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Methods and issues for the combined use of integral experiments and covariance data

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Stress Test of Cross-section Adjustment Based on JENDL-4.0

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Survey Cases

0.53 **Case J4: Reference adjustment based on JENDL-4.0 (20 integral data).**

0.63 **Stress test: Add one integral data to Case J4,**
21) keff of ZPR-9/34: *U235 core + SS reflector*.

1.11 **Case B: Add four integral data to Case J4,**
21) keff of ZPR-9/34: *U235* core + *SS* reflector,
22) ZPR-3/53: *Pu &U238 &C core + U238 blanket*,
23) ZPR-3/54: *Pu &U238 &C core + Fe reflector*,
and, 24) ZPR-6/10: *Pu &C &SS core + SS reflector*.

(chi-square / number of freedom)

Outline of Adjustment

- ✓ **Base library: JENDL-4.0 released in May 2010,**
- ✓ **Energy structure: 33 group structure of SG33 standard,**
- ✓ **Isotopes to be adjusted: B-10, O-16, Na-23, Fe-56, Cr-52, Ni-58, U-235, -238, Pu-239, -240, -241 (Total 11), (plus C-nat. for Case B).**
- ✓ **Reactions to be adjusted: Elastic, Total inelastic, Capture (n, alpha for B-10), Fission, Nu-total, Chi-p, Mu, Nu-d (Total 8),**
- ✓ **Nuclear data covariance: JENDL-4.0 processed with NJOY, (plus C-nat. from COMMARA-2.0 for Case B).**
- ✓ **Integral data for adjustment: JEZEBEL-Pu239 (keff, F28/F25, F49/F25, F37/F25), -Pu240 (keff), FLATTOP-Pu (keff, F28/F25, F37/F25), ZPR-6/7 (keff, F28/F25, F49/F25, C28/F25), -High Pu240 (keff), ZPPR-9 (keff, F28/F25, F49/F25, C28/F25, Na void reactivity (Step 3, 5)), JOYO Mk-I (keff) (Total 20), (plus ZPR-9/34 for Stress test, further, plus ZPR-3/53 & 54, ZPR-6/10 for Case B).**

Analytical Method applied to obtain C/E values

No.	Core	Parameter	Case J4 + Stress test &Case B (As-built MC for ZPPR-9)
1, 2, 3, 4	JEZEBEL-Pu	keff, F28/F25, F49/F25, F37/F25	ICSBEP benchmark model calculation with continuous energy Monte Carlo (MC) code, MVP
5	" -Pu240	keff	
6, 7, 8	FLATTOP-Pu	keff, F28/F25, F37/F25	
9, 10, 11, 12	ZPR-6/7	keff, F28/F25, F49/F25, C28/F25	2D MC of simple model + Corrective factor (C.F.) by INL
13	" -High Pu240	keff	
14	ZPPR-9	keff	As-Built MC by JAEA
15, 16, 17		F28/F25, F49/F25, C28/F25	2D MC + C.F. by INL
18, 19		Na void reactivity (Step 3, 5)	As-Built MC by JAEA
20	JOYO Mk-I	keff	2D MC + C.F. by JAEA (C.F. by INL=0.99666, by JAEA=0.99515)
21, 22, 23, 24	**ZPR-9/34, ZPR-3/53, -3/54, ZPR-6/10**	**keff**	**2D MC of simple model + Corrective factor (C.F.) by ICSBEP**

Integral Data for Adjustment

(Case J4: As-built Monte Carlo results for ZPPR-9 by JAEA) (+Stress test +Case B)

No.	Core	Parameter	Parameter value		C/E value	Relative uncertainty (%)		
			Experiment	Calculation		Experiment	Analytical modeling	*Sum*
1	JEZEBEL-Pu239	keff	1.00000	0.99865	0.9987	0.200	0.027	*0.202*
2		F28/F25	0.2133	0.20660	0.9686	1.1	0.94	*1.447*
3		F49/F25	1.4609	1.43701	0.9836	0.9	0.75	*1.172*
4		F37/F25	0.9835	0.96322	0.9794	1.4	0.80	*1.612*
5	JEZEBEL-Pu240	keff	1.00000	0.99839	0.9984	0.200	0.027	*0.202*
6	FLATTOP-Pu	keff	1.00000	0.99859	0.9986	0.300	0.033	*0.302*
7		F28/F25	0.1799	0.17582	0.9773	1.1	0.84	*1.384*
8		F37/F25	0.8561	0.84968	0.9925	1.4	0.69	*1.561*
9	ZPR-6/7	keff	1.00051	1.00581	1.0053	0.230	0.025	*0.231*
10		F28/F25	0.0223	0.0230	1.0336	3.0	2.24	*3.74*
11		F49/F25	0.9435	0.9237	0.9790	2.1	1.43	*2.54*
12		C28/F25	0.1323	0.1345	1.0167	2.4	1.22	*2.69*
13	ZPR-6/7 High-Pu240	keff	1.00080	1.00410	1.0033	0.220	0.030	*0.222*
14	ZPPR-9	keff	1.00080	1.00295	1.0021	0.117	0.020	*0.119*
15		F28/F25	0.0207	0.02034	0.9828	2.7	2.09	*3.41*
16		F49/F25	0.9225	0.9217	0.9992	2.0	1.21	*2.34*
17		C28/F25	0.1296	0.1320	1.0188	1.9	1.39	*2.35*
18		Central Na void*	29.39	31.39	1.0682	1.9	5.26	*5.59*
19		Large Na void*	31.68	33.34	1.0523	1.9	4.96	*5.31*
20	JOYO Mk-I	keff	1.00105	0.99923	0.9982	0.180	0.028	*0.182*
21	ZPR-9/34	keff	1.00037	1.01453	1.0142	0.112	0.238	*0.263*
22	ZPR-3/53	keff	1.00170	1.01009	1.0084	0.090	0.212	*0.230*
23	ZPR-3/54	keff	0.99810	1.01194	1.0139	0.170	0.213	*0.272*
24	ZPR-6/10	keff	1.00160	1.03549	1.0338	0.130	0.222	*0.257*

