DE LA RECHERCHE À L'INDUSTRIE

Improved MOX fuel calculations using new Pu-239, Am-241 and Pu-240 evaluations

Wonder 2012 | G. Noguere, O. Bouland, D. Bernard, P. Leconte, P. Blaise, Y. Penneliau, J.F. Vidal, C. De Saint Jean, L. Leal, P. Scjilleebeeckx, S. Kopecky, C. Lampoudis, C. Morariu, A. Tudora

27 Sept. 2012

Context

• Extensive experimental programs, carried out in the zero-power research reactor EOLE of the CEA Cadarache, were designed to study advanced LWR and BWR core configurations of MOX fuel assemblies.

• The parameter of interest in this work is the residual reactivity.

• New reactivity calculations using the TRIPOLI-4 Monte-Carlo Code with the JEFF-3.1.1 nuclear data library have confirmed the systematic overestimation of the keff.

Integral experiments

MH1.2 (EOLE, Cadarache)	PWR-MOx mixed core	4 years
BASALA-Hot (EOLE, Cadarache)	BWR-MOx BWR-MOx	12 years 13 years
MISTRAL-2 (EOLE, Cadarache)	PWR-MOx	8 years
MISTRAL-3 (EOLE, Cadarache)	PWR-MOx	9 years
MISTRAL-4 (EOLE, Cadarache)	MOx-REF MOx-AIC MOx-Hf MOx-B4C	10 years 10 years 10 years 10 years
FUBILA-Hot (EOLE, Cadarache)	BWR-REF (EPICURE) BWR-NORM (EPICURE) BWR-70% Void (EPICURE) BWR-10×10 (EPICURE) BWR-UGD (EPICURE)	1 years (16-17 years) 1 years (16-17 years) 1 years (16-17 years) 1 years (16-17 years) 1 years (16-17 years)
ERASME (EOLE, Cadarache)	ERASME/R, HCPWR ERASME/S	
OSMOSE (MINERVE, Cadarache)	Oscillation measurements (R1U02 and R1MOX lattices)	
Post Irradiated Experiments (PIE)	GRAVELINE (ALIX-HTC), GUNDREMMINGEN, DAMPIERRE, …	

Am-241 evaluation

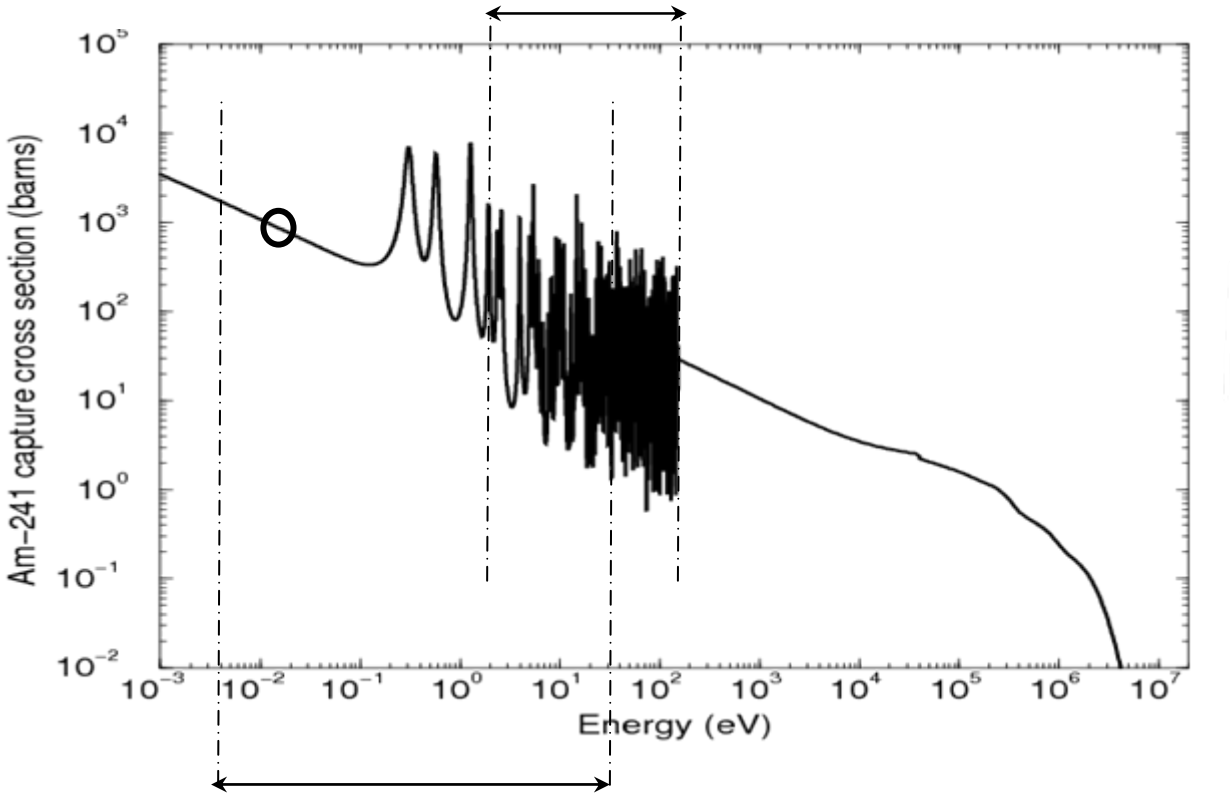
New evaluation of the Resolved Resonance Range (E<150 eV)
•IRMM/CEA Collaboration (PhD Thesis C. Sage, sample preparation, …)
•Neutron Resonance Shape Analysis with REFIT/CONRAD
•Resonance Parameter Covariance Matrix generated by marginalization

ECIS/TALYS description of the « continuum » (150 eV< E<20 MeV)
•Collaboration with the Bucarest University (PhD Thesis C. Morariu)
•Collaboration with Los Alamos National Lab. (« head band states »)

Integral benchmarks
•MELUSINE (Grenobles)
•MINERVE, EOLE, MASURCA (Cadarache)
•PHENIX (Marcoule)
•Monte Carlo code TRIPOLI-4
•Deterministic codes APOLLO-2.8 and ERANOS-2

Am-241 evaluation

Capture yield from G. Vanpraet, IRMM, 1985
Transmission from H. Derrien, Saclay, 1975

