

#### LA-UR-17-29998

Approved for public release; distribution is unlimited.

Title:	Missing uncertainties in the standards evaluations and updated 235U PFNS covariances
Author(s):	Neudecker, Denise
Intended for:	CSEWG, 2017-11-06/2017-11-08 (Upton, New York, United States) Web
Issued:	2017-11-01

**Disclaimer:** Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness. viewpoint of a publication or guarantee its technical correctness.

# Missing uncertainties in the standards evaluations and updated <sup>235</sup>U PFNS covariances

**CSEWG** 

11/7/2017

#### **DENISE NEUDECKER**

<u>Work by:</u> D. Neudecker, B. Hejnal, F. Tovesson, M.C. White, D.L. Smith, D. Vaughan, R. Capote, P. Talou

LA-UR-17-xxxxx



UNCLASSIFIED





#### Towards assessing missing uncertainties in the *NEXT* standards evaluations



UNCLASSIFIED





# Missing uncertainties in the standards evaluations

The evaluated <sup>235,238</sup>U and <sup>239</sup>Pu(n,f) uncertainties evaluated by the standards committee were considered to be unrealistically small. An analysis of unknown systematic uncertainties for these evaluations was included for the upcoming standards evaluation (A. Carlson et al., NDS (2018)) leading, e.g., to a correlated 1.2% systematic uncertainty on the <sup>235</sup>U(n,f).

Uncertainties are assumed be underestimated because:

- Unrecognized unc. across many data sets due to using the same method.
- Missing cross-correlations between experimental data.
- Missing uncertainty sources for single experimental data sets.



UNCLASSIFIED





#### It is assumed that (n,f) evaluated uncertainties are underestimated ...

The uncertainties were considered to be unrealistically small. An analysis of unknown systematic uncertainties for these evaluations was included for the upcoming standards evaluation (A. Carlson et al., NDS (2018)) leading, e.g., to a correlated 1.2% systematic uncertainty on the <sup>235</sup>U(n,f).

Uncertainties are assumed be underestimated because:

- Unrecognized unc. across many data sets due to using the same method.
- Missing cross-correlations between experimental data.
- > Missing uncertainty sources for single experimental data sets.



We investigate those.

UNCLASSIFIED





# Investigating missing cross-correlations between data sets and unc. for single data sets.

- A. Investigate classes of (n,f) cs measurements, uncertainties that apply and algorithms for total covariance.
- B. Extract data out of GMA and uncertainty sources typically encountered.
- C. Template of uncertainties sources expected, their typical size and correlations if no information is provided.
- D. Re-investigate selected GMA datasets.

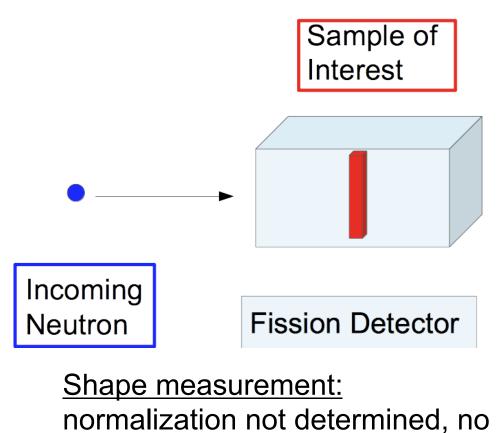


UNCLASSIFIED





# Absolute measurements: measure neutron flux, determine normalization



• Los Alamos

Neutron flux is measured, for instance by associated particle.

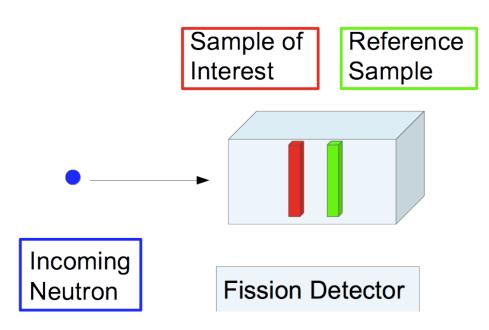
Normalization is given by determining the number of atoms in the sample.

