

SA/UQ of Critical VENUS-F Cores with Serpent

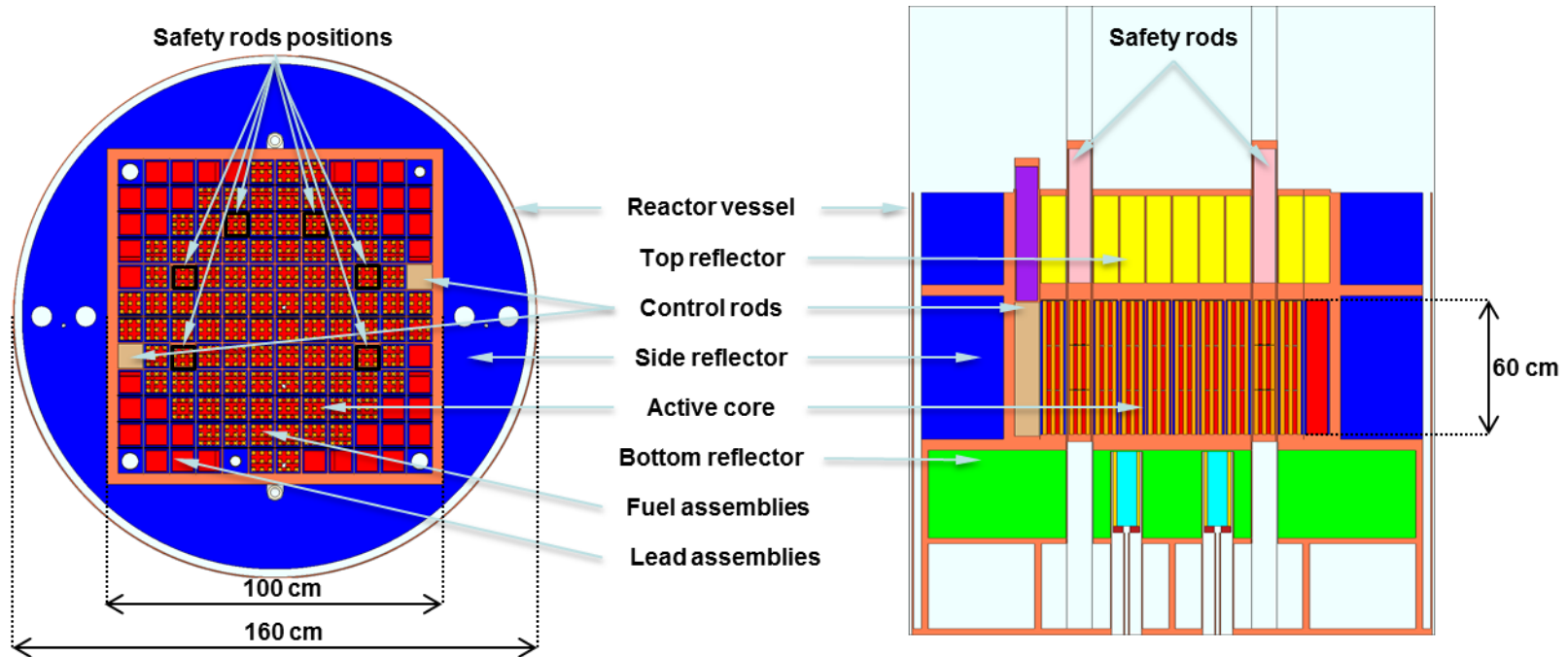
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Serpent User Group Meeting
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HZDR

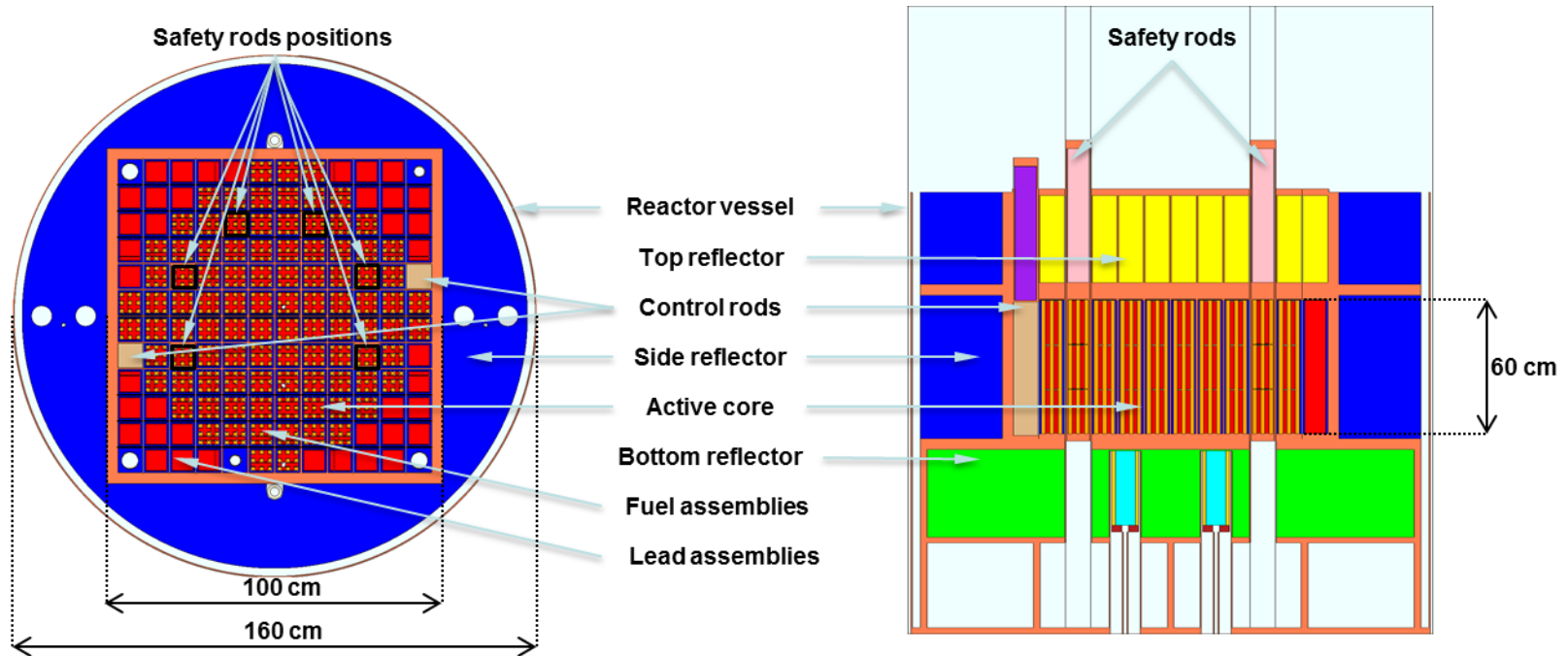
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VENUS-F reactor



- VENUS - Water-moderated zero power reactor
 - Located at SCK•CEN, Mol, Belgium
 - Dedicated to LWR-related experiments
- In 2011 VENUS converted in VENUS-F fast lead reactor
 - Increasing interest in lead fast reactor systems in Europe
 - Demand for integral experiments

VENUS-F reactor



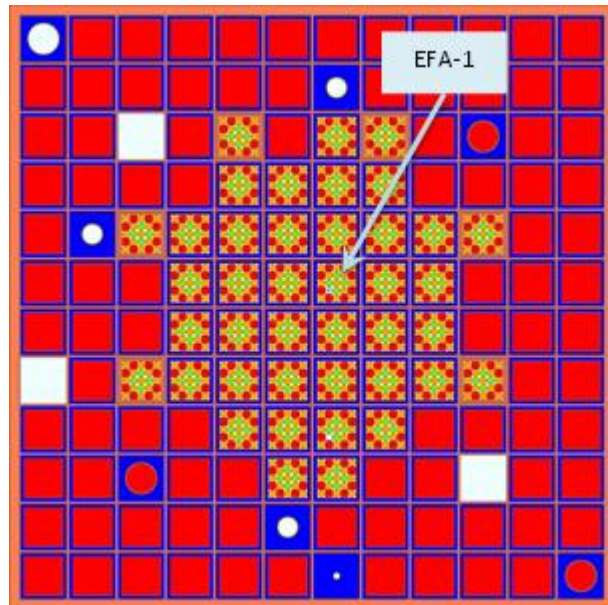
- Some reactor features
 - 30 wt% enriched uranium fuel
 - 12×12 square lattice (pitch = 8 cm)
 - Stainless steel casing
 - Lead reflector (radial and axial)
 - 6 safety + 2 control rods