*Cent unit (beta value of ZPPR-9 by JENDL-4.0 = 0.003594)

***Note: Analytical modeling error is twice as the MC statistical error.**

Experimental Error Matrix *Ve*

No.	Core	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Jezebel - Pu239	keff	0.2																							
2		F28/F25	0	1.1																						
3		F49/F25	0	+0.23	0.9																					
4		F37/F25	0	+0.23	+0.32	1.4																				
5	Jezebel -Pu240	keff	0	0	0	0	0.2																			
6	Flattop	keff	0	0	0	0	0	0.3																		
7		F28/F25	0	0	0	0	0	0	1.1																	
8		F37/F25	0	0	0	0	0	0	+0.23	1.4																
9	ZPR6-7	keff	0	0	0	0	0	0	0	0	0.23															
10		F28/F25	0	0	0	0	0	0	0	0	0	3.0														
11		F49/F25	0	0	0	0	0	0	0	0	0	+0.23	2.1													
12		C28/F25	0	0	0	0	0	0	0	0	0	+0.23	+0.32	2.4												
13	ZPR6-7 Pu240	keff	0	0	0	0	0	0	0	0	+0.13	0	0	0	0.22											
14	ZPPR-9	keff	0	0	0	0	0	0	0	0	+0.31	0	0	0	+0.30	0.117										
15		F28/F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.7									
16		F49/F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+0.23	2.0								
17		C28/F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+0.23	+0.32	1.9							
18		Central Na void	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.9						
19		Large Na void	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+0.41	1.9					
20	Joyo	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18				
21	ZPR-9/34	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11			
22	ZPR-3/53	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09		
23	ZPR-3/54	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	
24	ZPR-6/10	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13

Symmetric

* Diagonal term: Error value (1 sigma, %)

** Non-diagonal term : Correlation factor (between -1 and +1)

Core fuel information is not clear.

Analytical Modeling Error Matrix *Vm*

No.	Core	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Jezebel - Pu239	keff	0.03																							
2		F28/F25	0	0.9																						
3		F49/F25	0	+0.5	0.8																					
4		F37/F25	0	+0.5	+0.5	0.8																				
5	Jezebel -Pu240	keff	0	0	0	0	0.03																			
6	Flattop	keff	0	0	0	0	0	0.03																		
7		F28/F25	0	0	0	0	0	0	0.8																	
8		F37/F25	0	0	0	0	0	0	+0.5	0.7																
9	ZPR6-7	keff	0	0	0	0	0	0	0	0	0.03															
10		F28/F25	0	0	0	0	0	0	0	0	0	2.2														
11		F49/F25	0	0	0	0	0	0	0	0	0	+0.5	1.4													
12		C28/F25	0	0	0	0	0	0	0	0	0	+0.5	+0.5	1.2												
13	ZPR6-7 Pu240	keff	0	0	0	0	0	0	0	0	0	0	0	0	0.03											
14	ZPPR-9	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02										
15		F28/F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.1									
16		F49/F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+0.5	1.2								
17		C28/F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+0.5	+0.5	1.4							
18		Central Na void	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.3						
19		Large Na void	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.0					
20	Joyo	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03				
21	ZPR-9/34	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.24			
22	ZPR-3/53	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.21		
23	ZPR-3/54	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.21	
24	ZPR-6/10	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.21

Symmetric

* Diagonal term: Error value (1 sigma, %)

** Non-diagonal term : Correlation factor (between -1 and +1)

Calculated by MC method.

