

*Joint Meeting of CIELO and WPEC Subgroup 39 on  
Methods and approaches to provide feedback from nuclear and covariance data  
adjustment for improvement of nuclear data files*

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# **Revised Recommendations from ADJ2010 Adjustment**

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# Introduction

**ADJ2010** is a **70-group** adjusted library based on **JENDL-4.0**, where **488 integral experimental data** from **8 facilities** (ZPPR, ZEBRA, JOYO, MONJU, BFS, MASURCA, SEFOR and Los Alamos) were used for the adjustment.

Here, the major alteration of nuclear data by the adjustment is summarized for **5 nuclides** (Pu-239, U-238, U-235, Fe-56 and Na-23), and compared with **ENDF/B-VII.1** and **JEFF-3.1.2**.

Finally, we try to make some **recommendations** to nuclear-data evaluators, though it is not mature.

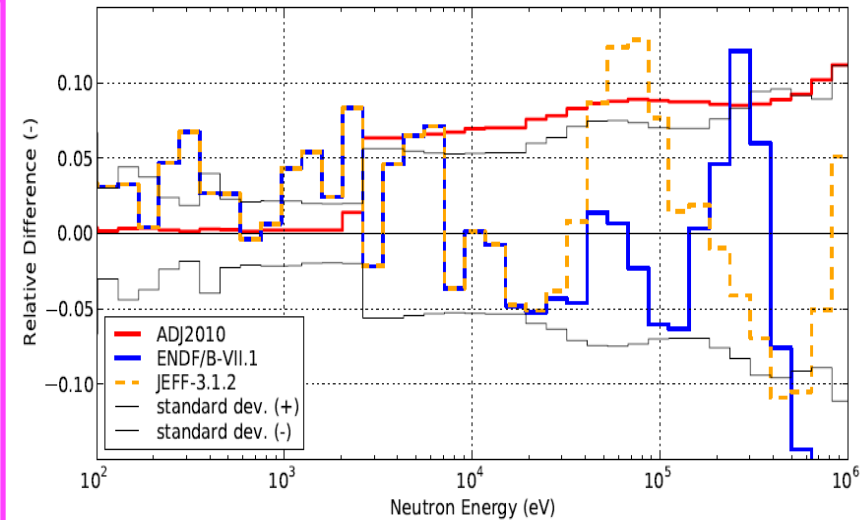
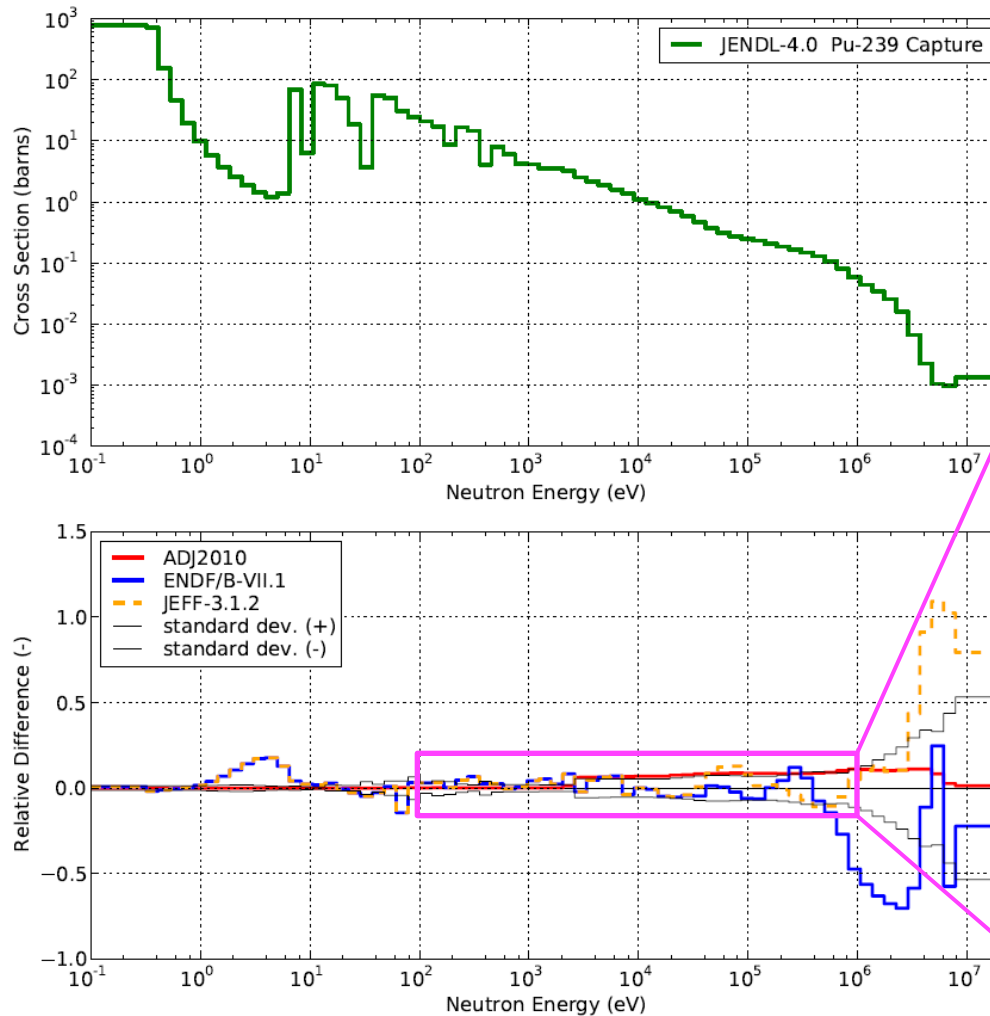
A **thick report** of ADJ2010 is available from the URL below with the **huge numerical results** in **digital files**.

<http://jolissrch-inter.tokai-sc.jaea.go.jp/search/servlet/search?5035118&language=1> 2

# Pu-239

# Pu-239

## Capture



- ADJ2010 **increases** Pu-239 capture cross-section **over 3keV** by **7 to 9%**. This large alteration is **at the variance bound** of JENDL-4, but agrees with **NEITHER** of the **three major libraries**. The increase is **determined by a combination of integral experiments**. -> next slides.
- Present measured data are quite old before 1976. **New DANCE data** will be published soon.

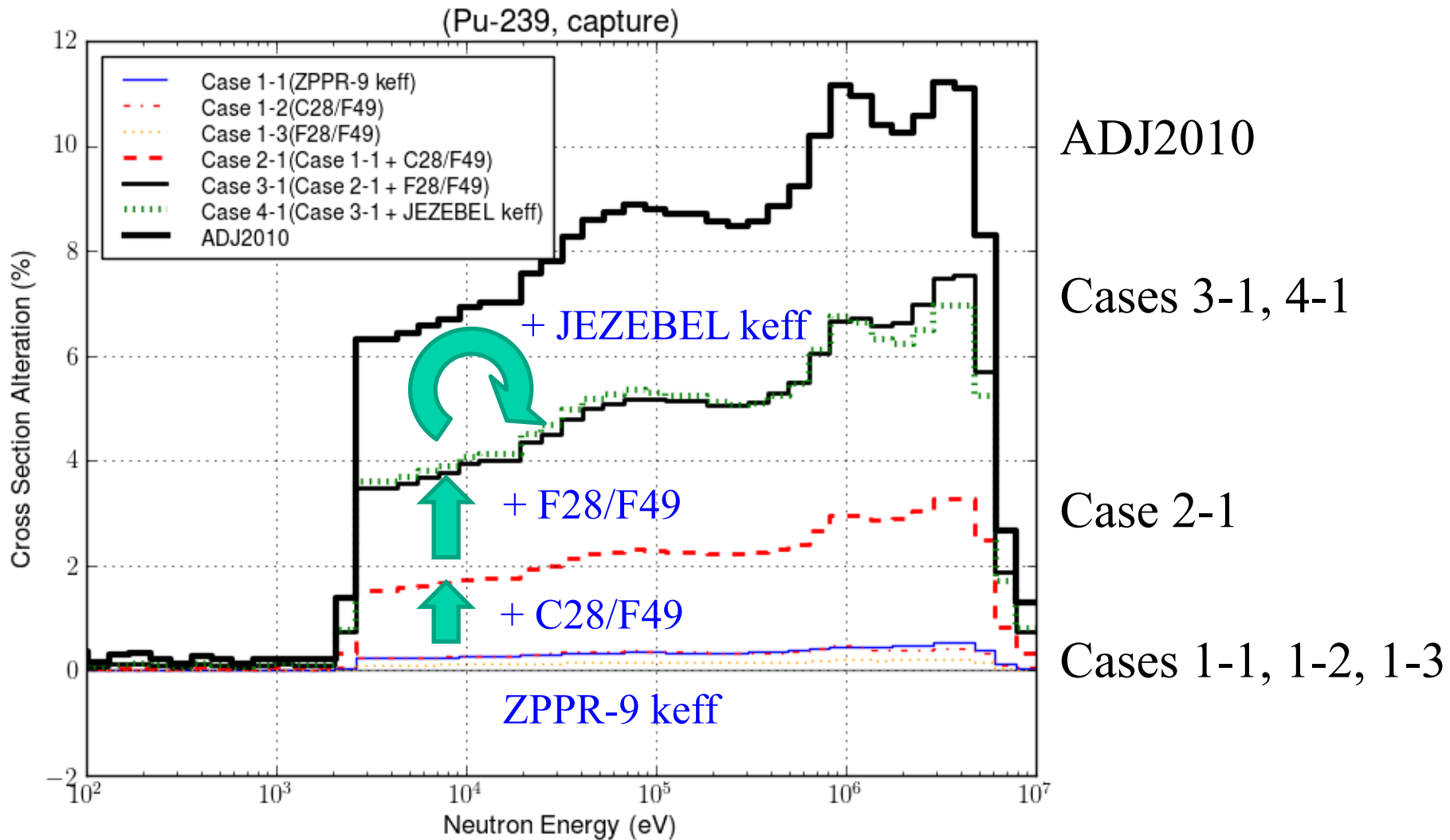
# Small Test Cases to Investigate Mechanisms

## Integral Experiments Used in Small Test Cases

	ZPPR-9			JEZEBEL
	keff	C28/F49	F28/F49	keff
Case 1-1	X			
Case 1-2		X		
Case 1-3			X	
Case 2-1	X	X		
<b>Case 3-1</b>	<b>X</b>	<b>X</b>	<b>X</b>	
Case 4-1	X	X	X	X

- It is heuristically found that **Case 3-1** reproduces well the cross-section alteration of Pu-239 capture of ADJ2010
- In spite of using only 3 data, compared with 488 data of ADJ2010

# Cross-section Alteration of Pu-239 capture



■ **Not moved** by using only ZPPR-9 keff (*motive force* = +2.45)

