Expanded Adjustment in Support of CIELO Initiative

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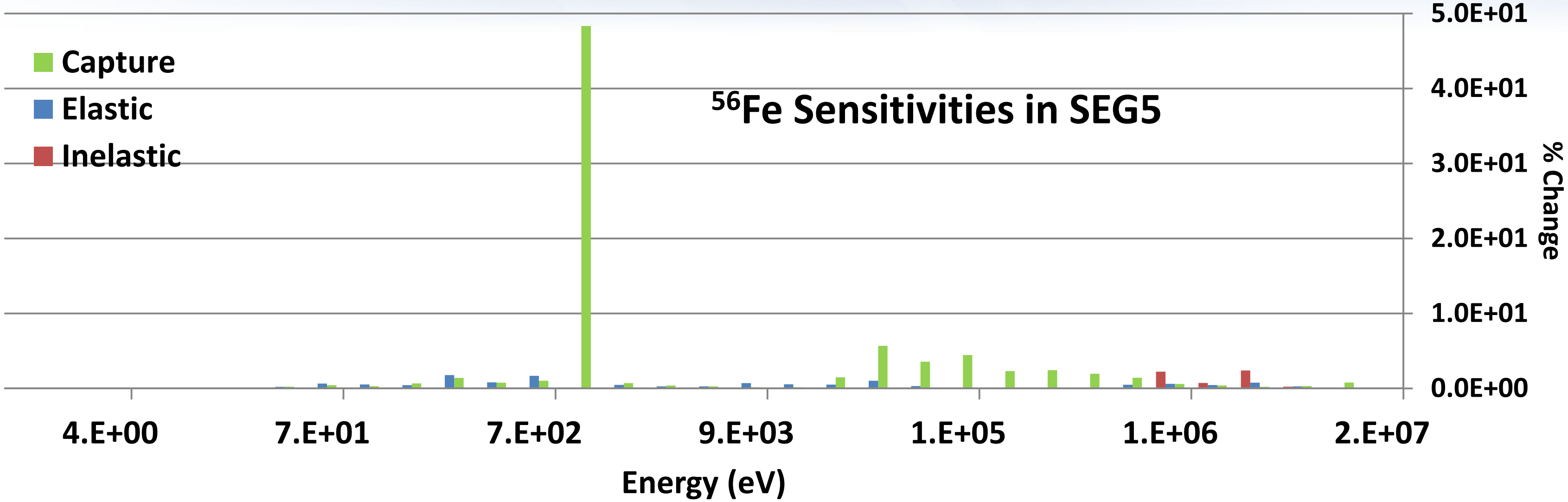
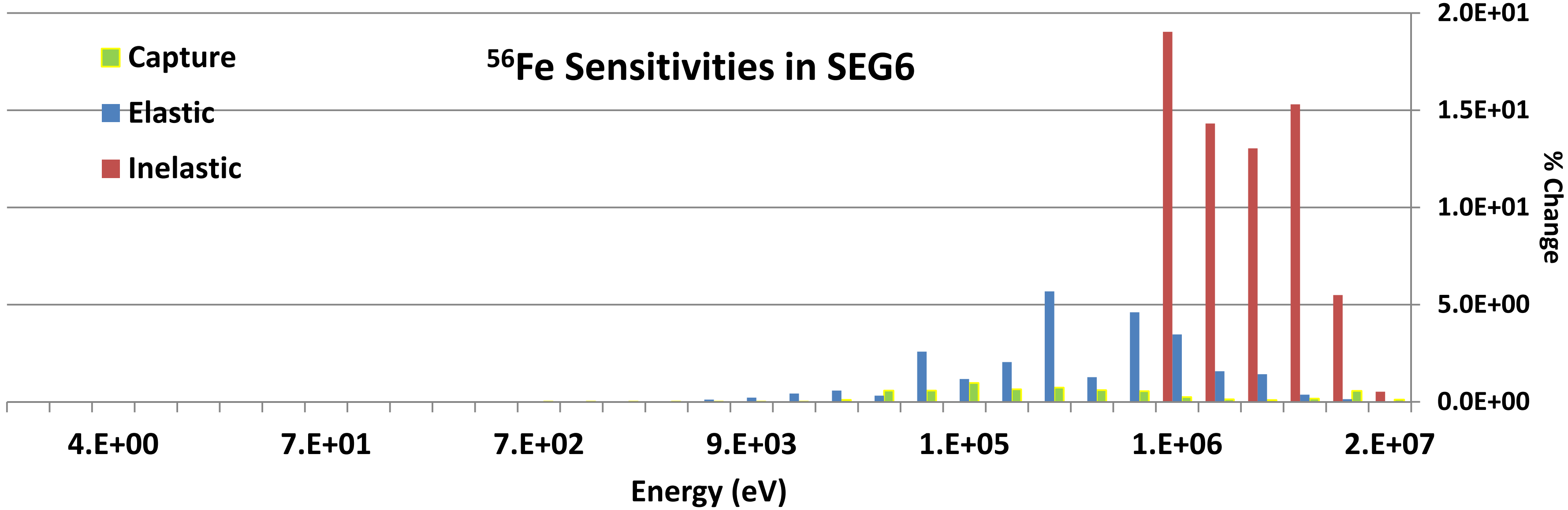
Extended Adjustment

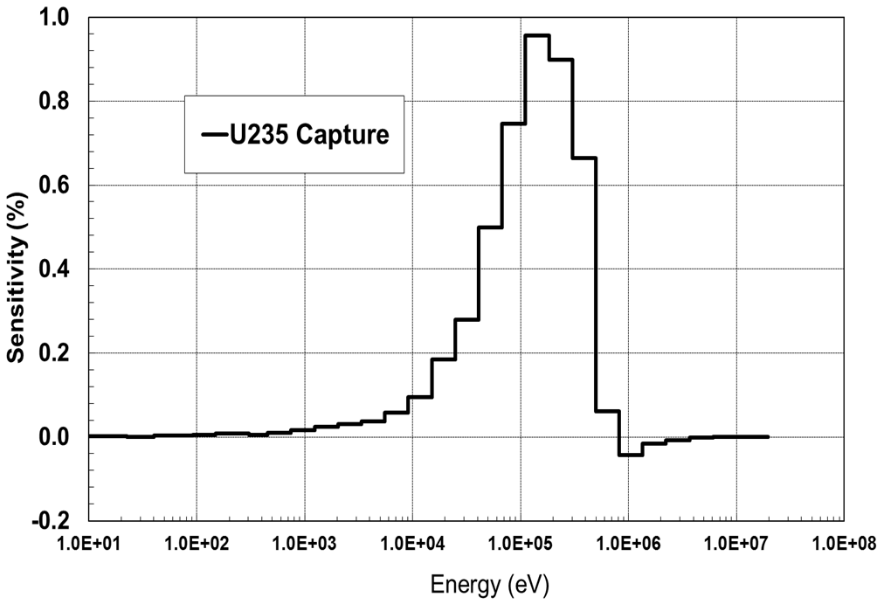
- In order to complement and support the effort of the WPEC CIELO Subgroup, most of the elementary experiments that have been selected and added to the extended adjustment provide high sensitivities to neutron cross sections of the 5 CIELO isotopes: ^{16}O, ^{56}Fe, ^{235}U, ^{238}U, and ^{239}Pu.
- In order to enlarge the “classical” set of integral experiments (criticality, reaction rates, reactivity coefficients) in the fast energy range, new more focused experiments are used, in particular:
  - New selective information on inelastic, elastic, fission and capture data (e. g. SEG experiments, FCA-IX)
  - Enhanced sensitivity to the actinide cross sections in the energy range ≤ 1 keV (k_∞, reaction rates, void reactivity effects performed at the PROTEUS facility)
  - Enhanced capture sensitivity in the range from few hundred eV to 1 eV (MANTRA irradiation experiments)
  - Specific feedbacks on elastic and inelastic structural materials (e. g. ASPIS-88 experiment for ^{56}Fe)

