Scattering Angular Distribution in the Fast Energy Range

Contribution of the Nuclear Data Group of Cadarache

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Outlines

In an evaluated nuclear data file, The SAD in the centre of mass can be tabulated or reconstructed with the following expression:

$$f(\mu, E) = \sum_{l=0}^{l=n} \frac{2l+1}{2} a_l(E) P_l(\mu)$$

In which a_l represents the Legendre coefficients with a_0=1.0. The mean anisotropy μ is given by:

$$\overline{\mu}(E) = \int_{-1}^{1} f(\mu, E) \mu d\mu = a_1(E)$$

Outlines

Blatt and Biedenharm formalism uses scattering matrix elements calculated with the R-Matrix theory (SAMMY, CONRAD, NJOY, …) or Optical Model (ECIS, …).

Studies performed with CONRAD and SAMMY, show that the description of the « fluctuations » of the elastic distributions with the Reich-Moore approximation is difficult for Iron and nearly impossible for Sodium.

❶The experimental data retreived from EXFOR are not correct ?
⇒ new measuremenst is needed

❷The Reich-Moore approximation is not adequate for Sodium ?
⇒ limits of the R-Matrix approximations have to be investigated

❸ …

What is the solution for the nuclear applications ?

Outlines

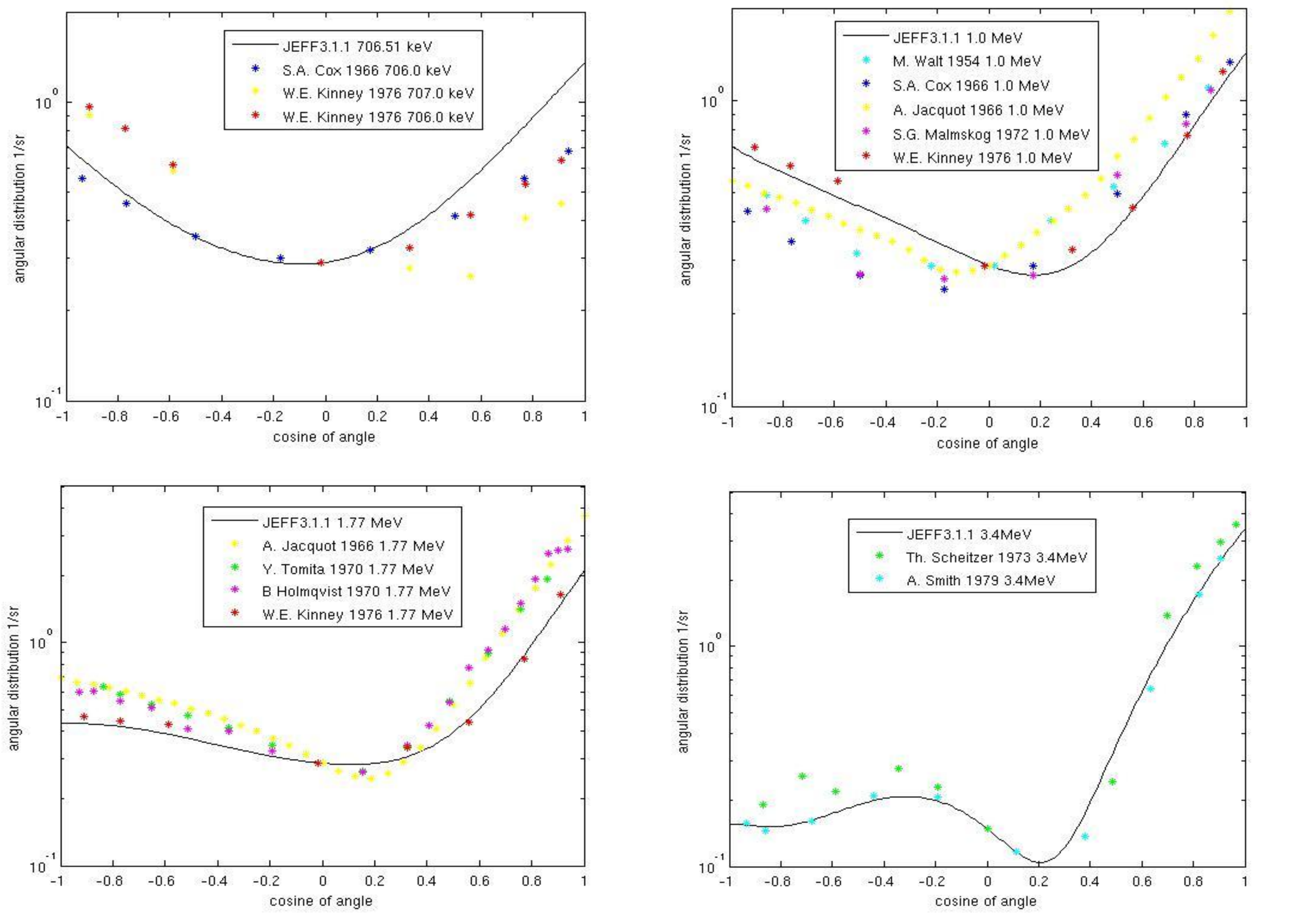
We try to understand if an accurate description of the « fluctuations » is needed for our applications. The impact of the « fluctuations » of the anisotropy μ on integral calculations is illustrated with benchmarks described in the following PhD thesis:

^{56}Fe — **C. Vaglio-Gaudard**, Validation des données nucléaires du fer pour le calcul neutronique des reacteurs nucléaires, PhD Thesis, Université de Grenobles, 2010

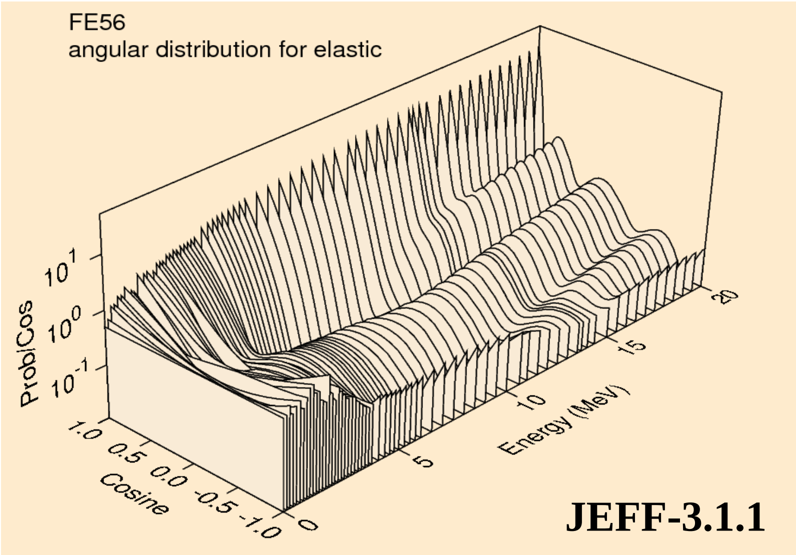
^{23}Na — **P. Archier**, Contribution à l'amélioration des données nucléaires du sodium pour le calcul des réacteurs de génération IV, PhD Thesis, Université de Grenobles, 2011

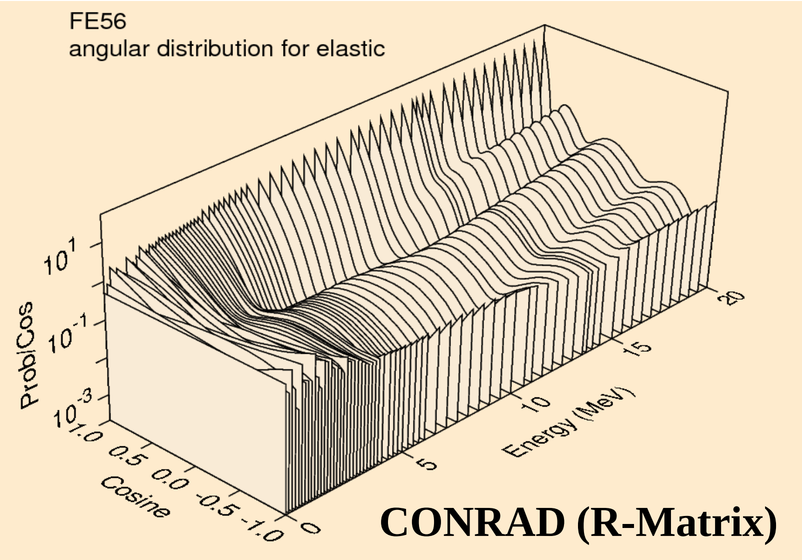
^{27}Al — **O. Leray**, PhD Thesis, Université de Grenobles, in progress

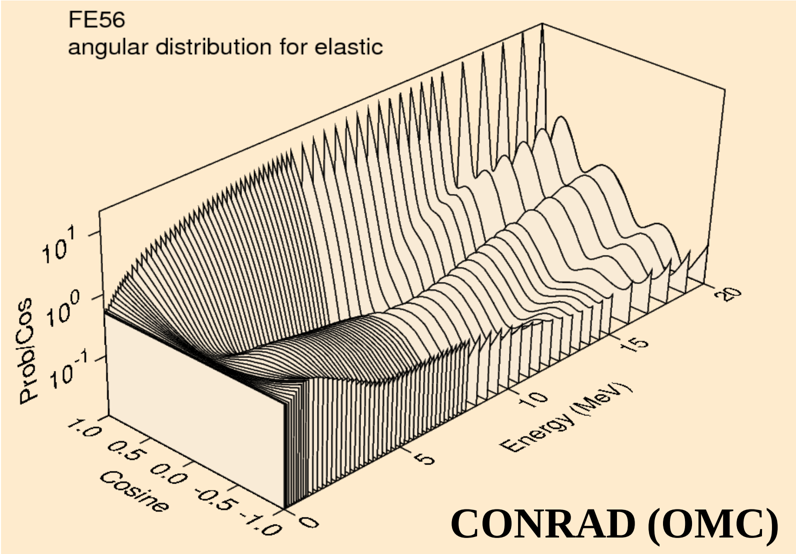
Impacts of the « fluctuations » of the anisotropy μ are deduced from sodium void reactivity effect, stainless steel heavy reflector experiment, mock-up and shielding benchmarks.