■ **Begin to move** by a combination of integral experiments

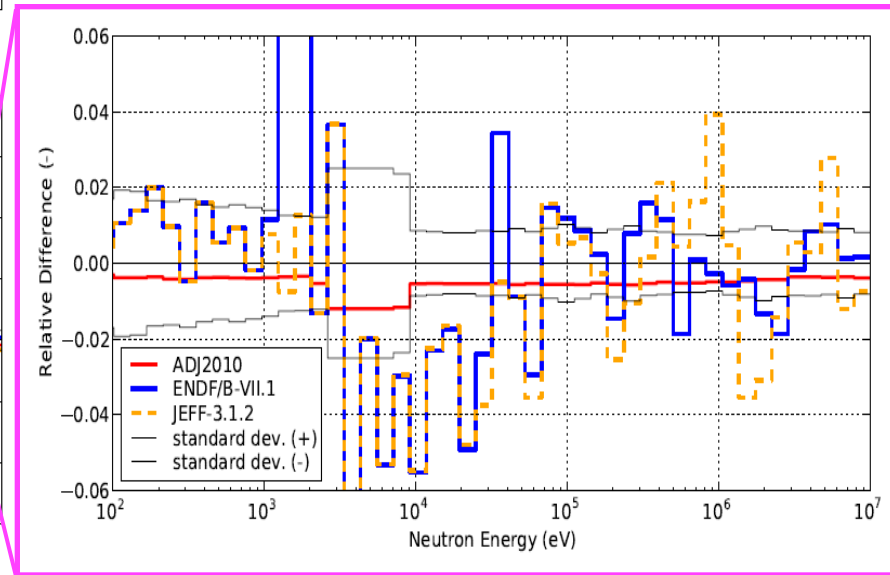
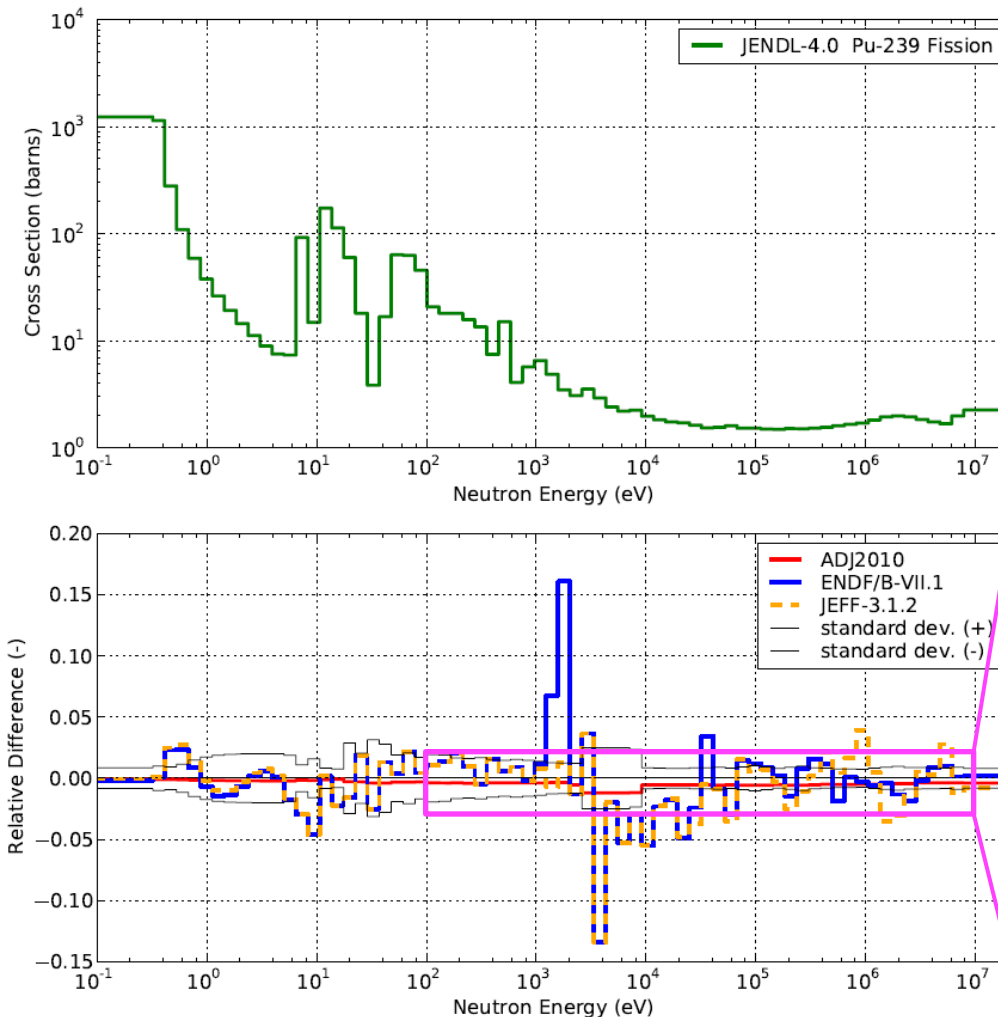
# Summary of “Conflict” and “Freely Adjustable”

Case	1-1	1-2	1-3	2-1	3-1	4-1
Integral experiments used for adjustment	Z9-keff	C28/F49	F28/F49	Z9-keff C28/F49	Z9-keff C28/F49 F28/F49	Z9-keff C28/F49 F28/F49 JZ-keff
Pu-239 capture	F	F	F	F	F	C
Pu-238 fission	F	F	F	C	C	C
Pu-239 $\chi$	F	F	F	C	C	C
Pu-239 (n, n)	-	-	-	-	-	F
U-238 capture	F	F	F	C	C	C
U-238 fission	F	F	F	F	C	C
U-238 (n, n')	F	F	F	C	C	C

- Case 2-1: Pu-239 capture begins to move
- Case 3-1: Pu-239 capture moves more
- Case 4-1: Conflict but Pu-239 (n, n) begins to move

# Pu-239

## Fission



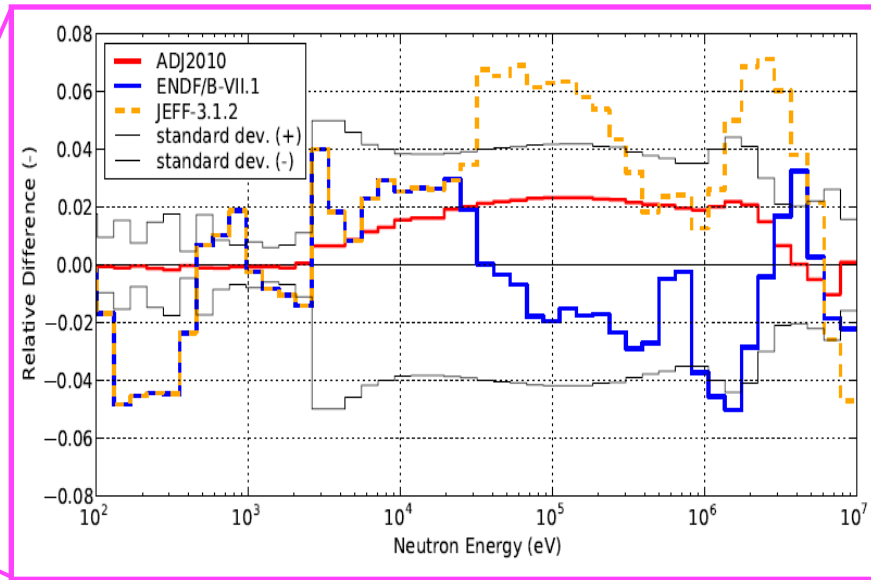
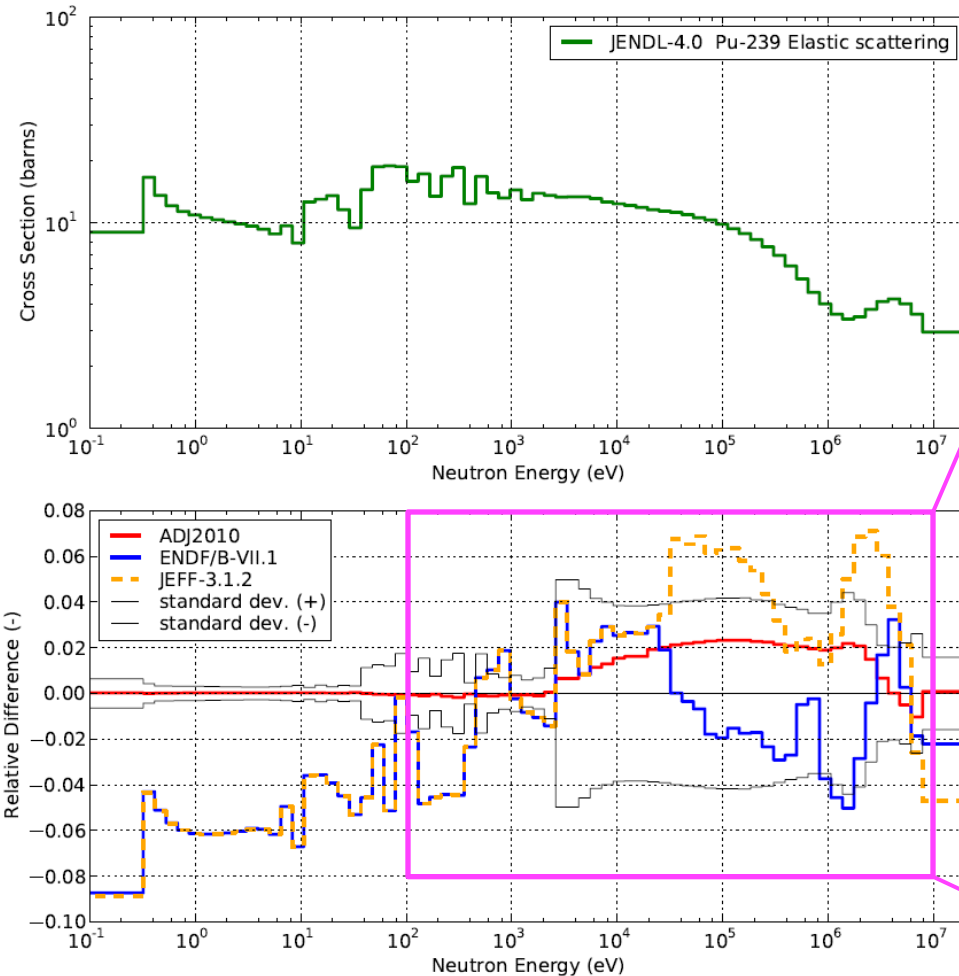
- ADJ2010 **decreases** Pu-239 fission cross-section by approximately **0.5%**.
- ENDF and JEFF seem to be **consistent** with JENDL-4.0 or ADJ2010 **in average**, but there are **large fluctuations exceeding the variance**. It may be better to consult nuclear data people about the reason.





# Pu-239

## Elastic scattering

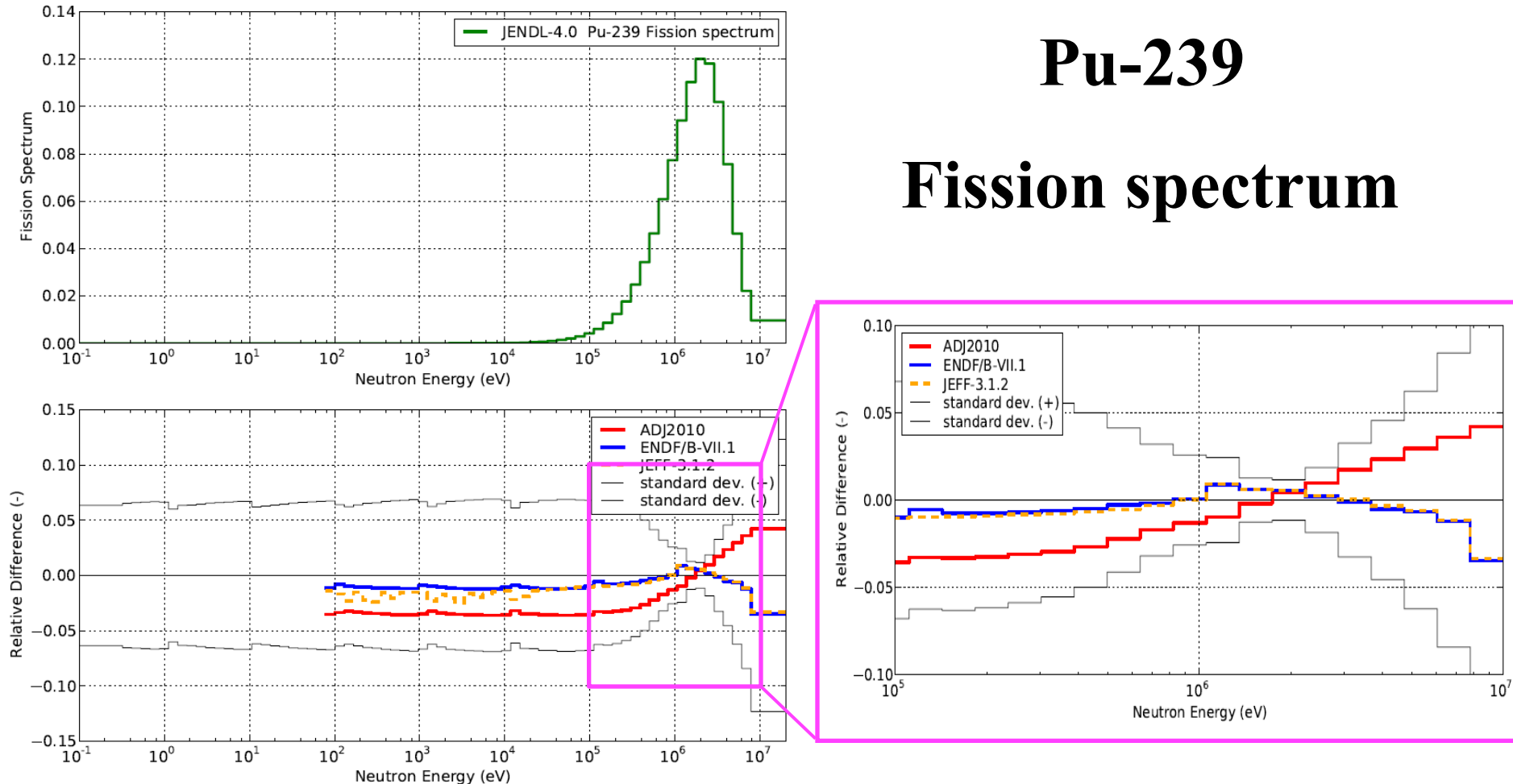


■ ADJ2010 **increases** Pu-239 elastic-scattering cross-section by **2% at the maximum**.