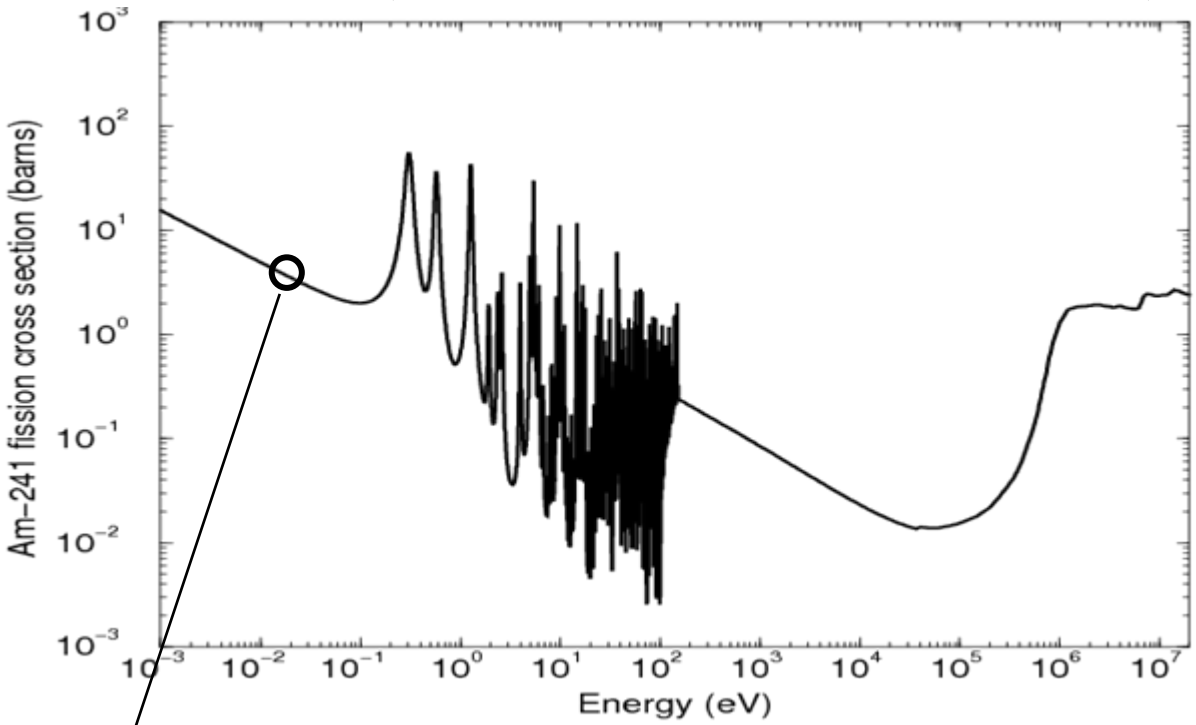


Capture yield and transmission
IRMM

See talk of C. Lampoudis

Am-241 evaluation

J.W.T. Dabbs, ORELA, 1983



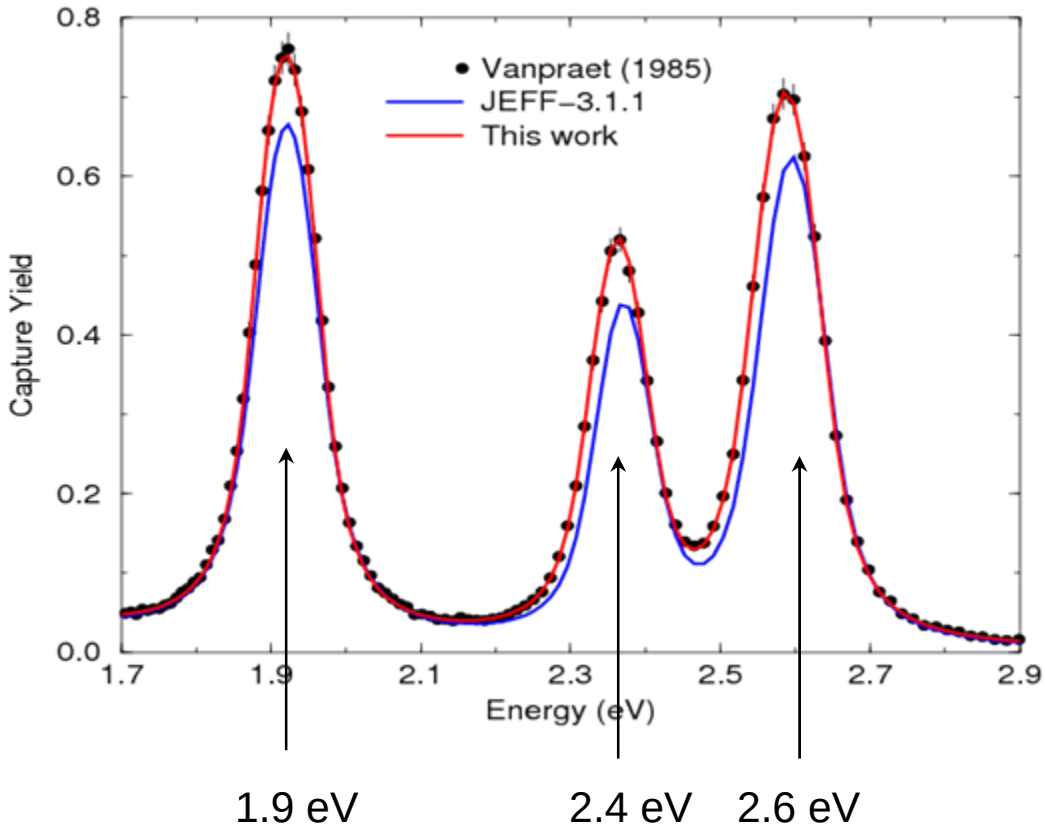
Alain Letourneau
MINI-INCA (ILL)

Derrien
Saclay
1975

Am-241 evaluation

Capture cross section (C6D6) : G. Vanpraet et al. (1985)

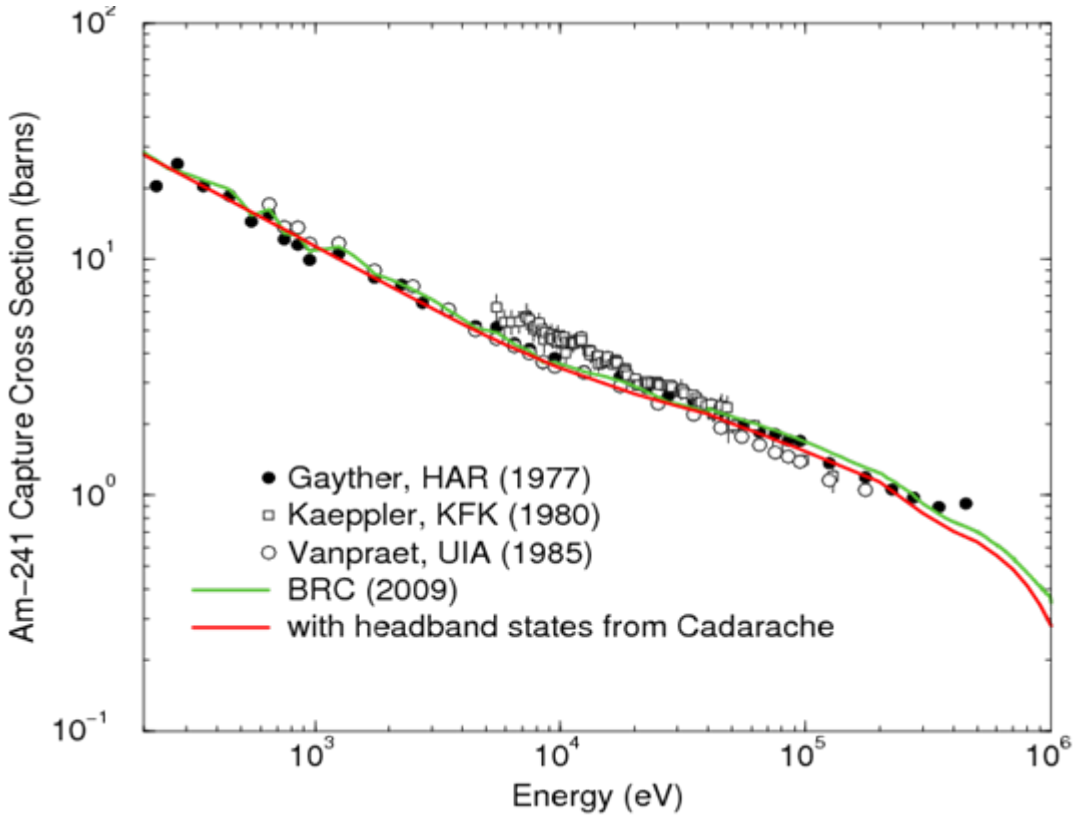
Re-normalization of the capture Yield measured by Vanpraet by using the transmission data measured at the IRMM



Am-241 evaluation

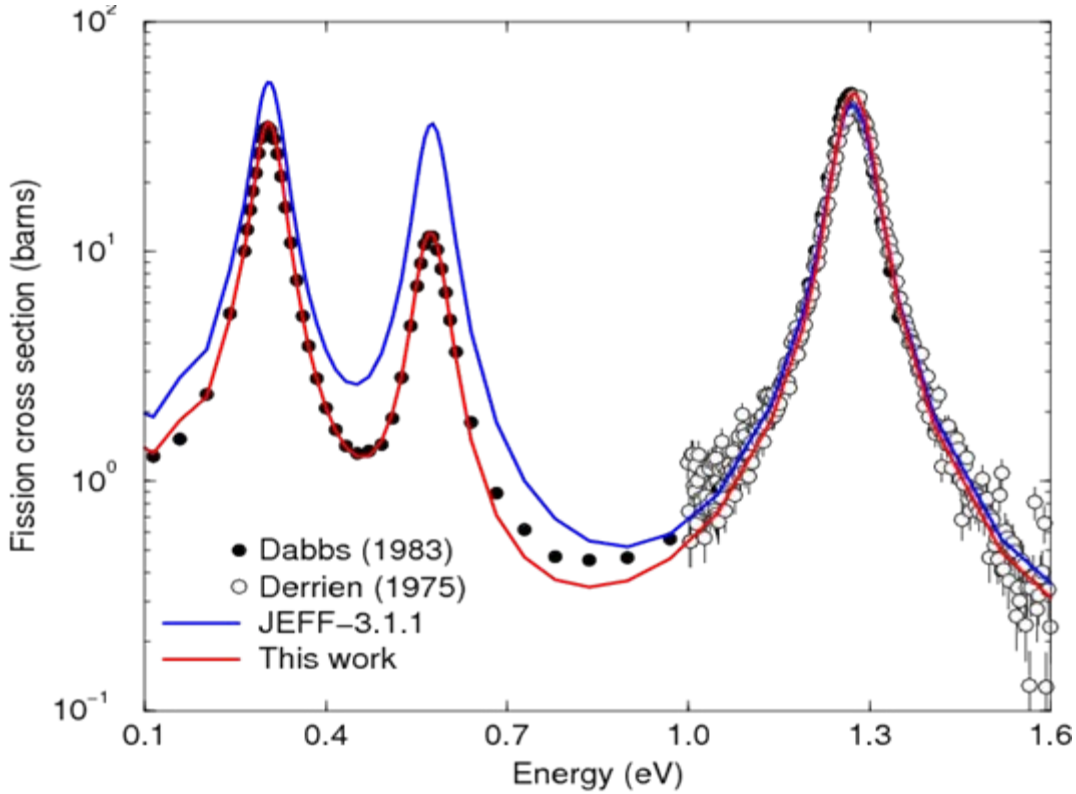
Capture cross section :

ECIS/TALYS calculations based on the Optical Model Parameters of Soukhovitskii et al, Phys. Rev. C72, 024604 (2005) ⇒ see talk of J.M. Quesada Molina



