UPM/IAEA contributions to inter-comparison study

Oscar Cabellos
UPM
oscar.cabellos@upm.es

A. Trkov, R. Capote
IAEA/NDS

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WPEC/SG44 inter-comparison study

“*The goal of this inter-comparison study is to* ***identify "stable" correlations*** *which come from the immutable nature of the reactor physics in the integral benchmarks and can be estimated almost independently of the choice of nuclear data library, integral experiments or methodology. Of primary focus for us will be comparing* ***correlations between fission, capture and nu-bar*** *for the three actinides.*”

[Vladimir Sobes by email October 23, 2019]

- Use whatever nuclear data library you are familiar working with
- Use a set of integral benchmarks representative of the testing suit
- Use whatever integral experiment assimilation technique you are familiar with
- Estimate the correlation coefficients which arise due to the application of your assimilation technique to your set of integral benchmarks with your nuclear data library
- Group structure to be fast (group 1), 20 MeV - 50 keV, intermediate (group 2), 50 keV - 0.625 eV, and thermal (group 3), 0.625 eV - 1e-5 eV.
- Report the results for the cross-reaction correlations

1. Introduction

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- **ND Users** would like the evaluated nuclear data libraries to predict small uncertainties for selected integral quantities consistent with the integral experimental uncertainties (e.g., in the multiplication factors k_{eff} of critical assemblies).

- **ND Evaluators** derive the covariance information from measured differential data and nuclear reaction modelling that result in relatively large propagated uncertainties for above mentioned integral quantities.

- **The aim of this work is**:
  - To derive cross-correlations that are not related to any particular reactor system and can be added to the general-purpose covariance information to reduce the calculated keff uncertainty without changing the uncertainty $\bar{\nu}$ of and $\sigma_{fission}$.
  - Then, **small uncertainties of integral quantities** (~ 100 pcm or 0.1%) are used as a constraint that combined with **a general 1D one-group simplified transport equation** allows generating large correlations between neutron multiplicity (nubar), fission and capture cross sections.
  - The proposed method is applied to existing ENDF/B-VIII.0 and JEFF-3.3 libraries.

2. Methodology based on "1D one-group transport equation"

- A general **1D one-group simplified transport equation**:

$$k_{eff} = \frac{\bar{\nu} \cdot \sigma_f}{\sigma_f + \sigma_\gamma + L} \qquad \textbf{(Eq. 1)}$$

- Assuming that the above equation is universally valid and that the **typical uncertainty reachable in critical experiments is ~300 pcm**, then we can derive strong anti-correlations between $\bar{\nu}$ and $\sigma_{fission}$.

- **Methodology:**
  - **Spectrum-averaged** for $\bar{\nu}$, σ_f and σ_γ values according Vlad's proposal:
    - fast (group 1): 20 MeV - 50 keV
    - intermediate (group 2): 50 keV - 0.625 eV
    - thermal (group 3): 0.625 eV - 1e-5 eV
  - In this work, **NJOY iwt=4 option is used**. This weight function combines a thermal Maxwellian at low energies, a 1/E function at intermediate energies, and a fission spectrum at high energies
  - **Here, the constrain** that the uncertainty of critical experiments is **100 pcm (Δk_0).**
  - Simple generic correlation coefficients are derived, focusing mainly on $\bar{\nu}$-σ_f .
  - The **UMC-B approach** is compared to results of a **GLSQ procedure**.

2.1 Spectrum-averaged values

- **Spectrum-averaged** for $\bar{\nu}$, σ_f and σ_γ

Table 1. Average over fission spectrum. NJOY iwt=4 value, weighted between 20 MeV and 50 keV (Group I)

		Nubar	rel_err (%)	(n,total) (b)	rel_err (%)	(n,fission) (b)	rel_err (%)	(n,gamma) (b)	rel_err (%)
U235	ENDF/B-VIII.0	2.587	0.6	8.94	2.6	1.31	1.2	0.19	20.0
	JEFF-3.3	2.567	0.4	8.98	0.9	1.31	1.1	0.20	6.6
diff (J3-E8)/E8(%)		-0.8		0.5		-0.2		4.6	
Pu239	ENDF/B-VIII.0	3.101	0.6	8.977	1.9	1.703	1.3	0.107	36.2
	JEFF-3.3	3.089	0.4	8.947	1.4	1.709	0.5	0.101	5.1
diff (J3-E8)/E8(%)		-0.4		-0.3		0.4		-5.7	

Table 2. Slowing-down region resonance integrals. NJOY iwt=4, weighted between 50 keV - 0.625 eV (Group II)

		Nubar	rel_err (%)	(n,total) (b)	rel_err (%)	(n,fission) (b)	rel_err (%)	(n,gamma) (b)	rel_err (%)
U235	ENDF/B-VIII.0	2.421	0.6	46.73	1.6	22.62	1.2	12.37	5.1
	JEFF-3.3	2.409	0.6	46.72	2.8	22.80	3.1	12.28	7.4
diff (J3-E8)/E8(%)		-0.5		0.0		0.8		-0.7	
Pu239	ENDF/B-VIII.0	2.863	0.3	50.890	3.4	23.590	2.8	14.710	9.2
	JEFF-3.3	2.847	0.5	53.890	1.4	24.910	0.9	15.900	3.7
diff (J3-E8)/E8(%)		-0.6		5.9		5.6		8.1	

2.1 Spectrum-averaged values

- **Spectrum-averaged** for $\bar{\nu}$, σ_f and σ_γ

Table 3. Average over thermal spectrum. NJOY iwt=4, weighted between 0.625 eV and 1.E-05 eV (Group III)

		Nubar	rel_err (%)	(n,total) (b)	rel_err (%)	(n,fission) (b)	rel_err (%)	(n,gamma) (b)	rel_err (%)
U235	ENDF/B-VIII.0	2.430	0.5	487.20	0.5	402.70	0.6	70.62	1.0
	JEFF-3.3	2.409	0.6	486.30	0.9	402.20	0.8	70.24	2.9
diff (J3-E8)/E8(%)		-0.9		-0.2		-0.1		-0.5	
Pu239	ENDF/B-VIII.0	2.864	0.3	1221.00	1.6	808.50	1.3	404.20	4.2
	JEFF-3.3	2.849	0.5	1232.00	1.4	815.10	1.4	408.30	2.4
diff (J3-E8)/E8(%)		-0.5		0.9		0.8		1.0	

UMC-B Approach

- Nuclear data ($\bar{\nu}$, σ_f and σ_γ) are randomly sampled, and weighting factors are calculated on the fly, one for each sampling history.

- Weighting factors are defined as follows:

$$\omega_i = \exp(-0.5 \cdot (\,(k_i - k_0)/\Delta k_0)^2) \quad \textbf{(Eq. 2)}$$

- There will be pairs of quantities: $\left\{\omega_i\,, \sigma_{f\,i}, \sigma_{\gamma\,i}, \nu_i\right\}$ for i=1, N (SAMPLES)

- From this info one can obtain the solution mean ($<\boldsymbol{\bar{\nu}}>$, $<\boldsymbol{\sigma_f}>$ and $<\boldsymbol{\sigma_\gamma}>$) values and covariance ($\boldsymbol{V_{\bar{\nu}}}$, $\boldsymbol{V_{\sigma_f}}$ and $\boldsymbol{V_{\sigma_\gamma}}$) as follows:

$$< \sigma_f > \approx \left[\sum_{i=1,N} \omega_i \cdot \sigma_{f\,i}\right] / \left[\sum_{i=1,N} \omega_i\right] \qquad \textbf{(Eq. 3)}$$

$$\boldsymbol{V_{\bar{\nu},\sigma_f}} \approx \left[\sum_{i=1,N} \omega_i \cdot \nu_i \cdot \sigma_{f\,i}\right] / \left[\sum_{i=1,N} \omega_i\right] - < \boldsymbol{\sigma_f} >< \boldsymbol{\bar{\nu}} > \qquad \textbf{(Eq. 4)}$$