This alteration is **within the variance** of JENDL-4.

# Pu-239

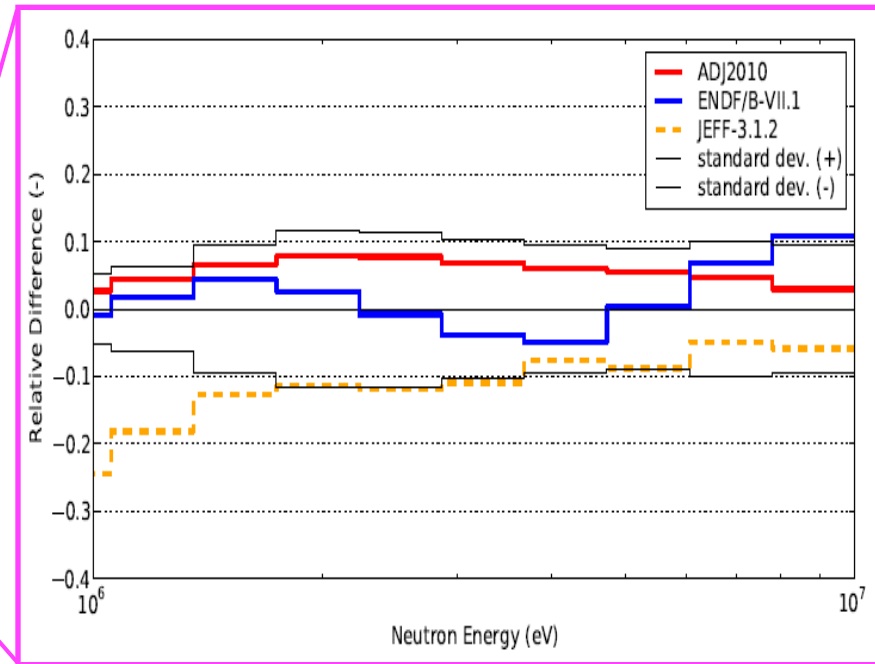
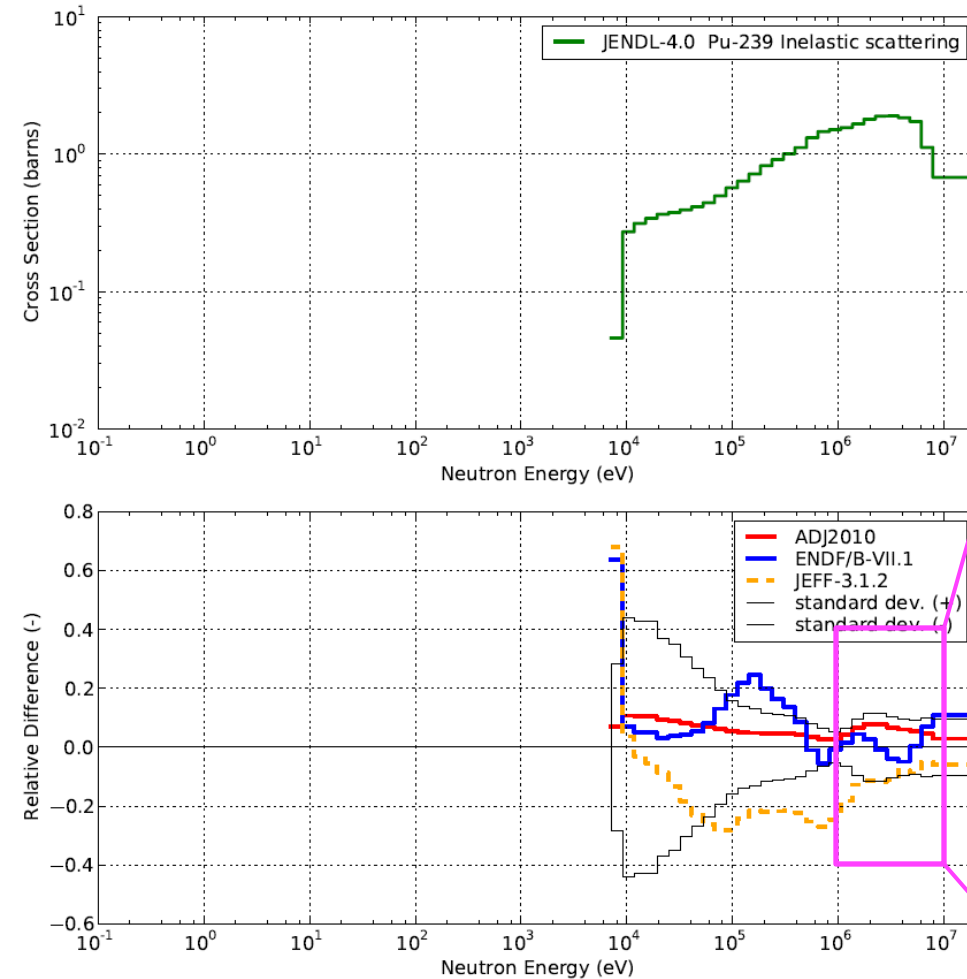
## Fission spectrum



- ADJ2010 **hardened** Pu-239 fission spectrum by **4% at the maximum**.
- This large alteration is **within the variance** of JENDL-4, but agrees with **NEITHER** of the three major libraries.
- Current covariance **fixes the peak value** of spectrum at 2MeV.

# Pu-239

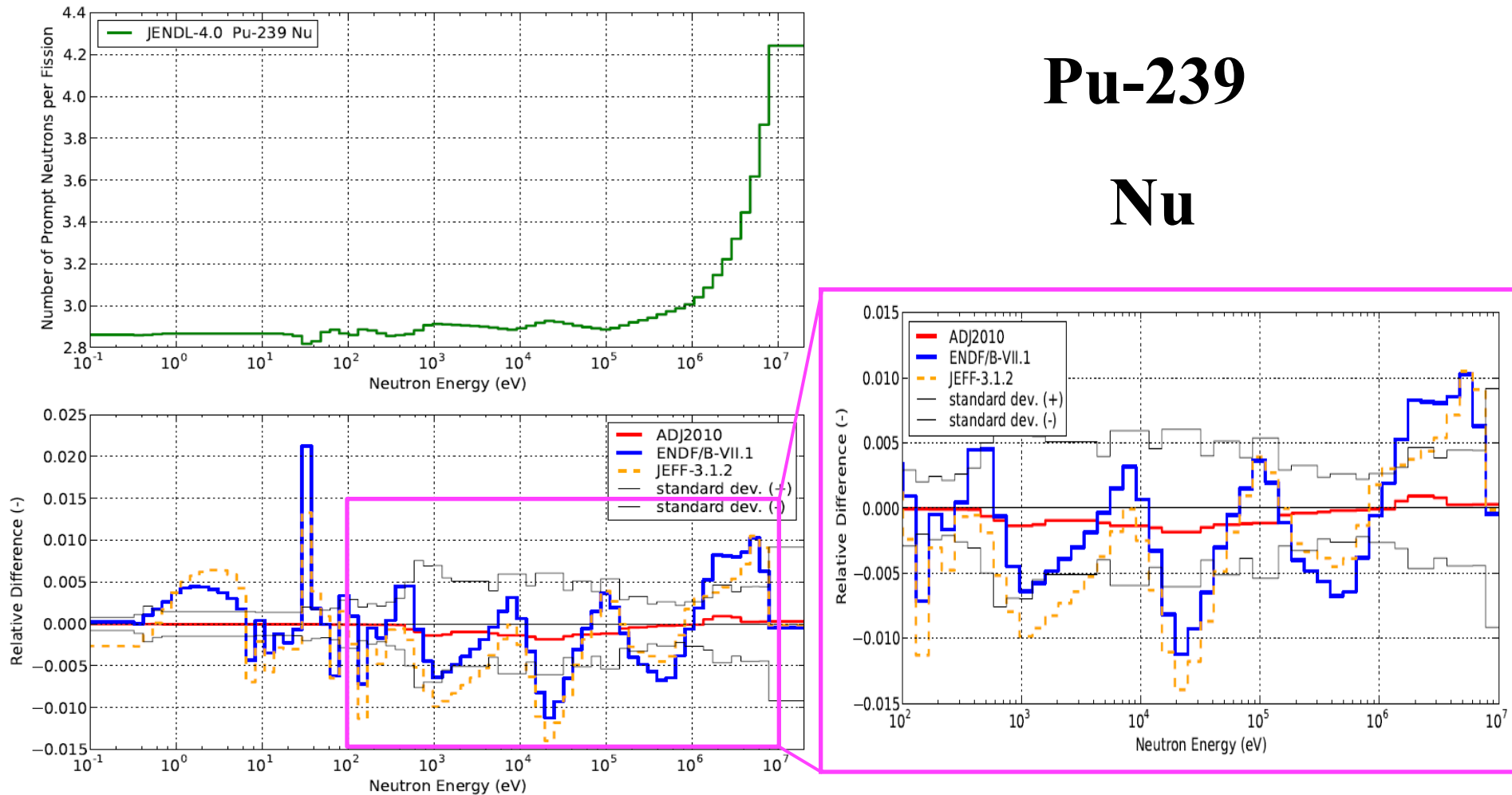
## Inelastic scattering



- ADJ2010 **increases** Pu-239 inelastic scattering cross-section by **10% at the maximum**. This alteration is **within the variance** of JENDL-4.
- Increase of inelastic scattering **compensates** the effect of the Pu-239 fission spectrum hardening on **Na void reactivity**, but the **mechanism** of increase is **NOT known**.

# Pu-239

## Nu

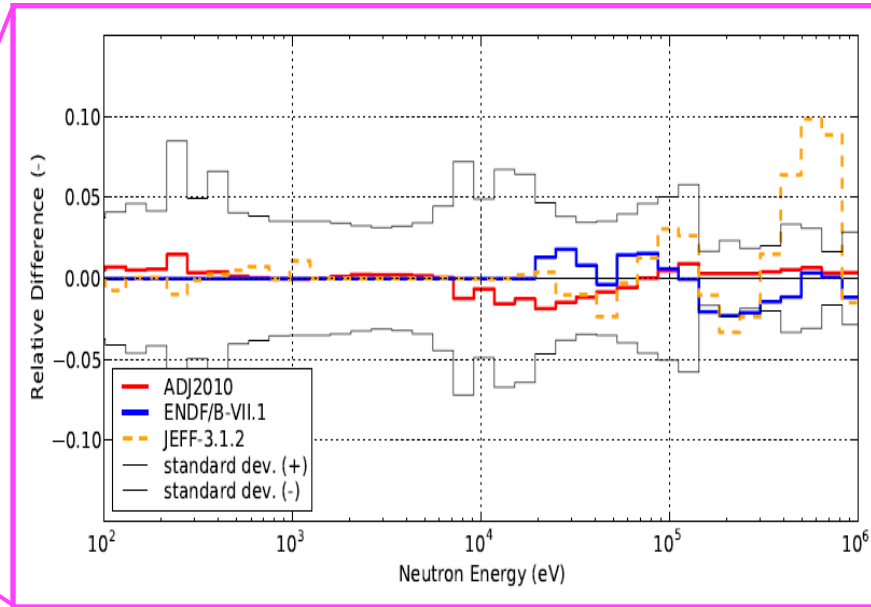
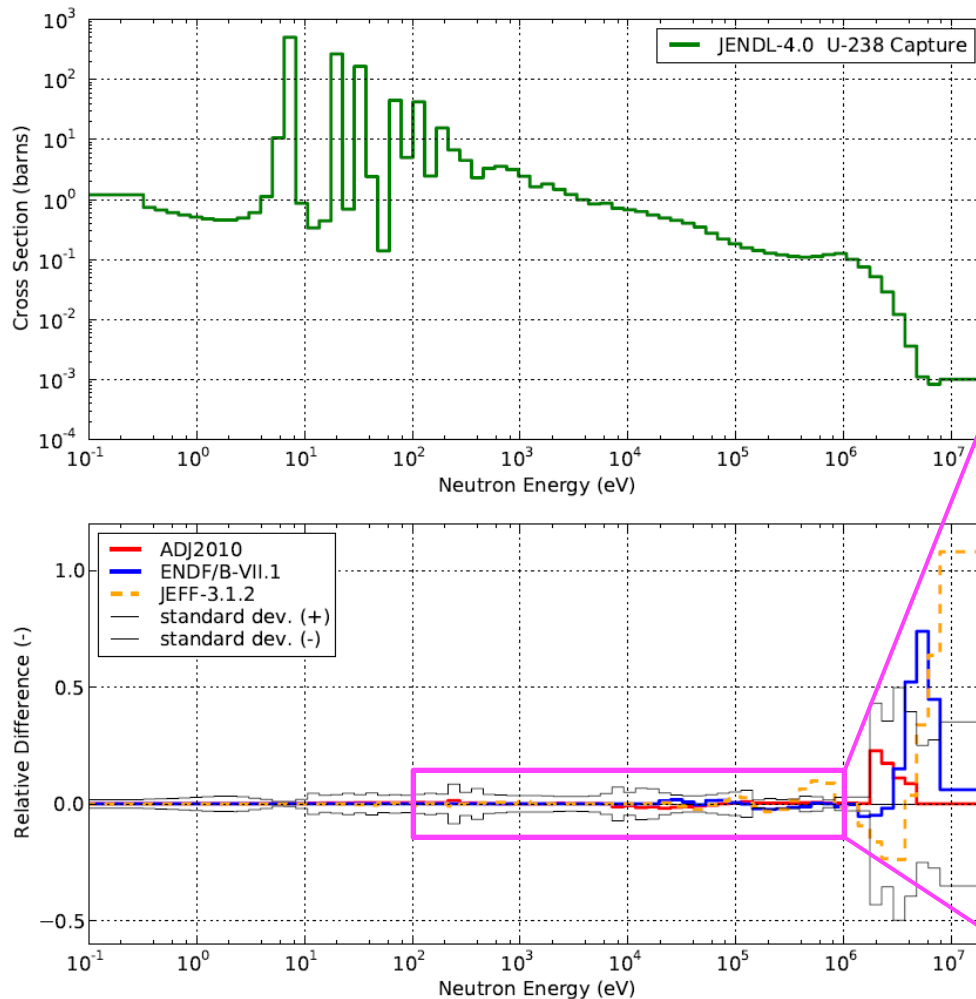


