The Development of Nuclear Data Adjustment Code at CNDC

WU Haicheng, QIN Yincan

China Nuclear Data Center(CNDC)
China Institute of Atomic Energy(CIAE)
P.O.Box 275-41,Beijing 102413, P.R.China
E-Mail: haicheng@ciae.ac.cn

OUTLINE

1. Introduction

2. Methodology

3. Trial calculation

4. Preliminary study on input parameters

5. Disscussion

1. Introduction

- **Our research on nuclear data adjustment began just when CNDC participated the WPEC/SG33.**
- **During SG33, the development of NDAC (Nuclear Data Adjustment Code) was started.**
  - **Methodology are the same as those illustrated in SG33 report.**
  - **The format of input files almost the same as those used in SG33 comparison;**
  - **SG33_plot and ORI codes are developed to prepare data and gnuplot scripts for group constants and covariance matrices.**
- **Benchmark exercises were performed to understand the adjustment method.**

2. Methodology

- **The methodology used at CNDC is based on Maximum Likelihood Method.**

$$\sigma' = \sigma + M_\sigma S^T (M_{EC} + S M_\sigma S^T)^{-1} (E - C)$$
$$= \sigma + M_\sigma S^T G^{-1} (E - C)$$
$$C' = C + S M_\sigma S^T G^{-1} (E - C)$$

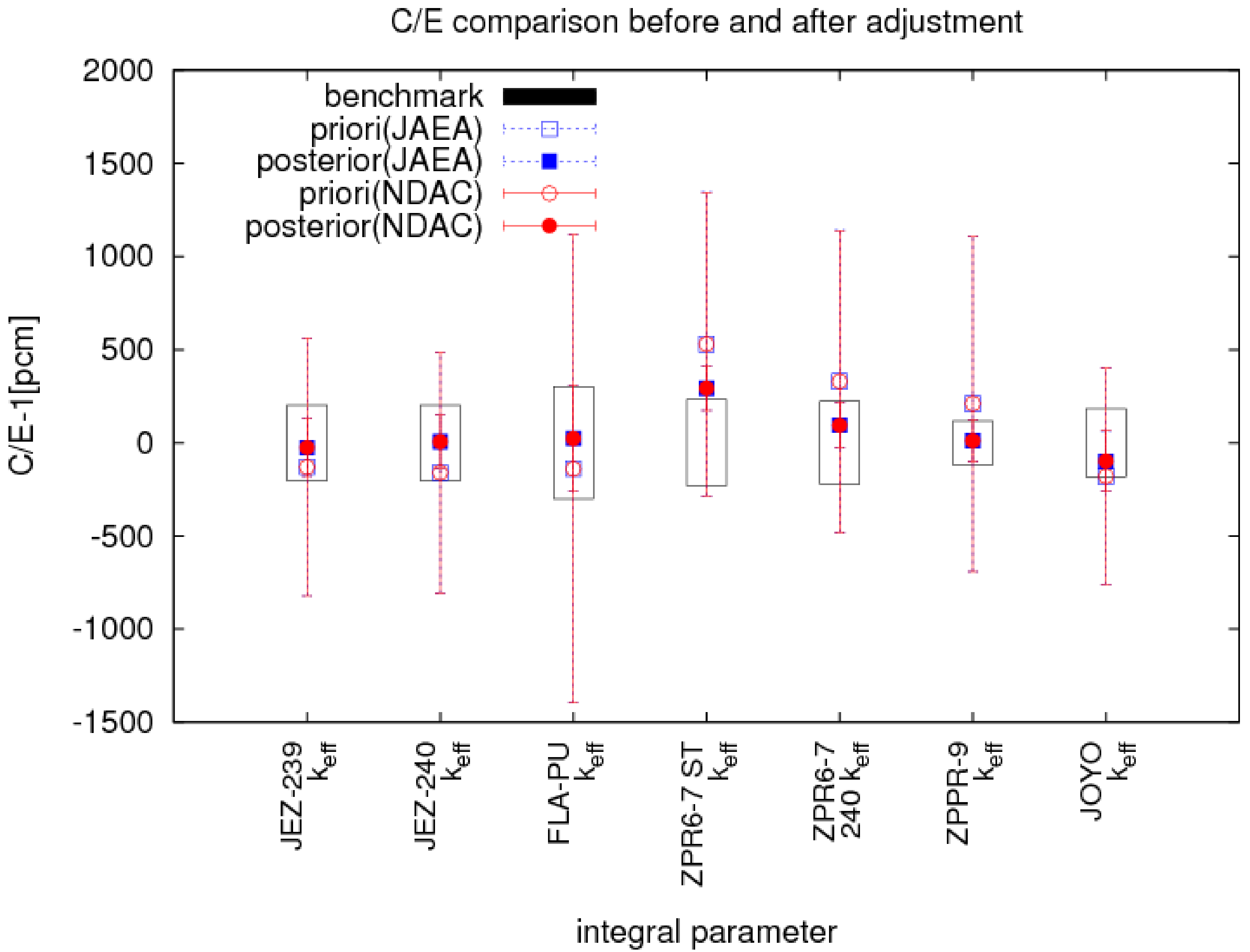
total experiment covariance matrix
$G=(M_{EC} + SM_\sigma S^T)$

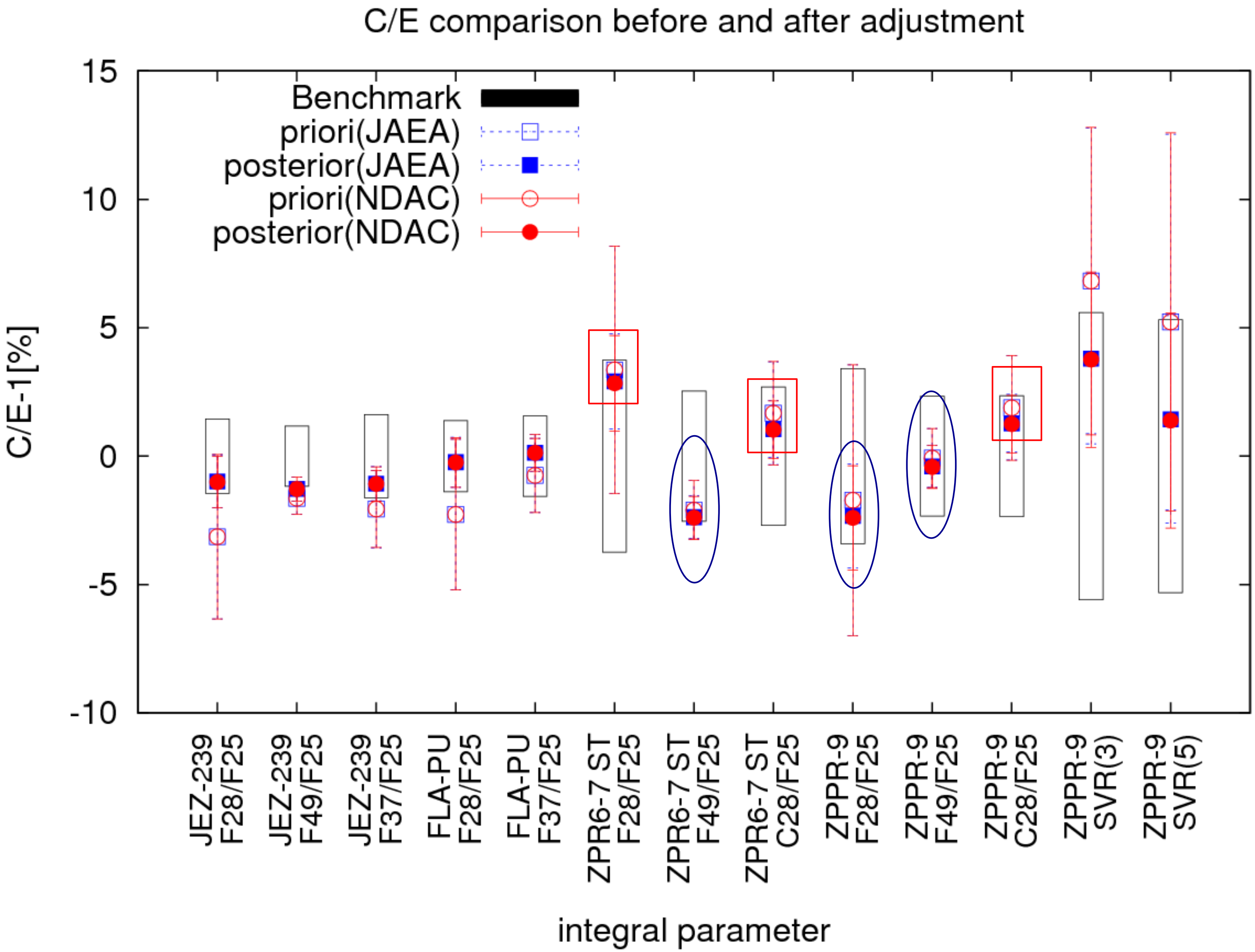
$$M'_\sigma = M_\sigma - M_\sigma S^T G^{-1} S M_\sigma = M_\sigma \left(I - S^T G^{-1} S M_\sigma \right)$$
$$U = S M_\sigma S^T$$
$$U' = S M'_\sigma S^T = U - S M_\sigma S^T G^{-1} S M_\sigma S^T$$
$$\chi^2 = (\sigma - \sigma')^T M_\sigma^{-1} (\sigma - \sigma') + (E - C)^T M_{EC}^{-1} (E - C)$$
$$\chi'^2 = (E - C)^T G^{-1} (E - C)$$