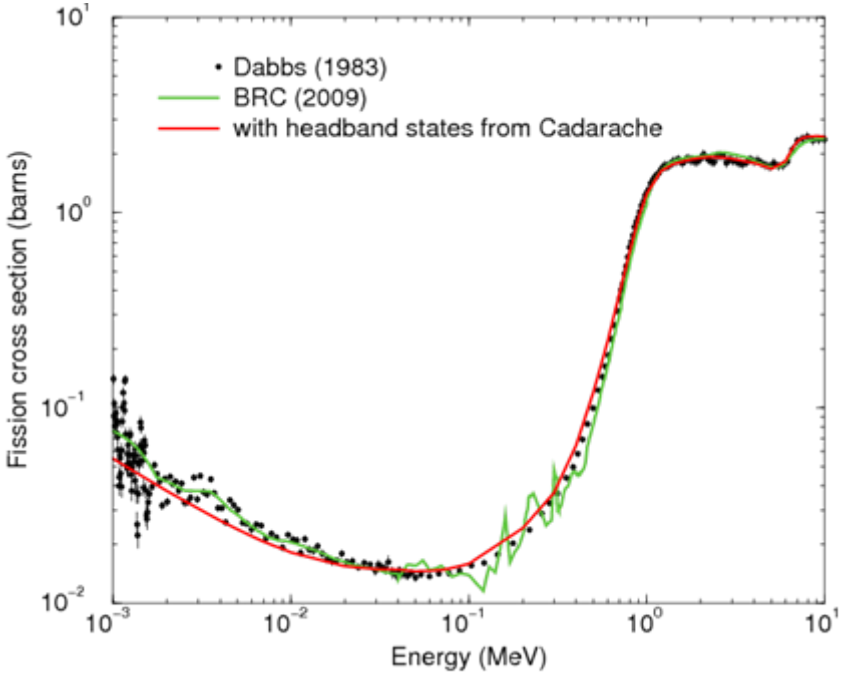
Am-241 evaluation

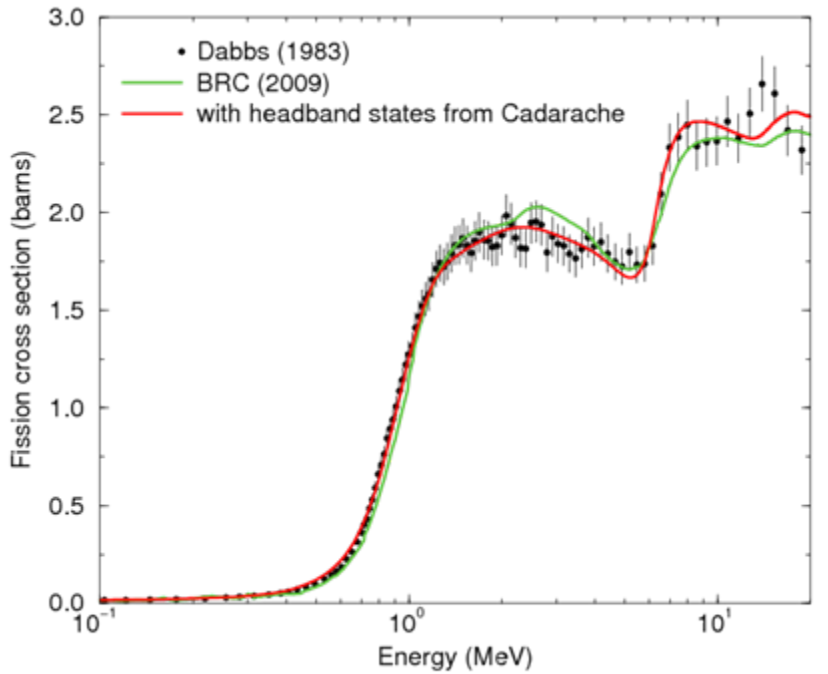
Fission cross section : Dabbs (ORELA, 1983) and Derrien (Saclay, 1975)



Am-241 evaluation

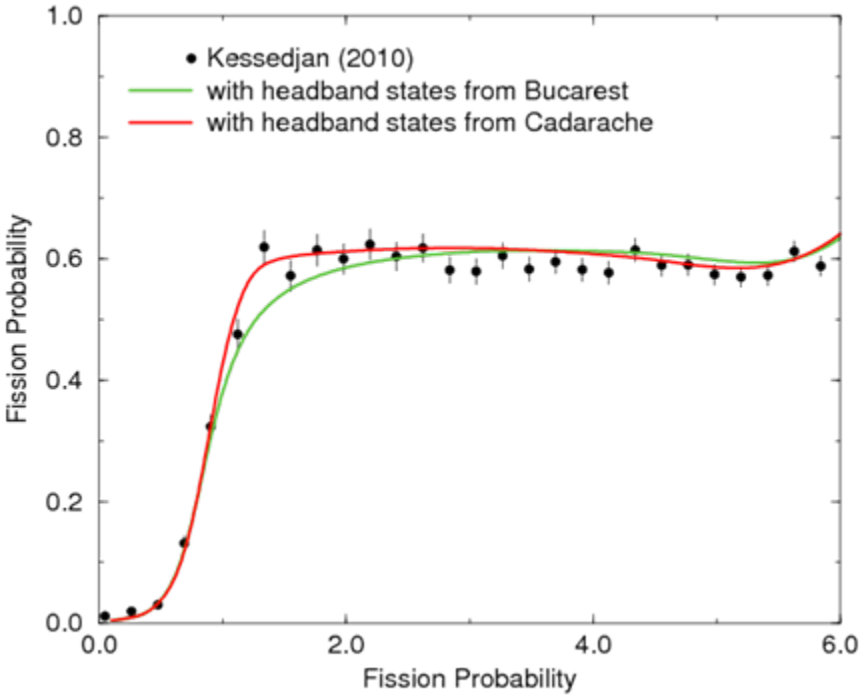
Fission cross section : ECIS/TALYS calculations
Head-band states based on the work of Olivier Bouland (LANL/CEA collaboration)

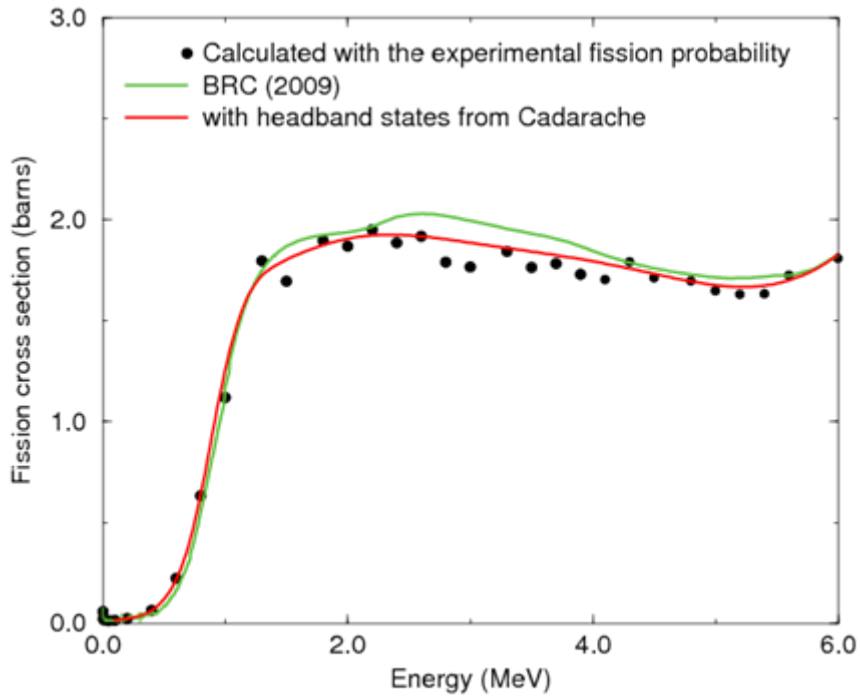




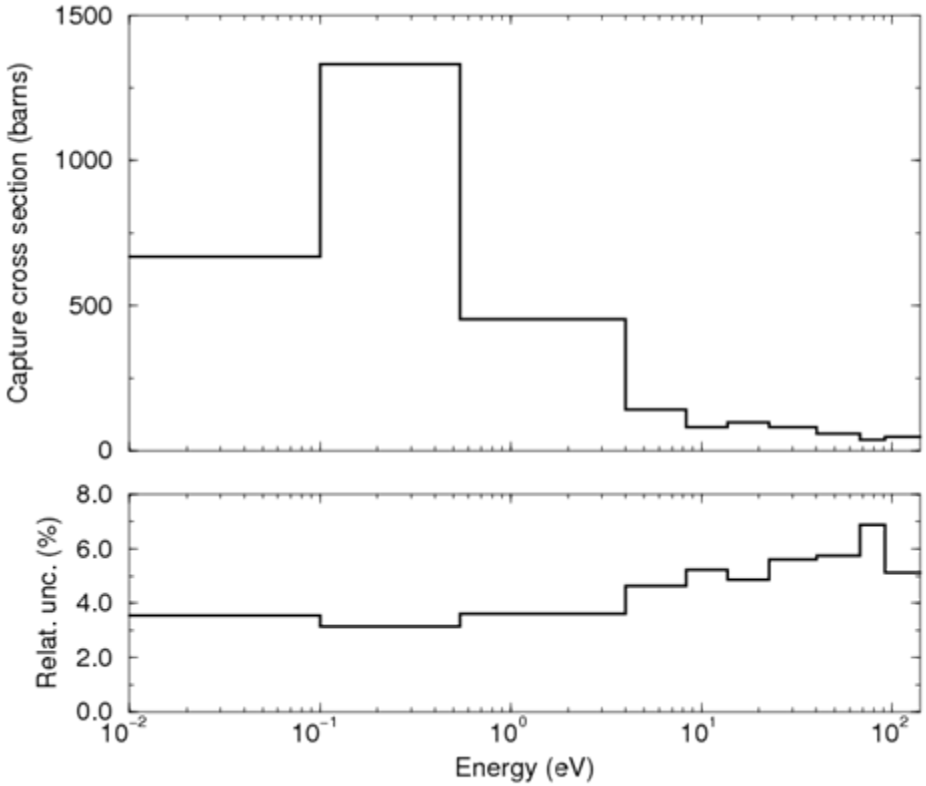
Am-241 evaluation

Fission Probability : surrogate-reaction method, CENBG
See talk of Beatriz Jurado