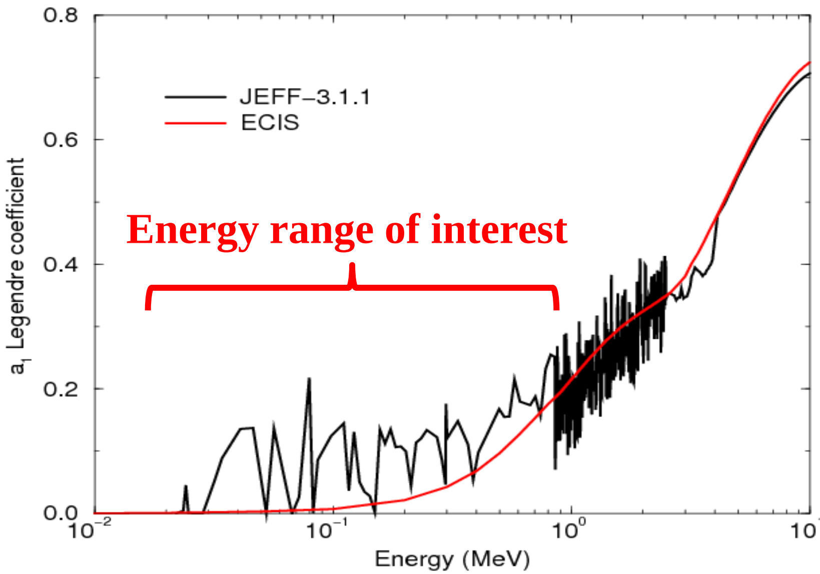


⇒ Large differences between the experimental data and JEFF-3.1.1 !









⇒ Huge fluctuations of a_1 in the energy range of interest (below 1 MeV)

Stainless steel heavy reflector : PERLE experiment in the EOLE facility*

$\Delta\theta$ (keff) = C(New SAD) - C(JEFF-3.1.1)

$\Delta\theta$ (FC) = C(New SAD) / C(JEFF-3.1.1)

		reactivity keff $\Delta\theta$ (keff)	Flux attenuation in reflector (20 cm) $\Delta\theta$ (FC)		
		(pcm)	^{235}U(n,f)	^{238}U(n,f)	^{237}Np(n,f)
Experimental uncertainties		± 22	± 2%	± 2%	± 2%
1st test :	Isotropic law	+860		-35%	
2nd test :	CONRAD (broad mesh)	-126 ± 6	< 1.5%	< 1.5%	< 1.5%
3rd test :	CONRAD (fine mesh)	-36 ± 6	< 1.5%	< 1.5%	< 1.5%
4th test :	ECIS (Optical Model)	+178 ± 6	-1.7 ± 0.9 %	-2.2 ± 1.3 %	-4.2 ± 0.5 %

*TRIPOLI4 calculations

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CONRAD (Reich-Moore formalism) and JEFF-3.1.1 give equivalent results

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Fine energy mesh is recommended

