DE LA RECHERCHE À L'INDUSTRIE

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Espace de Structure Nucléaire Théorique
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DE LA RECHERCHE À L'INDUSTRIE

Importance of the neutron slowing down through $^{238}U(n,n')$ for reactor applications.

Inherent nuclear structure uncertainties for the evaluation of its discrete levels.

Workshop Experimental and Theoretical problematic around actinides for future reactors
« Espace de Structure Nucléaire Théorique, DSM-DAM », Orme des Merisiers, Saclay, France
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OUTLINE

Neutron slowing down in reactor media.

Importance of $^{238}U(n,n')$ DDXS for accurate neutron transport calculation.

Integral trend tracking for $^{238}U(n,n')$ to the continuum.

Proposed reduction of neutron-TOF inelastic γ-production XS : inherent nuclear structure uncertainty

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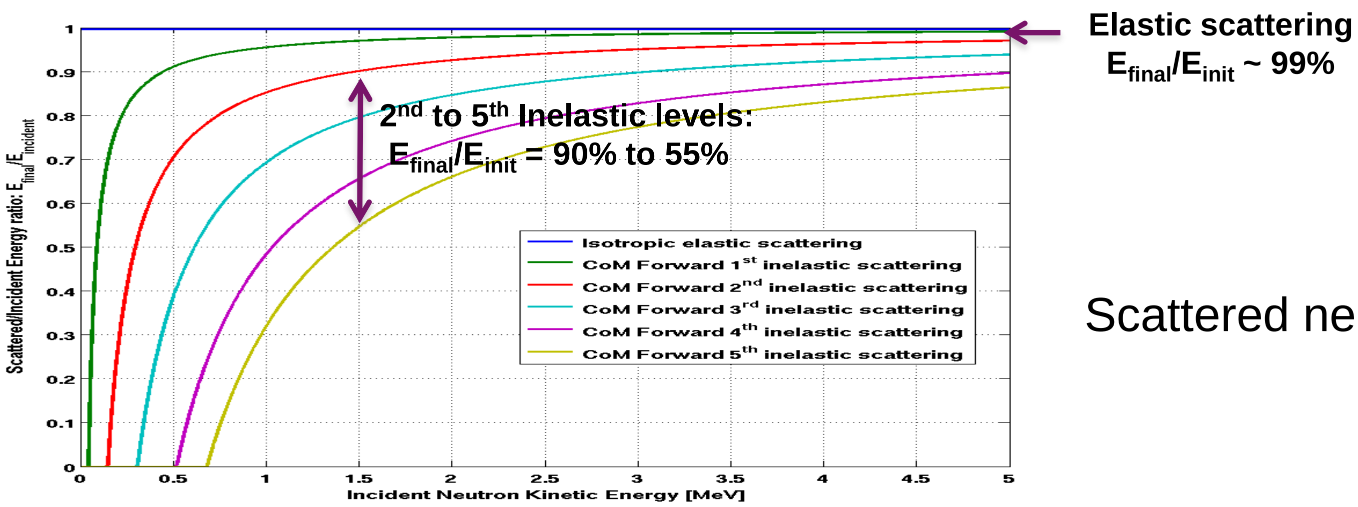
Neutron slowing down

^{238}U is responsible for the slowing down of (just born) neutrons (particularly in fast system, but in thermal aswell !)

NR kinematics

$$\left\{ \begin{aligned} \left.\frac{E_{final}}{E_{initial}}\right|_{elastic} &= \frac{A^2+1+2A\cos\left(\theta^{COM}_{elastic}\right)}{(A+1)^2} \\ \left.\frac{E_{final}}{E_{initial}}\right|_{inelastic} &= \frac{\gamma^2+1+2\gamma\cos\left(\theta^{COM}_{inelastic}\right)}{(A+1)^2} \quad \text{with } \gamma = A\sqrt{1-\frac{(A+1)}{A}\cdot\frac{Q_{inelastic}}{E_{initial}}} \end{aligned} \right.$$

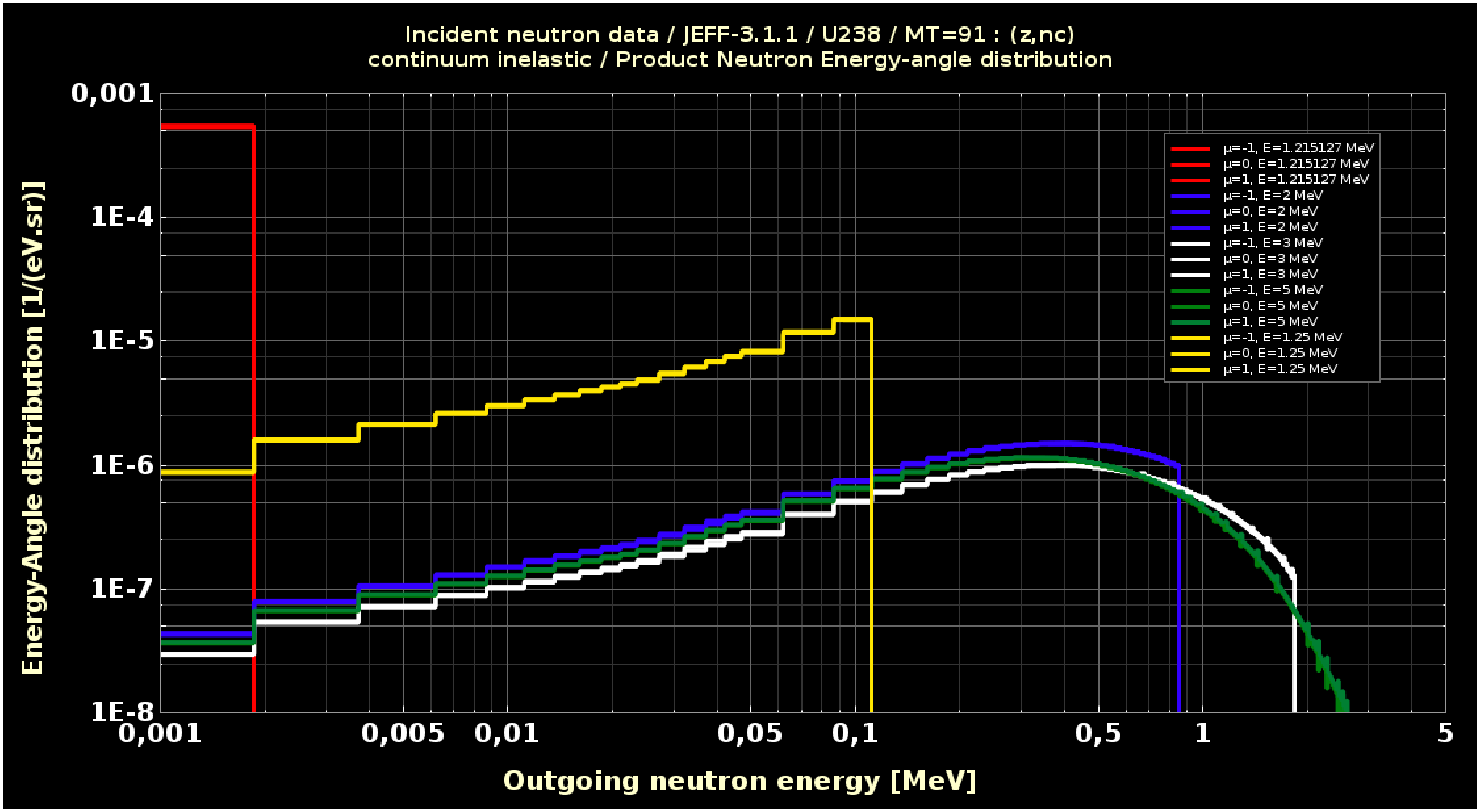
The inelastic scattering is more efficient that the elastic process (because of the small amount of kinetic energy available for the emittted neutron: residual nucleus is in an excited state).