Am-241 evaluation



Thermal Capture Xs (+15%)

JEFF-3.1.1 = 647 b

New = 746 ± 24 b

Capture resonance integral (+20%)

JEFF-3.1.1 : 1526 b

New : 1825 ± 65 b

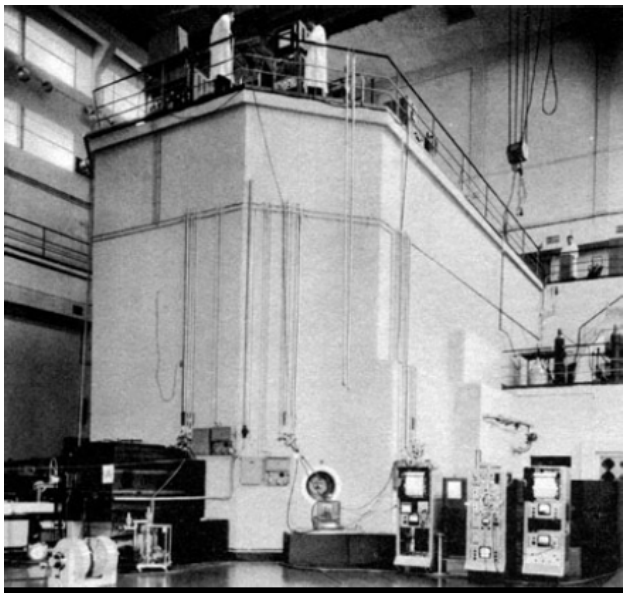
Fission resonance integral (-19%)

JEFF-3.1.1 : 17.3 b

New : 14.5 ± 1.0 b

Am-241 evaluation

ICARE-S program (1986)



Irradiation of two Am-241 samples in MELUSINE (Grenoble, France)

This experiment contained rods with samples of almost pure actinide isotopes separated into small quantities.

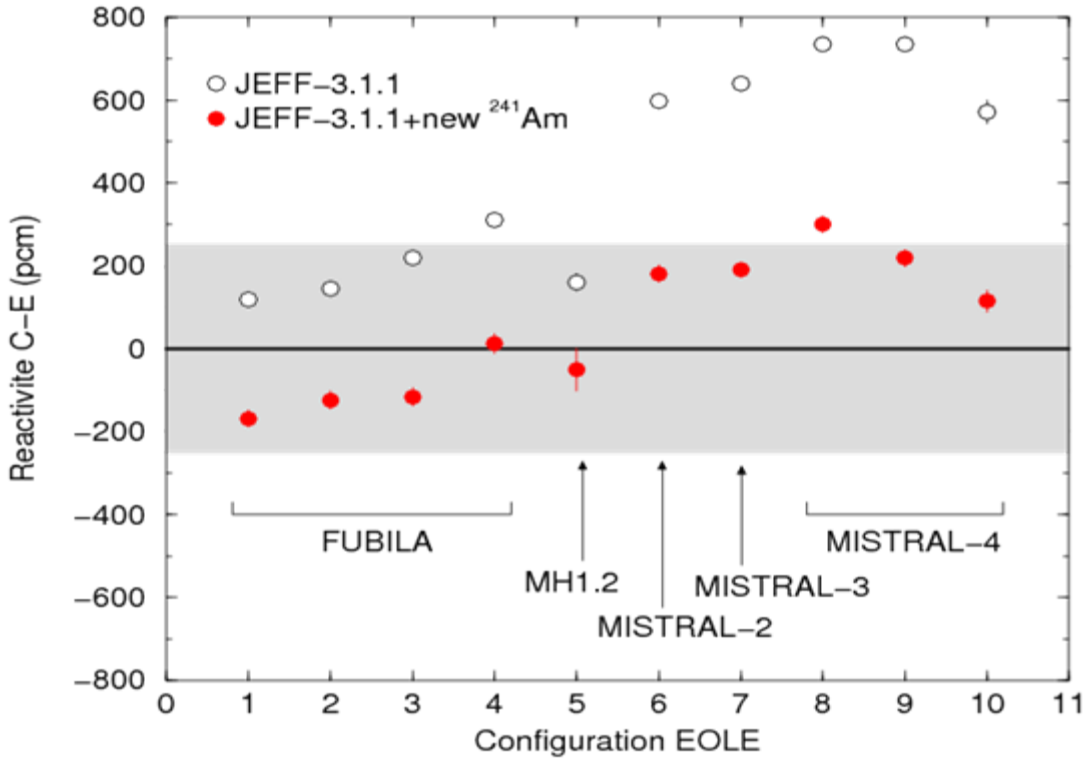
The variables of interest for the interpretation of ICARE are the sample composition at the beginning and at the end of the irradiation period (6 months)

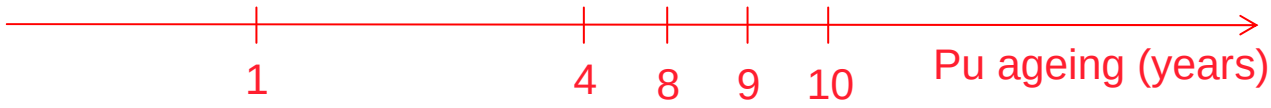
The **Integral Data Assimilation** technique implemented in the CONRAD code was used to extract the capture resonance integral from the ICARE-S experiment

I_0 (JEFF-311) = 1526 b
I_0 (new) = 1825 ± 65 b
I_0 (ICARE-S) = 1895 ± 90 b

Am-241 evaluation

zero-power research reactor
EOLE (Cadarache)





Pu-239 evaluation

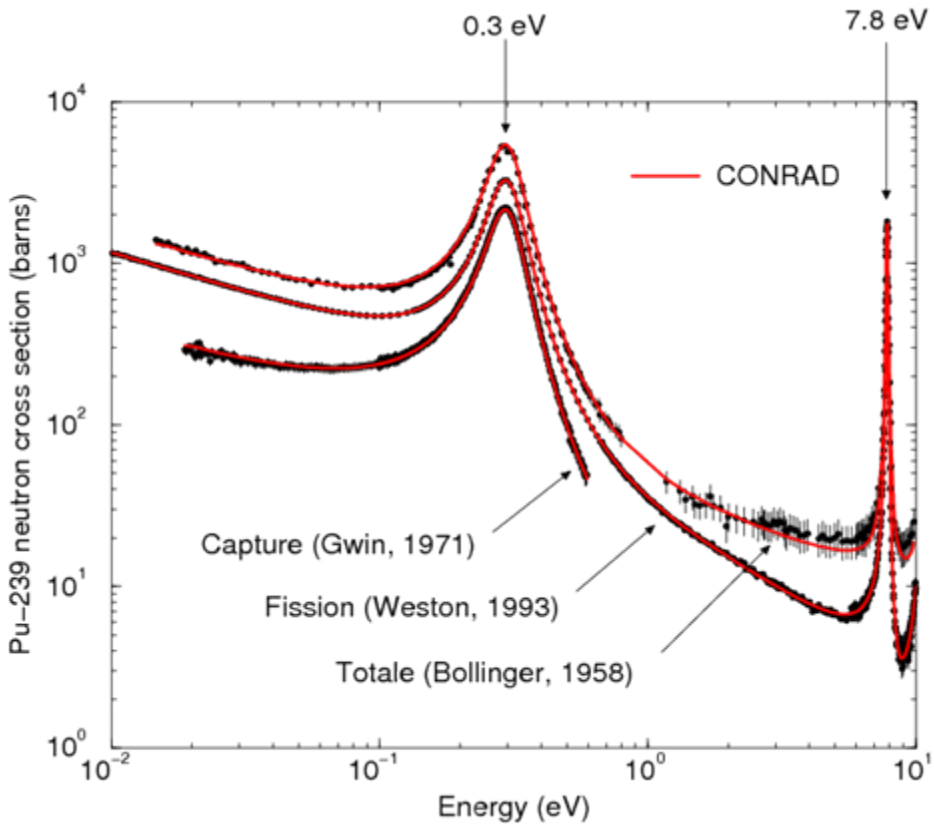
New evaluation of the Resolved Resonance Range (E<2.5 keV)
- ORNL/NEA/CEA Collaboration (Luiz Leal)
- Neutron Resonance Shape Analysis with SAMMY/CONRAD
- Resonance Parameter Covariance Matrix generated by marginalization
- Investigation of the (n,γf) reaction
- Phenomenological description of the neutron multiplicity ν_p