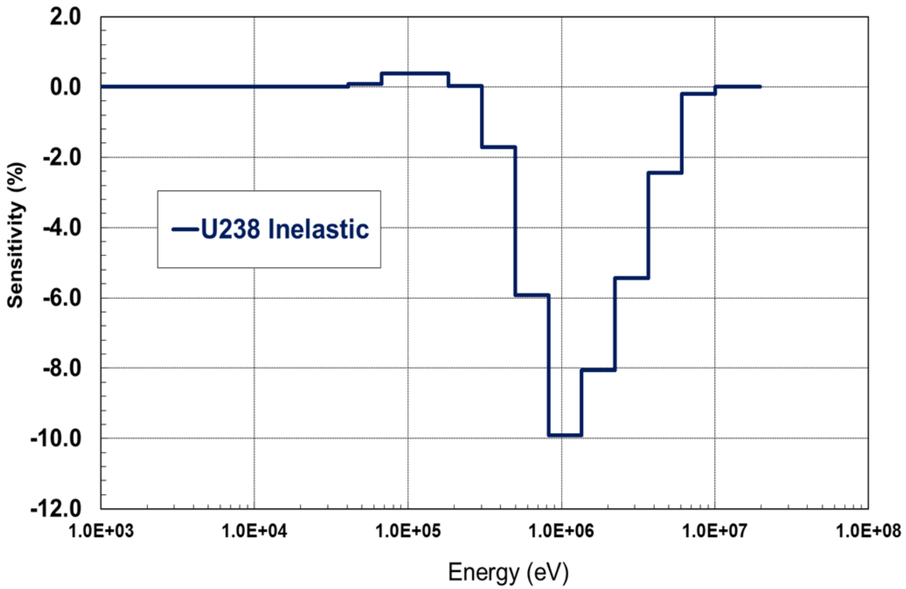
Sensitivity Coefficients





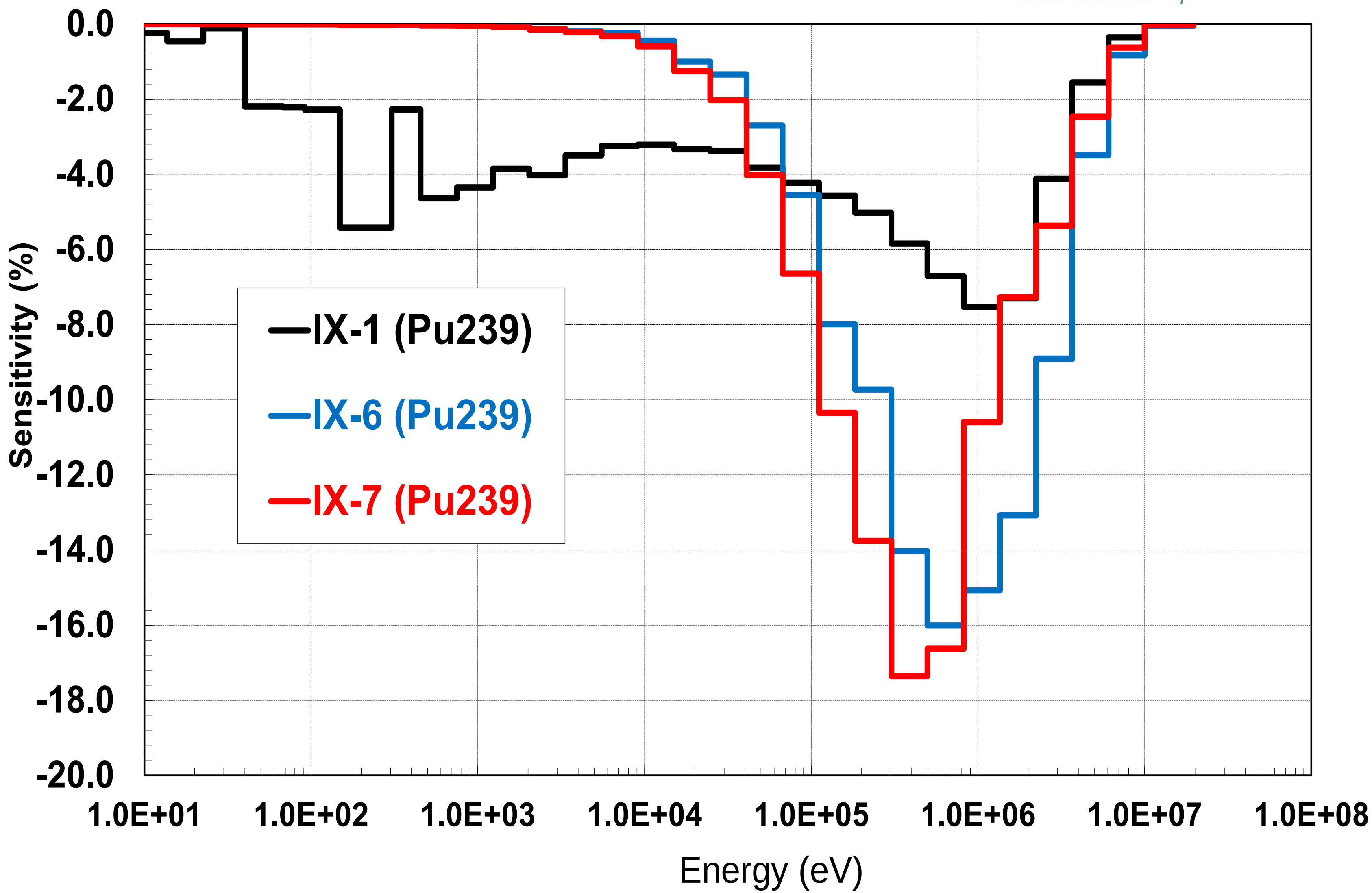
IX-7: Sensitivity of Np-237/Pu-239 spectrum index to $^{235}U\ \sigma_{cap}$ and $^{238}U\ \sigma_{inel}$



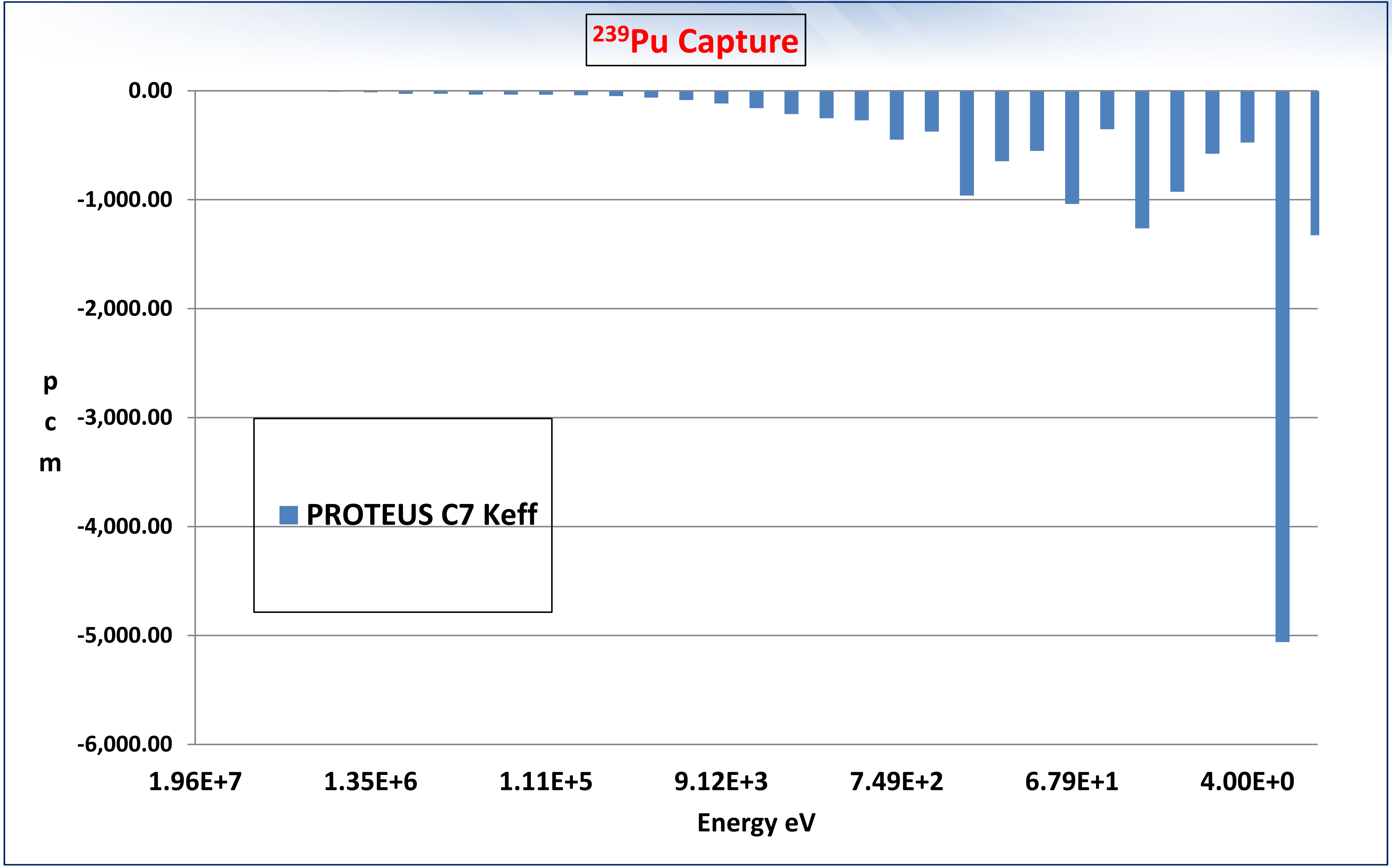


- IX-7 spectrum is the hardest. Inelastic cross sections sensitivity is high (and negative) at energies above the Np-237 fission threshold: the elastic/inelastic x-section increase in this energy region will reduce the high energy neutron contribution to the numerator
- Sensitivity to U-235 capture is still relatively high and positive in the high energy region: any increase of U-235 high energy capture will slightly reduce the high energy neutron contribution to the denominator.

Sensitivity of ^{239}Pu σ_{fiss} (direct effect on spectrum index denominator)