Generalized Linear Least Squares (GLLS) Procedure

- First-order Taylor series approximation

$$k(\sigma) \approx k(\sigma_0) + S(\sigma - \sigma_0)$$

$$V_k \approx S V_{\sigma_0} S^T$$

(Eq. 5)

- "A posteriori" mean and variance-covariance matrix

$$\boxed{\begin{aligned} \sigma' &= \sigma_0 + V_{\sigma_0} S^T \left[S V_{\sigma_0} S^T + V_E \right]^{-1} [E - \mathrm{k}(\sigma_0)] = \sigma_0 \\ V_{\sigma'} &= V_{\sigma_0} - V_{\sigma_0} S^T \left[S V_{\sigma_0} S^T + V_E \right]^{-1} S V_{\sigma_0} \\ V'_k &\approx S V'_{\sigma} S^T \end{aligned}}$$

$$V'_E = V_E - V_E \left[S V_{\sigma_0} S^T + V_E \right]^{-1} V_E$$

$$V'_{E-\sigma} = V_E \left[S V_{\sigma_0} S^T + V_E \right]^{-1} S V_{\sigma_0}$$

- Sensitivities to Eq. (1)

$$\begin{cases} S_{k,\bar{\nu}} = \dfrac{\partial k}{\partial \bar{\nu}} = \dfrac{\sigma_f}{(\sigma_f + \sigma_\gamma + L)} \\ S_{k,\sigma_f} = \dfrac{\partial k}{\partial \sigma_f} = \dfrac{\bar{\nu} \cdot (\sigma_\gamma + L)}{(\sigma_f + \sigma_\gamma + L)^2} \\ S_{k,\sigma_\gamma} = \dfrac{\partial k}{\partial \sigma_\gamma} = \dfrac{-\bar{\nu} \cdot \sigma_f}{(\sigma_f + \sigma_\gamma + L)^2} \end{cases}$$

(Eq. 6)

See Report WPEC/SG46 (page 16): https://www.oecd-nea.org/science/docs/2016/nsc-r2016-6.pdf

Results: U-235

Table 4. U-235 Vlad' correlations versus "1D one-group simplified transport equation constraint". Both methods, UMC-B and GLLS provide similar values.

		MAT	Vlad's correlations			1-D one group keff constraint					
						ENDF/B-VIII.0			JEFF-3.3		
		MT	452			452			452		
MAT	MT	Group	1	2	3	1	2	3	1	2	3
U-235	18	1	-22			-22			-34		
		2		-39	-39		-21			-16	
		3		-67	-67			-45			-45
	102	1	56			31			27		
		2		22	22		33			15	
		3		57	58			6			13

Fast (group 1): 20 MeV - 50 keV
Intermediate (group 2): 50 keV - 0.625 eV
Thermal (group 3): 0.625 eV - 1e-5 eV

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3. Inter-comparison of Results

Results: Pu-239

Table 5. Pu-239 Vlad' correlations versus "1D one-group simplified transport equation constraint". Both methods, UMC-B and GLLS provide similar values.

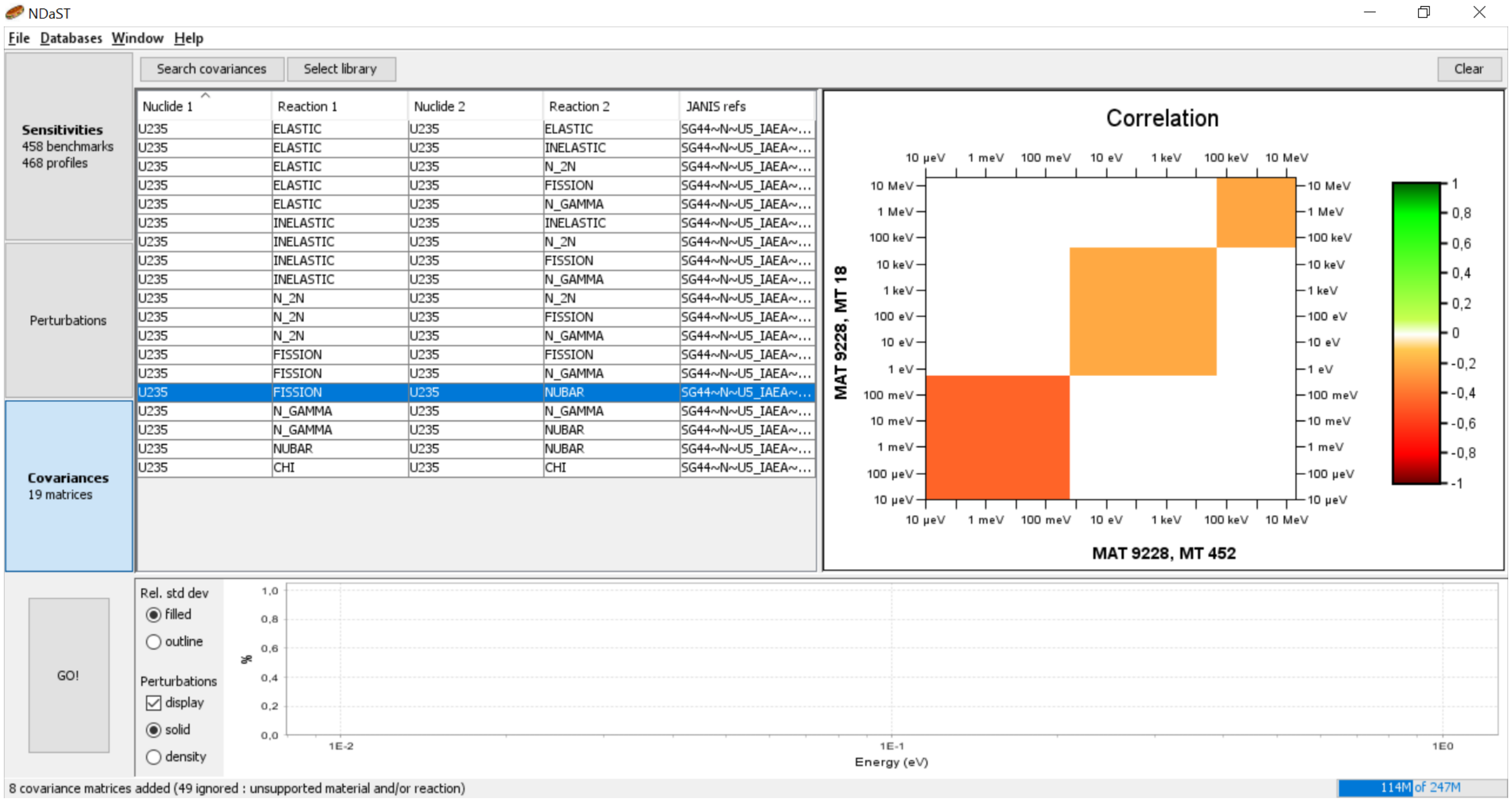
		MAT	Vlad's correlations			1-D one group keff constarint					
						ENDF/B-VIII.0			JEFF-3.3		
		MT	452			452			452		
MAT	MT	Group	1	2	3	1	2	3	1	2	3
Pu-239	18	1	-57	-37		-33			-49		
		2		-9	-87		-8			-26	
		3		-38	-40			-20			-39
	102	1	14	11		27			37		
		2		4	3		9			31	
		3		28	31			17			1

Fast (group 1): 20 MeV - 50 keV
Intermediate (group 2): 50 keV - 0.625 eV
Thermal (group 3): 0.625 eV - 1e-5 eV

4. Inter-comparison of Results and Implications

- NDaST tool for assessing the impact of new cross-correlations

Table 6.A NDaST screenshot. Base covariance is ENDF/B-VIII.0.
Plotting **IAEA cross-correlation: $\bar{\nu}$-σ_f for U235**