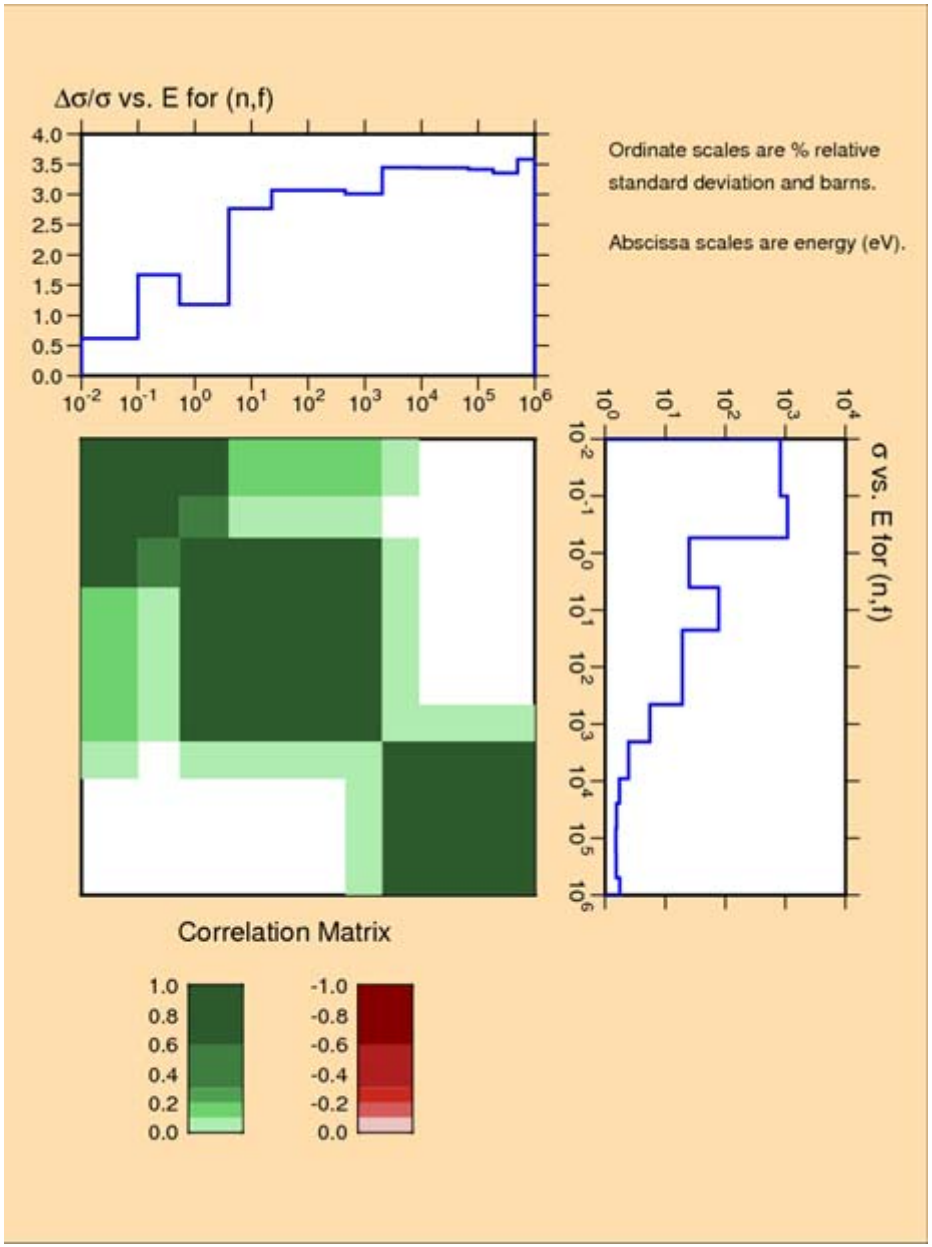
Description of the « continuum » (2.5 keV< E<30 MeV)
- CEA/Dam of Bruyère-Le-Châtel $\Rightarrow$ See talk of Yannick Peneliau
- LANL/CEA Collaboration $\Rightarrow$ See talk of Olivier Bouland

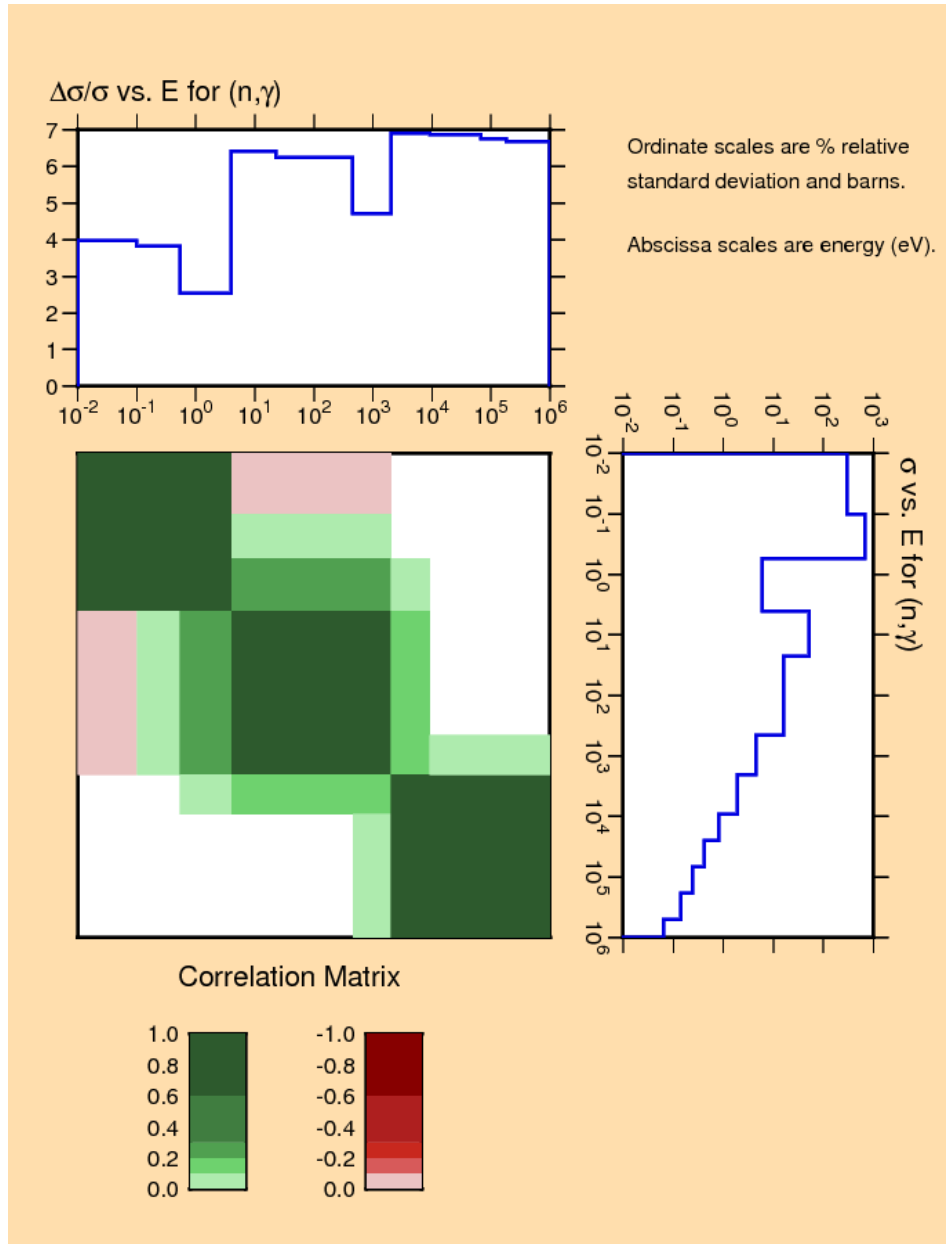
Integral benchmarks
- ICSBEP (Pu-Sol-Therm) and EOLE (Cadarache)
- Monte Carlo code TRIPOLI-4
- Deterministic code APOLLO-2.8

Pu-239 evaluation

WPEC/SG34, Co-ordinator : C. De Saint Jean
« Coordinated evaluation of Pu-239 in the resonance region »
See talk of A.C. (Skip) Kahler




Δσ/σ vs. E for (n,f)
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
σ vs. E for (n,f)
Correlation Matrix


Δσ/σ vs. E for (n,γ)
Ordinate scales are % relative standard deviation and barns.
Abscissa scales are energy (eV).
σ vs. E for (n,γ)
Correlation Matrix

Pu-239 evaluation

New investigation of the two-step (n,γf) process

1959 : unpublished estimation of the $\Gamma_{\gamma f}$ width for the (n,γf) reaction by E. Lynn

1965 : On the slow neutron, gamma-fission reaction, E. Lynn, Phys. Lett. 18

1967 : Evaluation des données neutroniques pour le Pu-239, G. LeCoq, PhD thesis

1973 : Etudes des sections efficaces de réaction des neutrons de resoanance avec Pu239, H. Derrien, PhD thesis

1974 : Etude des neutrons et des rayons gamma émis lors de la fission induite dans 235U et 239Pu par neutrons lents: mise en évidence de la réaction (n,gamma f), D. Shackleton, PhD thesis

1980 : The double-humped fission barrier, S. Bjornholm and E. Lynn, Rev. Mod. Phys. 52