- ADJ2010 **decreases** prompt neutron number from Pu-239 fission by **0.2%**. This small decrease is **consistent with the 0.2%dk overestimation** of JENDL-4 for large Pu-fueled cores.
- The difference between JENDL-4.0 and ENDF/JEFF shows **strange wave-shape**.

# U-238

# U-238

## Capture

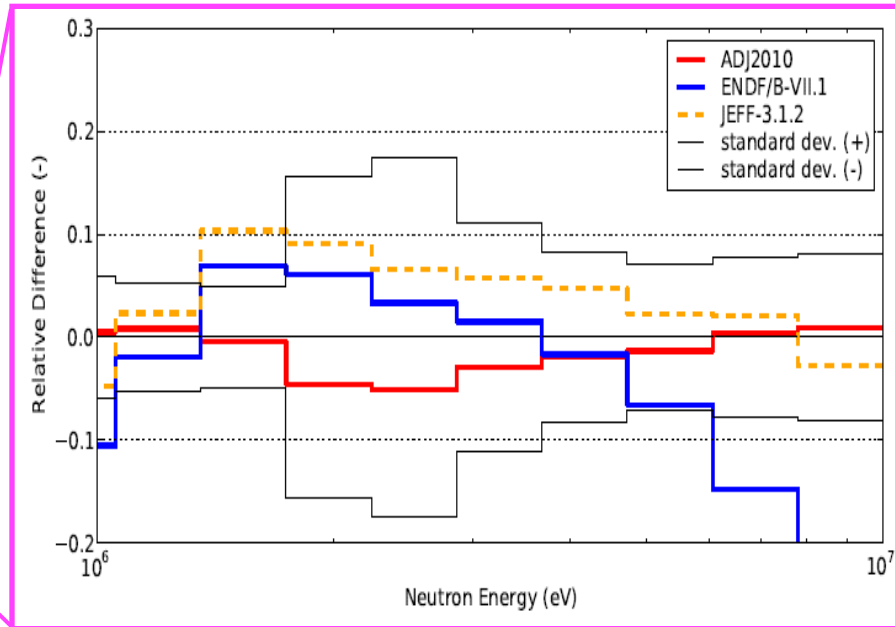
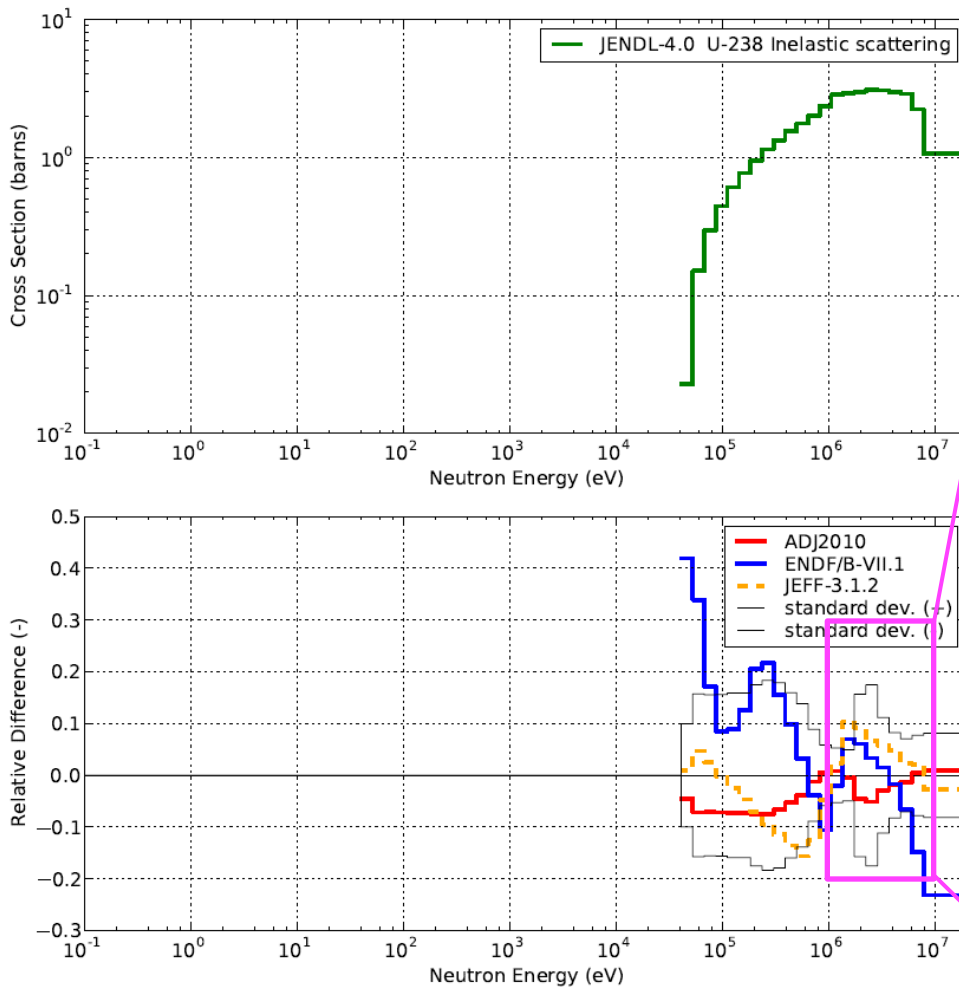


- ADJ2010 **changes** U-238 capture cross-section **between +2 and -2%**. This small alteration is **within the variance** of JENDL-4, and **agrees with the three major libraries**.



# U-238

## Inelastic scattering

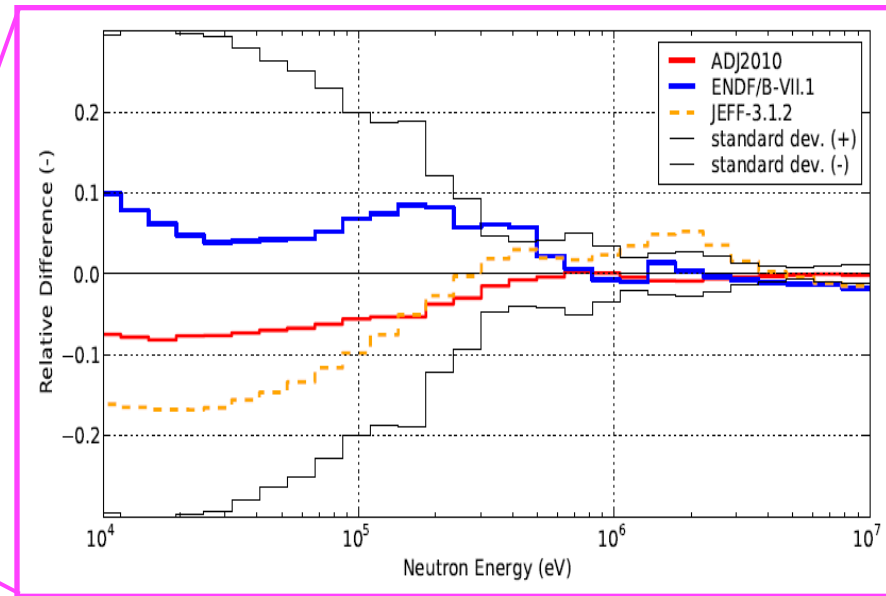
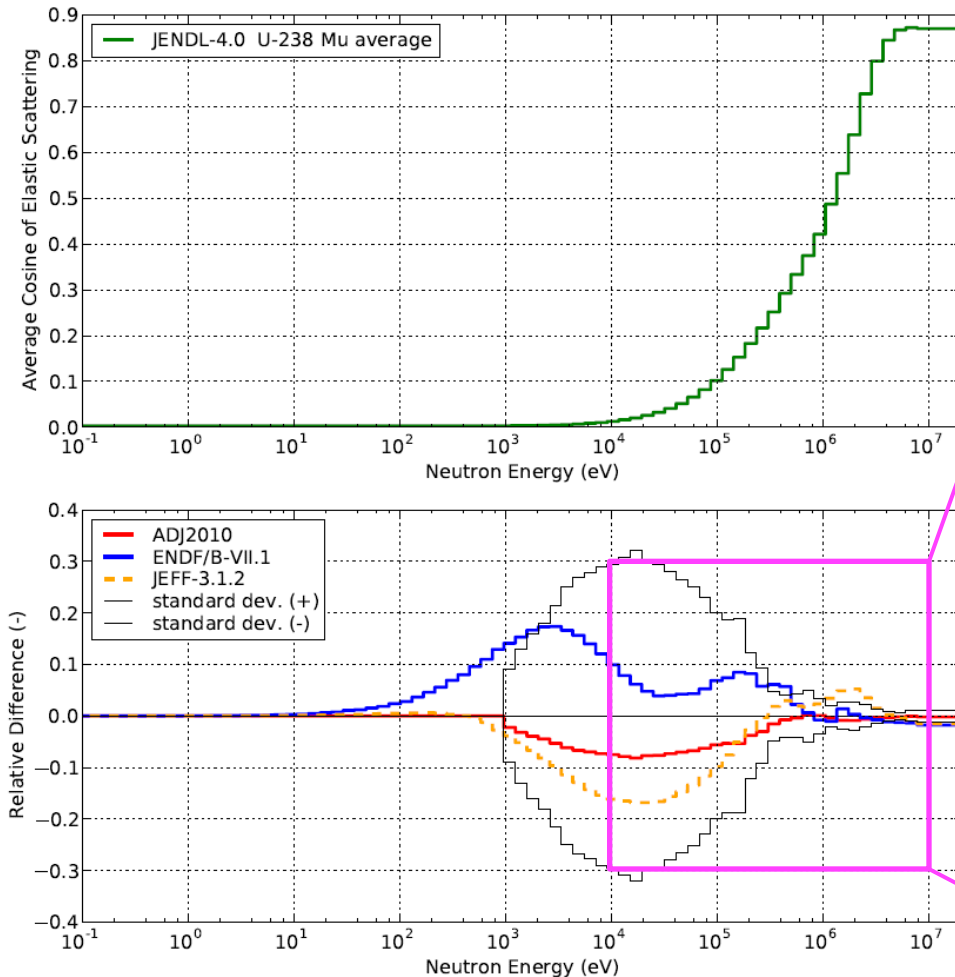


- ADJ2010 **slightly decreases** Pu-239 inelastic-scattering cross-section **between 0 and 5%** over 1MeV. This alteration is **within the variance** of JENDL-4.
- This decrease of inelastic-scattering is the **opposite direction** to correct the **overestimation of Na void reactivity** for Pu-fueled cores with JENDL-4.0.