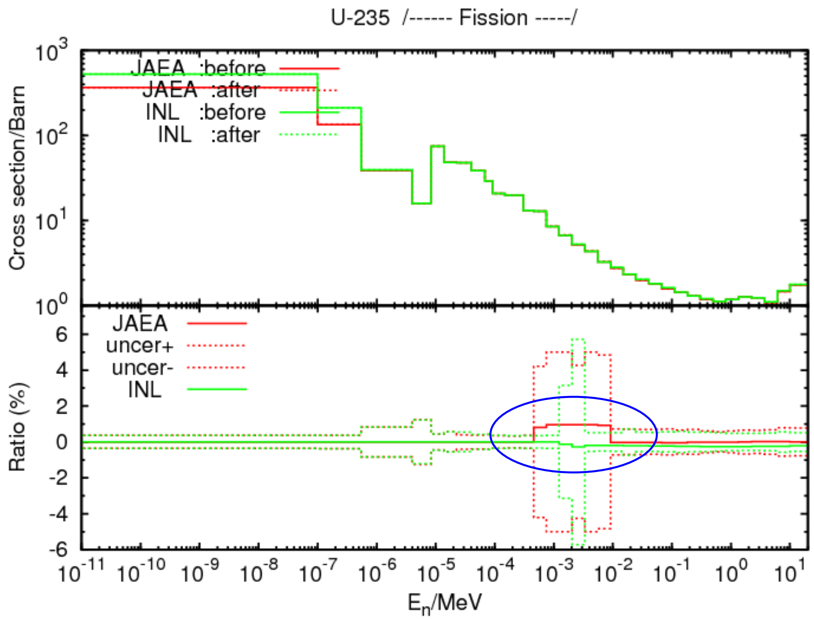
Same as reported in SG33 final report

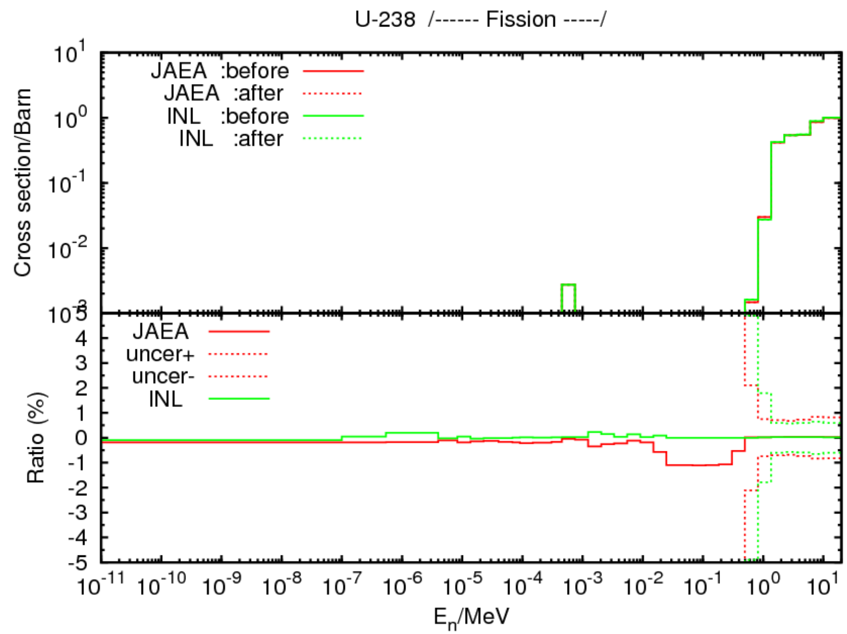
3. Trial calculation

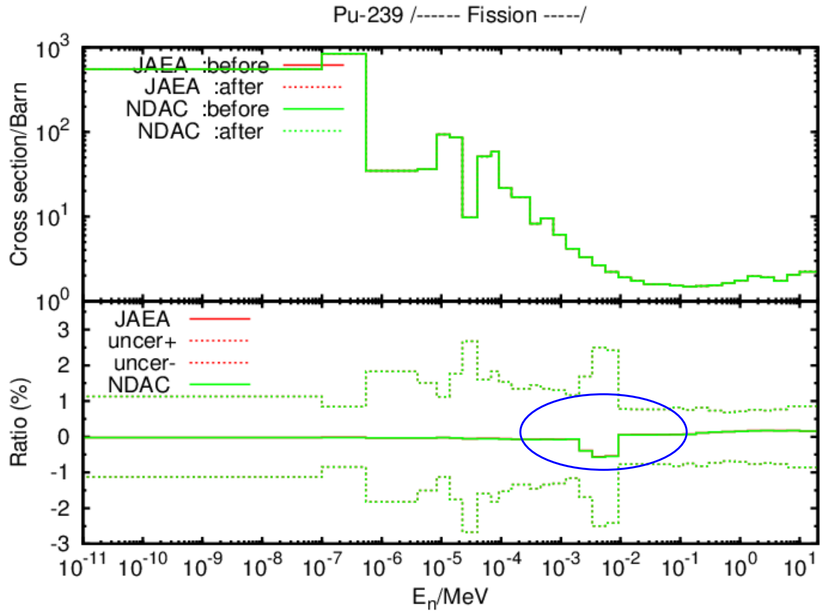
- **NDAC was tested with JAEA inputs**
- **11 isotope**
  - ^{10}B, ^{16}O, ^{23}Na, ^{52}Cr, ^{56}Fe, ^{58}Ni, ^{235,238}U, ^{239,240,241}Pu
- **8 Reactions**
  - (n, el), (n, inl), (n, disappearance),(n, f), Nu-total, Chi-p, Mu, Nu-delay.
- **Covariance: JENDL-4.0**
- **20 Integral data**
  - JEZEBEL-Pu239 (k_{eff}, F28/F25,F49/F25, F37/F25), -Pu240 (k_{eff}), FLATTOP-Pu (k_{eff}, F28/F25, F37/F25), ZPR-6/7 (k_{eff}, F28/F25, F49/F25, C28/F25), -High Pu240 (k_{eff}), ZPPR-9 (k_{eff}, F28/F25, F49/F25, C28/F25, Na void reactivity (Step 3, 5)), JOYO Mk-I (k_{eff}) .


C/E comparison before and after adjustment
benchmark
priori(JAEA)
posterior(JAEA)
priori(NDAC)
posterior(NDAC)
C/E-1[pcm]
2000
1500
1000
500
0
-500
-1000
-1500
JEZ-239 k_{eff}
JEZ-240 k_{eff}
FLA-PU k_{eff}
ZPR6-7 ST k_{eff}
ZPR6-7 240 k_{eff}
ZPPR-9 k_{eff}
JOYO k_{eff}
integral parameter

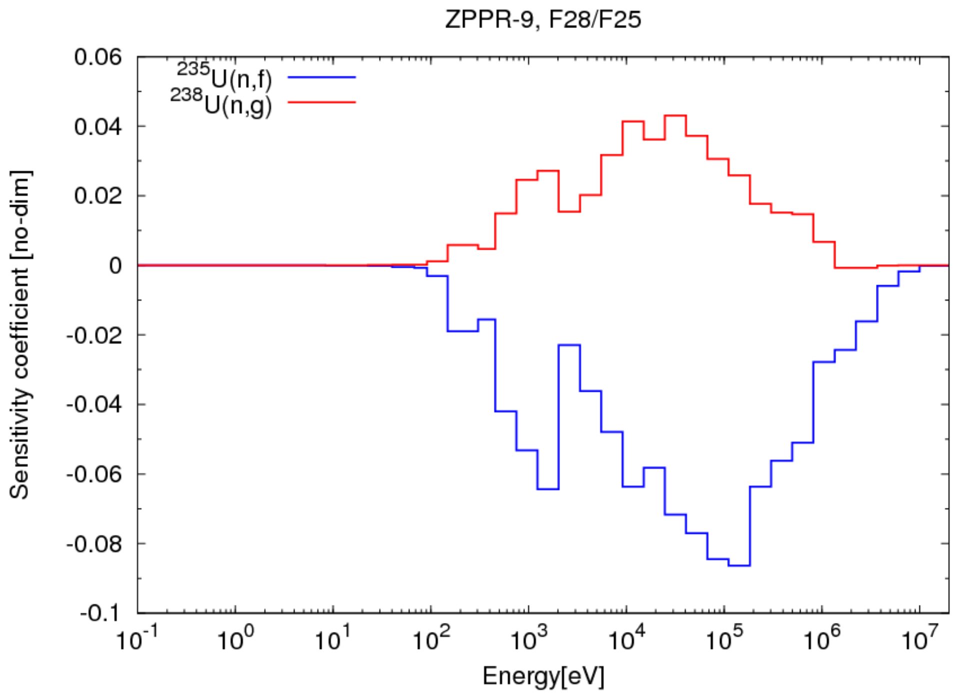

C/E comparison before and after adjustment
Benchmark
priori(JAEA)
posterior(JAEA)
priori(NDAC)
posterior(NDAC)
15
10
5
0
-5
-10
C/E-1[%]
JEZ-239 F28/F25
JEZ-239 F49/F25
JEZ-239 F37/F25
FLA-PU F28/F25
FLA-PU F37/F25
ZPR6-7 ST F28/F25
ZPR6-7 ST F49/F25
ZPR6-7 ST C28/F25
ZPPR-9 F28/F25
ZPPR-9 F49/F25
ZPPR-9 C28/F25
ZPPR-9 SVR(3)
ZPPR-9 SVR(5)
integral parameter