1988 : **Evaluation of υ_p for Pu-239, E. Fort et al. Nucl. Sci. Eng. 99**

Pu-239 evaluation

The evaluation of the neutron multiplicity ν_p takes into account

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

Phenomenological description

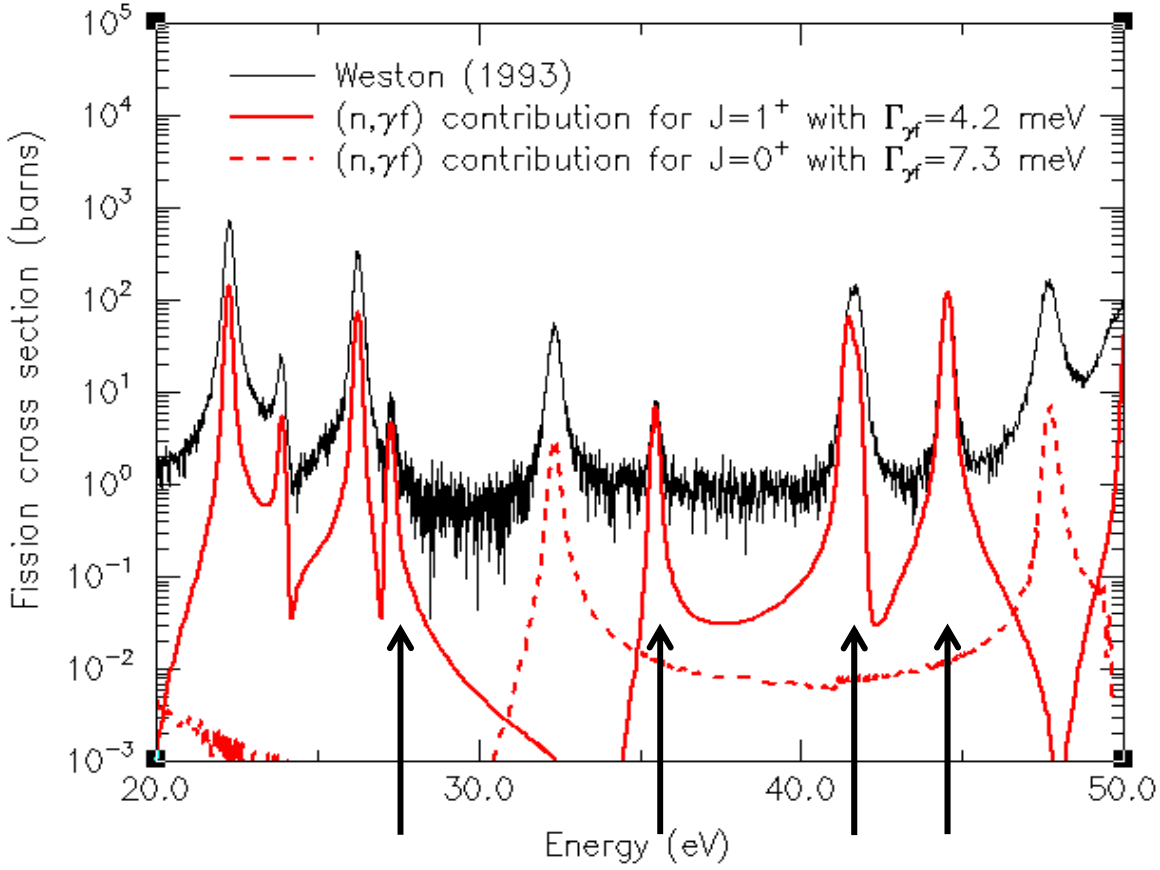
$$\upsilon_p(E) \approx \sum_{i=1}^{4} \nu_i P_i(E)$$