Sensitivity Coefficients



Sensitivity Coefficients

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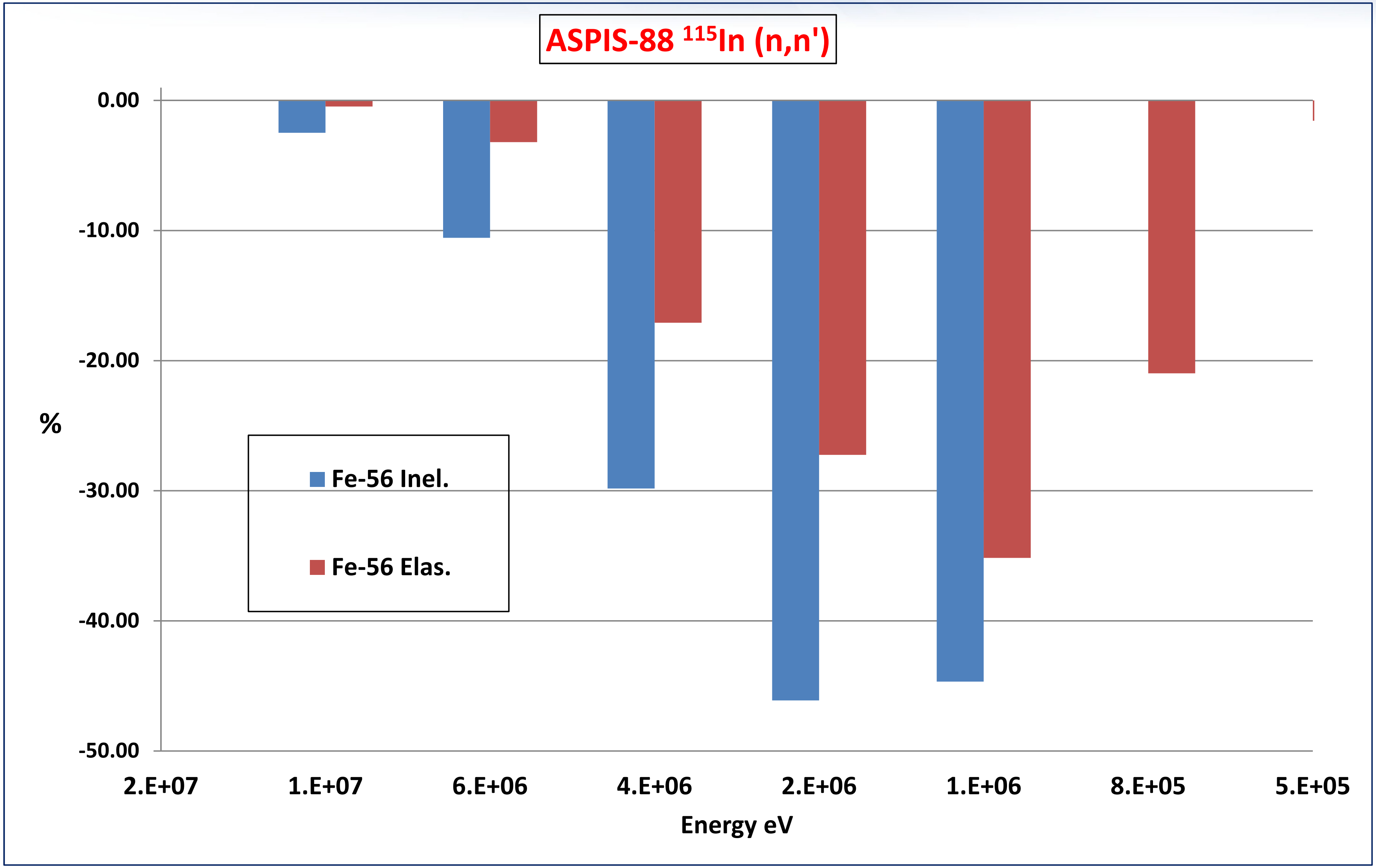
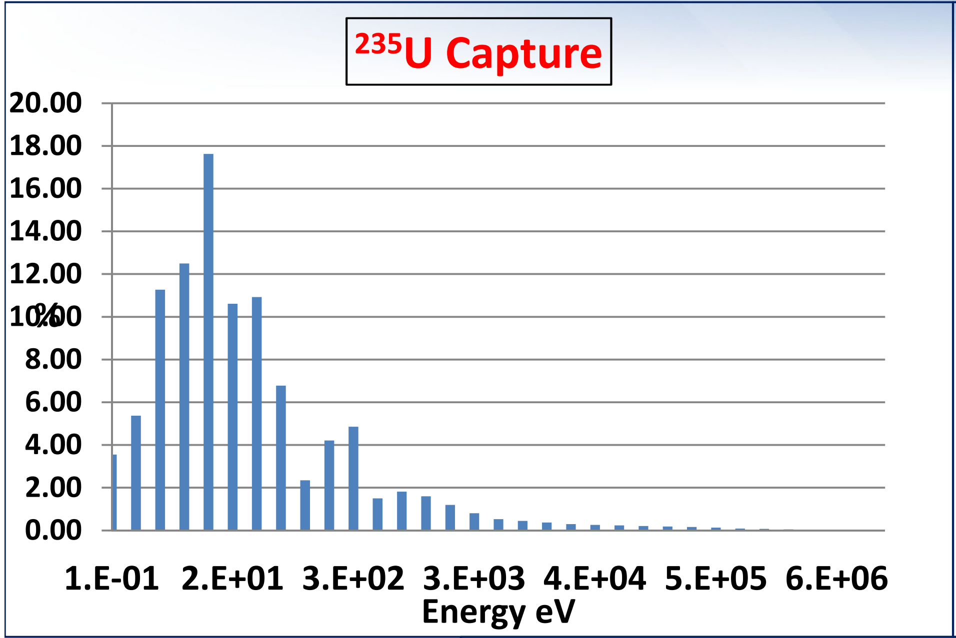
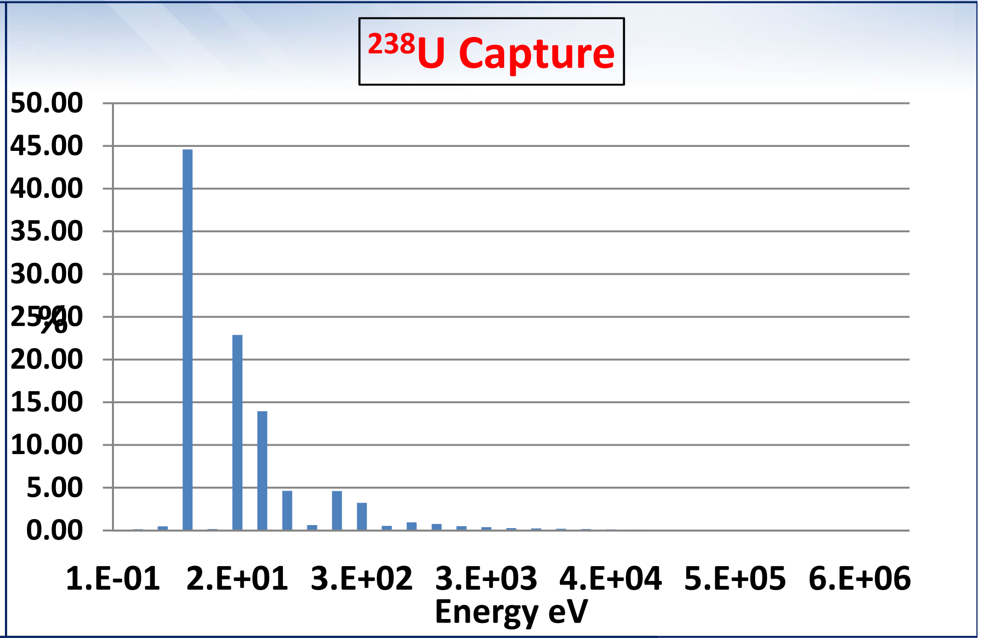
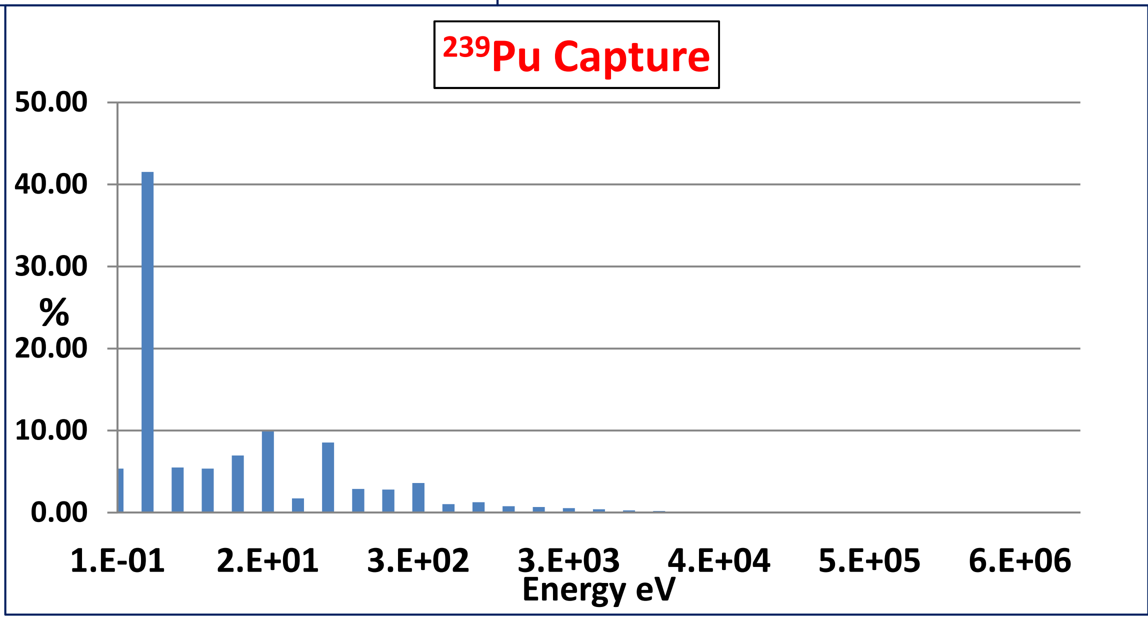


MANTRA Sensitivity Coefficients







Some Considerations On Provided Sensitivities

- **PROTEUS:**
  - The sensitivities for the void coefficients had to be calculated as difference of the two K_{eff}s (with and without water) ones.
  - The reaction rate ratios lacked the sensitivities associated to water (case with water). Most of them were rejected from the adjustment, likely for this reason. It would be useful to have the complete sensitivities.
  - It would be better in the future to use NJOY2012 for calculating the infinite dilution cross sections (with SERPENT fission spectrum was missing. I used those of JEFF3.1 instead of 3.1.1.)

- **ASPIS:**
  - It would have been useful to have the sensitivities and C/E for reaction rate ratios. Experimental uncertainties on absolute values are high.
  - Is there any comparison between deterministic and stochastic sensitivity coefficients (problem is highly non-linear)?

Adjustment Data

- The multigroup neutron cross section adjustment has been carried out using ENDF/B-VII.0 data files and COMMARA 2.0 covariance matrix (plus elastic anisotropy from JENDL-4 for the CIELO isotopes.
- An initial set of more than 200 integral experimental quantities has been analyzed (using the best calculational tools available) in order to provide C/E and associated calculational and experimental uncertainties and correlations.
- The initial set was reduced to 124 experimental values based on several considerations (duplications, sensitivities, inconsistency after adjustment, experimental uncertainties, etc.)
- 45 isotopes including major and minor actinides, fission products, structural, coolant, and light isotopes were adjusted.
- A 33 energy group structure was adopted and sensitivity coefficients were calculated.
- Final results have been compared against CIELO (ENDF/B-VIII.β3) and JEFF3.3 T2 cross sections.

