A Review of the Nuclear Data Adjustment Activities within WPEC Sub-groups

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Outline

- *Nuclear Data (ND) Adjustment Activities within NEA/NSC/WPEC Sub-groups*
- *WPEC/SG26 (2005-2008)…Target Accuracy Requirements (TAR) for ND Uncertainty reduction*
  - WPEC Expert Group - EGHPRL (SG-C)
- *WPEC/SG33 (2009-2013)… Successful identification of trends in ND and compensating errors*
- *WPEC/SG39 …. Methods to provide feedback from nuclear data adjustment for evaluators*
  - Feedback from WPEC/SG39 to WPEC/SG40(CIELO)
  - Covariance Nuclear Data Adjustment … WPEC/SG44 Exercise
- *WPEC/SG46 … An efficient & effective use of integral experiments for nuclear data validation*
  - WPEC/SG46: “TAR Exercise …. 2nd PART”
- *Conclusion*

The aim of this talk is to show with examples many very important points and benefits of ND Adjustment to the field of ND evaluation

NEA/NSC/WPEC Sub-groups

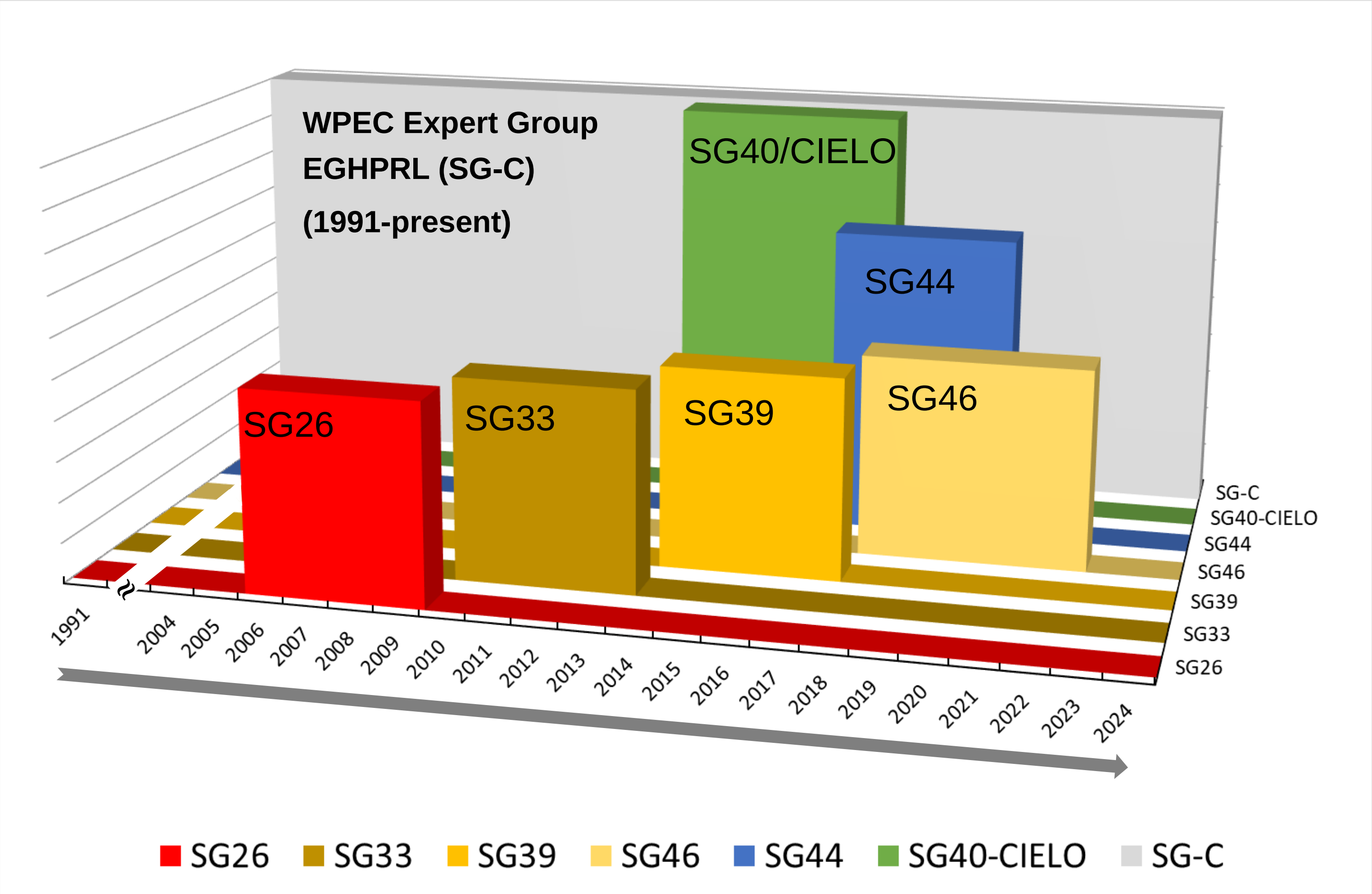
- Overview of NEA/NSC/WPEC Sub-groups using nuclear data adjustment

	SG	Title	Co-ordinator(s)	Status
NEA/NSC/WPEC SGs ND Adjustment	SG46	Efficient and Effective Use of Integral Experiments for Nuclear Data Validation	M. Salvatores and G. Palmiotti O. Cabellos and M. Hursin	Ongoing 2018-present
	SG39	Methods and approaches to provide feedback from nuclear and covariance data adjustment for improvement of nuclear data files	G. Palmiotti and M. Salvatores	Closed 2013-2018
	SG33	Methods and issues for the combined use of integral experiments and covariance data	G. Palmiotti and M. Salvatores	Vol. 33 (2013) 2009-2013
	SG26	Uncertainty and target accuracy assessment for innovative systems using recent covariance data evaluations	M. Salvatores	Vol. 26 (2008) 2006-2009
	SG44	Investigation of Covariance Data in General Purpose Nuclear Data Libraries	V. Sobes and C. de Saint Jean	Closed 2017-2020
	SG40	Collaborative International Evaluated Library Organisation (CIELO) Pilot Project	M. Chadwick	Vol. 40 (2019) 2013-2017
	SG-C	Expert Group on the High Priority Request List (HPRL) for Nuclear Data	D. Bernard	The HPRL (1991-present)

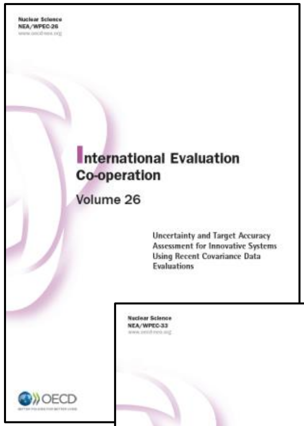
More information available at https://oecd-nea.org/download/wpec/

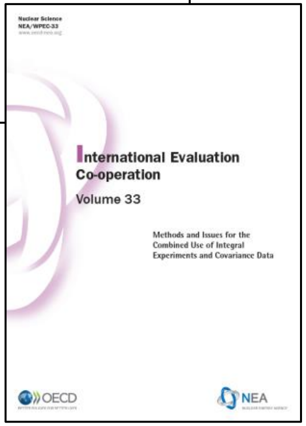
NEA/NSC/WPEC Sub-groups

- Overview of NEA/NSC/WPEC Sub-groups using nuclear data adjustment



- Different WPEC/SGs working in ND Adjustment





❑ Legacy Work WPEC/SG26 (2005-2008)

https://oecd-nea.org/download/wpec/volume26/volume26.pdf

- **SG26:** "*Uncertainty and target accuracy assessment for innovative systems using recent covariance data evaluations*"

○ Systems

ABTR: 250 MWth	Na cooled
SFR: (Burner: CR=0.25) 840 MWth	Na cooled
EFR: 3600 MWth	Na cooled
GFR: 2400 MWth	He cooled
LFR: 900 MWth	Pb cooled
ADMAB: 377 MWth	Pb-Bi cooled
VHTR	TRISO fuel
Extended BU PWR	8.5wo%

○ Integral parameters

Criticality (keff)	(in pcm)
Local Power Peak	(in %)
Burnup reactivity swing	(in pcm)
Reactivity coefficients	(in %)
Nuclide inventories/transmutation at EOL	(in %)

