gamma f}(0^{+})$ and $\Gamma_{\gamma f}(1^{+})$

New resonance analysis by including the (n,γf) process

Good agreement is obtained between the (n,γf) reaction deduced from the RRR and the AVXSF calculations (LANL/CEA collaboration)

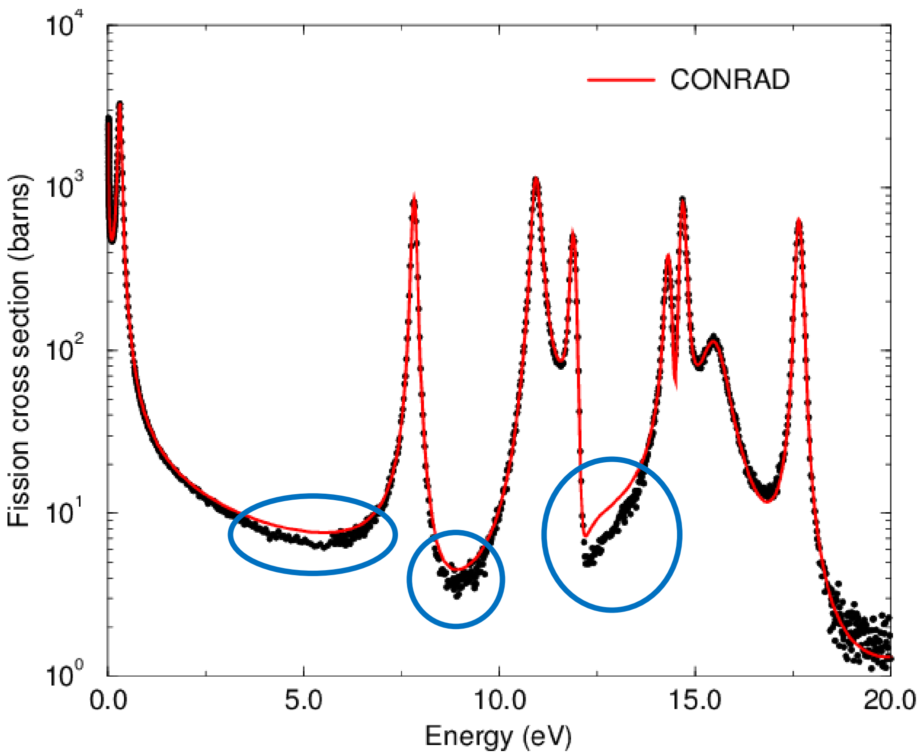




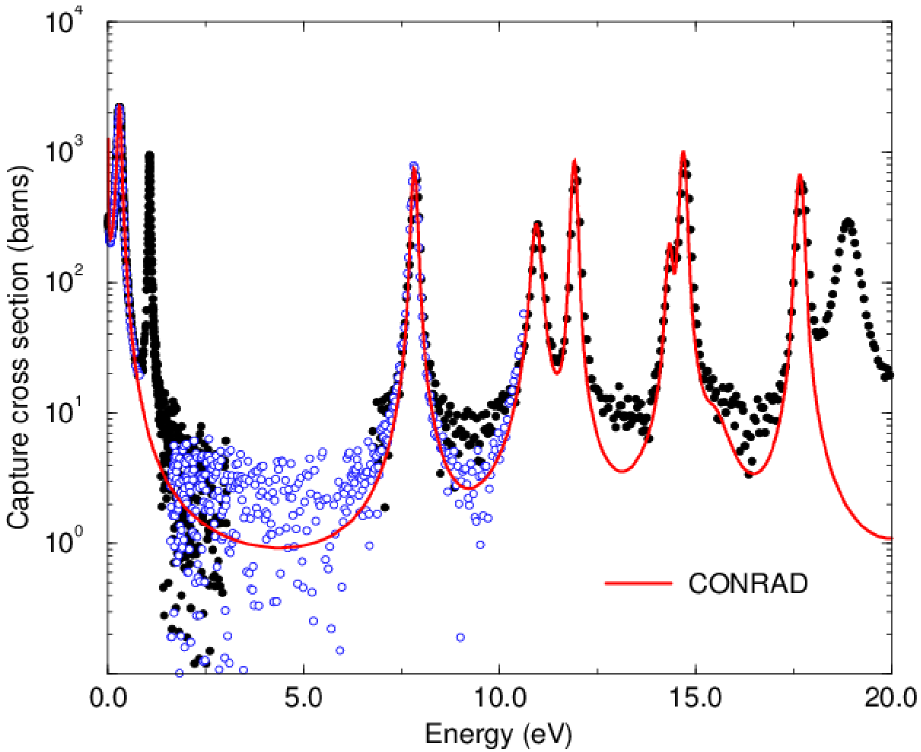
The smallest resonances with $J^{\pi}=1^{+}$ are dominated by the (n,γf) process