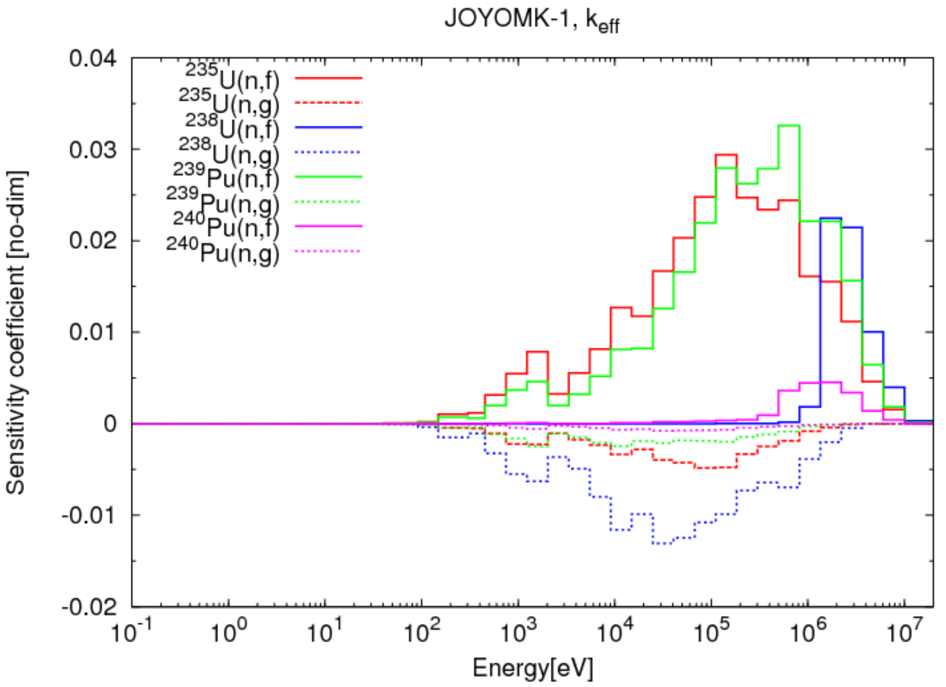






The decrease of ZPR6-7 F49/F25, ZPPR9 F28/F25 and F49/F25 reaction ratios are mainly caused by the increasing of ^{235}U(n,f) in 1~10 keV region.





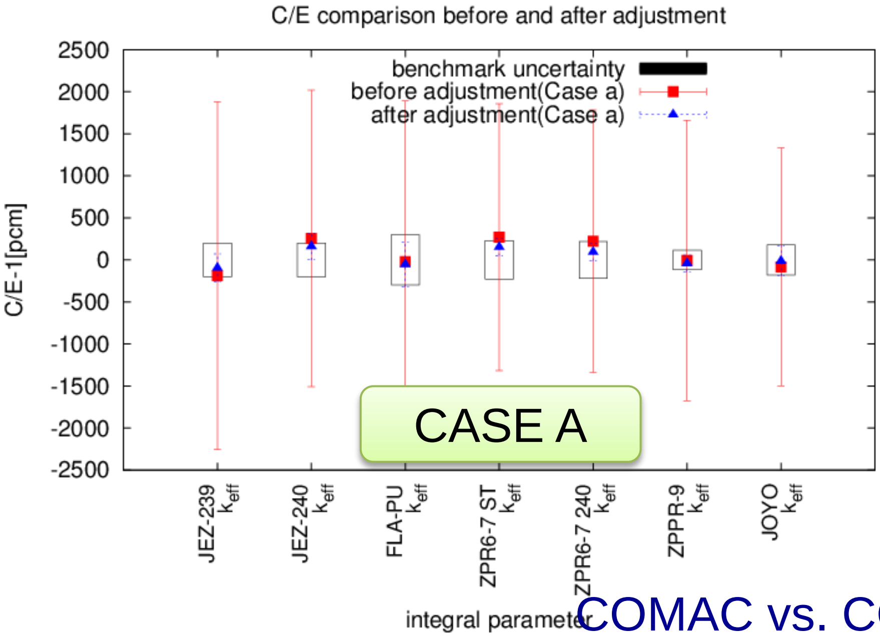
- No benchmark with strong k-eff sensitivities to ^{235}U(n,f) cross section in several keV region was included in adjustment.
- **Lesson: missing essential constraints, adjusted results can be driven to anywhere not expected.**
  - Integral benchmarks sensitive to specific energy region/ cross sections;
  - Too larger uncertainty in priori group constants for certain cross sections.
  - Missing covariance for certain ingredient which is responsible for the under estimation of F49/F25 , et al.

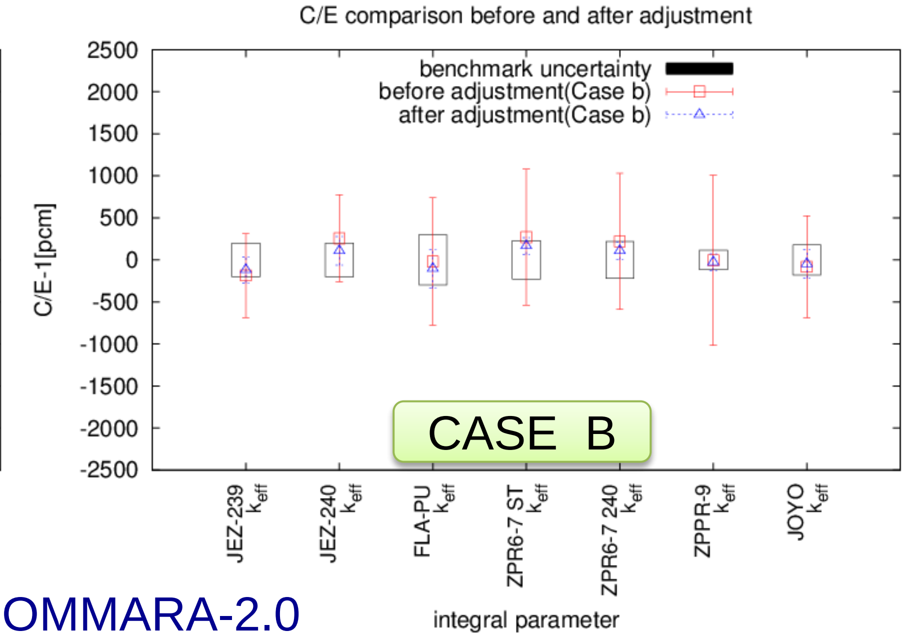
✓ **Missing essential constraints always lead to compensation errors!**

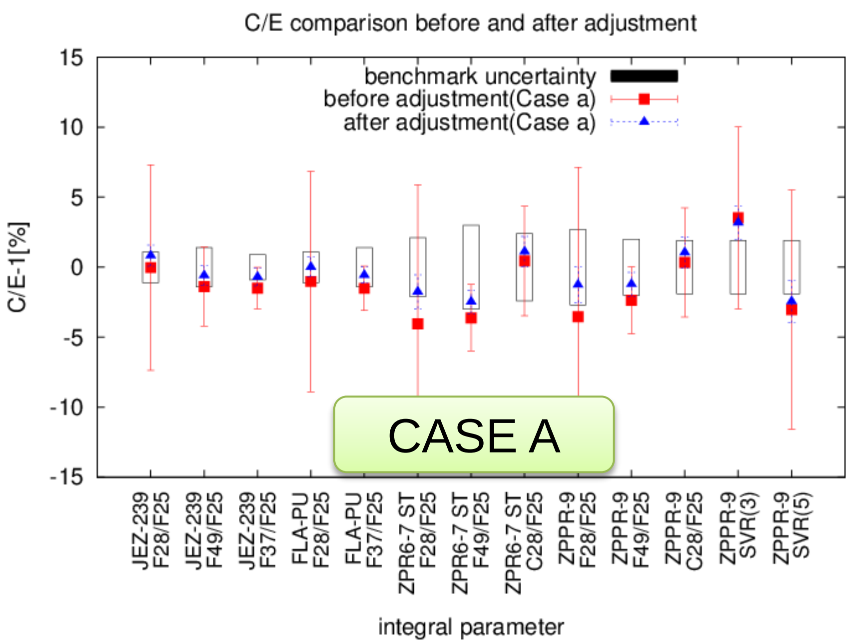
4. Preliminary study on input parameters