# U-238

## Mu-ave.



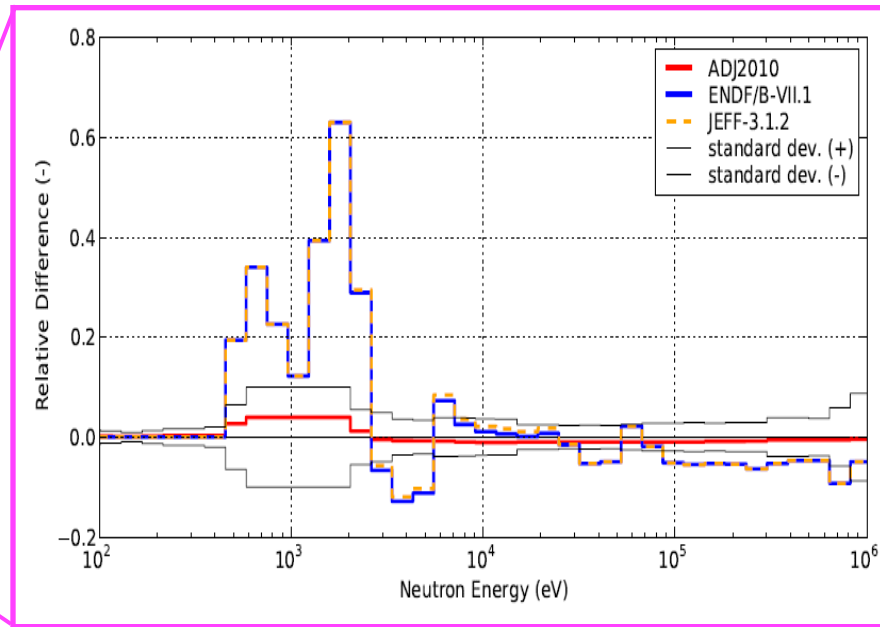
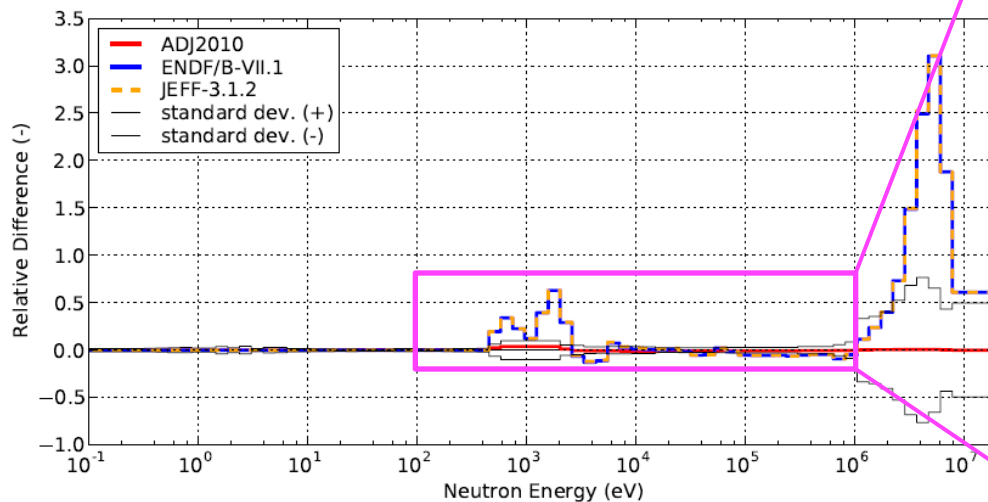
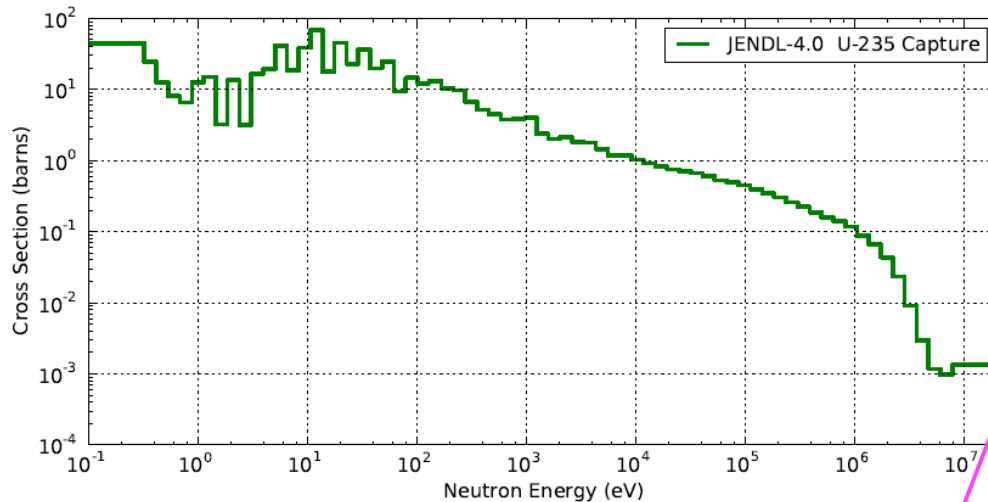
- ADJ2010 **decreases** U-238 mu-ave. by **8% at maximum**. The **effect** of this alteration to adjusted C/Es are **NOT clear**.
- The evaluation of mu-ave. does **NOT seem converged at all**. Expect to be improved by SG35.



# U-235

# U-235

## Capture

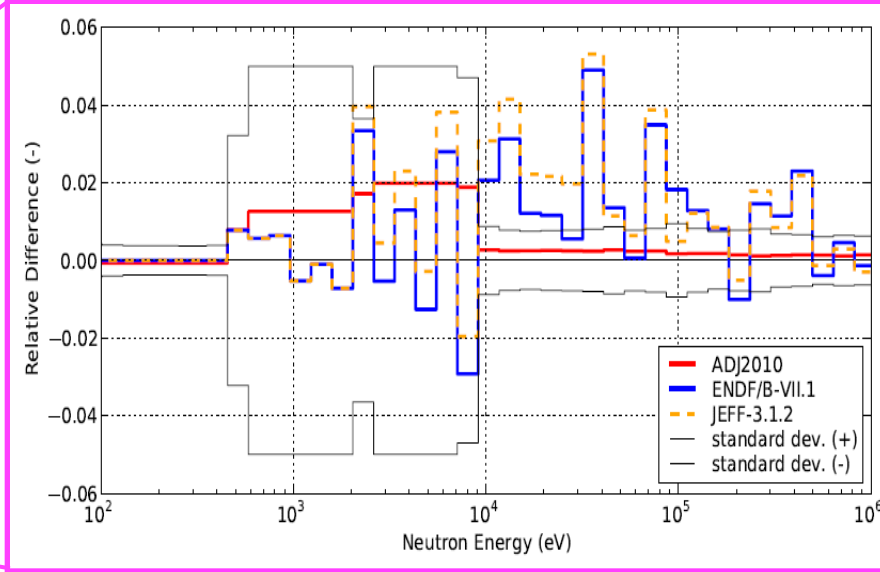
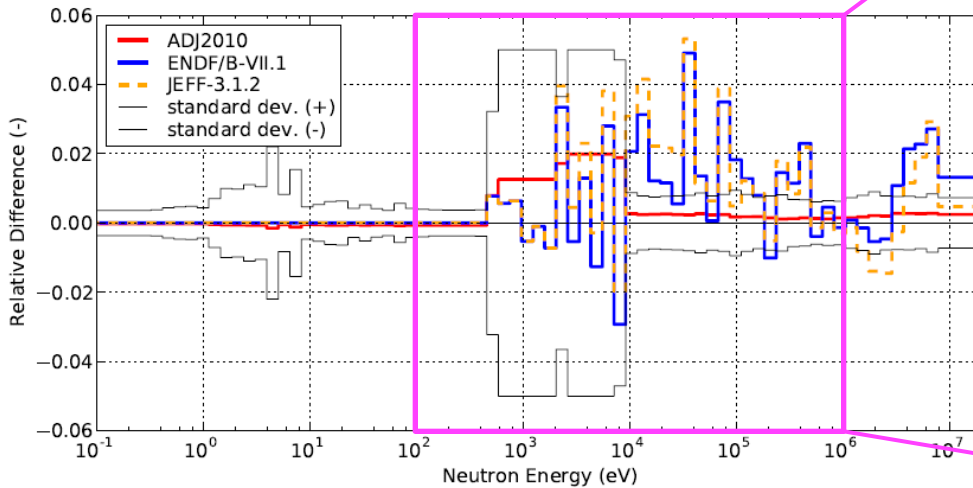
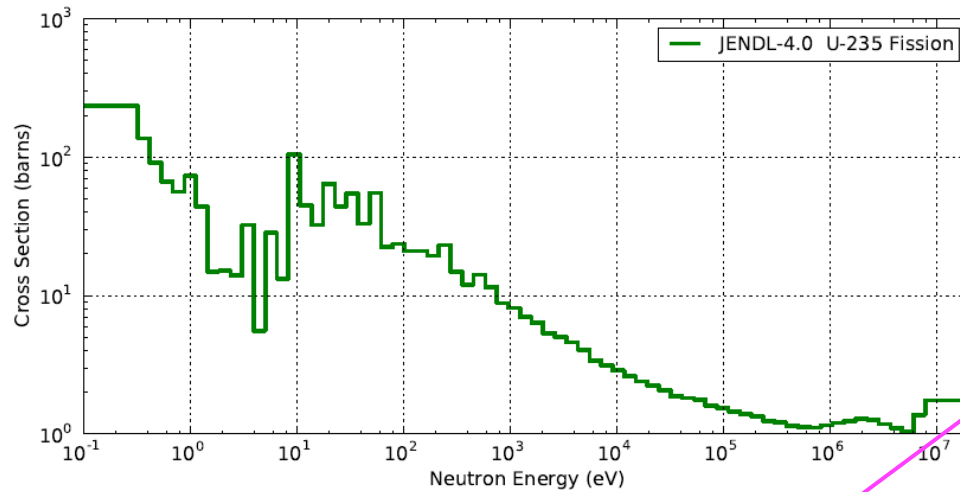


- ADJ2010 slightly changed U-235 capture cross-section only around 1 keV. This little alteration is consistent with CIELO evaluation, which is similar with JENDL-4.0.



# U-235

## Fission

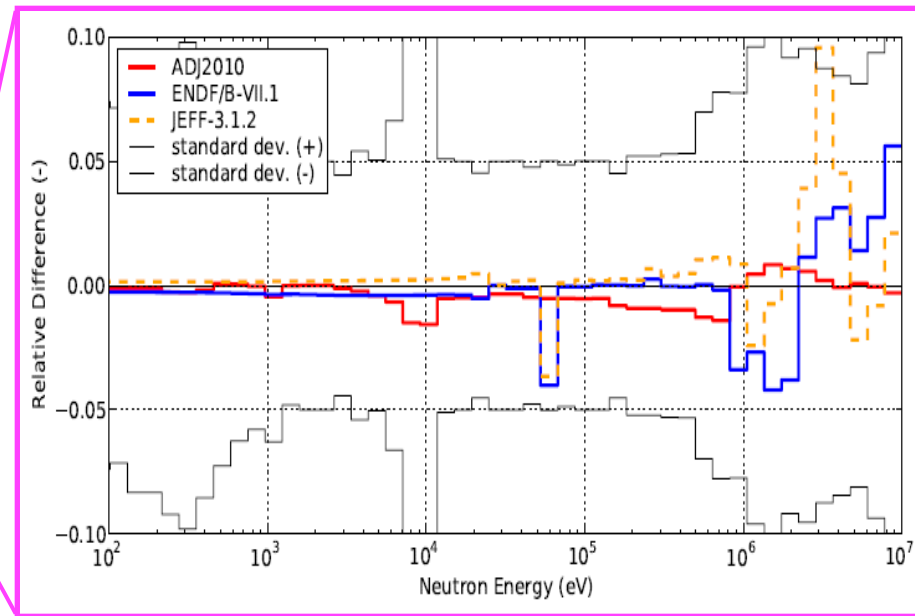
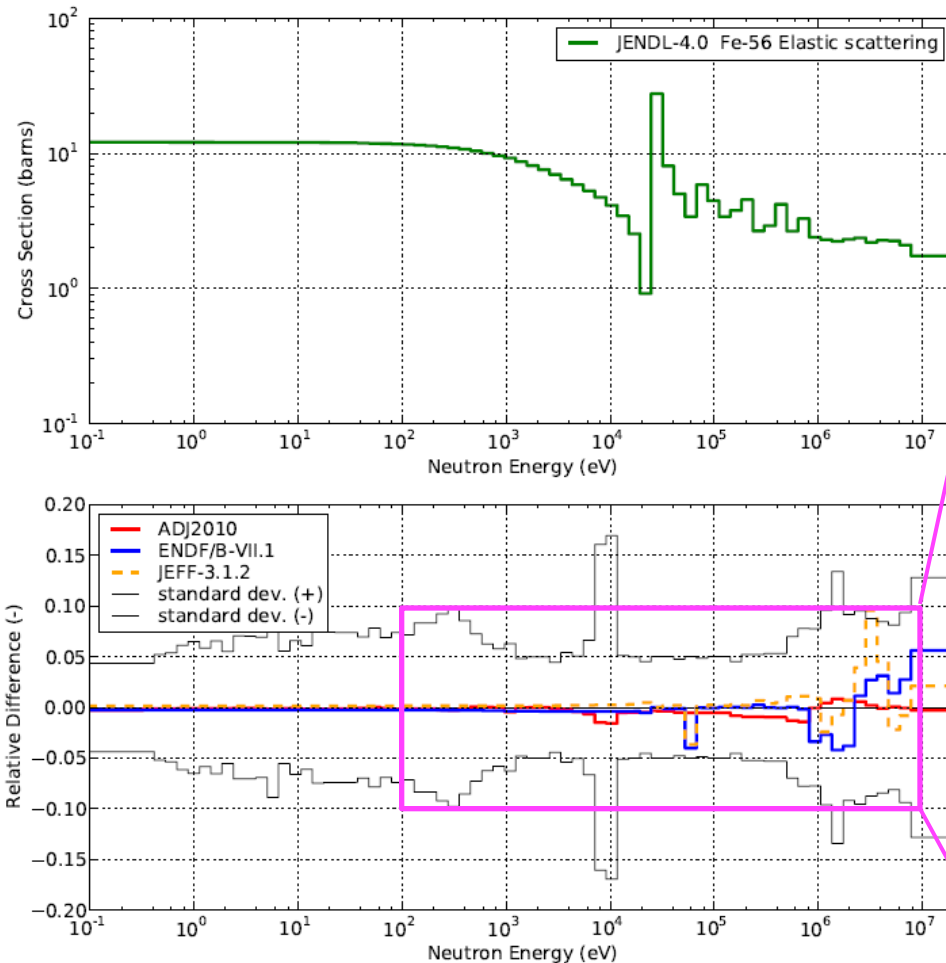


- No comments for ADJ2010.
- Even this major cross-section has quite large difference among libraries in high energy region, since it is not related to thermal reactors, maybe.

