DE LA RECHERCHE À L'INDUSTRIE

Investigation of Prompt Fission Neutron and Gamma Spectra with their covariance matrices. Application to $^{239}Pu+n_{th}$, $^{238}U+n_{1.8MeV}$, $^{235}U+n_{th}$

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NEMEA-7 / CIELO

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Plan

- Activities around PFNS
- PFNS and PFGS from Fission Fragment deexcitation
- Covariance matrices
- Conclusion, Outlook

Activities around PFNS

1. **Model for spectra**
   Monte Carlo simulation of the fission fragment deexcitation (**Fifrelin code**)
   → *Allows to estimate fission observables (spectra, multiplicities, correlations, fission yields, …)*

2. **Model for quantification of covariances**
   Production of covariance matrices (**Conrad code**)
   → *Used for cross sections but also any kind of model (in this work: Maxwell, Watt, Madland-Nix, Fifrelin PFNS Models)*

- PFNS and PFGS from Fission Fragment deexcitation

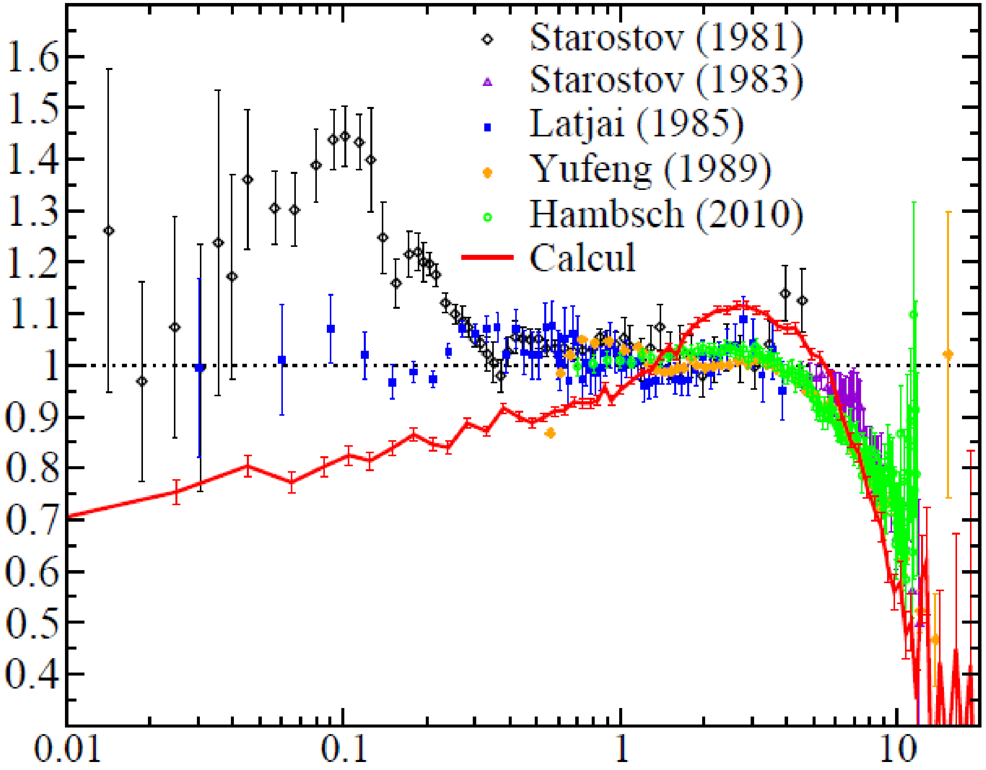
U235 / U238 / Pu239

FIFRELIN: a Monte Carlo code simulating the fission fragment deexcitation

Review of the model:

- Pre-neutron fission fragment mass sampling
- Pre-neutron fission fragment kinetic energy sampling
- Nuclear charge sampling
- Spin and parity sampling
- Excitation energy sharing after full acceleration ($E^{*}=aT^{2}$)
  - Ignatyuk's prescription for level density parameter (a)
  - Mass dependent temperature ratio law (T)
- Prompt particle (n/γ) emission (Weisskopf or Hauser-Feshbach model)

❑ Thermal fission of U235 (Prompt Fission Neutron Spectrum)



$^{235}U + n_{th}$

D. Regnier phD (october 2013)

❑ Thermal fission of U235 (Prompt Fission Gamma Spectrum)

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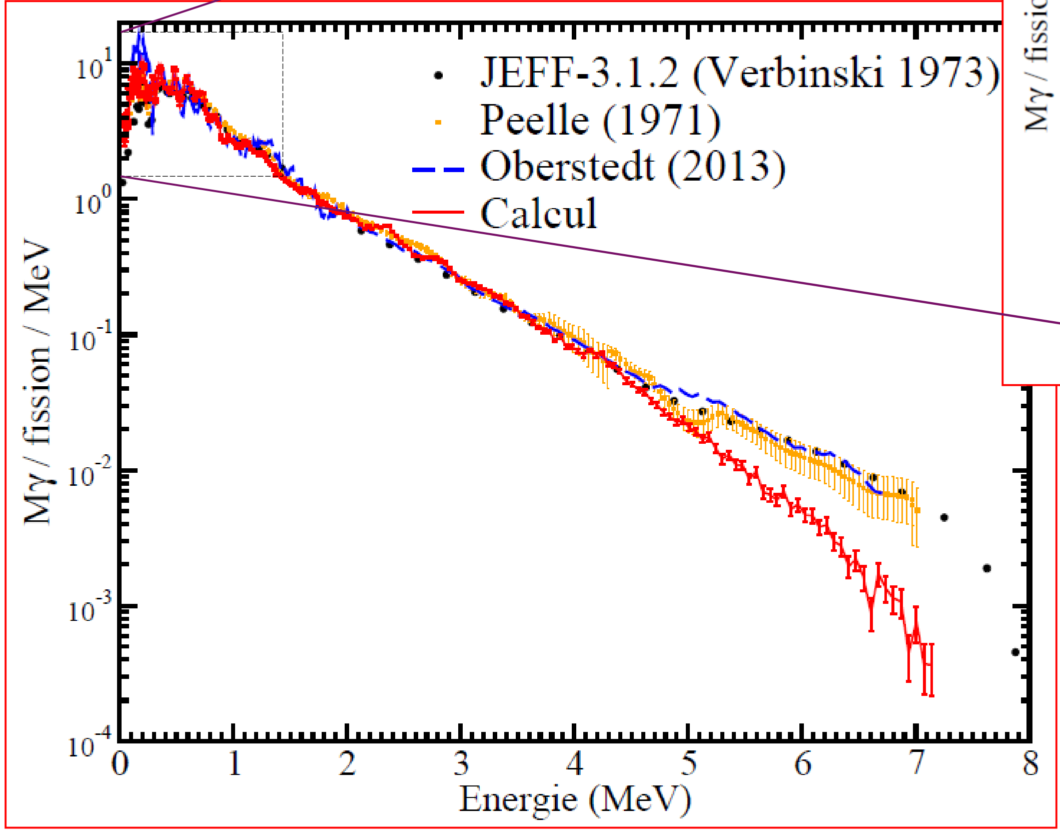
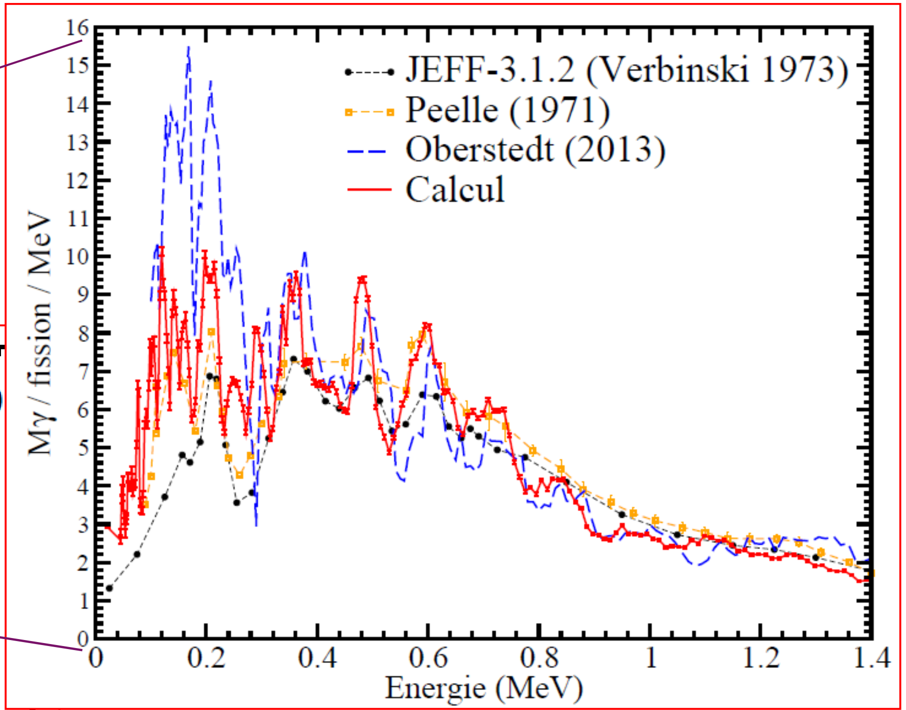
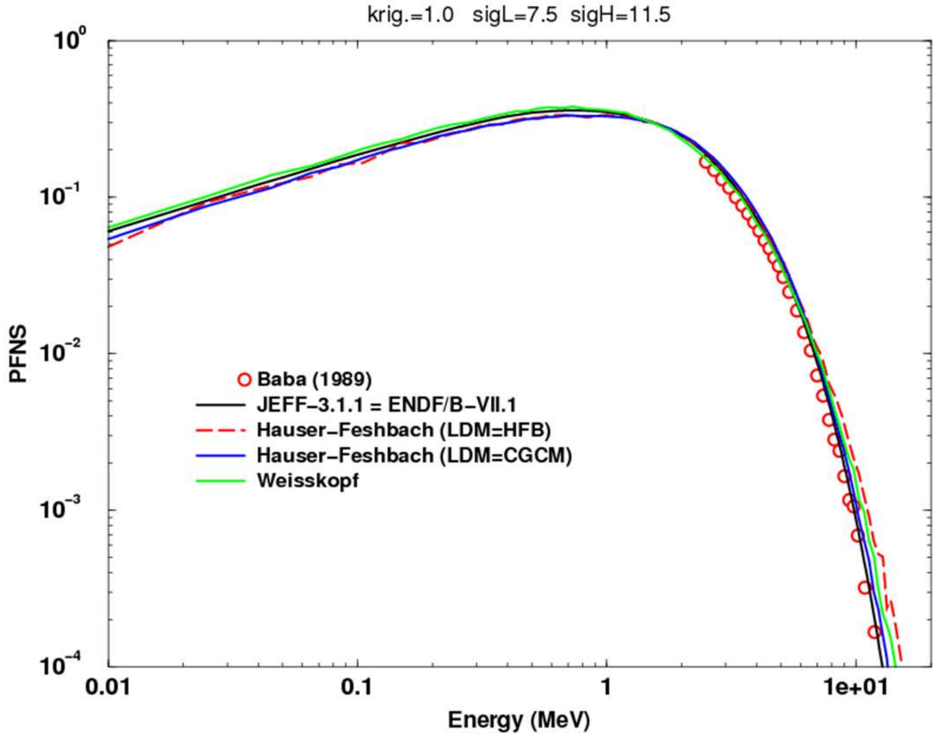


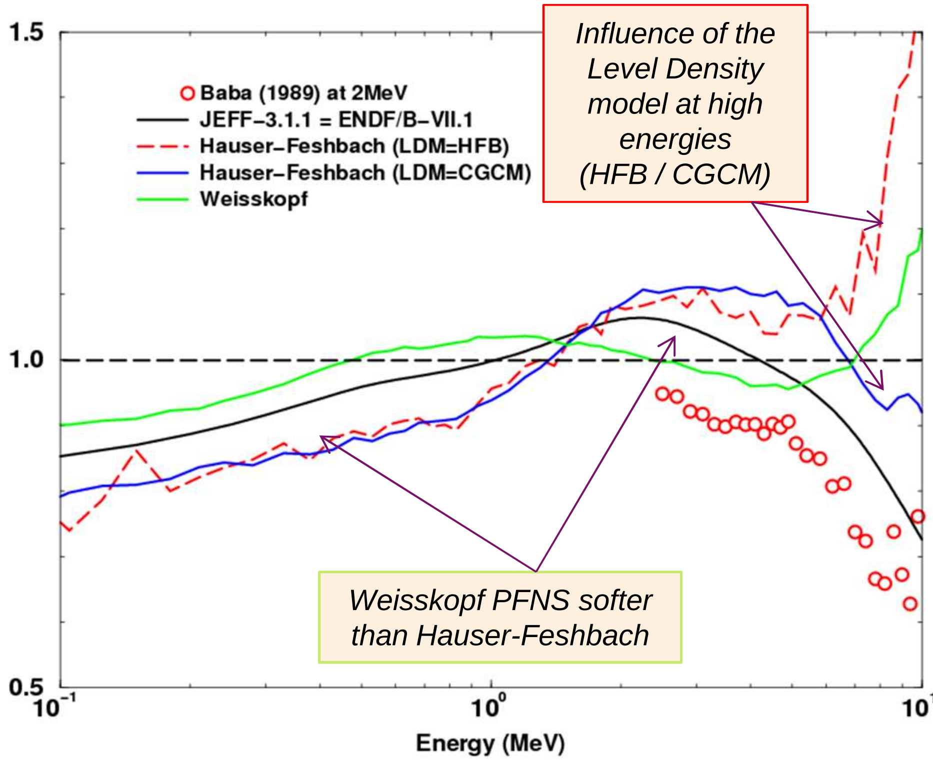


$^{235}U + n_{th}$

❑ U238 + $n_{1.8MeV}$ (Prompt Fission Neutron Spectrum)