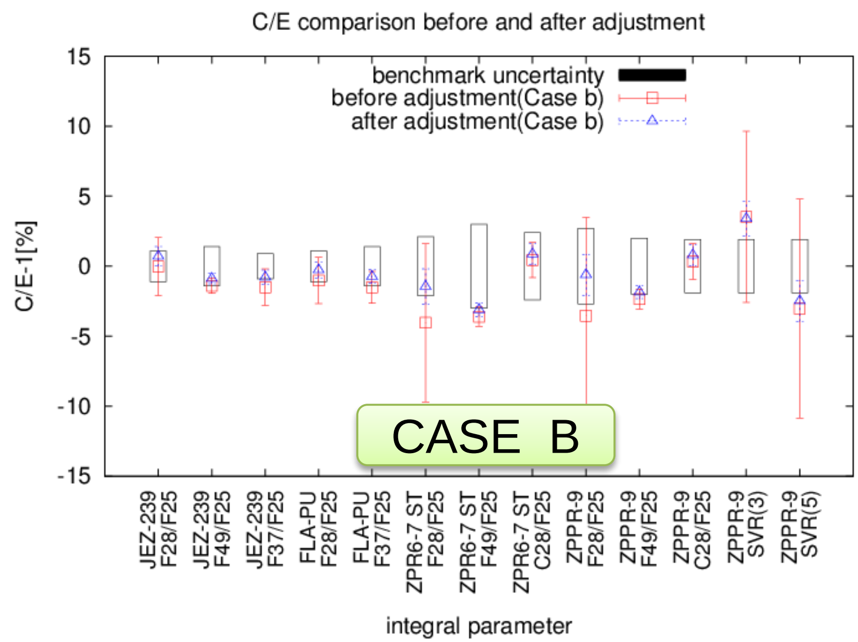
- **Replace one kind of parameters at a time, try to find out the influence of**
  - Covariance of group constants, sensitivities, covariance of integral quantities
- **Case A & B**
  - Group constants : JEFF3.1.1; Sensitivity : CEA/ERANOS
  - Covariance: COMAC vs. COMMARA-2.0
- **Case C & D**
  - Group constants: ENDF/B-7.0; Covariance : COMMARA-2.0
  - Sensitivity: INL vs. KAERI
- **Case E & F**
  - Group constants: JENDL-4.0; Sensitivity : JENDL-4.0
  - Correlation of Integral quantities: Yes vs. No.