# Fe-56

# Fe-56

## Elastic scattering

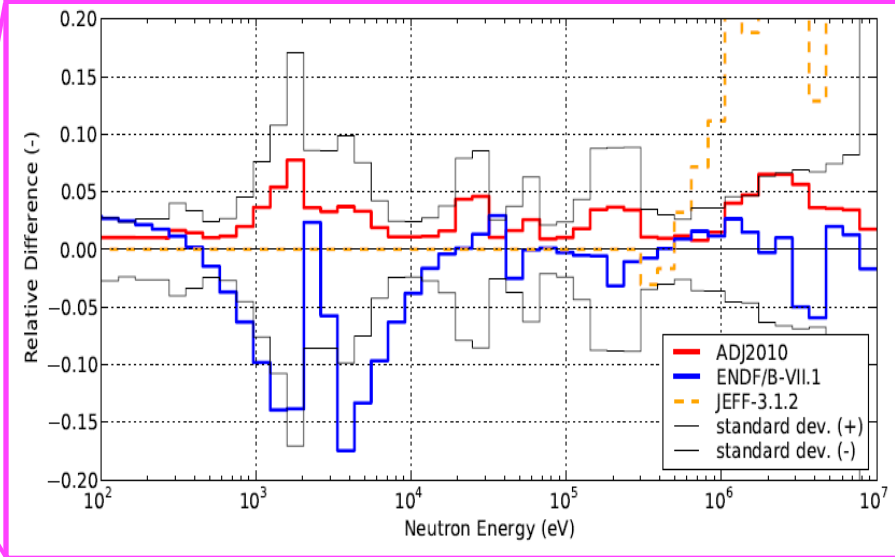
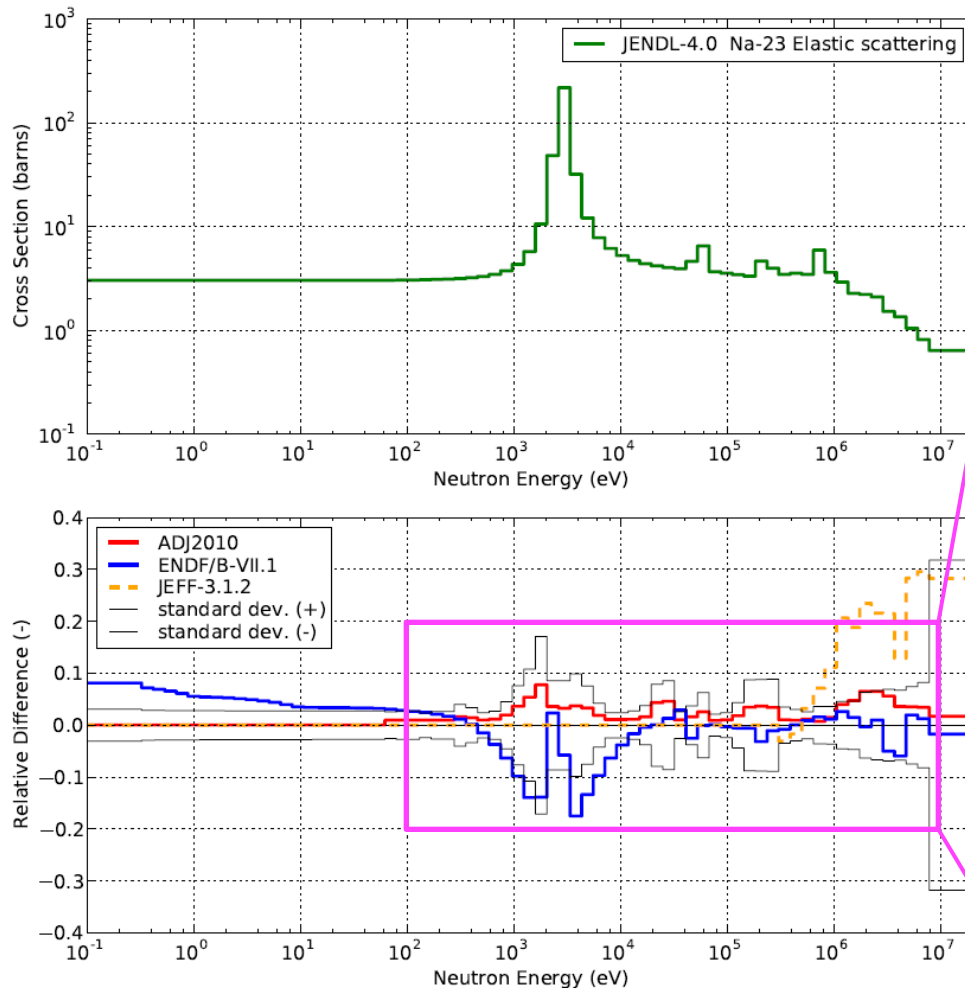


- No comments for ADJ2010.
- Three libraries are rather similar, but re-evaluation is underway in CIELO, using new measured data.

# Na-23

# Na-23

## Elastic scattering



- ADJ2010 **increases** Na-23 elastic-scattering cross-section between 2 and 8%. This alteration is **within the variance** of JENDL-4.
- **ENDF** largely **differs** from JENDL and JEFF, since it is **newer** evaluation. The **covariance of JENDL and COMMARA** is **consistent** with this fact. -> next slide. 23

# SG33 Final Report

## Chap.3 Covariance

(Feb.20, 2013)

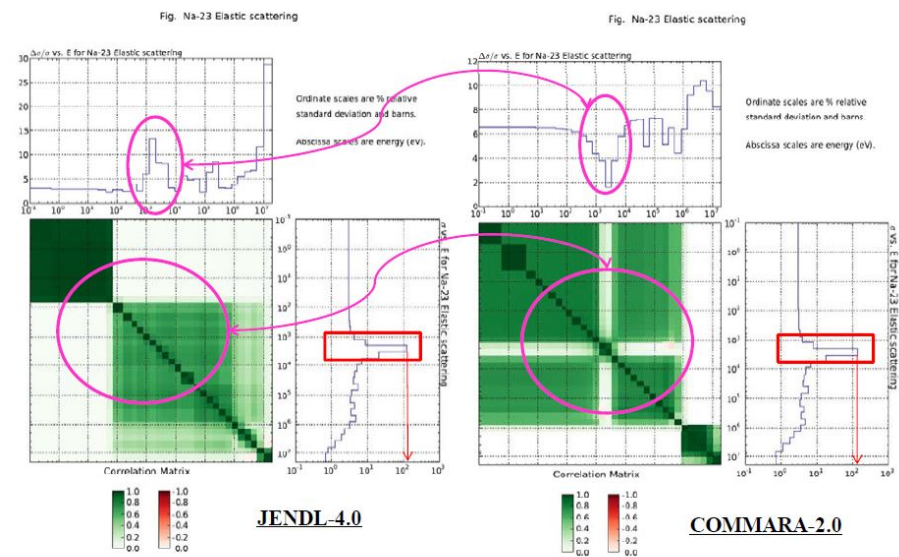


Figure 3.2 Comparison of JENDL-4.0 and COMMARA-2.0 Covariance (2/3) - Na-23 Elastic -

### 2) Na-23 elastic scattering data around 2 keV

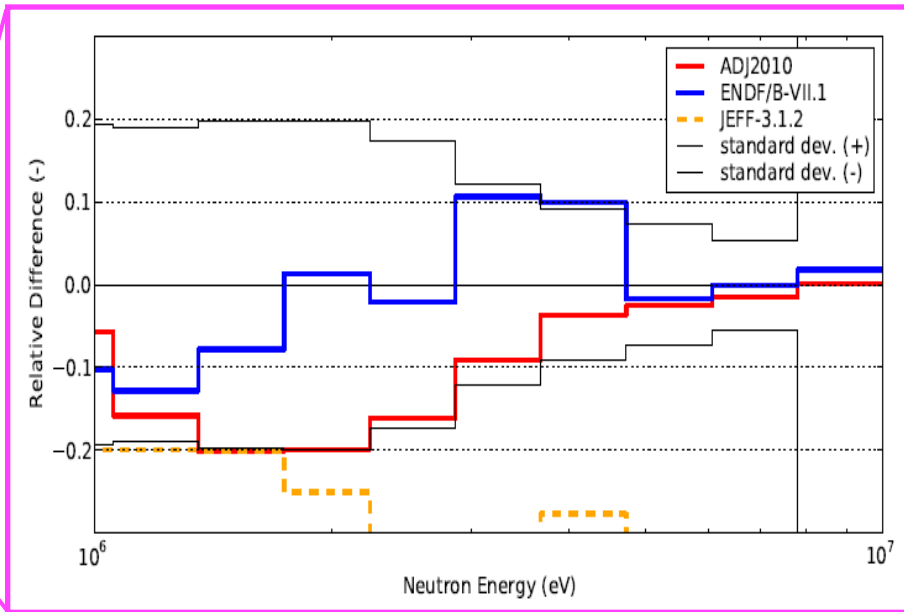
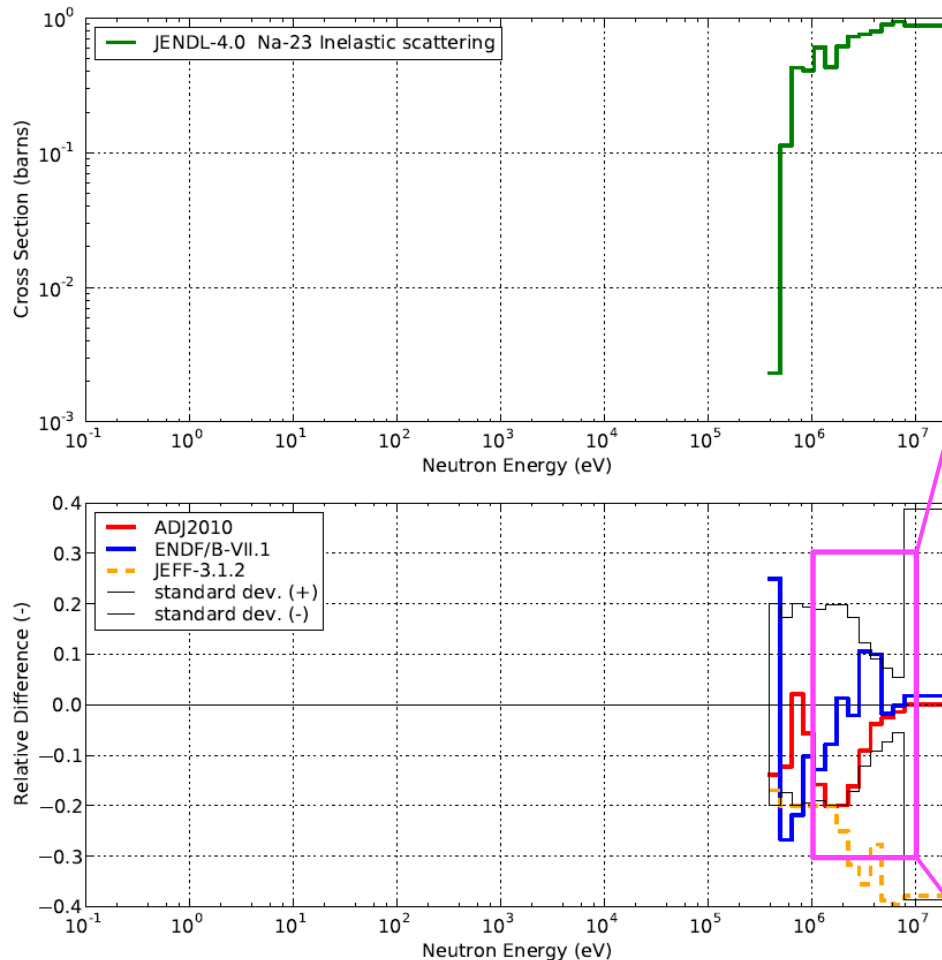
<sup>3</sup> This energy independency of 2 keV peak in the C-2.0 covariance is not well imagined from the general least-square analysis. There might have been some special treatments for the covariance evaluation in this resonance peak.