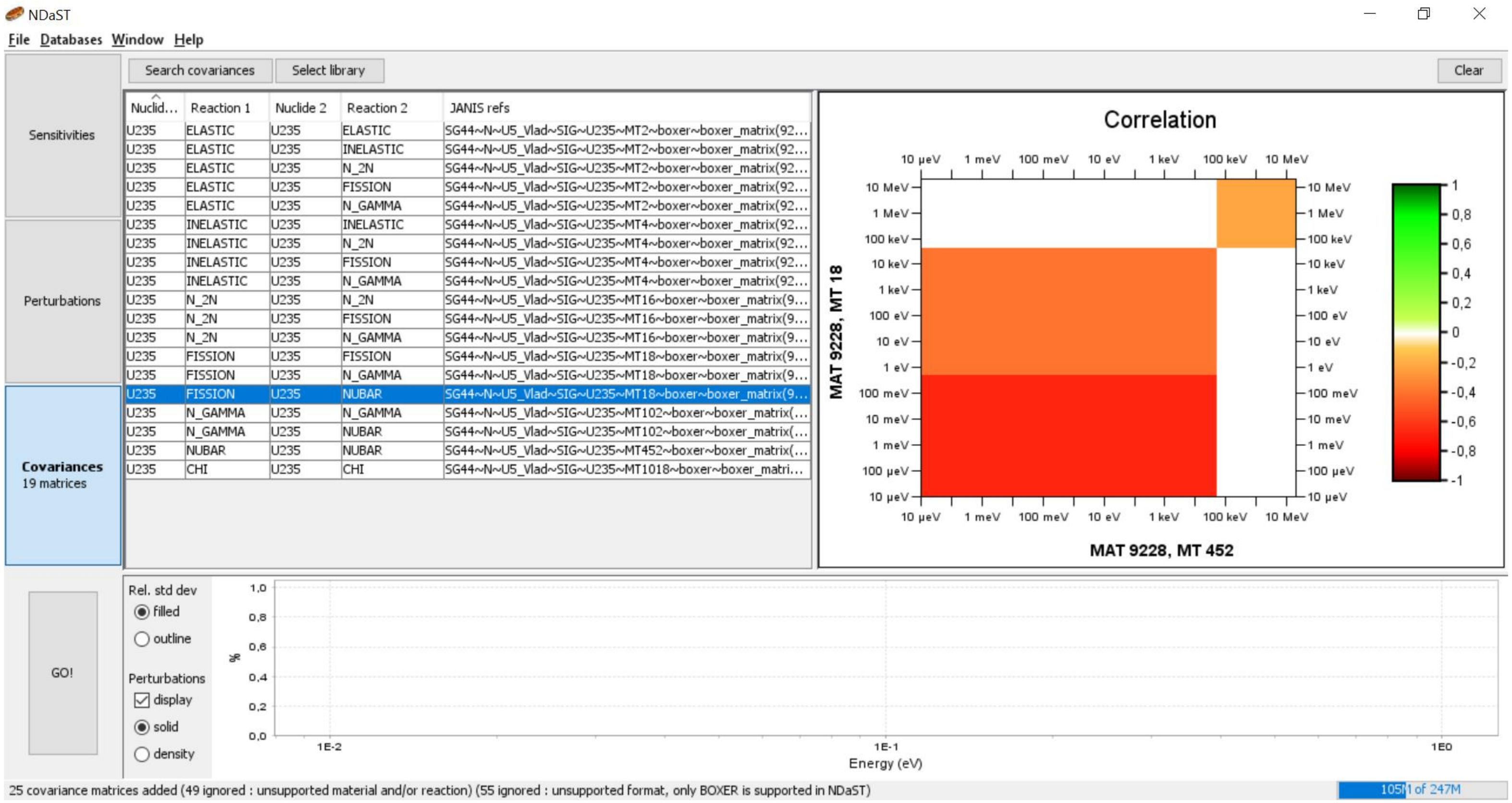


Nuclide 1	Reaction 1	Nuclide 2	Reaction 2	JANIS refs
U235	ELASTIC	U235	ELASTIC	SG44~N~U5_IAEA~...
U235	ELASTIC	U235	INELASTIC	SG44~N~U5_IAEA~...
U235	ELASTIC	U235	N_2N	SG44~N~U5_IAEA~...
U235	ELASTIC	U235	FISSION	SG44~N~U5_IAEA~...
U235	ELASTIC	U235	N_GAMMA	SG44~N~U5_IAEA~...
U235	INELASTIC	U235	INELASTIC	SG44~N~U5_IAEA~...
U235	INELASTIC	U235	N_2N	SG44~N~U5_IAEA~...
U235	INELASTIC	U235	FISSION	SG44~N~U5_IAEA~...
U235	INELASTIC	U235	N_GAMMA	SG44~N~U5_IAEA~...
U235	N_2N	U235	N_2N	SG44~N~U5_IAEA~...
U235	N_2N	U235	FISSION	SG44~N~U5_IAEA~...
U235	N_2N	U235	N_GAMMA	SG44~N~U5_IAEA~...
U235	FISSION	U235	FISSION	SG44~N~U5_IAEA~...
U235	FISSION	U235	N_GAMMA	SG44~N~U5_IAEA~...
U235	FISSION	U235	NUBAR	SG44~N~U5_IAEA~...
U235	N_GAMMA	U235	N_GAMMA	SG44~N~U5_IAEA~...
U235	N_GAMMA	U235	NUBAR	SG44~N~U5_IAEA~...
U235	NUBAR	U235	NUBAR	SG44~N~U5_IAEA~...
U235	CHI	U235	CHI	SG44~N~U5_IAEA~...

4. Inter-comparison of Results and Implications

- NDaST tool for assessing the impact of new cross-correlations

Table 6.B NDaST screenshot. Base covariance is ENDF/B-VIII.0.
Plotting **Vlad's cross-correlation: $\bar{\nu}$-σ_f for U235**