Stainless steel heavy reflector : PERLE experiment in the EOLE facility

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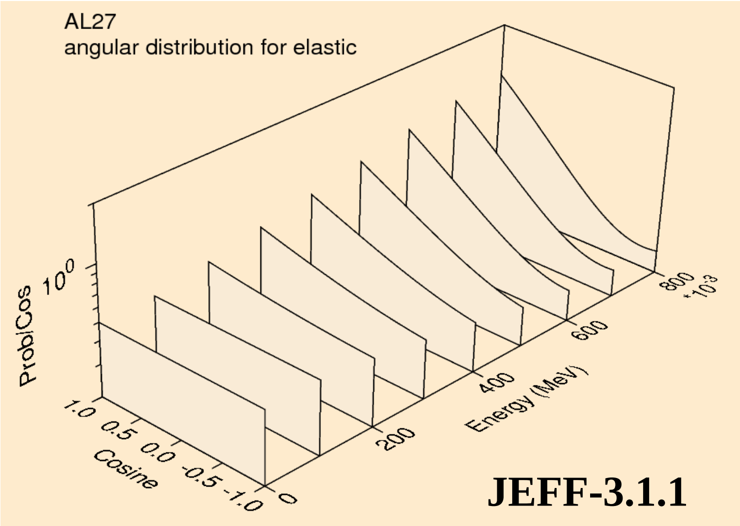
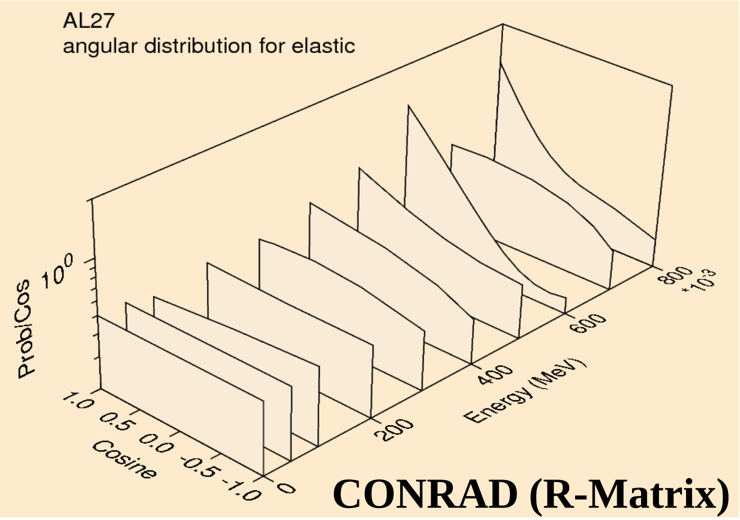
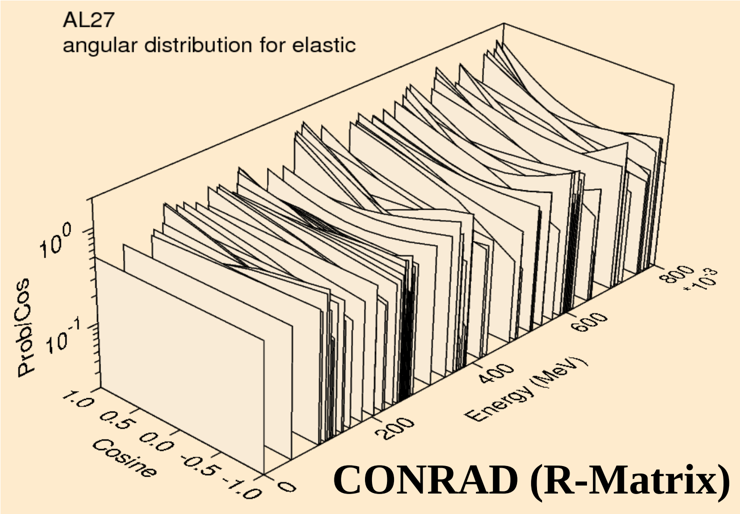
~ 200 pcm between OMC and R-Matrix calculations

Broad energy mesh





Fine energy mesh



Aluminium mock-up benchmark : AMMON experiment in the EOLE facility*

$$\Delta\theta \text{ (keff)} = C(\text{New SAD}) - C(\text{JEFF-3.1.1})$$

		reactivity keff
Experimental uncertainties		± 10 pcm
1st test	Isotropic law	+ 1340 pcm
2nd test	CONRAD (broad mesh)	+ 73 pcm
3rd test	CONRAD (fine mesh)	+ 57 pcm

NB: AMMON uncertainties due to the Al-27 cross sections
Capture cross section ⇒ 240 pcm
Elastic cross section ⇒ 150 pcm
Inelastic cross section ⇒ 272 pcm

*TRIPOLI4 calculations

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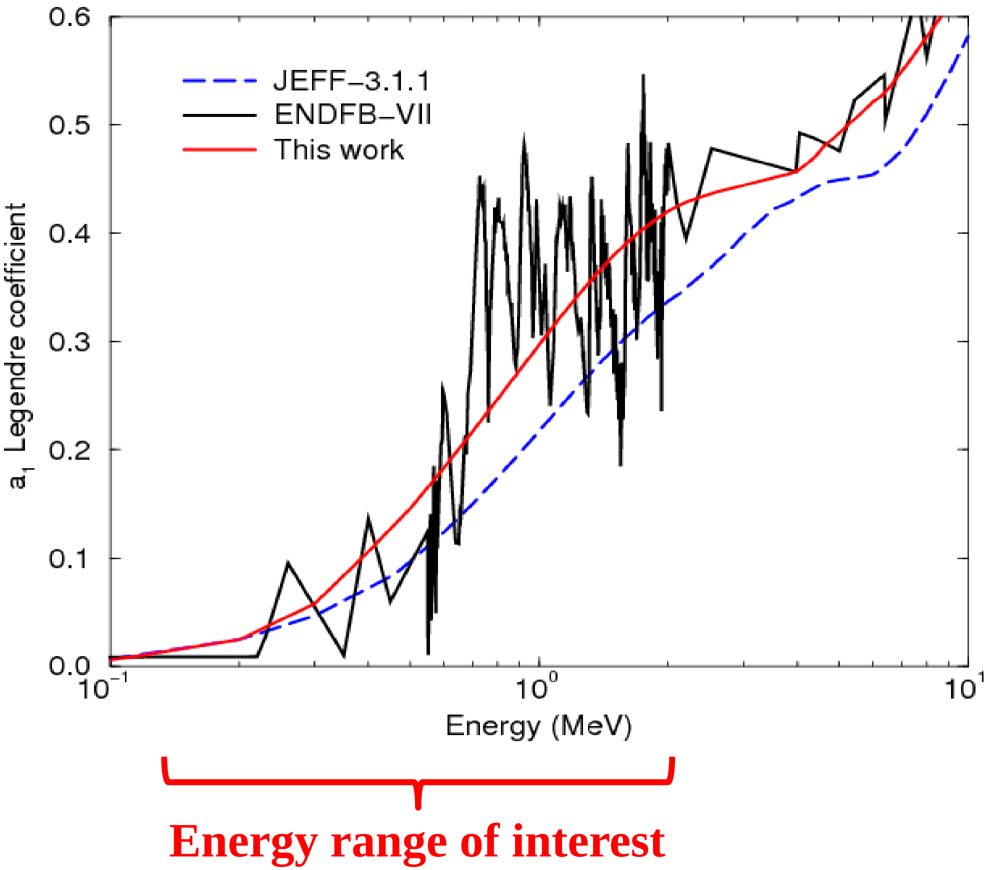
Preponderance of the elastic cross section uncertainty