Scattered neutron on ^{238}U

Neutron slowing down

Kallbach-Mann systematics (continuum) emphasize neutron slowing down from [1-5]MeV to [10keV to 2MeV] but **350keV for max probability**



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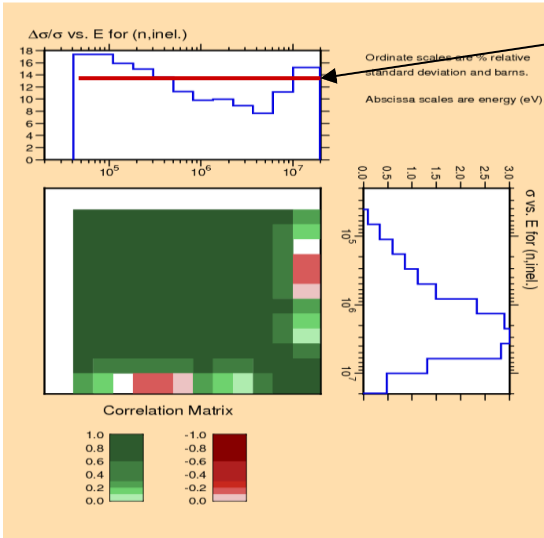
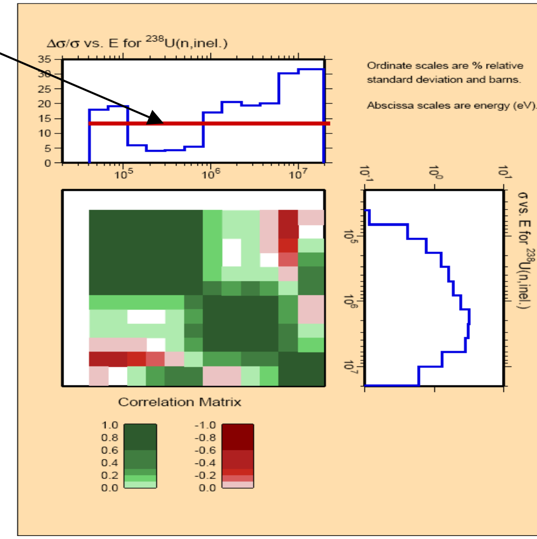
Importance of ^{238}U(n,n')

Constant σ=15%



French COMAC covariance

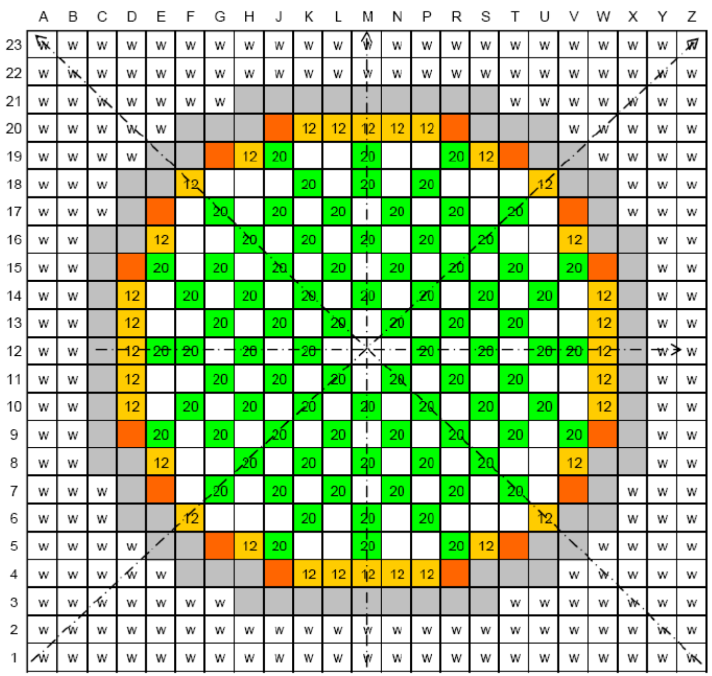


COMMARA-2 covariance

- ^{238}U covariance matrices amongst international evaluations (ENDF/B-VII, JENDL-4, TENDL-2009, French-COMAC) are not consistent
- More of that, the discrepancies between major evaluations can reach 10% on the plateau
- A 15% standard deviation, constant with neutron energy, seems realistic

Importance of ^{238}U(n,n')

OECD/Uncertainty Analysis and Modelling Benchmark



241 assemblages

cœur UOX

- UOX 2.1% ^{235}U assembly
- UOX 4.2% ^{235}U assembly
- 20 — UOX 3.2% ^{235}U assembly with 20 UO2-Gd_2O_3 rods
- 12 — UOX 4.2% ^{235}U assembly with 12 UO2-Gd_2O_3 rods
- Stainless steel reflector assembly
- W — Borated water reflector assembly

Conditions 'HFP, BOC'

Parameter	Value
Fuel Temperature (K)	900
Cladding Temperature (K)	610
Moderator (Coolant) Temperature (K)	584
Pression (Coolant) (bars)	155
Reactor Power (MWt)	4250
Bore (ppm)	1300

Table VI: Propagation of nuclear data uncertainties to the GEN-III assembly power

Isotope	Reaction	Core centre (%)	Power peak (%)	Neighbour of power peak (%)
^{235}U	(n,f)	0.4	0.2	0.3
	ν	0.1	0.0	0.0
	(n,γ)	0.6	0.3	0.3
	correlation (n,f)-(n,γ)	(-) 0.3	(-) 0.2	(-) 0.2
^{238}U	(n,f)	0.0	0.0	0.0
	ν	0.2	0.1	0.1
	(n,γ)	0.8	0.3	0.3
	(n,n')	**4.6**	**2.2**	**2.5**
^{1}H	(n,γ)	0.1	0.0	0.0
	(n,n)	1.8	0.9	1.1
^{16}O	(n,α)	0.1	0.0	0.0
^{10}B	(n,α)	0.1	0.0	0.0
^{155}Gd	(n,γ)	0.5	0.4	0.6
^{157}Gd	(n,γ)	1.0	0.8	1.3
^{56}Fe	(n,γ)	0.7	0.4	0.5
	(n,n)	0.9	0.4	0.6
	(n,n')	0.1	0.0	0.1
	correlation (n,n)-(n,n')	(-) 0.2	(-) 0.1	(-) 0.1
^{52}Cr	(n,γ)	0.1	0.0	0.1
	(n,n)	0.4	0.1	0.2
	(n,n')	0.0	0.0	0.0
Total	-	**5.3**	**2.7**	**3.2**

The total uncertainty reaches 5.3% @1σ. This is more than the required target accuracy (1%) on PWR power map calculation.

^{238}U(n,n') takes 85% of this overall uncertainty.

A slight modification of this XS can cause a tilt in the calculation of the flux and so on the deposited energy (burn-up)

Importance of $^{238}U(n,n')$

Target accuracy for $^{238}U(n,n')$ is about 3%.

In parallel of TOF measurements, $^{238}U(n,n')$ integral trend tracking can be done !

^{238}U new evaluation + associated new (and reduced) covariances has to be perform !

