On the evaluation of prompt fission neutron spectra: Normalization, low variances and other issues

D. Neudecker[1] CSEWG, Covariance session, 11/21/2013

Ongoing collaboration of:

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Evaluated covariance information was included for n(E_{inc}=0.5 MeV)+^{239}Pu PFNS in ENDF/B-VII.1.

Introduction

Impact of the normalization condition

Studying the evaluation

Summary & outlook

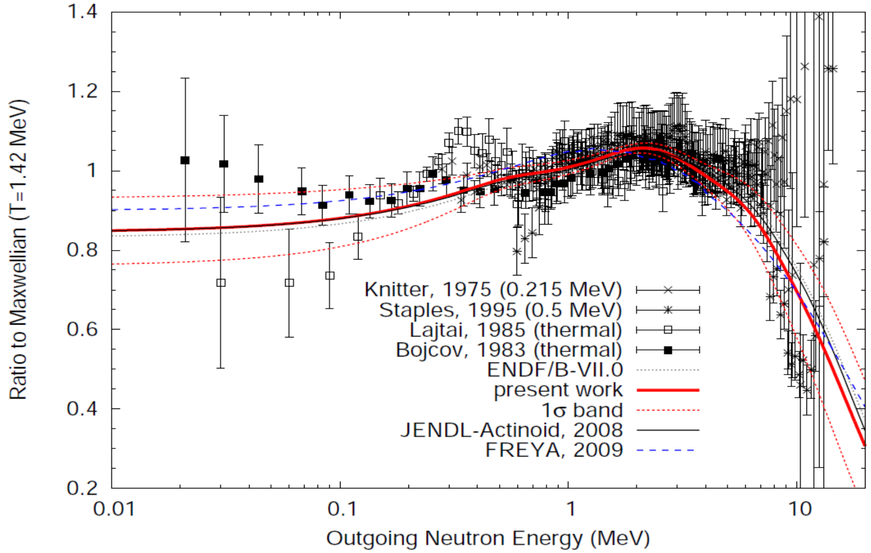
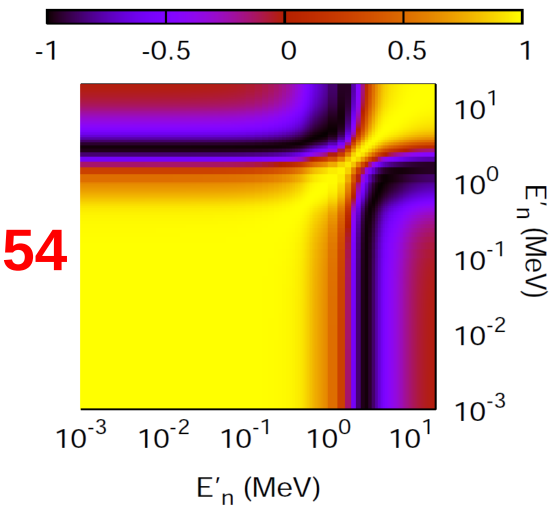


FIGURE 11. Final 1σ uncertainty band after including a "model error" component below 500 keV.

Model: Los Alamos model, D.G. Madland, J.R. Nix, NSE 81, 213 (1982).

Experiment: Knitter, Staples, Bojcov, Lajtai



Figures taken from:

P. Talou et al., NSE 166, No. 3, 254 (2010).

Open questions: low evaluated variances and maybe too strong model impact??

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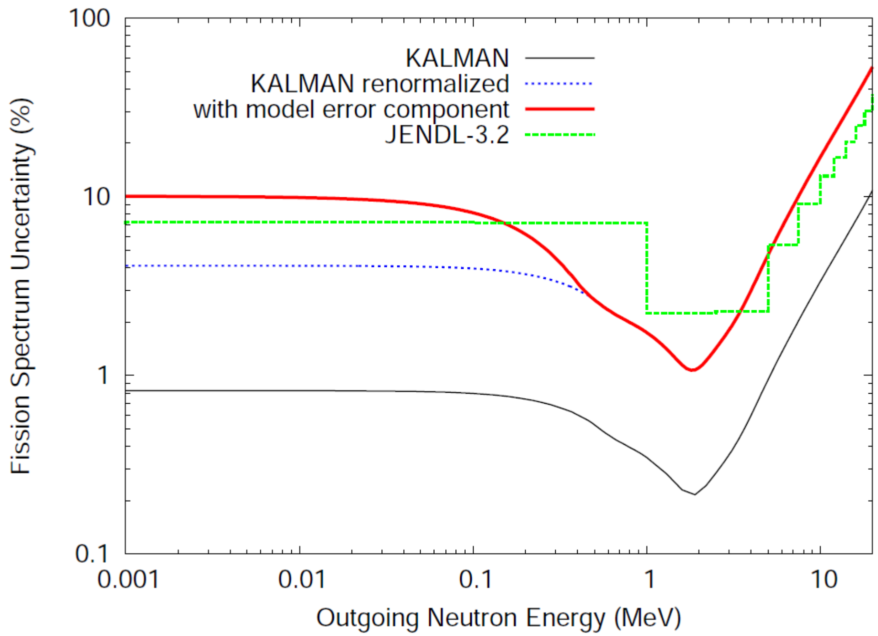


FIGURE 4. Calculated standard deviations for the evaluated PFNS of n(0.5 MeV)+^{239}Pu. See text for details.