COMAC vs. COMMARA-2.0

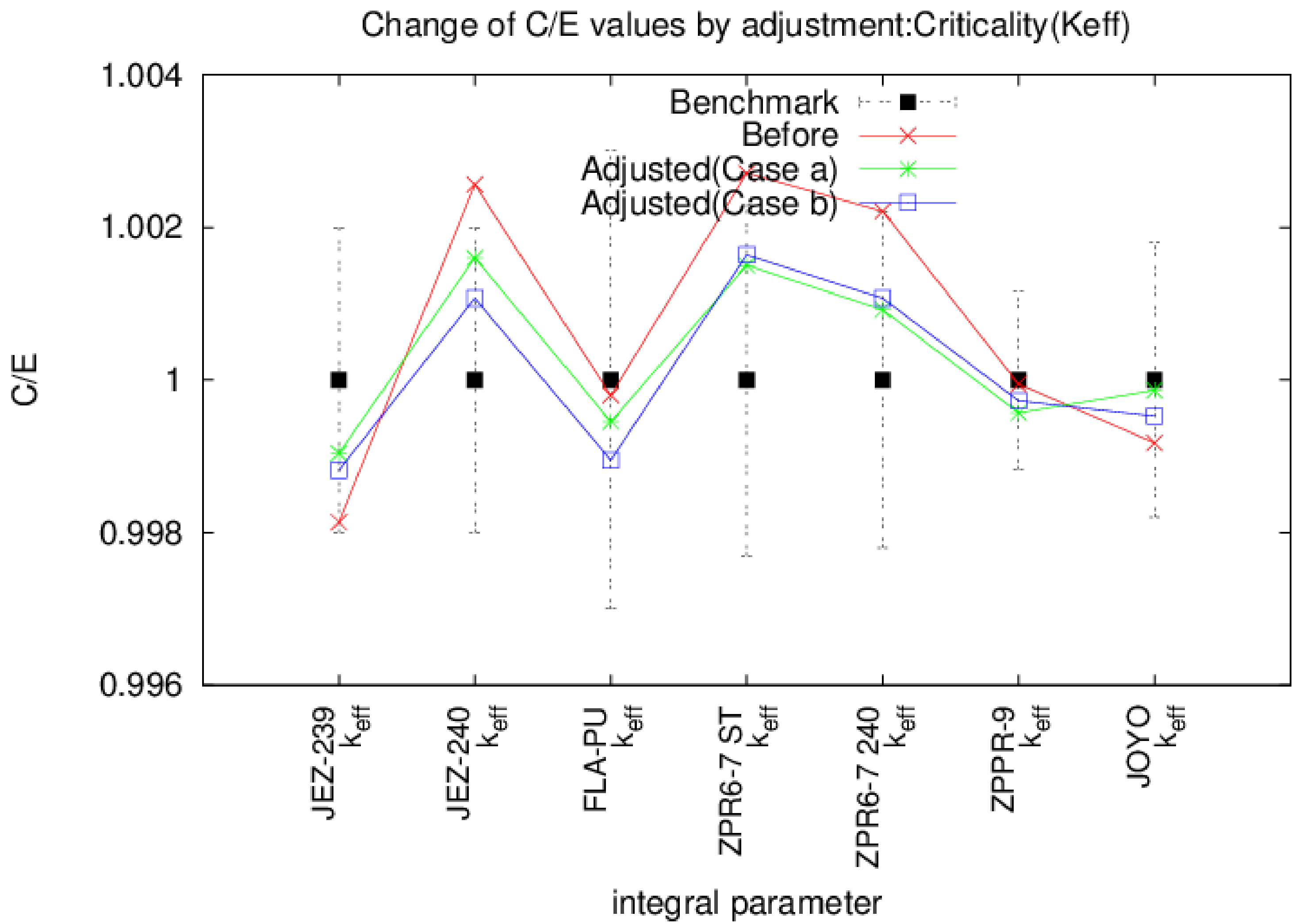


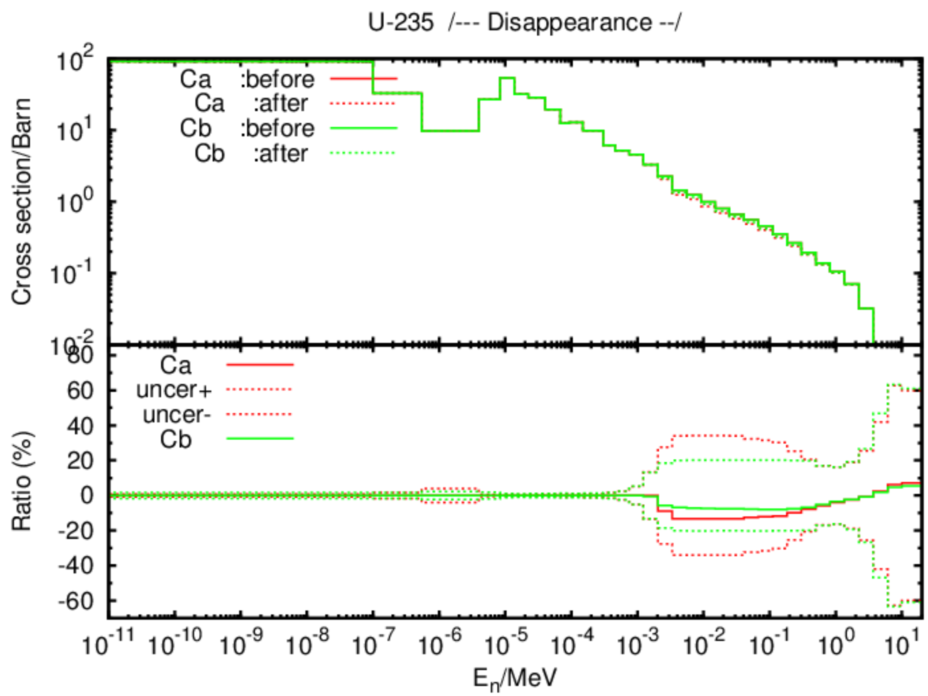


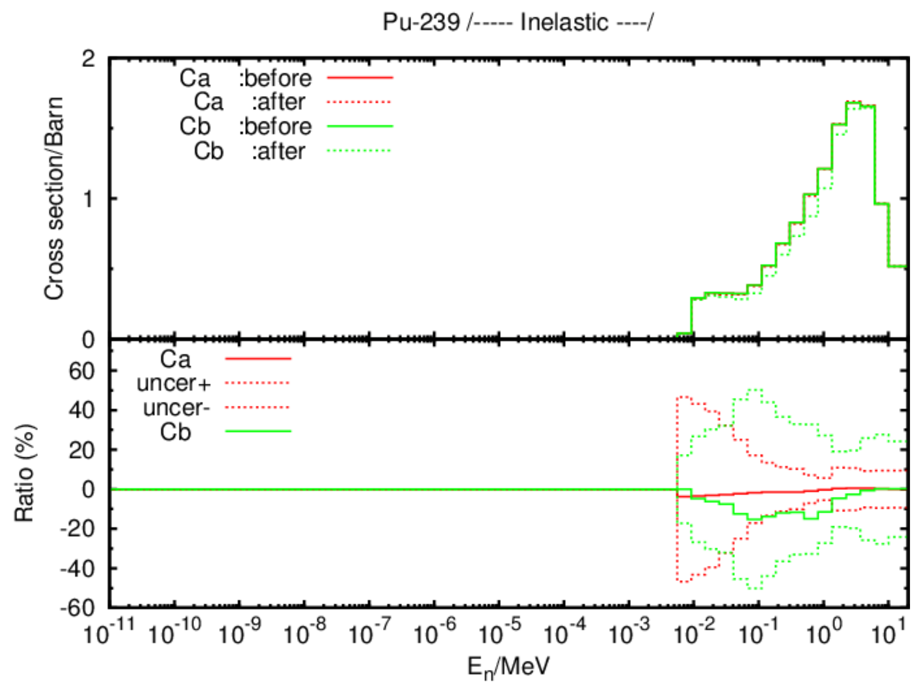




CaseA&B: Replace correlation coefficients of group constants

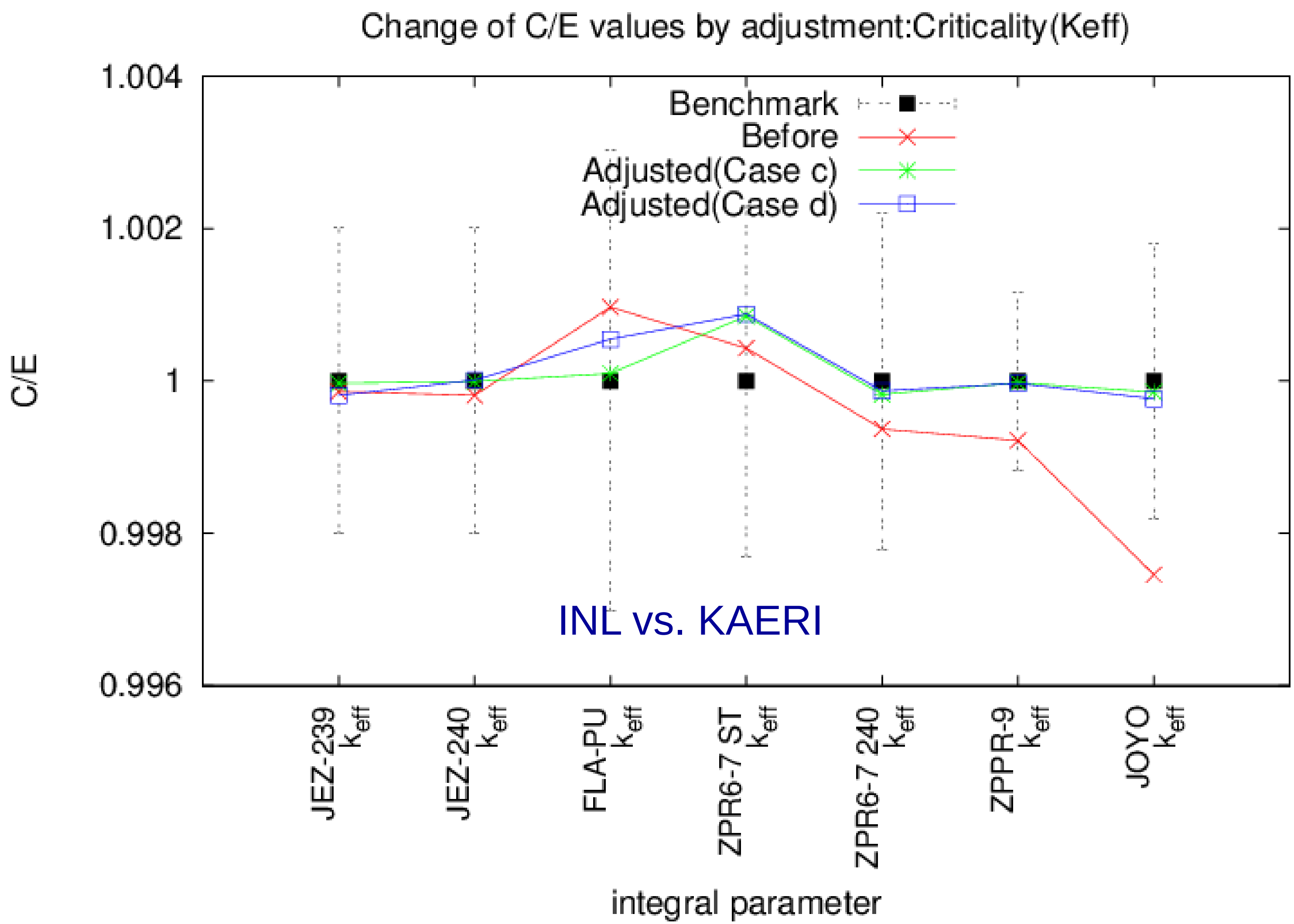


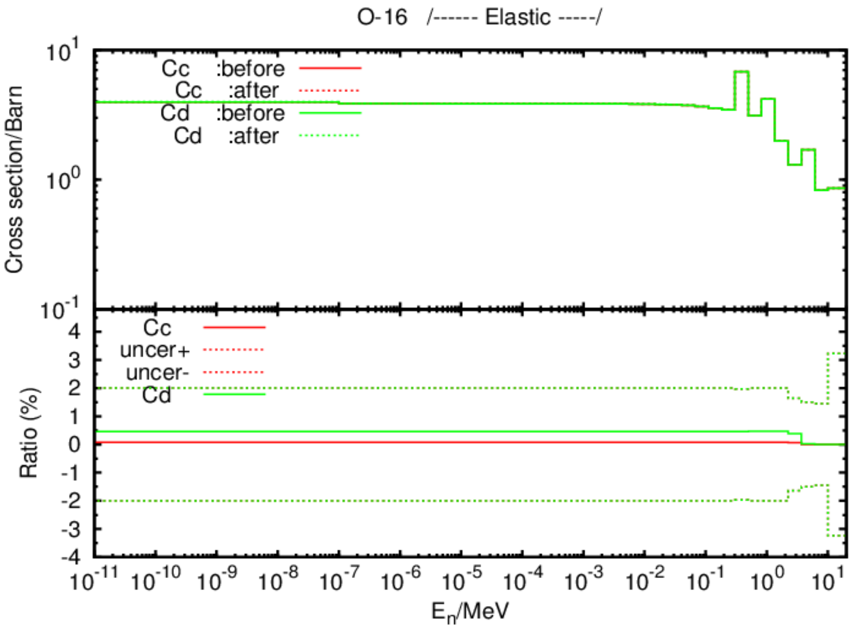


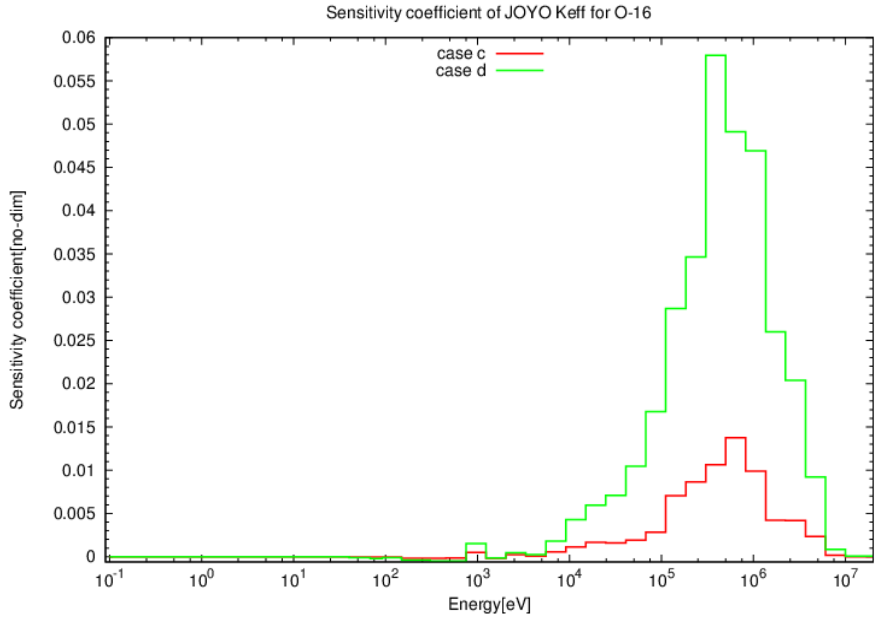


1. **With different priori covariance of group constants , the adjusted integral C/E values and uncertainties are quite similar, because differential-parameter covariance matrix $SM_{\sigma}S^{T}$ >> integral-parameter covariance matrix $M_{EC;}$**
2. **But the alteration of the cross sections are different.**
Larger uncertainties are corresponding to larger alternations.