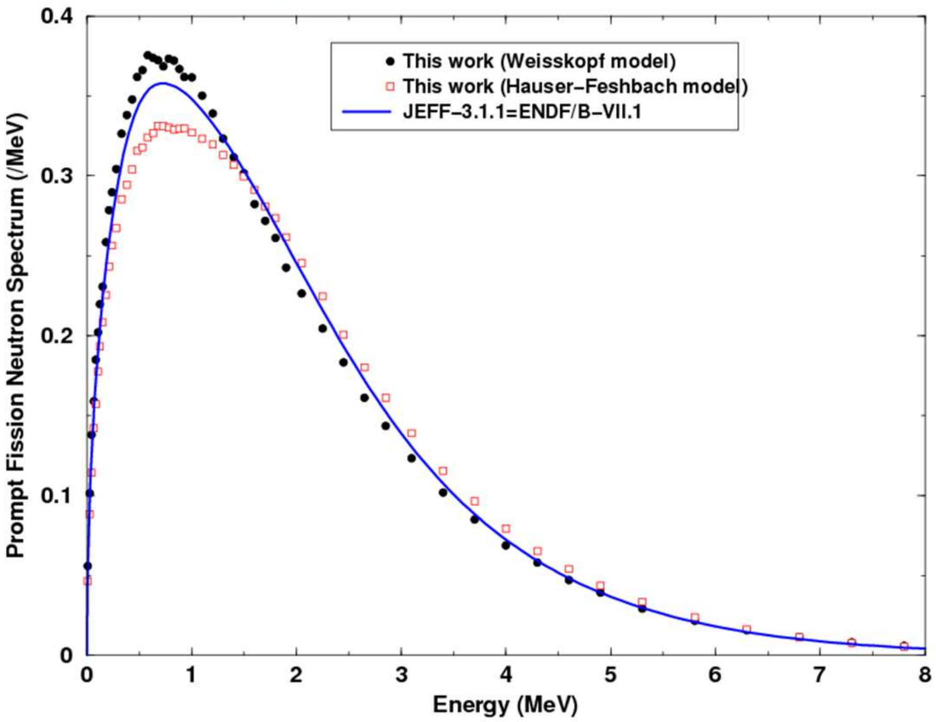
$^{238}U + n_{1.8MeV}$

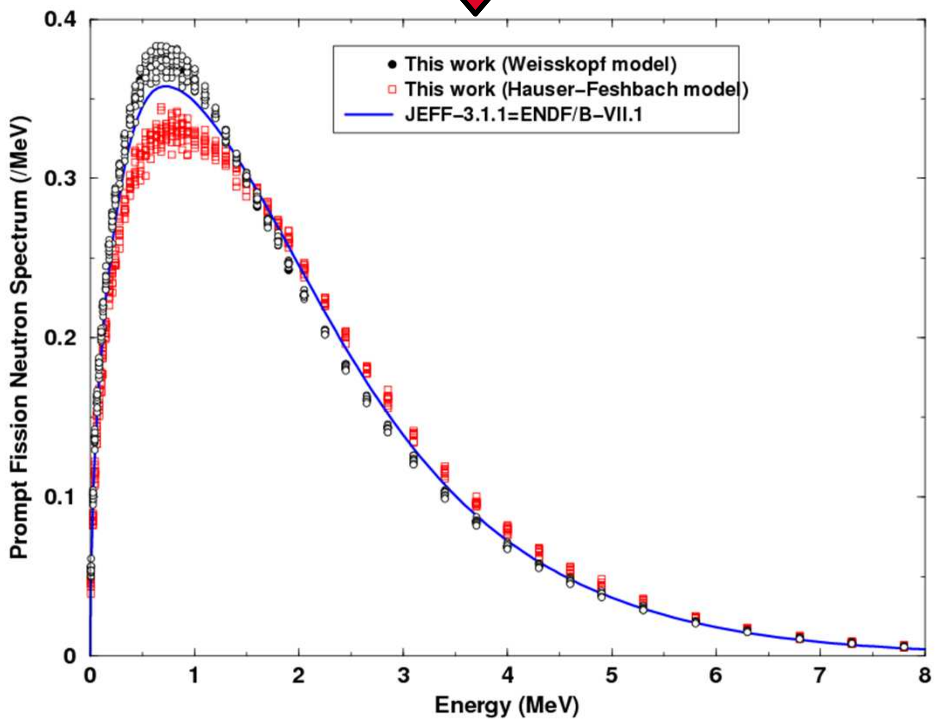




❑ U238 + $n_{1.8MeV}$ (Prompt Fission Neutron Spectrum)

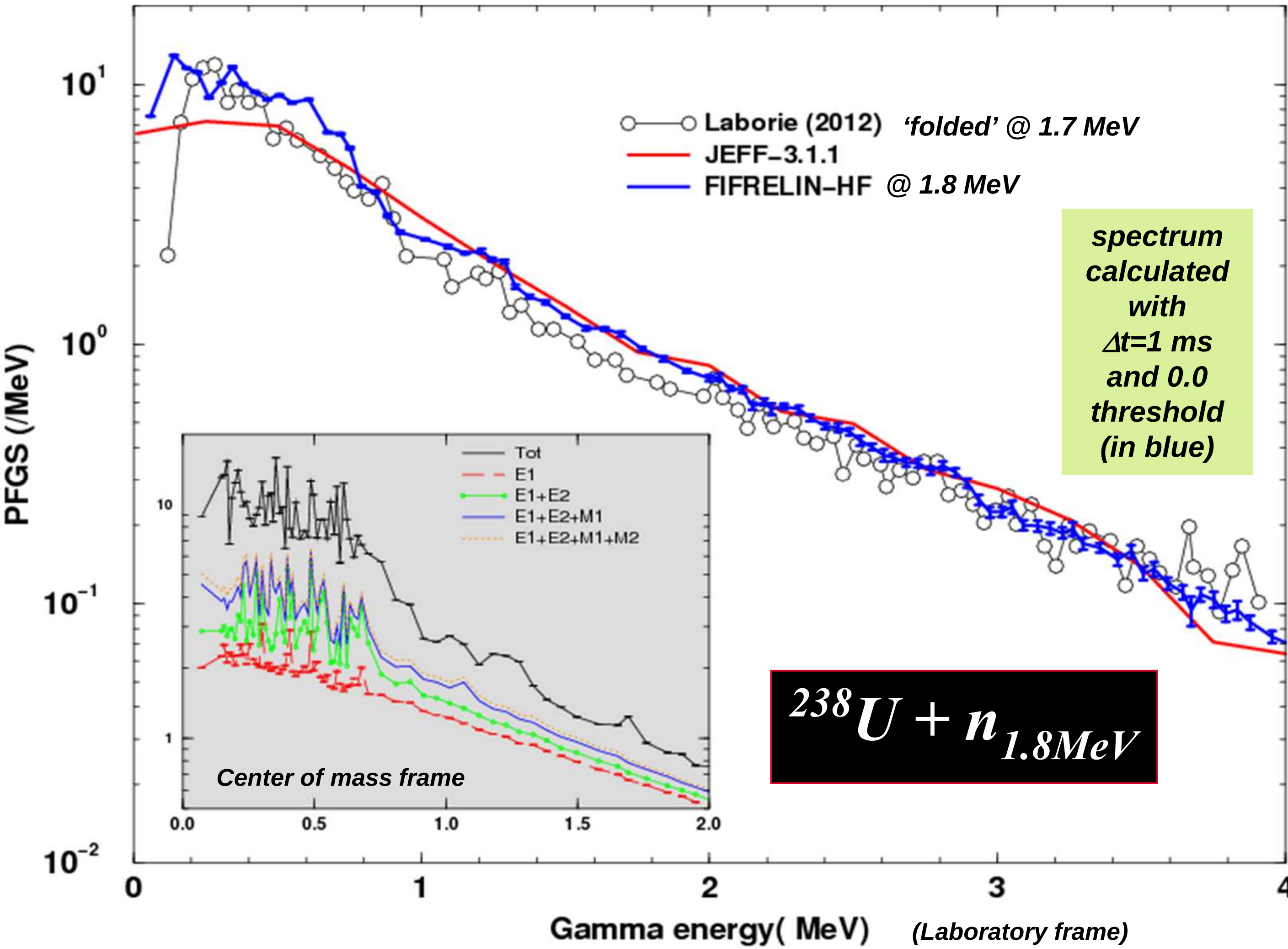
Same trend whatever the model parameters





$^{238}U + n_{1.8MeV}$

❑ U238 + $n_{1.8MeV}$ (Prompt Fission Gamma Spectrum)



❑ *Prompt Fission Gamma Multiplicity (PFGM)*

- JEFF-3.1.1

$$\overline{M}_{\gamma} = 8.2$$

- FIFRELIN-HF

with threshold : **0,1 MeV**
time window : **10 ns**

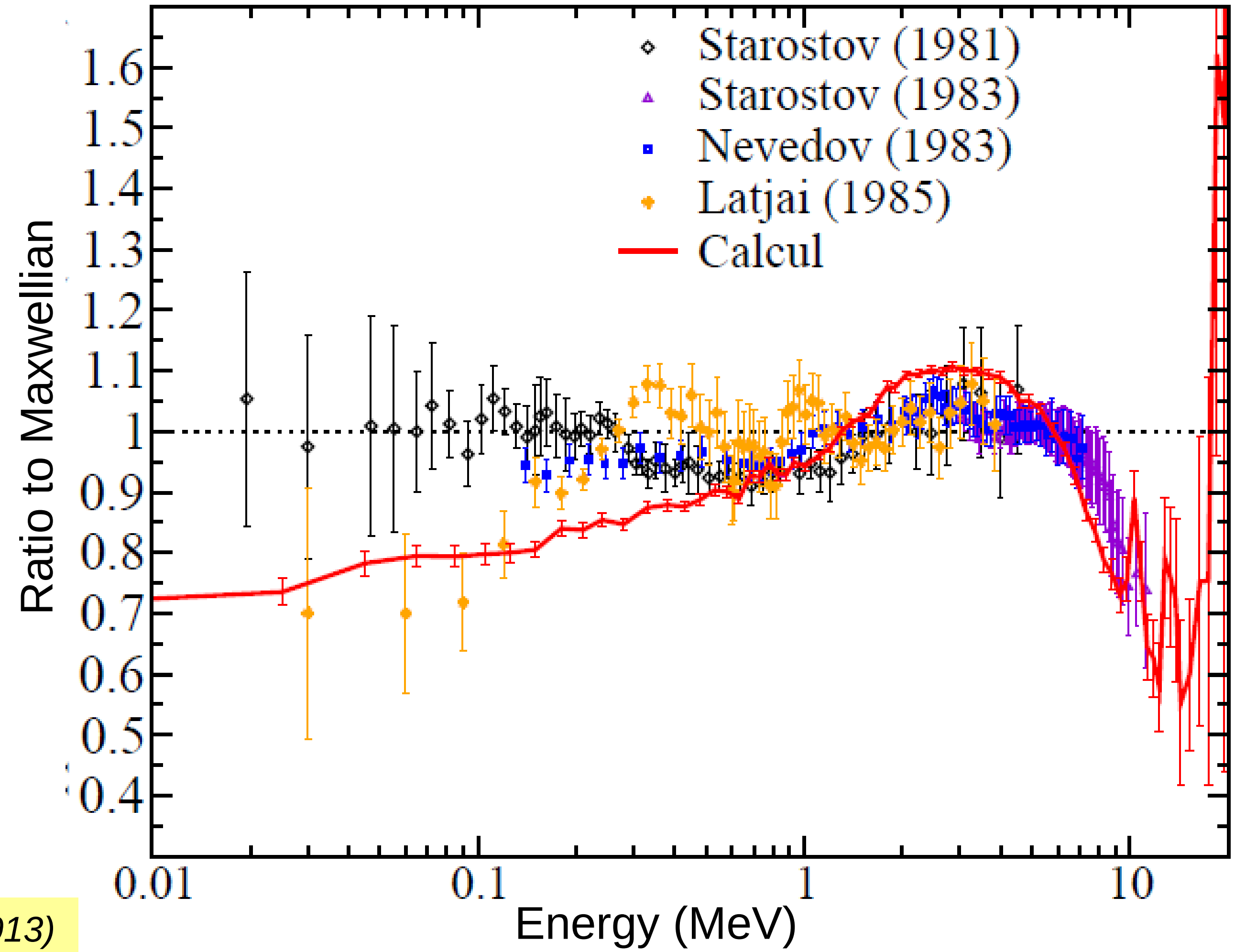
$$\overline{M}_{\gamma} \approx 9.0$$

$$< E_{\gamma}^{tot} > \approx 7.04$$

$$< \varepsilon_{\gamma} > \approx 0.78$$

❑ **Thermal fission of Pu239**
(Prompt Fission Neutron Spectrum : ratio to Maxwellian T=1.38 MeV)