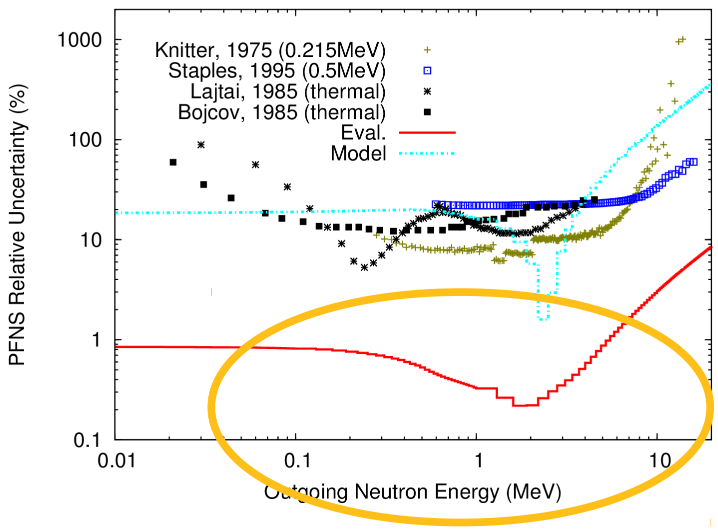
Figure taken from:
P. Talou et al., NSE 166, No. 3, 254 (2010).

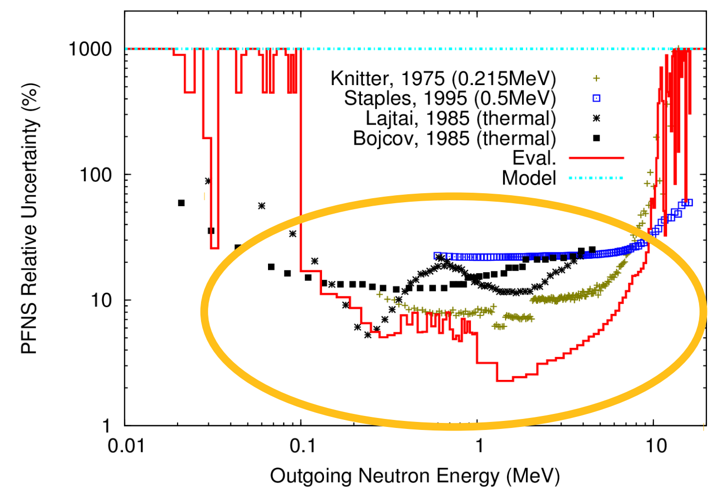
Low evaluated uncertainties?? (see also F.H. Froehner, NSE 106, No. 3, 345 (1990).)

Strong impact of model data on evaluation?? (issue raised by N. Kornilov)

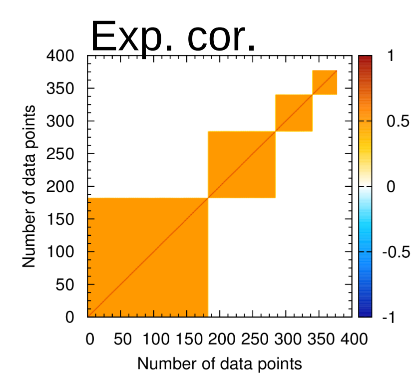
The variances obtained are surprisingly low compared to an evaluation with mainly exp. info.

In cross section evaluations, we expect evaluated variances of about the size of statistically combined exp. unc.





Evaluated uncertainties including model covariances are distinctly smaller over whole energy range than what we expect from experiment only.



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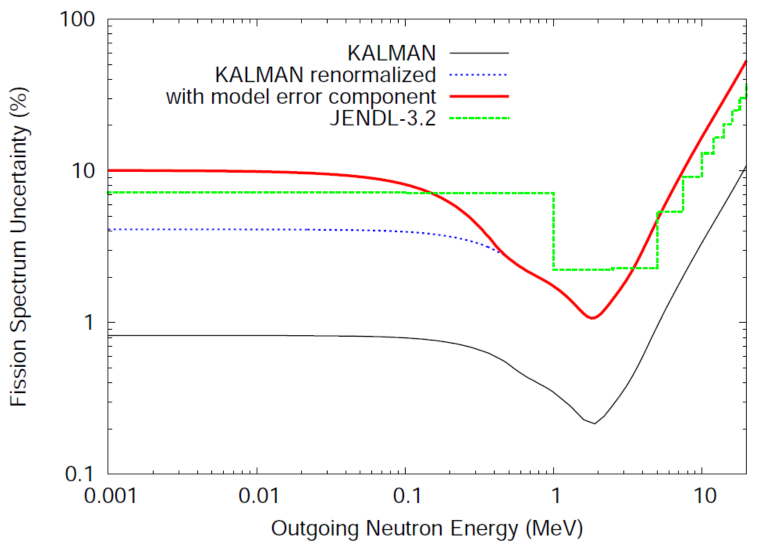
Low unc. directly at the pivot point are unproblematic, however they *are problematic close to the pivot point.*