○ A first list of data priorities (i.e**. for uncertainty reduction**) for GEN-IV reactors was established and implemented in the HPRL at NEA

Table 26. SFR: uncertainty reduction requirements needed to meet integral parameter target accuracies

Isotope	Cross-Section	Energy range	Uncertainty (%)			
			Initial	Required		
				λ=1	$\lambda\neq$1 [(a)]	$\lambda\neq$1 [(b)]
U238	σ_{capt}	24.8 - 9.12 keV	9	4	3	3
	σ_{inel}	6.07 - 0.498 MeV	20	5	6	10
Pu238	σ_{capt}	183 - 24.8 keV	20	12	12	10
	σ_{fiss}	6.07 – 0.09 MeV	20	3	3	3
	ν	1.35 - 0.067 MeV	7	3	3	2
Pu239	σ_{capt}	498 – 2.03 keV	12	6	4	4
	σ_{inel}	6.07 – 0.498 MeV	25	12	15	22

TAR Exercise in WPEC/SG26:

- *Covariance data matrices: **BOLNA***
- *Energy structure: "**15 energy groups**"*
- *No-correlations in energy, reactions and isotopes*
- ***15 HPRL entries based on SG26 studies!***

❑ WPEC Expert Group - EGHPRL (SG-C) (1991-present)

- **NEA/WPEC - High Priority Request List (HPRL):** A total list of **31** high-priority requests! (February 2022) https://oecd-nea.org/download/wpec/hprl/

#	Target	Reaction	Quantity	Energy range			Date	Status
1	8- O- 16	(n,a),(n,abs)	SIG	2 MeV	-	20 MeV	12-Sep-08	Work in progess
2	92- U-238	(n,inl)	SIG	65 keV	-	20 MeV	11-Sep-08	Work in progess
3	94-PU-238	(n,f)	SIG	9 keV	-	6 MeV	11-Sep-08	Work in progess
4	95-AM-241	(n,f)	SIG	180 keV	-	20 MeV	11-Sep-08	Work in progess
5	95-AM-242M	(n,f)	SIG	0.5 keV	-	6 MeV	11-Sep-08	Work in progess
6	96-CM-244	(n,f)	SIG	65 keV	-	6 MeV	12-Sep-08	Work in progess
7	96-CM-245	(n,f)	SIG	0.5 keV	-	6 MeV	12-Sep-08	Work in progess
8	94-PU-239	(n,g)	SIG	0.1 eV	-	1.35 MeV	12-Sep-08	Work in progess
9	94-PU-241	(n,g)	SIG	0.1 eV	-	1.35 MeV	12-Sep-08	Work in progess
10	94-PU-240	(n,f)	SIG	0.5 keV	-	5 MeV	15-Sep-08	Work in progess
11	94-PU-240	(n,f)	nubar	200 keV	-	2 MeV	15-Sep-08	Work in progess
12	94-PU-242	(n,f)	SIG	200 keV	-	20 MeV	15-Sep-08	Work in progess
13	82-PB-206	(n,inl)	SIG	0.5 MeV	-	6 MeV	15-Sep-08	Work in progess
14	82-PB-207	(n,inl)	SIG	0.5 MeV	-	6 MeV	15-Sep-08	Work in progess
15	11-NA-23	(n,inl)	SIG	0.5 MeV	-	1.3 MeV	15-Sep-08	Completed!!

- As a main outcome of SG26, **a list of 15 data priorities** (i.e. uncertainty reductions!) for GEN-IV reactors in the HPRL at NEA.
- ND Adjustment allows us to highlight which nuclear-data uncertainties need to be reduced through targeted experiments for increased understanding of applications.

11-NA-23 (n,inl) SIG -0.5 MeV-1.3 MeV
Status Entry:
Completed !!! (as of SG-C review of May 2021) - The Na-23 inelastic scattering cross section has been accurately measured at JRC-Geel [Rouki, 2012]. In the framework of the ASTRID SFR project a new evaluation based on both differential and integral information has been prepared for JEFF-3.2 [Archier, 2011, 2014] and adopted in JEFF-3.3 with uncertainties matching the request.

❑ WPEC/SG33 (2009-2013)

https://oecd-nea.org/download/wpec/sg33/

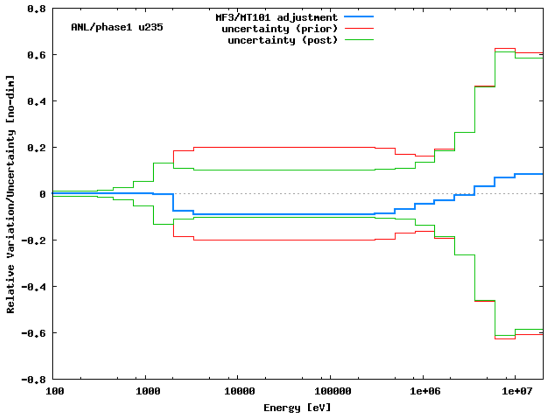
❑ **SG33:** "*Methods and issues for the combined use of integral experiments and covariance data*"

- The statistical adjustment methodologies used worldwide are well understood and essentially equivalent
- An example of **successful identification of trends in nuclear data**

1) SG33/Exercise

"*The necessity of decreasing the ^{235}U capture cross-section in the unresolved resonance range*"

Figure. Rel. change to ENDF/B-VII.0 after adjustment



2) SG39/V. Huy et al. CEA

"Assimilation results suggest a significant modification for ***U235 capture****:*

~30% decrease around 1-2 keV

~10% increase in Unresolved Reson. Range (URR)

when using JEFF3.1.1 as "a priori" data."

Ref.: V. Huy et al. (CEA) SG39 draft report

- ND Adjustments can suggest needed changes in nuclear data to better predict applications

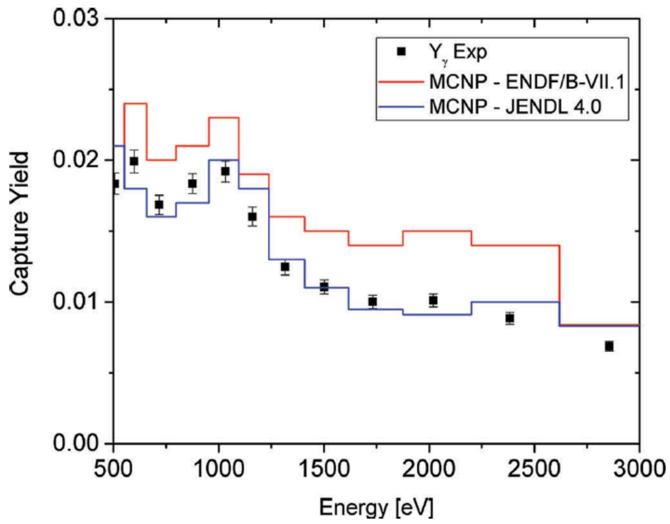
- This trend was confirmed by new measurements (RPI/USA) and adopted in recent evaluations.

Ref: *SG33 results are availabe at: https://www.oecd-nea.org/download/wpec/sg33/benchmark/results/*

❑ **SG33:** "*Methods and issues for the combined use of integral experiments and covariance data*"

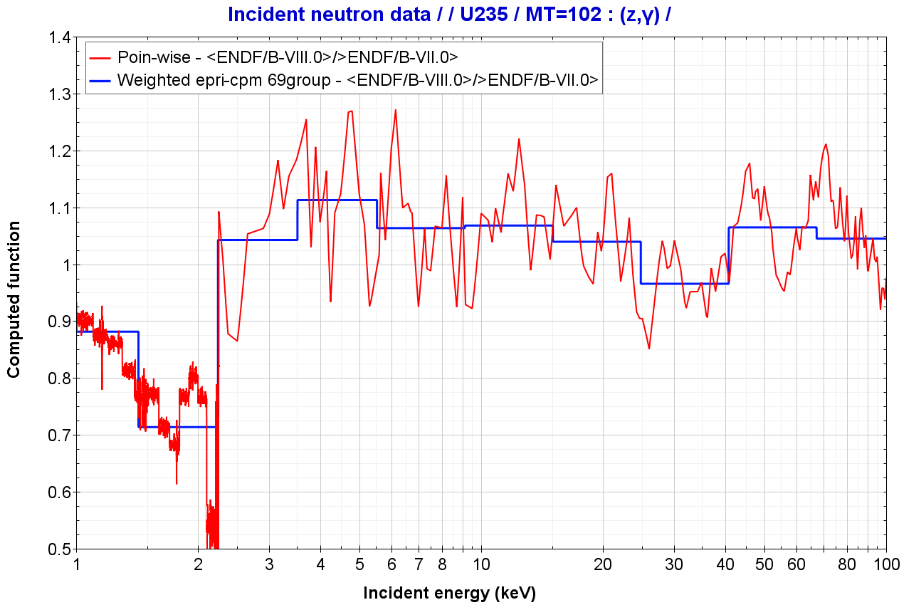
- This trend in $^{235}U(n,\gamma)$ was confirmed by new measurements (RPI/USA) and adopted in recent evaluations.