FREYA project

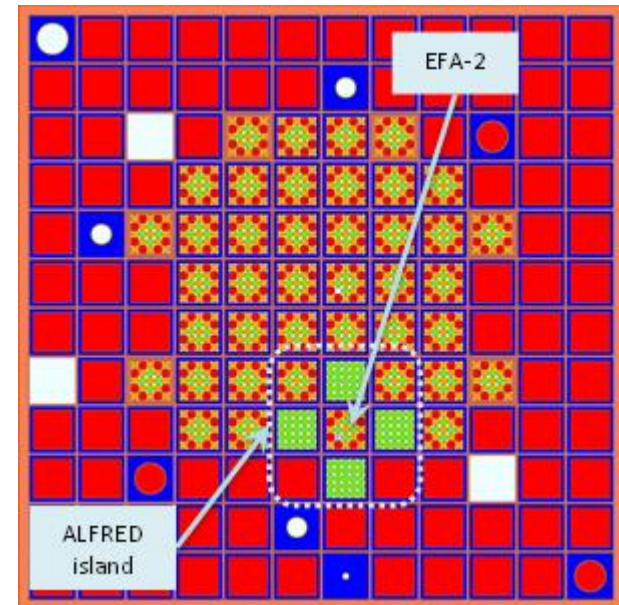
- FREYA - Fast Reactor Experiments for hYbrid Applications
 - FP7 EU project executed between 2011 – 2016
 - Experiments to support design & licensing of ADS and Lead-cooled Fast Reactors
- 4 critical VENUS-F cores were characterized with Serpent
 - k-eff, β -eff, control rod worth
 - Axial and radial distributions of reaction rates
 - Lead void effect
 - Spectral indices (SI)
- Typically good C/E ...but systematic biases in k-eff and F28/F25 SI
- Incentive for the SA/UQ study!!!

VENUS-F cores considered for SA/UQ

CC5 - “clean” MYRRHA core mockup



CC6 = CC5 + ALFRED “Island”



Parameters considered for SA/UQ

- Reactivity (ρ)
- Spectral indices (SI) - fission rate ratios of actinides to that of U235

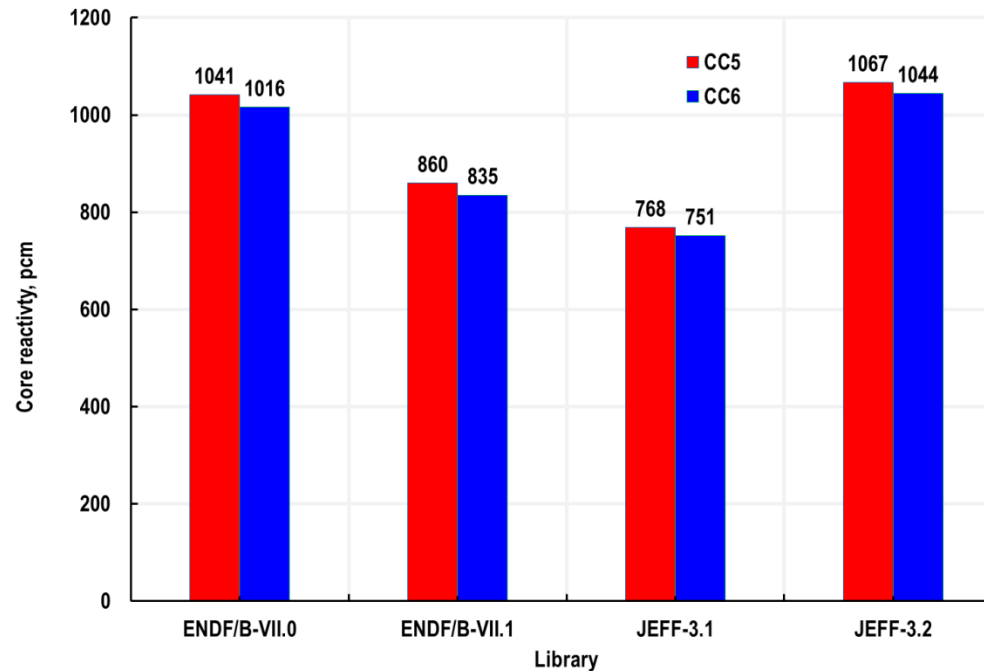
$$F_{28}/F_{25} = \frac{\int \sigma_{\text{fiss}}^{\text{U}238}(E) \phi(E) dE}{\int \sigma_{\text{fiss}}^{\text{U}235}(E) \phi(E) dE}$$

$$F_{49}/F_{25} = \frac{\int \sigma_{\text{fiss}}^{\text{Pu}239}(E) \phi(E) dE}{\int \sigma_{\text{fiss}}^{\text{U}235}(E) \phi(E) dE}$$

$$F_{37}/F_{25} = \frac{\int \sigma_{\text{fiss}}^{\text{Np}237}(E) \phi(E) dE}{\int \sigma_{\text{fiss}}^{\text{U}235}(E) \phi(E) dE}$$

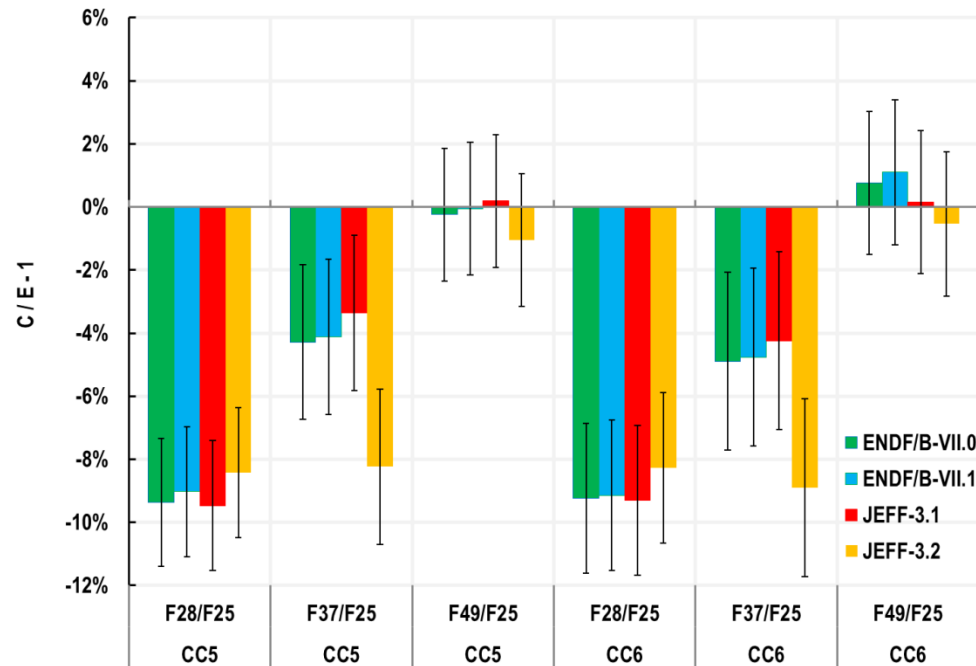
Observed biases

Observed biases: reactivity



- Systematic bias of 750-1060 pcm

Observed biases: spectral indices



- F28/F25 is underestimated by about 9% ($>3\sigma$ exp.+ MC uncertainty)
- F37/F25 is within 1σ
- F49/F25 is within 2σ
 - exception: JEFF-3.2 library.