*TRIPOLI4 calculations

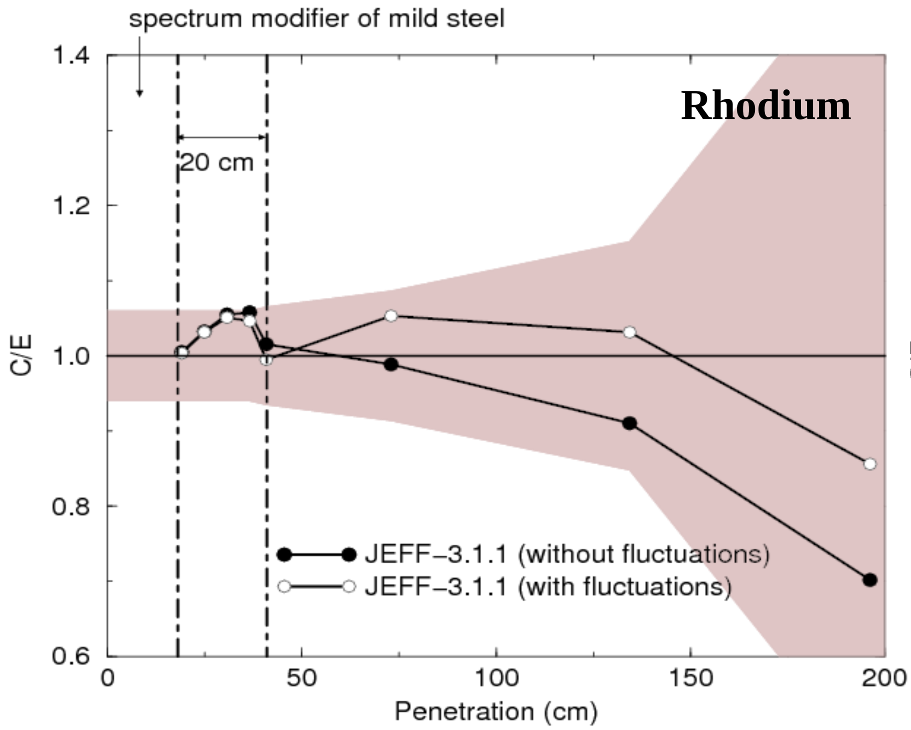
ERANOS2 and TRIPOLI4 calculations

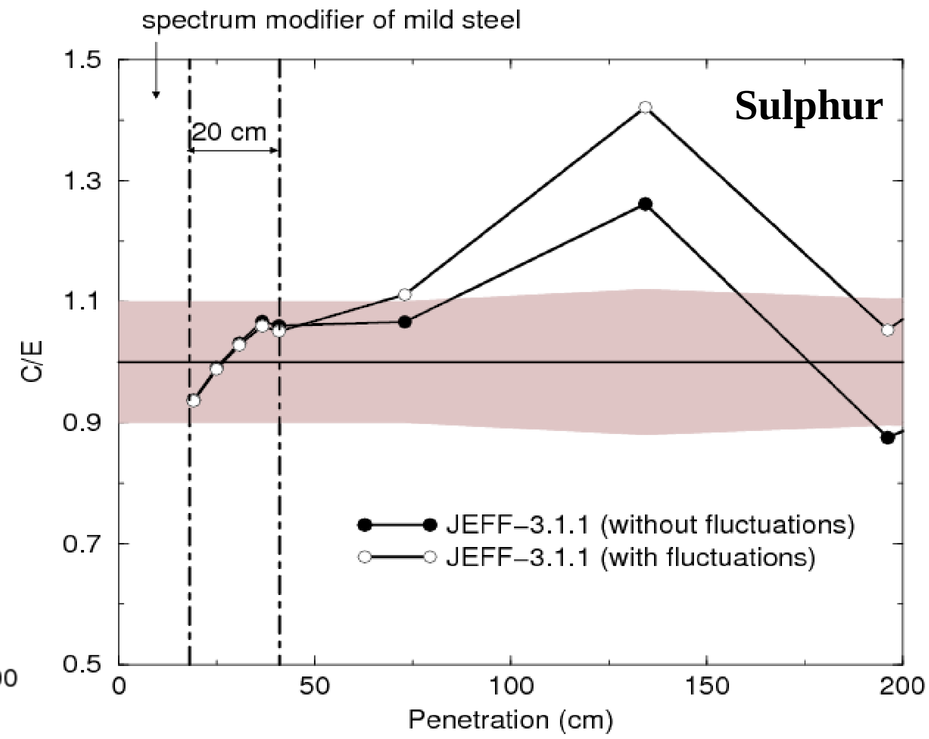
(a) JEFF-3.1.1 + elastic distributions « without fluctuations » (in blue)