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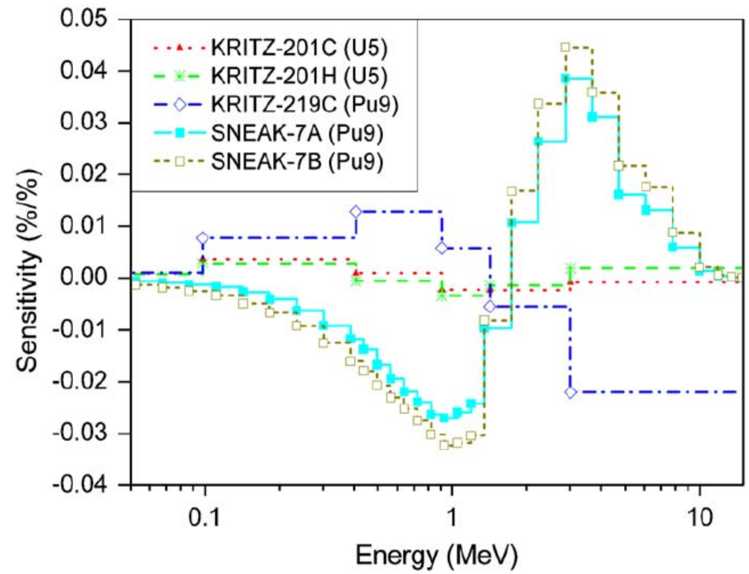

Fig. 6. Sensitivity of k_{eff} with respect to the ^{235}U and ^{239}Pu PFNS for the KRITZ and SNEAK experiments calculated using the constrained sensitivity method.

Figure taken from:
I. Kodeli et al., NIMA 610, p. 540 (2009).

One additional condition compared to cross section evaluations: Normalization of the spectrum.

Missing correlations between the same and different experiments. (see e.g. described in A. Carlson et al., “Internat. Eval. of Neutron Cross-Section Standards”, IAEA Report STI/PUB/1291 (2007).)

Lower model uncertainties than those of the majority of the *experiments* due to pathologically chosen parameter uncertainties or due to model deficiencies. (D.N., R.C. and H. Leeb, NIM A 723, 163 (2013)).

Peelle's Pertinent Puzzle (described e.g. in A. Carlson et al., IAEA Report STI/PUB/1291 (2007).)

→ One additional condition: **normalization of spectrum**

ENDF-6 format requires the PFNS to be normalized to 1 & the rows of cov. to sum to 0.

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In the ENDF-6 format, the energy spectrum of outgoing fission neutrons is parted into 2 quantities: the neutron-multiplicity and the **PFNS which is a probability distribution**. → hence, **normalization conditions apply.**

$\Phi\left(E^{i}_{out}\right)$... Bin average values

$\varphi\left(E^{i}_{out}\right)$... Bin probability of PFNS

ΔE^{i}_{out} ... Bin width

$$\sum_i \varphi\left(E^{i}_{out}\right)\Delta E^{i}_{out} = \sum_i \Phi\left(E^{i}_{out}\right) = 1$$

$$\frac{\sum_j Cov\left(\varphi\left(E^{i}_{out}\right), \varphi\left(E^{j}_{out}\right)\right)}{\varphi\left(E^{i}_{out}\right)} < 10^{-5}$$

ENDF-6 formats manual, edited by A. Trkov, M. Herman and D. Brown, BNL Report BNL-90365-2009 Rev. 2 (2012).

Normalization does not change shape of PFNS. How about covariances??

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If the PFNS and covariances are not-normalized quantities, the normalization transformation using linear error propagation reads:

$$\Omega(E^i_{out}) = \frac{\Phi(E^i_{out})}{G} \qquad G = \sum_i \Phi(E^i_{out})$$

Shape of PFNS remains the same.

$$Cov_\Omega = T\, Cov_\Phi\, T^+ \qquad T_{ij} = \frac{G\,\delta_{ij} - \Phi_i}{G^2}$$

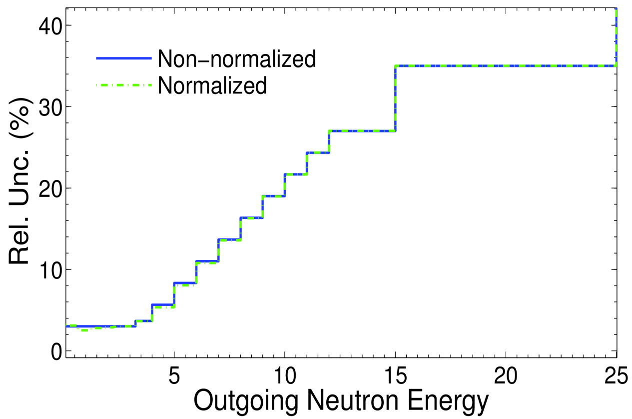
COVARIANCES MIGHT BE CHANGED, BUT HOW???

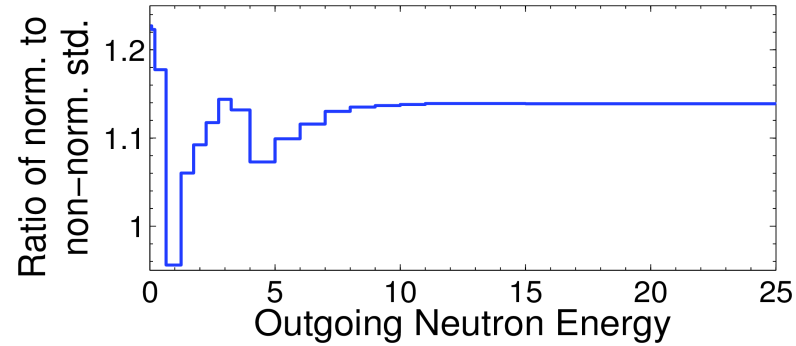
Model and exp. data have intrinsically different uncertainty sources.