Results of Adjustment (Case J4: Reference)

Result of Case J4) Reference adjustment based on JENDL-4.0 (20 integral data)

No.	Core	Parameter	C/E value		Relative uncertainty (%)		Nuclea-data-induced error (%)		Ratio of C/E-1 to prior total-error*
			Before	After	Experiment (Ve)	Analytical modeling (Vm)	Before (GMG)	After (GM'G)	
1	JEZEBEL-Pu239	keff	0.9987	0.9997	0.20	0.03	0.69	0.15	0.18
2		F28/F25	0.969	0.990	1.1	0.94	3.20	1.02	0.89
3		F49/F25	0.984	0.987	0.9	0.75	0.63	0.47	1.23
4		F37/F25	0.979	0.989	1.4	0.80	1.50	0.67	0.93
5	JEZEBEL-Pu240	keff	0.9984	1.0001	0.20	0.03	0.65	0.14	0.24
6	FLATTOP-Pu	keff	0.9986	1.0002	0.30	0.03	1.26	0.28	0.11
7		F28/F25	0.977	0.998	1.1	0.84	2.94	0.97	0.70
8		F37/F25	0.993	1.001	1.4	0.69	1.44	0.72	0.35
9	ZPR-6/7	keff	1.0053	1.0029	0.23	0.03	0.82	0.12	0.62
10		F28/F25	1.034	1.029	3.0	2.24	4.82	1.85	0.55
11		F49/F25	0.979	0.976	2.1	1.43	1.15	0.83	0.75
12		C28/F25	1.017	1.011	2.4	1.22	2.00	1.12	0.50
13	ZPR-6/7 High-Pu240	keff	1.0033	1.0010	0.22	0.03	0.81	0.12	0.39
14	ZPPR-9	keff	1.0021	1.0001	0.117	0.02	0.90	0.11	0.23
15		F28/F25	0.983	0.977	2.7	2.09	5.28	2.02	0.27
16		F49/F25	0.999	0.996	2.0	1.21	1.15	0.83	0.03
17		C28/F25	1.019	1.013	1.9	1.39	2.03	1.12	0.60
18		Central Na void*	1.068	1.038	1.9	5.26	5.95	3.32	0.84
19		Large Na void*	1.052	1.014	1.9	4.96	7.31	4.04	0.58
20	JOYO Mk-I	keff	0.9982	0.9990	0.18	0.03	0.58	0.16	0.29
Chi-square/Freedom = 0.53							* = (((C/E-1)**2)/(GMG+Ve+Vm))**1/2		

Results of Adjustment (Stress test)

Result of Stress test) Add keff of ZPR-9/34 to Case J4

No.	Core	Parameter	C/E value		Relative uncertainty (%)		Nuclea-data-induced error (%)		Ratio of C/E-1 to prior total-error*
			Before	After	Experiment (Ve)	Analytical modeling (Vm)	Before (GMG)	After (GM'G)	
1	JEZEBEL-Pu239	keff	0.9987	0.9997	0.20	0.03	0.69	0.15	0.18
2		F28/F25	0.969	0.989	1.1	0.94	3.20	1.02	0.89
3		F49/F25	0.984	0.987	0.9	0.75	0.63	0.47	1.23
4		F37/F25	0.979	0.989	1.4	0.80	1.50	0.67	0.93
5	JEZEBEL-Pu240	keff	0.9984	1.0000	0.20	0.03	0.65	0.14	0.24
6	FLATTOP-Pu	keff	0.9986	1.0007	0.30	0.03	1.26	0.28	0.11
7		F28/F25	0.977	0.997	1.1	0.84	2.94	0.97	0.70
8		F37/F25	0.993	1.001	1.4	0.69	1.44	0.72	0.35
9	ZPR-6/7	keff	1.0053	1.0028	0.23	0.03	0.82	0.12	0.62
10		F28/F25	1.034	1.033	3.0	2.24	4.82	1.84	0.55
11		F49/F25	0.979	0.979	2.1	1.43	1.15	0.81	0.75
12		C28/F25	1.017	1.011	2.4	1.22	2.00	1.12	0.50
13	ZPR-6/7 High-Pu240	keff	1.0033	1.0009	0.22	0.03	0.81	0.12	0.39
14	ZPPR-9	keff	1.0021	1.0002	0.117	0.02	0.90	0.11	0.23
15		F28/F25	0.983	0.979	2.7	2.09	5.28	2.01	0.27
16		F49/F25	0.999	0.999	2.0	1.21	1.15	0.82	0.03
17		C28/F25	1.019	1.013	1.9	1.39	2.03	1.12	0.60
18		Central Na void*	1.068	1.046	1.9	5.26	5.95	3.29	0.84
19		Large Na void*	1.052	1.019	1.9	4.96	7.31	4.03	0.58
20	JOYO Mk-I	keff	0.9982	0.9984	0.18	0.03	0.58	0.16	0.29
21	ZPR-9/34	keff	1.0142	1.0012	0.11	0.24	1.15	0.25	1.21
Chi-square/Freedom = 0.63							* = (((C/E-1)**2)/(GMG+Ve+Vm))**1/2		