Approach to SA/UQ

Sensitivity analysis (SA) with Serpent

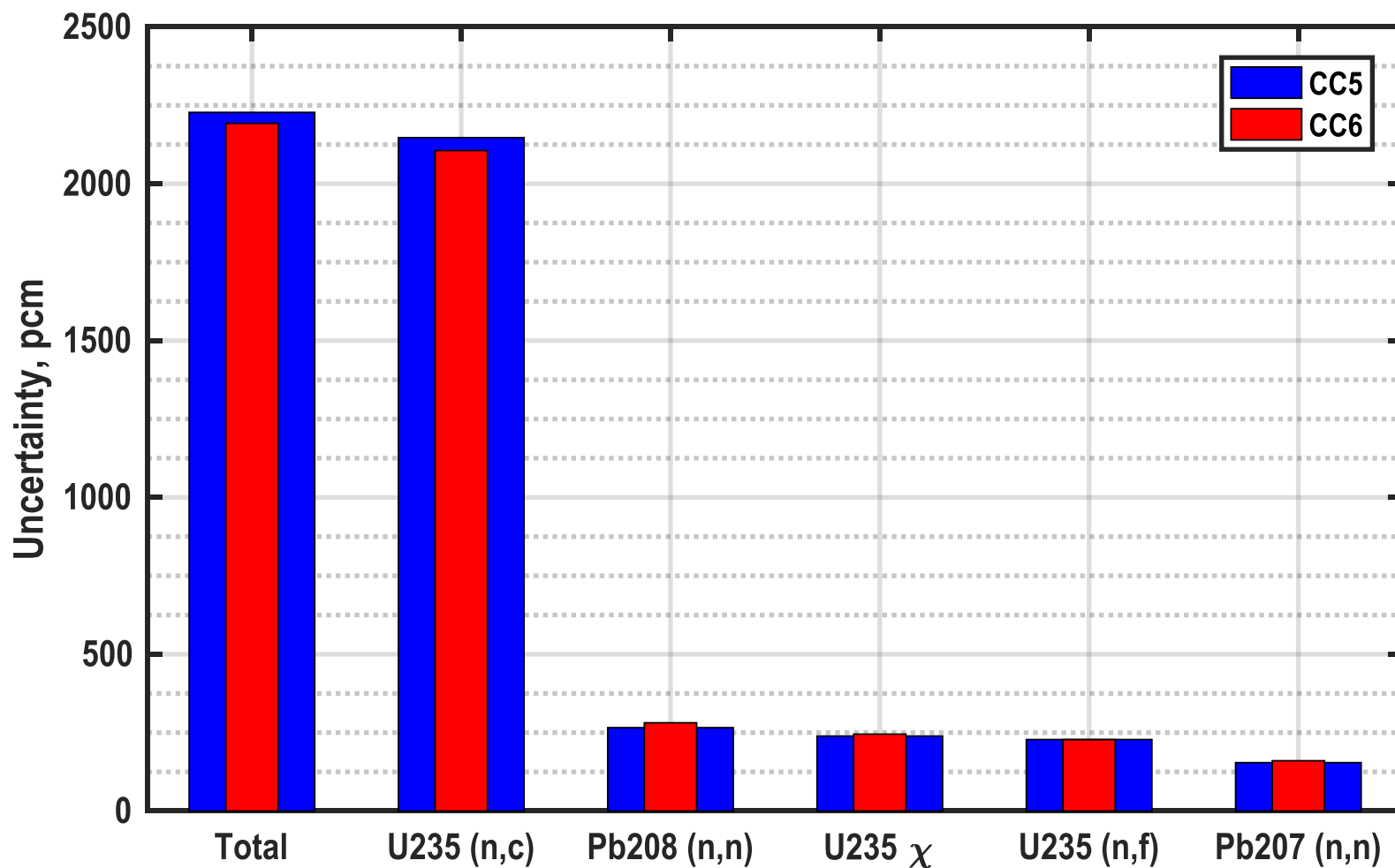
- Sensitivity calculations capabilities are available in Serpent from 2015
 - Initially, as various custom versions
 - Included in the official distribution (from v2.1.30)
- Based on a collision history approach (equivalent to first order GPT)
- Sensitivities of various responses to various perturbations
 - $K_{\text{inf/eff}}$, reaction rate ratios, adjoint-weighted quantities
- A detailed description can be found in Serpent WIKI:
http://serpent.vtt.fi/mediawiki/index.php/Sensitivity_calculations

Uncertainty quantification (UQ) with Serpent

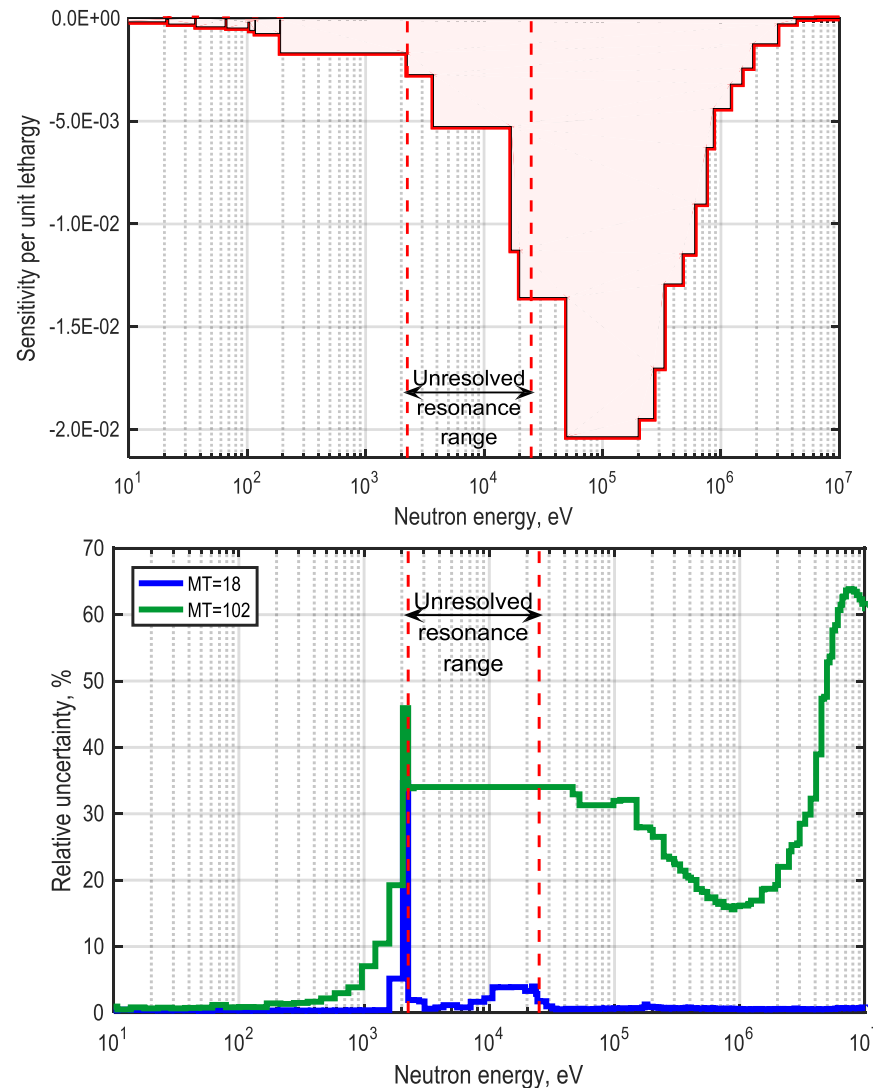
- Currently, automated UQ capabilities are being implemented in Serpent
 - Reading, processing and utilizing multi-group nuclear covariance data
 - Support for ASCII COVERX format of SCALE-6.0 (44 groups)
 - Support for binary COVERX format of SCALE-6.2 (56 and 252 groups)
 - Evaluating both direct and indirect sensitivity terms
 - Combining sensitivities and the covariance data for UQ
 - Special emphasis on few-group constants
- New capabilities are applied to the VENUS-F cores:
 - Geometry: exact
 - Library: ENDF/B-VII.1
 - Covariance data: SCALE6.2 56g