	Model	Experiment
Statistical uncertainty source	**NO**	**YES**
Scaling uncertainty source	**NO**	**POSSIBLE**
Normalized uncertainty source	**YES**	**POSSIBLE**

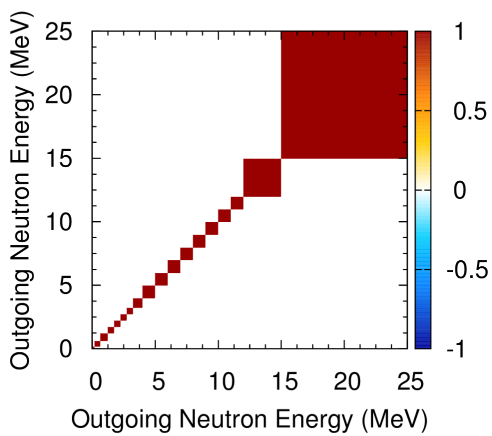
The Los Alamos model produces intrinsically normalized model data and covariances, while experimental data are mainly not normalized observables.

Statistical unc. are hardly changed by the normalization transformation.

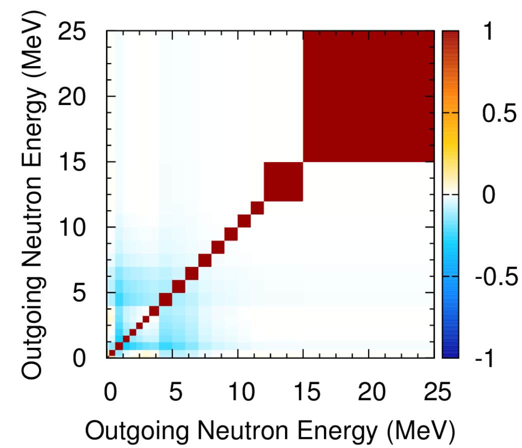




Before

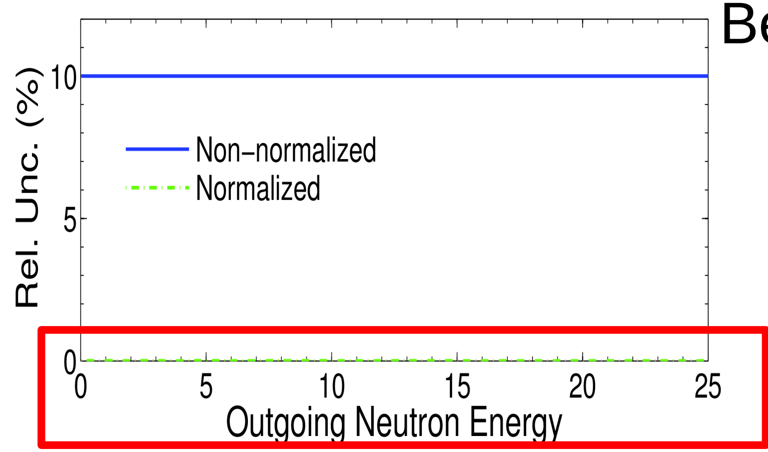


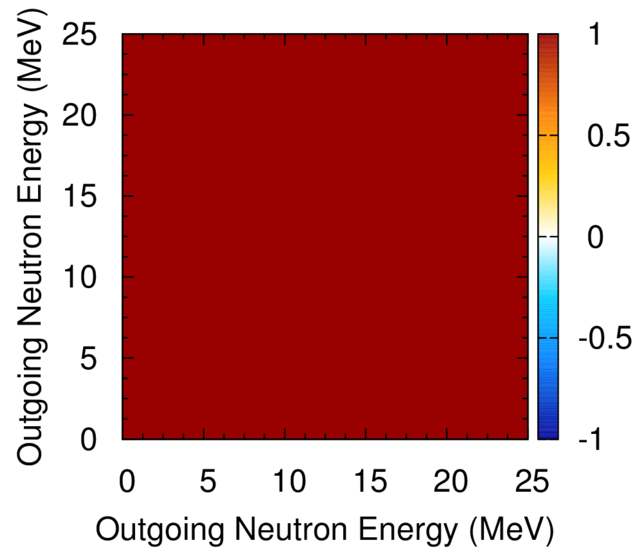
After



Scaling unc. reduce to zero in the normalization transformation.

Before

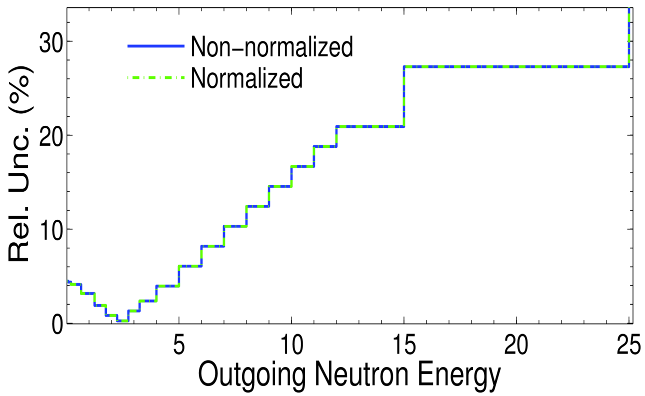


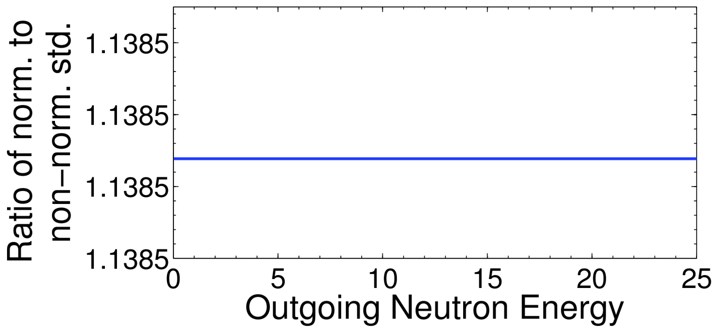


By the **normalization** of the PFNS, **we fix the scaling constant of the PFNS with 1/G.**

Hence, it is only natural that all uncertainties pertinent to the scaling factor drop out.