Experiments used in the Adjustment

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Facility	Experiment	Type of experiment	Number of experim.
LANL Small criticals	GODIVA, JEZEBEL BIGTEN, Np SPHERE	K_{eff}, reaction rate ratios	17
ZPR/ZPPR	ZPR6/7 ; ZPR3/53 and 54 ZPR9-34 ZPPR-9 ZPPR-10 ZPPR-15	K_{eff}; void reactivity, central control rod Fission and capture rate ratios major actinides Flux radial distribution slopes	19
MASURCA	CIRANO COSMO	K_{eff}; reaction rate ratios (major and minor actinides)	9
PHENIX	PROFIL1 ; PROFIL2 ; TRAPU	Separated isotope irradiations: major, minor actinides, fission products. Variable actinide content pins	36
ATR	MANTRA*	Separated isotope irradiations: major and minor actinide isotopes	3
PROTEUS	HCLWR phase II *	K_{∞}; void reactivity; reaction rate ratios	8
SEG	SEG5 ; SEG6 *	Sample reactivity worths	2
ASPIS	ASPIS 88 *	Foil detectors at several radial positions	11
JOYO		K_{eff}	1
FCA	FCA-IX*	Reaction rate ratios	18

Most significant (E-C)/C reduction

Experiment	Initial (C-E)/E %	Final (C-E)/E %	Experiment	Initial (C-E)/E %	Final (C-E)/E %
ZPR3-54 K_{eff}	-1.188	0.017	BIGTEN F28/F25	5.6	0.6
ZPR3-53 K_{eff}	-0.915	-0.028	BIGTEN F37/F25	3.4	-0.4
ZPR9-34 K_{eff}	-0.874	-0.007	BIGTEN F49/F25	2.6	0.9
PROTEUS Void Coef.	480.0	2.3	BIGTEN F28/F25	5.6	0.6
PROTEUS-C8 keff	3.950	1.881	FCA-IX-7 F53/F49	6.7	-2.2
PROTEUS-C8 C42/F49	-10.7	0.07	FCA-IX-1 F53/F49	8.7	0.0
PROTEUS-C8 F25/F49	-2.2	-0.4	FCA-IX-6 F53/F49	10.2	2.8
TRAPU Cm243 Build-up	107.0	0.07	FCA-IX-7 F51/F49	7.0	1.5
PROFIL1 Pu238 in Pu239 sample	32.8	8.3	FCA-IX-1 F51/F49	5.5	0.5
PROFIL1 Cm245 in Cm244 sample	-8.7	1.9	FCA-IX-6 F51/F49	7.6	4.1
PROFIL1 Am243 in Pu242 sample	-5.6	0.8	FCA-IX-7 F42/F49	-4.5	-2.2
PROFIL1 Pu240 in Pu239 sample	10.3	5.5	FCA-IX-6 F42/F49	-3.5	0.6
PROFIL1 Pu238 in Np237 sample	6.7	3.3	ASPIS-FE-88 Al (n,α)A7	-25.9	1.6
NP Sphere K_{eff}	0.562	0.247	ASPIS-FE-88 S(n,p) A12	6.5	0.2
SEG6 Fe sample	5.5	3.0	ASPIS-FE-88 Rh(n, n')A14	-9.0	1.1
Godiva F28/F25	4.7	0.5	ASPIS-FE-88 Rh(n, n')A7	-5.1	1.5

Contribution to parameter change by adjusted data (%)

ZPR9-34 keff				ZPR3-53 keff			
Isotope	Reaction	Energy Group	Contribution %	Isotope	Reaction	Energy Group	Contribution %
^{235}U	χ	3	0.37	^{239}Pu	χ	3	-0.264
		4	0.95			4	-0.144
		5	0.25			5	0.140
		6	-0.22			6	0.191
		7	-0.34			7	0.115
		8	-0.38		fission	20	-0.087
		9	-0.27			21	-0.083
		10	-015		capture	16	-0.091
		11	-0.08			17	-0.113
^{56}Fe	capture	7	-0.07	^{238}U	χ	2	-0.247
		20	-0.12			3	-0.329
	elastic	7	0.10			4	-0.088
		8	0.11			5	0.131
		9	0.10			6	0.139
		10	0.10			7	0.098
Total		-0.867%		Total		-0.887%	

Contribution to parameter change by adjusted data (%)

SEG6 Fe sample				ASPIS-88 S(n,p) A14			
Isotope	Reaction	Energy Group	Contribution %	Isotope	Reaction	Energy Group	Contribution %
^{56}Fe	elastic	5	-0.13	^{56}Fe	elastic	2	0.14
		6	-0.06			3	1.65
		7	0.17			4	8.00
		8	0.11			5	7.28
		9	0.10		P1 elastic	3	0.08
		10	0.09		inelastic	1	-0.08
		11	0.13			2	-0.52
		12	0.12			3	-2.33
		13	0.12			4	-2.48
	capture	7	0.10			5	-6.71
		8	0.06	^{235}U	χ	1	-0.61
	inelastic	3	0.24			2	-0.30
		4	0.12			3	1.08
		5	0.68			4	1.90
		6	0.40			5	0.10
Total change		2.4%		Total change		7.4%	

Contribution to parameter change by adjusted data (%)

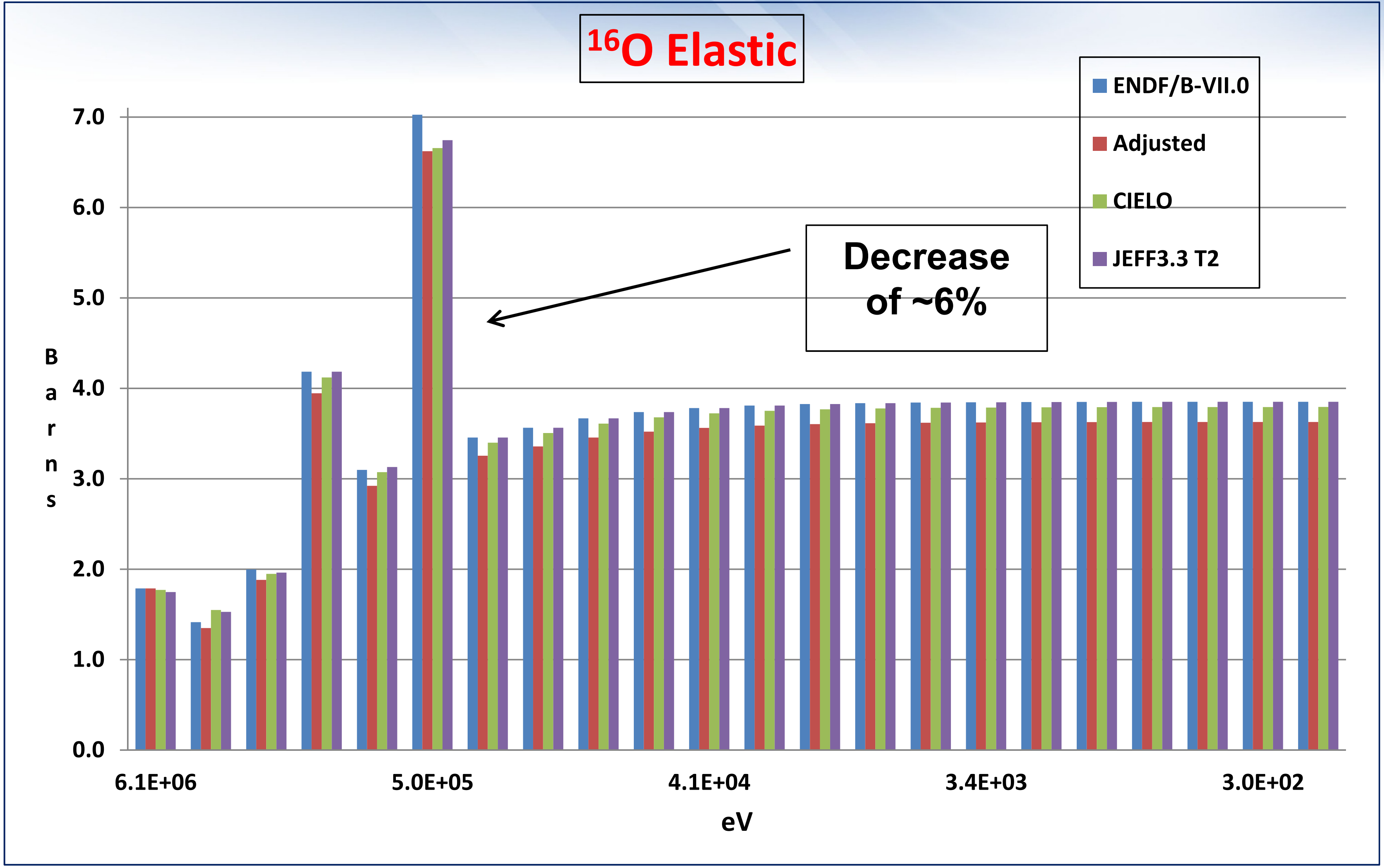
FCA IX-6 F53/F49				FCA IX-1 F53/F49			
Isotope	Reaction	Energy Group	Contribution %	Isotope	Reaction	Energy Group	Contribution %
^{243}Am	fission	2	0.16	^{243}Am	fission	2	0.13
		3	0.65			3	0.57
		4	1.62			4	1.47
		5	1.97			5	2.17
		6	0.78			6	0.75
^{235}U	χ	3	0.16	^{235}U	χ	3	0.33
		4	0.47			4	0.68
		7	0.28			7	0.33
		8	0.36			8	0.39
		9	0.23			9	0.26
	inelastic	4	0.16			10	0.14
		5	0.21	^{239}Pu	fission	19	0.15
		6	0.21			20	0.17
^{238}U	inelastic	6	0.22			21	0.17
^{56}Fe	inelastic	5	-0.15			23	0.22
Total change		7.3%		Total change		8.7%	