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Integral trend tracking

First set: critical spheres (Radius r1) with fissile material

Second set: critical spheres (Radius r2<r1) with the same fissile material are reflected by ^{238}U

First order perturbation theory shows that the sensitivity to this reflector saving can be expressed as $S_{Reflector} = S(G) = S_{r2} - S_{r1}$

Proof by deterministic calculations:

[pcm/%]	Flattop	Jezebel	$S_G = \Delta S$
^{239}Pu	+589	+639	-50
^{240}Pu	+17	+20	-2
^{241}Pu	+2	+2	0
^{235}U	+5	+0	5
^{238}U	-30	+0	-30

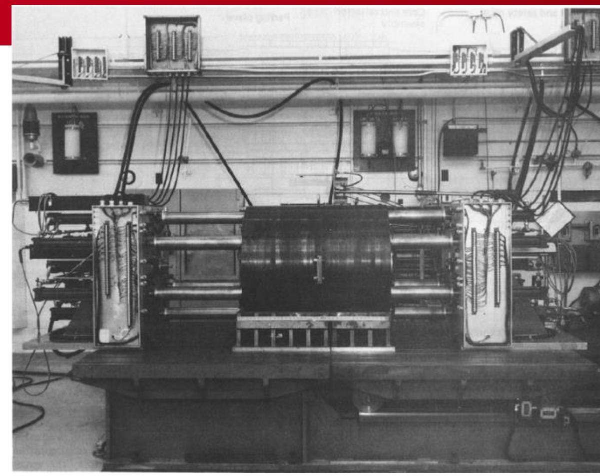
Constraint by JEZEBEL k_{eff} uncertainties
639pcm/% = ΔExp / ΔPu239 → ΔPu239 = 200 / 639 ≈ 0.3%

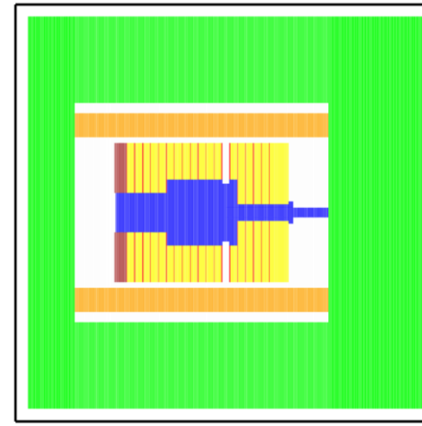
Then, the reflector saving uncertainty due to ^{239}Pu is about:
ΔG= 50pcm/% * 0.3% = 15 pcm.

$$S(G,{}^{238}U) = S(G,{}^{238}U(n,n'\gamma)+(n,n)) + S(G,{}^{238}U(n,f)+\chi+\nu) + S(G,{}^{238}U(n,\gamma)) + S(G,{}^{238}U(n,xn))$$

- $S(G,{}^{238}U(n,n'\gamma)+(n,n))$: -110pcm/%
- $S(G,{}^{238}U(n,f)+\chi+\nu)$: +115pcm/%
- $S(G,{}^{238}U(n,\gamma))$: -36pcm/%
- $S(G,{}^{238}U(n,xn))$: +2pcm/%

Large core k_{eff}: Big-10





NUCLEAR SCIENCE AND ENGINEERING: 72, 230-236 (1979)

A Critical Assembly of Uranium Enriched to 10% in Uranium-235

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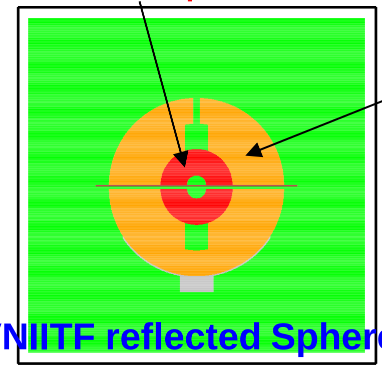
With ENDF/B-V over the horizon, our comparisons of calculated and experimental parameters must be considered tentative. The 1% disagreement of eigenvalues, for example, would increase as the result of a proposed hardening of the thermal fission spectrum, unless there is compensation such as increased inelastic scattering by ^{238}U. Similarly, the change by itself, proposed to improve agreement with spectral indexes measured in the thermal fission spectrum, would lead to further disagreement of Big Ten spectral indexes, most notably, the value of $\bar{\sigma}_f(^{238}U)/\bar{\sigma}_f(^{235}U)$.

Infinite core k_{eff}=k_∞=1.0: SCHERZO+MINERVE+SNEAK8
($^{235}U/^{238}U$=6.7% enrichment is needed to be just critical for an infinite geometry)
avoiding so the sensitivity to Secondary Angular Distributions !!!

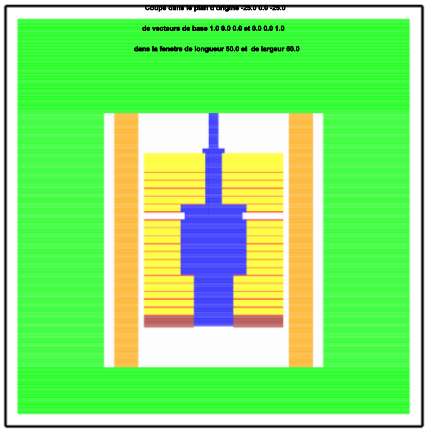
Integral Exp. with strong sensitivity to ^{238}U(n,n') are :

- **Reactivity worth of ^{nat}U reflectors**
  - LANL U235 spheres
    Godiva bare sphere(HMF-001)
    Topsy(HMF-002), Flattop (HMF-028)
  - Russian Pu spheres
    PMF-022, PMF-041, PMF-020
  - LANL Pu spheres
    PMF-001, PMF-010, PMF-006



VNIITF reflected Sphere

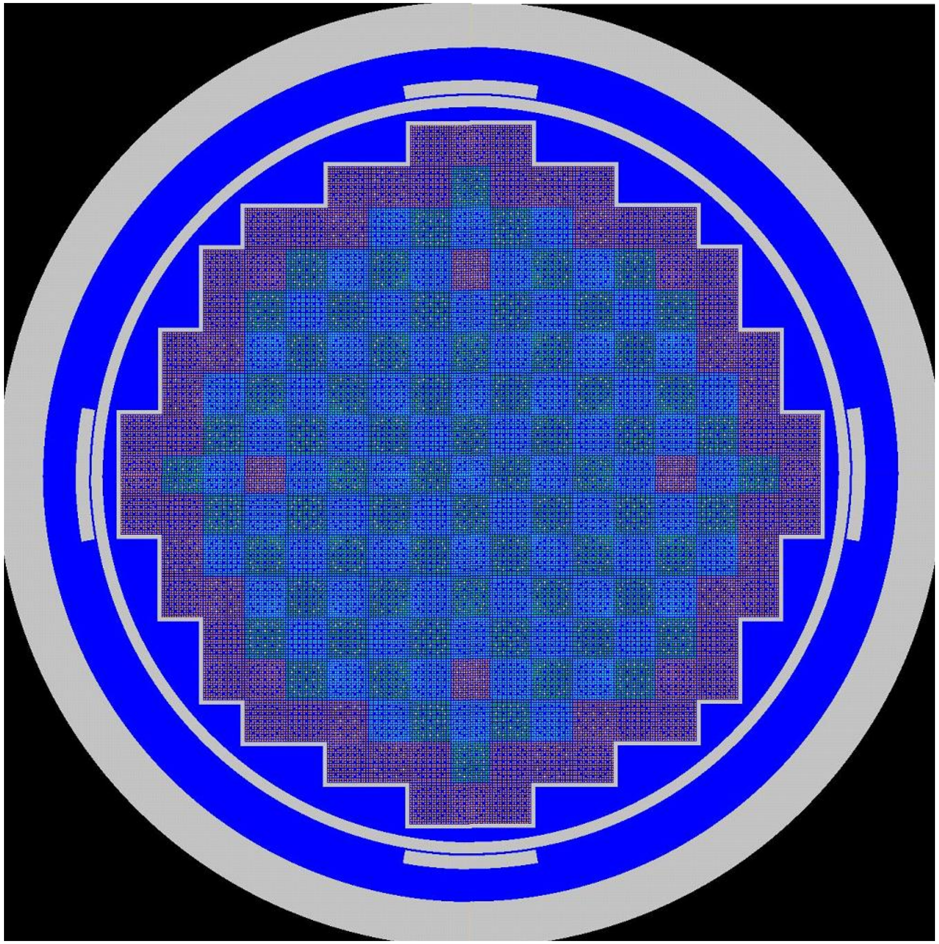
- **Fast reactors with metallic U slightly-enriched fuel**
  - SCHERZO : K∞ = 1 (Minerve + Sneak)
  - BIG-TEN : large critical core 10%^{235}U