Already 'normalized cor.' and rel. unc. are unchanged by normal. transfor.





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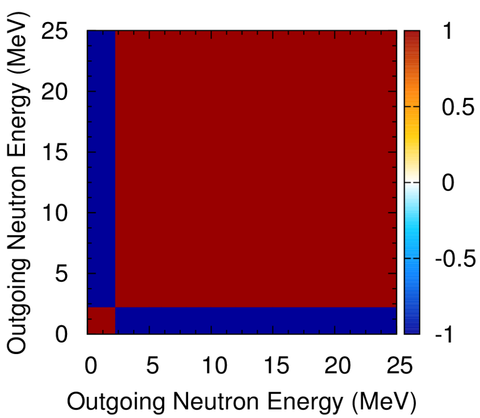

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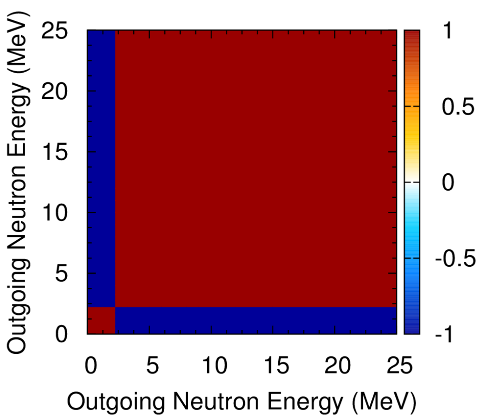
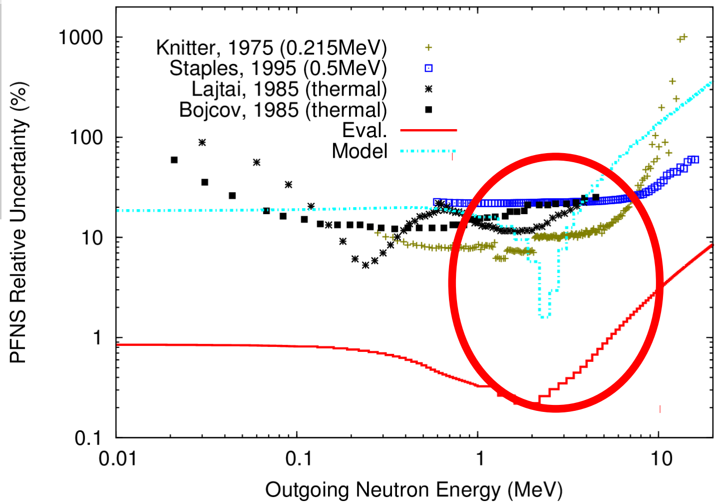


Model unc. is normalized and is smaller than exp. unc. around the mean energy.

	Model	Experiment
Statistical uncertainty source	NO	YES
Scaling uncertainty source	NO	POSSIBLE
Normalized uncertainty source	YES	POSSIBLE

Model unc. of Los Alamos model are already normalized and have a **minimum near the mean energy distinctly smaller than exp. unc.**



Eval. unc. using model cov. are surprisingly low compared to an evaluation with mainly exp. info.

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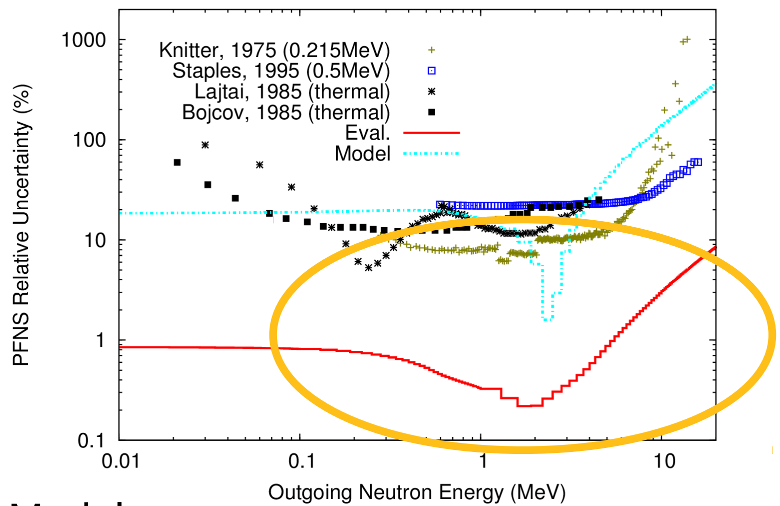
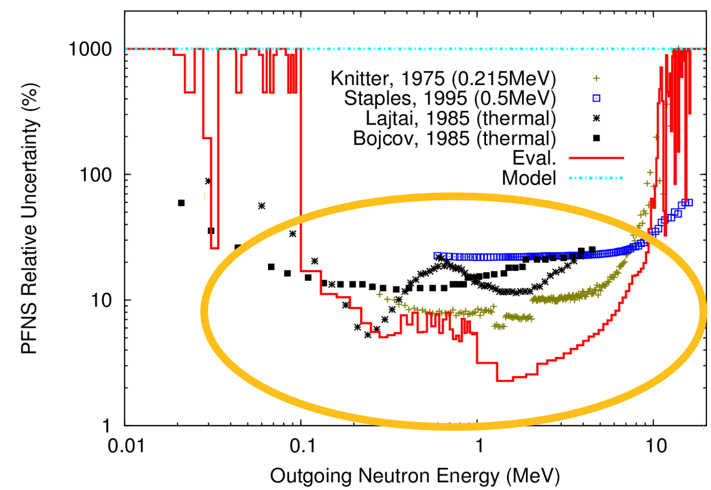
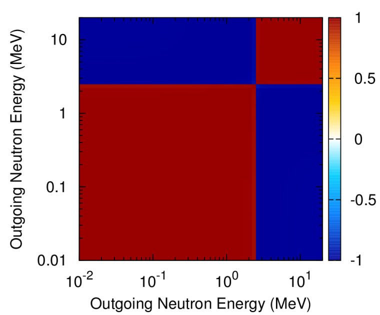
Eval. with model & exp. data and cov.