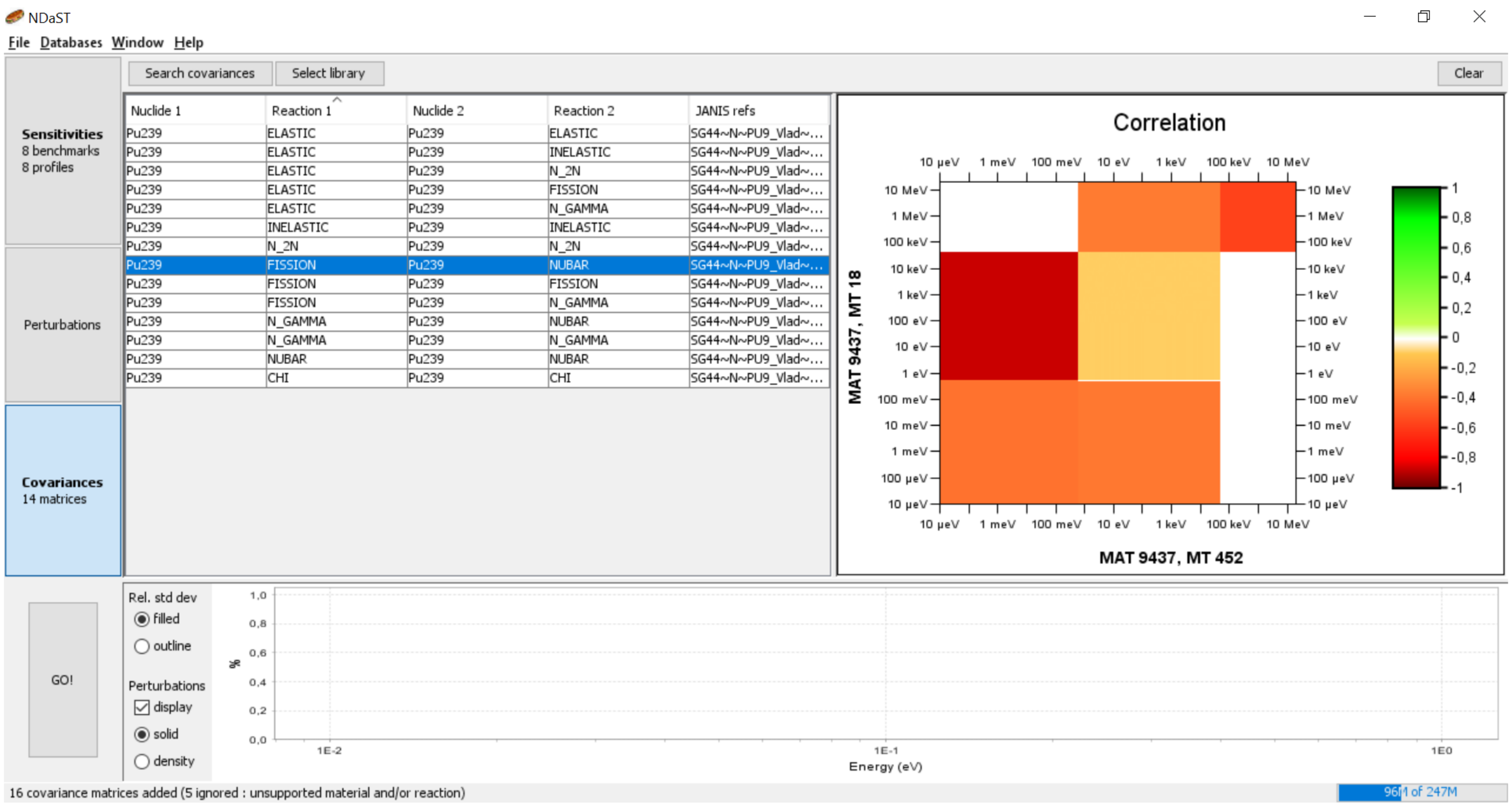


Nuclid...	Reaction 1	Nuclide 2	Reaction 2	JANIS refs
U235	ELASTIC	U235	ELASTIC	SG44~N~U5_Vlad~SIG~U235~MT2~boxer~boxer_matrix(92...
U235	ELASTIC	U235	INELASTIC	SG44~N~U5_Vlad~SIG~U235~MT2~boxer~boxer_matrix(92...
U235	ELASTIC	U235	N_2N	SG44~N~U5_Vlad~SIG~U235~MT2~boxer~boxer_matrix(92...
U235	ELASTIC	U235	FISSION	SG44~N~U5_Vlad~SIG~U235~MT2~boxer~boxer_matrix(92...
U235	ELASTIC	U235	N_GAMMA	SG44~N~U5_Vlad~SIG~U235~MT2~boxer~boxer_matrix(92...
U235	INELASTIC	U235	INELASTIC	SG44~N~U5_Vlad~SIG~U235~MT4~boxer~boxer_matrix(92...
U235	INELASTIC	U235	N_2N	SG44~N~U5_Vlad~SIG~U235~MT4~boxer~boxer_matrix(92...
U235	INELASTIC	U235	FISSION	SG44~N~U5_Vlad~SIG~U235~MT4~boxer~boxer_matrix(92...
U235	INELASTIC	U235	N_GAMMA	SG44~N~U5_Vlad~SIG~U235~MT4~boxer~boxer_matrix(92...
U235	N_2N	U235	N_2N	SG44~N~U5_Vlad~SIG~U235~MT16~boxer~boxer_matrix(9...
U235	N_2N	U235	FISSION	SG44~N~U5_Vlad~SIG~U235~MT16~boxer~boxer_matrix(9...
U235	N_2N	U235	N_GAMMA	SG44~N~U5_Vlad~SIG~U235~MT16~boxer~boxer_matrix(9...
U235	FISSION	U235	FISSION	SG44~N~U5_Vlad~SIG~U235~MT18~boxer~boxer_matrix(9...
U235	FISSION	U235	N_GAMMA	SG44~N~U5_Vlad~SIG~U235~MT18~boxer~boxer_matrix(9...
U235	FISSION	U235	NUBAR	SG44~N~U5_Vlad~SIG~U235~MT18~boxer~boxer_matrix(9...
U235	N_GAMMA	U235	N_GAMMA	SG44~N~U5_Vlad~SIG~U235~MT102~boxer~boxer_matrix(...
U235	N_GAMMA	U235	NUBAR	SG44~N~U5_Vlad~SIG~U235~MT102~boxer~boxer_matrix(...
U235	NUBAR	U235	NUBAR	SG44~N~U5_Vlad~SIG~U235~MT452~boxer~boxer_matrix(...
U235	CHI	U235	CHI	SG44~N~U5_Vlad~SIG~U235~MT1018~boxer~boxer_matri...

4. Inter-c EXTRA SLIDE of Results and Implications

- NDaST tool for assessing the impact of new cross-correlations

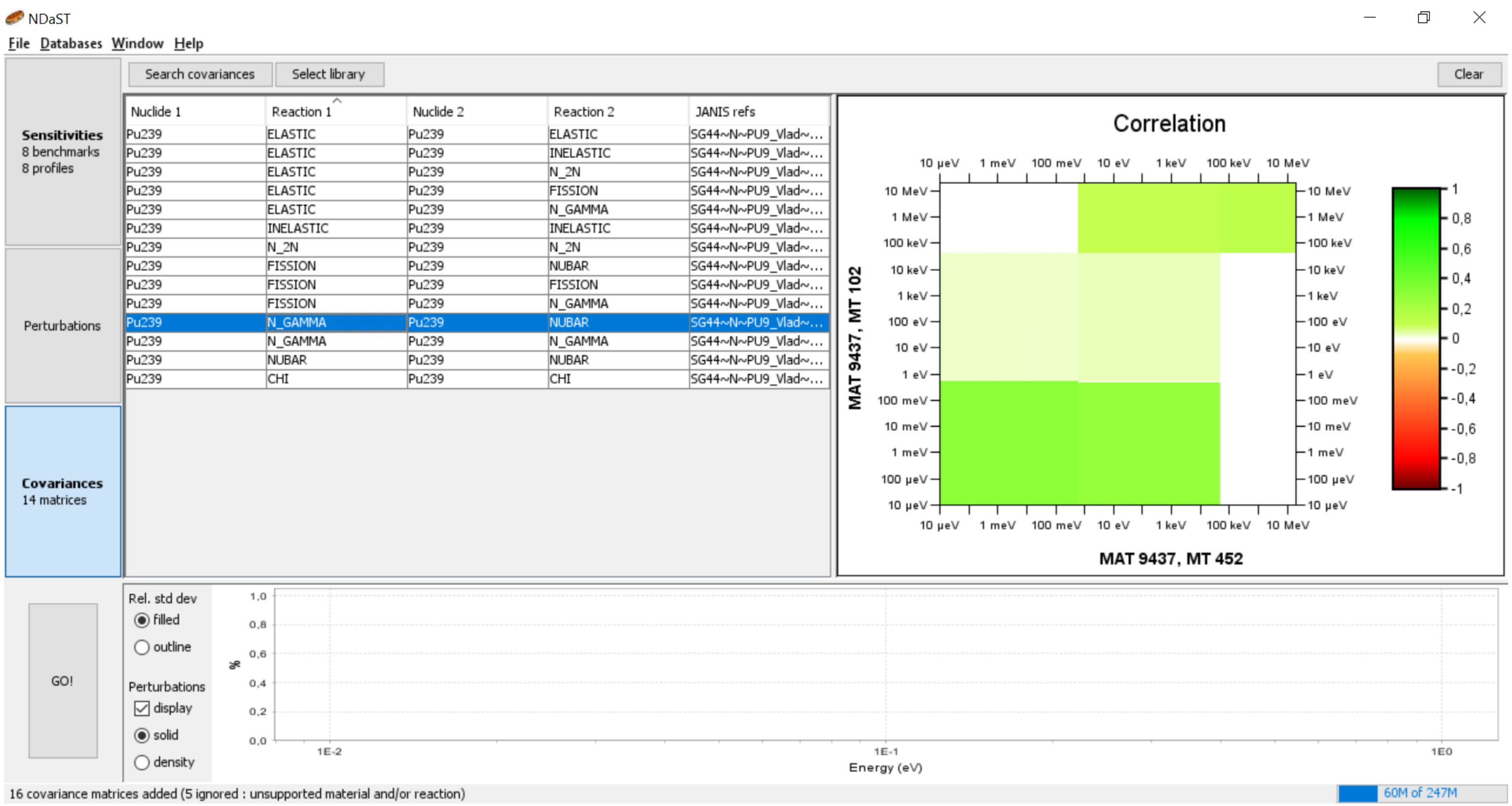
Table 6.B NDaST screenshot. Base covariance is ENDF/B-VIII.0.
Plotting **Vlad's cross-correlation: $\bar{\nu}$-σ_f for PU239**