Detector efficiency, background, multiple scattering, attenuation, etc., have to be estimated.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA



### **``Clean ratio measurements'': measure cs relative to another (n,f) cs with same detector**



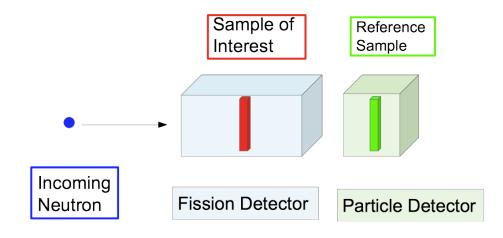
There exist absolute and shape clean ratio measurements.

E.g., 
$${}^{239}$$
Pu(n,f)/ ${}^{235}$ U(n,f),  
• Los Alamos  ${}^{239}$ Pu(n,f)/ ${}^{238}$ U(n,f)  $_{UNCLASSIFIED}$ 

- Neutron flux cancels.
- Detector efficiency might cancel or correction factor reduces.
- Multiple scattering effects reduce.
- Attenuation effects increase.



# ``Indirect ratio measurements": measure cs relative to other reaction with different detector



There exist absolute and shape indirect ratio measurements.

- Neutron flux cancels.
- Detector efficiency uncertainties & time resolution unc. need to be given for both detectors.
- Multiple scattering effects reduce less than for clean ration measurements.
- Attenuation effects increase.

UNCLASSIFIED



# List of typical uncertainties and reasonable estimates for unc. and cor. if missing:

Unc. Source	Typical range	Correlations	Cor(Exp <sub>1</sub> ,Exp <sub>2</sub> )
Sample Mass	> 1%	Full	Possible (same sample)
<b>Counting Statistics</b>	Sample-dependent	Diagonal	0
Attenuation	0.02-2%	Gaussian	Likely
Detector Efficiency	0-0.3%, 1-2%	Full < 10 MeV	Likely, 0.5-1.0
FF Angular Distrib.	~0.1%	Gaussian	Likely, 0.75-1.0
Background	0.2 - >10%	Gaussian	Possible
Energy Unc.	1%, 1-2 ns	Arises from conv.	Technique-dependent
Neutron Flux	0%, >1%	Full-0.5	Technique-dependent
Multiple Scattering	0.2-1%	Gaussian	0.5-0.75
Impurit. in Sample	Sample-dependent	1.0-0.9	0.5-0.75
Dead Time	>0.1%	Full	0



UNCLASSIFIED

Slide 9



### **Comparing typical uncertainties for absolute measurements:**

Unc. Source	Absolute	Clean Ratio	Indirect Ratio	
Sample Mass	> 1%	Both Samples	Both samples	
<b>Counting Statistics</b>	Sample-dependent	Both, combined	Both samples	
Attenuation	0.2-2%	0.02-0.2%	0.2-2%	
Detector Efficiency	1-2%	0-0.3%	1-2%, 0.5-1%	
FF Angular Distrib.	~0.1%	Less than for abs.	~0.1%	
Background	0.2 - >10%	0.2 - >10%	0.2 - >10%	
Energy Unc.	1%, 1-2 ns	Combined	Both detectors	
Neutron Flux	>1%	Cancels or small	Cancels or small	
Multiple Scattering	0.2-1%	Reduced for abs.	0.2-1%	
Impurit. in Sample	Sample-dependent	Both samples	Both samples	
Dead Time	>0.1%	Both, combined	Both detectors	