Results of Adjustment (Case B)

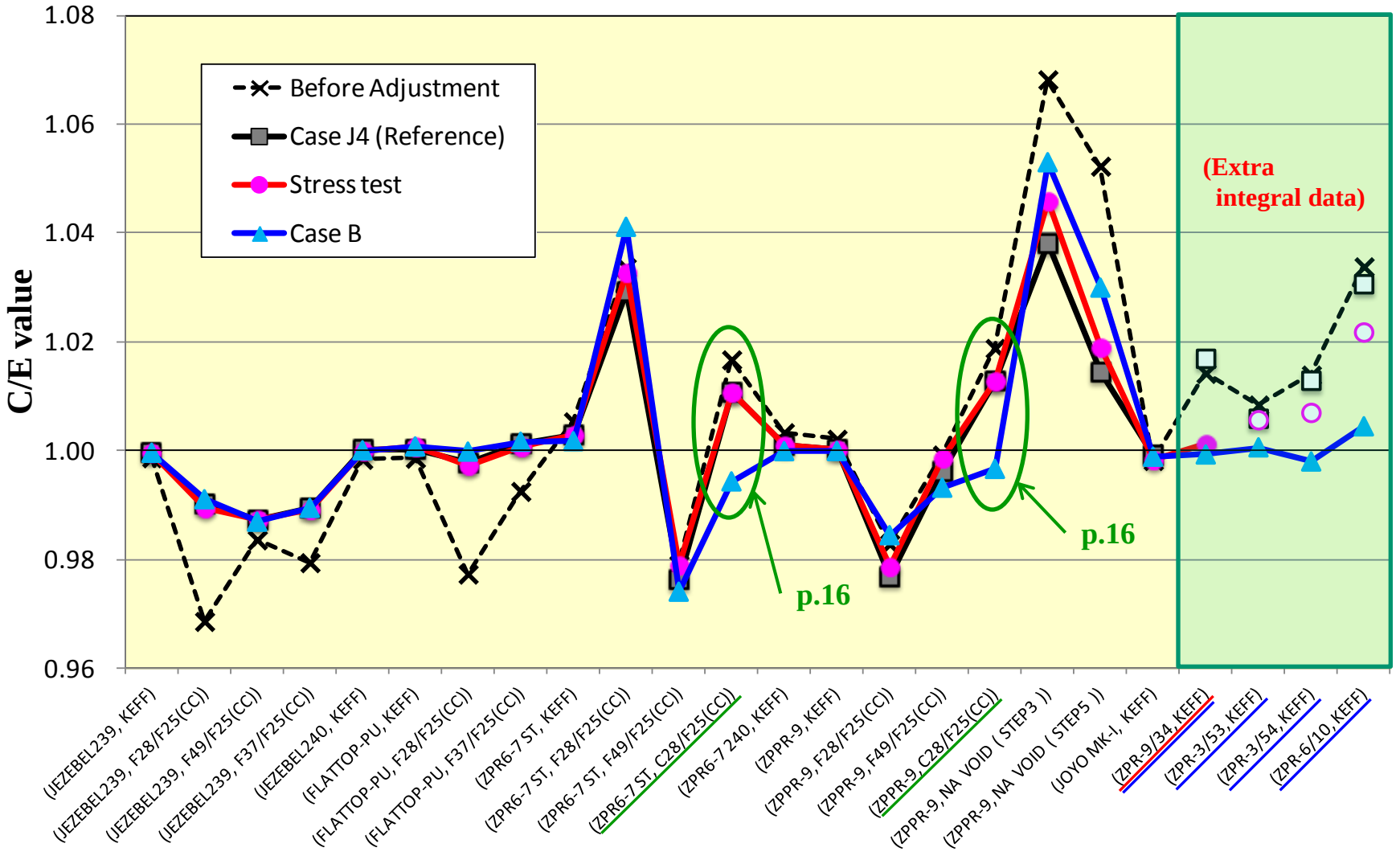
Result of Case B) Add keff of ZPR-9/34 and other 3 cores to Case J4