BIG-TEN: TRIPOLI4 geometry

- **$\sigma_f^{U238}/\sigma_f^{U235}$ spectral index in U media**
  (SCHERZO, ERMINE, BIG-TEN)

3D flux measurements in large PWRs :

⇒ Fission Chamber measurements at BOL HZP start-up : French N4 1500 MWe



N4 Radial cut
TRIPOLI4 geometry

Accurate 3D Monte-Carlo TRIPOLI4 calc. using JEFF3.1.1

Critical spheres

Experiments	Pu bare PMF-22	Pu reflected PMF-20&41	Pu bare PMF-01	Pu reflected PMF-06	Pu reflected PMF-10	^{235}U bare HMF-01	^{235}U reflected HMF-02	^{235}U reflected HMF-28
$k_{eff}^{exp} \pm \delta k_{eff}^{exp}$ (1σ)	1.±0.0020	1.±0.0019	1.±0.0015	1.±0.0014	1.±0.0015	1.±0.0015	1.±0.0015	1.±0.0030
TRIPOLI4/JEFF-3.1.1	0.9983	1.0034	1.0001	1.0032	1.0016	0.9969	1.0003	1.0022
^{nat}U reflector worth	C-E = 510±280 pcm		C-E = 240±200 pcm			C-E = 370±200 pcm		

Satisfactory Keff prediction

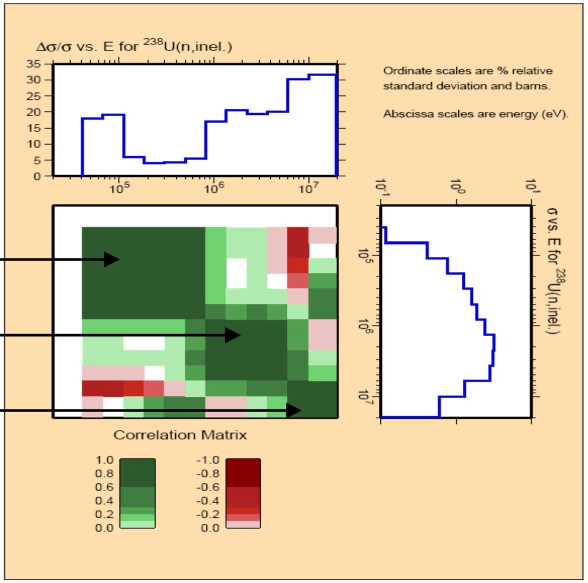
But the reactivity worth of ^{238}U reflector is overestimated by about 400 pcm

K∞=1 – BIG TEN – $\sigma_f^{U238}/\sigma_f^{U235}$ – PWR radial map

Experiments	SCHERZO k_∞	BIG TEN k_{eff}	SCHERZO $\sigma_{^{238}U(n,f)}/\sigma_{^{235}U(n,f)}$	PWR-N4 P_{center}/P_{periph}
Measured Value	1.0000±0.0030	1.0045±0.0020	0.0227±0.0003	
TRIPOLI4/JEFF-3.1.1	0.9903	0.9987	0.0209	
(C-E)/E	-970±300 pcm	-580±200 pcm	-8.1±1.5%	-4.0±2.0%

- Keff of large cores with metallic U slightly-enriched fuel is strongly underestimated
- F8/F5 strongly underestimated

Integral trend tracking



^{238}U(n,n') Correlation matrix :

- Full correlation En < 0.8 MeV
- Full correlation 0.8 MeV < En < 5 MeV
- Full correlation E_n > 5 MeV

⇒ ^{238}U fast-XS trend tracking is carried-out on 4 macrogroups :

- Group 1 E_n > 5 MeV
- Group 2 2 MeV < En < 5 MeV
- Group 3 0.8 MeV < En < 2 MeV
- Group 4 En < 0.8 MeV

-By using Monte Carlo direct calculations for sensitivity vectors

Trend results (Generalized Least Square)

Nuclear Data Data	*Prior* uncert.	Pu Spheres VNIITF	Pu Spheres LANL	^{235}U Spheres LANL	SCHERZO k_{eff}	BIG TEN k_{eff}	SCHERZO $\sigma_f^{238}/\sigma_f^{235}$	PWR-N4 Powermap
^{238}U(n,n′) G1	15%	-2.2±14.5	-0.9±14.5	-1.3±14.7	-2.2±13.6	-2.2±13.6	-6.2±13.0	-4.1±13.5
^{238}U(n,n′) G2	15%	-5.7±10.7	-2.5±10.7	-4.0±12.0	-4.3±8.9	-3.7±10.4	-12.0±3.5	-8.4±6.9
^{238}U(n,n′) G3	15%	-5.9±10.4	-2.6±10.5	-4.4±11.3	-3.8±10.5	-2.9±12.3	-10.0±8.7	-7.4±9.4
^{238}U(n,n′) G4	15%	-3.7±13.4	-1.6±13.5	-3.5±12.8	-2.3±13.6	-0.3±15.0	0.0±15.0	-1.7±14.7
^{238}U(n,n) G1	7%	0.0±7.0	0.0±7.0	0.0±7.0	0.0±7.0	0.0±7.0	0.0±7.0	0.0±7.0
^{238}U(n,n) G2	7%	-0.2±7.0	-0.1±7.0	-0.2±7.0	0.0±7.0	0.1±7.0	0.0±7.0	0.0±7.0
^{238}U(n,n) G3	7%	-0.6±6.9	-0.3±6.9	-0.6±6.9	0.0±7.0	0.1±7.0	0.0±7.0	0.0±7.0
^{238}U(n,n) G4	3%	-0.5±2.9	-0.2±2.8	-0.5±2.8	0.0±3.0	0.1±3.0	0.0±3.0	0.0±3.0
^{238}U(n,n) SAD-P1	3%	0.5±2.8	0.3±2.8	0.4±2.8	0.0±3.0	-0.1±3.0	0.0±3.0	0.1±3.0
^{238}U(n,γ) G4	3%	0.2±3.0	0.1±3.0	0.1±3.0	-0.4±2.8	-0.5±2.5	0.0±3.0	-0.4±2.9
^{238}U(n,f)	1%	-0.03±1.00	-0.01±1.00	-0.03±1.00	0.02±1.00	0.03±1.00	0.08±1.00	0.00±1.00
^{235}Uν	0.7%	0.00±0.70	0.00±0.70	0.00±0.70	0.06±0.68	0.09±0.65	0.00±0.70	0.01±0.70

Nuclear Data Data	*Prior* uncert.	Whole Experiments with ND Correlation	Whole Experiments no correlations
^{238}U(n,n′) G1	15%	-5.4±12.8	-1.6±14.8
^{238}U(n,n′) G2	15%	-11.4±3.0	-12.7±5.6
^{238}U(n,n′) G3	15%	-9.7±7.7	-6.4±12.9
^{238}U(n,n′) G4	15%	+3.2±6.6	+3.3±6.7
^{238}U(n,n) G4	3%	0.1±2.6	-0.2±2.6
^{238}U(n,γ) G4	3%	+0.8±1.8	+0.7±1.8
^{238}U(n,f)	1.0%	+0.08±0.96	+0.09±0.96
^{235}Uν	0.7%	-0.15±0.52	-0.14±0.52

Integral trend tracking

No particular trend on JEFF-3.1.1 ^{238}U elastic or fission cross section (the reduction of the *a priori* uncertainty is not significant).

But the ^{238}U(n$_{[2;5]MeV}$,n'γ) cross section (including so double differential XS) seems to be overestimated by about (11±3)%.
(note that *a priori* uncertainty was about 15%)
This result is not that much sensitive to correlation matrix or initial variances !