UNCLASSIFIED

Slide 10



#### Having a template of uncertainties helps pinpoint missing uncertainties:

$\begin{array}{ c c c c c c } \hline Data Sets & 611 & 1038 & 620 \\ \hline Uncertainty Data Types & E,CS,C & CS,C & E,CS,C \\ \hline P1 & 1.5 & 1.0 \\ \hline P2 & 0.3 - 0.3 & 0.9 - 1.8 & 1.5 - 1.8 \\ \hline P3 & 0.36 & 0.5 - 0.70 \\ \hline P4 & 1.04 & 1.47 & 1.84 - 1.94 \\ \hline P5 & 1.01 - 1.01 & 2.82 - 26.3 \\ \hline P7 & 0.3 & & & & & & & & \\ \hline P7 & 0.3 & & & & & & & \\ \hline P8 & 1.01 - 1.01 & 2.82 - 26.3 \\ \hline P9 & & & & & & & & \\ \hline P10 & 10 & 5.0 & 0.5 - 0.5 \\ \hline P11 & 1 & & & & & & \\ \hline P5 & 0 & 0.5 - 0.5 \\ \hline P1 & 1.0 & 1.5 & 1.0 \\ \hline P2 & 0.3 - 0.3 & 0.9 - 1.8 & 1.5 - 1.8 \\ \hline P10 & 1 & & & & & \\ \hline P10 & 1 & & & & & \\ \hline P10 & 1 & & & & & \\ \hline P11 & 1 & & & & & \\ \hline P5 & 0 & 0 & 0.5 - 0.5 \\ \hline P1 & 1.0 & 1.5 & 1.0 \\ \hline P2 & 0.3 - 0.3 & 0.9 - 1.8 & 1.5 - 1.8 \\ \hline P3 & 0.36 & 0 & 0.5 - 0.70 \\ \hline P4 & 1.04 & 1.47 & 1.84 - 1.94 \\ \hline P5 & 0 & 0.5 & 1.15 - 1.5 & 0.8 - 1.0 \\ \hline P7 & 0.3 & 0 & 0 & & \\ \hline P7 & 0.3 & 0 & 0 & & \\ \hline P7 & 0.3 & 0 & 0 & & \\ \hline P9 & & & & & & \\ \hline P10 & 0 & 0 & & & & \\ \hline P10 & 0 & 0 & & & & \\ \hline P11 & 0 & 0 & & & \\ \hline P11 & 0 & 0 & & & & \\ \hline P11 & 0 & 0 & & & \\ \hline P11 & 0 & 0 & & & & \\ \hline P11 & 0 & 0 & & & & \\ \hline P11 & 0 & 0 & & & & \\ \hline P11 & 0 & 0 & & & \\ \hline P11 & 0 & 0 & & & & \\ \hline P11 & 0 & 0 & & & & \\ \hline P11 & 0 & 0 & & & \\ \hline P11 & 0 & 0 & & & \\ \hline P1 & 0 & 0 & & & & \\ \hline P1 & 0 & 0 & & & \\ \hline P1 & 0 & 0 & & & \\ \hline P1 & 0 & 0 & & & \\ \hline P1 & 0 & 0 & & & \\ \hline P1 & 0 & 0 & & & \\ \hline P1 & 0 & 0 & & & \\ \hline P1 & 0 & 0 & $								
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Data Sets	611	1038	620				
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	Uncertainty Data Types	E,CS,C	CS,C	E,CS,C				
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	P1		1.5	1.0				
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	P2	0.3 - 0.3	0.9 - 1.8	1.5 - 1.8	3			
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	P3	0.36		0.5 - 0.7				
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	P4	1.04	1.47	1.84 - 1.9	04			
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	P5			1.0 - 1.0				
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	P6		1.15 - 1.5	0.8 - 1.0		011	1000	620
P8 1.01 - 1.01 2.82 - 26.3 rtainty Data Types E,CS,C CS,C E,CS,C   P9 P1 1.0 1.5 1.0   P10 5.0 0.5 - 0.5 P3 0.3 - 0.3 0.9 - 1.8 1.5 - 1.8   P11 P4 1.04 1.47 1.84 - 1.94   P5 Ok Ok 1.0 - 1.0   P6 0.5 1.15 - 1.5 0.8 - 1.0   P7 0.3 Ok Ok   P7 0.3 Ok Ok   P8 1.01 - 1.01 ? 2.82 - 26.3   P9 ? Ok 5.0 0.5 - 0.5	P7	0.3			— Data Sets			
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$				<u></u>		E,CS,C	CS,C	$_{\rm E,CS,C}$
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		1.01 - 1.01		2.02 - 20	. <u>.</u> P1	1.0	1.5	1.0
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	P9				P2	0.3 - 0.3	0.9 - 1.8	
P11 P4 1.04 1.47 1.84 - 1.94   P5 ok ok 1.0 - 1.0   P6 0.5 1.15 - 1.5 0.8 - 1.0   P7 0.3 ok ok   P8 1.01 - 1.01 ? 2.82 - 26.3   P9 ? ok ?   P10 ok 5.0 0.5 - 0.5			5.0	0.5 - 0.5				
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	P11							
P7 0.3 ok ok   P8 1.01 - 1.01 ? 2.82 - 26.3   P9 ? ok ?   P10 ok 5.0 0.5 - 0.5					P5	ok	ok	1.0 - 1.0
P8 1.01 - 1.01 ? 2.82 - 26.3   P9 ? ok ?   P10 ok 5.0 0.5 - 0.5					P6	0.5	1.15 - 1.5	0.8 - 1.0
P9   ?   ok   ?     P10   ok   5.0   0.5 - 0.5					P7	0.3	ok	ok
P10 <b>ok</b> 5.0 0.5 - 0.5					P8	1.01 - 1.01	?	2.82 - 26.3
					P9	?	ok	?
P11 ok ok ok							5.0	0.5 - 0.5
	6				P11	ok	ok	ok