Figure. Differences between the experiment and evaluations in the energy range from 0.5-3 keV of the capture yield for ^{235}U



Ref.: Y. Danon et al, NSE, 187, 291-301 (2017)

Figure. Differences in $^{235}U(n,\gamma)$ between recent/CIELO evaluations and ENDF/B-VII.0: RRR 1keV-2keV & URRR 2keV-60keV



Ref: *SG33 results are availabe at: https://www.oecd-nea.org/download/wpec/sg33/benchmark/results/*

❑ WPEC/SG33 (2009-2013)

https://oecd-nea.org/download/wpec/sg33/

❑ **SG33:** “*Methods and issues for the combined use of integral experiments and covariance data*”

- An example of successful identification of compensations in nuclear data… **“correlated trends for the Pu-239 inelastic xs and the prompt fission n spectra”**
  - slight decrease of (n,n’) and harder fission spectrum ➟ better C/E
  - strong decrease of (n,n’) and same fission spectrum ➟ better C/E

Figure. Relative variation 239Pu(n,n’)

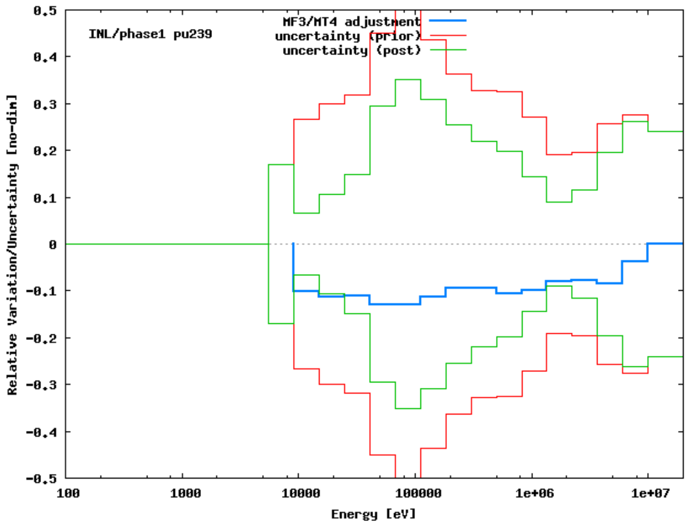
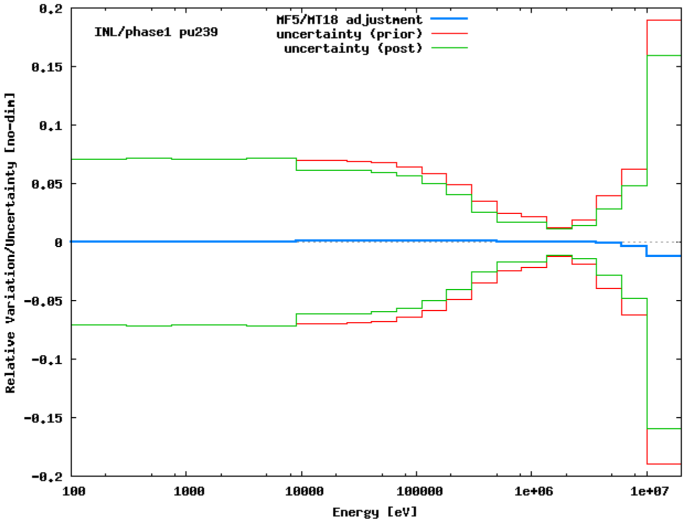


Figure. Relative variation 239Pu(PFNS)



- ND Adjustment allows us to highlight compensating errors

❑ WPEC/SG39 (2013-2017)

https://oecd-nea.org/download/wpec/sg39/

- **SG39:** "*Methods and approaches to provide feedback from nuclear data and covariance data adjustment for improvement*"

- SG39 reviewed the state-of-the-art methods in nuclear data adjustment and identified several challenges and limitations in the current tools and data
  - **Integral experiments** play a crucial role in any nuclear data adjustment/calibration study
  - **Selection of integral benchmarks (keff, RRs, etc..)** focused on specific nuclear data and/or energy ranges
  - **Integral criticality experiments** (i.e keff), although very important, should be handled with precaution in ND adjustment. Discrepancy between keff-C/E can result from multiple effects and their use in adjustment may provoke **compensating adjustments**
  - **Specific adjustment procedures** (e.g. PIA or APIA methods described in this report) and by the choice of appropriate experiments **can avoid such compensations**
- Covariance data assessment: required completeness, consistency, etc…: WPEC/SG44
- Feedbacks between SG39 and evaluators in WPEC/SG40-CIELO

ND Compensating Effects in Criticality

- Example of a good selection of integral benchmarks focused on specific nuclear data and/or energy ranges: **The Big10 (IEU-MET-FAST-007)** –> Energy region: URR for ^{238}U and ^{235}U

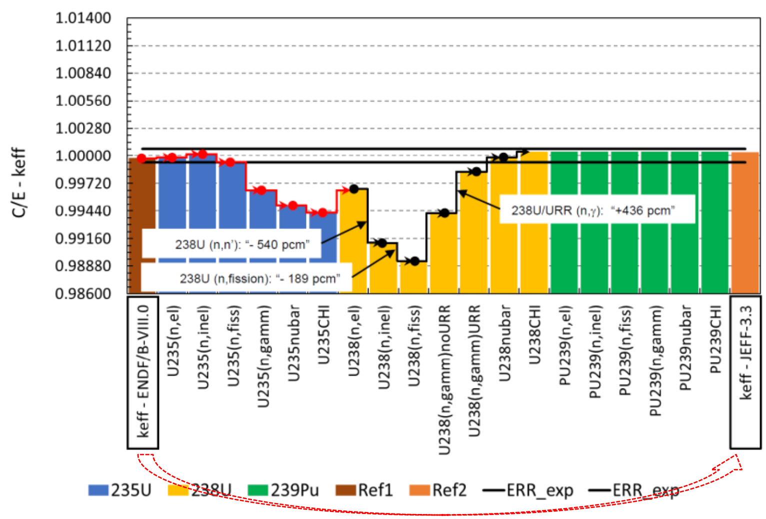
Table. C/E comparison with IEU-MET-FAST-007: **Big-10**

Quantity	ΔEexp/E	C/E	
		JEFF-3.3	ENDF/B-VIII.0
K-eff (detailed model)	±70 (pcm)	1.00041	0.99979
K-eff (Improved simplified model)	±80 (pcm)	0.99997	0.99951

- Good performance in keff !!

- **Indications from integral benchmarks on ^{238}U evaluation: Criticality**

Figure. Changes in criticality for **Big-10** when individual cross-section channels are substituted between ENDF/B-VIII.0 and JEFF-3.3. Perturbations in keff calculated with **NDaST code**.