4. Inter-c EXTRA SLIDE of Results and Implications

- NDaST tool for assessing the impact of new cross-correlations

Table 6.B NDaST screenshot. Base covariance is ENDF/B-VIII.0.
Plotting **Vlad's cross-correlation: $\bar{\nu}$-σ_γ for PU239**



4. Inter-comparison of Results and Implications

Table 7. Data uncertainties for **HEU-MET-FAST-001 case** using U-235 cross-correlations.

Base library is ENDF/B-VIII.0. New cross-correlations for $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from IAEA method.

HMF001-001 (Shell Model) - NDaST

C/E | Data uncertainties

	Std Dev (pcm)	<U235,ELASTIC>	<U235,INELASTIC>	<U235,N_2N>	<U235,FISSION>	<U235,N_GAMMA>	<U235,NUBAR>	<U235,CHI>
<U235,ELASTIC>	275,6	7,596e-6	1,742e-6	3,559e-8	-1,461e-6	4,898e-7	-	-
<U235,INELASTIC>	244,3	1,742e-6	5,967e-6	9,822e-8	1,648e-6	-1,839e-7	-	-
<U235,N_2N>	21,2	3,559e-8	9,822e-8	4,511e-8	3,627e-8	4,657e-9	-	-
<U235,FISSION>	788,1	-1,461e-6	1,648e-6	3,627e-8	6,212e-5	6,586e-7	-8,133e-6	-
<U235,N_GAMMA>	281,2	4,898e-7	-1,839e-7	4,657e-9	6,586e-7	7,907e-6	-5,616e-6	-
<U235,NUBAR>	399,6	-	-	-	-8,133e-6	-5,616e-6	1,597e-5	-
<U235,CHI>	124	-	-	-	-	-	-	1,538e-6

Table 8. Predicted uncertainty (in pcm) for **HEU-MET-FAST-001**. Base library is ENDF/B-VIII.0. New cross-correlations for 235U $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from IAEA method.

	ENDF/B-VIII.0	ENDF/B-VIII.0 + IAEA c-c	ENDF/B-VIII.0 + Vlad c-c
HET-MET-FAST-001	1035.7	893.2	836.7

4. Inter-c EXTRA SLIDE of Results and Implications

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Table 7. Data uncertainties for **PU-MET-FAST-001 case** using PU-239 cross-correlations. Base library is ENDF/B-VIII.0. New cross-correlations for $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived by Vlad's method.

PMF001-001 (Detailed Model) - NDaST

C/E | Data uncertainties

	Std Dev (pcm)	<Pu239,ELASTIC>	<Pu239,INELASTIC>	<Pu239,N_2N>	<Pu239,FISSION>	<Pu239,N_GAMMA>	<Pu239,NUBAR>	<Pu239,CHI>
<Pu239,ELASTIC>	463	2,144e-5	-3,321e-5	-4,9e-10	-2,402e-6	5,63e-8	-	-
<Pu239,INELAST…	796,8	-3,321e-5	6,349e-5	-	-	-	-	-
<Pu239,N_2N>	9,2	-4,9e-10	-	8,492e-9	-	-	-	-
<Pu239,FISSION>	903	-2,402e-6	-	-	8,155e-5	-4,947e-13	-2,332e-5	-
<Pu239,N_GAMM…	66,3	5,63e-8	-	-	-4,947e-13	4,401e-7	-5,495e-7	-
<Pu239,NUBAR>	316,3	-	-	-	-2,332e-5	-5,495e-7	1e-5	-
<Pu239,CHI>	185,5	-	-	-	-	-	-	3,441e-6

Table 8. Predicted uncertainty (in pcm) for **HEU-MET-FAST-001**. Base library is ENDF/B-VIII.0. New cross-correlations for 239Pu $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from Vlad's method.

	ENDF/B-VIII.0		ENDF/B-VIII.0 + Vlad c-c
HET-MET-FAST-001	1045.3		784.4

4. Inter-comparison of Results and Implications

Table 9. Predicted uncertainty (in pcm) for **HEU/IEU/LEU - FAST** cases (521 Benchmarks). Base library is ENDF/B-VIII.0. New cross-corr. for 235U $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from IAEA method.

Results - NDaST

File

Filter

- Filter
  - ☑ ICBEVALS.NUMBER_CASES
  - ☑ Nuclides / Reactions
  - ☑ Benchmarks calculations
  - ☑ Sensitivities calculations

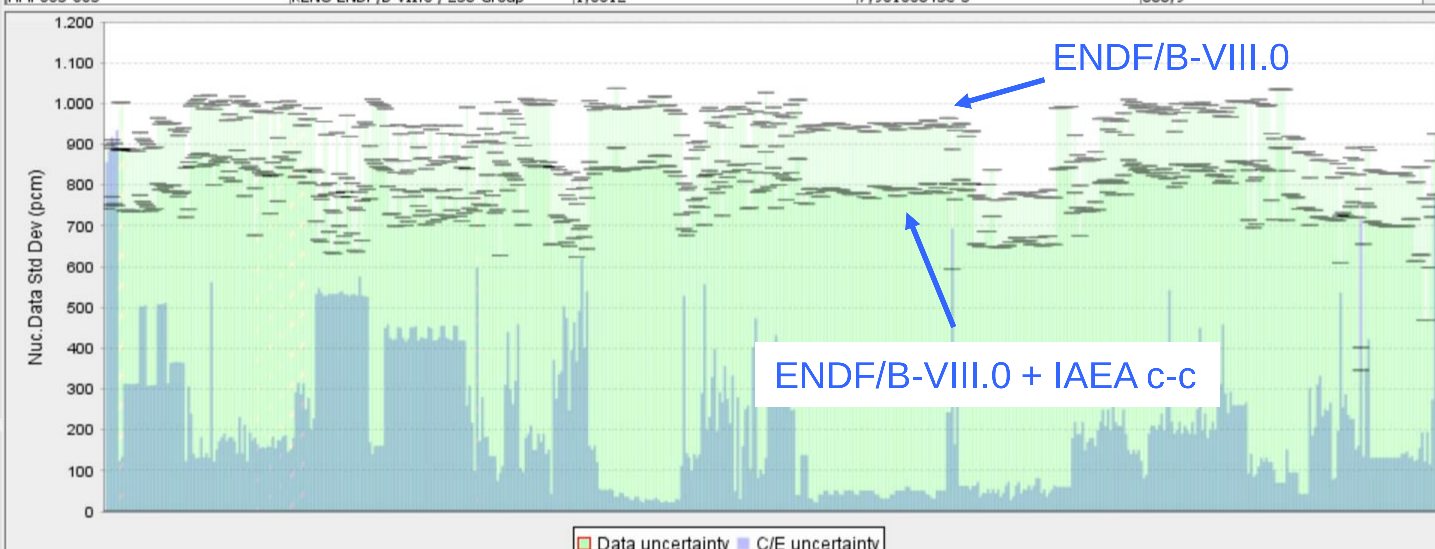
Benchmark	Sensitivity	Keff C/E	Nuc.Data Variance	Nuc.Data Std Dev (pcm)
HMF001-001 (Godiva)	KENO ABBN-93 / 299-Group	1,00002857	9,38026133e-5	968,5
HMF001-001 (Godiva)	MCNP ENDF/B-VII.0 Continuous	1,00002857	1,07270621e-4	1035,7
HMF001-001 (Shell Model)	KENO ABBN-93 / 299-Group	1,0007	9,38026133e-5	968,5
HMF001-001 (Shell Model)	MCNP ENDF/B-VII.0 Continuous	1,0007	1,07270621e-4	1035,7
HMF002-001	KENO ENDF/B-VII.0 / 238-Group	1,00354	7,90394117e-5	889
HMF002-002	KENO ENDF/B-VII.0 / 238-Group	1,00446	7,89324074e-5	888,4
HMF002-003	KENO ENDF/B-VII.0 / 238-Group	1,00188	7,8224731e-5	884,4
HMF002-004	KENO ENDF/B-VII.0 / 238-Group	1,0018	7,85708204e-5	886,4
HMF002-005	KENO ENDF/B-VII.0 / 238-Group	1,00354	7,77724374e-5	881,9
HMF002-006	KENO ENDF/B-VII.0 / 238-Group	1,0028	7,79749089e-5	883
HMF003-001	KENO ENDF/B-VII.0 / 238-Group	9,9541e-1	8,61635141e-5	928,2
HMF003-002	KENO ENDF/B-VII.0 / 238-Group	9,94638e-1	8,31919472e-5	912,1
HMF003-003	KENO ENDF/B-VII.0 / 238-Group	9,98912e-1	8,21066481e-5	906,1
HMF003-004	KENO ENDF/B-VII.0 / 238-Group	9,97158e-1	8,08633504e-5	899,2
HMF003-005	KENO ENDF/B-VII.0 / 238-Group	1,0012	7,90100843e-5	888,9