Eval. with exp. data and cov. and uncertain model

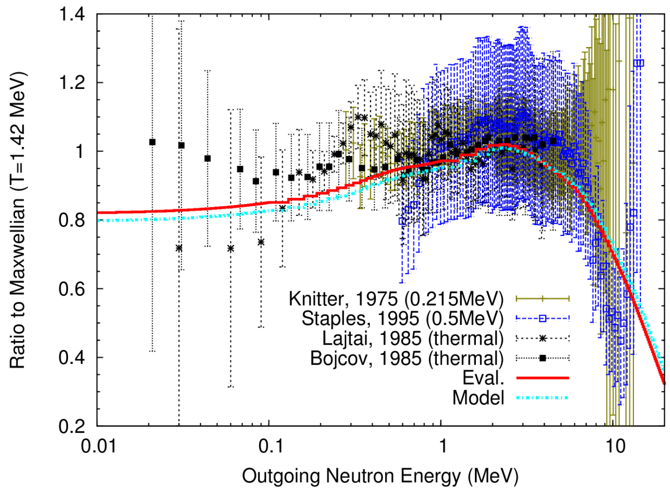


Model cor.

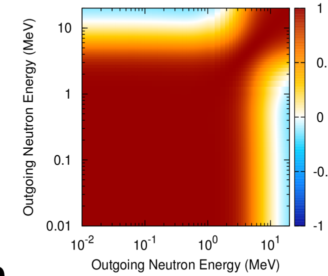


Evaluated uncertainties including model covariances are distinctly smaller over whole energy range than what we expect from experiment only.

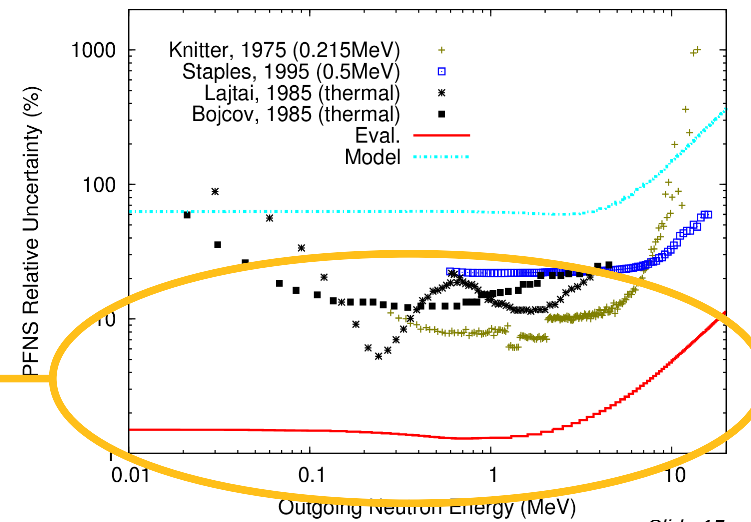
Adding scaling unc. and thus breaking the cov. normal. cond. → more realistic unc. near <E>.



Model: scaling unc. added to model unc. such that larger than exp. unc., **normal. cond. of cov. broken.**



Eval. unc. near pivot point in better correspondence to evaluation with exp. data only but **low unc. near tail because of strong model cor.**



… however enforcing the normal. cond. after the evaluation leads again to low unc.