Results of SA/UQ

K-eff uncertainty, total and major contributors

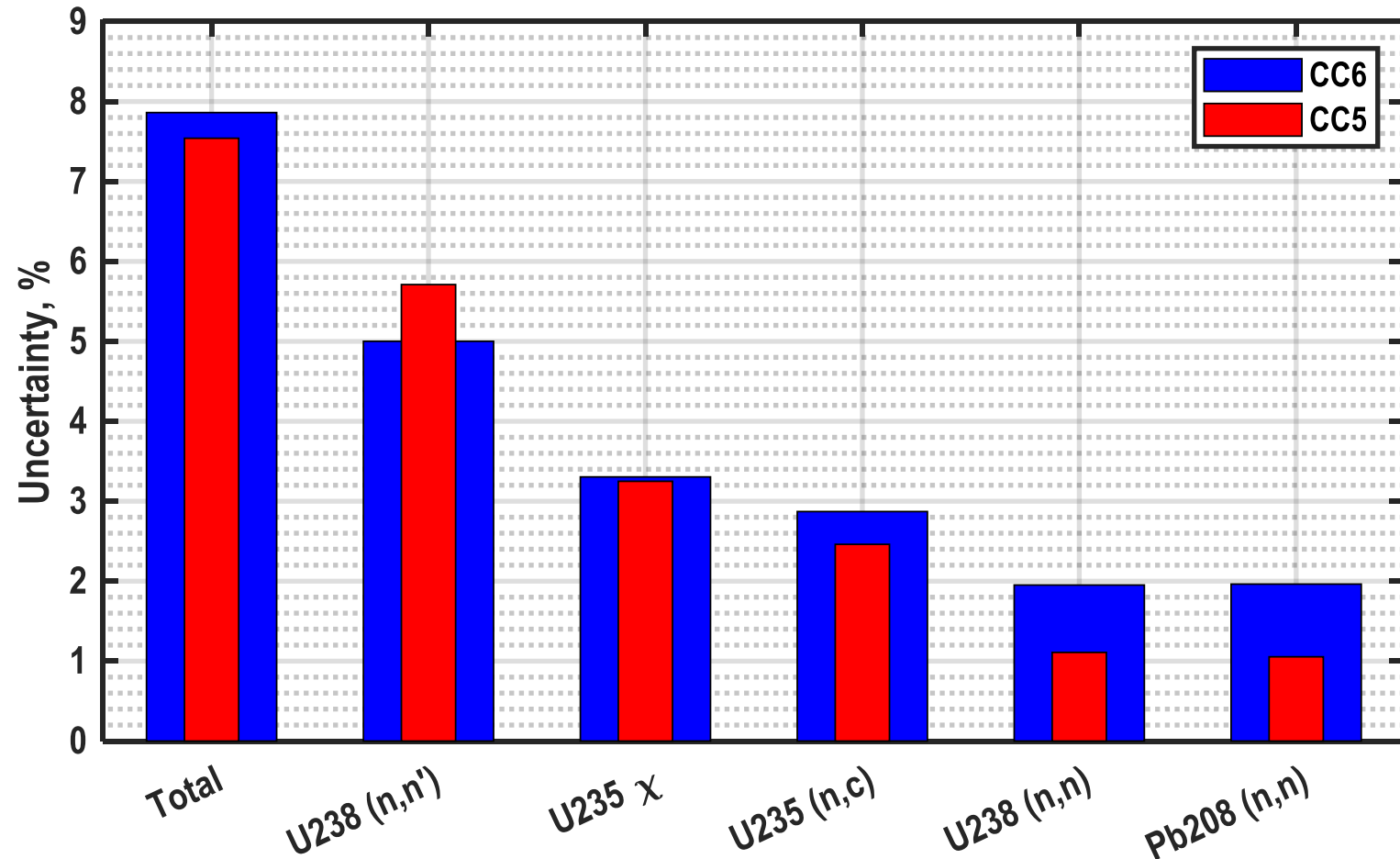


K-eff sensitivity to U235 σ_c + uncertainty of U235 σ_f and σ_c