UNCLASSIFIED

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA



## Having a template of uncertainties can help experimentalists in quantifying their unc.

- Templates were, e.g., developed for providing EXFOR data and uncertainties in the resonance region in F. Gunsing et al., INDC(NDS)-0647 (2013).
- Can provide guidelines what uncertainties need to be provided for an evaluation.
- Helps pinpoint cross-correlations between other experiments if the same terminology is used.



UNCLASSIFIED





#### Example 1, the absolute <sup>239</sup>Pu(n,f)/<sup>235</sup>U(n,f) exp. with lowest uncertainties in the GMA database:

Data Set	Data Type	$\operatorname{Min}\delta$	$Max \ \delta$	$\operatorname{Min} E$	$\operatorname{Max} E$	EXFOR #
611	absolute	1.0	-1.0	1.45E+01	$1.45E{+}01$	
644	absolute	-2.0	-2.0	1.45E+01	$1.45E{+}01$	30634
615	absolute	2.1	2.1	5.00E + 00	5.00E + 00	
1038	absolute	2.3	7.7	1.00E+00	$5.50E{+}00$	30670
640	absolute	2.4	3.1	1.50E-01	9.60E-01	10314
620	absolute	2.8	-6.6	3.00E-02	9.80E-01	20567

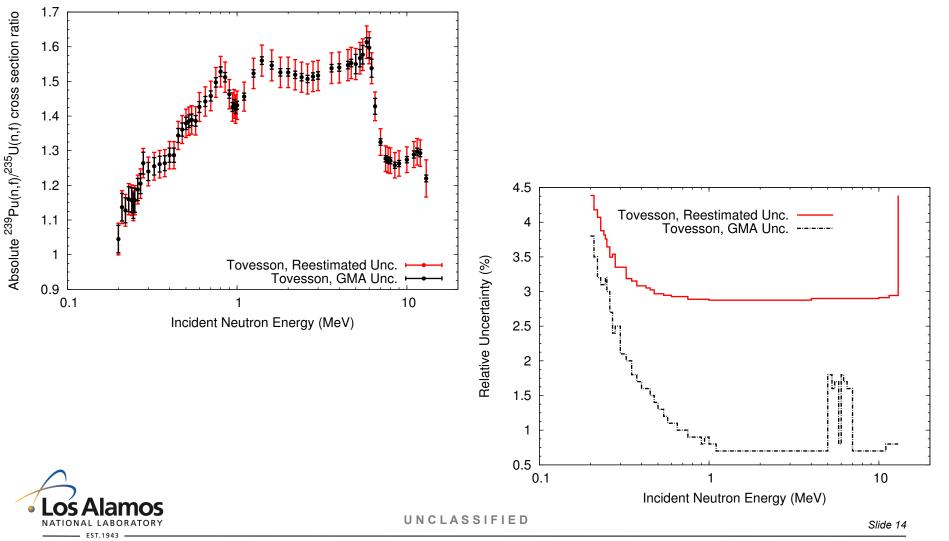
Sample mass unc. should be 1% questionably small!!!