Case C&D: Replace sensitivities



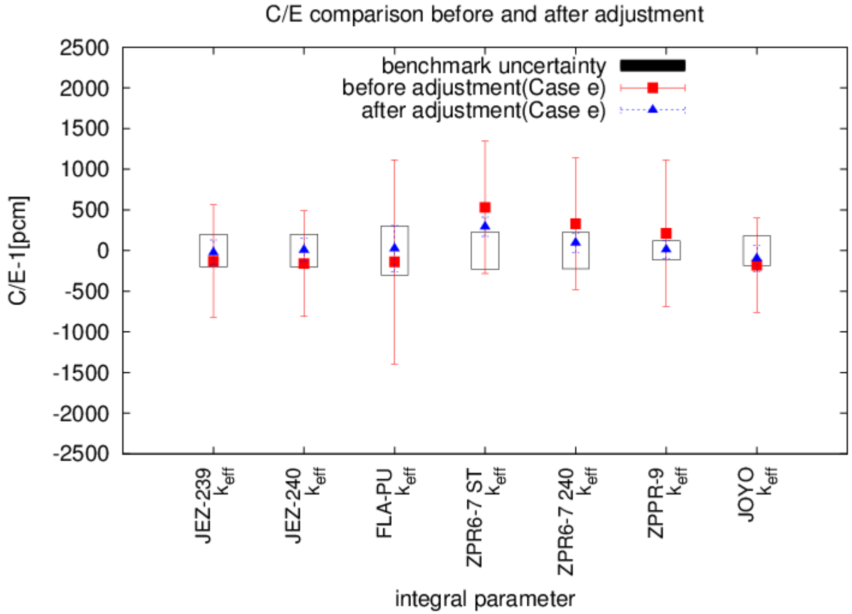


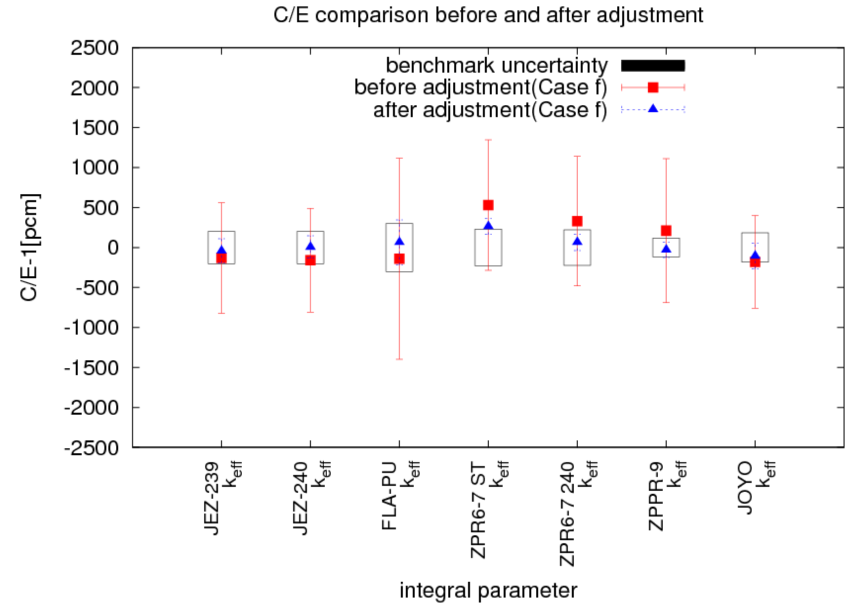


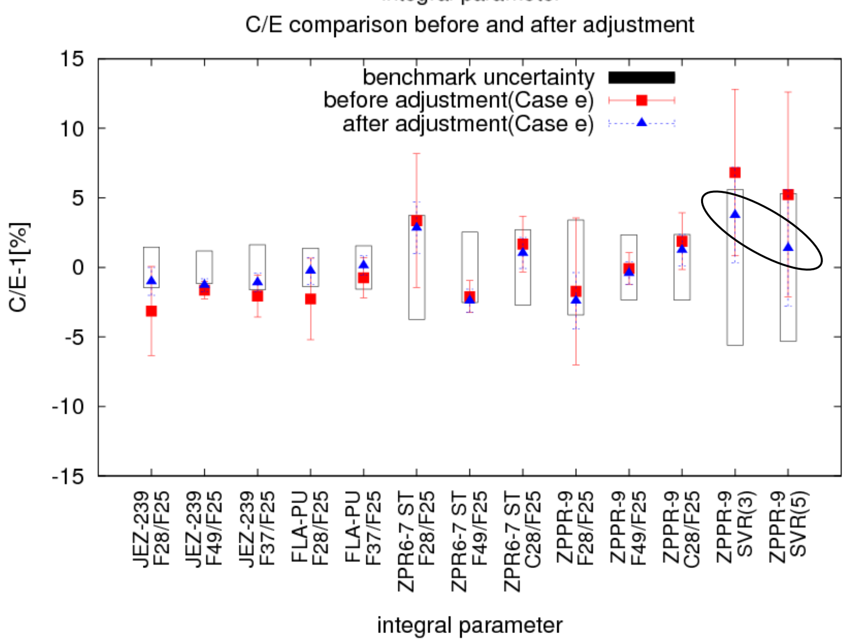
1. **With different sensitivity matrices, the adjusted integral C/E values are quite similar, because the influence of integral-parameter covariance matrix M_{EC} is still dominant.**

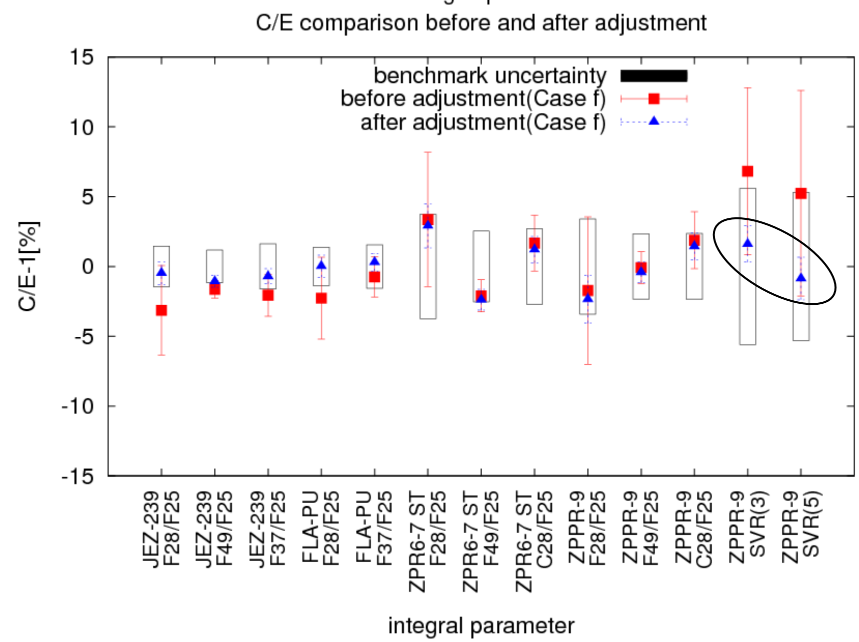
2. **But the alteration of the cross sections are different. Larger sensitivities are corresponding to larger alternations.**

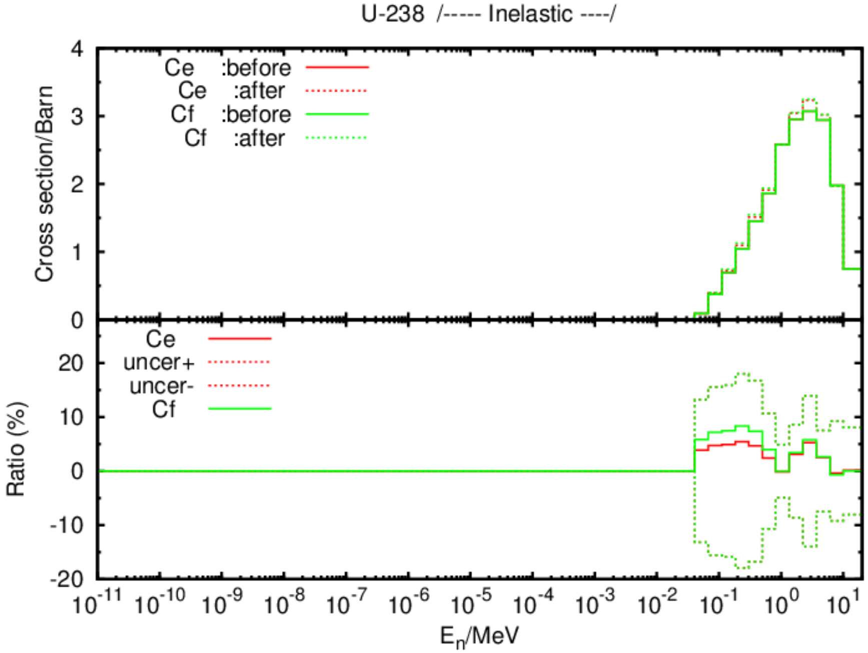
Case E&F: with and without the correlation of integral experiments

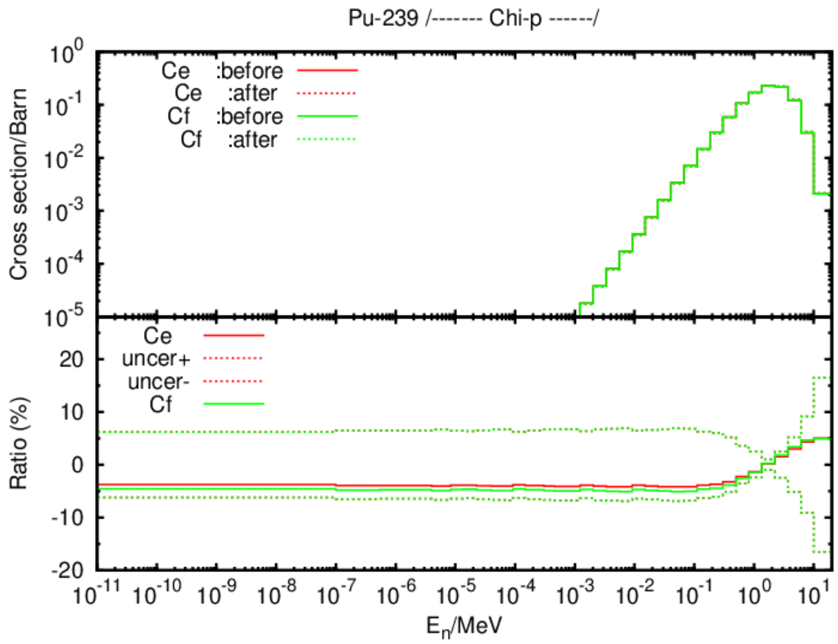












1. **With and without the correlation of integral experiments, the adjusted integral C/E values and uncertainties are quite similar, except for SVR.**