At this energy, there appears a giant resonance peak which affects significantly the sodium-voiding reactivity in sodium-cooled fast reactor cores. As found in Fig.3.2, the shape of Standard deviation (STD) is extremely different between two libraries, that is, the minimum STD value occurs at the cross-section peak energy in C-2.0, on the contrary, the maximum appears there in J-4.0. With a simple consideration, the trend of C-2.0 seems more natural, since the larger cross-sections would be more accurate due to the small statistical error in the measurement. The correlations are also quite different. In the C-2.0 covariance, the 2 keV peak has no correlations with other energy<sup>3</sup>, while J-4.0 is partially positive everywhere above 100 eV. The covariance of C-2.0 is evaluated by the EMPIRE/KALMAN combination, where the prior resonance model parameter uncertainties are derived from Mughabghab (Ref.15), on the other hand, J-4.0 applies the GMA code with some corrections to meet the measured cross-sections with the evaluated ones of J-4.0 which is based on the multi-level Breit-Wigner formula with rather old resonance parameter values recommended by BNL in 1981. The cross-section difference between ENDF/B-VII.0 and J-4.0 is -17~+4% around 2keV, therefore, the difference of STDs might be reasonable if we take into account the corrections given to J-4.0 covariance.



# Na-23

## Inelastic scattering



- ADJ2010 **largely decreases** Na-23 inelastic-scattering cross-section **between 5 and 20%** over 1MeV. This alteration is **at the variance bound** of JENDL-4.
- Na-23 inelastic-scattering has a similar sensitivity profile with total (elastic-scattering).
- This decrease of inelastic-scattering is **consistent** with the **overestimation of Na void reactivity** for **ZPPR** and **underestimation** for **BES (negative reactivity)** → next slide

# Sensitivity for ZPPR-10A Na Void Reactivity

C/E Change by ADJ2010 Adjustment  
- Na void reactivity -

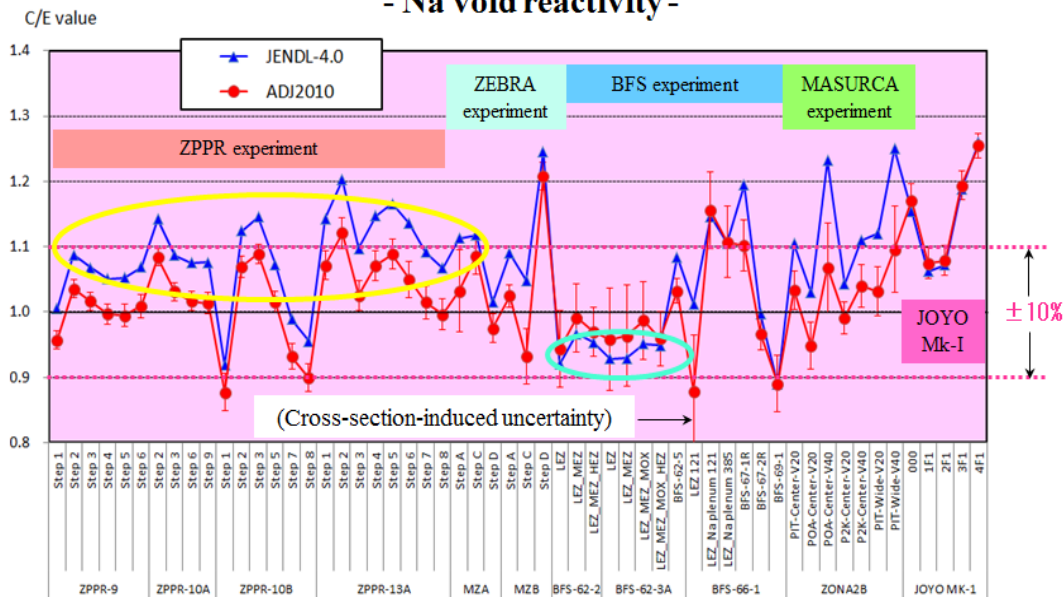


Fig. (ZPPR-10A, NaV step3(172drawer, 8inch)) U-238

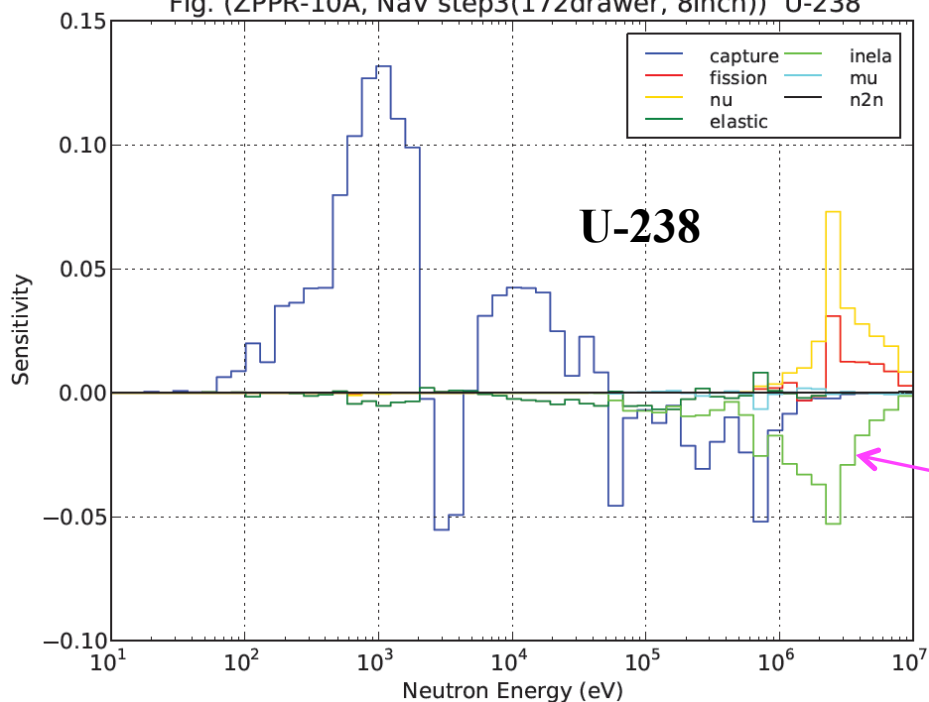
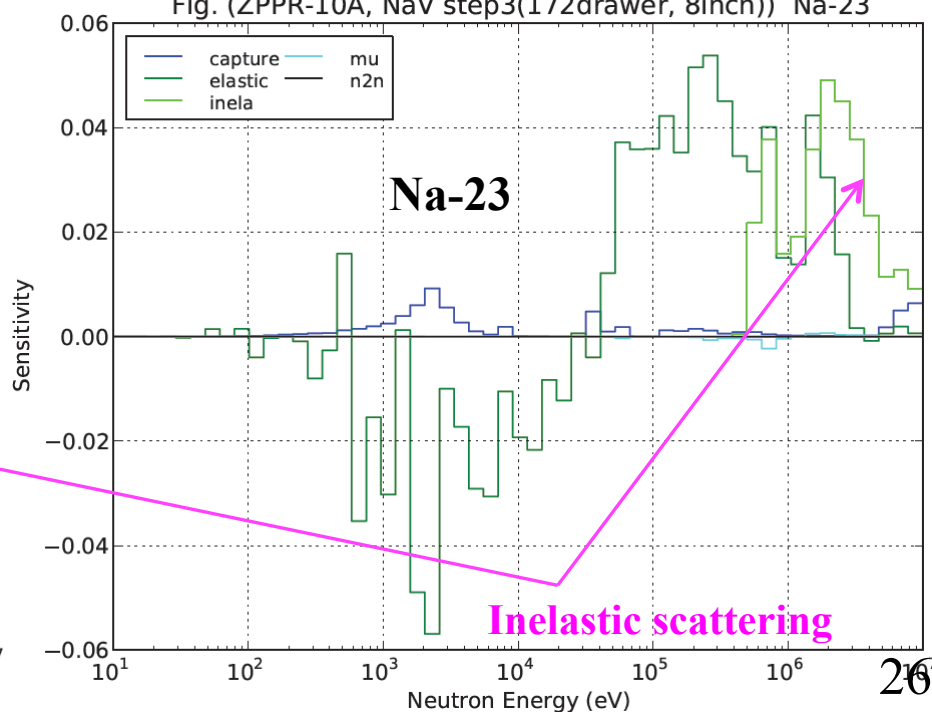


Fig. (ZPPR-10A, NaV step3(172drawer, 8inch)) Na-23



# Concluding Remarks

1. From ADJ2010 adjustment, we may recommend the followings to nuclear data evaluators: *<These have high sensitivity to good integral data.>*
  - **Pu-239 capture** --> Increase **over 3keV** by **7 to 9%**.
    - The increase is determined by a combination of integral experiments.
    - The adjustment mechanism is complicated but explainable.
  - **Pu-239 fission** --> Keep current data within **0.5% in average**.
  - **Pu-239 nu** --> Keep current data within **0.2% in average**.
  - **U-238 capture** --> Keep current data within **2%**.
  - **U-235 capture** --> Follow **JENDL-4.0** within **its variance**.
2. Although large alteration is observed, we cannot make comments:
  - ◆ **Pu-239 fission spectrum** and **Na-23 inelastic** --> should study more as one combined set including **U-238 inelastic** and **Pu-239 inelastic**.  
*<compensation problem exists.>*
  - ◆ **U-238 mu-ave.** --> Need to be converged among the major libraries.
  - ◆ **U-235 fission** --> Current fast-region integral database is **not sufficient**.
  - ◆ **Fe-56 elastic scattering** and **Na-23 elastic** --> Should be improved in **CIELO** project.

# Appendix: Theory of Cross-section Adjustment

✧ J.B.Dragt, et al.: “Methods of Adjustment and Error Evaluation of Neutron Capture Cross Sections; Application to Fission Product Nuclides,” NSE 62, pp.117-129, 1977

- Based on the Bayes theorem, i.e., the conditional probability estimation method  
→ To maximize the posterior probability that a cross-section set,  $T$ , is true, under the condition that the information of integral experiment,  $Re$ , is obtained.

$$J(T) = (T - T_0)^t M^{-1} (T - T_0) + [Re - Rc(T)]^t [Ve + Vm]^{-1} [Re - Rc(T)]$$

Minimize the function  $J(T)$ . →  $dJ(T)/dT = 0$

- The adjusted cross-section set  $T'$ , and its uncertainty (covariance),  $M'$  (Algebra)

$$T' = T_0 + MG^t [GMG^t + Ve + Vm]^{-1} [Re - Rc(T_0)]$$

$$M' = M - MG^t [GMG^t + Ve + Vm]^{-1} GM$$



✓ If  $GMG^t \ll Ve + Vm$ ,  $T' \doteq T_0$  and  $GM'G^t \doteq GMG^t$   
 ✓ If  $GMG^t \gg Ve + Vm$ ,  $GM'G^t \doteq Ve + Vm$   
 ✓ If  $GMG^t \doteq Ve + Vm$ ,  $GM'G^t \doteq 1/2 \times GMG^t$

- Prediction error induced by the cross-section errors

Before adjustment:  $GMG^t$

After adjustment:  $GM'G^t$

Where,  $T_0$ : Cross-section set before adjustment

$Ve$ : Experimental errors of integral experiments

$M$ : Covariance before adjustment experiments

$Vm$ : Analytical modeling errors of integral

$Re$ : Measured values of integral experiments

$G$ : Sensitivity coefficients,  $(dR/R)/(d\sigma/\sigma)$

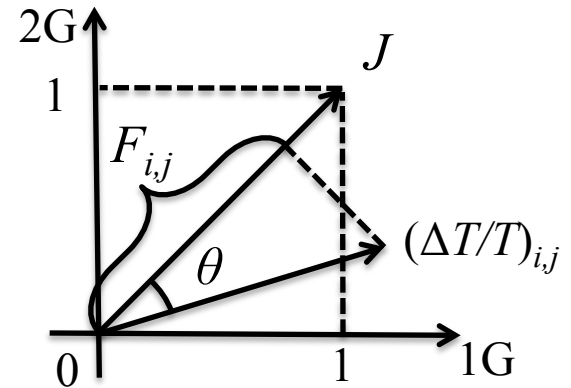
$Rc$ : Analytical values of integral experiments



# Adjustment Motive Force

Motive force: 
$$F_{i,j} = \frac{\|(\Delta T/T)_{i,j}\|}{\|J\|} \cos \theta$$

where 
$$\cos \theta = \frac{(\Delta T/T)_{i,j} \cdot J}{\|(\Delta T/T)_{i,j}\| \|J\|}$$



Example of 2 energy-group case

$$(\Delta T/T)_{i,j} = M_j G_{i,j}^T [G_{i,j} M_j G_{i,j}^T + V_i]^{-1} [J - R_{c,i}/R_{e,i}]$$

$1 - C/E$

A special adjustment result, in which only one reaction,  $j$ , is adjusted by using only one integral experiment,  $i$ .