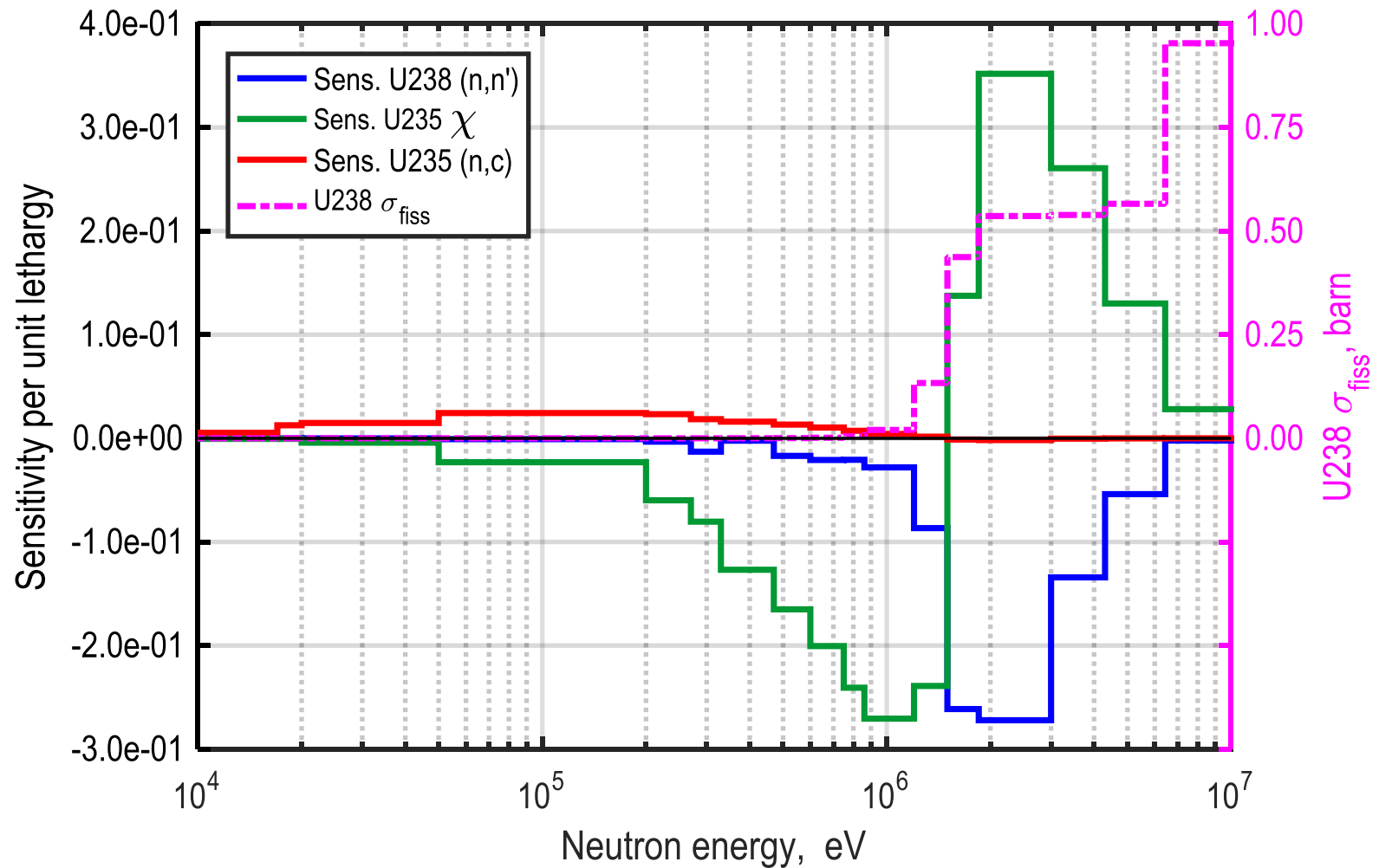


ENDF/B-VII.1

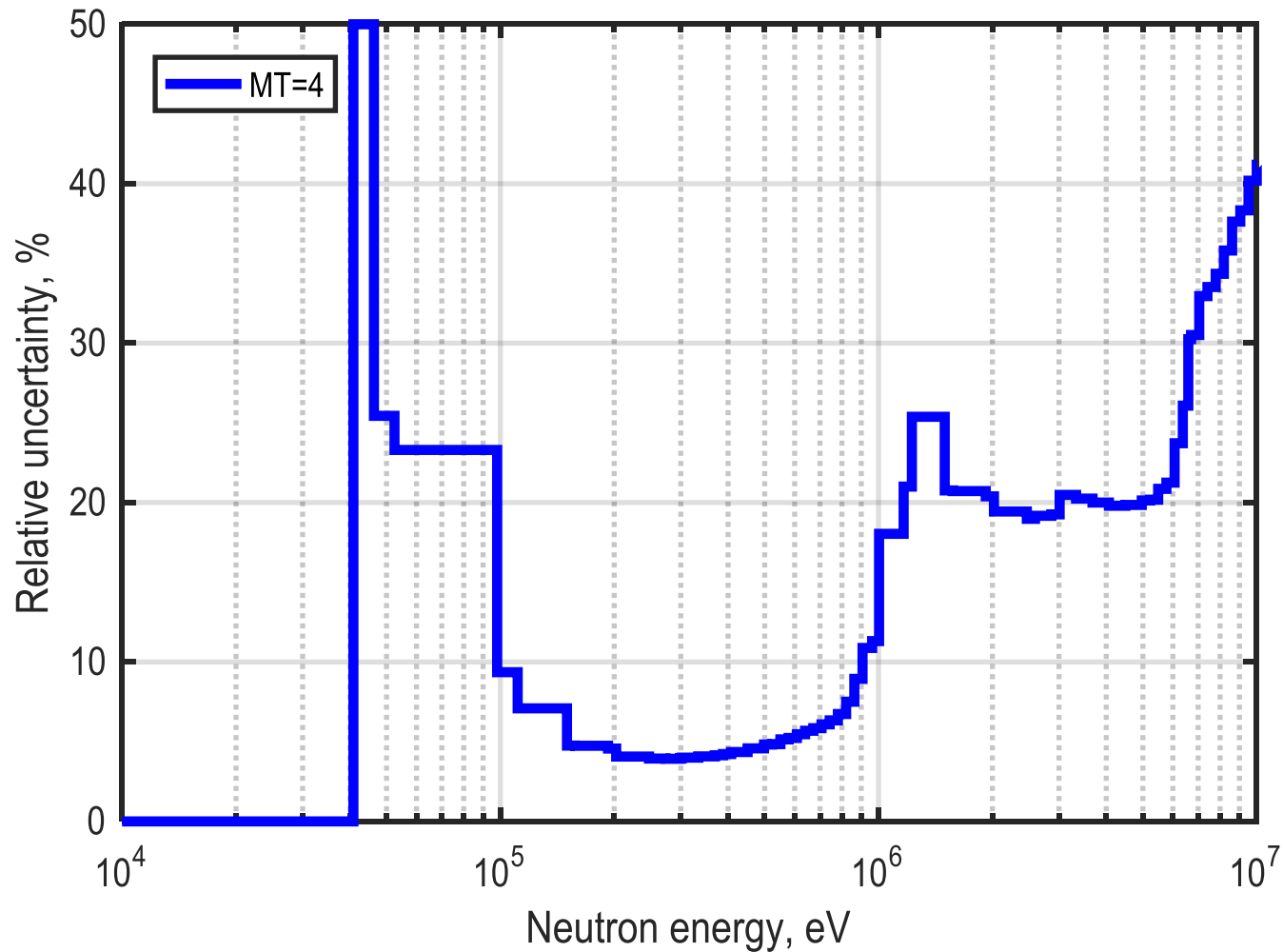
F28/F25 uncertainty, total and major contributors