0000						
8002	ratio absolute <sup>235</sup> U(n,f)	0.7	3.8	2.00E-01	$1.30E{+}01$	14271
	ratio absolute <sup>239</sup> U(n,f)	0.8	6.8	2.53E-08	1.00E+01	
654	ratio absolute <sup>235</sup> U(n,f)	1.0	5.7	2.40E-02	$7.50\mathrm{E}{+}00$	
685	ratio absolute $^{235}$ U(n,f)	1.1	1.1	1.45E+01	1.45E+01	
653	ratio absolute <sup>235</sup> U(n,f)	1.2	6.9	1.20E-01	7.00E+00	40824
1014	ratio absolute <sup>235</sup> U(n,f)	1.3	1.6	8.50E-01	$6.00E{+}01$	13801
600	ratio absolute ${}^{235}$ U(n,f)	1.7	27.4	8.50E-04	$3.00E{+}01$	10562
605	ratio absolute <sup>235</sup> U(n,f)	1.7	15.3	5.50E-03	$1.00E{+}00$	20363
608	ratio absolute <sup>235</sup> U(n,f)	2.0	12.6	4.50E-02	5.00E-01	21463
	ratio absolute ${}^{235}$ U(n,f)	2.0	2.1	1.00E+00	$1.40E{+}01$	21195
631	ratio absolute <sup>235</sup> U(n,f)	2.1	2.1	2.53E-08	1.50E-01	
1012	ratio absolute <sup>235</sup> U(n,f)	2.1	5.8	5.70E-01	2.00E + 02	41455





#### A normalization uncertainty was overlooked for Tovesson et al. <sup>239</sup>Pu(n,f)/<sup>235</sup>U(n,f)





#### Example 2, the absolute <sup>239</sup>Pu(n,f) exp. with lowest uncertainties in the GMA database:

	Data Set	Data Type	$\operatorname{Min} \delta$	Max 8	$\operatorname{Min} E$	$M_{\rm SY} E$	EXFOR #
This	<b>61</b> 1	absolute	1.0	1.0	1.45E+01	$1.45E{+}01$	
measurement	644	absolute	2.0	2.0	$1.45E \pm 01$	$1.45E \pm 01$	30634
measurement	615	absolute	2.1	-2.1	5.00E + 00	5.00E + 00	
is part of a	1038	absolute	2.3	7.7	1.00E+00	5.50E+00	30670
series and	640	absolute	2.4	3.1	1.50E-01	9.60E-01	10314
	620	absolute	2.8	6.6	3.00E-02	9.80E-01	20567
correlated with				•			
615-617.				-			
010-017.	8002	ratio absolute <sup>235</sup> U(n,f)	0.7	3.8	2.00E-01	$1.30E{+}01$	14271
	602	ratio absolute <sup>235</sup> U(n,f)	-0.8	6.8	2.53E-08	1.00E+01	
Also, sample	654	ratio absolute <sup>235</sup> U(n,f)	1.0	5.7	2.40 E-02	$7.50\mathrm{E}{+}00$	
AISU, Sample	685	ratio absolute $^{235}$ U(n,f)	1.1	1.1	1.45E+01	$1.45E{+}01$	
mass unc.	653	ratio absolute $^{235}$ U(n,f)	1.2	6.9	1.20E-01	7.00E + 00	40824
Should be 1%,	1014	ratio absolute <sup>235</sup> U(n,f)	-1.3	1.6	8.50E-01	$6.00\mathrm{E}{+}01$	13801
Should be 170,	600	ratio absolute $^{235}$ U(n,f)	1.7	27.4	8.50E-04	$3.00E{+}01$	10562
questionably	605	ratio absolute <sup>235</sup> U(n,f)	1.7	15.3	5.50 E-03	1.00E + 00	20363
	608	ratio absolute $^{235}U(n,f)$	-2.0	12.6	4.50E-02	5.00E-01	21463
small.	609	ratio absolute $^{235}$ U(n,f)	2.0	2.1	1.00E+00	$1.40E{+}01$	21195
	631	ratio absolute ${}^{235}U(n,f)$	2.1	2.1	2.53E-08	1.50E-01	
	1012	ratio absolute <sup>235</sup> U(n,f)	2.1	5.8	5.70E-01	$2.00\mathrm{E}{+}02$	41455
$\sim$				•			