$^{239}Pu + n_{th}$



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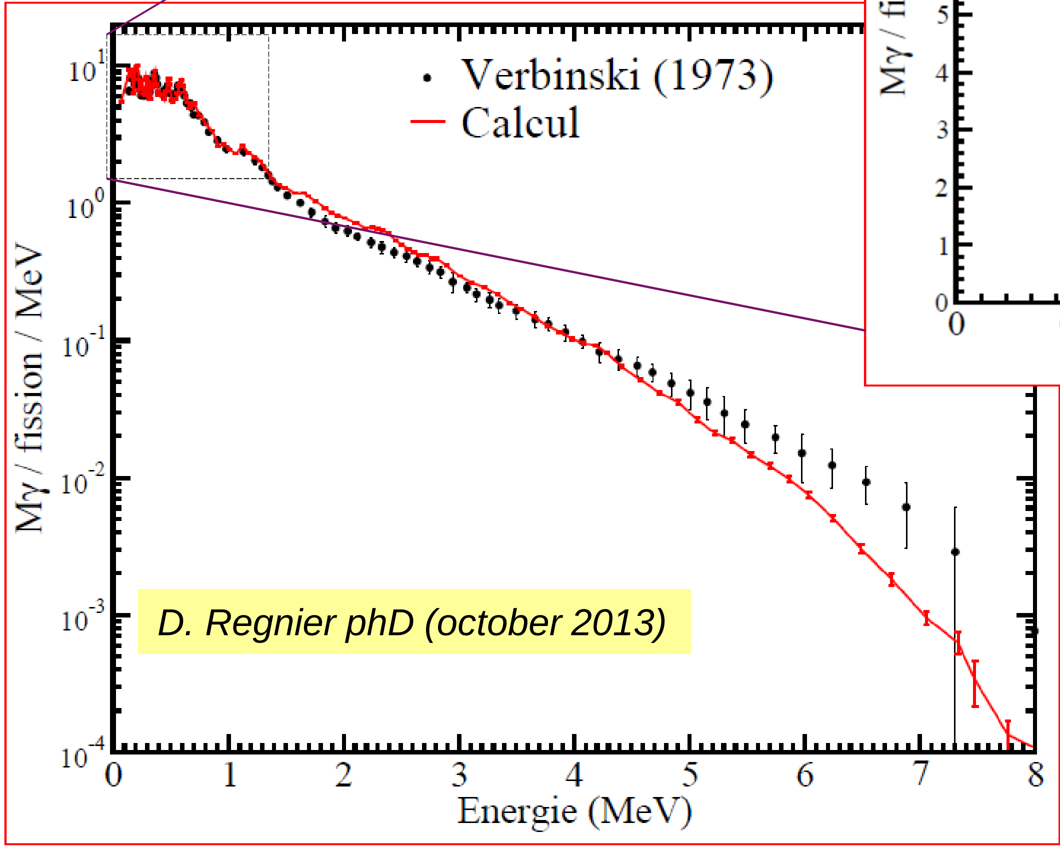
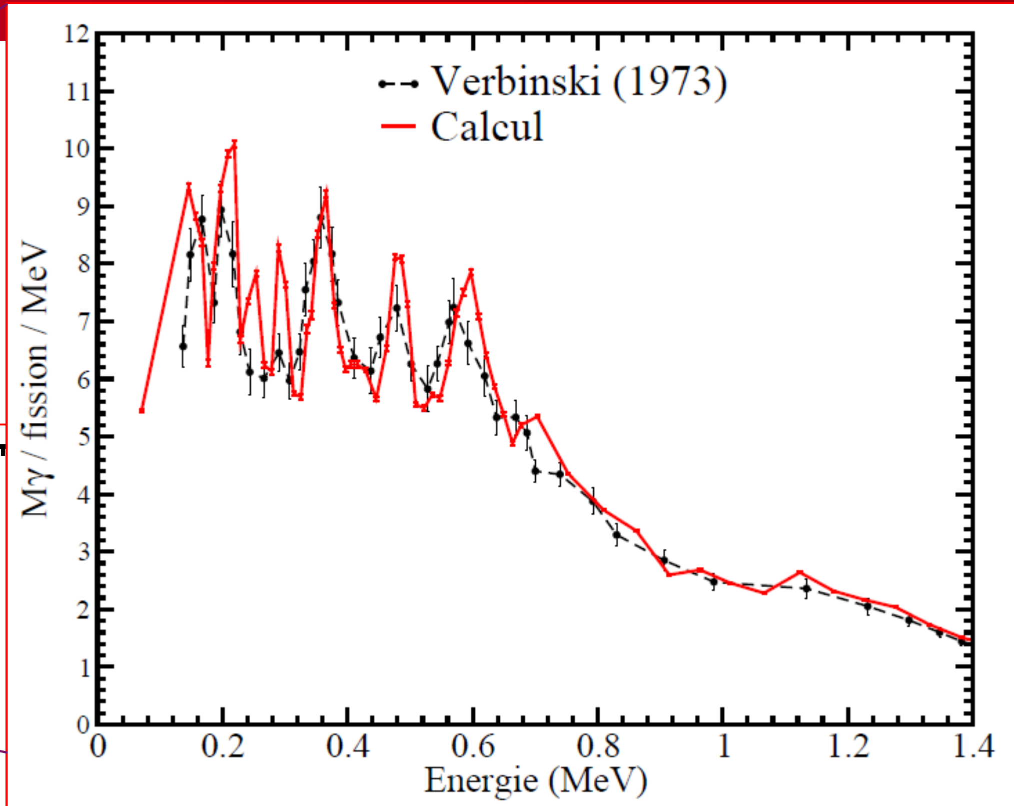
Thermal fission of Pu239 (Prompt Fission Gamma Spectrum)

$^{239}Pu + n_{th}$





	M_γ [γ/f]	$E_{\gamma,tot}$ [MeV]	ε_γ [MeV]
Verbinski	7.23	6.81±0.3	0.94
FIRELIN	7.23	6.83	0.94

Covariance matrices (U235)

- Model parameter adjustment in Conrad code
  - *Experimental statistical uncertainty associated to the spectrum at each energy point*
  - *Experimental systematic uncertainty due to normalization, detection efficiency, ...*

$$M_x^{marg} = M_x^{stat} + \left(G_x^{\mathrm{T}} \cdot G_x\right)^{-1} \cdot G_x^{\mathrm{T}} \cdot G_\theta \cdot M_\theta \cdot G_\theta^{\mathrm{T}} \cdot G_x \cdot \left(G_x^{\mathrm{T}} \cdot G_x\right)^{-1}$$

❑ Thermal fission of U235 (Correlation matrix for Prompt Fission Neutron Spectrum)

$^{235}U + n_{th}$

Model	parameters	Prior (MeV)	Posterior (MeV)
Maxwell	T	1.32 ± 10%	1.32 ± 0.2% ± 2.3%
Watt	T_W	0.90 ± 10%	1.06 ± 1.0% ± 15.1%
	E_W	0.78 ± 10%	0.38 ± 4.2% ± 44.7%
Madland-Nix	T	1.01 ± 10%	0.96 ± 2.3% ± 15.4%
	E_f^L	1.07 ± 10%	1.16 ± 4.8% ± 14.9%
	E_f^H	0.50 ± 10%	0.25 ± 3.3% ± 36.1%

Fit based on 5 experiences

Statistical uncertainties

Systematic uncertainty (normalization) ± 5%

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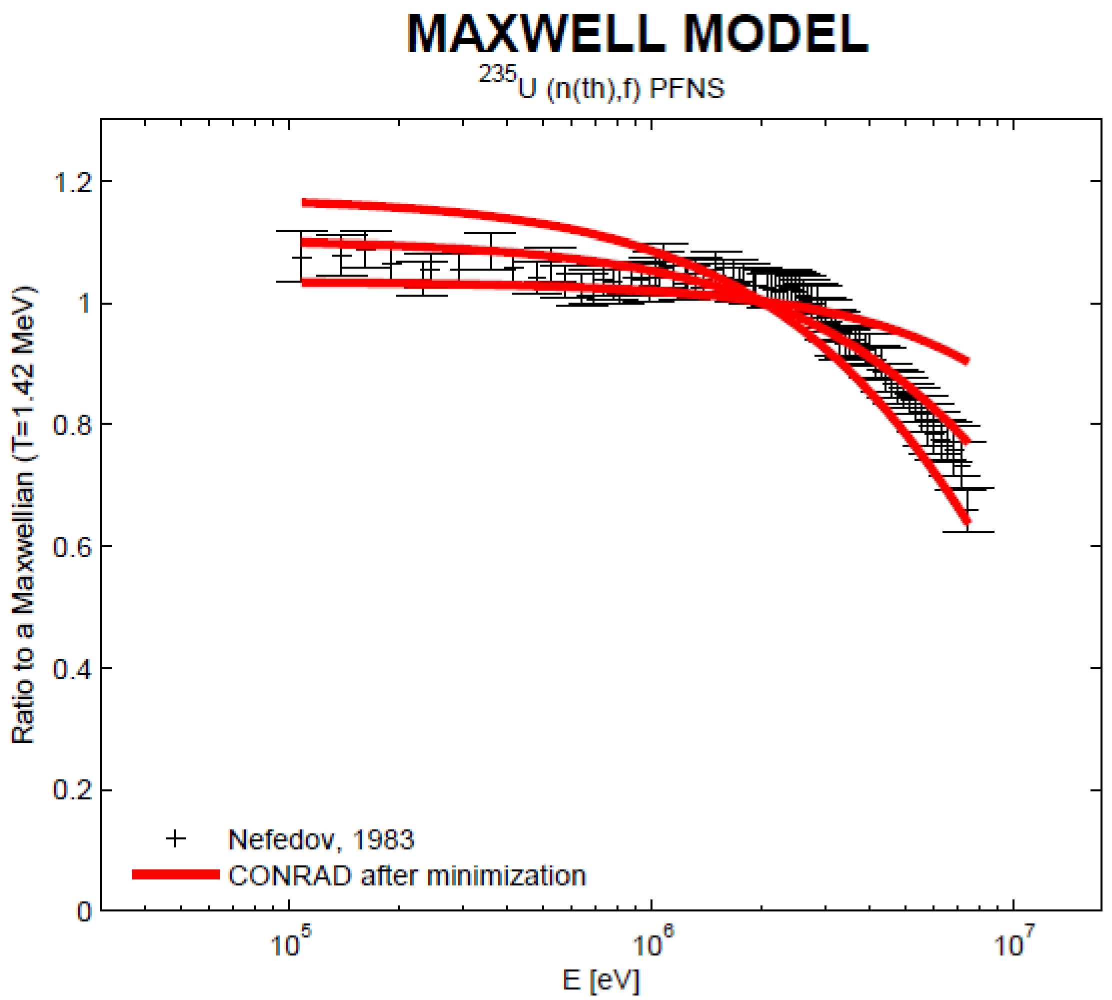
❑ Thermal fission of U235
(Correlation matrix for Prompt Fission Neutron Spectrum)



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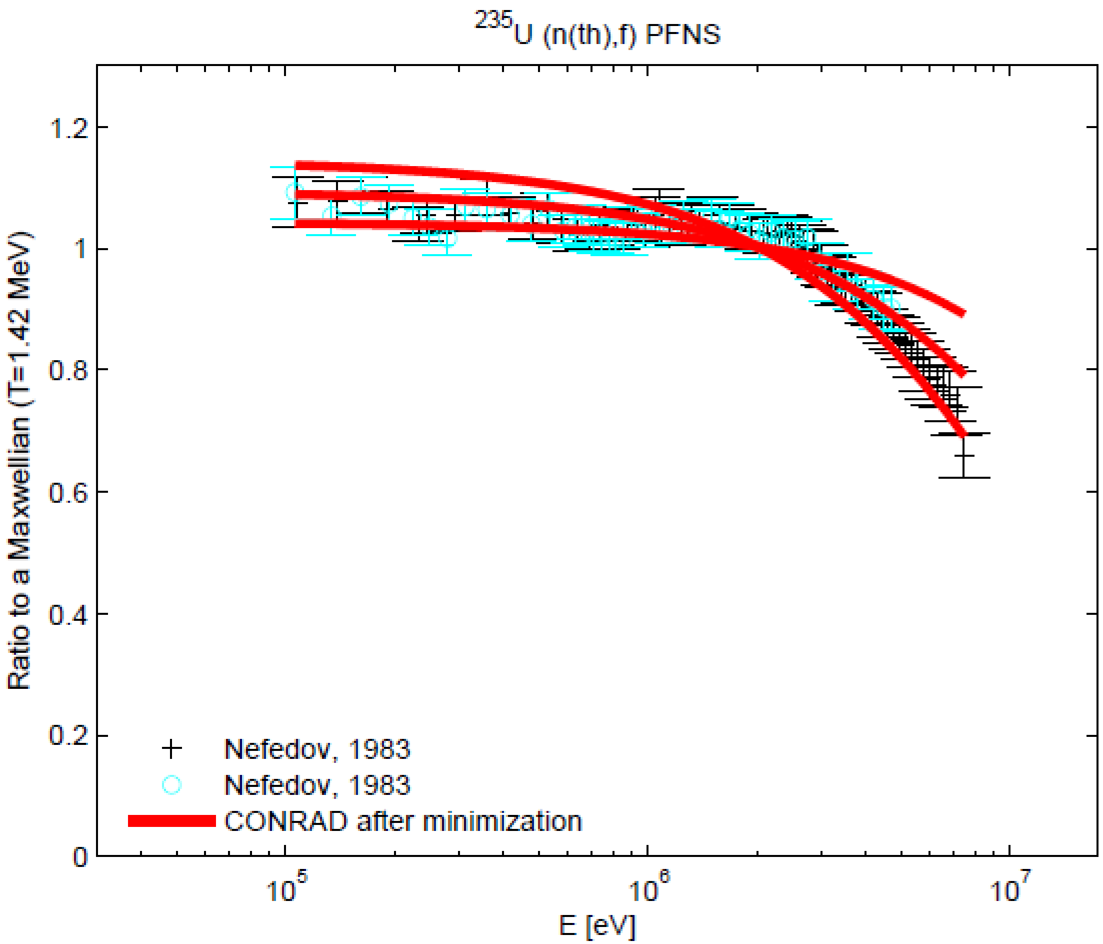
❑ Thermal fission of U235
(Correlation matrix for Prompt Fission Neutron Spectrum)