F28/F25 sensitivity to U238 σ_{inl} and U235 χ

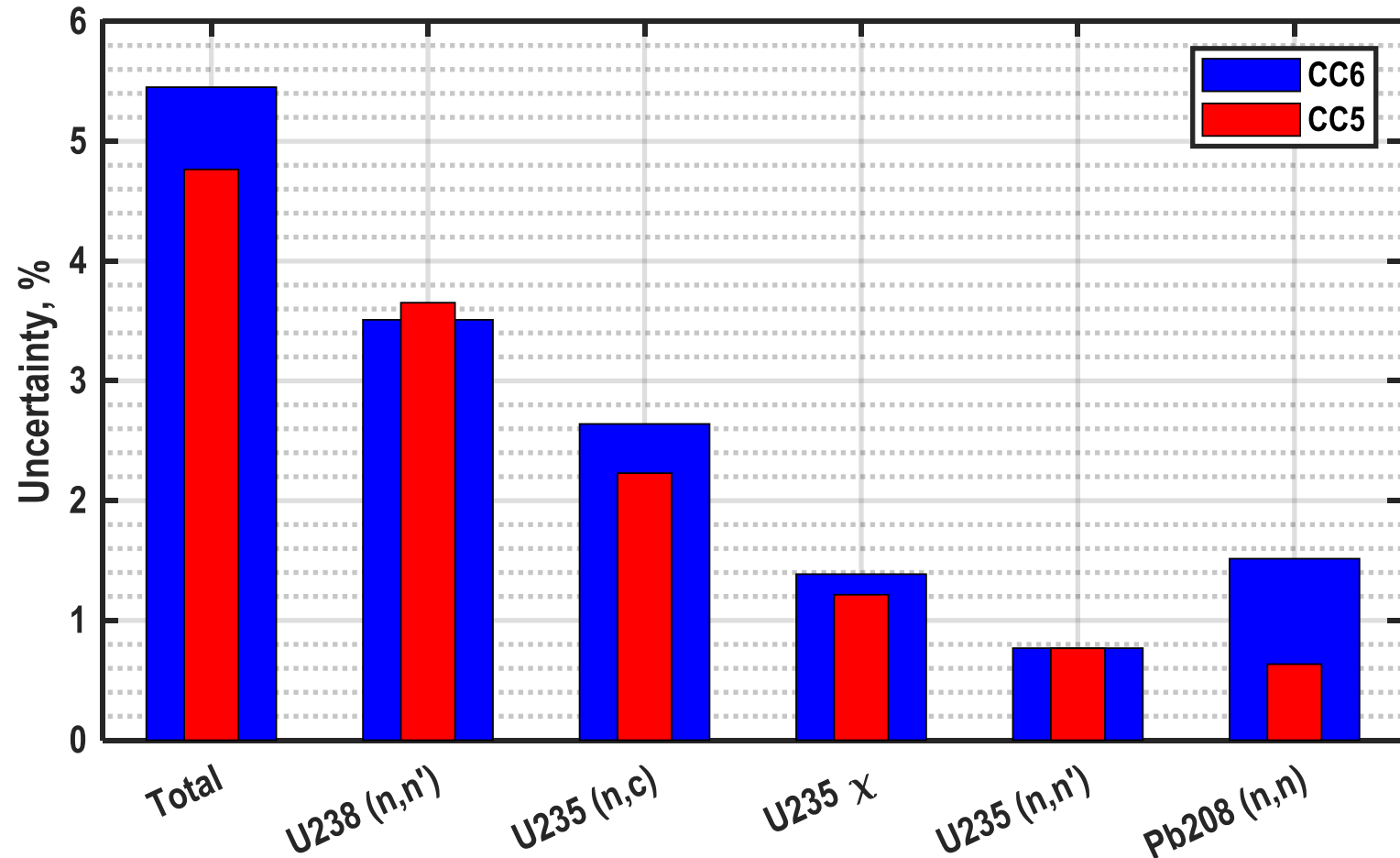


Uncertainty of U238 σ_{inl}

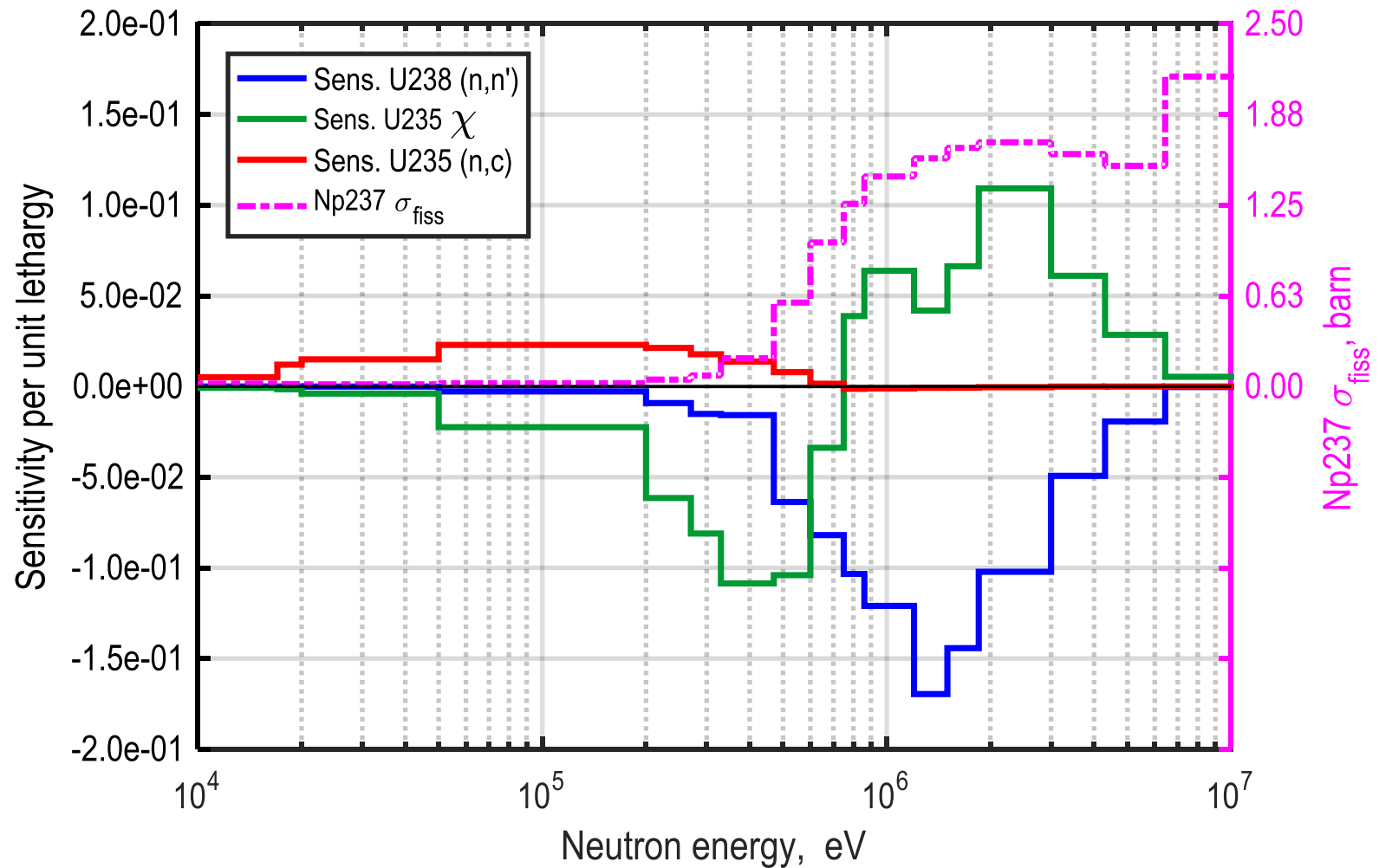


ENDV/B-VII.1

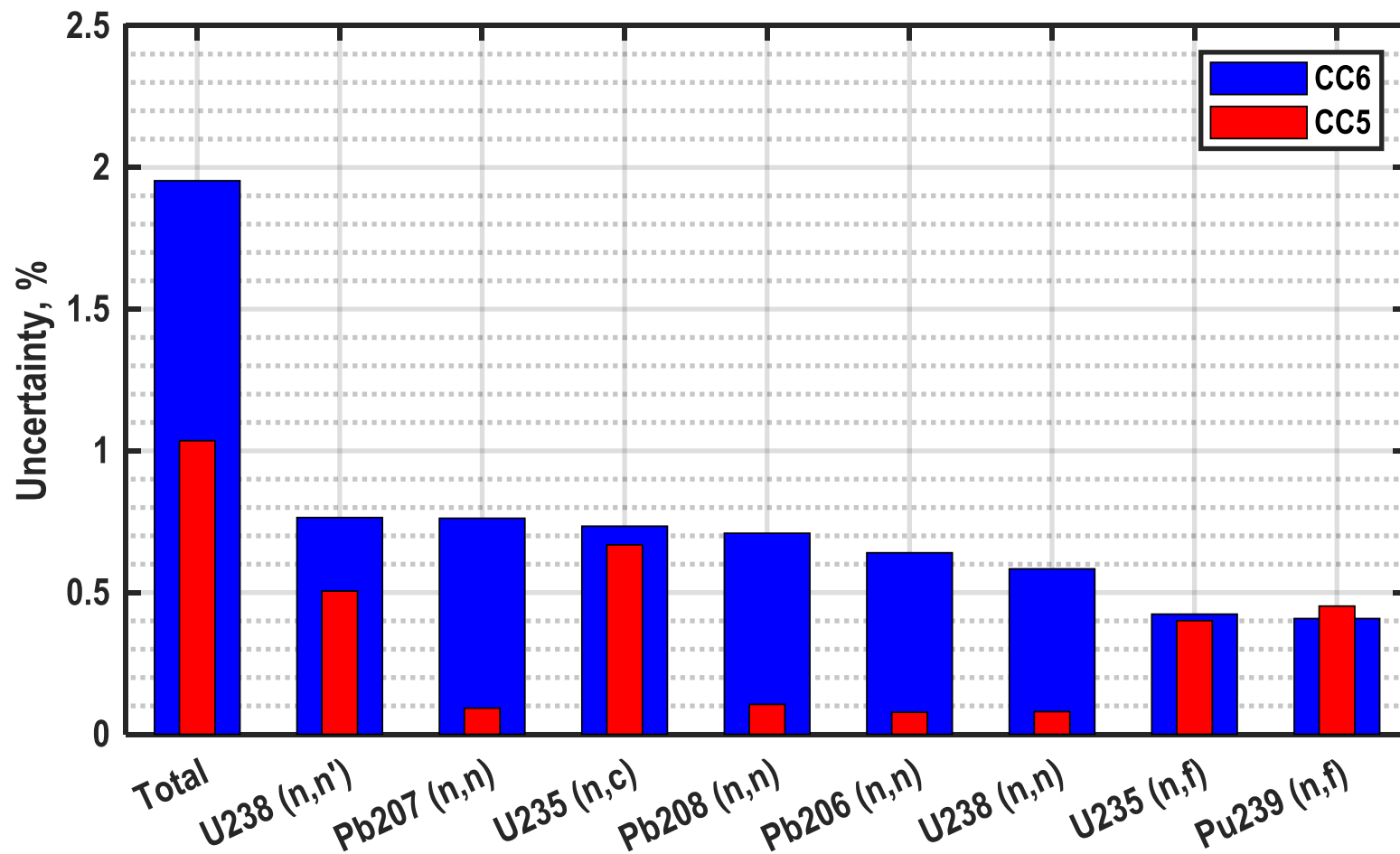
F37/F25 uncertainty, total and major contributors