The same analysis is now performed for discrete and continuum inelastic channels (sensitivity vectors are performed the same way)

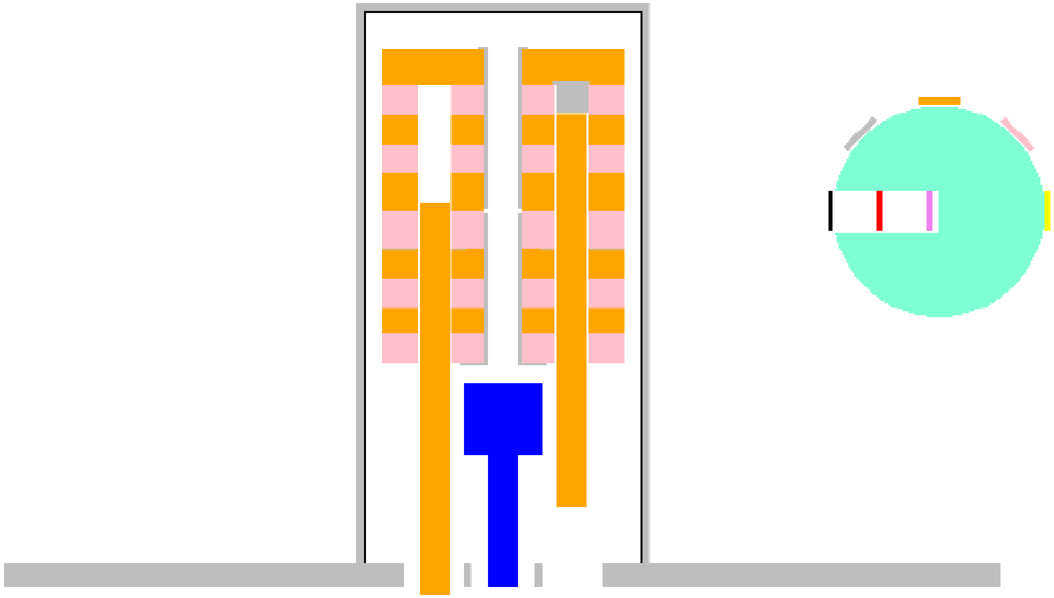
Whatever the correlation is between levels (-0.9 $\rightarrow$ 0.9), the consistent conclusion is:

JEFF-3.1.1 ^{238}U(n,n'$_c\gamma$)+(SAED) seems to be overestimated by about (10±3)%

Integral trend tracking: not yet finished…

New experiments were perform 1.5 months ago at CEA-DAM CALIBAN facility to achieve inelastic scattering by fast neutron propagation through ^{238}U sphere by dosimetric measurements.

This slowing down process (Age in the Fermi sense) is highly and specifically sensitive to $^{238}U(n,n')$.



Analysis is on-going…

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Proposed reduction of neutron-TOF inelastic γ-production XS : inherent nuclear structure uncertainty

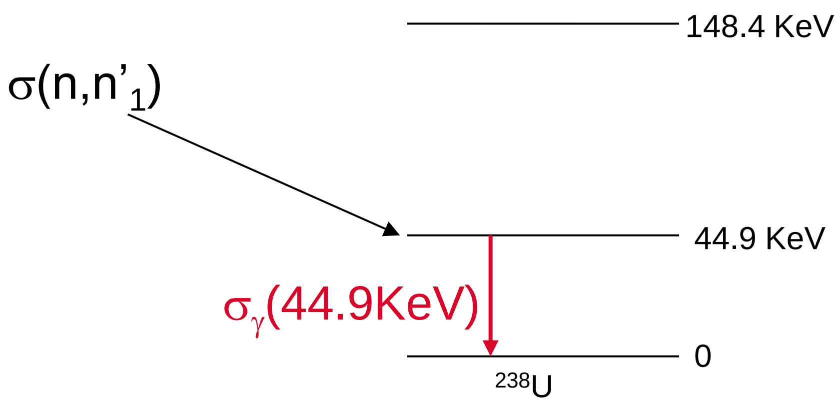
Because of possible quasi-elastic scattering (mixing so first inelastic levels and elastic channel) in **EXFOR scattered neutron measurements** (see R. Capote et al. ND2013), the deduced inelastic channel (continuum) should be overestimated.

(sort of Pandemonium for low lying levels versus “deeply” inelastic scattering)

Hopefully, **γ-production XS** measurements are on going at IRMM !

IRMM-TOF Data Reduction: from discrete γ-production to n-XS

Considering 1rst inelastic level:

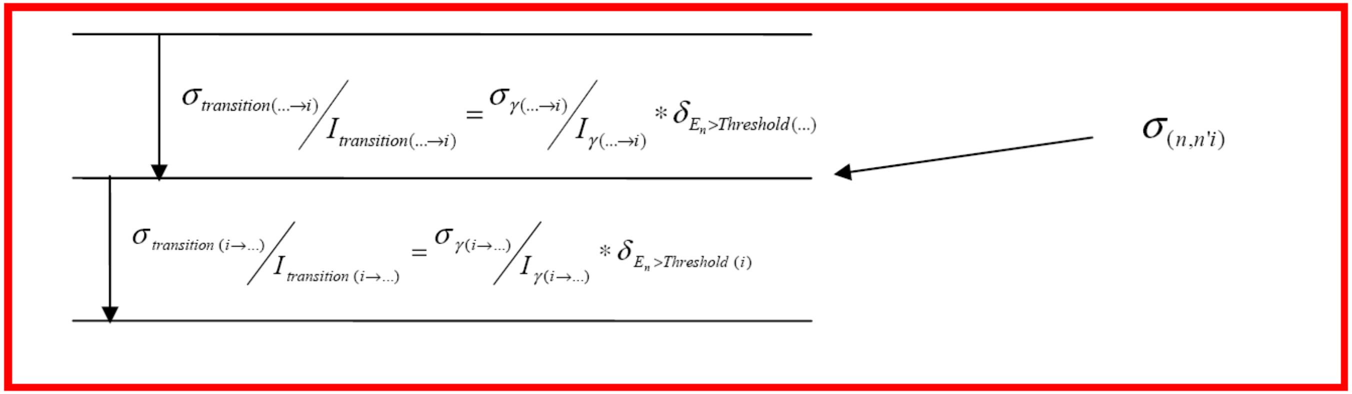


$$\sigma_{(n,n'1)}\left(44.9 * {}^{239}\!/_{238} < E_n < 148.4 * {}^{239}\!/_{238}\right) = {\sigma_{\gamma(44.9KeV)}(E_n)}\Big/{I_\gamma}$$

$$= {\sigma_{\gamma(44.9KeV)}(E_n)}\Big/{\left(I_{transition}/(1+\alpha)\right)}$$

IRMM-TOF Data Reduction: from discrete γ-production to n-XS

Generalization to discrete levels ($E_n<E_{continuum}<S_{2n}$)