- Motive force is **determined by reaction and integral experiment**
  - independent from a combination of integral experiments
- Motive force is a **scalar value** (averaged over all energy group)
  - $\pm 100\%$  alterations for all energy group  $\rightarrow$  motive force  $= \pm 1$
  - 0 % alterations for all energy group  $\rightarrow$  motive force  $= 0$

# Adjustment Potential

*Potential* is calculated as well as *motive force* by using

$$(\Delta T/T)'_{i,j} = M_j G_{i,j}^T [G_{i,j} M_j G_{i,j}^T + V_i]^{-1} [J - \overline{R_{c,I}} / \overline{R_{e,I}}]$$

in place of

$$(\Delta T/T)_{i,j} = M_j G_{i,j}^T [G_{i,j} M_j G_{i,j}^T + V_i]^{-1} [J - R_{c,i} / R_{e,i}]$$

Average of  $1 - C/E$   
over a set of  
core parameters  
related to  $i$

$1 - C/E$  of  
the core parameter  $i$

■ *Motive force* becomes **null in two cases**:

■ Not sensitive to the integral experiment:  $G \sim 0.0$

→ There is *no motive force*

■ Sensitive but not necessary to adjust the cross sections:  $G \gg 0.0$  and  $C/E \sim 1.0$

→ There is *force that keeps the present values*, or *frictional force*

■ Therefore, *Potential* is needed to distinguish the two cases.

■ The amplitude of *Potential* is comparable with that of a different kind of integral experiments, such as criticality and Na void reactivity

# Motive Forces for Pu-239 capture

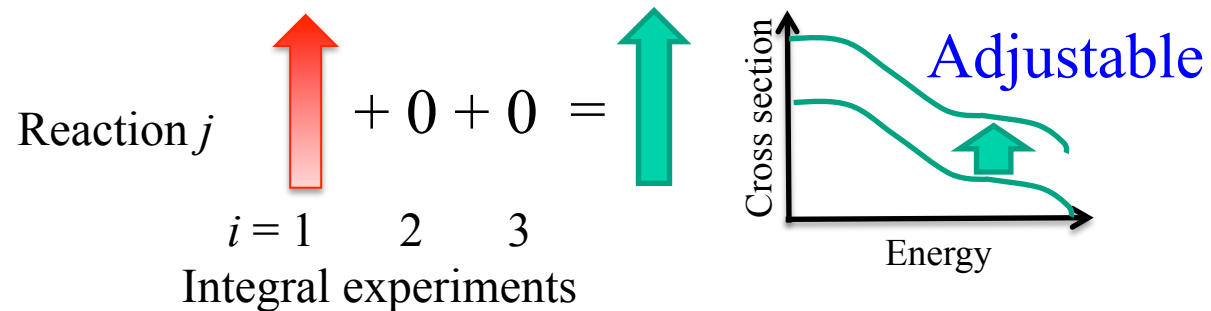
No.	Motive force	Integra experiments
1	+4.65	BFS-66-1 control rod worth [Ring 1-4]
2 – 8	+4.40 -- +2.60	ZPPR-18A control rod worths (including 7 cases)
9	+2.92	ZPPR-10A criticality
<b>10</b>	<b>+2.45</b>	<b>ZPPR-9 criticality</b>
	:	:
484, 485	-0.98	ZPPR-18A control rod worths (including 2 cases)
486	-0.99	JOYO MK-I criticality (64 fuel S/As)
<b>487</b>	<b>-1.06</b>	<b>JEZEBEL criticality</b>
488	-1.07	JOYO MK-I criticality (70 fuel S/As)

- A lot of experiments have large positive *motive forces*
- Even if some of them are removed, the cross-section alteration of Pu-239 capture is not changed significantly

# Assumption of Two Situations for Motive Forces

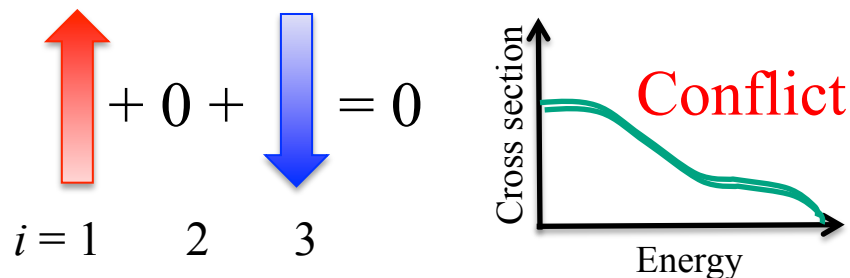
## ■ F: freely adjustable

If only one integral experiment has a large *motive force* for a reaction, the cross section of the reaction is “freely adjustable” and altered.

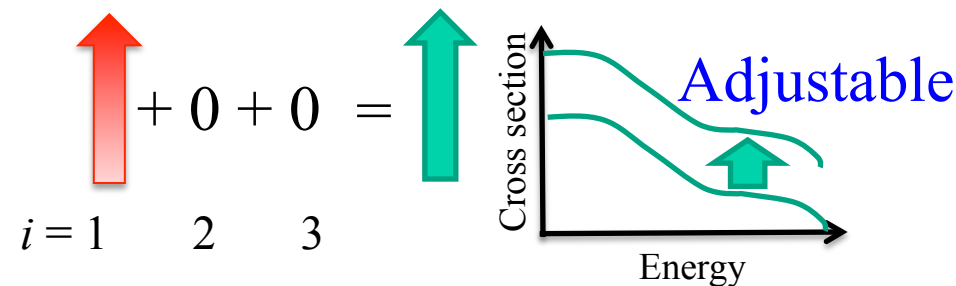


## ■ C: conflict

If more than two *motive forces* with large potentials have opposite signs, it is considered as a “conflict”. In this case, the cross section of the reaction is not significantly adjusted. Then, the other “freely adjustable” cross sections are altered.



Reaction  $j = 1$



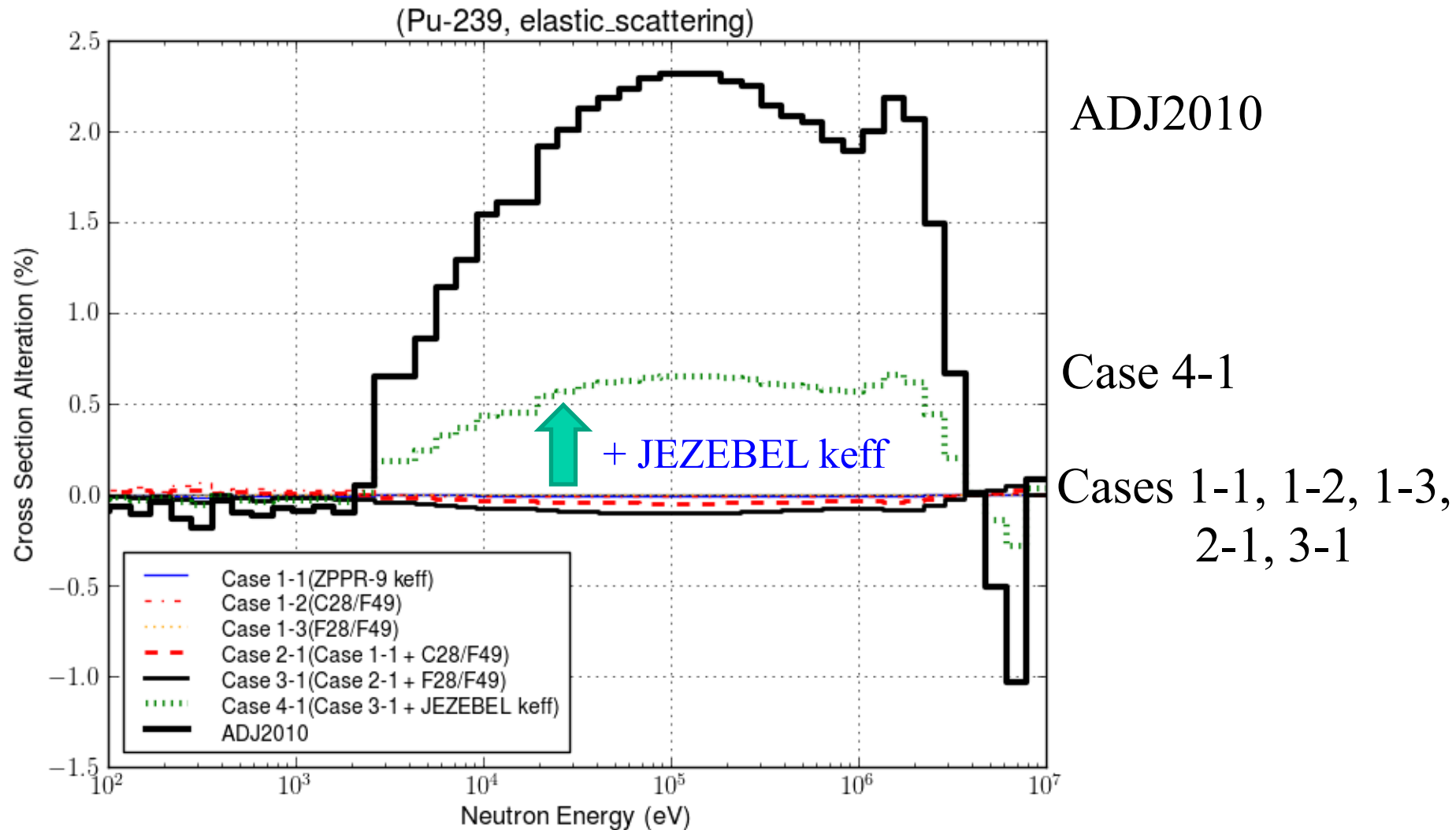
Reaction  $j = 2$



# Motive Forces & Potentials for Integral Experiments used for Small Test Cases

	ZPPR-9						JEZEBEL	
	keff		C28/F49		F28/F49		keff	
<b>Pu-239 capture</b>	+2.45 (-1.84)	↑	+0.28 (-0.15)	0	+0.34 (+0.37)	0	-1.06 (-0.94)	↓
<b>Pu-239 fission</b>	-0.24 (+0.18)	↓	+0.18 (-0.10)	↑	-0.07 (-0.07)	0	+0.07 (+0.06)	0
<b>Pu-239 <math>\chi</math></b>	+2.26 (-1.70)	↑	-1.20 (+0.66)	↓	-2.83 (-3.07)	↓	-1.98 (-1.77)	↓
<b>Pu-239 (n, n)</b>	-0.12 (+0.09)	0	-0.01 (+0.00)	0	-0.00 (-0.01)	0	+0.57 (+0.51)	↑
<b>U-238 capture</b>	+0.55 (+1.20)	↑	-1.04 (+0.579)	↓	+0.21 (+0.23)	↑	-0.00 (-0.00)	0
<b>U-238 fission</b>	-1.59 (+1.20)	↓	+0.02 (-0.01)	0	+0.62 (+0.67)	↑	+0.00 (+0.00)	0
<b>U-238 (n, n')</b>	+0.57 (-0.43)	↑	-1.13 (+0.62)	↓	-0.39 (-0.43)	↑	+0.00 (+0.00)	0

# Cross-section Alteration of Pu-239 (n, n)



■ Not moved by using the set of ZPPR-9 keff, C28/F49, and F28/F49

■ Begin to move by adding JEZEBEL keff