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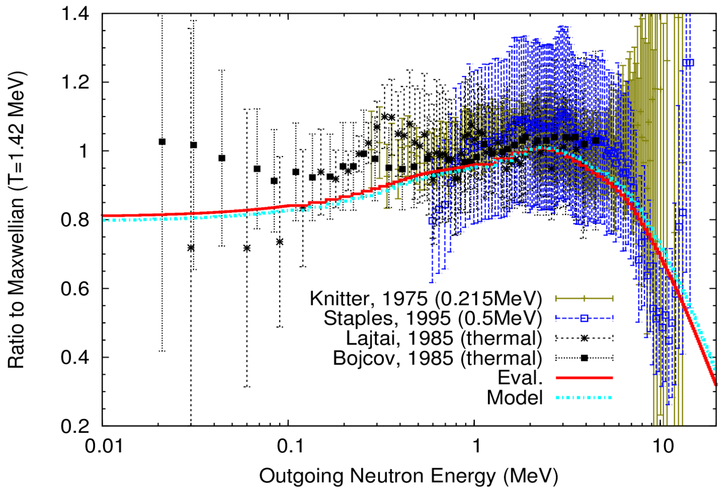
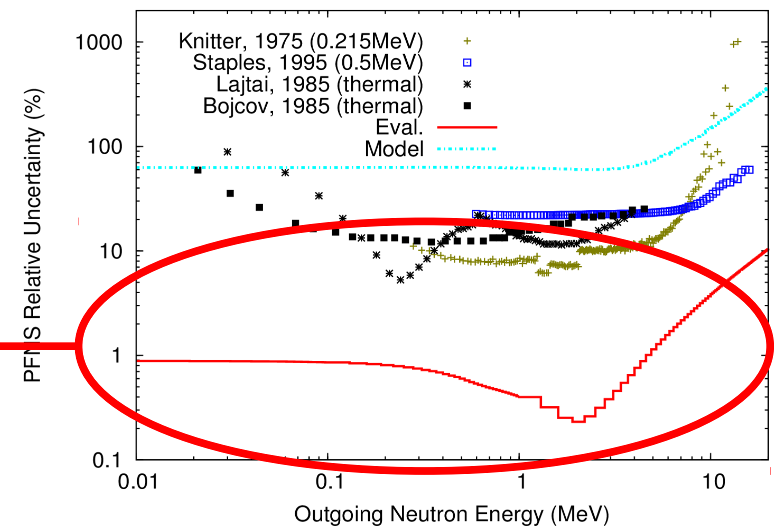
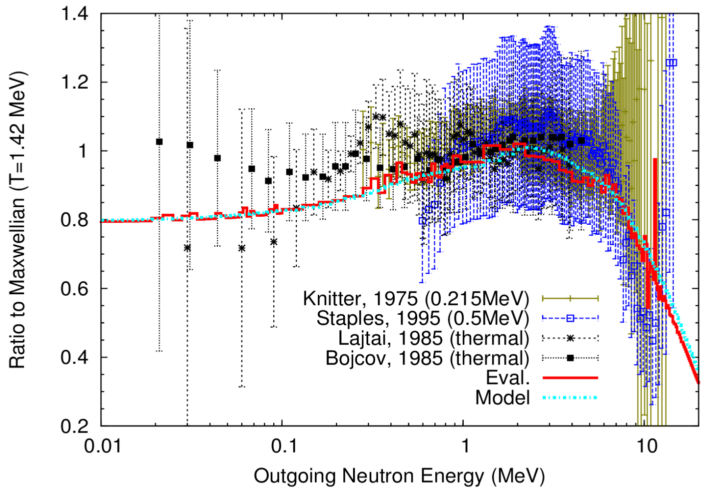


Model: scaling unc. added to model unc. such that larger than exp. unc., **normalization condition of cov. broken → restored after evaluation.**

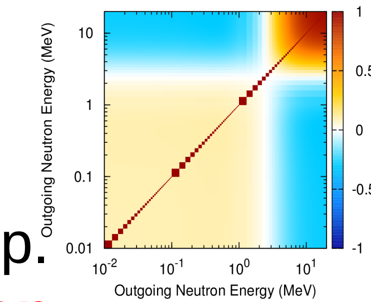
If we normalize evaluated results → we end up with low eval. unc. again!



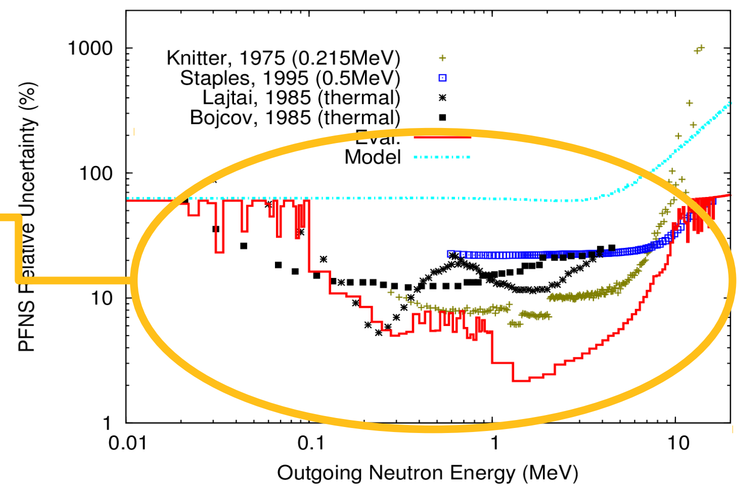
If we add a statistical unc. to model unc., we obtain reasonable unc. despite the normal.



Model: statistical unc. added to model unc. such that larger than exp. unc., **normalization condition on model cov. enforced.**



If we add statistical uncertainties to the model cov., we obtain reasonable eval. unc.



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The strong model cor. in combination with the normal. cond. lead to low eval. unc.