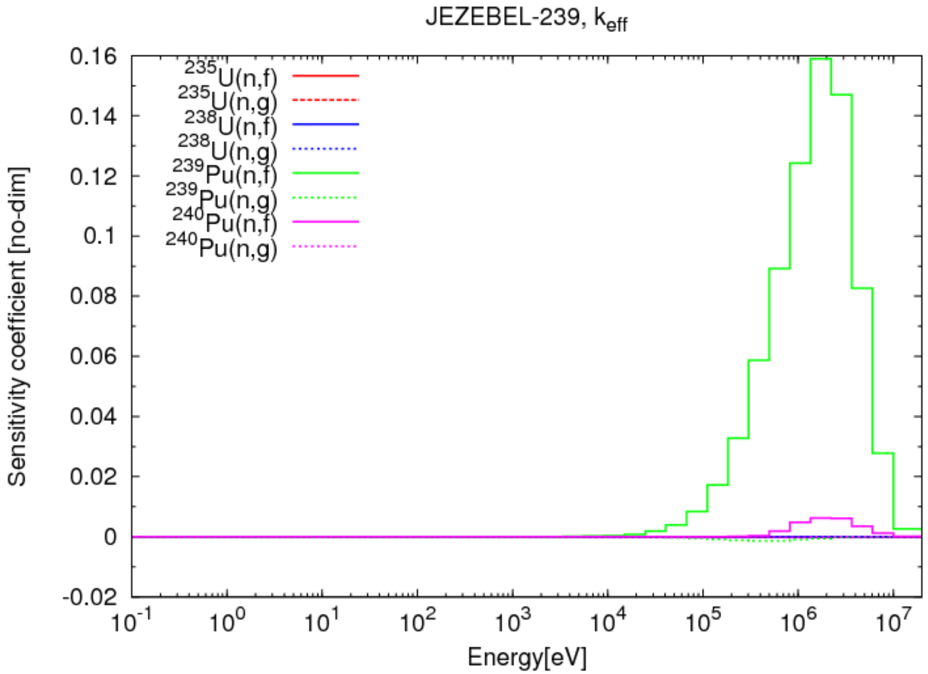
2. **The correlation of integral experiments do show some impact on adjustment results.**

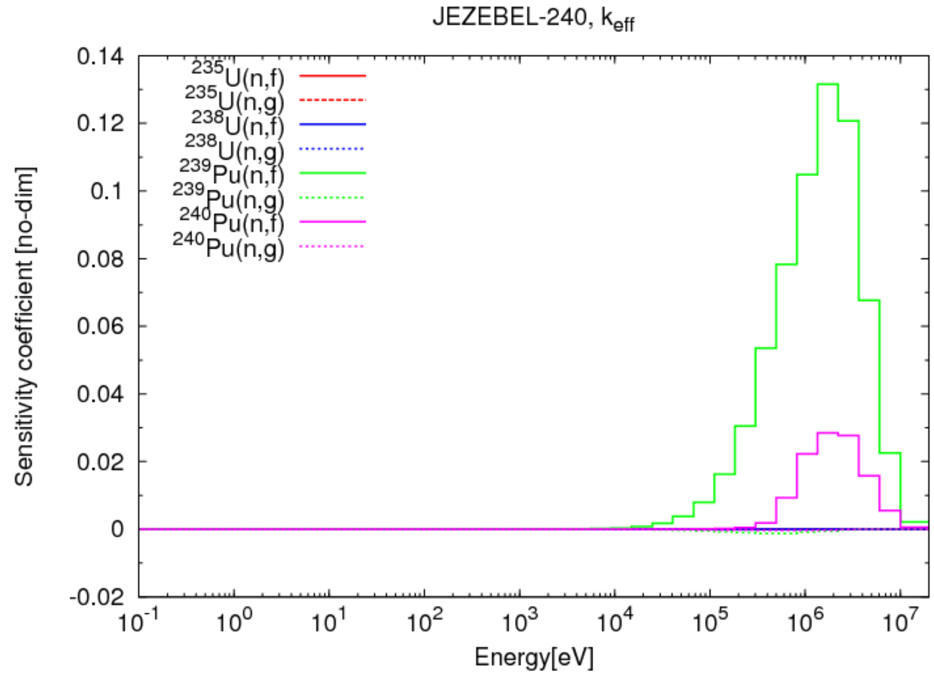
5. Discussion on applying nuclear data adjustment method to provide quantitative feedbacks to evaluators

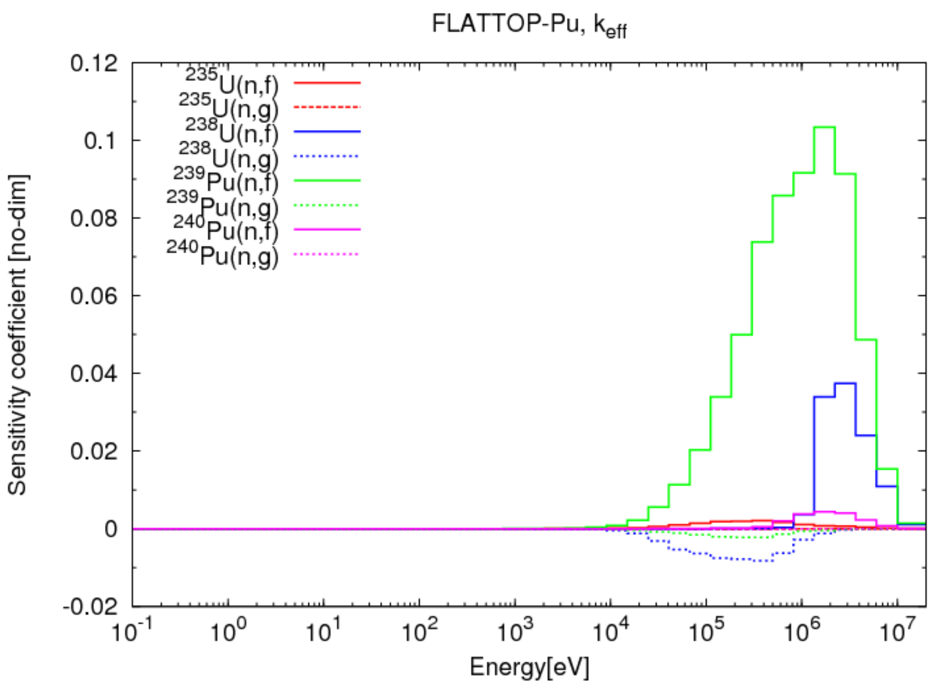
- **All ingredient in adjustment affect the results**
  - Integral part: benchmark sets, integral quantities and their correlations, uncertainties of calculation methods, sensitivities, et al;
  - Differential part: covariance for all components of the nuclear data library, including cross sections, angular distributions , energy spectra, double differential spectra, resonance parameters, nubar, branches, et al.
- **Missing essential constraints, adjusted results can be driven to somewhere we don't expected and always lead to compensation errors.**

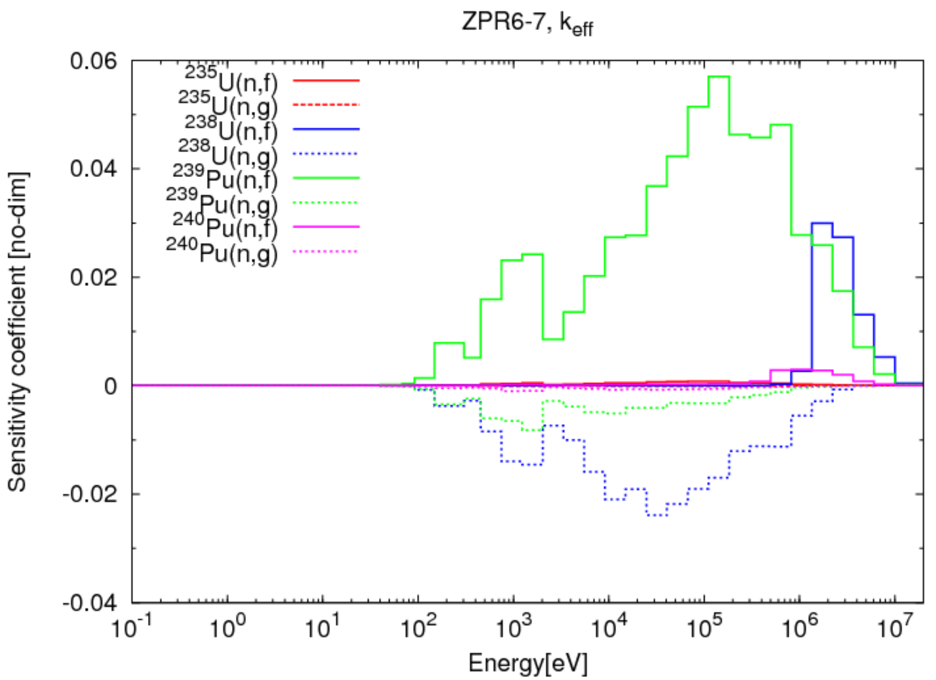
- To have an easy understand, applying nuclear data adjustment method to provide quantitative feedbacks to evaluators can be translated to the follow questions
  - If we want to tell where a flood should go beyond the dyke, we have to illustrate all the landform outside the dyke.
  - Does it possible to describe the landform in multi-dimension space for GLS adjustment?
  - How precisely we can make this landform map?
    - Do we have enough benchmarks? No.
    - Are we able to calculate all the sensitivities? Not yet.
    - Do we have all the covariance matrices of microscopic and macroscopic data? Not yet.
- There is still a long way to go.