No.	Core	Parameter	C/E value		Relative uncertainty (%)		Nuclea-data-induced error (%)		Ratio of C/E-1 to prior total-error*
			Before	After	Experiment (Ve)	Analytical modeling (Vm)	Before (GMG)	After (GM'G)	
1	JEZEBEL-Pu239	keff	0.9987	0.9996	0.20	0.03	0.69	0.15	0.18
2		F28/F25	0.969	0.991	1.1	0.94	3.20	1.01	0.89
3		F49/F25	0.984	0.987	0.9	0.75	0.63	0.47	1.23
4		F37/F25	0.979	0.989	1.4	0.80	1.50	0.67	0.93
5	JEZEBEL-Pu240	keff	0.9984	1.0000	0.20	0.03	0.65	0.14	0.24
6	FLATTOP-Pu	keff	0.9986	1.0007	0.30	0.03	1.26	0.28	0.11
7		F28/F25	0.977	1.000	1.1	0.84	2.94	0.97	0.70
8		F37/F25	0.993	1.002	1.4	0.69	1.44	0.72	0.35
9	ZPR-6/7	keff	1.0053	1.0017	0.23	0.03	0.82	0.11	0.62
10		F28/F25	1.034	1.041	3.0	2.24	4.82	1.79	0.55
11		F49/F25	0.979	0.974	2.1	1.43	1.15	0.79	0.75
12		C28/F25	1.017	0.994	2.4	1.22	2.00	1.02	0.50
13	ZPR-6/7 High-Pu240	keff	1.0033	0.9999	0.22	0.03	0.81	0.11	0.39
14	ZPPR-9	keff	1.0021	0.9999	0.117	0.02	0.90	0.11	0.23
15		F28/F25	0.983	0.984	2.7	2.09	5.28	1.98	0.27
16		F49/F25	0.999	0.993	2.0	1.21	1.15	0.79	0.03
17		C28/F25	1.019	0.997	1.9	1.39	2.03	1.02	0.60
18		Central Na void*	1.068	1.053	1.9	5.26	5.95	3.27	0.84
19		Large Na void*	1.052	1.030	1.9	4.96	7.31	4.01	0.58
20	JOYO Mk-I	keff	0.9982	0.9988	0.18	0.03	0.58	0.16	0.29
21	ZPR-9/34	keff	1.0142	0.9993	0.11	0.24	1.15	0.25	1.21
22	ZPR-3/53	keff	1.0084	1.0006	0.09	0.21	0.62	0.16	1.28
23	ZPR-3/54	keff	1.0139	0.9980	0.17	0.21	0.83	0.22	1.59
24	ZPR-6/10	keff	1.0338	1.0044	0.13	0.21	0.93	0.21	3.53
Chi-square/Freedom = 1.11									

More than 3 sigma.

* = (((C/E-1)**2)/(GMG+Ve+Vm))**1/2

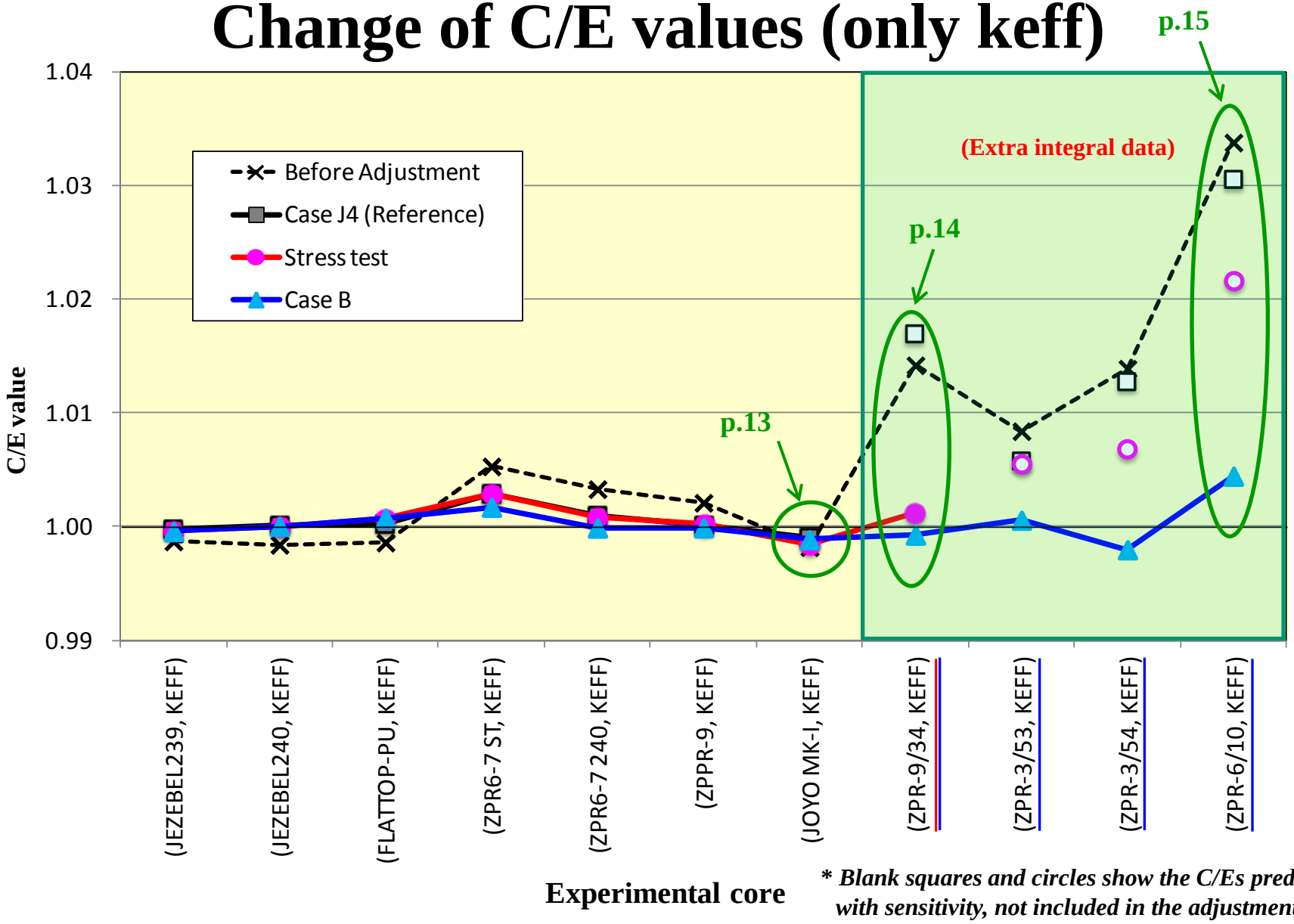
Change of C/E values (All integral data)