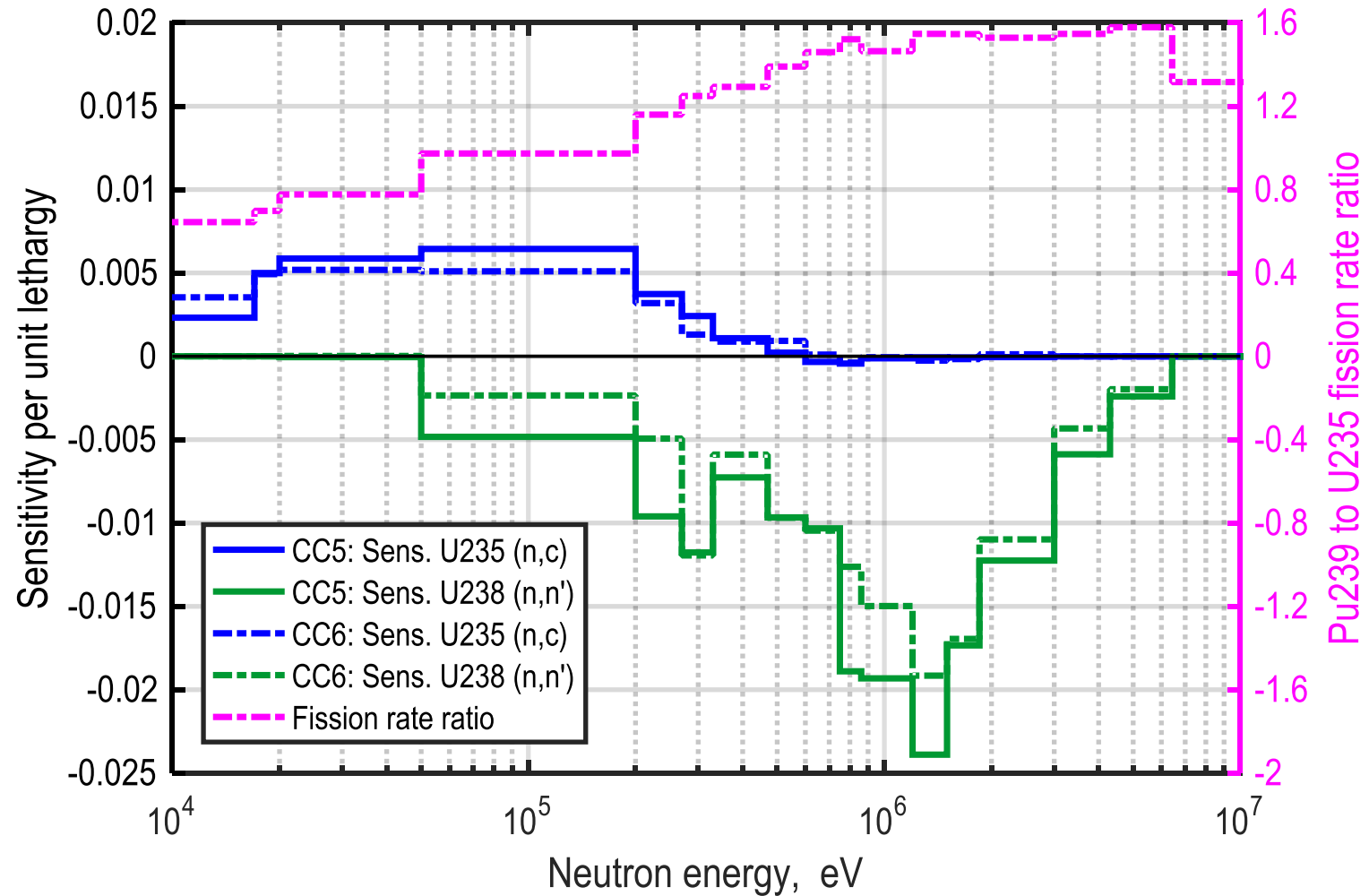
F37/F25 sensitivity to U238 σ_{inl} and U235 χ



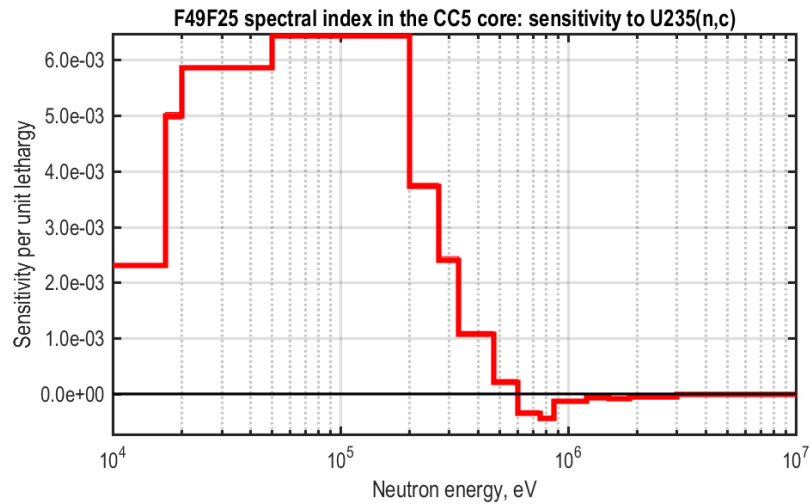
F49/F25 uncertainty, total and major contributors



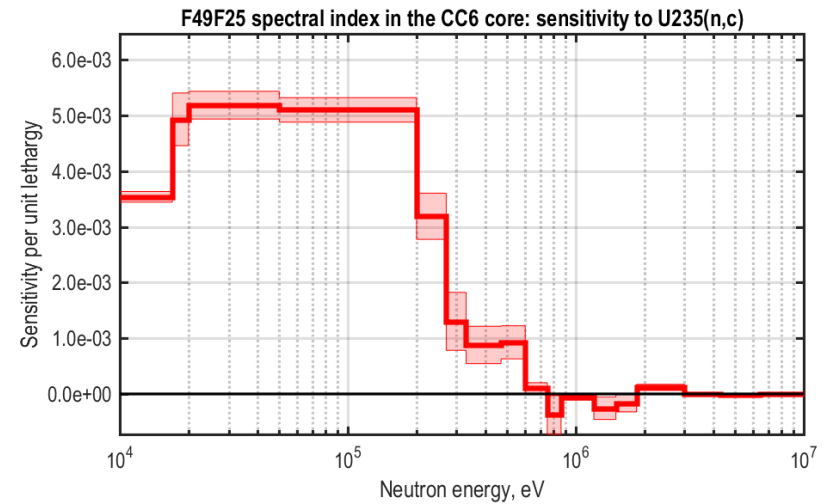
F49/F25 sensitivity to U238 σ_{inl} and U235 σ_c