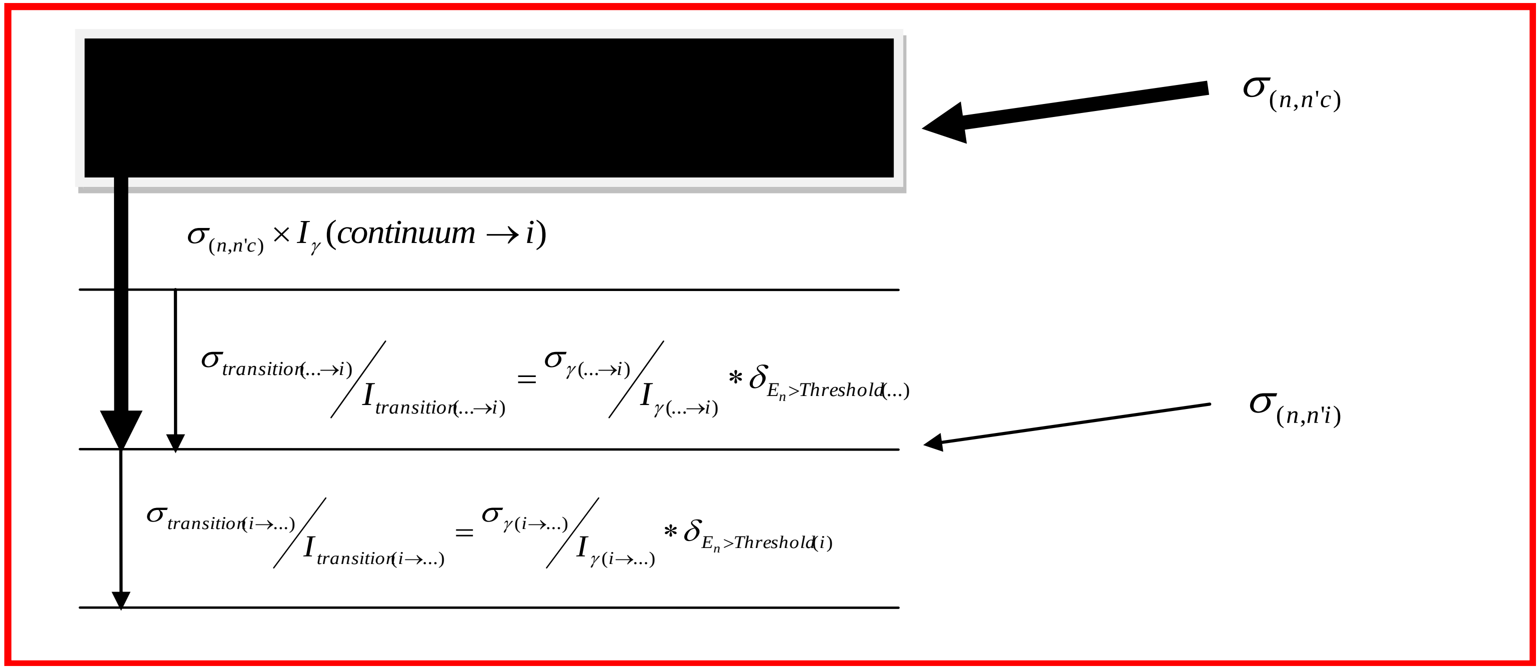


No metastable state → Each populated level decays,
Flux conservation is enforced:

$$\sigma_{(n,n'i)}(E_n) = \left(\sum_{down=0}^{i-1} \delta_{E_n>Threshold\,(i)} \times \sigma_{\gamma(i\to down)}(E_n) \Big/ I_{\gamma(i\to down)} \right) - \left(\sum_{up=i+1}^{Alldiscret} \delta_{E_n>Threshold\,(up)} \times \sigma_{\gamma(up\to i)}(E_n) \Big/ I_{\gamma(up\to i)} \right)$$

IRMM-TOF Data Reduction: from discrete γ-production to n-XS

Generalization to discrete and continuum levels ($E_n<S_{2n}$)



IRMM-TOF Data Reduction: from discrete γ-production to n-XS

$$\sigma_{(n,n'i)}(E_n) = \left(\sum_{down=0}^{i-1} \delta_{E_n > Threshold(i)} \times \frac{\sigma_{\gamma(i \to down)}(E_n)}{I_{\gamma(i \to down)}} \right) - \left(\sum_{up=i+1}^{Alldiscrete} \delta_{E_n > Threshold(up)} \times \frac{\sigma_{\gamma(up \to i)}(E_n)}{I_{\gamma(up \to i)}} \right) - \sigma_{(n,n'c)} \times I_{\gamma}$$

$$\sigma_{(n,n'i)}(E_n) = \left(\sum_{down=0}^{i-1} \delta_{E_n > Threshold(i)} \times \frac{\sigma_{\gamma(i \to down)}(E_n)}{I_{\gamma(i \to down)}} \right) - \left(\sum_{up=i+1}^{Alldiscrete} \delta_{E_n > Threshold(up)} \times \frac{\sigma_{\gamma(up \to i)}(E_n)}{I_{\gamma(up \to i)}} \right) - \sigma_{(n,n'c)}(E_n) \times \left(\sum_{XL} y_{XL}^2 \times (S_n + E_n - E_i)^{2L+1} \times \frac{f_{XL}(S_n + E_n - E_i)}{\rho(S_n + E_n)} \right)$$

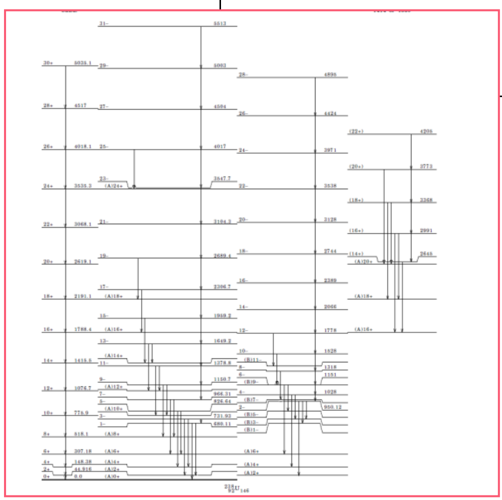
- Discrete XS are linked to continuum XS.
- Measuring discrete levels versus incident energy can constraint continuum XS.

But,

- Low lying level nuclear structure data uncertainties have to be accounted for (as A. Plompen proposed, a coincidence analysis could be very helpful !)
- Model parameter as well: giant resonance, level density parameters…RIPL E_{max}

Uncertainty of discrete levels nuclear structure data

$$\frac{\mathrm{var}\left[\sigma_{(n,n'i)}(E_n)\right]}{\sigma^2_{(n,n'i)}(E_n)} \approx \left(\sum_{down=0}^{i-1} \delta_{E_n > Threshold\,(i)} * \sigma^2_{\gamma(i\to down)}(E_n) \Big/ \sigma^2_{(n,n'i)}(E_n)\cdot I^2_{\gamma(i\to down)} * \frac{\mathrm{var}\left[I_{\gamma(i\to down)}\right]}{I^2_{\gamma(i\to down)}} \right) - \left(\sum_{up=i+1}^{\infty} \delta_{E_n > Threshold\,(up)} * \sigma^2_{\gamma(up\to i)}(E_n) \Big/ \sigma^2_{(n,n'i)}(E_n)\cdot I^2_{\gamma(up\to i)} * \frac{\mathrm{var}\left[I_{\gamma(up\to i)}\right]}{I^2_{\gamma(up\to i)}} \right)$$



$$\text{using}: I_\gamma = I_t / (1+\alpha) \text{ and},$$

$$\mathrm{var}\left[I_\gamma\right] \Big/ I_\gamma^2 = \left\{ \mathrm{var}\left[I_t\right] \Big/ I_t^2 \right\} + \left\{ \mathrm{var}[\alpha] \Big/ \alpha^2 \times \alpha^2 \Big/ (1+\alpha)^2 \right\}$$

With

$[I_t$, var(I_t), α, var(α) if $\exists]$ $\rightarrow$ ENSDF up to E*=1.106MeV (21^{th} excited level)