New resonance analysis by including the (n,γf) process

CONRAD analysis with the (n,γf) contribution



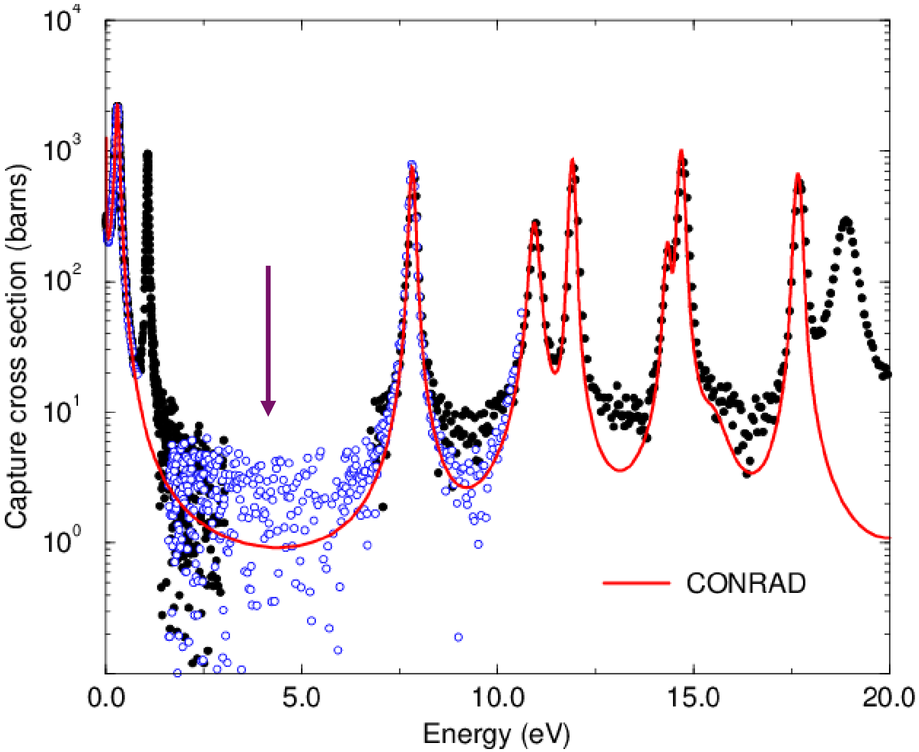
Strong impact ⇒interferences between the resonances