(b) JEFF-3.1.1 + elastic distributions « with fluctuations » from ENDFB-VII (in black)



Shielding benchmark : interpretation of the JANUS-8 experiments, ASPIS facility





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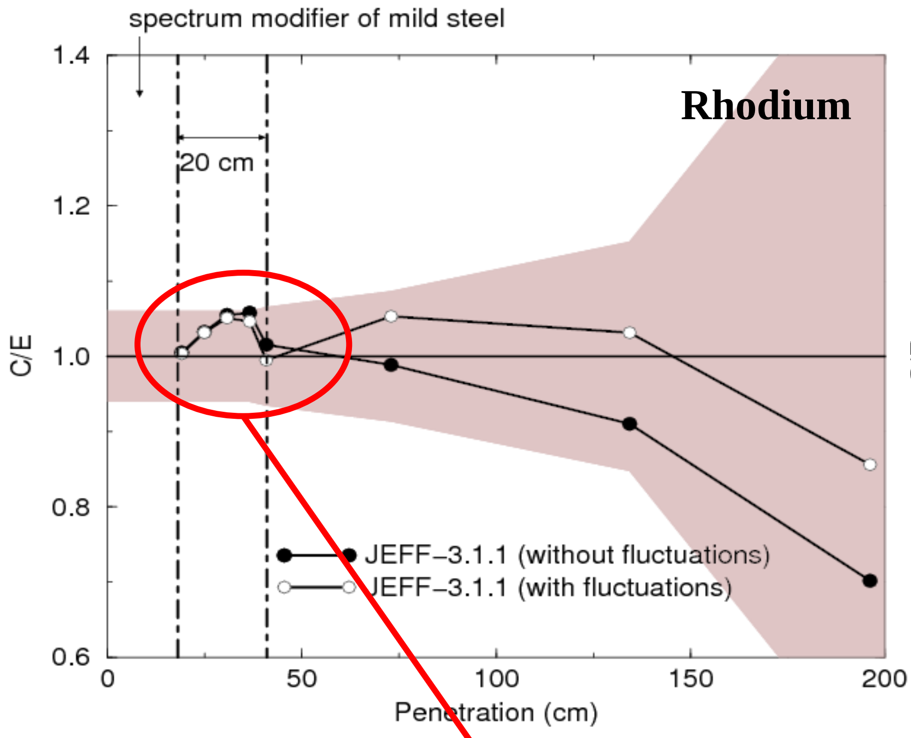
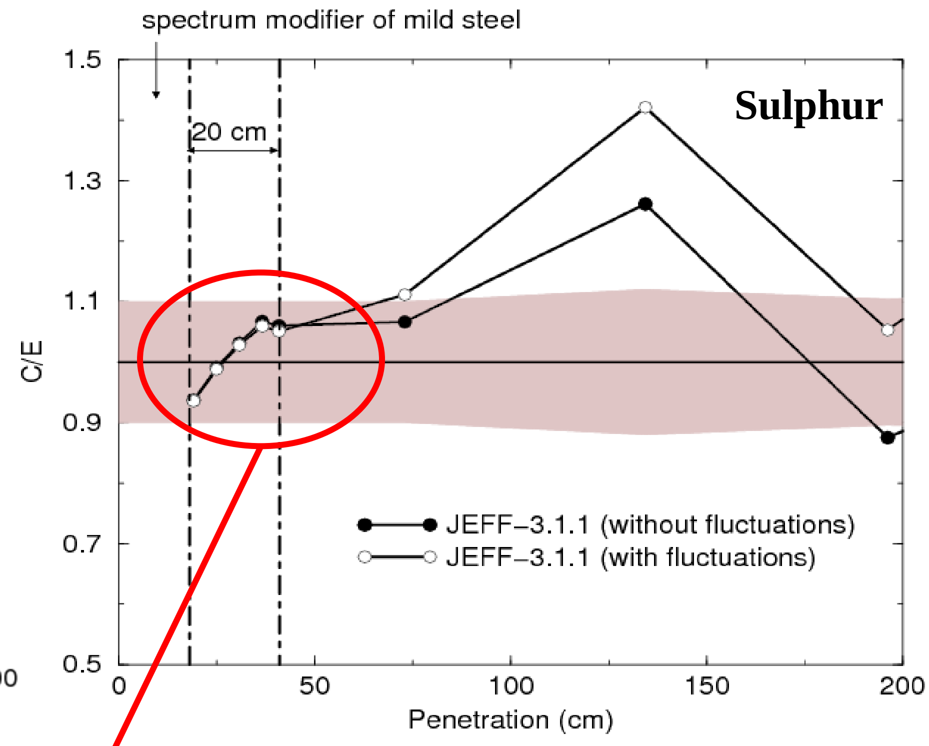
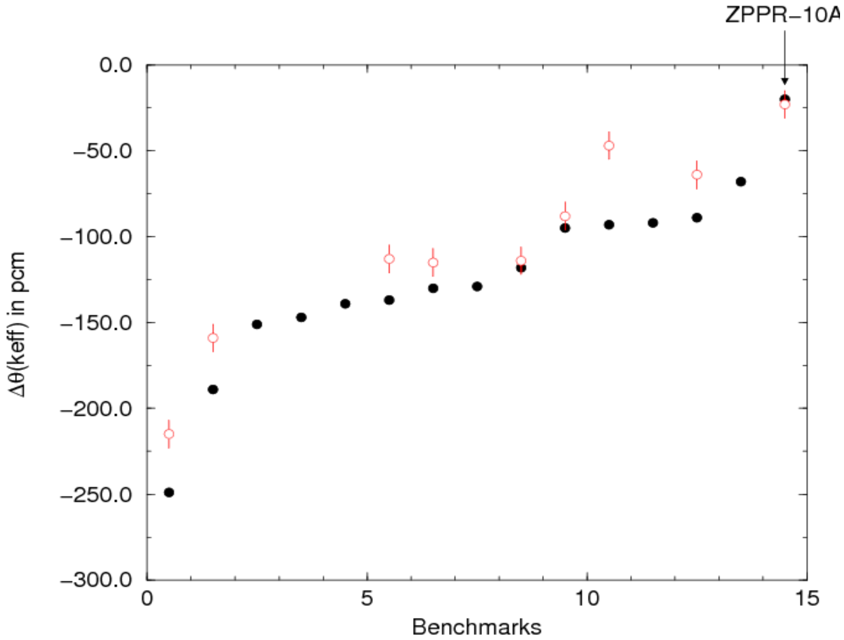