MAXWELL MODEL



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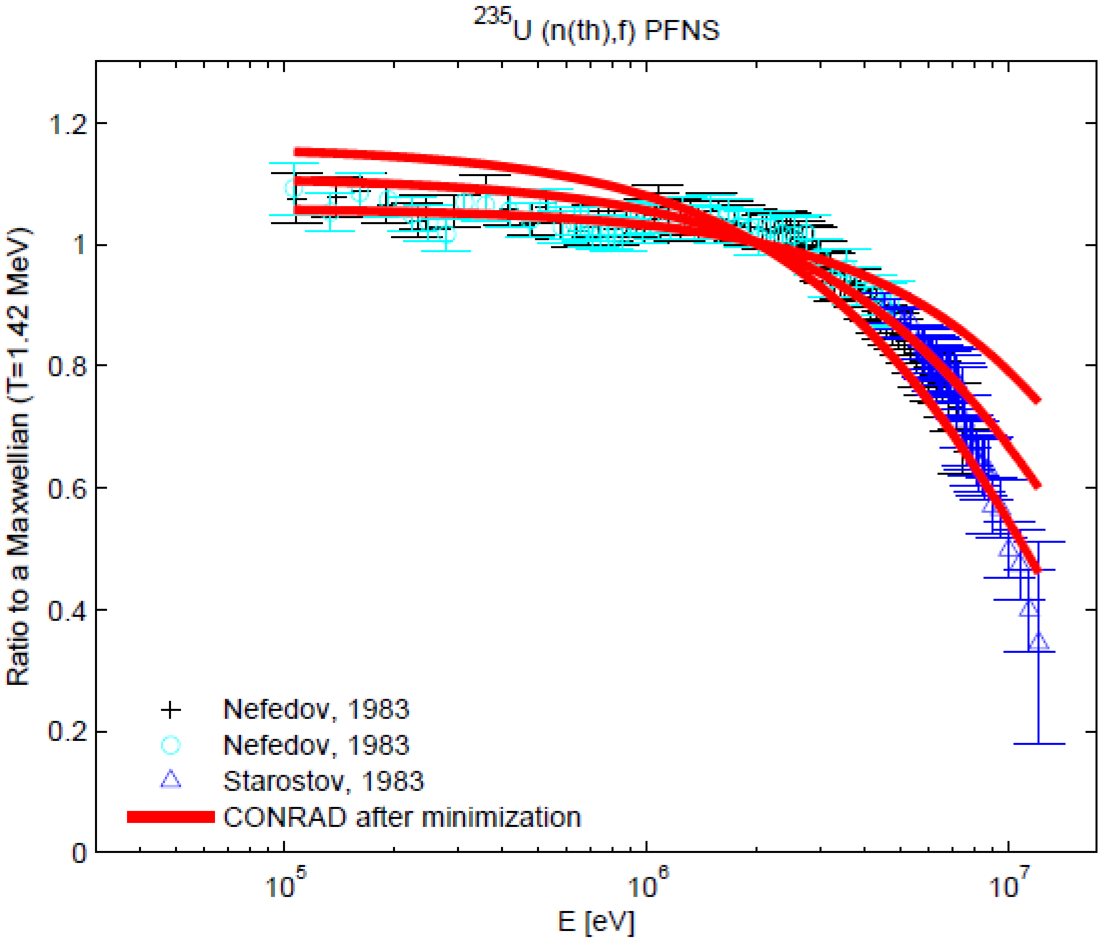

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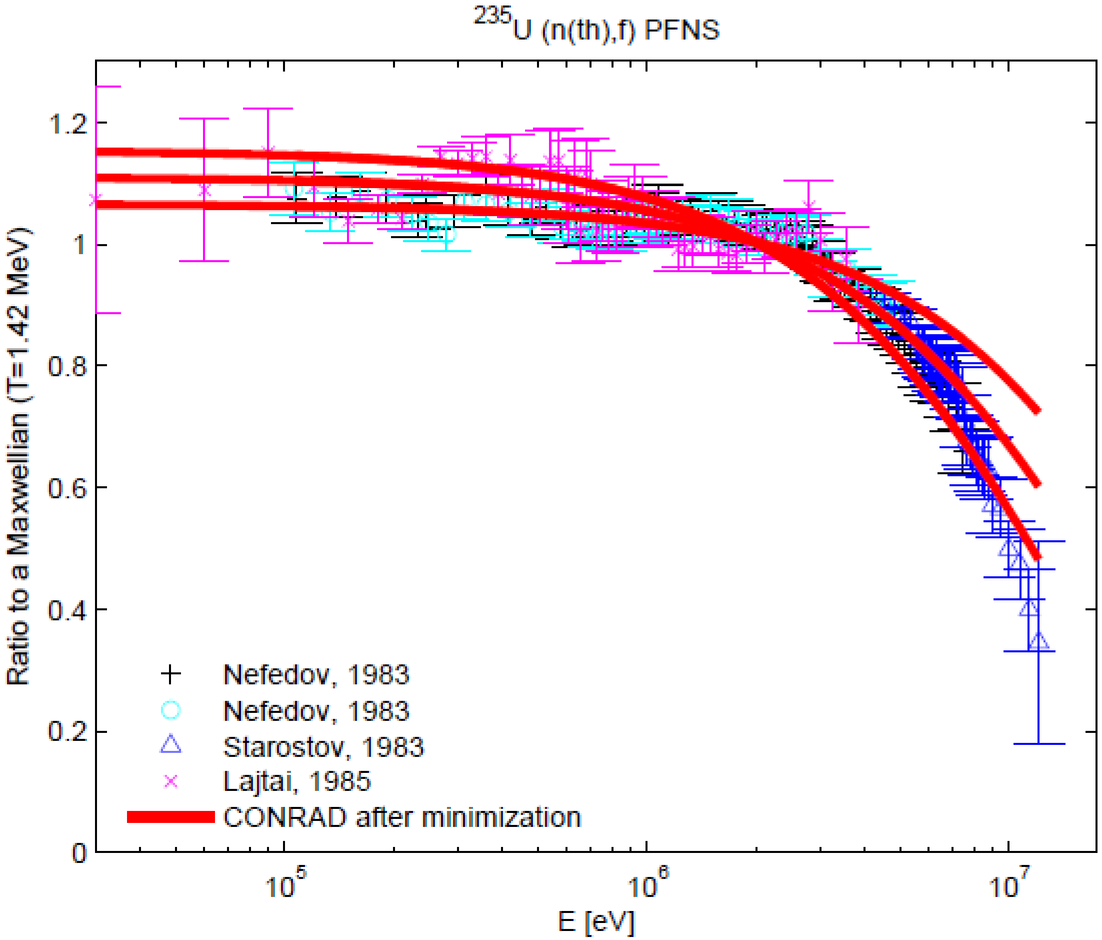

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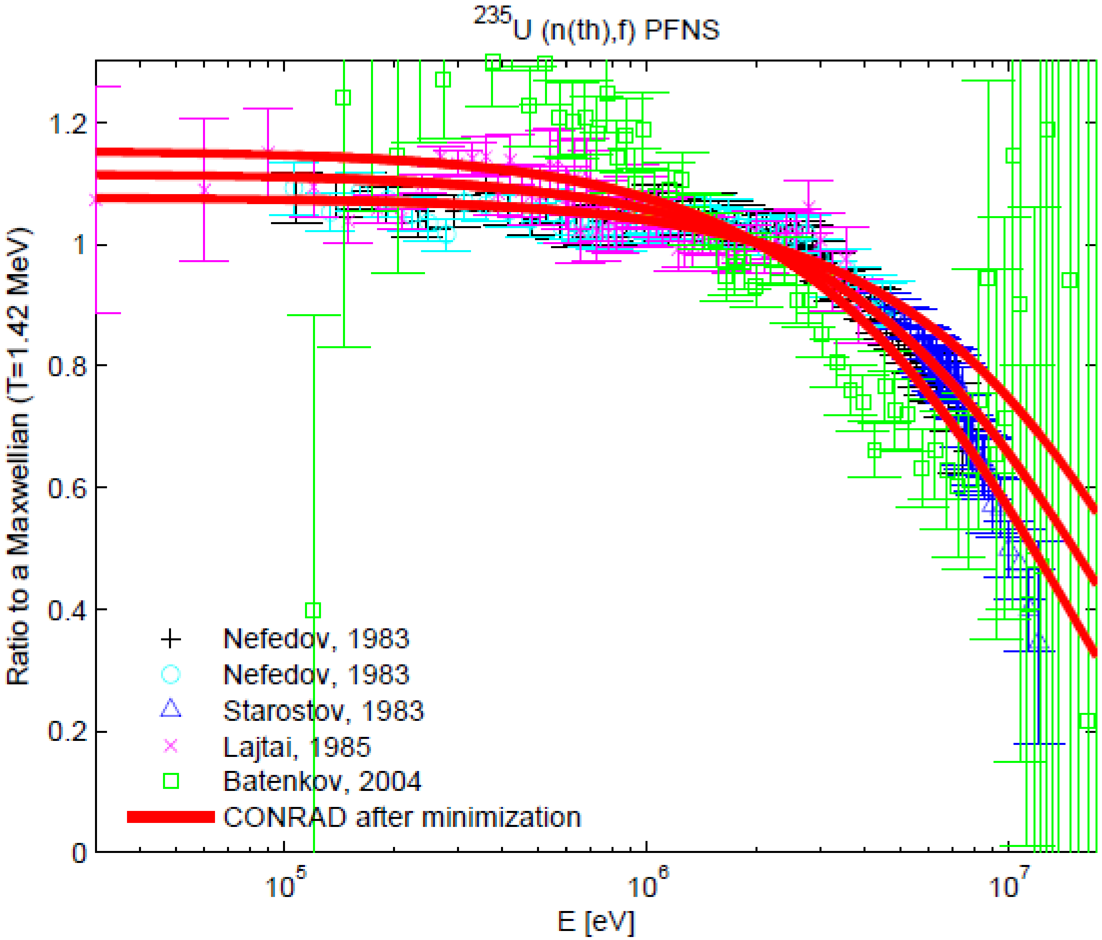

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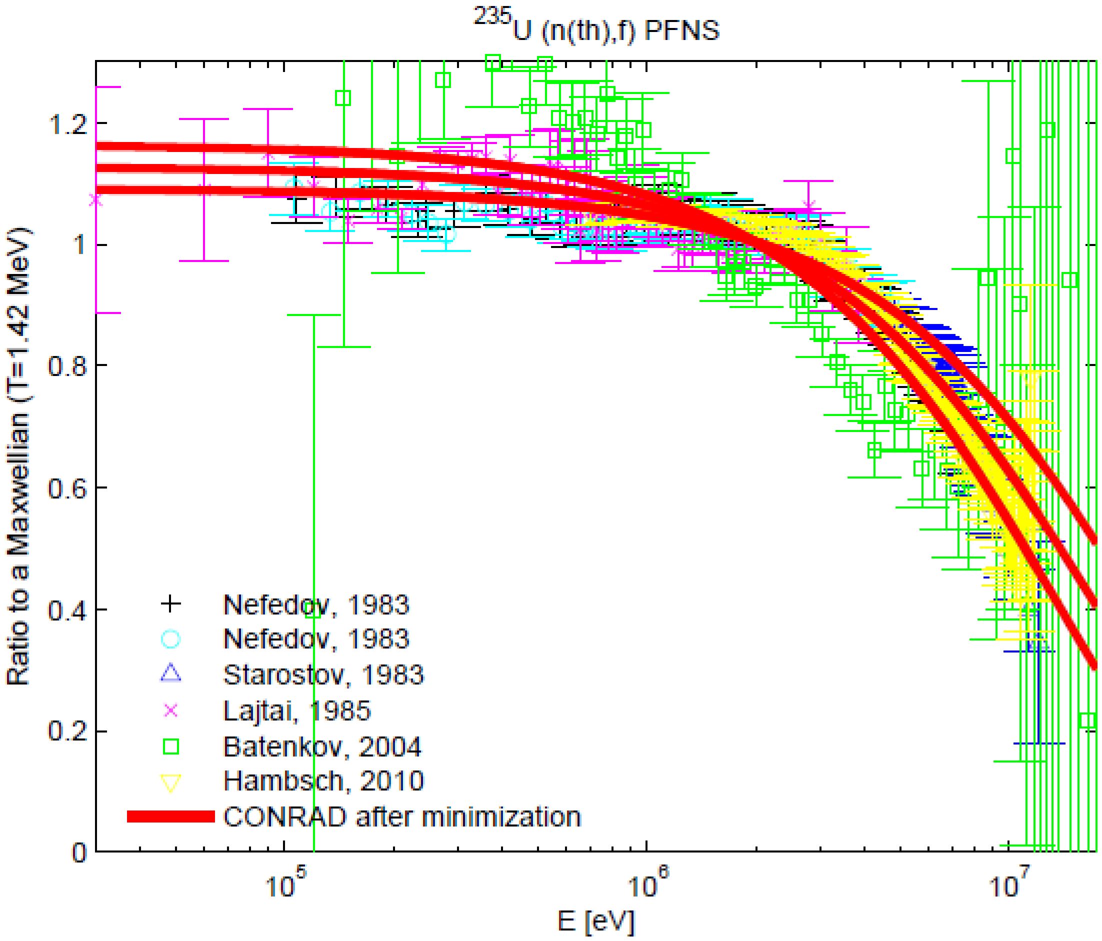