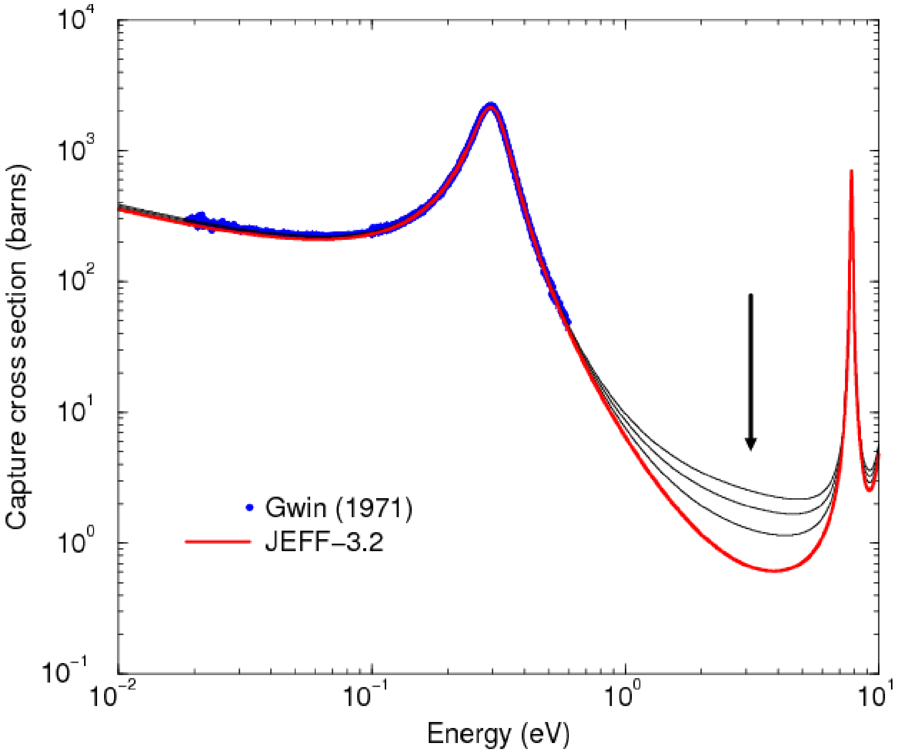


Slight modification of the radiation widths (0.5 meV in average)

New resonance analysis by including the (n,γf) process

Behavior of the cross section between the resonance can be changed by using the imaginary part of the distant level parameter R^∞





Simultaneous analysis of the Neutron multiplicity

Channel widths for the direct fission (n,f) and for the two step (n,γf) reaction

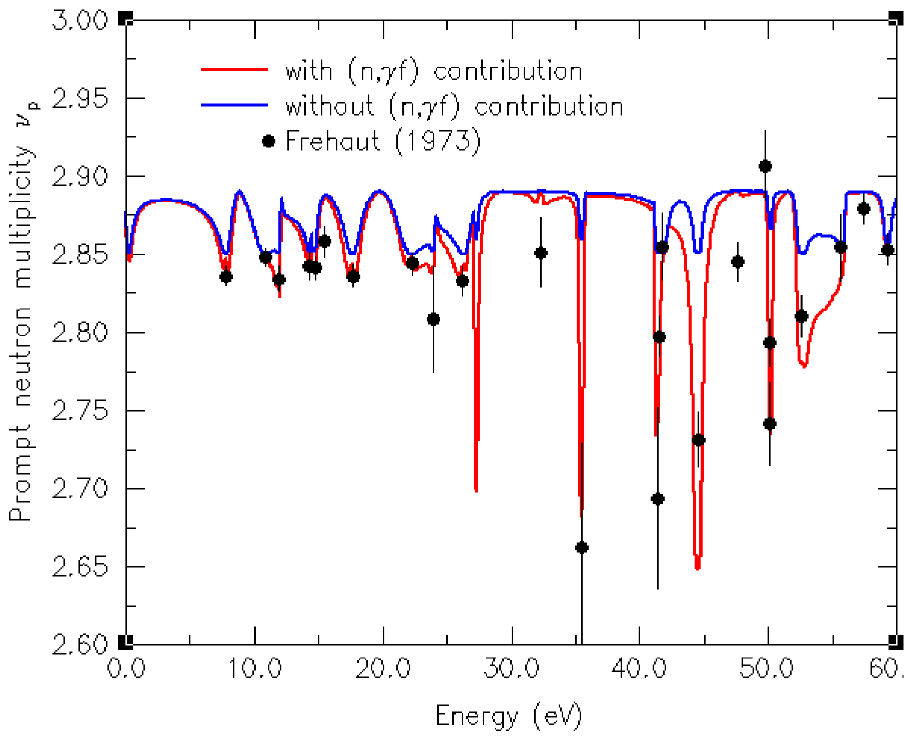
- Two openened fission channels for $J^{\pi}=0^{+} \Rightarrow \Gamma_{f1}(0^{+})$ and $\Gamma_{f2}(0^{+})$ $\Rightarrow$ **$\Gamma_{f}(0^{+})$**
- One openened fission channels for $J^{\pi}=1^{+}$ $\Rightarrow$ **$\Gamma_{f}(1^{+})$**
- Two J-dependent widths for the (n,γf) reaction $\Rightarrow$ **$\Gamma_{\gamma f}(0^{+})$ and $\Gamma_{\gamma f}(1^{+})$**