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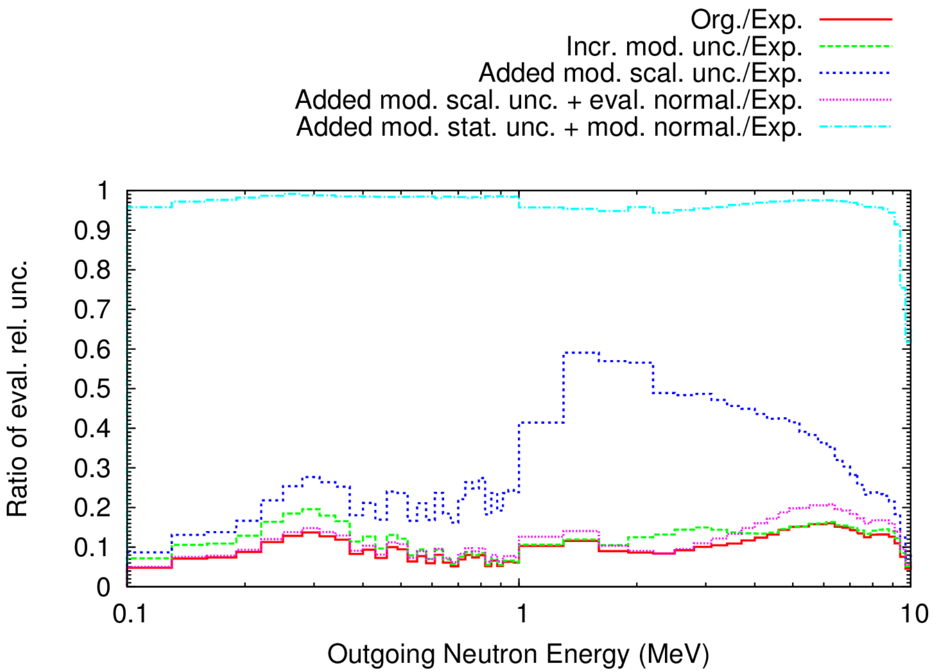
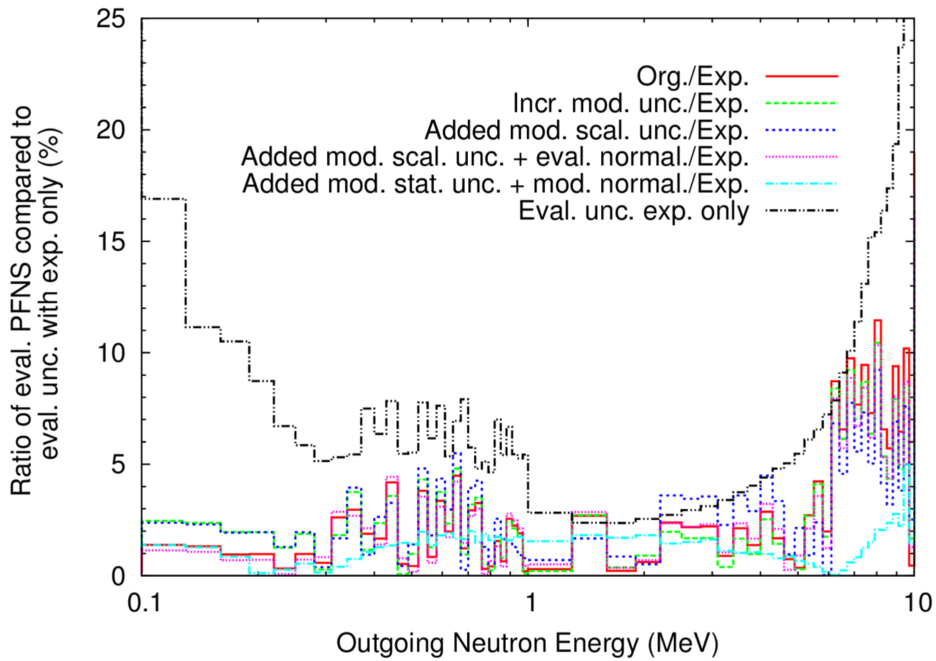


The strong model correlations in combination with the normalization condition on the model cov. lead to low evaluated uncertainties.

Part of this problem is that the **Los Alamos model cov.** consider only unc. of **4 model parameters**. Is that **physical?** → If not, the low evaluated uncertainties might be an artifact. → tests with MCHF planned (e.g. B. Becker et al., Phys. Rev. C 87, 014617 (2013).)

The eval. shape depends strongly on the model correlations.



The strong model correlations have a clear impact on the model shape.

However, given exp. unc. we cannot verify the goodness of the Los Alamos model.

Again, we ***might*** question if it is **physical to consider only unc. for 4 model parameters for the Los Alamos model**
→ tests with enlarged parameter space planned.

Summary and ...

- Under the **constraint of normalization**, uncertainties are smaller than what we expect from e.g. integral cross section evaluations as **scaling uncertainties drop out.**

- The **low evaluated uncertainties** in the NSE (2010) evaluation are caused by the **strong** Los Alamos **model correlations** in combination with the **normalization condition.**

- The **evaluated shape** is strongly influenced by the **rigid model correlations.**

... and outlook

- In the **next ^{239}Pu PFNS evaluation**, **an enlarged parameter space** will be used for the Los Alamos model covariances.

- The next evaluation will be undertaken in 3-steps:
  (1) exp. information
  (2) exp. with non-normalized model information
  (3) normalization of evaluated results

  → only then, it is possible to **quantify if model correlations bias the results compared to experimental input** and **how much eval. unc. are reduced by model correlations and the normalization condition.**

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Nuclear Data Covariances

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