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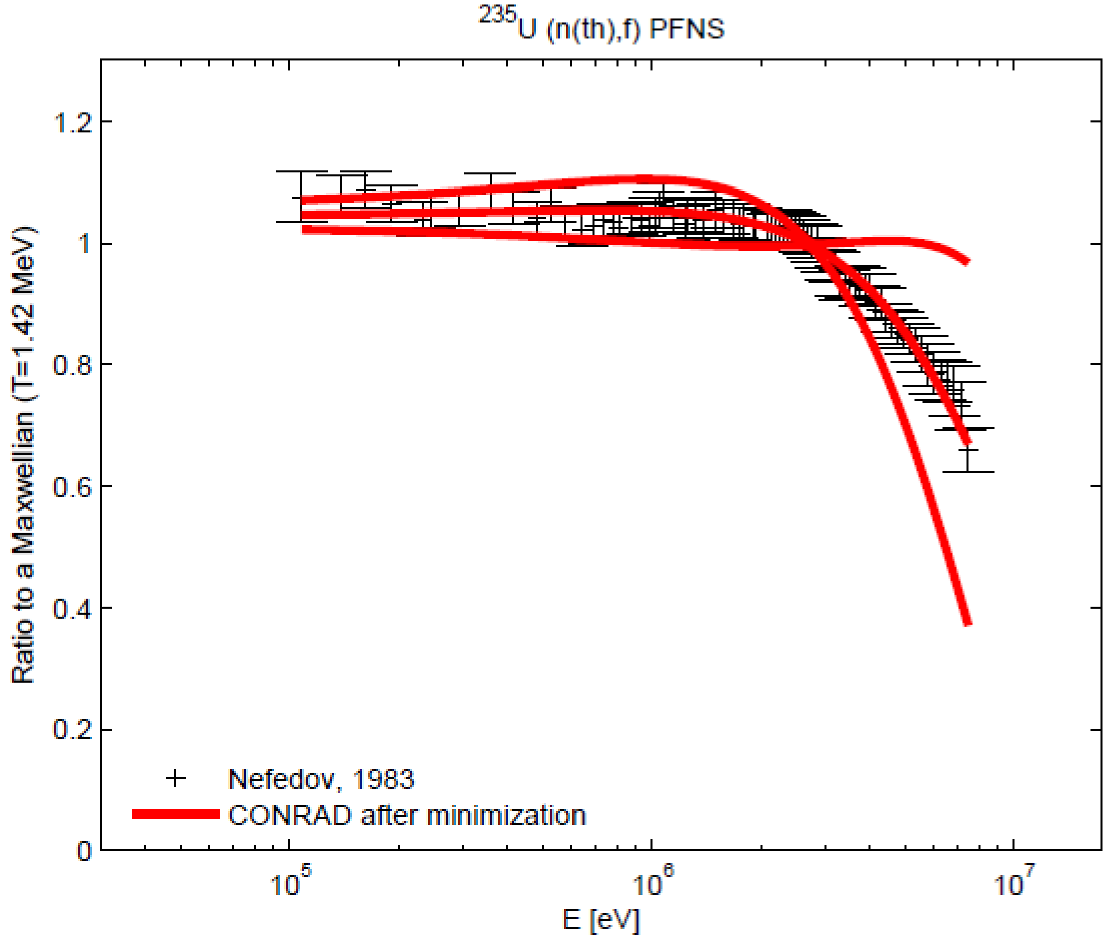
❑ **Thermal fission of U235 (Correlation matrix for Prompt Fission Neutron Spectrum)**

WATT MODEL



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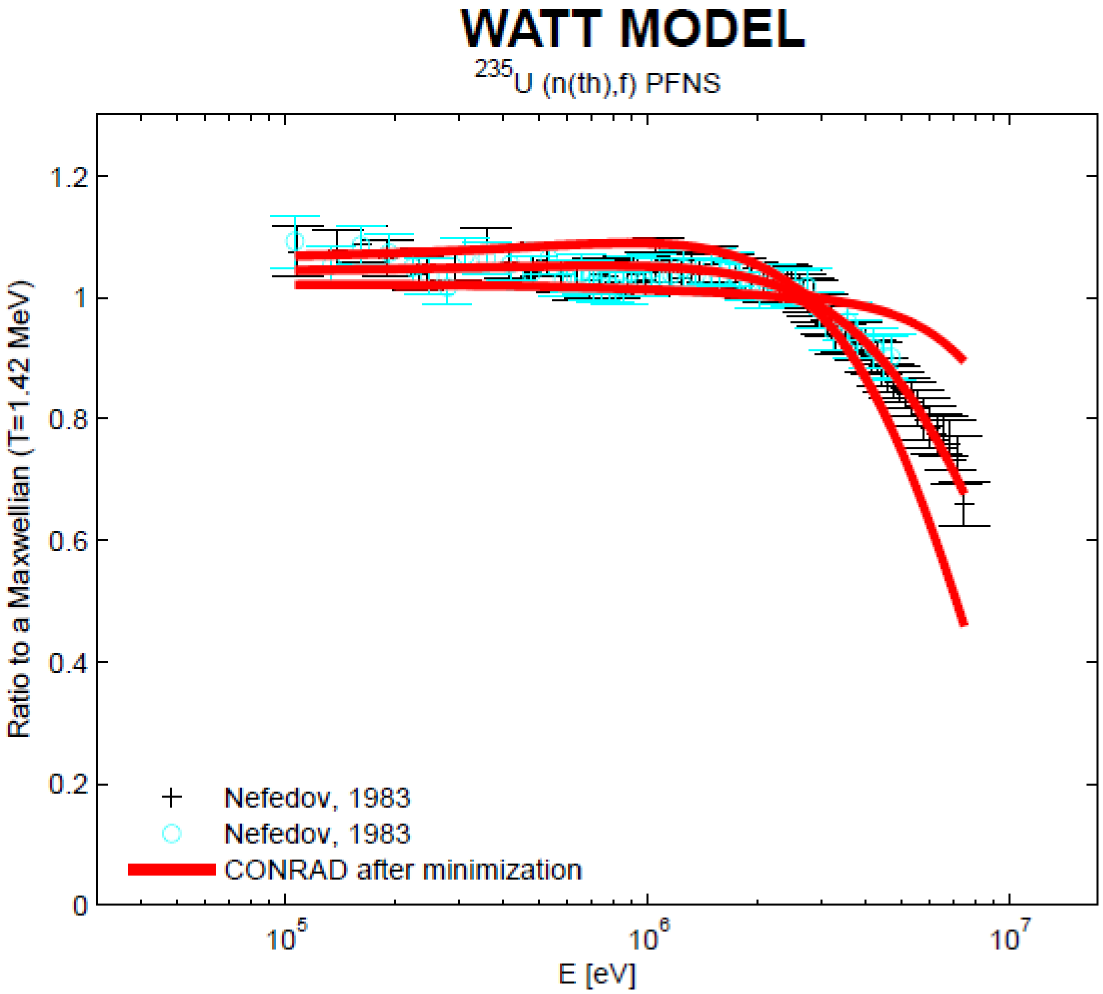
❑ Thermal fission of U235
(Correlation matrix for Prompt Fission Neutron Spectrum)



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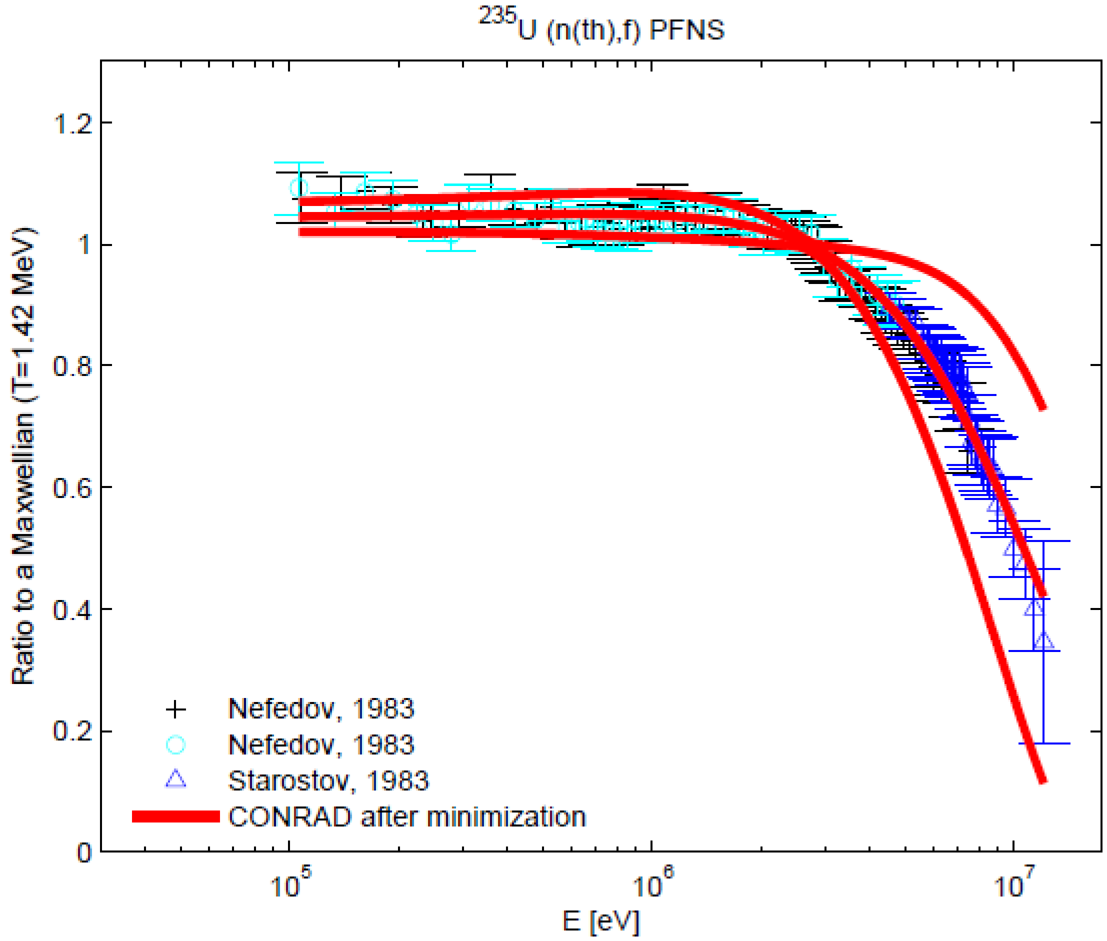