** Blank squares and circles show the C/Es predicted with sensitivity, not included in the adjustment.*

=> **Stress test & Case B gave no harm to the original 20 integral data.**
In detail, C/Es of C28/F25 in Case B decreased by ~ 2%.

Change of C/E values (only keff)



** Blank squares and circles show the C/Es predicted with sensitivity, not included in the adjustment.*

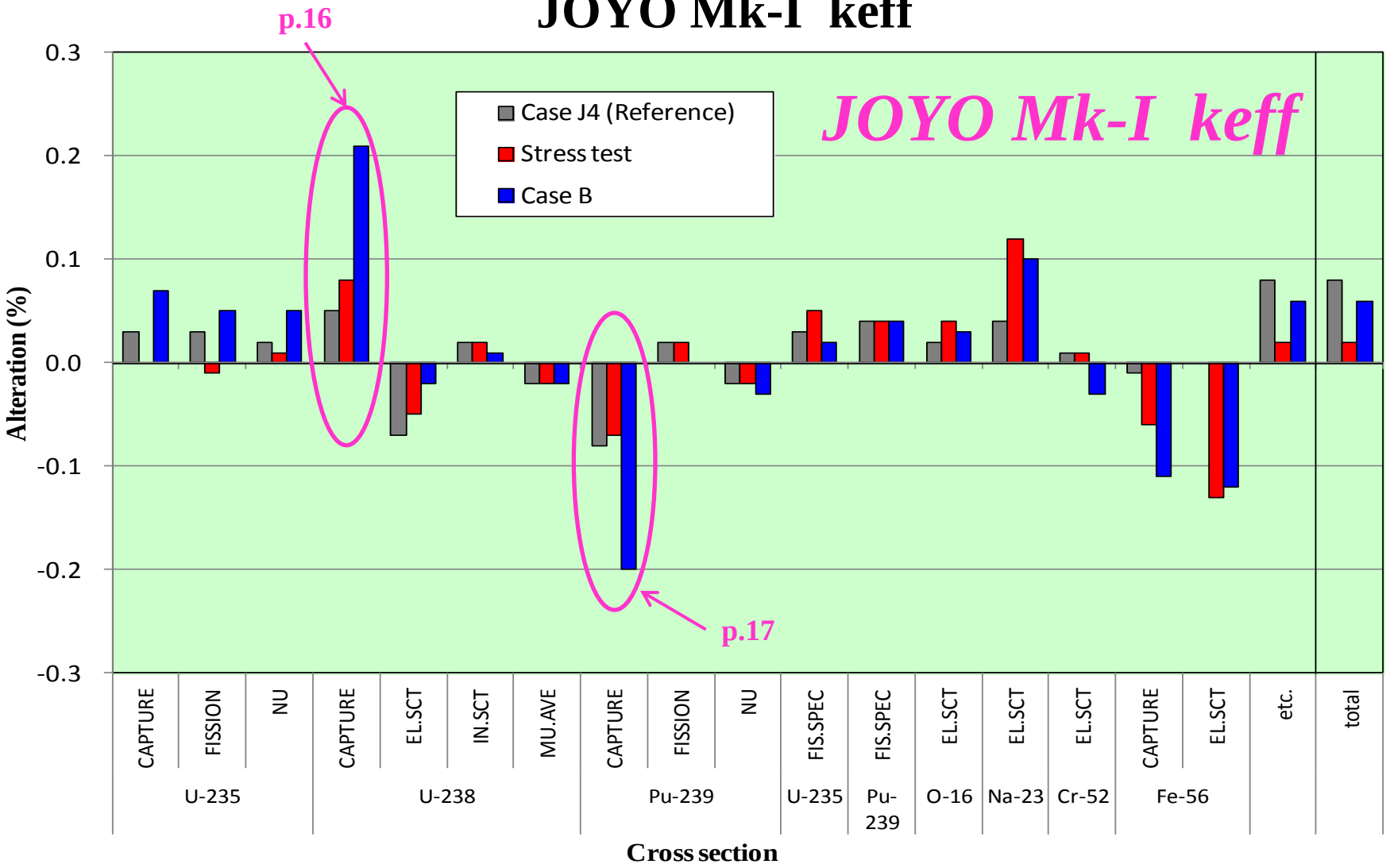
⇒ **Case J4 gave no improvements to the extra four core data.**