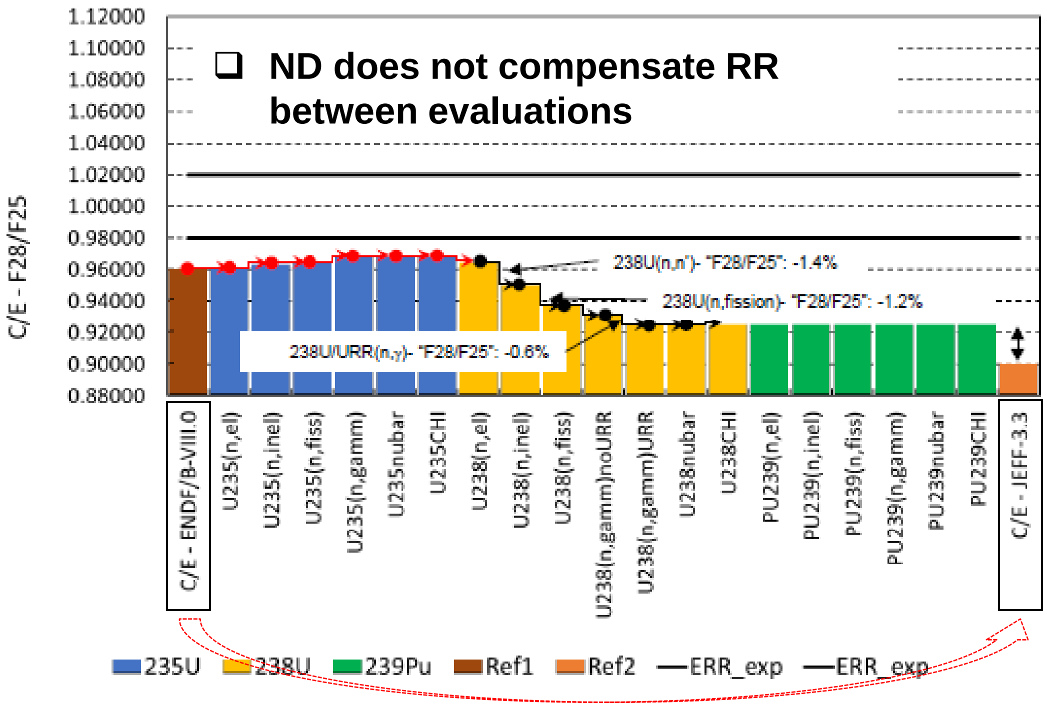
- **ND compensations between JEFF-3.3 and ENDF/B-VIII.0 in keff:**
  - U238(n,n') : - 540 pcm
  - U238(n,γ) : +436 pcm

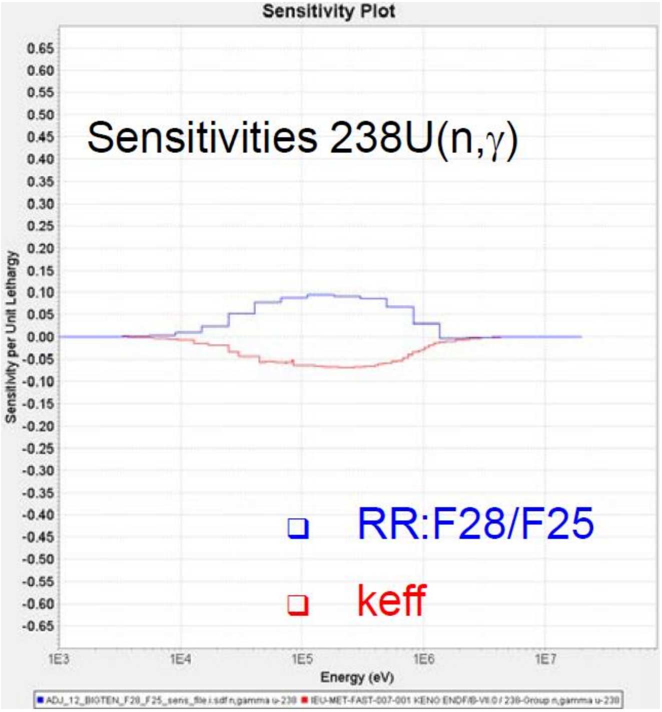
Ref.: *O Cabellos et al, The importance of using different integral benchmarks to provide valuable feedbacks to the evaluation process, JEFDOC-2015, Nov. 2020*

ND Compensating Effects in Reaction Rates

- Indications from integral benchmarks on ^{238}U evaluations: **Reaction Rates (RRs)**

Figure. Changes in F28/F25 for **Big-10** when individual cross-section channels are substituted between ENDF/B-VIII.0 and JEFF-3.3. Perturbations in keff calculated with **NDaST code**.





- **Using different integral benchmarks (with different sensitivities) may avoid compensating effects in the evaluation!!**

Figure. The energy dependent sensitivity profiles of keff and F28/F25 with respect to ^{238}U nuclear data are compared in Big-10.

Ref.: *JEFDOC-2015, Nov. 2020*

- **SG46:** "*Efficient and Effective Use of Integral Experiments for Nuclear Data Validation*"

  - **Guidelines/protocols for selecting and prioritizing integral experiments for ND validation**
    - Various approaches to assess selection of integral experiments
    - Integral Experiments beyond keff: $\beta_{effective}$/shielding/depletion benchmarks… for ND validation
    - Effects of combining differential and integral experiments were investigated
    - Marginalized Likelihood Optimization (MLO)…a more inclusive use of the integral experiments
    - Machine Learning algorithms
  - **Generalized adjustment methodologies to provide unambiguous feedbacks to evaluators**
    - CE sensitivity coefficients and CE covariances to mitigate method bias on posterior distribution
    - NEA Sensitivity coefficients database to allow more efficient use of the existing knowledge
    - For deterministic adjustments : APIA, bias factor methods approaches were presented
    - For stochastic approaches: BMC, MOCABA,…
  - **To provide updated Target Accuracy requirements (TAR) for ND uncertainty reduction**
    - Preliminary results provided

- SG46: “New TAR Exercise …. An updated work of SG26”

- **TAR WPEC/SG46 methodology** based on:
  - *New covariance data matrices: ENDF/B-VIII.0, JEFF-3.3 and JENDL-4.0u*
  - *Using correlations in energy, reactions and isotopes*
  - *Energy structure: “7 energy groups (based on physical considerations)”*

- To provide **updated TAR for nuclear data uncertainty reduction:**
  - *“It is essential to **verify the status of design target accuracies** and their potential evolution (reactor operation and fuel cycle parameters)”*
  - *To establish TARs for Nuclear Data Libraries*
  - *New reactors concepts are presently explored besides Gen-IV, MA burners, and ADS: MSR, SMR, micro reactors, and test reactors*

- **WPEC/SG46** is again a new **bridge** between ND evaluators and end-users in the utilisation of integral experiments

- *“The **HPRL** will certainly benefit from an update, to motivate and focus new experiments and to meet potential new requirements”*

❑ J-SFR: TAR preliminary results for ENDF/B-VIII.0: Other integral parameters

Table. Target accuracy requirement on top-10 most important reactions. **Correlations** in TAR exercise - set C, **ENDF/B-VIII.0**: **keff**

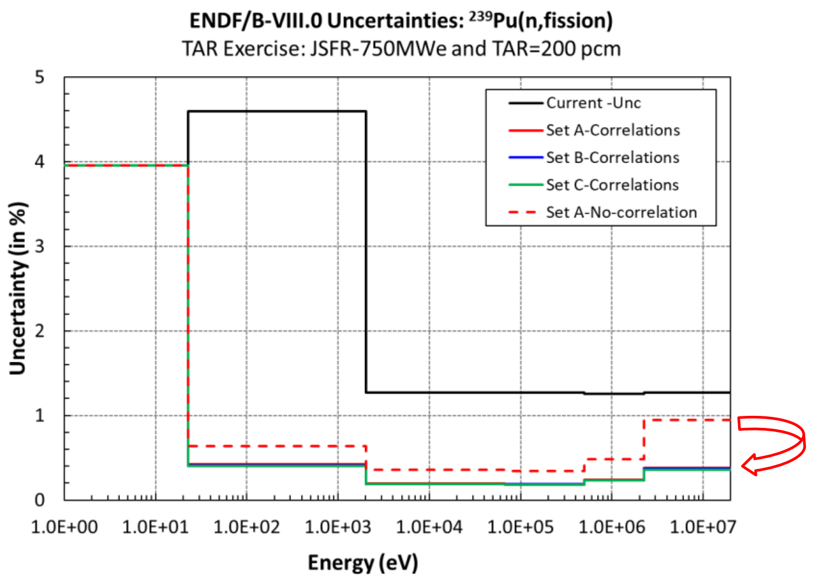
Rank #	Reaction	Energy Group	Current (%)	Target (%)	Rel. Unc. Reduction (%)
1	pu-239(n,fission)	3	1.3	0.2	18.5
2	pu-239(n,fission)	4	1.3	0.2	17.3
3	pu-239(n,fission)	2	1.3	0.2	9.4
4	fe-56(n,inelastic)	2	18.9	1.5	8.4
5	pu-239(n,fission)	5	4.6	0.4	5.2
6	u-238(n,gamma)	4	1.5	0.3	5.1
7	pu-239(n,gamma)	4	7.5	0.6	4.0
8	u-238(n,gamma)	3	1.8	0.3	3.8
9	pu-239(n,fission)	1	1.3	0.4	2.2
10	pu-239(n,gamma)	3	9.3	0.9	1.9
11	u-238(n,inelastic)	1	5.7	1.3	1.8