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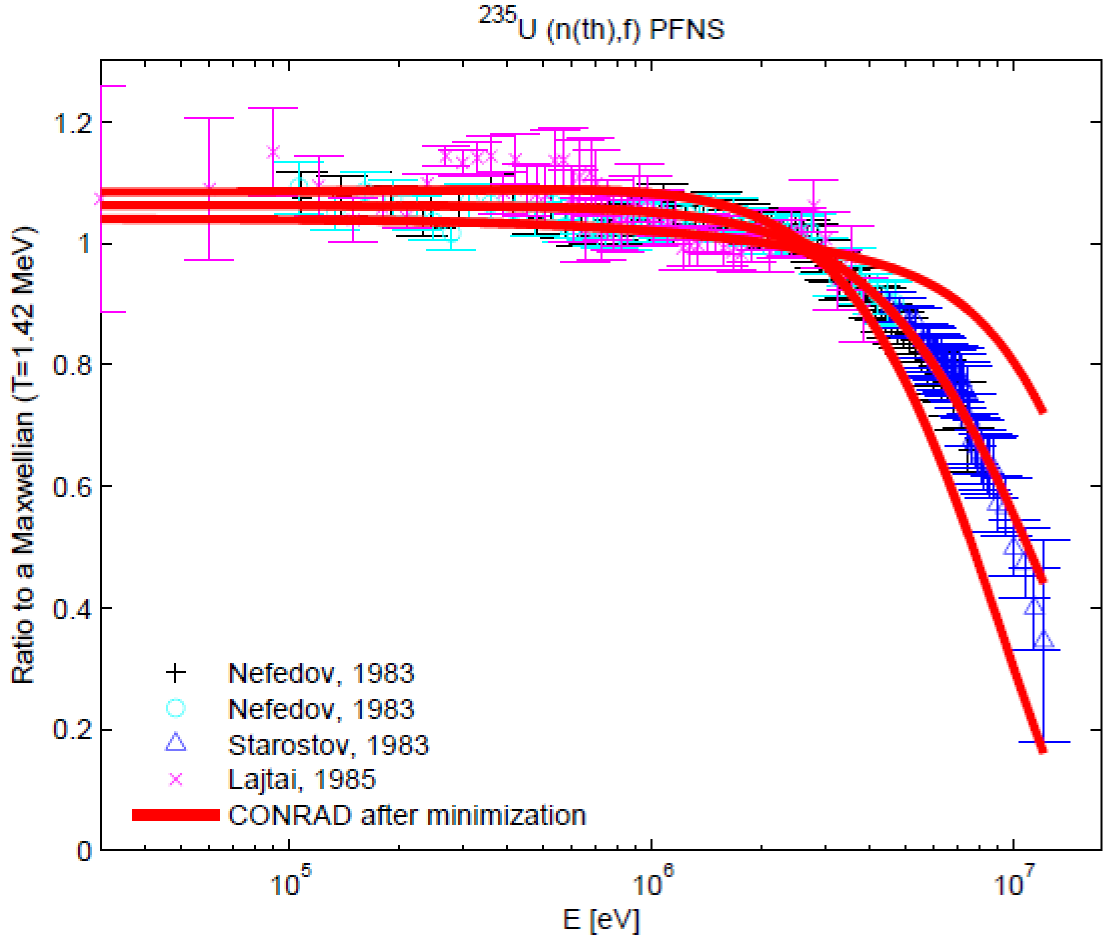
WATT MODEL



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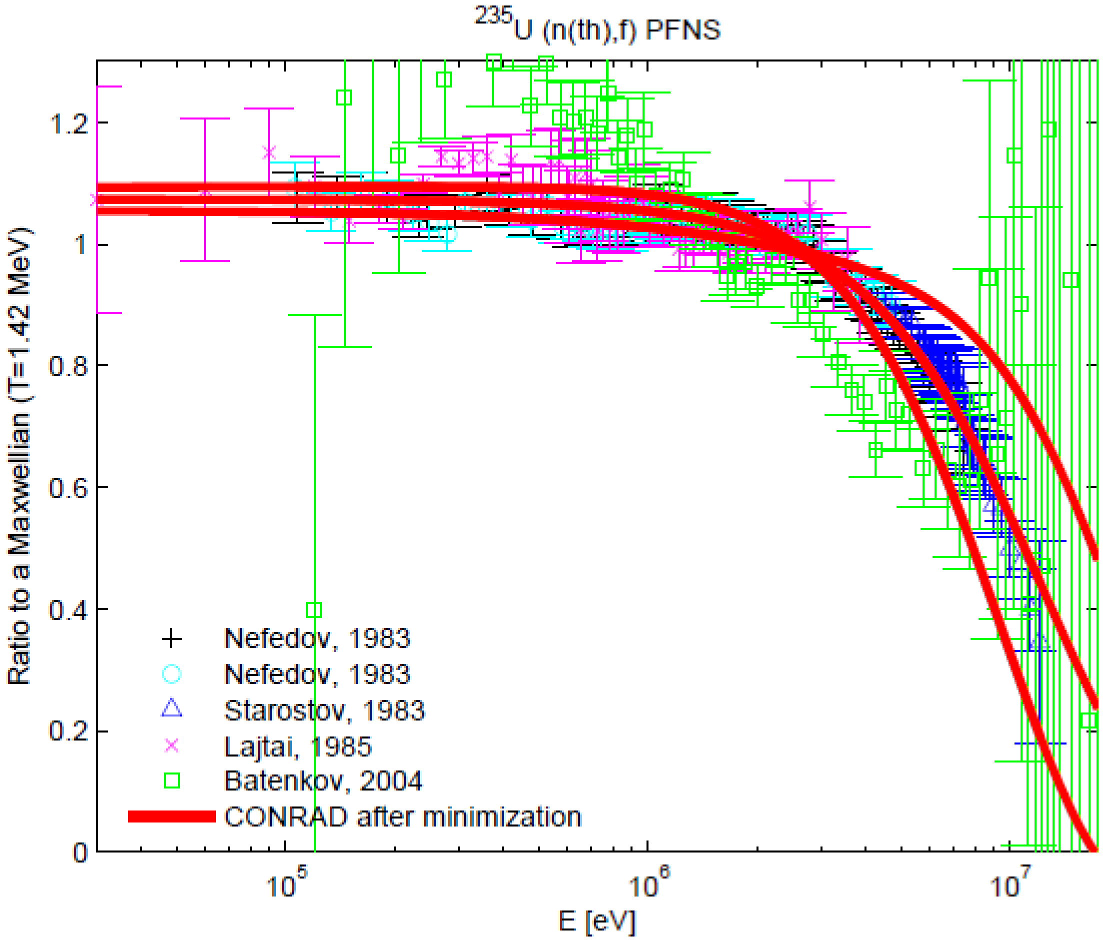
WATT MODEL



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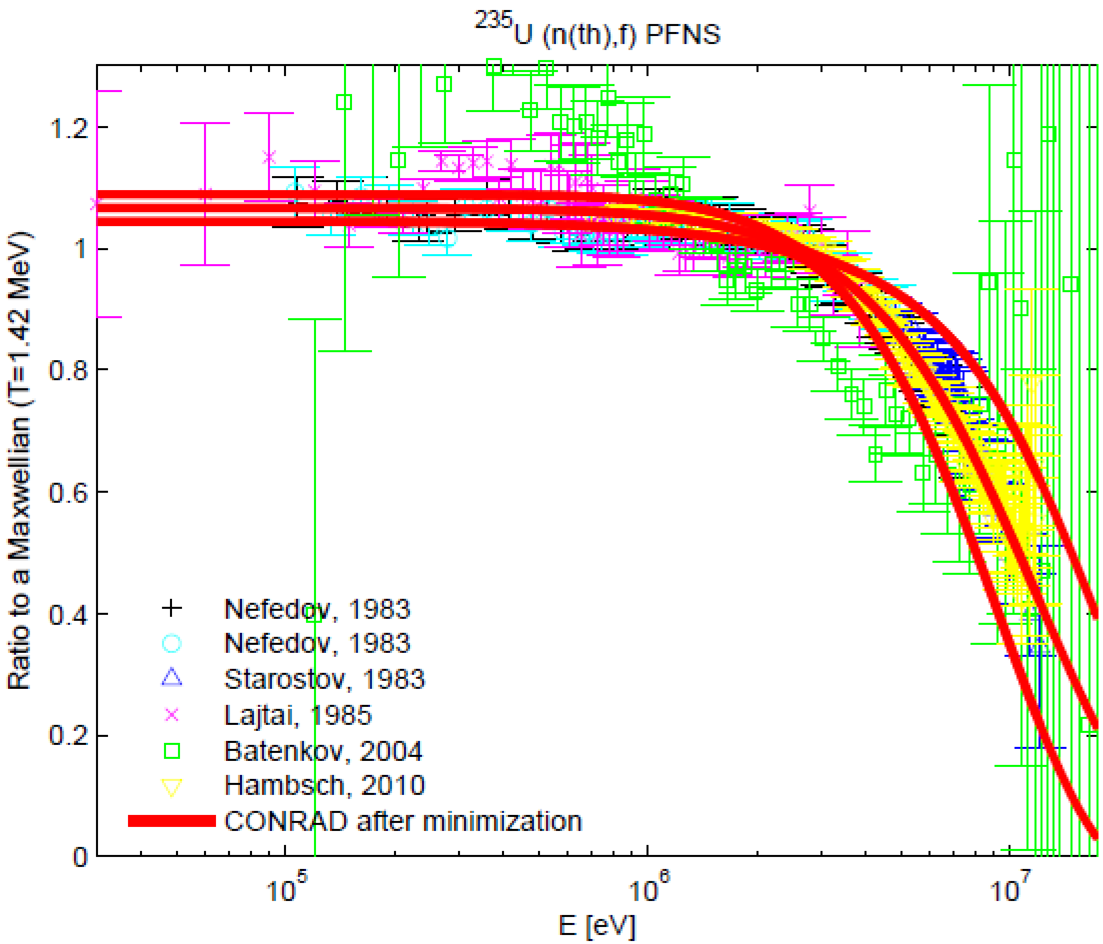

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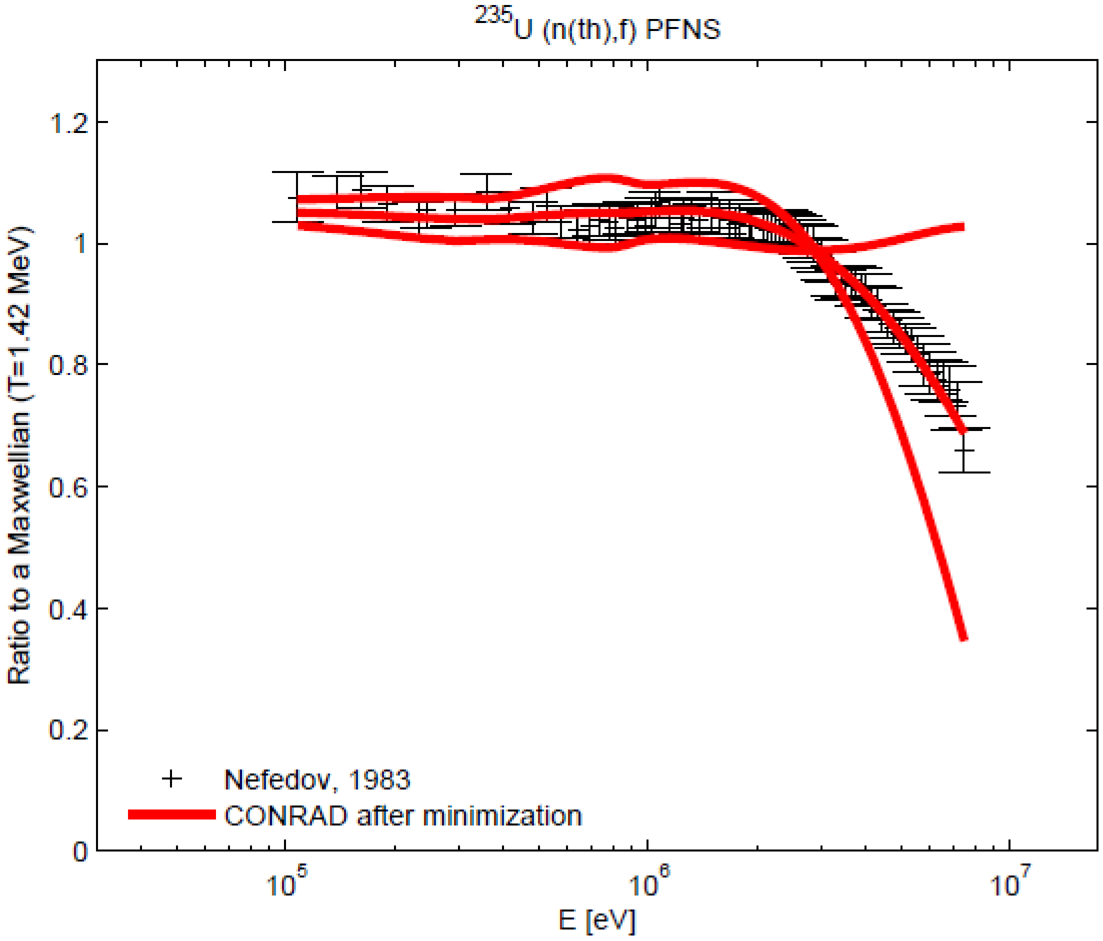
❑ **Thermal fission of U235**
(Correlation matrix for Prompt Fission Neutron Spectrum)