Major Findings for the 5 CIELO Isotopes

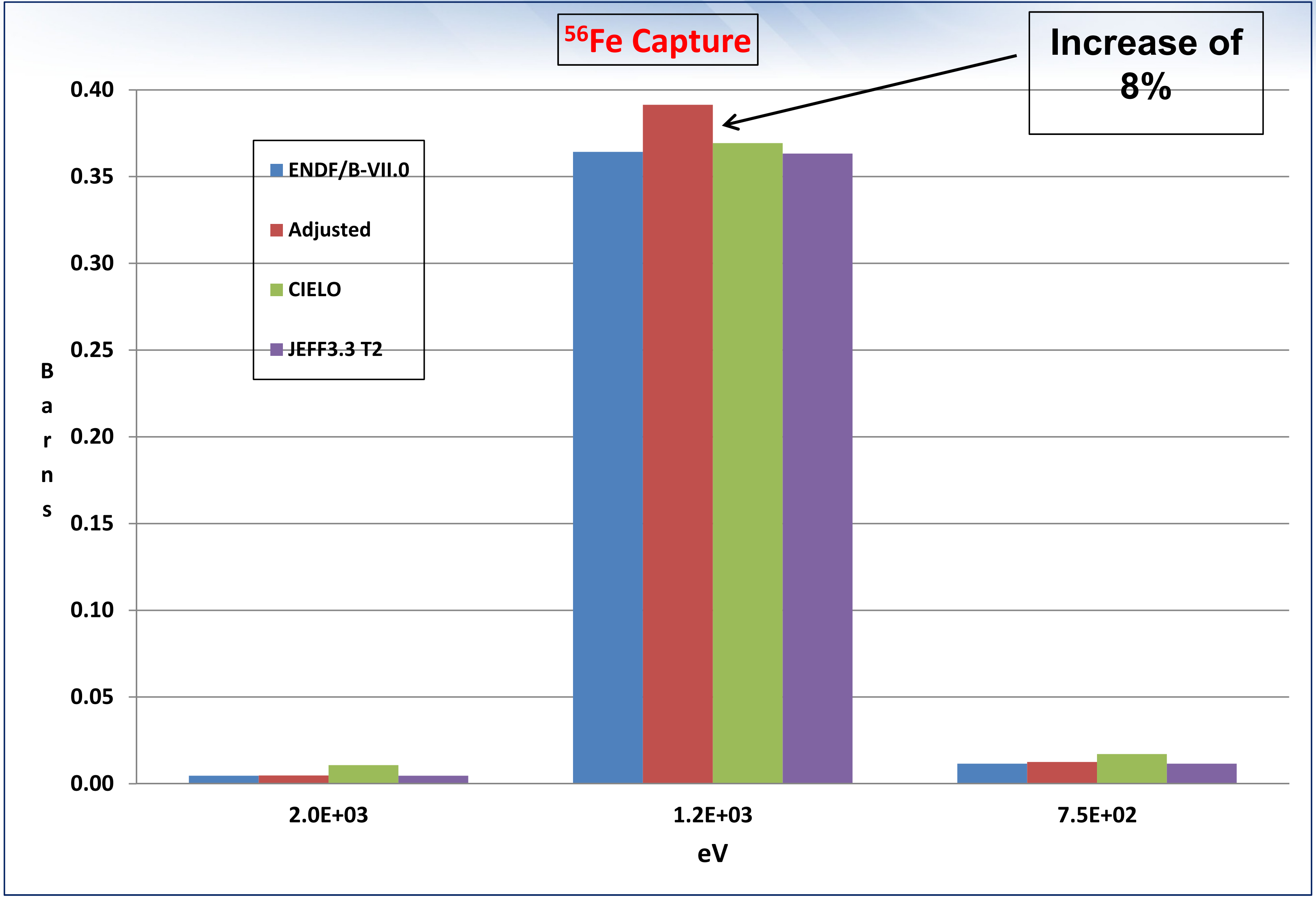
- ^{16}O: Significant elastic cross section decrease (~6% and outside current standard deviation) and some impact on P_1 scattering.
- ^{56}Fe: Systematic increase of capture (higher at low energy). 5-6% increase at 1.23 KeV resonance. No major change in inelastic. Some change in P_1.
- ^{235}U: little changes in capture. Significant decrease of χ below 500 KeV. P_1 elastic decreases between 800 and 100 KeV. Systematic decrease of inelastic (with respect to ENDF/B-VII.0).
- ^{238}U: decrease in capture (~4% average from 25 KeV to 1 KeV). Decrease of inelastic ~5-10%. Change in shape of χ. Very significant increase of P_1 (200 KeV to 5 KeV).
- ^{239}Pu: Significant increase (~10%) of capture from 10 to 1 KeV; some also at thermal energies. Significant decrease of fission (average ~4%) below ~1 KeV (also at thermal energies). Change in shape of inelastic (significant). No significant change in χ. Large change of n,2n (~+30% from 10 to 6 MeV).

Some General Considerations

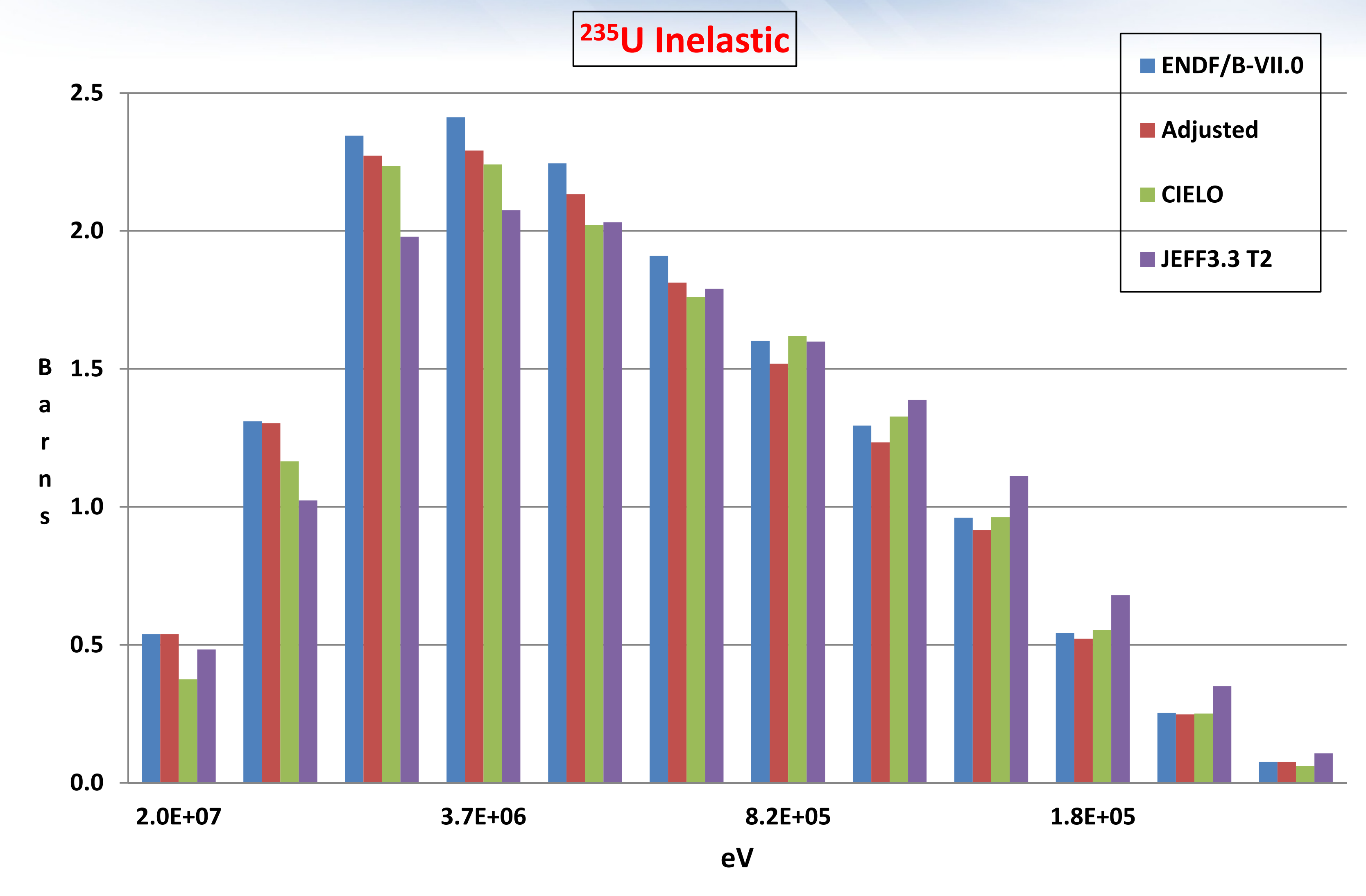
- **Taking into account the fission spectrum (last time was not done) has a very large impact in the adjustment.**
- **For small criticals (JEZEBEL, FLATTOP, BIGTEN) there is a lot of compensation among χ, fission, and inelastic for the major actinides.**
- **Similar compensations also for large criticals (JOYO, ZPR-6/7, ZPR-9/34, ZPR-3/53 and /54) with some role from the ^{238}U capture.**
- **MA irradiation experiments have impact also on major actinides.**
- **FCA experiments impacted by ^{238}U inelastic (i.e. change in spectrum).**
- **The reduction of the significant C/E discrepancy on the PROTEUS void reactivity is due to many competing effects: low energy data of ^{239}Pu and ^{241}Pu play an important role.**
- **Adjoint tailored experiments show clearly role of ^{238}U inelastic (SEG6 steep adjoint) and ^{56}Fe elastic and inelastic (SEG5-6).**
- **ASPIS-88 impact ^{56}Fe capture, elastic, and inelastic.**