ratio shape  ${}^{10}B(n,\alpha)$ 

5.0 2.53E-08

2.3

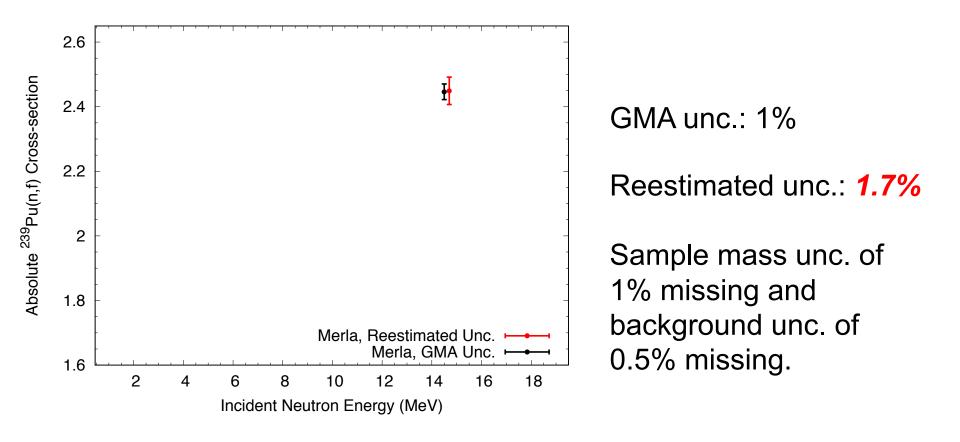
1.50E-01

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

630



#### Example 2, the absolute <sup>239</sup>Pu(n,f) exp. with lowest uncertainties in the GMA database:



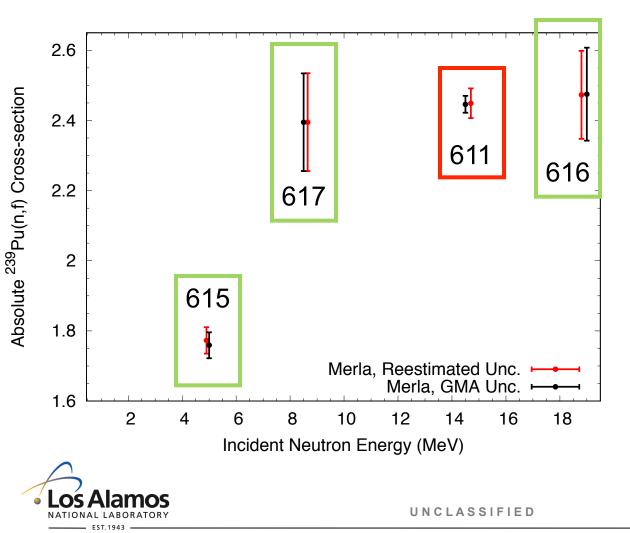


UNCLASSIFIED

Slide 16



#### Example 3, correlations between experimental data sets of Merla because part of a series:

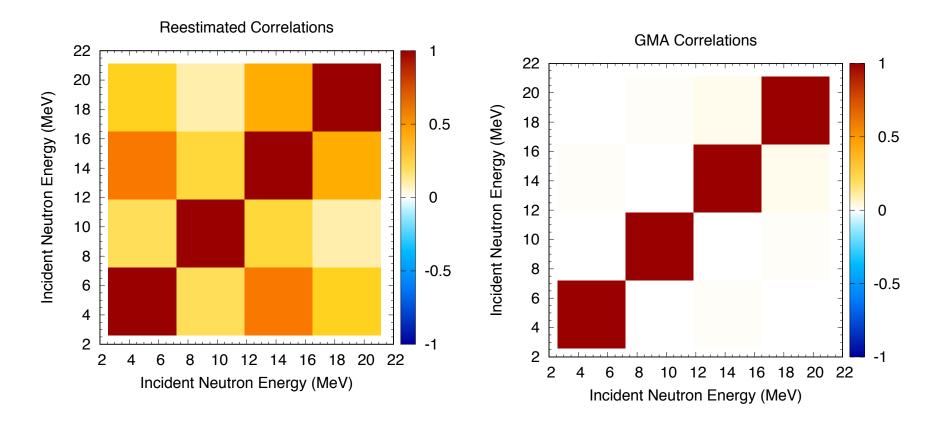


Cross-correlations arise because same sample was used, same detector, same multiple scattering correction, etc.