Where

$$P_i(E) = \frac{\sigma_{fi}(E)}{\sigma_f(E) + \sigma_{\gamma f}(E)}$$

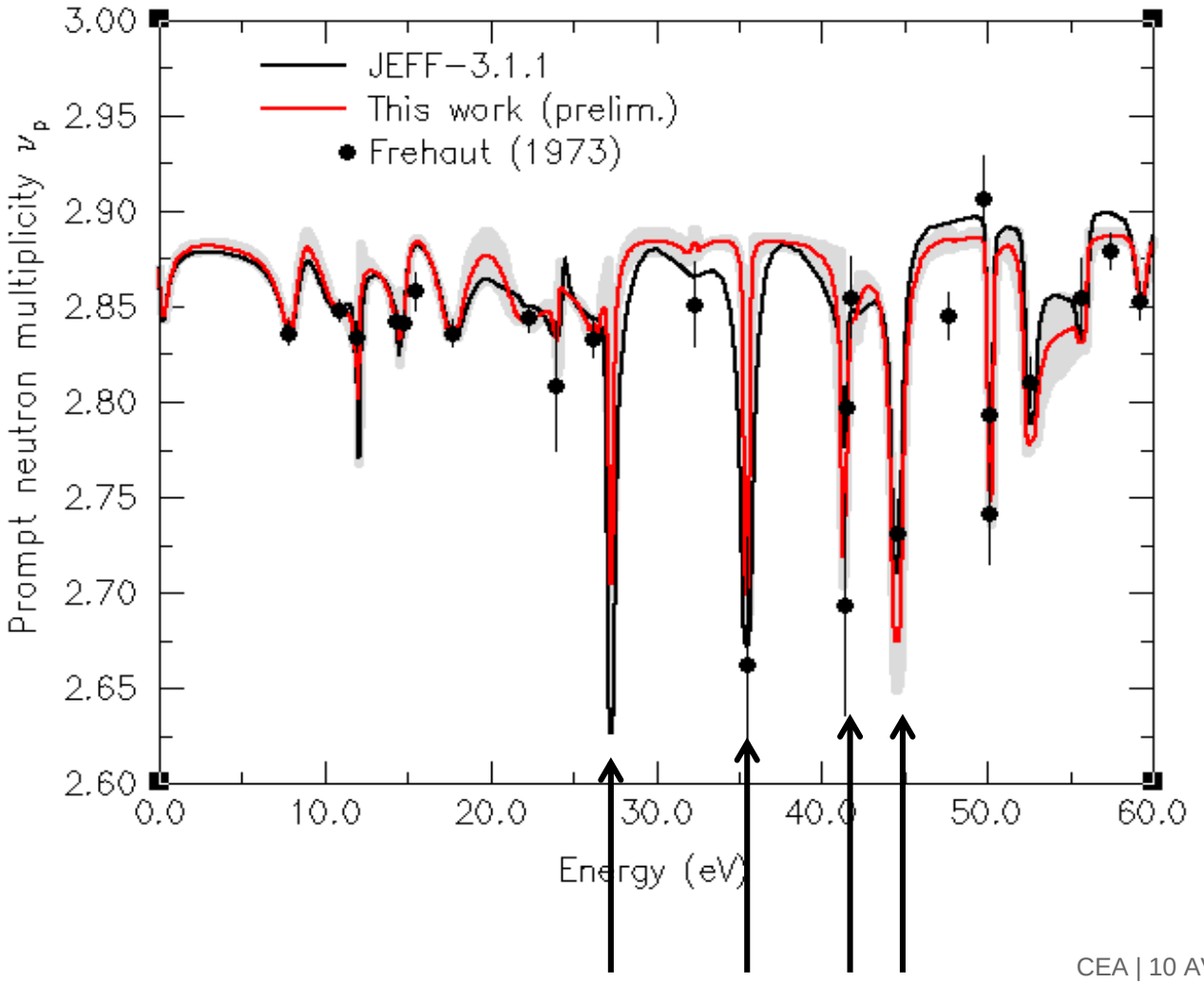
Pu-239 evaluation

For $J^{\pi}=1^{+}$, the smallest resonances are due to the (n,γf) process



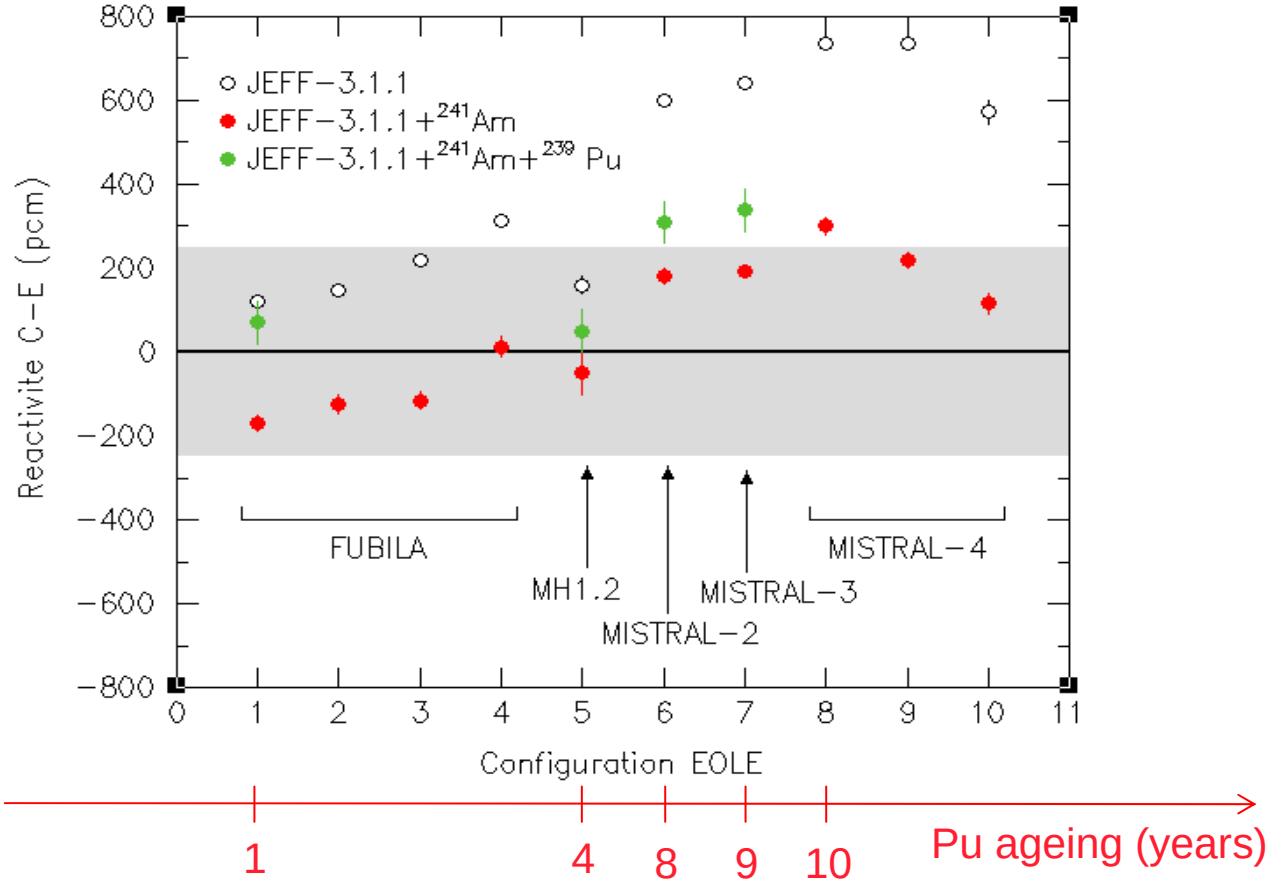
Pu-239 evaluation

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



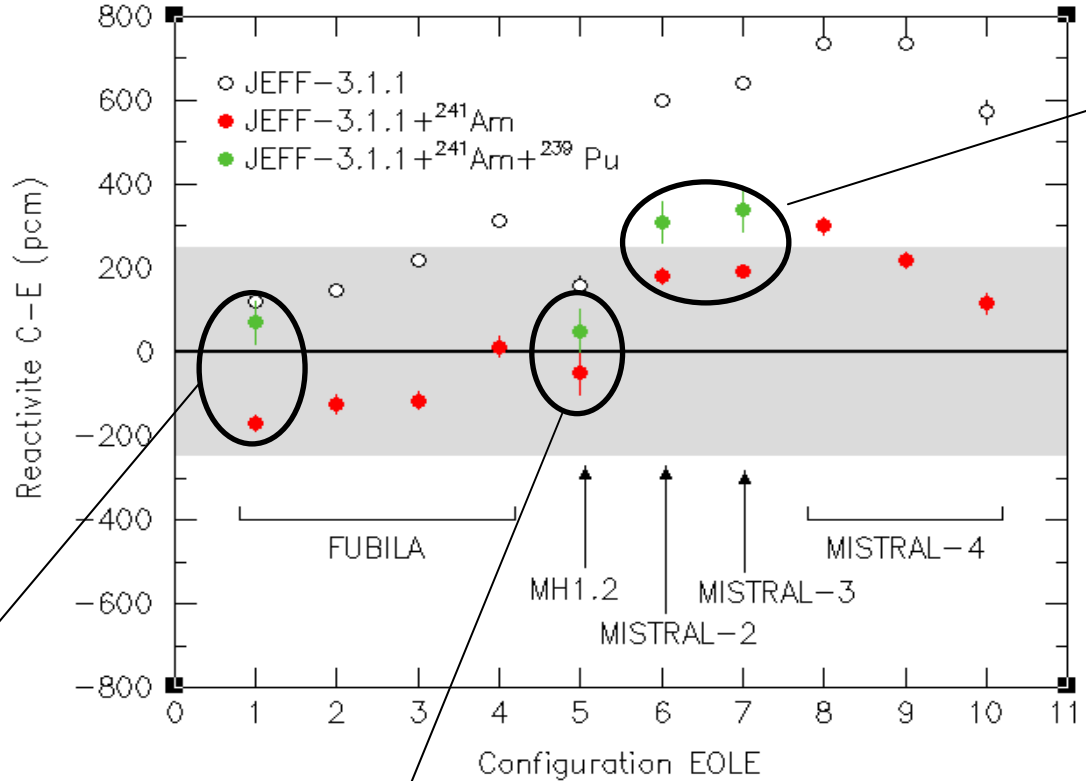
Pu-239 evaluation

zero-power research reactor
EOLE (Cadarache)



Pu-239 evaluation

zero-power research reactor
EOLE (Cadarache)