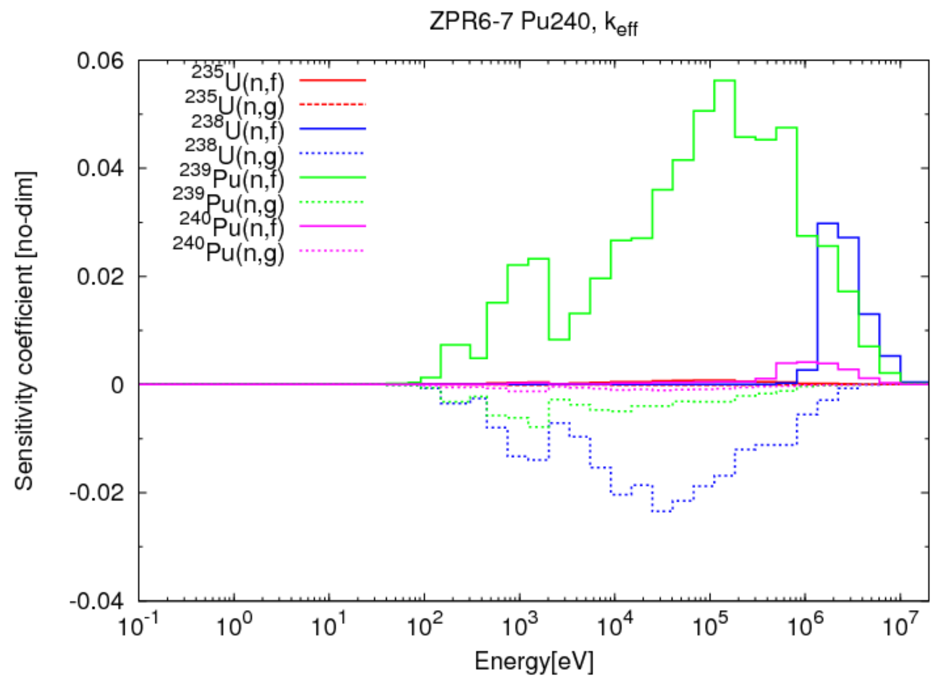
Thank you for your attention !

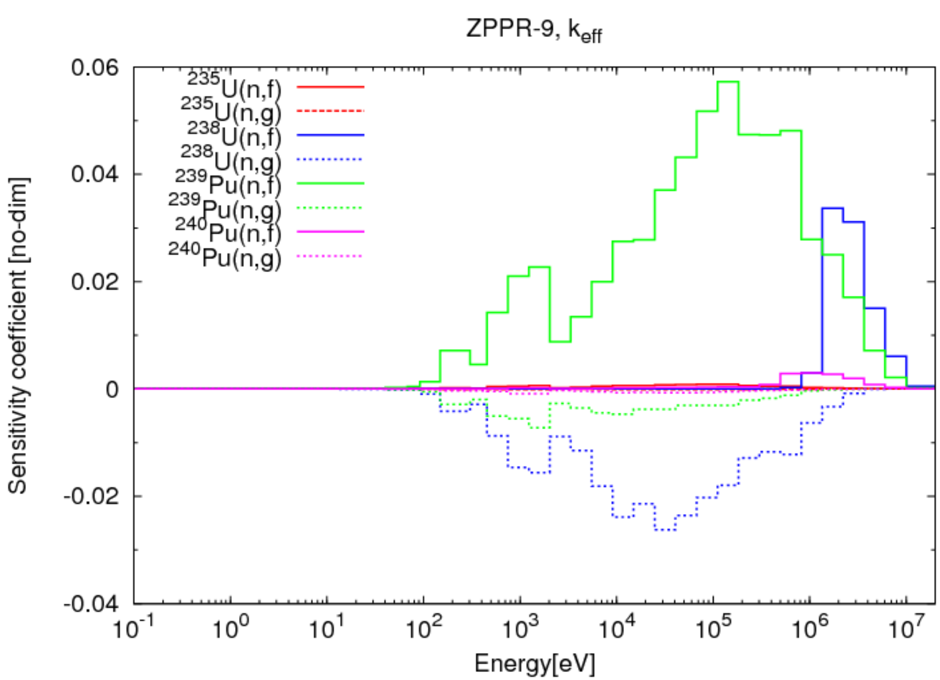

JEZEBEL-239, k_{eff}
^{235}U(n,f)
^{235}U(n,g)
^{238}U(n,f)
^{238}U(n,g)
^{239}Pu(n,f)
^{239}Pu(n,g)
^{240}Pu(n,f)
^{240}Pu(n,g)
Sensitivity coefficient [no-dim]
Energy[eV]

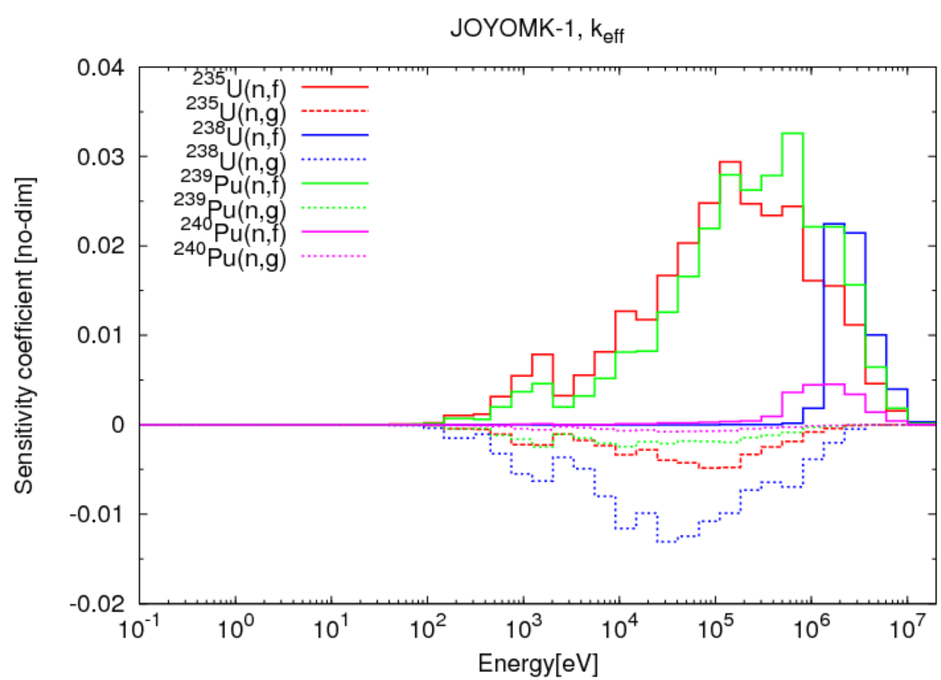

JEZEBEL-240, k_{eff}
^{235}U(n,f)
^{235}U(n,g)
^{238}U(n,f)
^{238}U(n,g)
^{239}Pu(n,f)
^{239}Pu(n,g)
^{240}Pu(n,f)
^{240}Pu(n,g)
Sensitivity coefficient [no-dim]
Energy[eV]


FLATTOP-Pu, k_{eff}
^{235}U(n,f)
^{235}U(n,g)
^{238}U(n,f)
^{238}U(n,g)
^{239}Pu(n,f)
^{239}Pu(n,g)
^{240}Pu(n,f)
^{240}Pu(n,g)
Sensitivity coefficient [no-dim]
Energy[eV]


ZPR6-7, k_eff
Sensitivity coefficient [no-dim]
Energy[eV]
235U(n,f)
235U(n,g)
238U(n,f)
238U(n,g)
239Pu(n,f)
239Pu(n,g)
240Pu(n,f)
240Pu(n,g)


ZPR6-7 Pu240, k_eff
Sensitivity coefficient [no-dim]
Energy[eV]
235U(n,f)
235U(n,g)
238U(n,f)
238U(n,g)
239Pu(n,f)
239Pu(n,g)
240Pu(n,f)
240Pu(n,g)


ZPPR-9, k_eff
Sensitivity coefficient [no-dim]
Energy[eV]
235U(n,f)
235U(n,g)
238U(n,f)
238U(n,g)
239Pu(n,f)
239Pu(n,g)
240Pu(n,f)
240Pu(n,g)


JOYOMK-1, k_eff
Sensitivity coefficient [no-dim]
Energy[eV]
235U(n,f)
235U(n,g)
238U(n,f)
238U(n,g)
239Pu(n,f)
239Pu(n,g)
240Pu(n,f)
240Pu(n,g)