Total keff unc. due to ND with ENDF/B-VIII.0: 969 pcm

TAR JSFR/keff value : 200 pcm

Ref.: K. Yokoyama, Input Information for SG46 Target Accuracy Requirements (TAR) Exercise using Models of 750MWe JSFR Core, WPEC/SG46 November 2019

Figure. An example of uncertainty reduction for ^{239}Pu(n,fission) using different TAR solving approaches



NOTE: Set-A no correlations is equivalent to set-A/SG26

Ref.: *O Cabellos, WPEC/SG46 TAR Exercise: Preliminary results WPEC/SG46 Meeting , Dec. 2021*

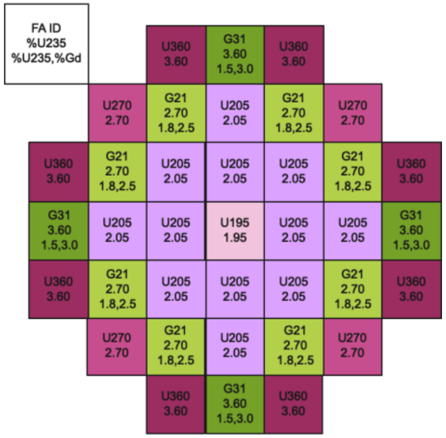
TAR Exercise: Preliminary Results

❑ NuScale SMR core (160 MWth): TAR preliminary results - ENDF/B-VIII.0: keff

Table. Target accuracy requirement on top-10 most important reactions. **Correlations** in TAR exercise - set A, **ENDF/B-VIII.0**: **keff**

Rank #	Reaction	Energy Group	Current (%)	Target (%)	Rel. Unc. Reduction (%)
1	U235 (nubar)	7	0.7	0.2	67.8
2	U238 (n,gamma)	7	1.9	0.5	12.2
3	U238 (n,gamma)	5	2.2	0.7	6
4	U238 (n,gamma)	6	2.3	0.8	5.3
5	U235 (n,gamma)	7	1.6	0.6	4.7
6	U235 (n,gamma)	5	6	1.7	0.8
7	U235 (nubar)	6	0.7	0.6	0.6
8	U238(n,inelastic)	1	24.3	4.2	0.5
9	U235-CHI	1	5.2	1.9	0.4
10	U238 (n,gamma)	4	1.5	1.1	0.3

Total keff unc. due to ND with ENDF/B-VIII.0: 530 pcm

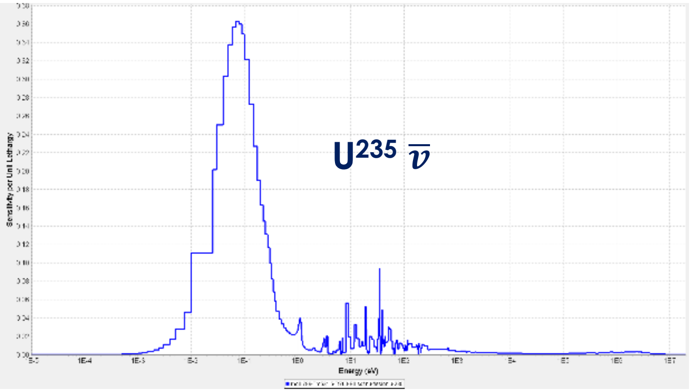


Core loading pattern

UQ in keff

- ENDF/B-VII.1 : 777 pcm
- **ENDF/B-VIII.0: 530 pcm**
- JEFF-3.3 : 678 pcm
- JENDL-4.0 : 536 pcm

Figure. Energy-dependent sensitivity profile for ^{235}U(nubar) in NuScale



TAR NuScale keff value : 300 pcm

Ref.: *UPM, TAR Exercise in NuScale, Preliminary results, Jan. 2022*

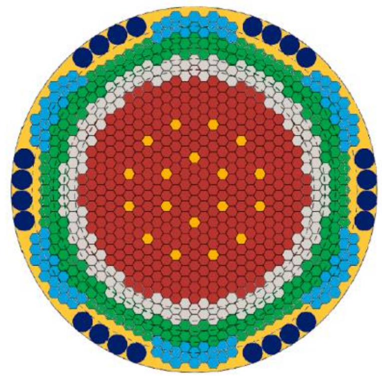
TAR Exercise: Preliminary Results

❑ MOLTEX SSR-W (300 MWe): TAR preliminary results - ENDF/B-VII.1: keff

Table. Target accuracy requirement on top-10 most important reactions. **Correlations** in TAR exercise - set A, **ENDF/B-VII.1**: **keff**

Rank #	Reaction	Energy Group	Current (%)	Target (%)	Rel. Unc. Reduction (%)
1	Cl35 (n,p)	2	6.6	0.9	37.4
2	Cl35 (n,p)	3	12.0	1.6	14.9
3	Pu239(n,gamma)	4	8.4	1.3	12.0
4	Cl35 (n,p)	1	8.4	1.2	8.9
5	Pu239(n,gamma)	3	10.4	2.0	4.6
6	Fe56(n,elastic)	3	9.2	1.9	4.3
7	Fe56(n,gamma)	3	16.8	2.8	1.8
8	Pu240(n,gamma)	2	59.3	4.2	1.8
9	Cl35(n,p)	4	11.1	3.7	1.5
10	Fe56(elastic)	2	5.4	1.9	1.3

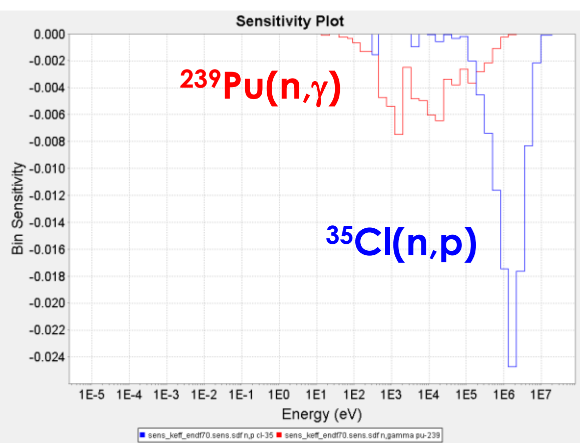
Total keff unc. due to ND with ENDF/B-VII.1: 836 pcm
+ with unc. Cl35(TENDL2021)



UQ in keff

- **ENDF/B-VII.1 : 584 pcm**
- ENDF/B-VIII.0: 922 pcm
- JEFF-3.3 :1090 pcm

Figure. Energy-dependent sensitivity profile for ^{35}Cl(n,p) and ^{239}Pu(n,γ) in MOLTEX SSR-W



TAR MOLTEX keff value : 300 pcm

Ref.: *UPM & MOLTEX Clean Energy, TAR Exercise in MOLTEX SSR-W, Preliminary results, Jan. 2022*

Conclusion

- **In summary ...**

"WPEC was established in 1989 to promote the exchange of information on nuclear data evaluations, measurements, nuclear model calculations, validation, and related topics, and to provide a framework for co-operative activities between the participating projects".

https://www.oecd-nea.org/jcms/pl_23072/working-party-on-international-nuclear-data-evaluation-co-operation-wpec

Since 2006, four NEA/WPEC/SGs (WPEC/SG26, SG33, SG39 and SG46) were launched working on Nuclear Data Adjustment Activities. These SGs were led by Massimo Salvatores with more that 30 participants from all over the world including US, Europe, Japan and China.