Plot options

Group by: BENCHMARK_ID

Group

☐ Top 10 , ☐ over 100 points



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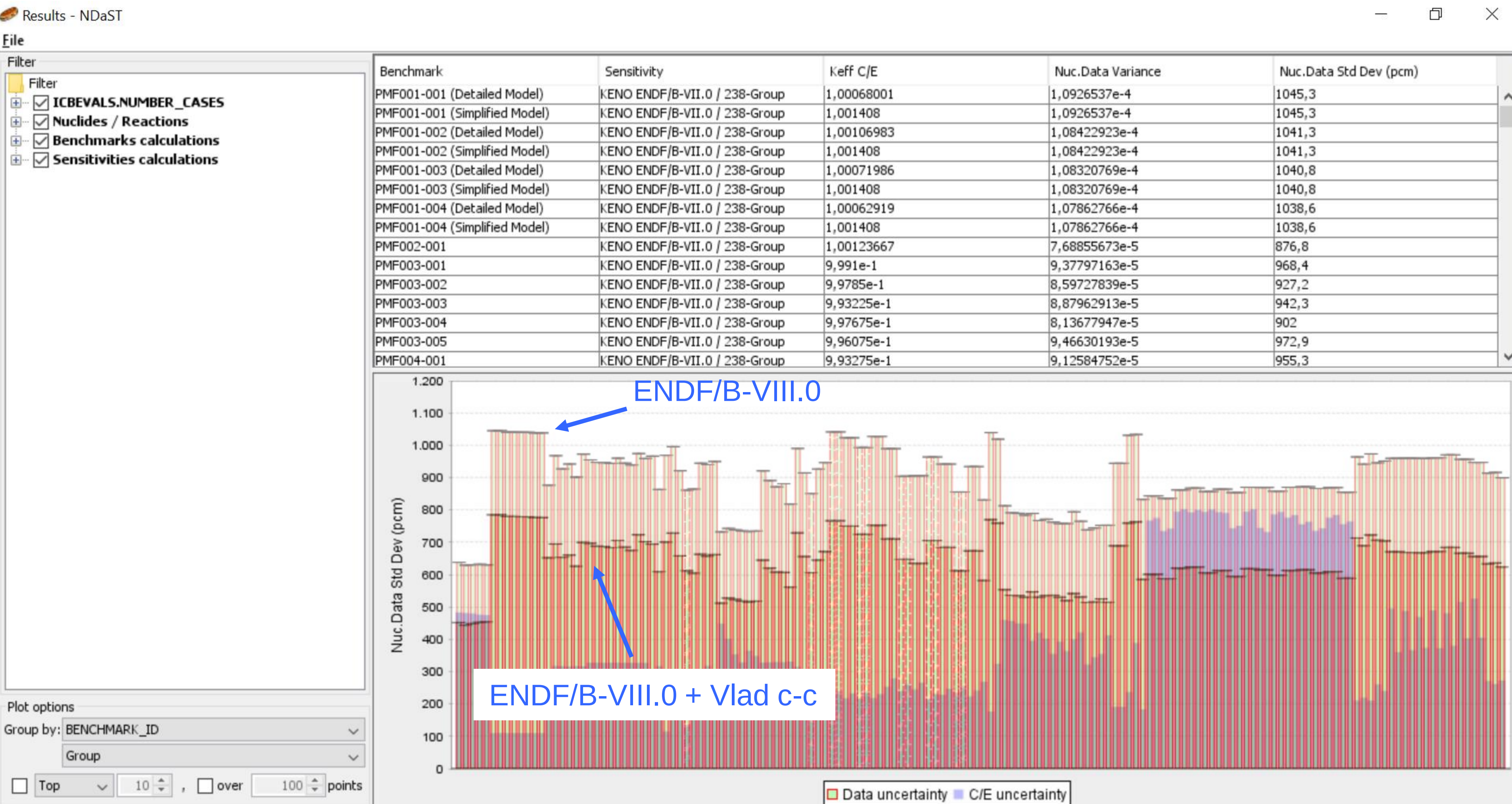
4. Inter-c EXTRA SLIDE
of Results and Implications

Table 9. Predicted uncertainty (in pcm) for **PU - FAST** cases (164 Benchmarks).
Base library is ENDF/B-VIII.0. New cross-corr. for 239Pu $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from Vlad's method.



Benchmark	Sensitivity	Keff C/E	Nuc.Data Variance	Nuc.Data Std Dev (pcm)
PMF001-001 (Detailed Model)	KENO ENDF/B-VII.0 / 238-Group	1,00068001	1,0926537e-4	1045,3
PMF001-001 (Simplified Model)	KENO ENDF/B-VII.0 / 238-Group	1,001408	1,0926537e-4	1045,3
PMF001-002 (Detailed Model)	KENO ENDF/B-VII.0 / 238-Group	1,00106983	1,08422923e-4	1041,3
PMF001-002 (Simplified Model)	KENO ENDF/B-VII.0 / 238-Group	1,001408	1,08422923e-4	1041,3
PMF001-003 (Detailed Model)	KENO ENDF/B-VII.0 / 238-Group	1,00071986	1,08320769e-4	1040,8
PMF001-003 (Simplified Model)	KENO ENDF/B-VII.0 / 238-Group	1,001408	1,08320769e-4	1040,8
PMF001-004 (Detailed Model)	KENO ENDF/B-VII.0 / 238-Group	1,00062919	1,07862766e-4	1038,6
PMF001-004 (Simplified Model)	KENO ENDF/B-VII.0 / 238-Group	1,001408	1,07862766e-4	1038,6
PMF002-001	KENO ENDF/B-VII.0 / 238-Group	1,00123667	7,68855673e-5	876,8
PMF003-001	KENO ENDF/B-VII.0 / 238-Group	9,991e-1	9,37797163e-5	968,4
PMF003-002	KENO ENDF/B-VII.0 / 238-Group	9,9785e-1	8,59727839e-5	927,2
PMF003-003	KENO ENDF/B-VII.0 / 238-Group	9,93225e-1	8,87962913e-5	942,3
PMF003-004	KENO ENDF/B-VII.0 / 238-Group	9,97675e-1	8,13677947e-5	902
PMF003-005	KENO ENDF/B-VII.0 / 238-Group	9,96075e-1	9,46630193e-5	972,9
PMF004-001	KENO ENDF/B-VII.0 / 238-Group	9,93275e-1	9,12584752e-5	955,3

4. Inter-comparison of Results and Implications

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Table 10. Predicted uncertainty (in pcm) for **HEU/IEU/LEU - MIXED** cases (91 Benchmarks). Base library is ENDF/B-VIII.0. New cross-corr. for 235U $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from IAEA method.