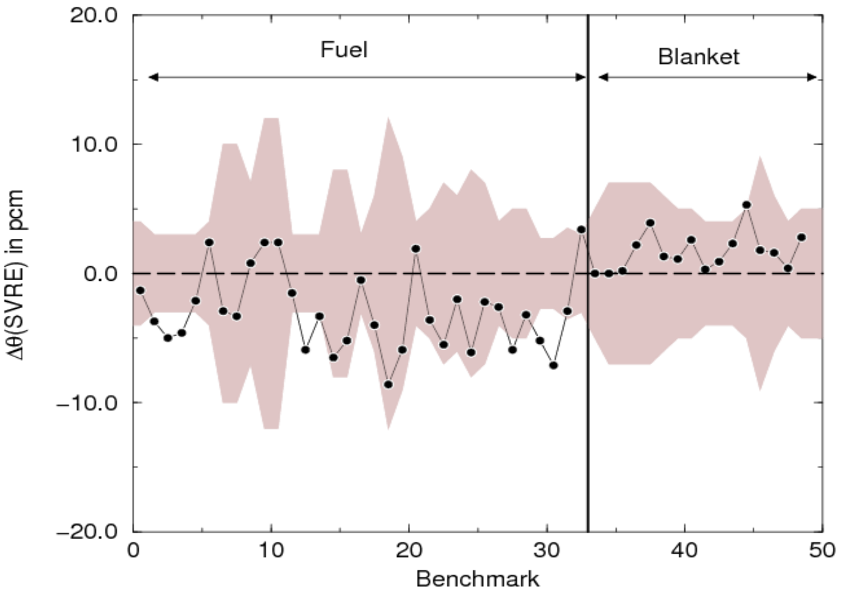


Below 20-40 cm, negligible impact of the fluctuations

Sodium Void Reactivity effect: Interpretation of MASURCA and ZPPR experiments

$$\Delta\theta \equiv C(\text{with } \mu \text{ fluctuations}) - C(\text{without } \mu \text{ fluctuations})$$