These WPEC/SGs were/are mainly devoted for improving the ND quality (i.e. evaluation) and the use of nuclear data in reactor design. They use scientific-based adjustment and assimilation methodologies that exploits the information gathered through the measurements carried out in integral experiments.

Back-up Slides

Selection of "clean" benchmarks focused on specific ND and/or energy ranges

INDUSTRIALES ETSII | UPM

- Example of ND adjustment using PWR simulations… This is a typical example of a "problem-dependent" adjustment with many other physics/effects affecting the bias

Figure: Differences in Boron let-down with measurements in a typical 1000MWe- PWR Westinghouse: Prior – Posterior

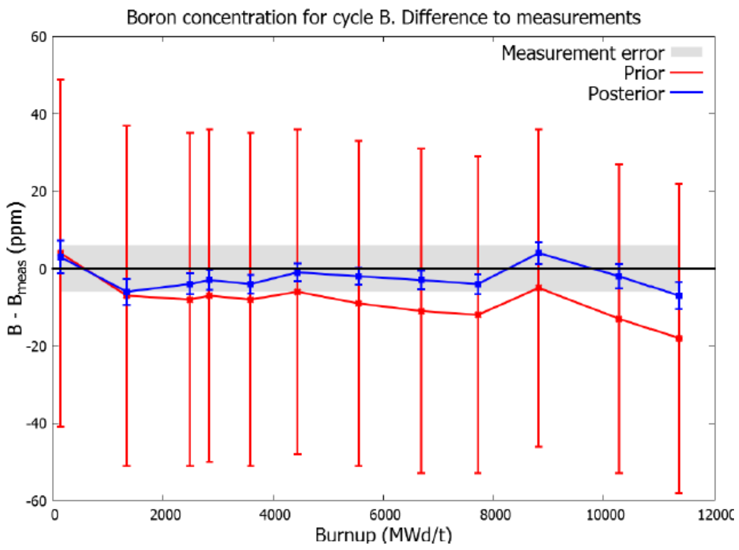
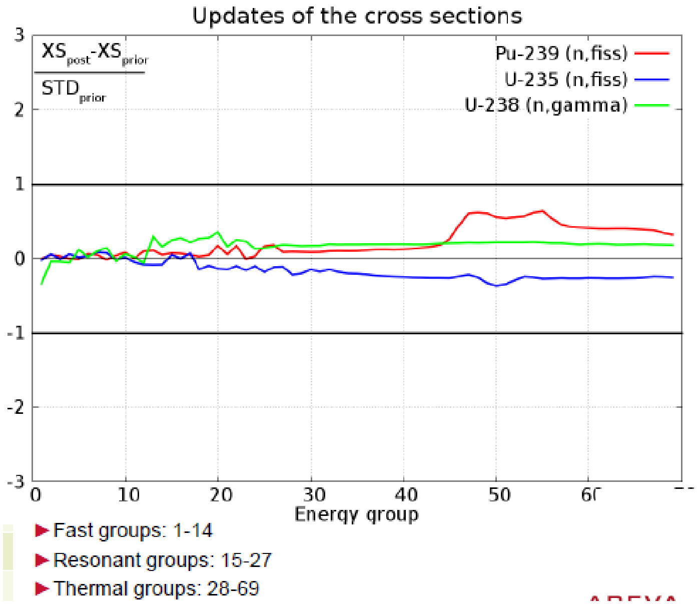


Figure: Updates of the cross-sections for this specific application



Ref.: *E. Castro et al., Improved PWR Simulations by Monte-Carlo Unc. Analysis and Bayesian Inference, WPEC/SG39, April 2015*

Feedback from SG39 to SG40/CIELO…. too late!?

INDUSTRIALES ETSII | UPM

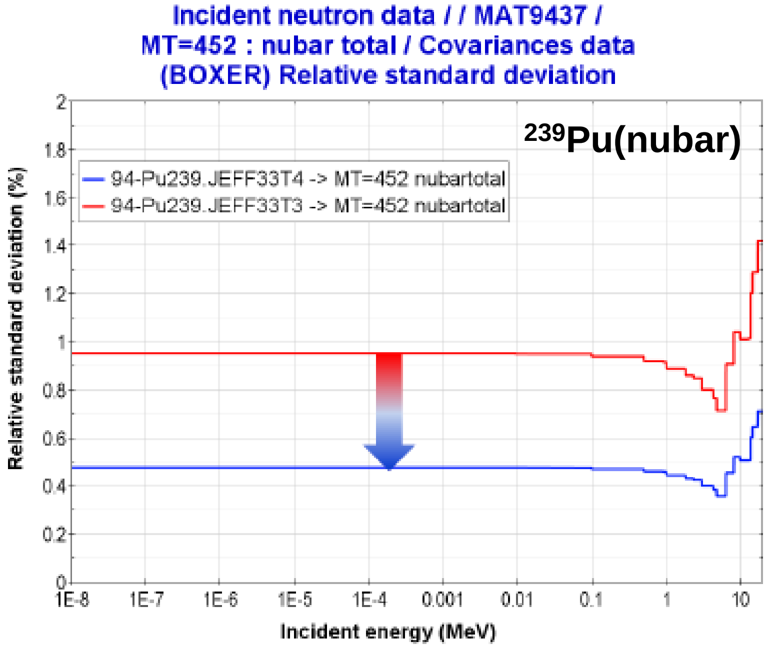
- **SG40:** "*Collaborative International Evaluated Library Organisation (CIELO) Pilot Project*"
  - *Large differences between CIELO1=ENDF/B-VIII.0 and CIELO2=JEFF3.3 covariance data*
  - *In many cases calculated 1σ-uncertainties would not cover the C/E spread of the experiments*
  - *When covariance will be available, more relevant feedback could be provided through data assimilation trying to avoid compensations*
    - *Generate covariance data at the same time and consistently with the cross-section evaluation*
    - *Provide the missing data in covariance matrix: P1 elastic, secondary energy distribution for inelastic,…"*
    - *Avoid processing issues of new covariance data*
  - *CIELO does a good job on critical masses that are mostly used in validation, but perform poorly on others not so often used ones (e. g. ZPR/9-34, ZPR3-54) or reactivity variations (e.g.coolant reactivity void, rod worth)…**this may indicate compensations in nuclear data***
  - *Adjustment is bigger than the standard deviation:*
    - *^{56}Fe inelastic from 10 MeV to 800 Kev and capture from 800Kev to 60 Kev*
    - *^{238}U inelastic from 1.3 MeV to 800 Kev*
    - *^{239}Pu capture from 15 KeV to 2 KeV and (n,2n) from 10 to 6 MeV*

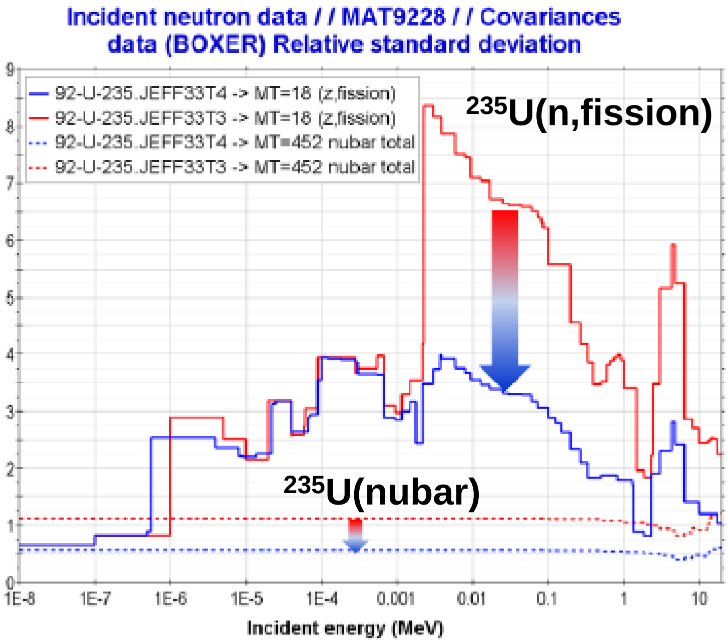
Ref.: *G. Palmiotti, M. Salvatores, CIELO1 and CIELO2 C/E impact on selected integral experiments and consistency with current covariance matrices, WPEC/SG39, Nov. 2017(and May 2018)*

Integral Adjustment of ND Uncertainties

- Differences between JEFF-3.3T4 (=JEFF-3.3) and JEFF-3.3T3: Adjusting covariances to IE?