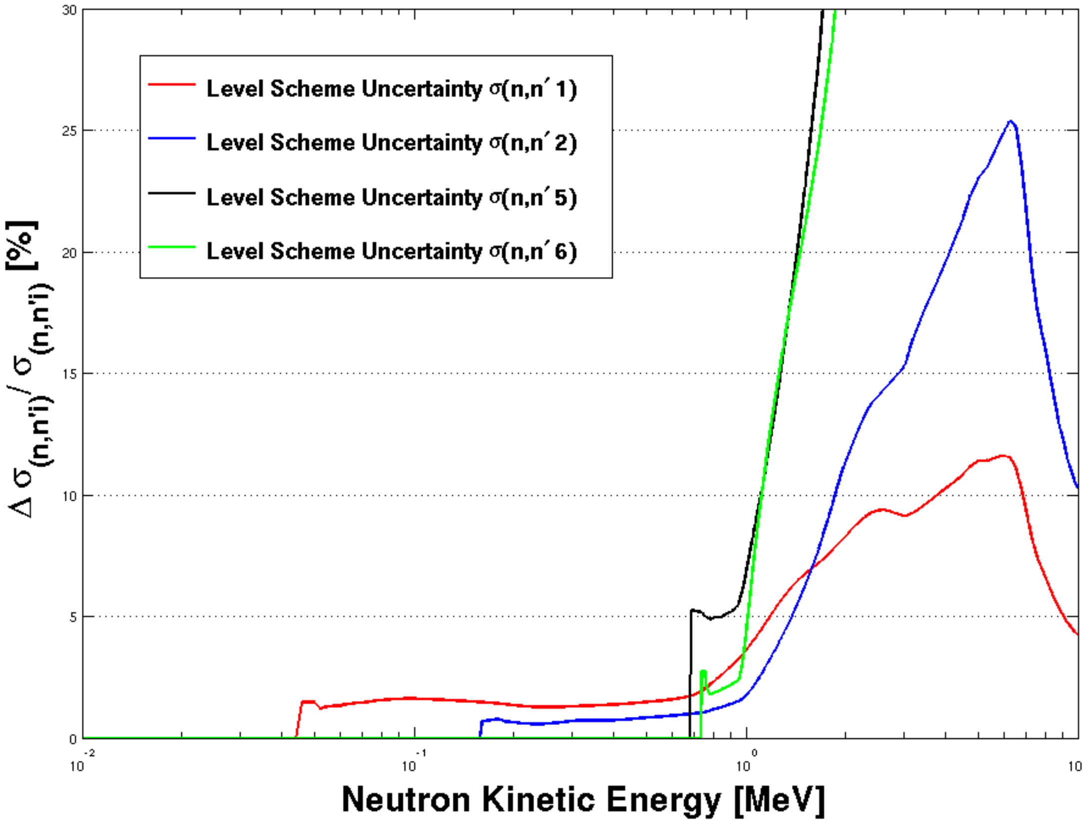
+[var$(\alpha)/\alpha^2=(1.5\%)^2$] $\rightarrow$ NIMA-589(2008)pp202-229

$[\sigma_{(n,n'i)}(E_n)$, $\sigma_{\gamma(x\to y)}(E_n)]$ $\rightarrow$ TENDL-2011

Uncertainty of discrete levels nuclear structure data

A priori nuclear structure uncertainty reaches
12% for $^{238}U(n,n'_1)$ and 25% for $^{238}U(n,n'_2)$.

For others, no data reduction is achievable (*a priori* >100% !) after 1MeV !



Uncertainty of discrete levels nuclear structure data

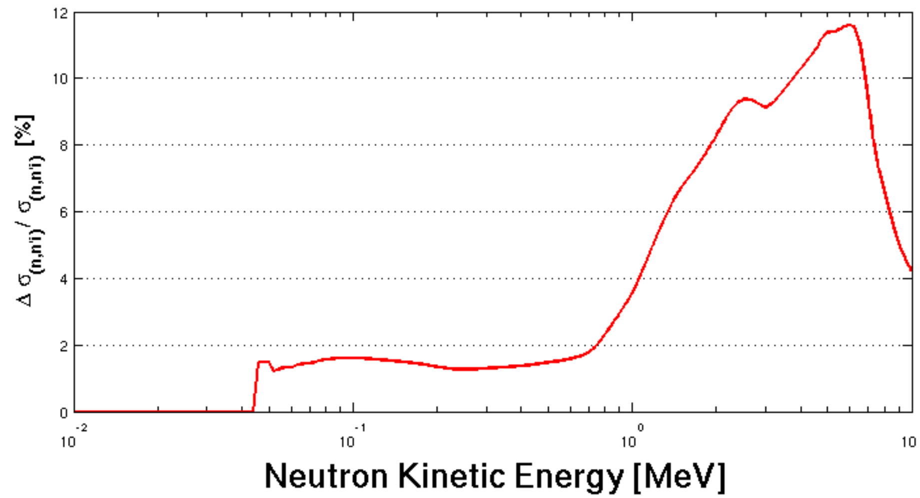
Which transition is responsible of 12% for n1 and 25% for n2 ?

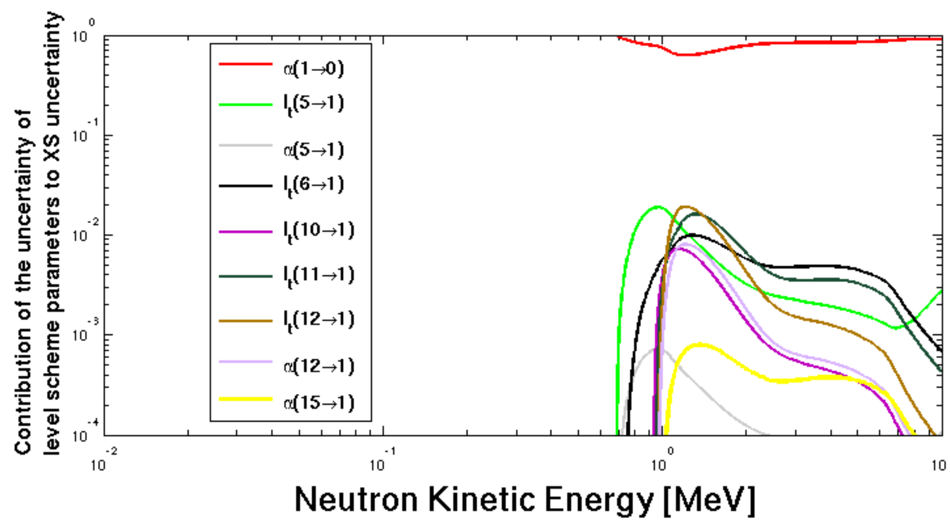
- For (n,n'1) data reduction:

o	L1(44.916KeV;2^+) →	L0(0KeV;0^+);	α=609±9
o	L5(680.11KeV;1^-) →	L1(44.916KeV;2^+);	I_t=100±2
o	L12(966.13KeV;2^+) →	L1(44.916KeV;2^+);	I_t=60±3
o	L11(950.12KeV;2^-) →	L1(44.916KeV;2^+);	I_t=100±6
o	L6(731.39KeV;3^-) →	L1(44.916KeV;2^+);	I_t=100±2
o	L12(966.13KeV;2^+) →	L1(44.916KeV;2^+);	α=0.23±0.04
o	L10(930.55KeV;(1^-)) →	L1(44.916KeV;2^+);	I_t=100±4

- For (n,n'2) data reduction:

o	L2(148.38KeV;4^+) →	L1(44.916KeV;2^+);	α=11.6±0.1714
o	L6(731.93KeV;3^-) →	L2(148.38KeV;4^+);	I_t=81.4±1.6
o	L8(826.64KeV;5^-) →	L2(148.38KeV;4^+);	I_t=100±6
o	L12(966.13KeV;2^+) →	L2(148.38KeV;4^+);	I_t=100±4
o	L15(997.58KeV;3^-) →	L2(148.38KeV;4^+);	I_t=100±3
o	L16(1037.25KeV;2^+) →	L2(148.38KeV;4^+);	I_t=71.7±1.5