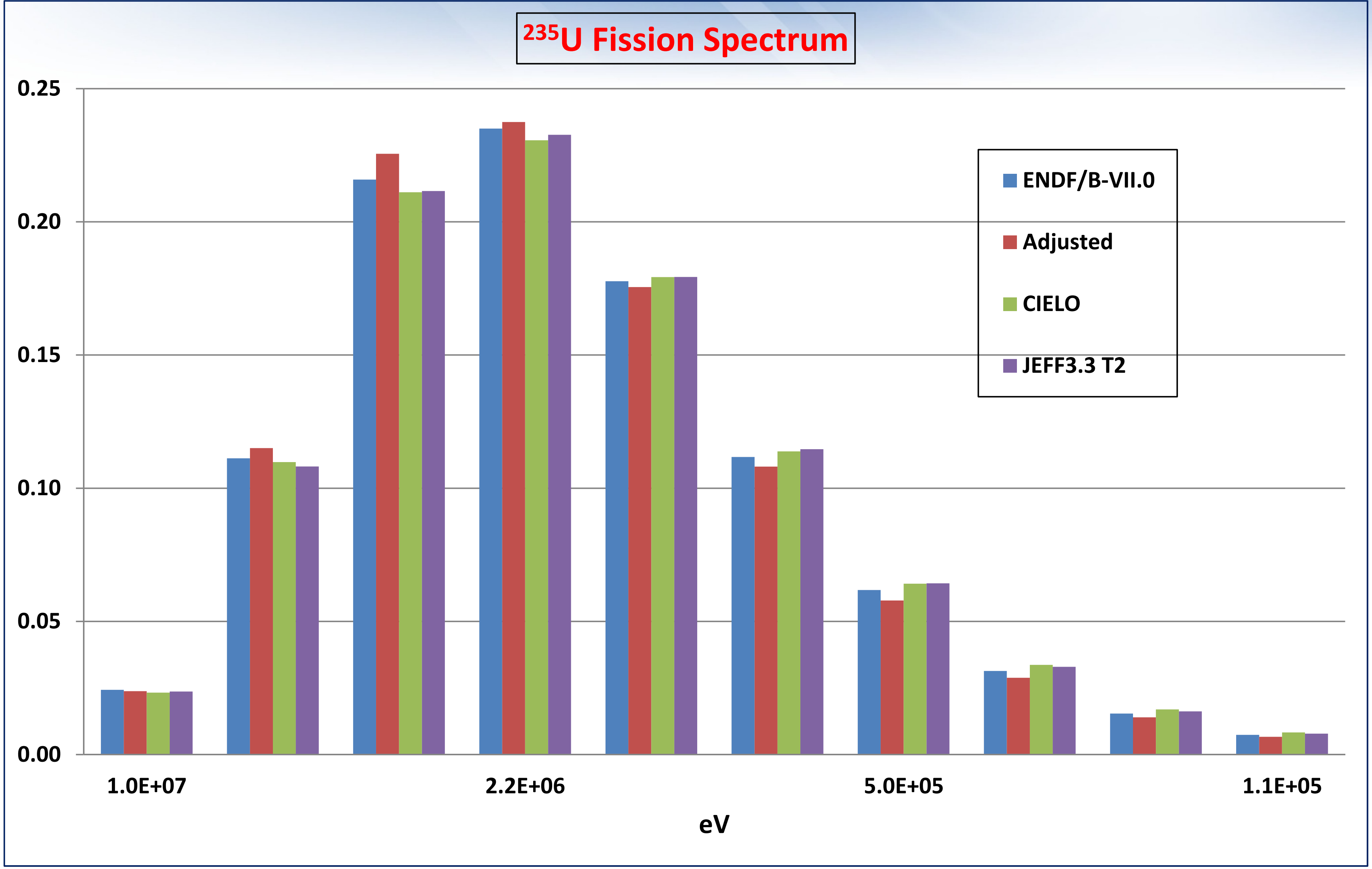
16O Elastic
ENDF/B-VII.0
Adjusted
CIELO
JEFF3.3 T2
Decrease of ~6%
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Barns
6.1E+06
5.0E+05
4.1E+04
3.4E+03
3.0E+02
eV



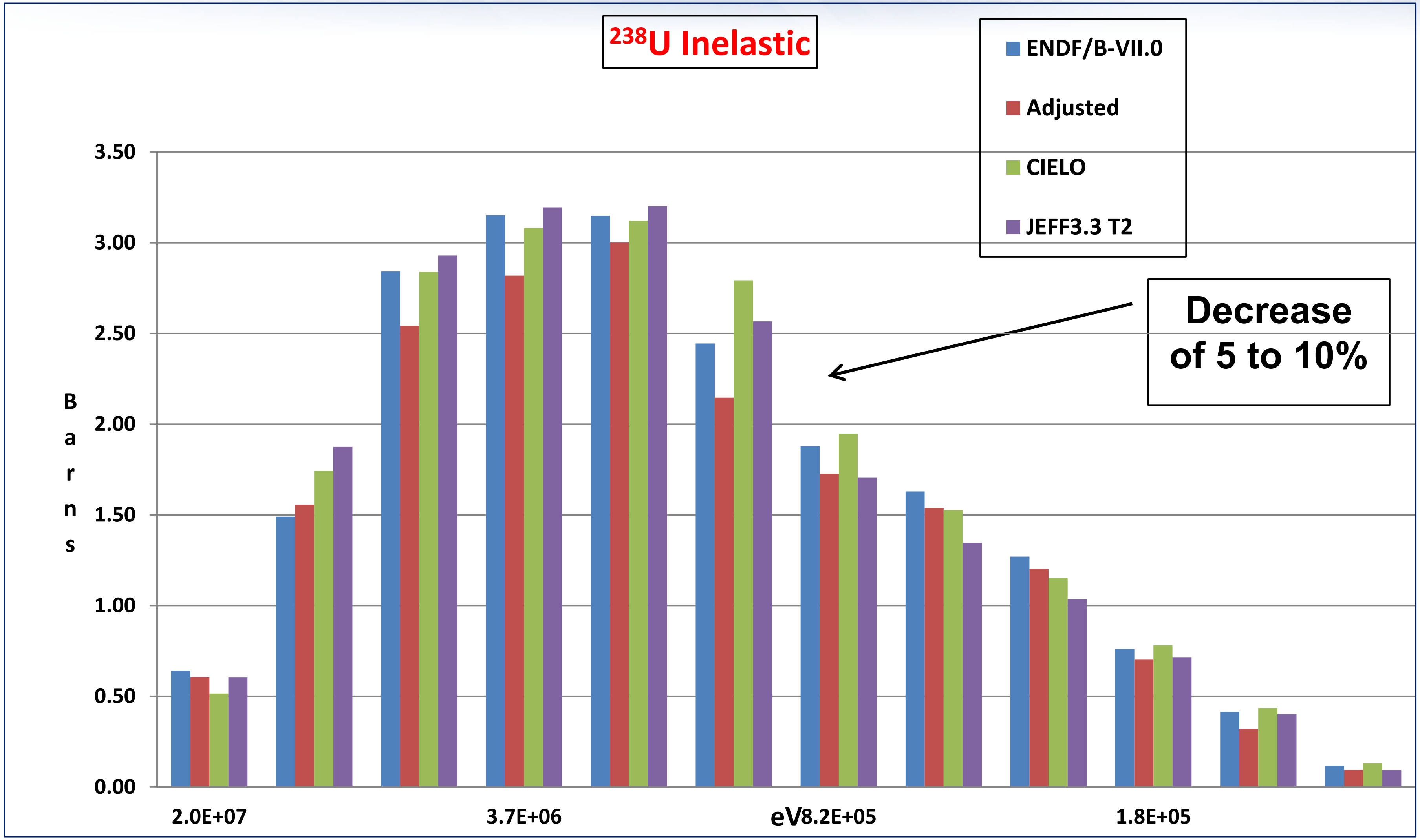
56Fe Capture
Increase of 8%
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Barns
ENDF/B-VII.0
Adjusted
CIELO
JEFF3.3 T2
2.0E+03
1.2E+03
7.5E+02
eV



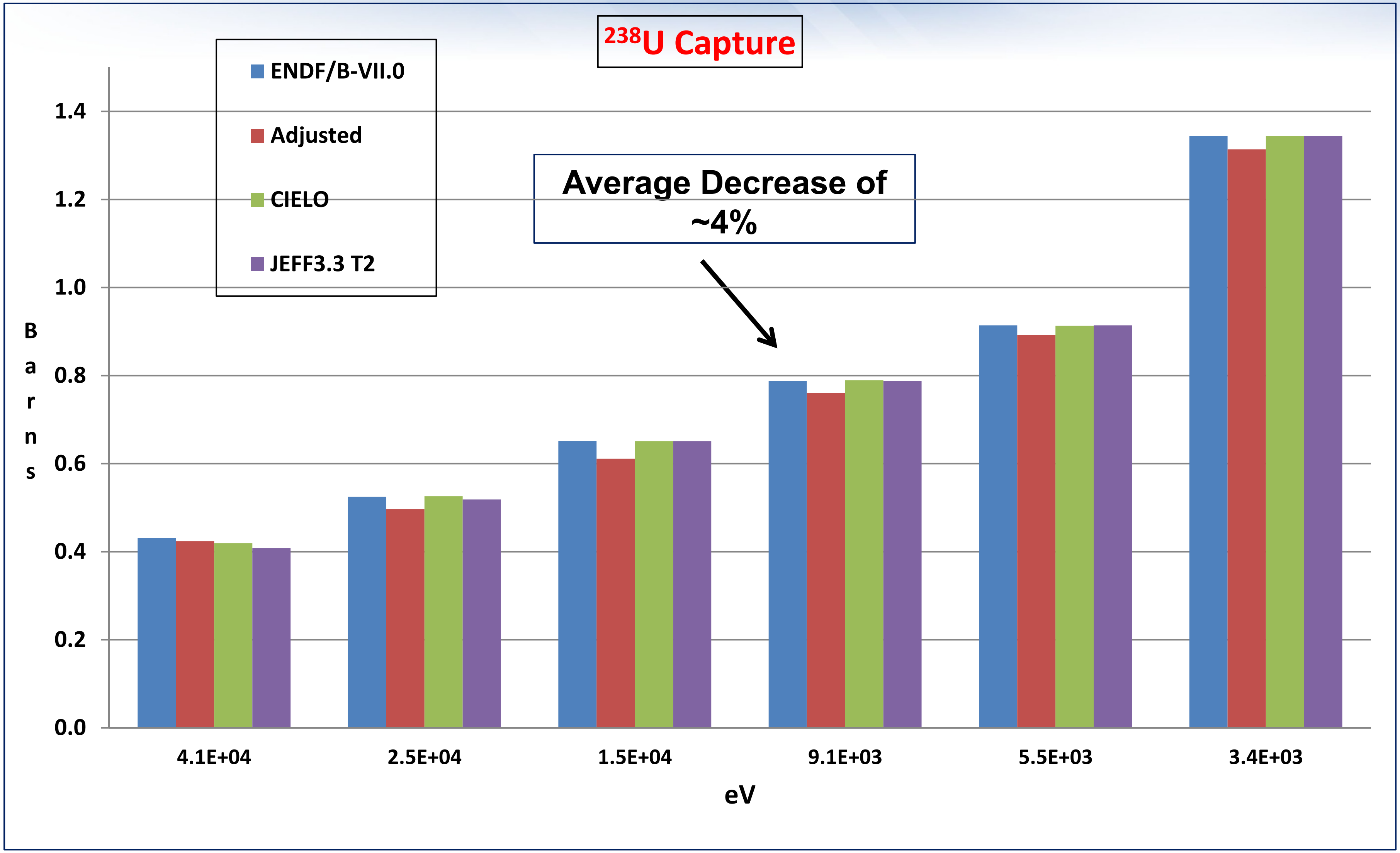
235U Inelastic
ENDF/B-VII.0
Adjusted
CIELO
JEFF3.3 T2
Barns
2.5
2.0
1.5
1.0
0.5
0.0
2.0E+07
3.7E+06
8.2E+05
1.8E+05
eV