  - **JEFF-3.3T3:** uncertainty in the fast range was based on microscopic experiment only.
    See files at: http://www.oecd-nea.org/dbdata/jeff-beta/JEFF33T3/neutrons/
  - **JEFF-3.3T4:** reduced uncertainties to reflect adjustment (e.g. fast range to JEZEBEL).
    See files at: http://www.oecd-nea.org/dbdata/jeff-beta/JEFF33T4/neutrons/





Ref.: *O. Cabellos et al, Checking, processing and verification of nuclear data covariances, JEFDOC-1887, Nov. 2017*

Covariance Nuclear Data Adjustment … WPEC/SG44 Exercise

INDUSTRIALES ETSII | UPM

- **SG44:** "*Investigation of Covariance Data in General Purpose Nuclear Data Libraries*"

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ELSEVIER

WPEC Subgroup 44 computational Inter-comparison exercise on correlations in nuclear data libraries

Check for updates

Vladimir Sobes[a,*], Cyrille de Saint Jean[b], Dimitri Rochman[c], Oscar Cabellos[d], Andrew Holcomb[e], Eric Bauge[a], Roberto Capote[f], Andrej Trkov[g], Michael Fleming[h]

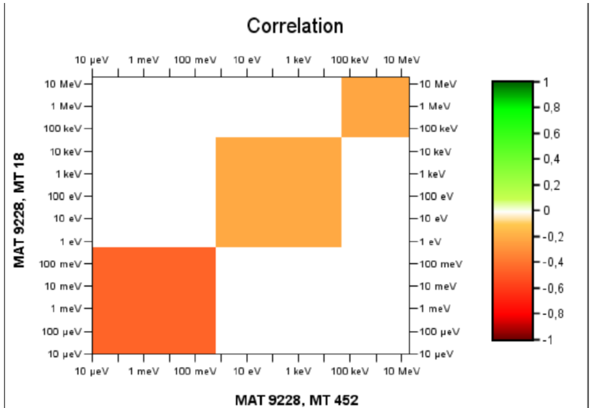
A general and simple 1D one-group simplified transport equation used in the adjustment…

$$k_{eff} = \frac{\bar{\nu} \cdot \sigma_f}{\sigma_f + \sigma_\gamma + L}$$

Table: Correlation matrix ^{239}Pu derived from the "fit" of Jezebel critical assembly for three different methodologies.

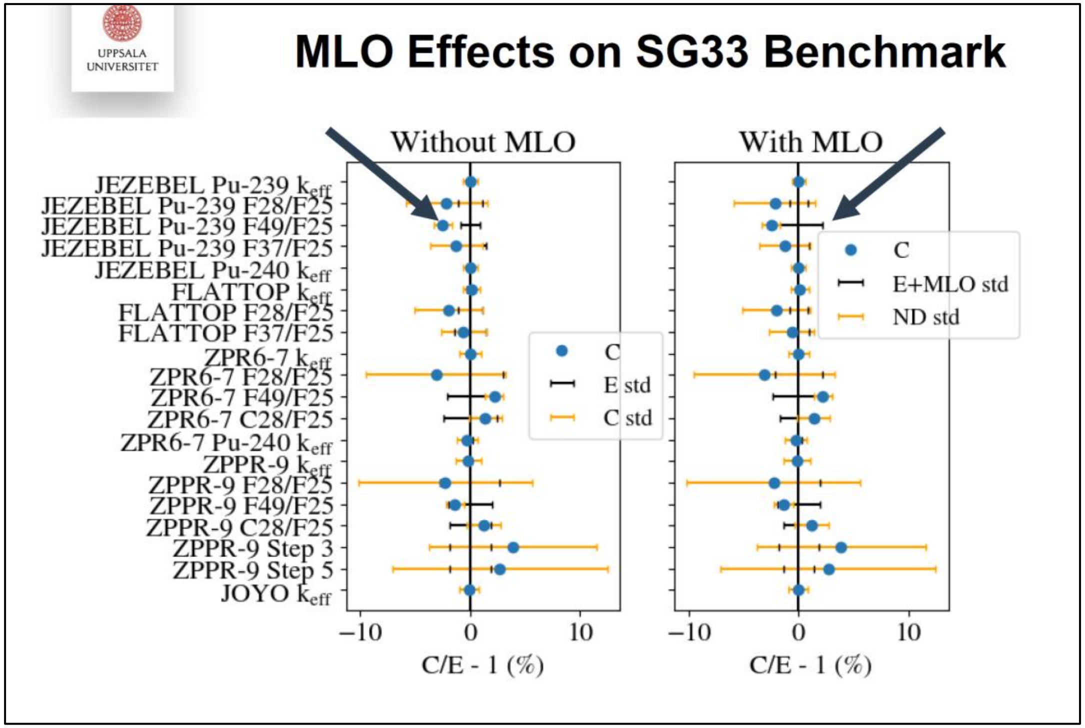
239Pu – correlations	Sobes et al. ENDF/B-VIII.0	Yokoyama et al. JENDL-4.0	IAEA&Cabellos et al ENDF/B-VIII.0	IAEA&Cabellos et al JEFF-3.3	IAEA&Cabellos et al JENDL-4.0
Fission-nubar	-48	-58	-49	-87	-13
Capture-nubar	+10	+28	+34	+19	+32
Fission-capture	-	+26	+63	+15	+87

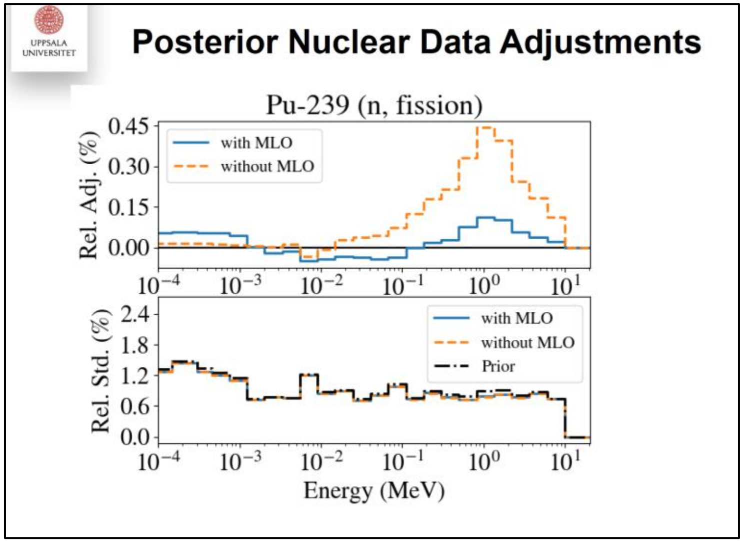
Figure: Correlation matrix ^{235}U(nubar-fission) from the "fit" of Godiva critical assembly using 1D-keff.