⇒ **Stress test is perfect for the adjusted 21 data, and also improves the extra three cores.**

⇒ **Even Case B seems to adjust the all 24 data very well, from the integral viewpoint.**

Contribution to C/E change (1/3)

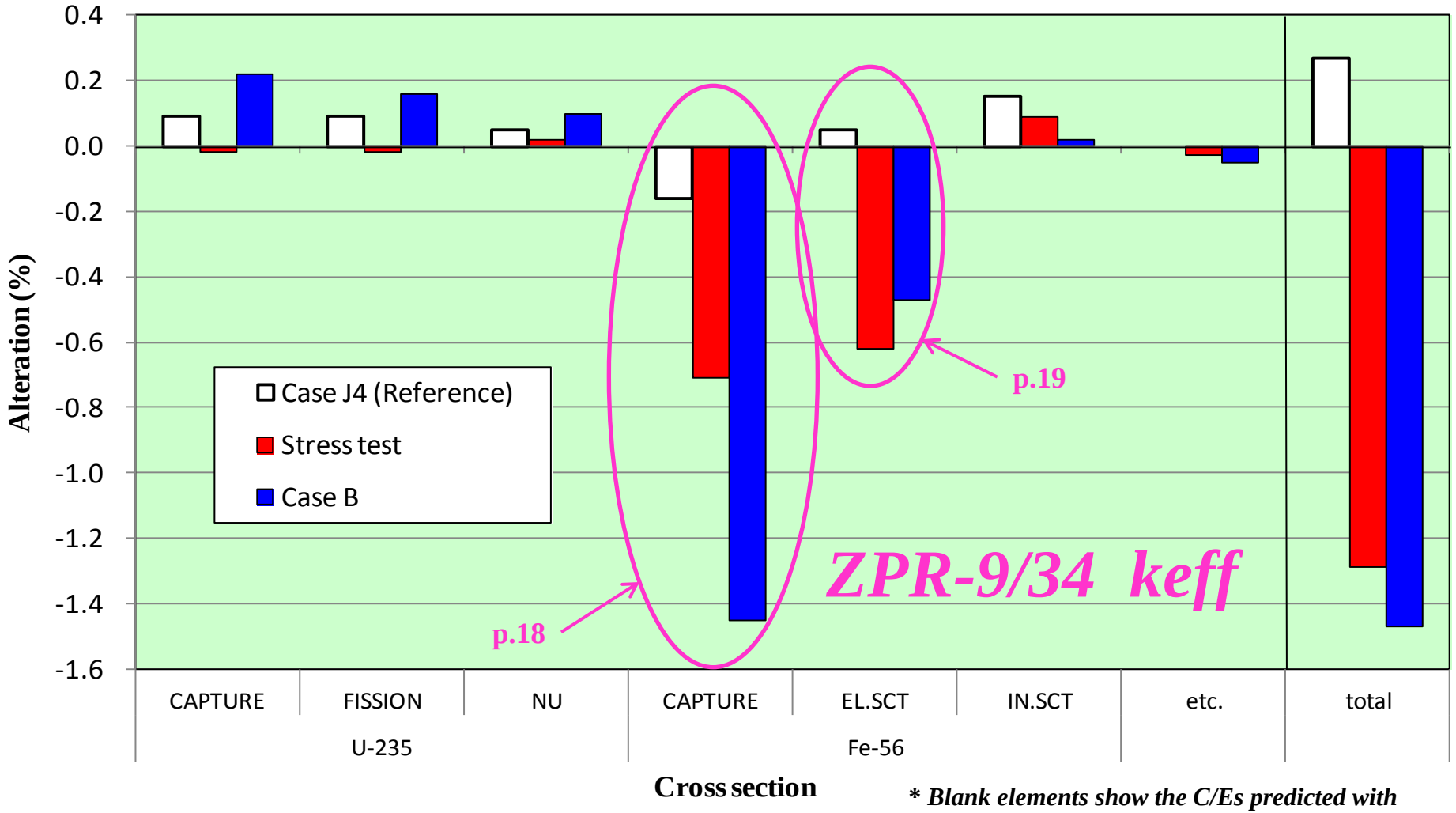
JOYO Mk-I keff



⇒ **The adjusted keffs are quite similar among three cases, but the components of cross-section contributions are significantly different in Case B, especially, with the cancellation of U-238 capture and Pu-239 capture.**