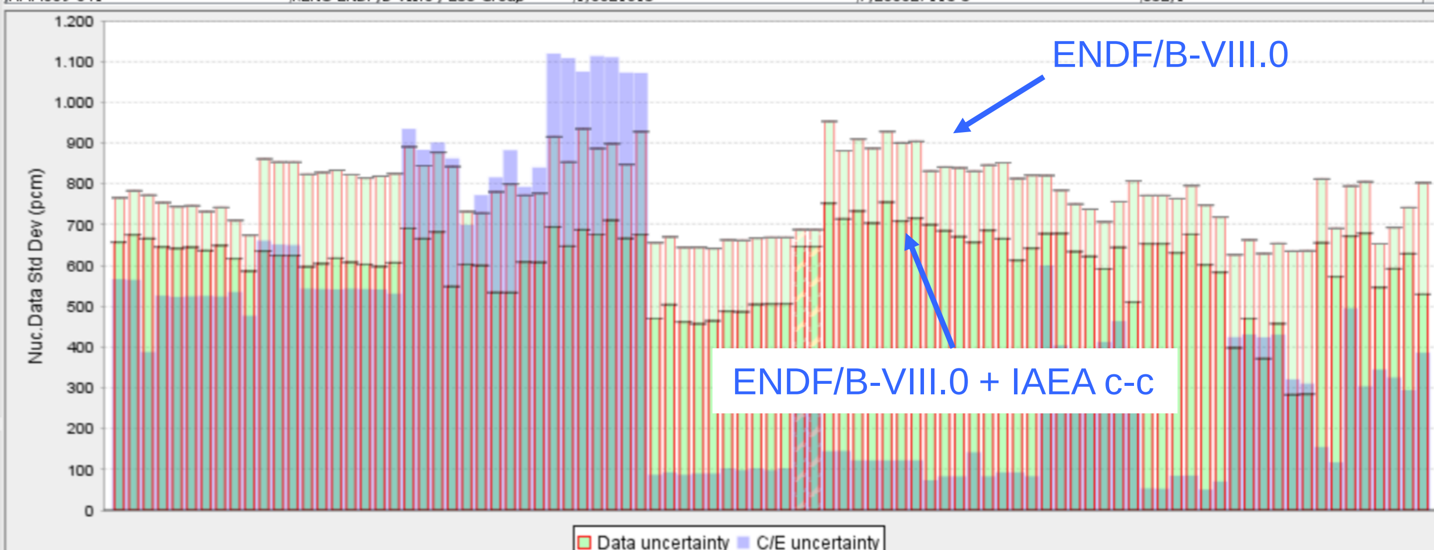
Results - NDaST

File

Filter

Filter
- ICBEVALS.NUMBER_CASES
- Nuclides / Reactions
- Benchmarks calculations
- Sensitivities calculations

Benchmark	Sensitivity	Keff C/E	Nuc.Data Variance	Nuc.Data Std Dev (pcm)
HMM002-001	KENO ABBN-93 / 299-Group	1,00528	4,73593349e-5	688,2
HMM003-001	KENO ABBN-93 / 299-Group	1,00692	4,73442803e-5	688,1
HMM006-001	MCNP ENDF/B-VII.0 Continuous	1,00013345	9,09187413e-5	953,5
HMM006-002	MCNP ENDF/B-VII.0 Continuous	9,97397658e-1	7,76984003e-5	881,5
HMM009-013	KENO ENDF/B-VII.0 / 238-Group	1,00182182	8,28396819e-5	910,2
HMM009-015	KENO ENDF/B-VII.0 / 238-Group	1,00142585	7,87684304e-5	887,5
HMM009-016	KENO ENDF/B-VII.0 / 238-Group	1,00120373	8,62004115e-5	928,4
HMM009-017	KENO ENDF/B-VII.0 / 238-Group	1,00245152	8,10779127e-5	900,4
HMM009-018	KENO ENDF/B-VII.0 / 238-Group	1,00312876	8,17550366e-5	904,2
HMM009-036	KENO ENDF/B-VII.0 / 238-Group	1,00122012	6,90888745e-5	831,2
HMM009-037	KENO ENDF/B-VII.0 / 238-Group	1,00170204	7,07879712e-5	841,4
HMM009-038	KENO ENDF/B-VII.0 / 238-Group	1,00146	7,04177282e-5	839,2
HMM009-039	KENO ENDF/B-VII.0 / 238-Group	1,00201637	6,90398639e-5	830,9
HMM009-040	KENO ENDF/B-VII.0 / 238-Group	1,00333566	7,15434694e-5	845,8
HMM009-041	KENO ENDF/B-VII.0 / 238-Group	1,0021613	7,26002711e-5	852,1



Plot options

Group by: BENCHMARK_ID

Group

Top 10 , over 100 points

4. Inter-comparison of Results and Implications

Table 11. Predicted uncertainty (in pcm) for **HEU/IEU/LEU - INTER** cases (29 Benchmarks). Base library is ENDF/B-VIII.0. New cross-corr. for 235U $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from IAEA method.

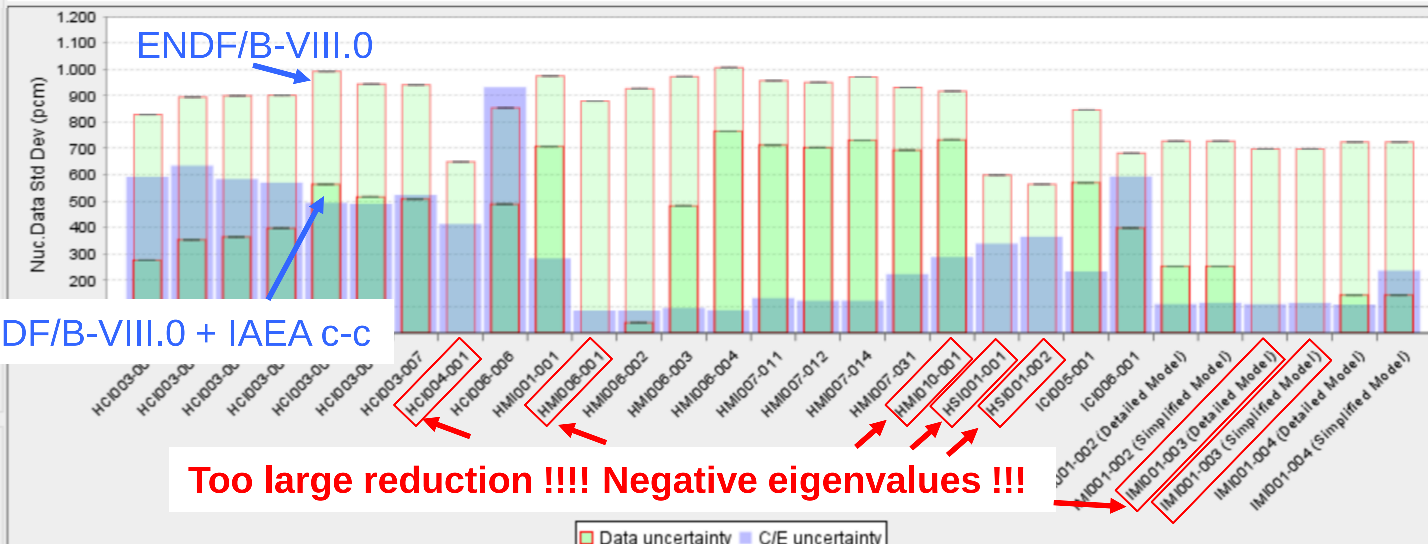
Results - NDaST

File

Filter

- Filter
  - ☑ ICBEVALS.NUMBER_CASES
  - ☑ Nuclides / Reactions
  - ☑ Benchmarks calculations
  - ☑ Sensitivities calculations