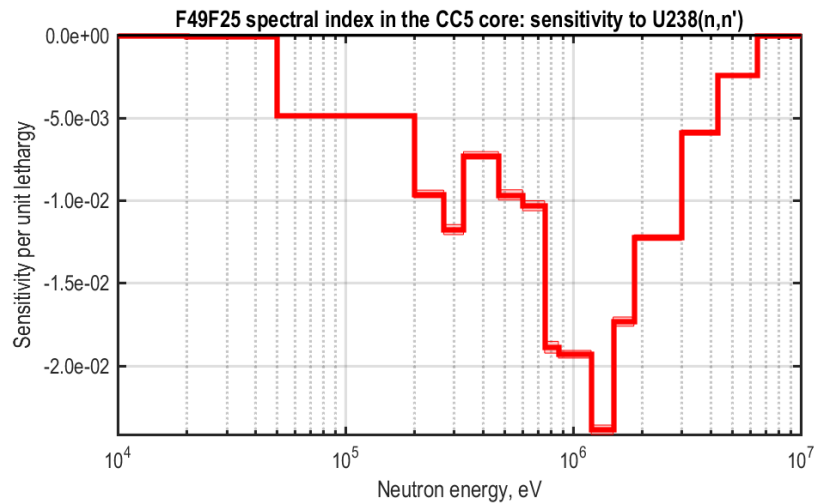
F49/F25 sensitivities: CC5 vs. CC6



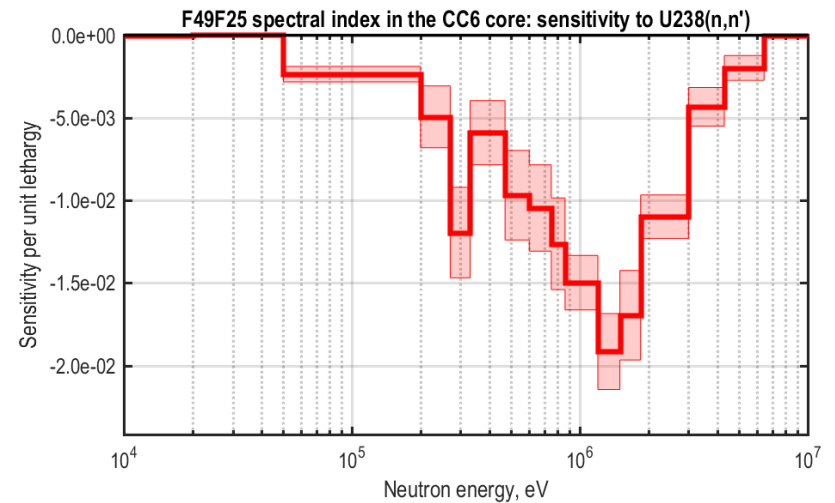
a. U235(n,c), the CC5 core



b. U235(n,c), the CC6 core

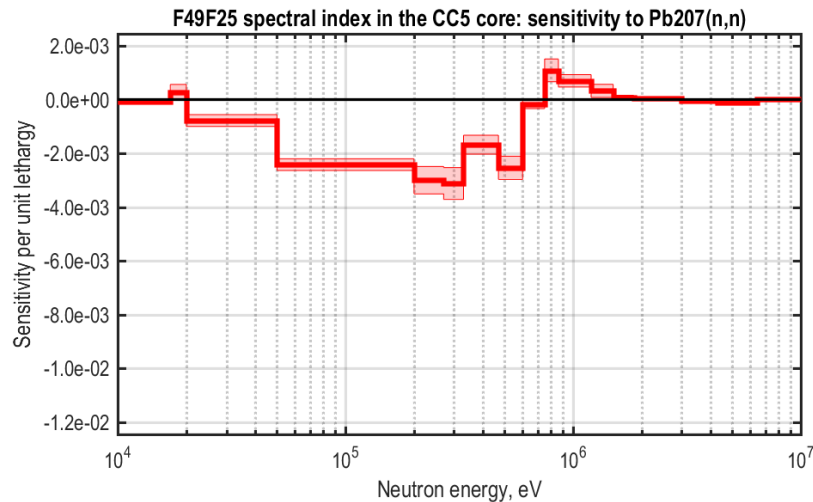


c. U238(n,n'), the CC5 core

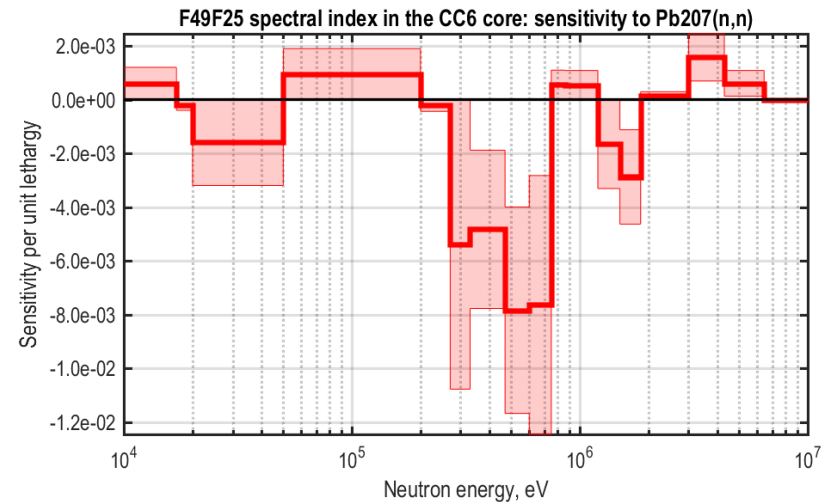


d. U238(n,n'), the CC6 core

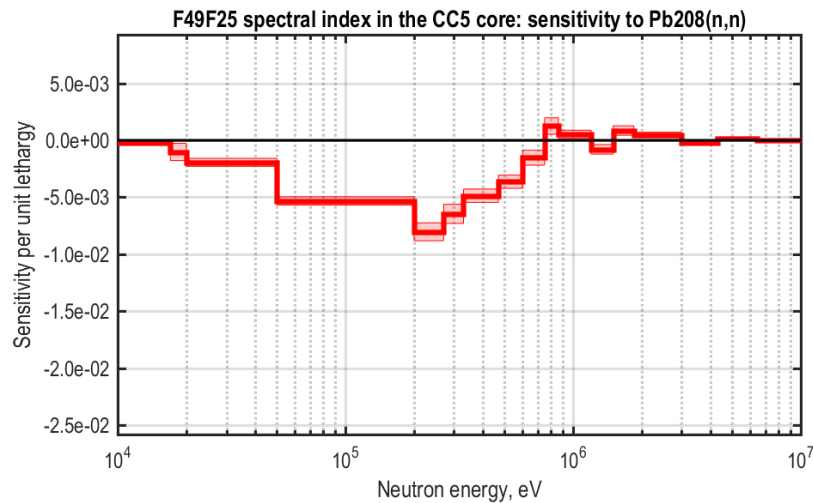
F49/F25 sensitivities: CC5 vs. CC6



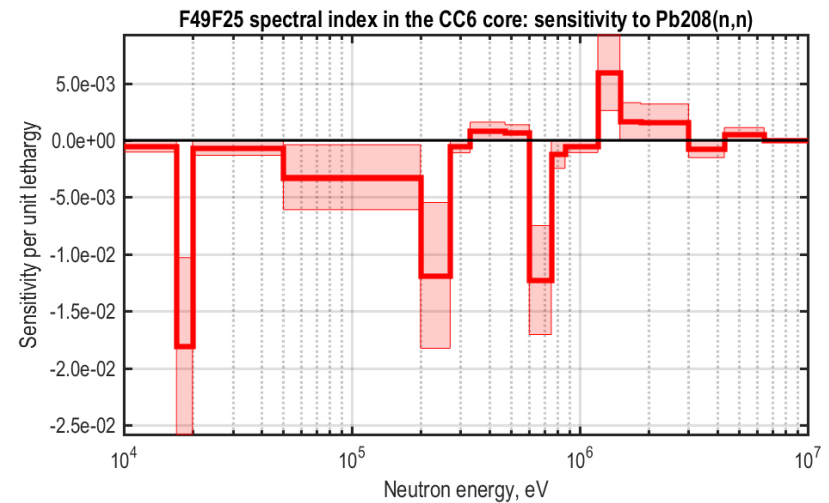
a. Pb207(n,n), the CC5 core



b. Pb207(n,n), the CC6 core



c. Pb208(n,n), the CC5 core



d. Pb208(n,n), the CC6 core

Summary and future work

Parameter	Data uncertainty	Main contributors
K-eff	2200 pcm	U235 σ_c
F28/F25	$\approx 8\%$	U238 σ_{inl} U235 χ
F37/F25	$\approx 5\% - 6\%$	U238 σ_{inl} U235 σ_c
F49/F25	$< 2\%$	U238 σ_{inl} U235 σ_c

- Drastically reduced uncertainty of U238 σ_{inl} /U235 σ_c in the latest libraries
 - ENDF/B-VIII.0 and JEFF-3.3
- Re-analysis might be interesting ... but requires generation of new data
 - Both ACE and COV

Thank you!

F28/F25 vs. F49/F25