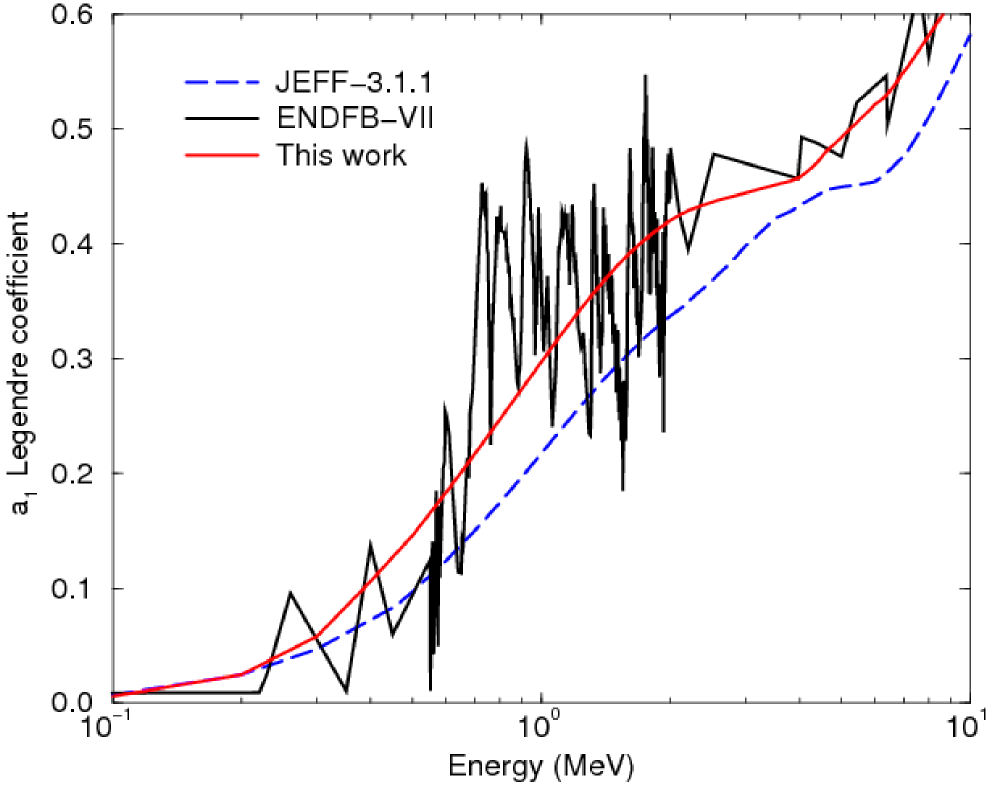
Negligible impact of the fluctuations on keff value for « large » core configurations

ERANOS2 calculations

(a) JEFF-3.1.1 with elastic distributions « without fluctuations » (in blue)

(b) JEFF-3.1.1 with elastic distribution « with fluctuations » from ENDFB-VII (in black)

(c) JEFF-3.1.1 with a smooth fit of a_1 coefficient on ENDF\B-VII (in red)



Sodium Void Reactivity effect: Interpretation of ZPPR-10A experiments

$$\Delta\theta(\text{SVRE}) = C - E$$

SVRE	exp. unc. (pcm)	1st test without μ fluctuations (Optical Model)	2rd test with μ fluctuations (From ENDF/B-VII)	3rd test without μ fluctuations (smooth fit of a1 coefficient)
01	± 0.5	2.6	1.8	1.0
02	± 0.9	4.6	1.8	3.9
03	± 1.7	7.3	2.0	2.3
04	± 1.7	10.0	4.5	4.2
05	± 1.9	10.6	4.5	5.4
06	± 2.2	9.0	2.2	2.0
07	± 2.1	7.3	0.8	0.5
08	± 2.0	7.6	1.7	1.0
09	± 1.9	5.9	0.8	-0.6
10	± 1.8	7.8	3.0	1.2
11	± 1.6	12.7	8.6	7.1
12	± 1.4	18.4	15.2	13.1

SVRE are significantly improved

Conclusions

Isotropic law produces impacts on the reactivity (keff) of about 1000 pcm.

The differences on keff for "realistic" descriptions of the SAD may reach 200 pcm (mock-up experiments) and become negligible for large core configurations (ZPPR, SPX).

For the flux attenuation, below 20 cm of penetration, the impact of the SAD remains below the experimental uncertainties.

The analysis of AMMON (Al-27) and ZPPR-10A (Na-23) shows that the Reich-Moore formalism (with a fine energy mesh) and the optical model (with a smooth fit of the anisotropy μ) give equivalent keff values and sodium void coefficients effect.

Conclusions

The SAD in the resonance range could be determined as follows:

Models	Resonance Parameters	Experimental data for SAD
Blatt-Biedenharm and R-Matrix	✓	
Fit a_l coefficients to the data	✓	✓
Fit a_l coefficients to the data		✓
Blatt-Biedenharm and Optical Model		

If needed (i.e. for application library), "improved" description of the integral results could be achieved from the smooth fit of the anisotropy (uncertainties on Legendre coefficients is then needed).

This procedure suggests to combine different methodologies/models in the uncertainty propagation work (File MF=34 in ENDF-6 format).