Benchmark	Sensitivity	Keff C/E	Nuc.Data Variance	Nuc.Data Std Dev (pcm)
HMI001-001	KENO ENDF/B-VII.0 / 238-Group	1,03306241	9,47628969e-5	973,5
HMI006-001	KENO ENDF/B-VII.0 Continuous	9,97853635e-1	7,71665899e-5	878,4
HMI006-002	KENO ENDF/B-VII.0 Continuous	9,98612996e-1	8,56308884e-5	925,4
HMI006-003	KENO ENDF/B-VII.0 Continuous	1,00046787	9,42656877e-5	970,9
HMI006-004	KENO ENDF/B-VII.0 Continuous	1,00456983	1,01056368e-4	1005,3
HMI007-011	KENO ENDF/B-VII.0 / 238-Group	1,00377586	9,13950122e-5	956
HMI007-012	KENO ENDF/B-VII.0 / 238-Group	1,00175191	9,0044291e-5	948,9
HMI007-014	KENO ENDF/B-VII.0 / 238-Group	1,00246889	9,40553954e-5	969,8
HMI007-031	KENO ENDF/B-VII.0 / 238-Group	1,00623583	8,64730349e-5	929,9
HMI010-001	KENO ENDF/B-VII.0 / 238-Group	1,00603197	8,38651183e-5	915,8
HSI001-001	KENO ENDF/B-VII.0 / 238-Group	9,94175e-1	3,57796041e-5	598,2
HSI001-002	KENO ENDF/B-VII.0 / 238-Group	9,86675e-1	3,17244836e-5	563,2
HCI003-001	KENO ENDF/B-VII.0 / 238-Group	1,008375	6,84302179e-5	827,2
HCI003-002	KENO ENDF/B-VII.0 / 238-Group	1,011725	7,98209547e-5	893,4
HCI003-003	KENO ENDF/B-VII.0 / 238-Group	1,0072	8,07698971e-5	898,7



Plot options

Group by: BENCHMARK_ID

Group

☐ Top 10 , ☐ over 100 points

4. Inter-comparison of Results and Implications

Table 12. Data Uncertainties for **HEU-MET-INTER-006-001** using U-235 cross-correlations. Base library is ENDF/B-VIII.0. New cross-corr. for 235U $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from IAEA method.

HMI006-001 - NDaST

C/E | Data uncertainties

	Std Dev (pcm)	<U235,ELASTIC>	<U235,INELASTIC>	<U235,N_2N>	<U235,FISSION>	<U235,N_GAMMA>	<U235,NUBAR>	<U235,CHI>
<U235,ELASTIC>	12,4	1,545e-8	2,241e-8	4,492e-11	-7,109e-9	5,108e-8	-	-
<U235,INELASTIC>	31,1	2,241e-8	9,674e-8	1,954e-9	4,762e-6	-1,187e-6	-	-
<U235,N_2N>	2,5	4,492e-11	1,954e-9	6,249e-10	6,194e-9	1,492e-9	-	-
<U235,FISSION>	349,5	-7,109e-9	4,762e-6	6,194e-9	1,221e-5	2,703e-6	-1,047e-5	-
<U235,N_GAMMA>	365	5,108e-8	-1,187e-6	1,492e-9	2,703e-6	1,332e-5	-3,47e-5	-
<U235,NUBAR>	561,2	-	-	-	-1,047e-5	-3,47e-5	3,15e-5	-
<U235,CHI>	270,3	-	-	-	-	-	-	7,307e-6

(NDaST screenshot)

- **Too large reduction due to $(\bar{\nu}$-$\sigma_c)$!!!! …….. Negative eigenvalues !!!**

4. Inter-comparison of Results and Implications

Table 13. Decrease in average, maximum and minimum uncertainty (in pcm) for **HEU/IEU/LEU** ICSBEP cases. Base library is ENDF/B-VIII.0. New cross-corr. for 235U $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from **IAEA method**.

	IAEA-cc			Problems (negative variance!!)
CASE (# benchmarks)	**Average**	**Max**	**Min**	
FAST (521)	144	297	43	-
INTER (29)	411	886	184	HMI006-001, HSI001-001, HSI001-002, HCI004-001, IMI001-003
MIXED (91)	173	353	42	-
THERMAL (2434)	72	237	33	HST004-003

4. Inter-comparison of Results and Implications

Table 14. Decrease in Average, maximum and minimum uncertainty (in pcm) for **HEU/IEU/LEU** ICSBEP cases. Base library is ENDF/B-VIII.0. New cross-corr. for 235U $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from **Vlad's method**.

	Vlad-cc			Problems (negative variance!!)
CASE (# benchmarks)	Average	Max	Min	
FAST (521)	206	334	69	-
INTER (29)	427	729	268	HMI006-001, HSI001-001, HSI001-002, HCI004-001, IMI001-003, IMI001-004, ICI006-001
MIXED (91)	283	598	84	ICM001-001, ICM001-017, ICM001-021, ICM001-022, ICM004-004, ICM004-005
THERMAL (2434)	241	544	117	HMT022-001, HST004-003, ... Total 211 cases

4. Inter-c EXTRA SLIDE of Results and Implications

Table 14. Decrease in Average, maximum and minimum uncertainty (in pcm) for PU ICSBEP cases. Base library is ENDF/B-VIII.0. New cross-corr. for 239Pu $\bar{\nu}$-σ_f and $\bar{\nu}$-σ_c derived from **Vlad's method**.

	Vlad-cc			Problems (negative variance!!)
CASE (# benchmarks)	**Average**	**Max**	**Min**	
FAST (91)	258	293	177	-
INTER (4)	115	141	62	
MIXED (9)	147	157	136	-
THERMAL (607)	151	199	124	-

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5. Conclusion

- **Contributing in the WPEC/SG44 inter-comparison study**

- **In this work, we have presented a methodology**
  - Allowing us to generate large correlations between neutron multiplicity (nubar), fission and capture cross sections…other cross-correlations (e.g. nubar-(n,n’), nubar-PFNS,…)?

  - **Methodology based on:**
    - 1D one-group simplified transport equation … To show that a simple equation is able to generate cross-correlations… can it be extended to other applications (e.g. Shielding) ?
    - Assumption of uncertainty of critical experiments is ~100 pcm

  - **Inter-comparison results**
    - Reasonable agreement with Vlad’s cross-correlations.
    - Group structure … in the same energy–range to current ND evaluations?
      - Fast (group 1): 20 MeV - 50 keV
      - Intermediate (group 2): 50 keV - 0.625 eV
      - Thermal (group 3): 0.625 eV - 1e-5 eV
    - Applied to ENDF/B-VIII.0 and JEFF-3.3 libraries … a-priori cross-correlations (e.g. fis-cap)?
    - Impact on ICSBEP … Re-evaluation keff uncertainties! … **NEGATIVE EIGENVALUES!!!**