MADLAND-NIX MODEL



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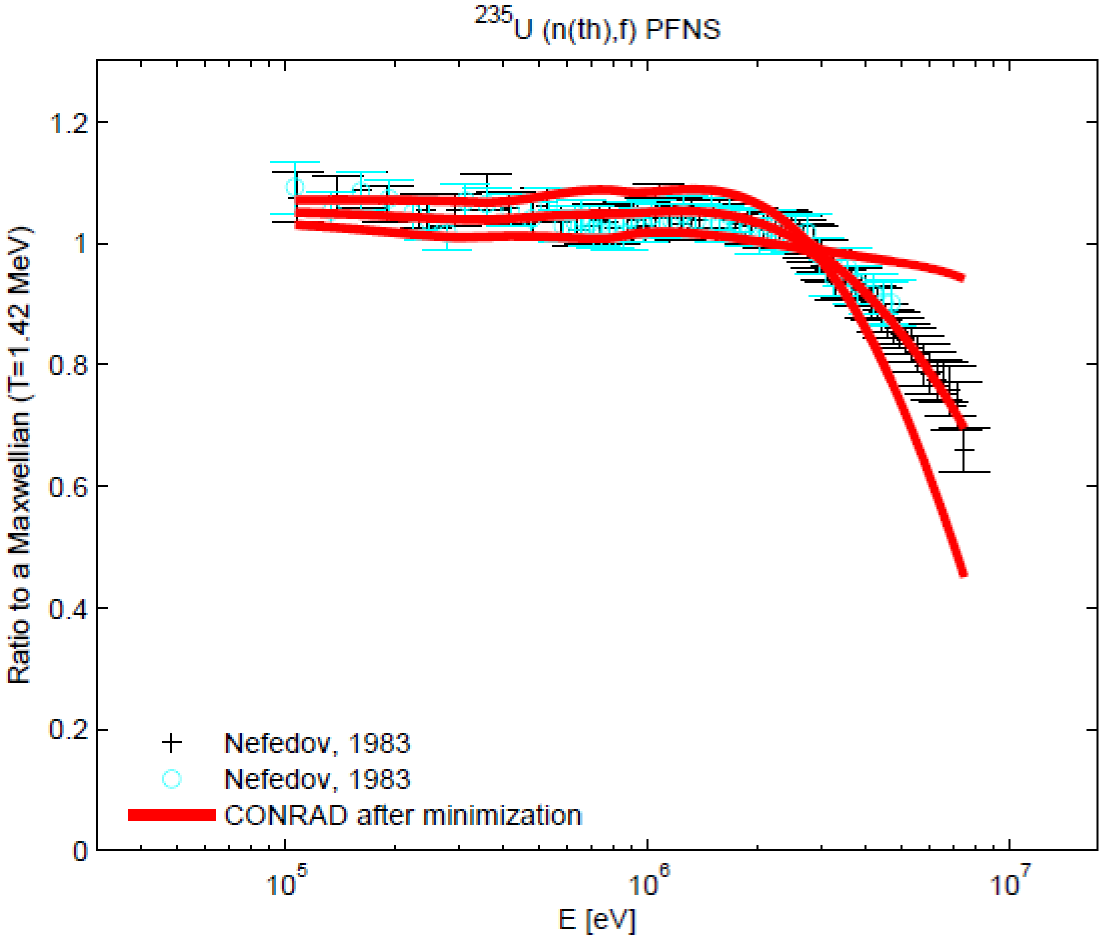
MADLAND-NIX MODEL



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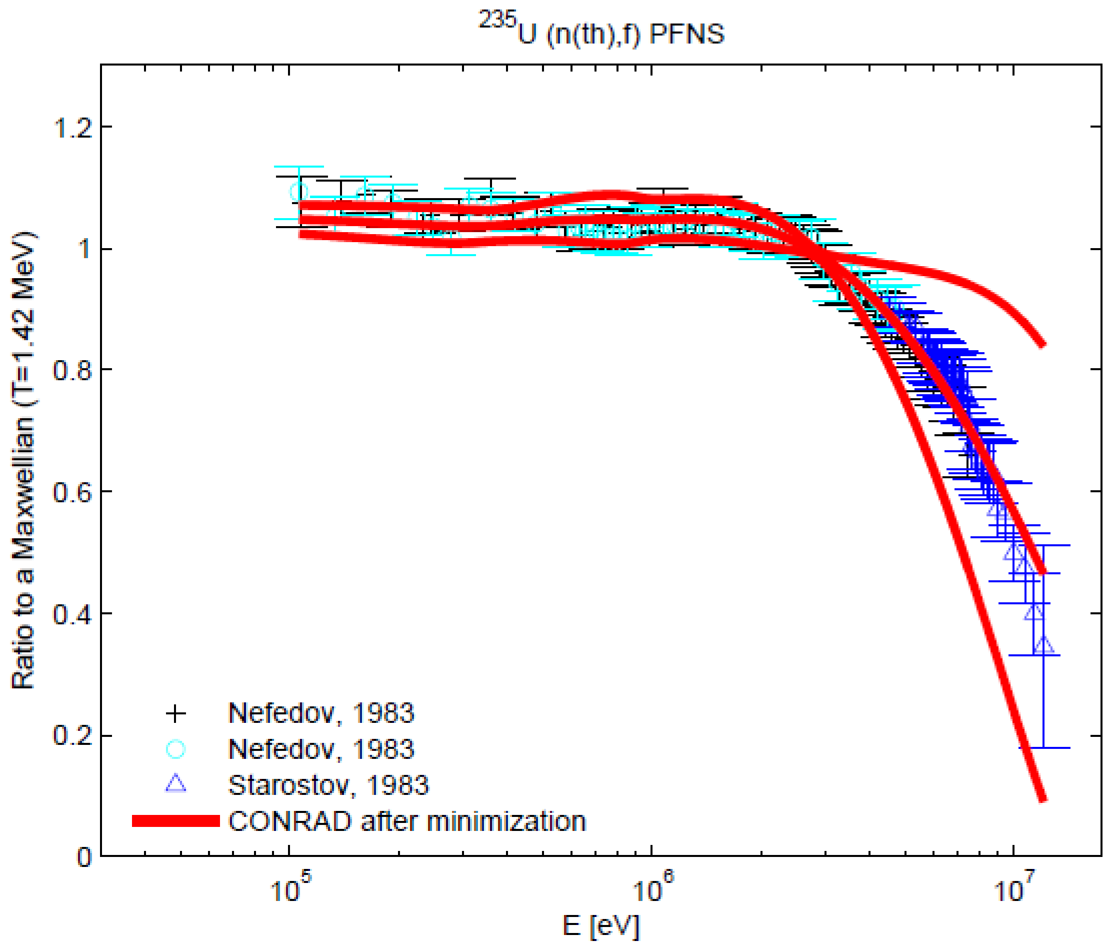

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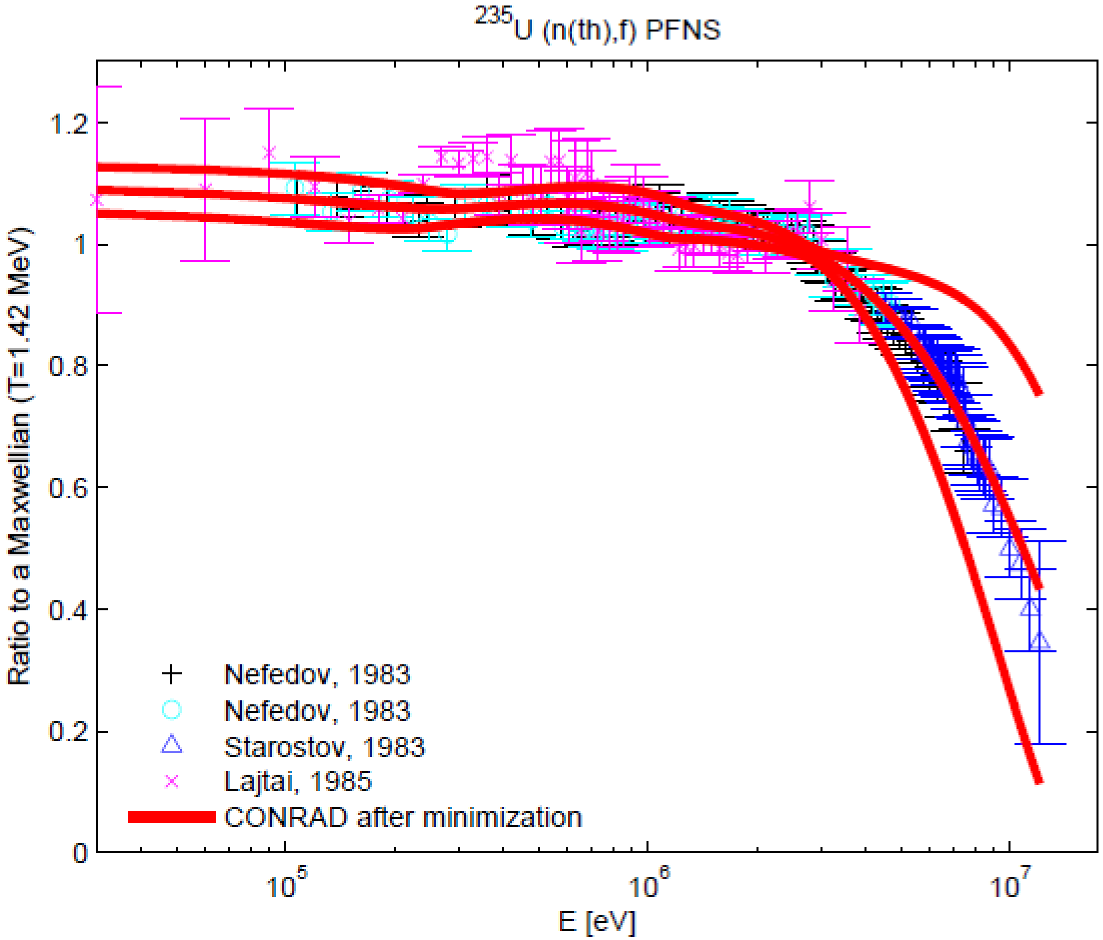

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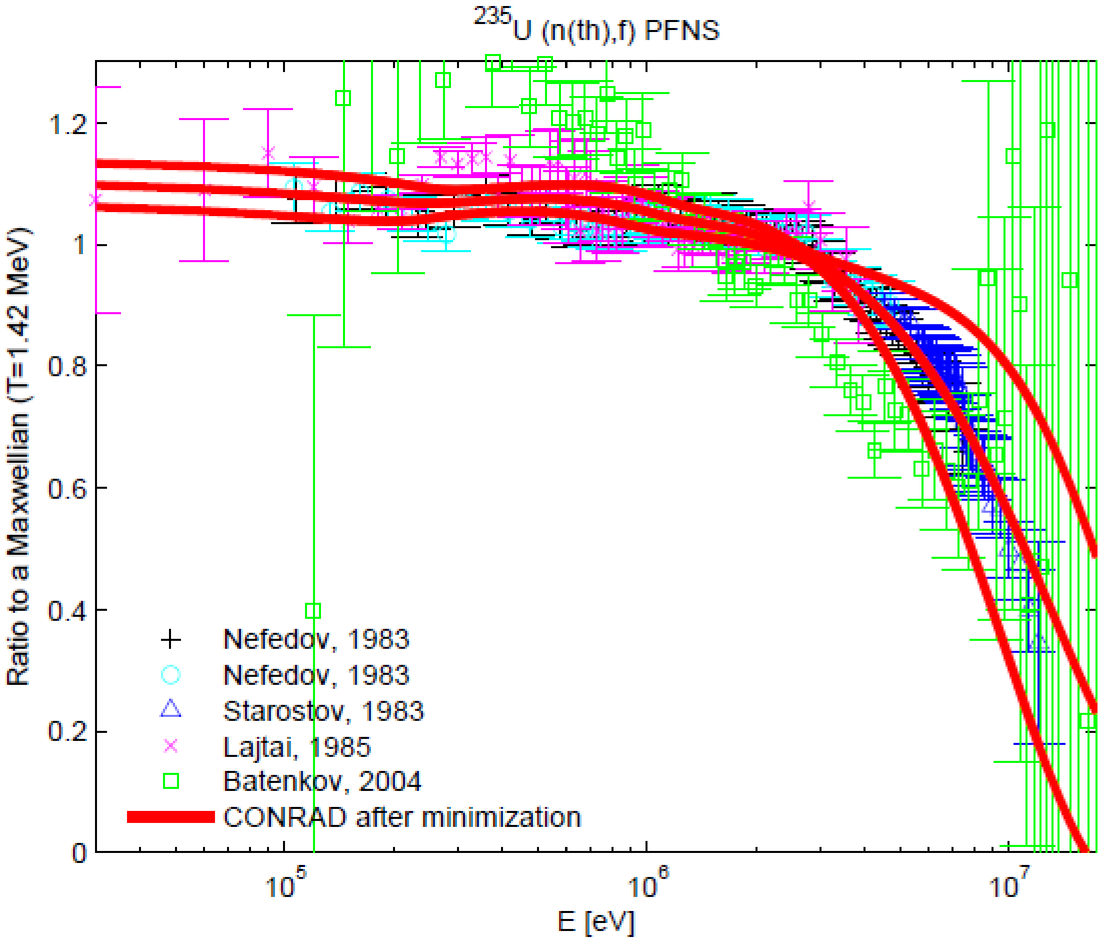