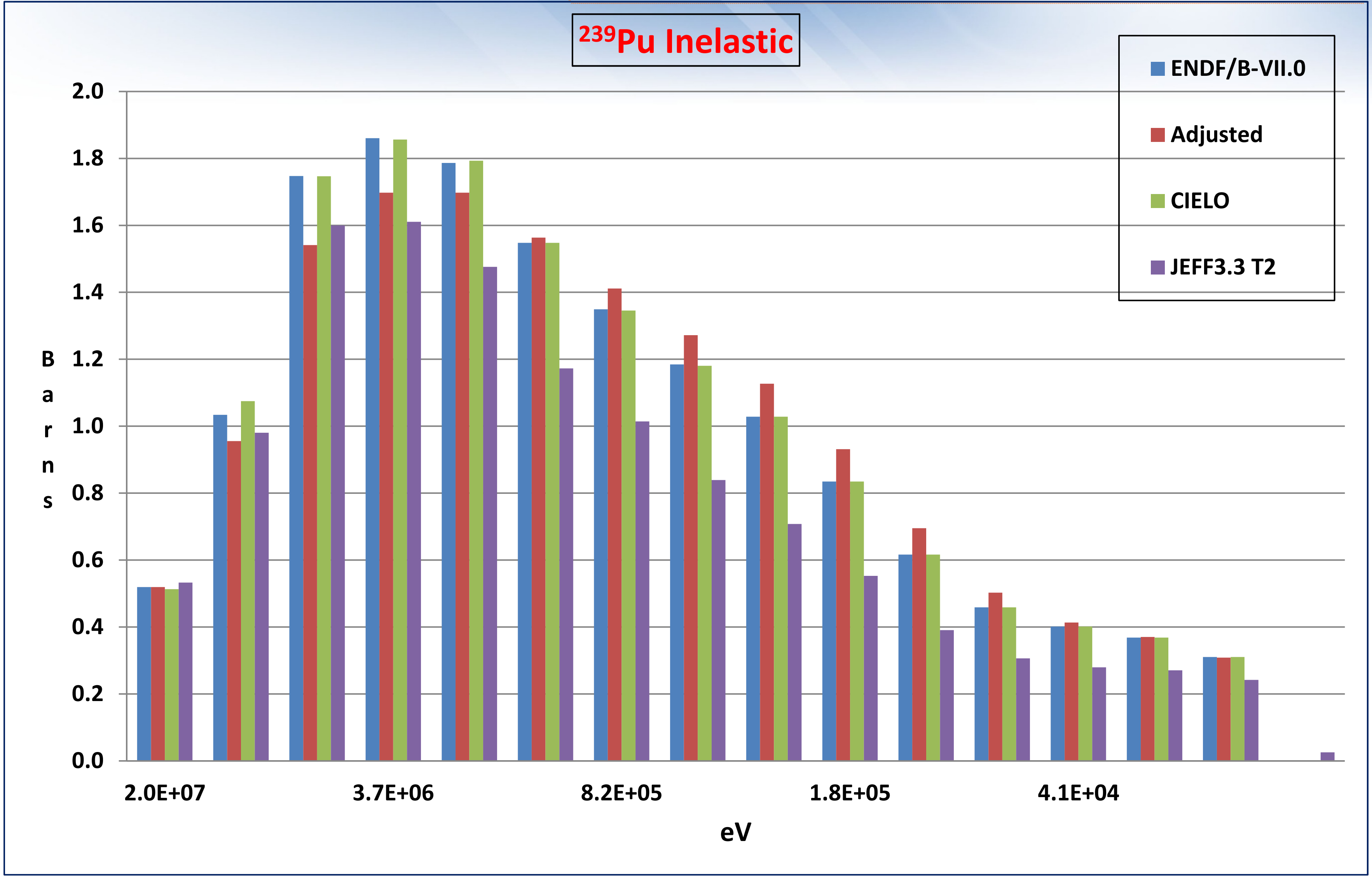
^{235}U Fission Spectrum
0.25
0.20
0.15
0.10
0.05
0.00
ENDF/B-VII.0
Adjusted
CIELO
JEFF3.3 T2
1.0E+07
2.2E+06
5.0E+05
1.1E+05
eV



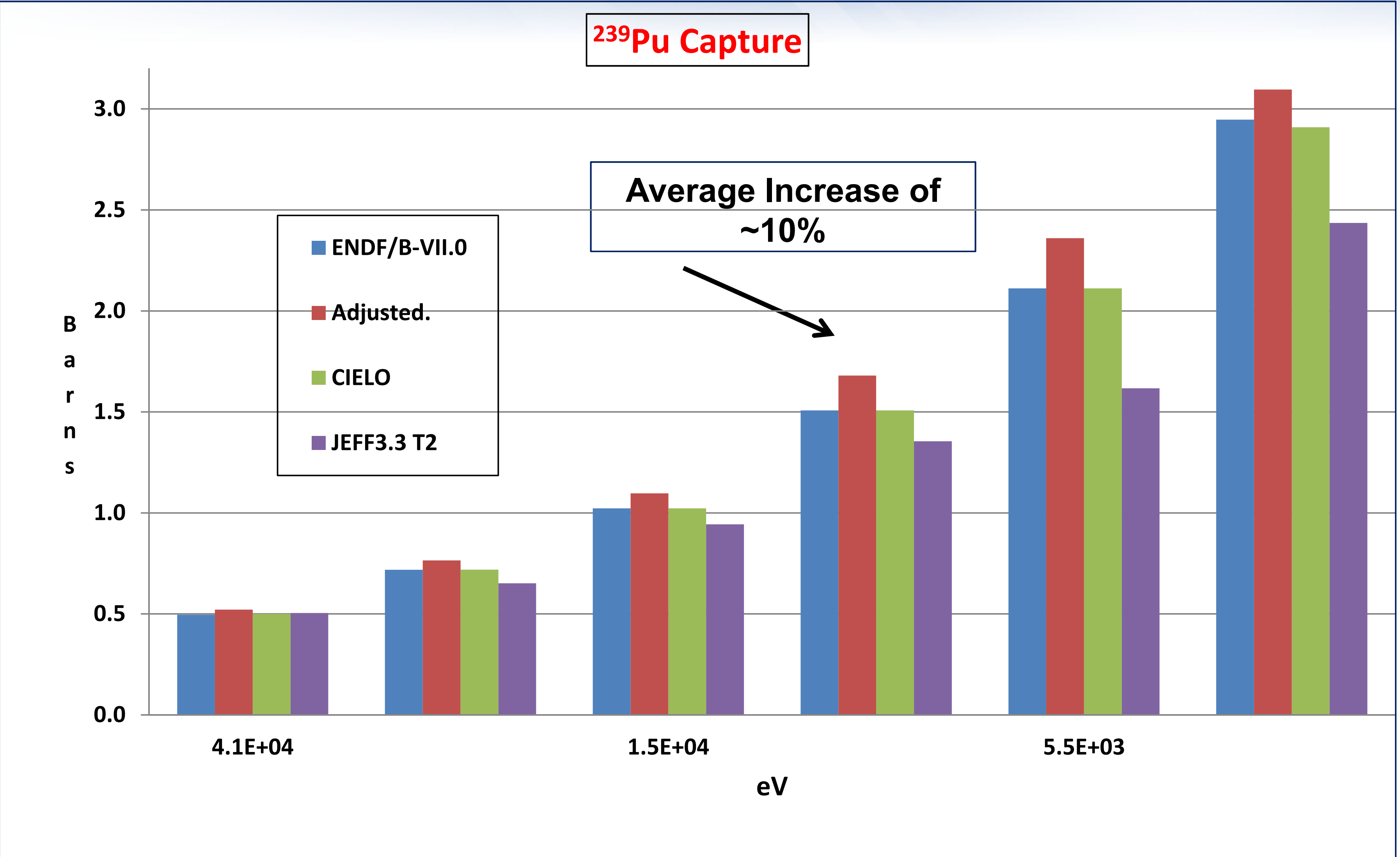
238U Inelastic
ENDF/B-VII.0
Adjusted
CIELO
JEFF3.3 T2
Decrease of 5 to 10%
Barns
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2.0E+07
3.7E+06
eV
8.2E+05
1.8E+05