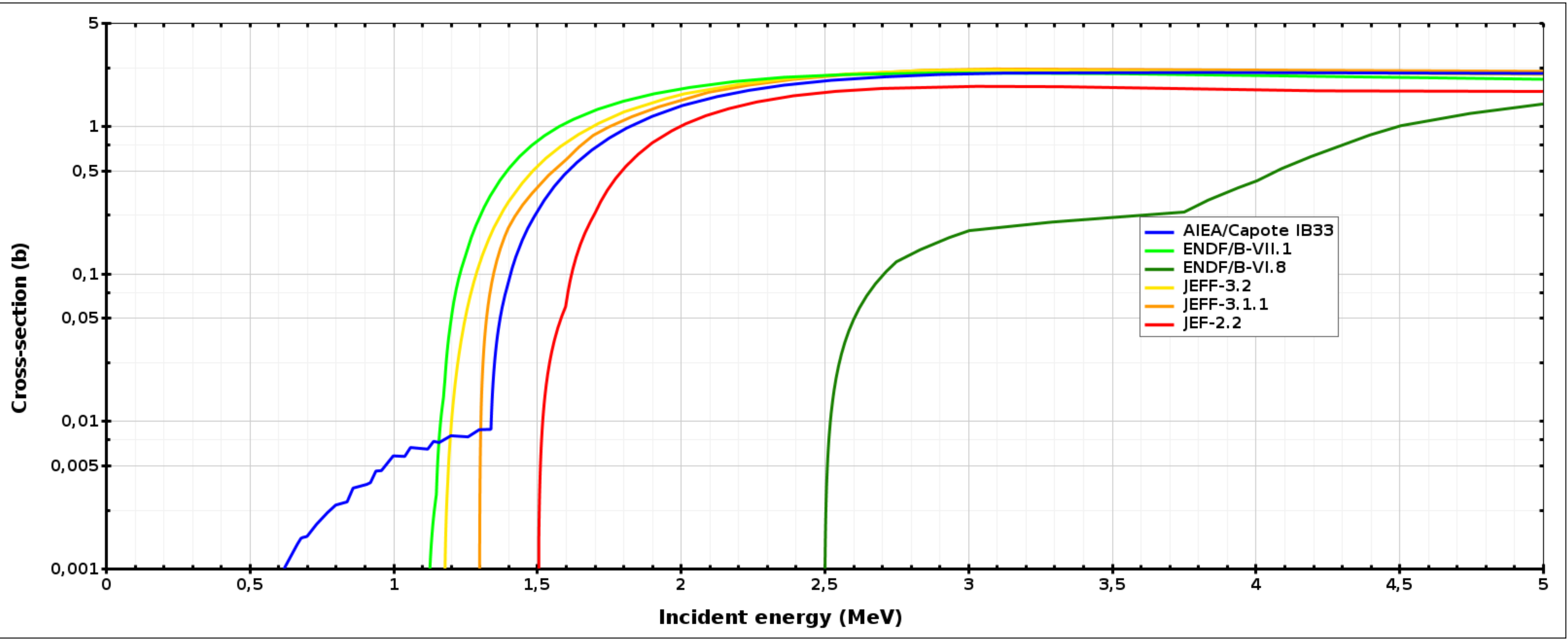
Uncertainty of discrete levels nuclear structure data

Beforehand, neutron-XS reduction from TOF measurements, one should improved drastically following discrete transitions:

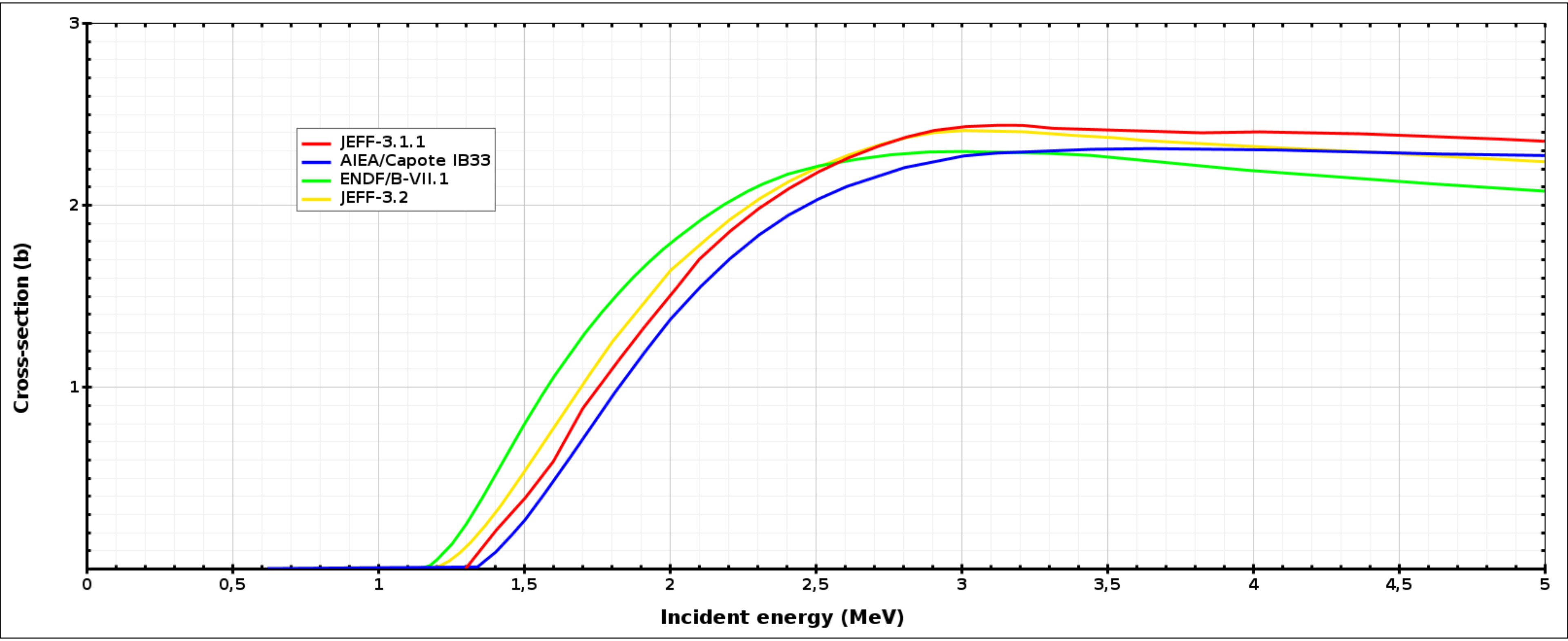
- For (n,n'5) data reduction:
  - L11(950.12KeV;2^-) → L5(680.11KeV;1^-); I_γ=48±8 (XS unc. ~ 0 to 140%)
  - L5(680.11KeV,1^-) → L0(0KeV,0^+); I_γ=79±4 (XS unc. ~ 0 to 50%)
- For (n,n'6) data reduction:
  - L16(1037.25KeV,2^+) → L6(731.93KeV,3^-); I_γ=11.8±0.5 (XS unc. ~ 0 to 220%)
  - L11(950.12KeV,2^-) → L6(731.93KeV,3^-); I_γ= 53±6 (XS unc. ~ 0 to 30%)
- For (n,n'8) data reduction:
  - L8(826.64KeV,5^-) → L2(148.38KeV,4^+); I_γ=100±6 (XS unc. ~ 0 to 250%)
  - L8(826.64KeV,5^-) → L3(307.18KeV,6^+); I_γ= 50±3 (XS unc. ~ 0 to 250%)

Nuclear model parameters

Starting from $^{238}U(n,n_c'\gamma)$ **in JEF-2.2 stored in MF3-MT91**



Focus on existing recent evaluations



Continuum channels open between E_n =1.2 MeV to 1.34MeV
(could it be treated as virtual-discrete levels instead of continuum ?)
NB: E_{max} values: 1.45 (RIPL2.0) and 1.41 (RIPL3.0) MeV

As a consequence, the threshold-tail is then more or less strong.
The inelastic to continuum reaction rate (convoluted to PFNS) can change (by -10% from JEFF-3.1.1 to IAEA/IB33)!!

Conclusions

1. Accurate calculations of Fast Breeder and Light Water reactors need better knowledge for $^{238}U(n,n')$. Moreover, an integral trend is to reduce this XS (starting from JEFF311).

2. A new evaluation is needed. A tight covariance matrix is necessary as well in order to reduce the final uncertainty of parameters (k_{eff}, power map…) of specific designed reactors.

3. n-TOF γ-production will be very helpful for this, but nuclear structure data uncertainties have to be handle carefully.

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Thank you.

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