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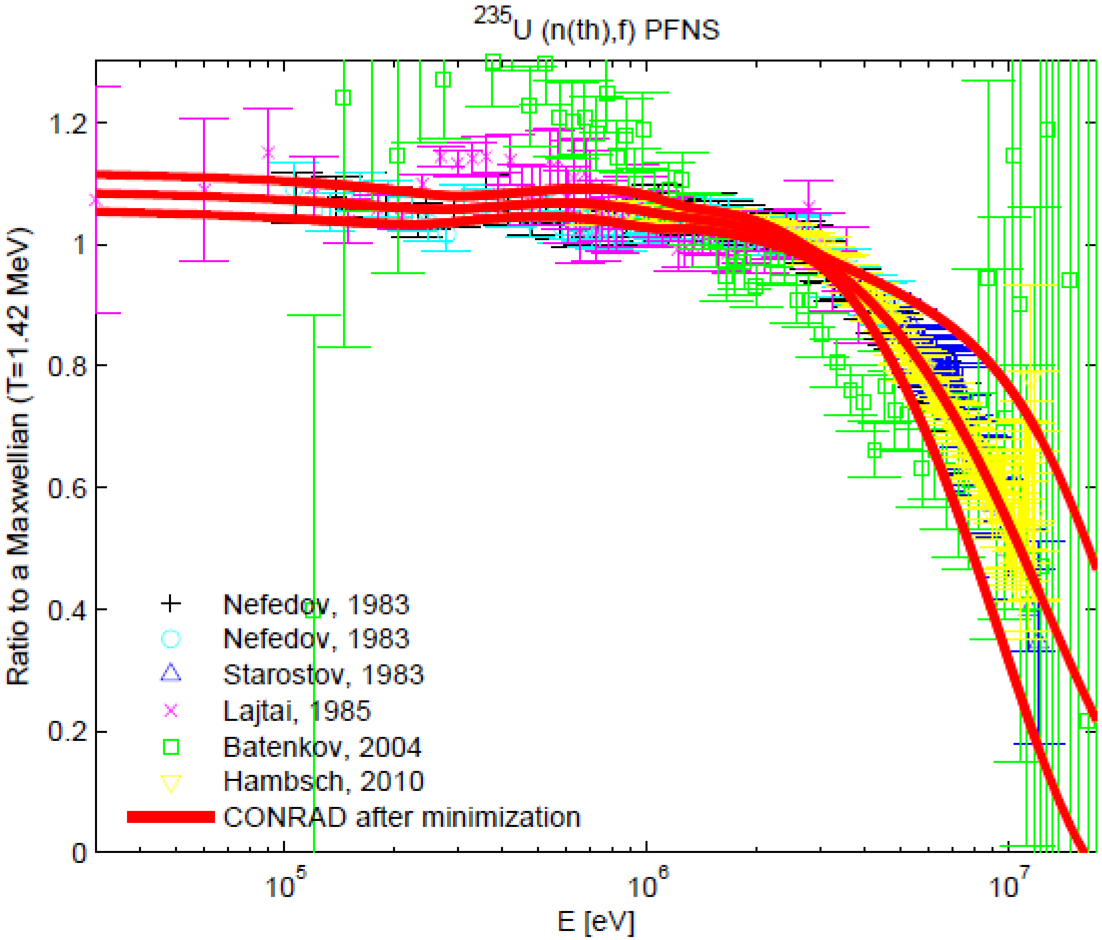
(Correlation matrix for Prompt Fission Neutron Spectrum)

MADLAND-NIX MODEL



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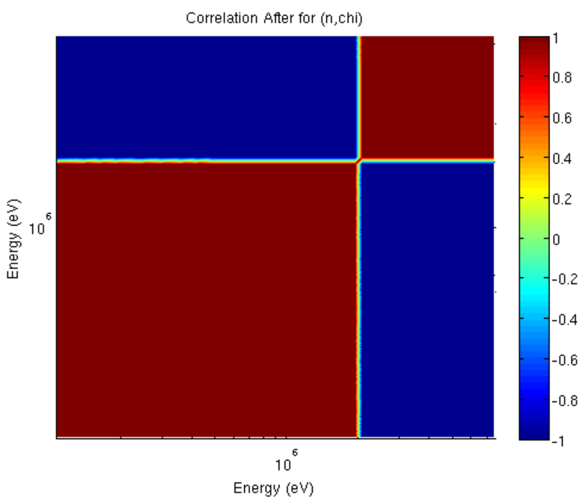
❑ Thermal fission of U235 (Correlation matrix for Prompt Fission Neutron Spectrum)

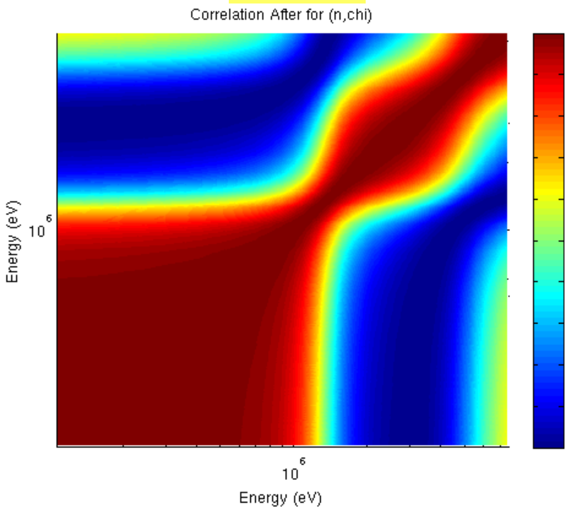
$^{235}U + n_{th}$

Without marginalization of the normalization

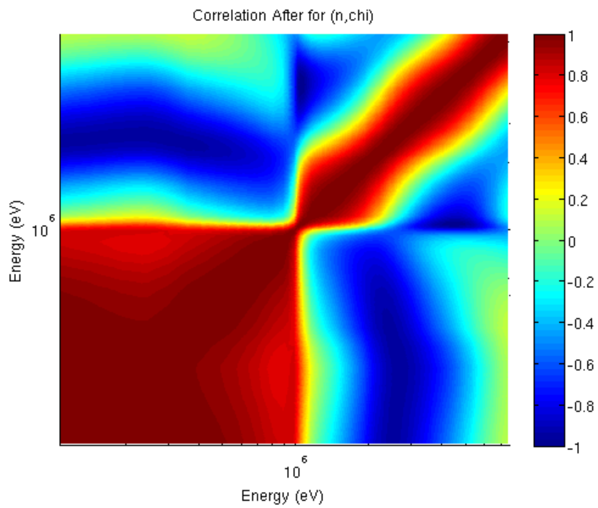
Maxwell



Watt



Madland-Nix



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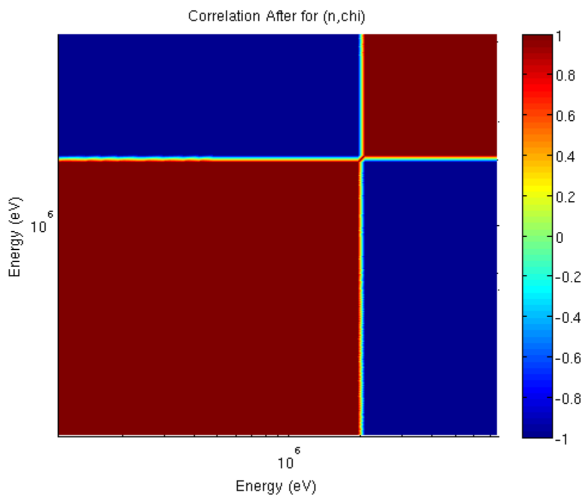
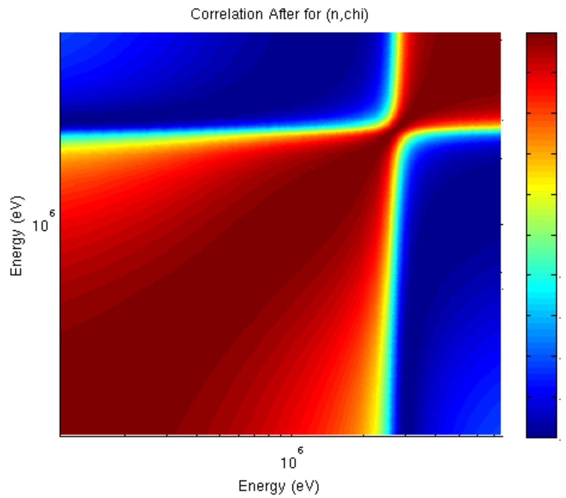
$^{235}U + n_{th}$

With marginalization of 5% normalization uncertainty

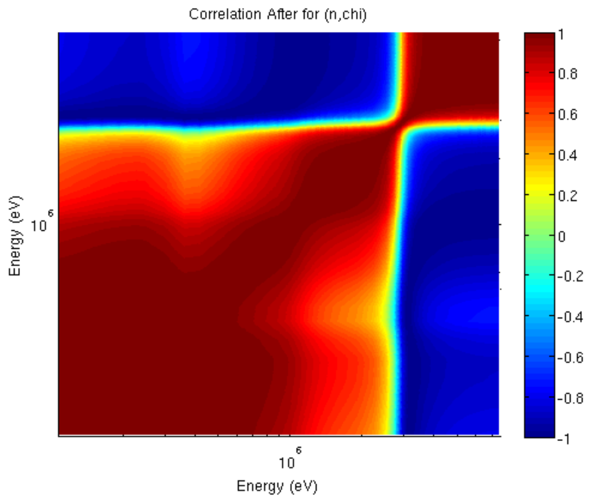
Maxwell



Watt



Madland-Nix



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❑ Thermal fission of U235
(Correlation matrix for Prompt Fission Neutron Spectrum)

5% uncertainty on **normalization parameter** is a more or less realistic value !

→ *Depends on the **data** (past and present),*

→ *Uncertainty can be higher/lower for a **given energy range** : need for another experimental parameter : **neutron detector efficiency** (work in progress).*

Fifrelin model parameter adjustement from a Conrad/Fifrelin coupled scheme

→ Fifrelin is used as a 'Nuclear Model' inside Conrad to adjust some of the 5 free parameters of the code and generate correlation matrices…(from D. Regnier Phd work , in progress …)

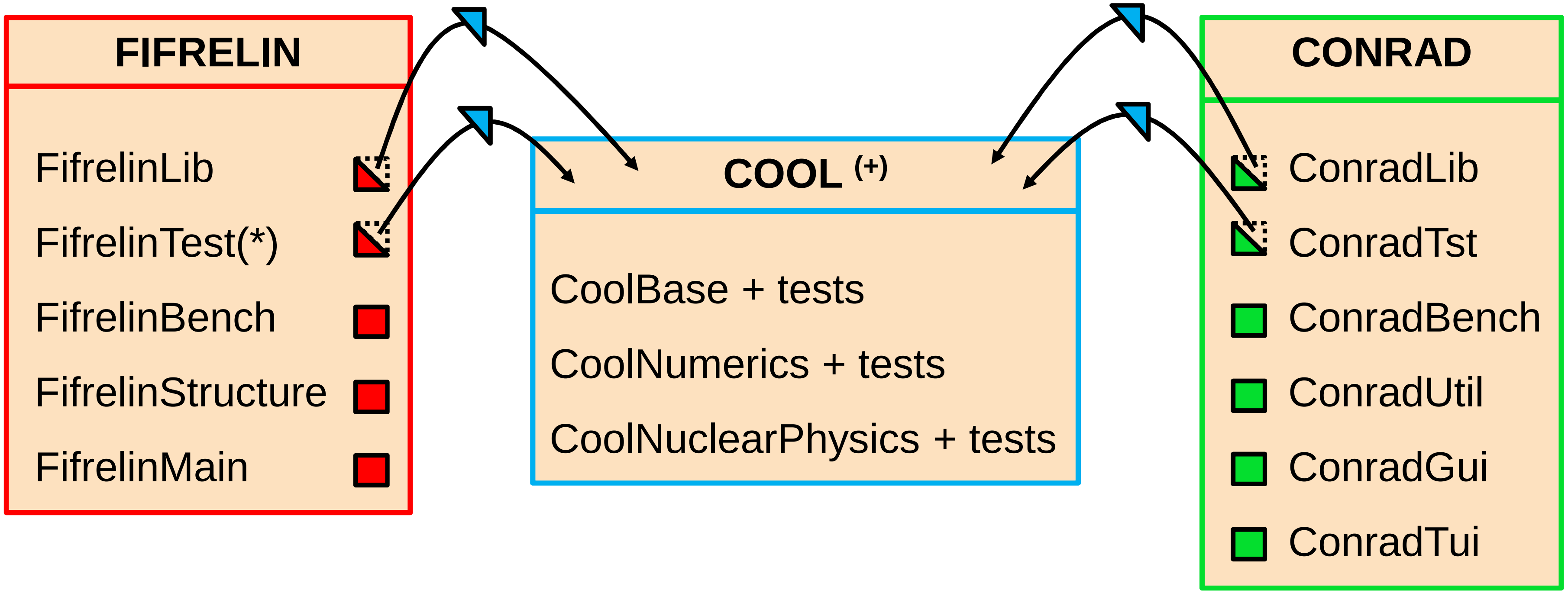
- Covariance matrices related to prompt fission neutron spectra can be calculated using so-called Maxwell, Watt or Madland-Nix spectra within the CONRAD code et COOL libraries.

- Fission observables such as neutron *and* gamma spectra, multiplicities, fission yields can be calculated through a Hauser-Feshbach model within the FIFRELIN Monte Carlo code and COOL libraries.

- Improvement of the fission fragment deexcitation model still in progress within FIFRELIN.

- CONRAD / FIFRELIN coupling under investigation for covariance matrix generation

Annexe



(*)
- *Unitary tests*
- *Physics tests for a given 'parameter' related to a given nucleus (average radiation width, branghing ratio, …)*

(+) ***Cadarache Object Oriented Libraries***

Thank you for your attention

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