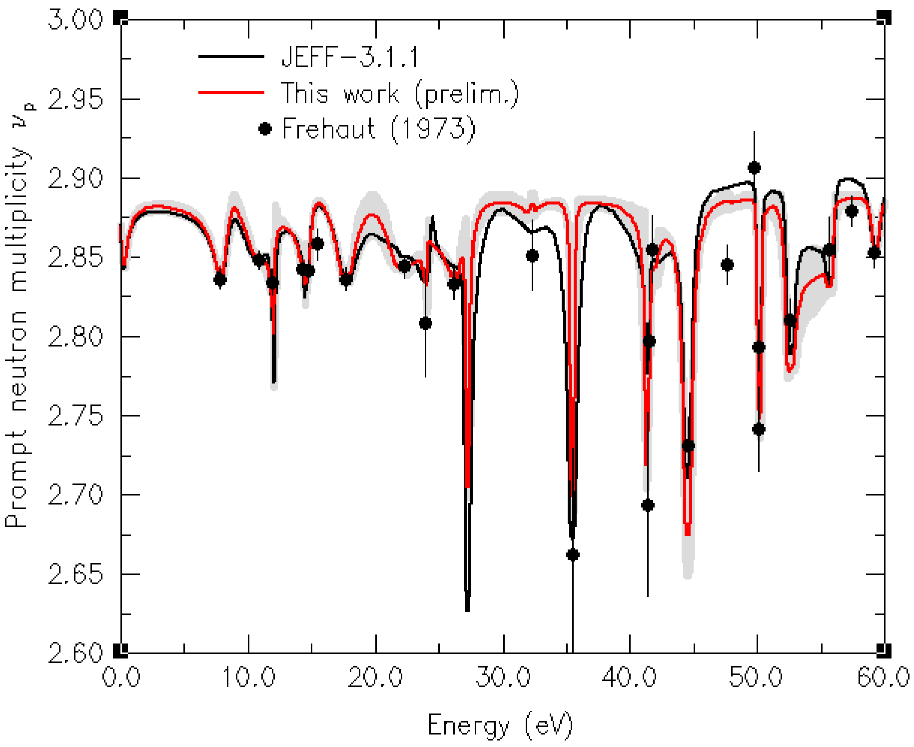
Four partial widths are introduced in the phenomenological description of υ_p

$$\upsilon_p(E) \approx \sum_{i=1}^{4} \nu_i P_i(E) \qquad P_i(E) = \frac{\sigma_i(E)}{\sigma_{(n,f)}(E) + \sigma_{(n,\gamma f)}(E)}$$

Simultaneous analysis of the Neutron multiplicity

Contribution of the (n,γf) process can be observed for resonances with $J^{\pi}=1^{+}$

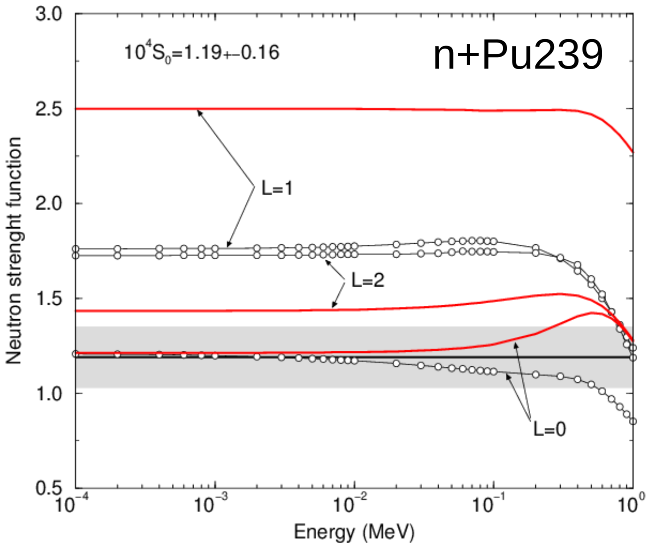




Link with optical model calculations

Equations of the SPRT method have been implemented in the OPTMAN code (ND2016)