- **SG46:** "*Efficient and Effective Use of Integral Experiments for Nuclear Data Validation*"

  - **Example of MLO technique for treating inconsistent data in integral adjustment**
    - Adding an extra uncertainty to each experiment by maximizing the Likelihood function





Ref.: *H. Sjöstrand et al.,Treating inconsistent data in integral adjusting using MLO, WPEC/SG46, Nov. 2019*

❑ TAR Benchmark Specifications:

https://oecd-nea.org/download/wpec/sg46/

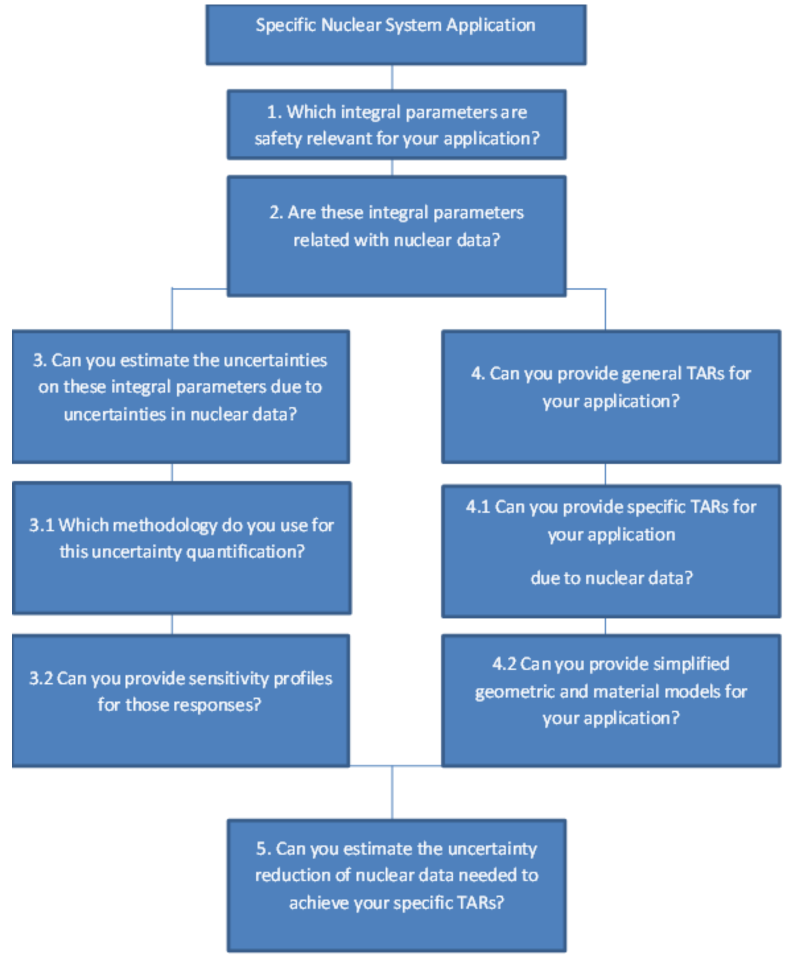
❑ Benchmark Specifications: WPEC/SG46 Exercise on Target Accuracy Requirement (TAR)

WPEC/SG46, May 2021

Table 1. Energy group structure

Group #	Lower Energy (eV)	Upper Energy (eV)	
1	$2.23130\ 10^{6}$	$1.96403\ 10^{7}$	Above Threshold fertile
2	$4.97871\ 10^{5}$	$2.23130\ 10^{6}$	Above Threshold inelastic
3	$6.73795\ 10^{4}$	$4.97871\ 10^{5}$	Continuum to URR
4	$2.03468\ 10^{3}$	$6.73795\ 10^{4}$	URR
5	$2.26033\ 10^{1}$	$2.03468\ 10^{3}$	RRR
6	$5.40000\ 10^{-1}$	$2.26033\ 10^{1}$	EPITHERMAL
7	$1.40000\ 10^{-5}$	$5.40000\ 10^{-1}$	THERMAL

Figure 1. Procedure for any specific application to participate in WPEC/SG46 exercise on TAR



https://oecd-nea.org/download/wpec/sg46/materials/documents/WPEC_SG46_TAR_Exercise-v2_HM41-OC_GP-OC-v1.pdf

TAR Exercise: ND Uncertainty Reduction

❑ Who is involved in it?

$$\boldsymbol{To\ minimize}: \left(\sum_i \frac{\lambda_i}{\Delta x_i^2}\right)$$
$$\boldsymbol{i = 1, \ldots, K}$$

❑ ND Differential measurement experts
- Cost parameters assigned to isotopes, reactions, and/or energy group

The objective function is constrained to:

1) $\boldsymbol{\Delta x_{i0} \geq \Delta x_i \geq 0; i = 1 \ldots K}$

❑ ND Processing
- AMPX/NJOY codes
- Issues to be solved:
  - MF34/O16-P_1 for JENDL
  - MF34/235U and 238U in ENDF/B-VIII.0
- Limitations in NJOY: unique Ein value for MF35/PFNS
- Correlations between MATs-MTs-Energy to be processed and used

❑ ND Evaluators
- Uncertainties for all MATs/MTs
- Credible uncertainties
- Mathematically "positive definite" for full covariance data

❑ ND Exp/Evaluators
- Exp./Eva. lower uncertainties
- Standards?

❑ Reactor Designers
- Safety margins
- Licensing

2) $\sum_i S_{ni}^2 \cdot \Delta x_i^2 + \sum_{ii'} \boldsymbol{S_{ni}} \cdot \boldsymbol{\Delta x_i} \cdot \boldsymbol{corr_{ii'}} \cdot \boldsymbol{\Delta x_{i'}}\ \boldsymbol{S_{ni}^+} \leq (R_n^T)^2; n = 1 \ldots N$

❑ Reactor Physicists
- Reactor Model
- Sensitivity Profiles

❑ TAR Solving
- Assumptions
- Inverse method + others ML/AI?
- **Note:** TAR calculations performed by UPM using the solver DONLP2 (Spelluci P., 1998)

Ref.: Spellucci, P. "*An SQP method for general nonlinear programs using only equality constrained subproblems*". Math. Program. 82, 413–448 (1998)

TAR Exercise: Preliminary Results

❑ J-SFR: TAR preliminary results for ENDF/B-VIII.0: Other integral parameters

Table. Target accuracy requirement on top-10 most important reactions. **Correlations** in TAR exercise - set C, **ENDF/B-VIII.0**: **keff**

Rank #	Reaction	Energy Group	Current (%)	Target (%)	Rel. Unc. Reduction (%)
1	pu-239(n,fission)	3	1.3	0.2	18.5
2	pu-239(n,fission)	4	1.3	0.2	17.3
3	pu-239(n,fission)	2	1.3	0.2	9.4
4	fe-56(n,inelastic)	2	18.9	1.5	8.4
5	pu-239(n,fission)	5	4.6	0.4	5.2
6	u-238(n,gamma)	4	1.5	0.3	5.1
7	pu-239(n,gamma)	4	7.5	0.6	4.0
8	u-238(n,gamma)	3	1.8	0.3	3.8
9	pu-239(n,fission)	1	1.3	0.4	2.2
10	pu-239(n,gamma)	3	9.3	0.9	1.9
11	u-238(n,inelastic)	1	5.7	1.3	1.8

Total keff unc. due to ND with ENDF/B-VIII.0: 969 pcm

TAR JSFR/keff value : 200 pcm

Ref.: K. Yokoyama, Input Information for SG46 Target Accuracy Requirements (TAR) Exercise using Models of 750MWe JSFR Core, WPEC/SG46 November 2019

Table. Target accuracy requirement on top-10 most important reactions. **Correlations** in TAR exercise - set C, **ENDF/B-VIII.0**: **SVR**

Rank #	Reaction	Energy Group	Current (%)	Target (%)	Rel. Unc. Reduction (%)
1	pu-239(n,fission)	5	4.6	1.7	50.2
2	na-23(n,elastic)	3	7.3	2.8	18.2
3	na-23(n,inelastic)	2	11.8	6.1	17.8
4	pu-239(n,gamma)	5	7.7	3.8	4.8
5	na-23(n,elastic)	2	6.8	3.9	3.6
6	o-16(n,elastic-P1)	2	58.5	13.7	2.9
7	na-23(n,gamma)	1	56.9	16.5	1.3
8	o-16(n,inelastic)	1	265.2	55.1	0.3
9	pu-240(n,fission)	5	18.9	12.6	0.3
10	na-23(n,gamma)	2	67.5	25.8	0.3
11	u-238(n,elastic-P1)	2	0	10	-0.2

Total SVR unc. due to ND with ENDF/B-VIII.0: 5.9%

TAR JSFR/SVR (sodium void reactivity): 3%

Ref.: *O Cabellos, WPEC/SG46 TAR Exercise: Preliminary results WPEC/SG46 Meeting , Dec. 2021*