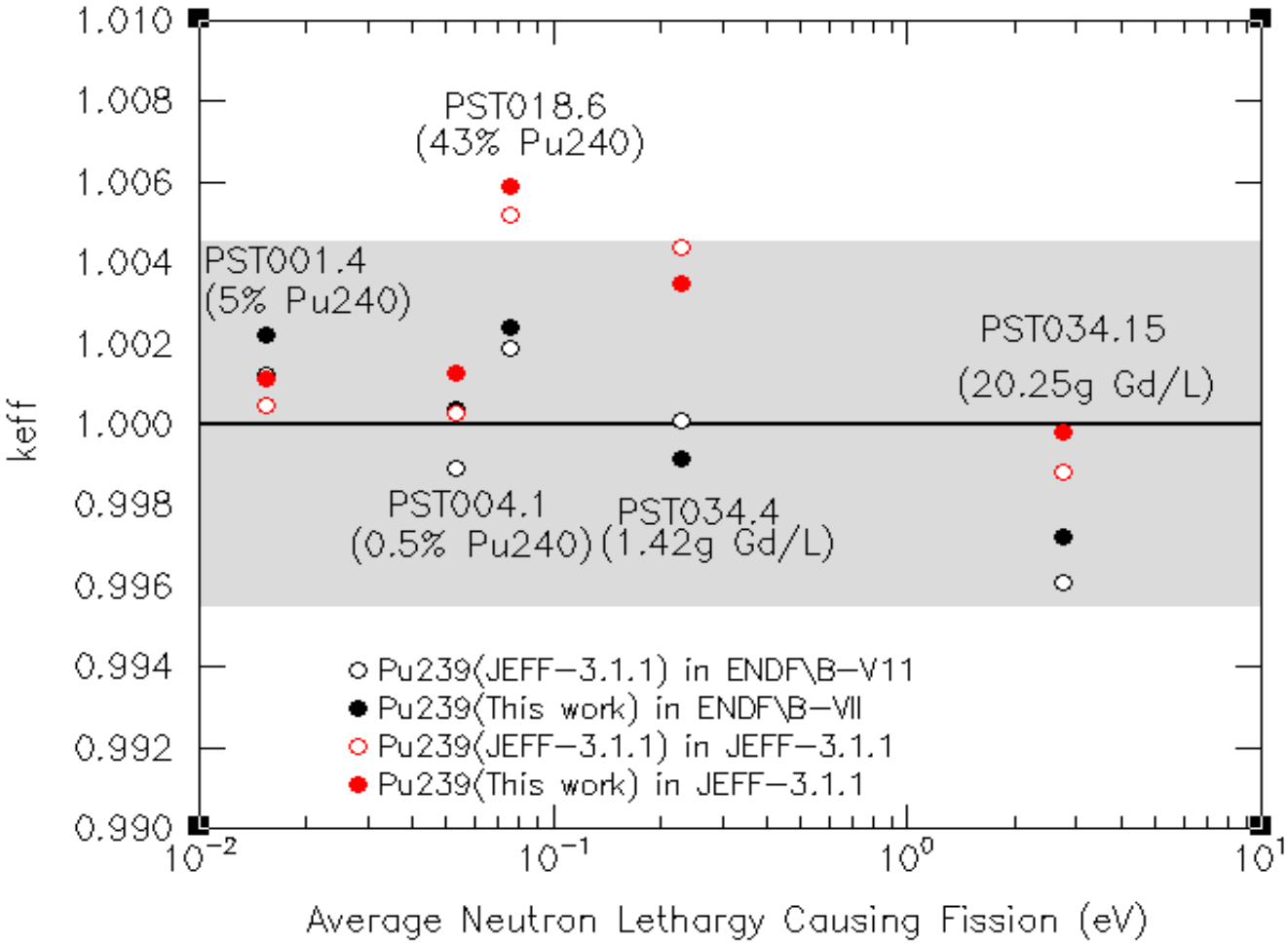
PWR-MOx

BWR-MOx

PWR-Mox, mixed core

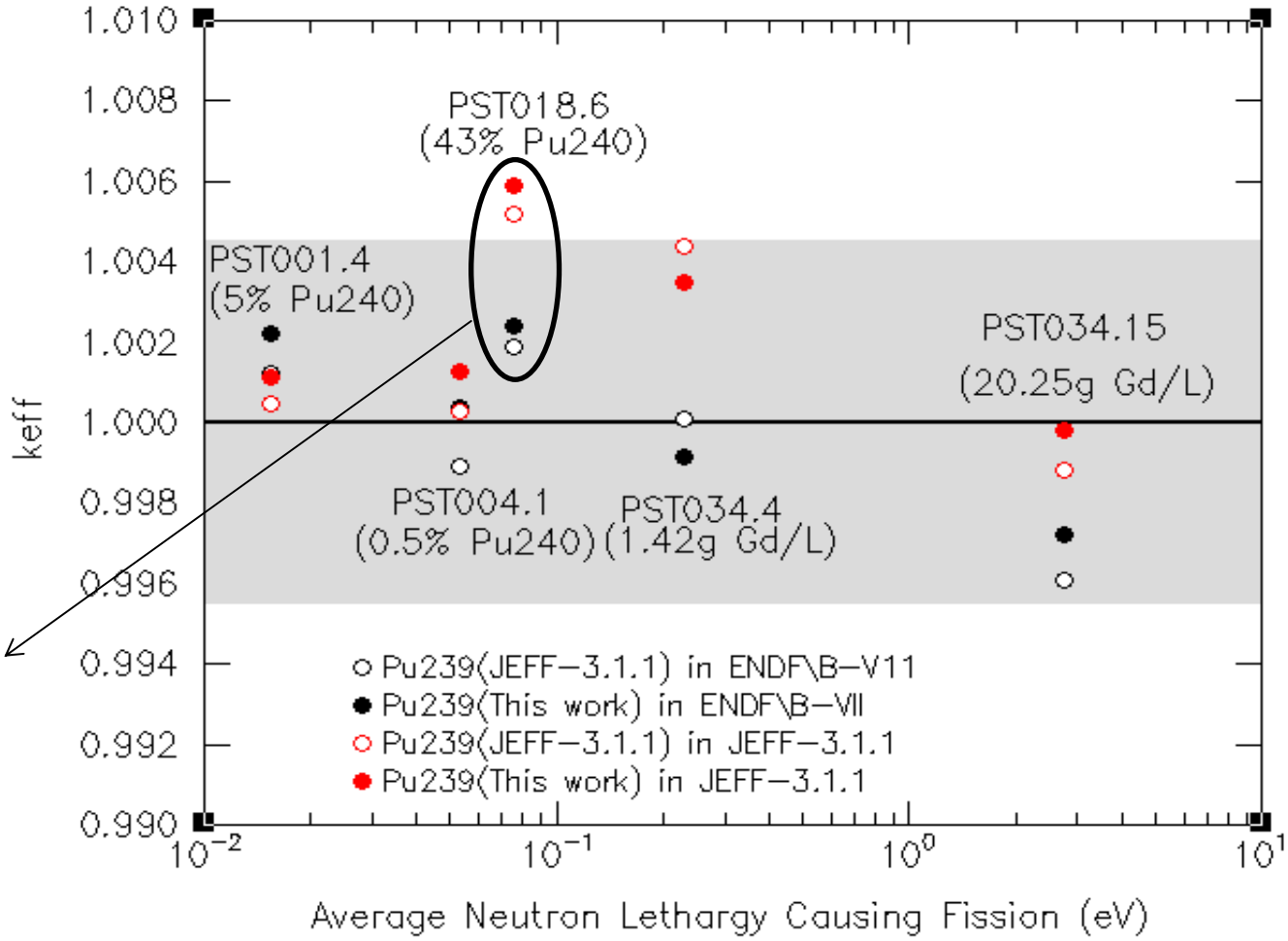
Pu-239 evaluation

ICSBEP benchmark results : JEFF-3.11 Vs. ENDF\B-VII



Pu-239 evaluation

ICSBEP benchmark results : JEFF-3.11 Vs. ENDF\B-VII



Pu-240

Pu-240 evaluation

A new evaluation of Pu-240 is in progress (Luiz Leal, ORNL)

The present work can give some recommendations on the radiation width of the first resonance at 1 eV

Author	Reference	Radiation width $\Gamma\gamma$
O. Bouland	NSE 127, 105 (1997)	29.14 ± 0.6 meV (2%)
S.F. Mughabghab	Atlas of Neutron Resonances, 2006	29.14 ± 0.6 meV (2%)
JEFF-3.1.1		29.15 meV
A. Meister	Private communication	30.50 ± 0.31 meV (1%) 30.39 ± 0.13 meV (0.4%)

Cristal Latice Model

Free Gas Model

Pu-240 evaluation

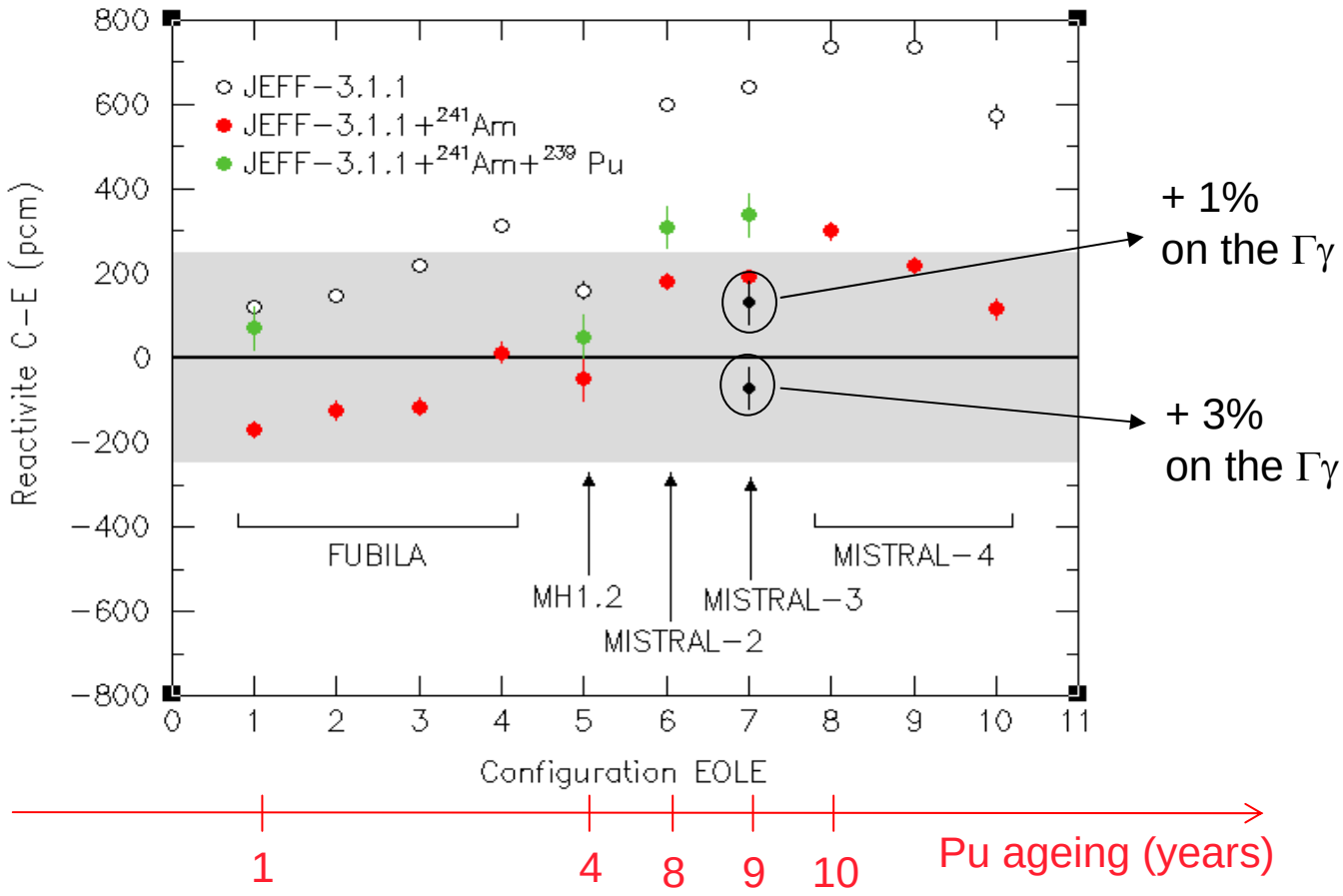
Impact of the Pu-240 evaluation of ENDF\B-VII

Direct perturbation of the radiation width of JEFF-3.1.1 (first resonance at 1 eV)

Benchmark	ENDF\B-VII	+ 3 %	+ 1 %
FUBILA-REF	-190±50 pcm		
MISTRAL-2	-390±50 pcm		
MISTRAL-3	-340±50 pcm	-410±50 pcm	
PST-18.6	-420±50 pcm	-420±50 pcm	-230±50 pcm

Pu-240 evaluation

zero-power research reactor
EOLE (Cadarache)



Conclusions

• Significant improvements of the keff results by using the new Am-241 et Pu-239 evaluation

• The remaining overestimation (~200 pcm) could be explained by Pu-240

• New Time Of Flight measurements of the totale cross section of Pu-239 and Pu-240 (77K, 300 K and T>300 K) are needed

• Use of the Cristal Lattice Model for the Neutron Resonance Shape Analysis (phonon spectrum is needed)