SPRT method from Delaroche and Lagrange (IAEA-190, 1976)




```
NEUTRON ENERGY =  0.000100
TOTAL  CR-SECT.= 61.538557
ELASTIC  CR-SECT. = 11.624466
REACTION CR-SECT. = 49.914091
REACTION CR-SECT. incl. coupled levels = 49.914091
SCATTERING RADIUS =  9.617929

 Nlev     Elev    Jpi          CR-SECT(Nlev)
  1     0.0000   0.5+            11.624466

                             STRENGTH  FUNCTIONS
SF0 =   0.1208258E-03        SF1 =   0.1761140E-03        SF2 =   0.1725711E-03

                    STRENGTH  FUNCTIONS FROM ESW
S0   =  0.1212866E-03        S1   =  0.2498198E-03        S2   =  0.1434415E-03
R0   =  0.9597059E+01        R1   =  0.7080428E+01        R2   =  0.8832262E+01
```

This work

⇒ Consistent description of the phase shift and neutron penetration factor

Evolution of the JEFF library for MOX fuel calculations

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- Good performances of the JEFF-3.1.1 library on PST benchmarks
- However, several physical problems still unsolved

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JEFF-x.x

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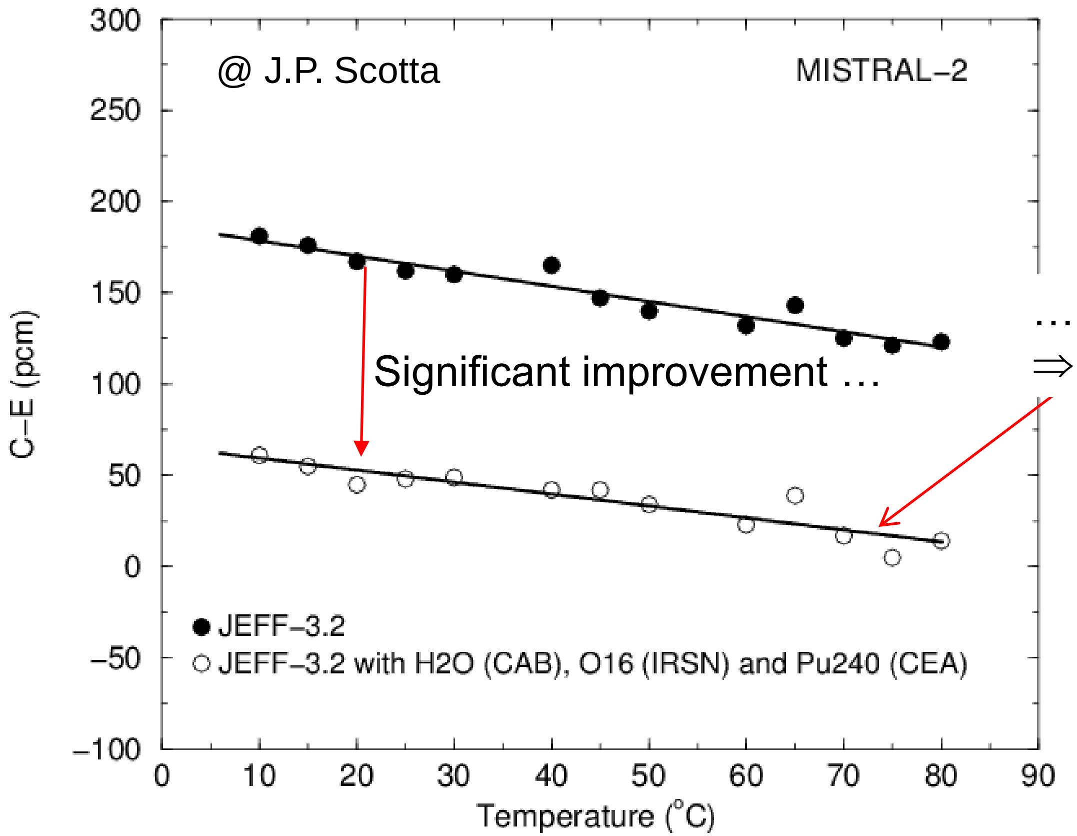
- New Thermal Neutron Constants
- New modeling of the fission process: Include (n,γf) reaction, add class II states …

Solve inconsisent RTC results with measurements performed in the EOLE reactor

RTC experipments (MOX fuel)

Integral validation with EOLE experiments as a function of the temperature (CEA Cadarache)



… but negative slope not yet solved

⇒ **α(Pu239)**