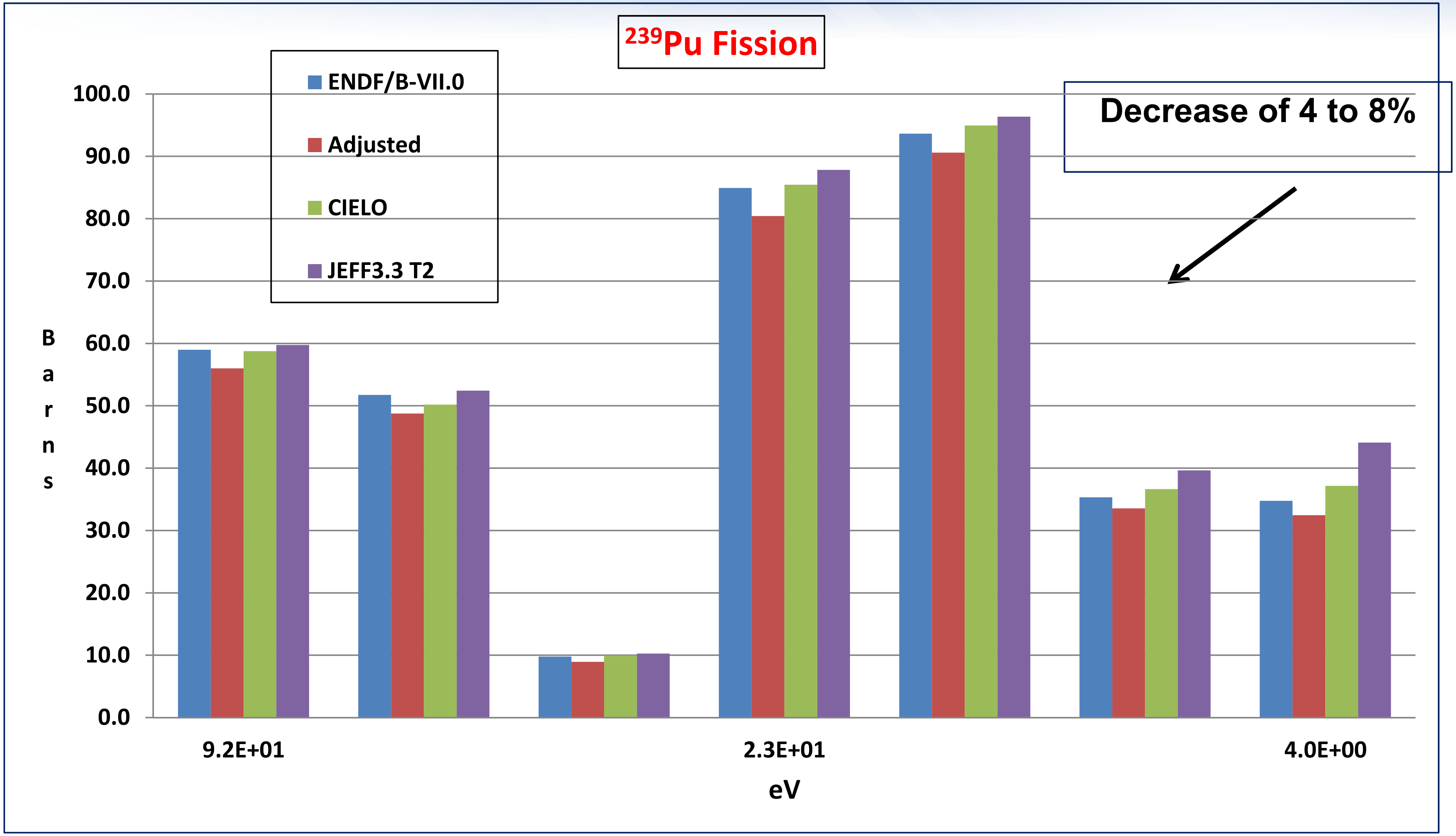
238U Capture
ENDF/B-VII.0
Adjusted
CIELO
JEFF3.3 T2
Average Decrease of ~4%
Barns
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4.1E+04
2.5E+04
1.5E+04
9.1E+03
5.5E+03
3.4E+03
eV



239Pu Inelastic
ENDF/B-VII.0
Adjusted
CIELO
JEFF3.3 T2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Barns
2.0E+07
3.7E+06
8.2E+05
1.8E+05
4.1E+04
eV

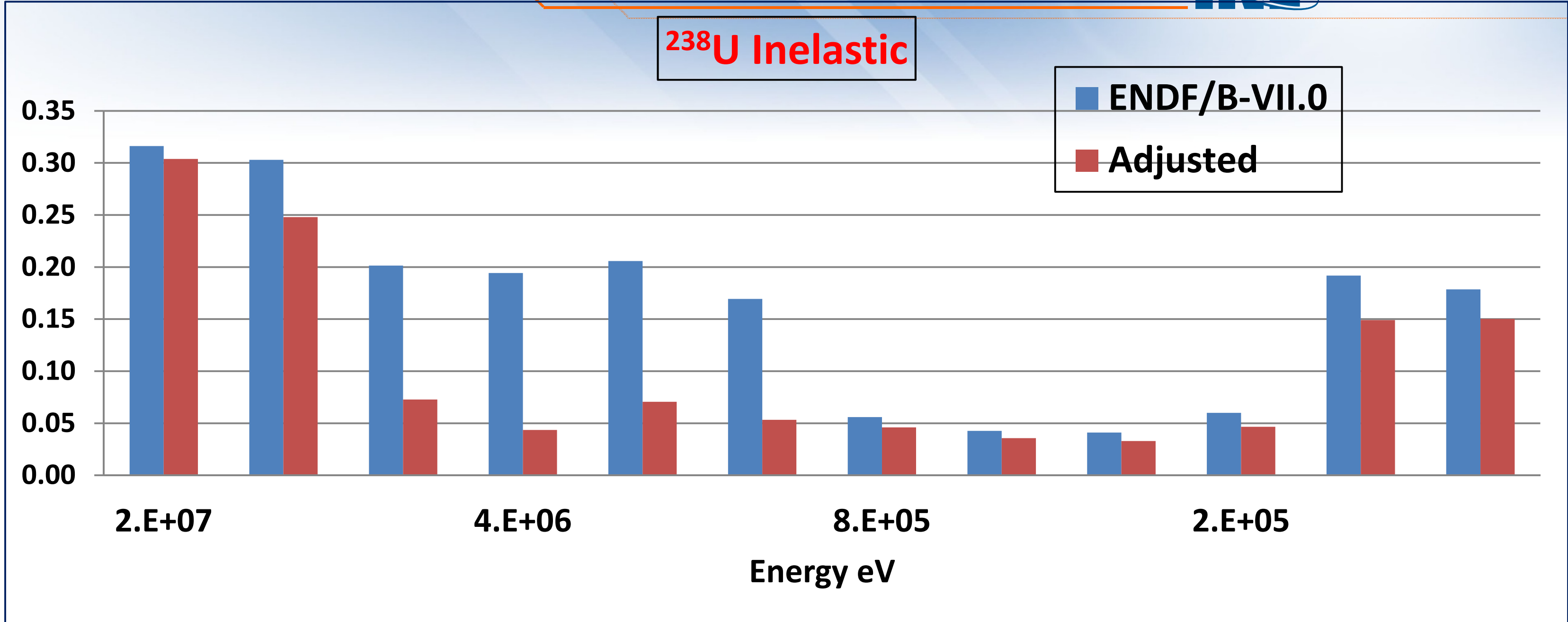


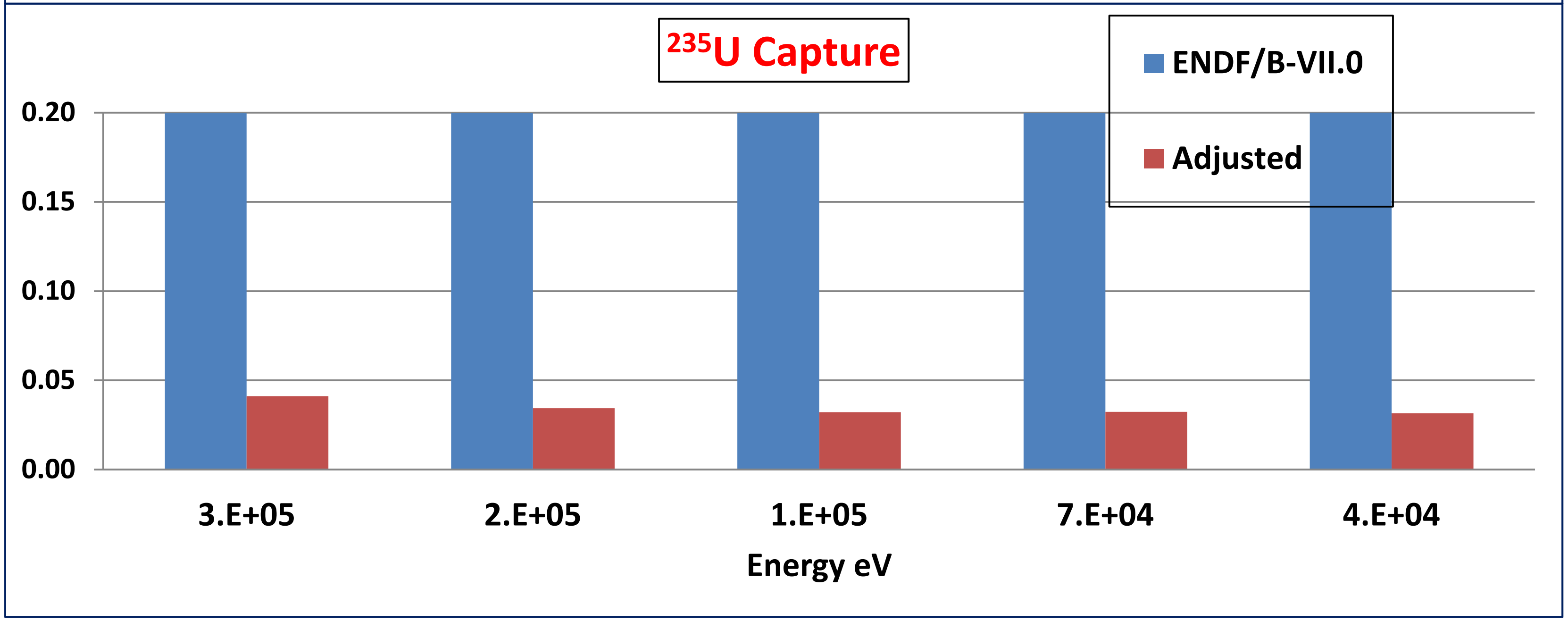
^{239}Pu Capture
Average Increase of ~10%
ENDF/B-VII.0
Adjusted.
CIELO
JEFF3.3 T2
Barns
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4.1E+04
1.5E+04
5.5E+03
eV



239Pu Fission
ENDF/B-VII.0
Adjusted
CIELO
JEFF3.3 T2
Decrease of 4 to 8%
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Barns
9.2E+01
2.3E+01
4.0E+00
eV

Standard Deviations





Conclusions

- An extended adjustment has been carried out adding "elementary type" of experiments often intended for specific reactions and energy range of the 5 isotopes of interest of the CIELO Subgroup.
- Feedback have been provided for these 5 isotopes: some discrepancies with the current proposed CIELO and JEFF3.3 evaluations for the 5 isotopes have been found. Moreover, major uncertainty reduction has been observed.
- However, especially in view of new method development (e.g. PIA, continuous energy adjustment), and most importantly for avoiding, as far as possible, compensations is very important that reliable and improved covariance data are provided by the evaluation community.
- In particular we need the missing data in covariance matrix: P_1 elastic, secondary energy distribution for inelastic cross sections (multigroup transfer matrix), cross correlations (reactions and isotopes), delayed data (nubar and fission spectra).
- Finer energy grid and eigenvalue decomposition of the covariance matrix will be welcome.
- In the future impact of CIELO evaluations on current C/E will be provided.