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA



#### Example 3, correlations of Merla series differ between GMA and ARIADNE estimate:





UNCLASSIFIED

Slide 18



# Updating the <sup>235</sup>U PFNS covariances

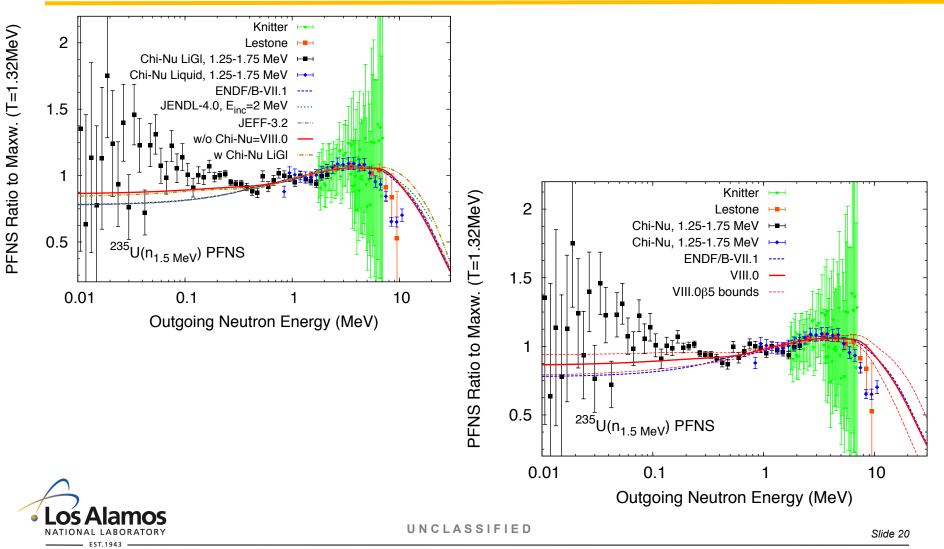


UNCLASSIFIED

Slide 19

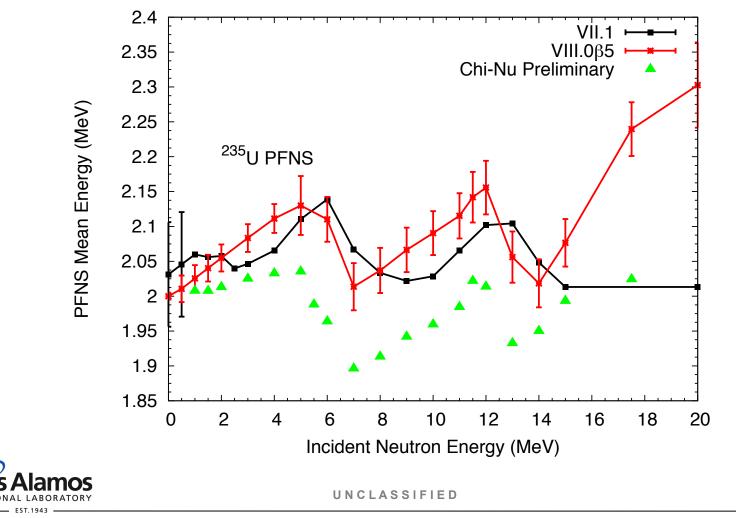


#### **PRELIMINARY Chi-Nu data of 10/2017 are not** within the current VIII.0β5 unc.:





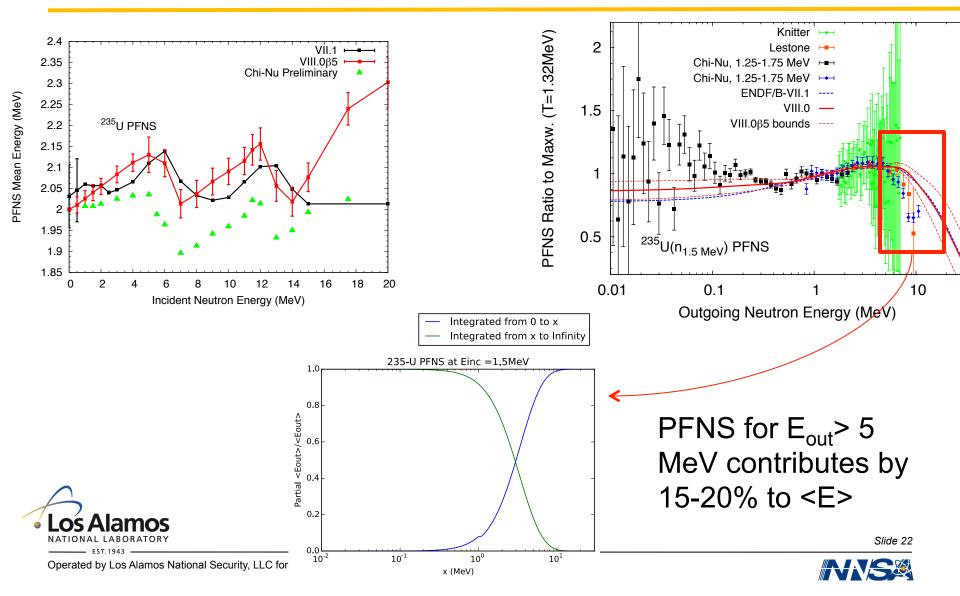
#### The evaluated mean energy uncertainties also do not include those from preliminary Chi-Nu data:



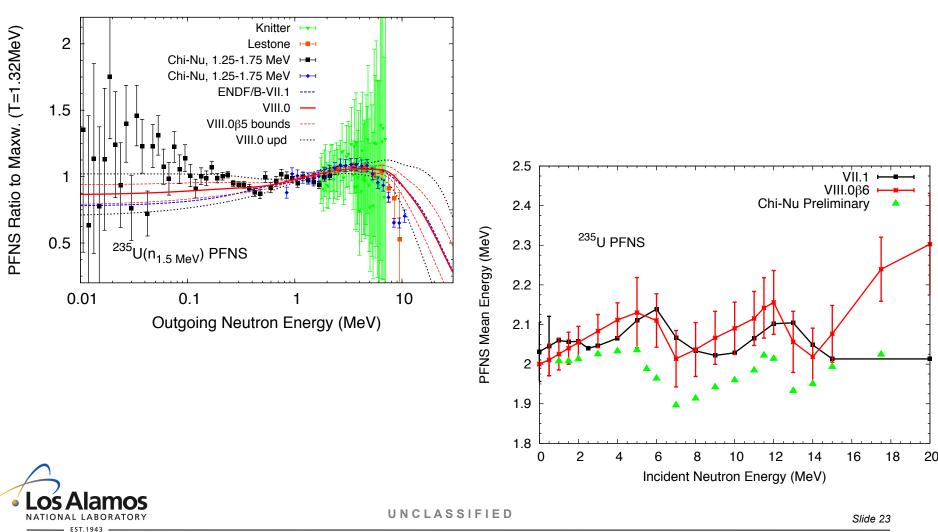
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA



# Chi-Nu(E<sub>out</sub>>5 MeV) tail can impact the mean energy …



#### **Proposed increase of PFNS uncertainties:**





#### **Summary and outlook:**

- A template for typical (n,f) cross-section uncertainty sources encountered in absolute, shape, clean and indirect ratio measurement was established including ranges of uncertainties and suggestions for correlation matrices if information is missing which should help in pinpointing missing uncertainties in future standard evaluations.
- <sup>235</sup>U PFNS covariances are planed to be enlarged after comparison to preliminary Chi-Nu data.

Thank you for your attention! Questions?



UNCLASSIFIED