Contribution to C/E change (2/3)

ZPR-9/34 keff

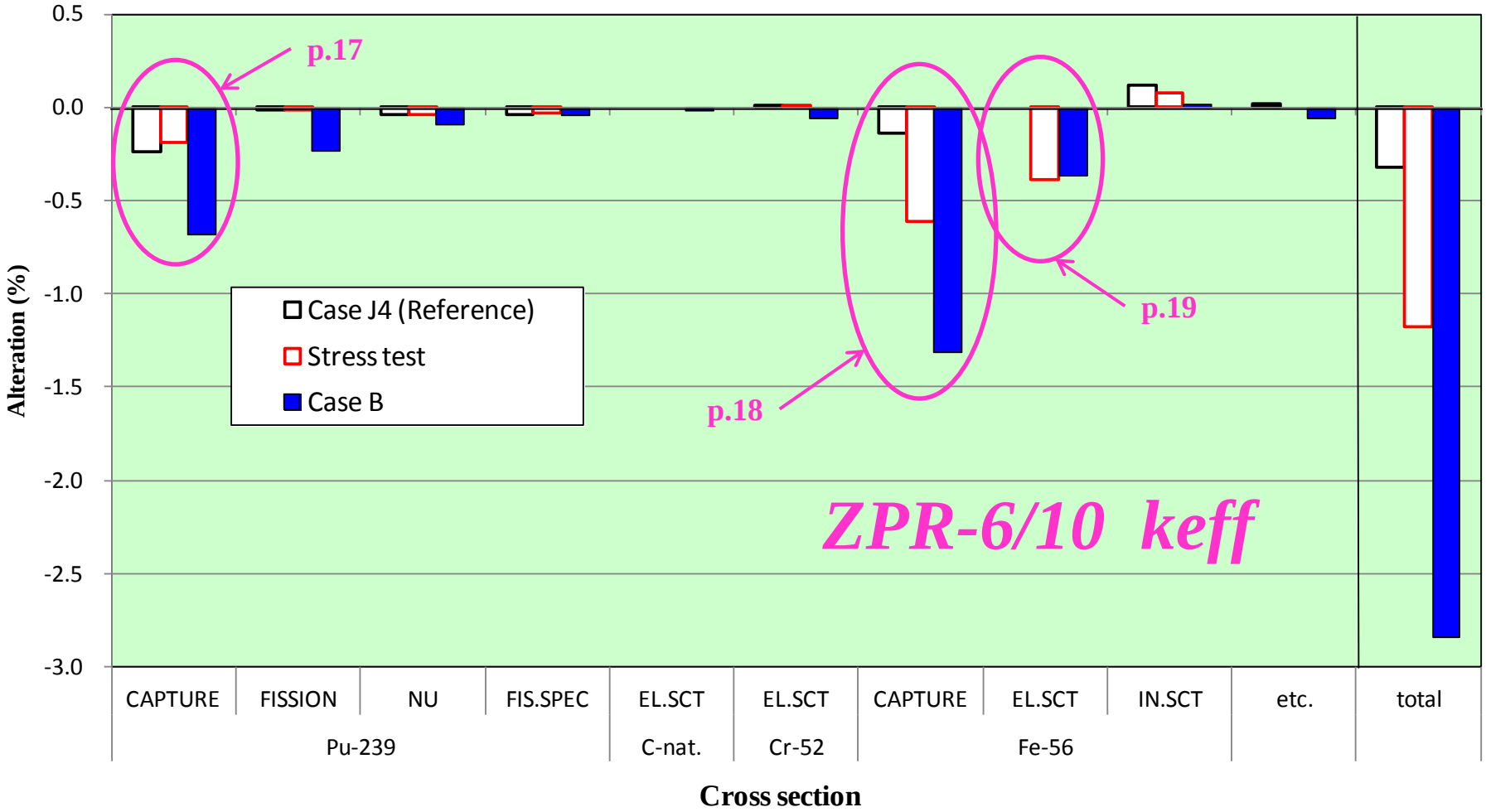


** Blank elements show the C/Es predicted with sensitivity, not included in the adjustment.*

⇒ **For the core of Stress test, ZPR-9/34, Fe-56 shows large contributions from and elastic (reflector effect to adjust ZPR-9/34, -3/54 and -6/10) and capture (core negative reactivity to adjust ZPR-6/10).**

Contribution to C/E change (3/3)

ZPR-6/10 keff



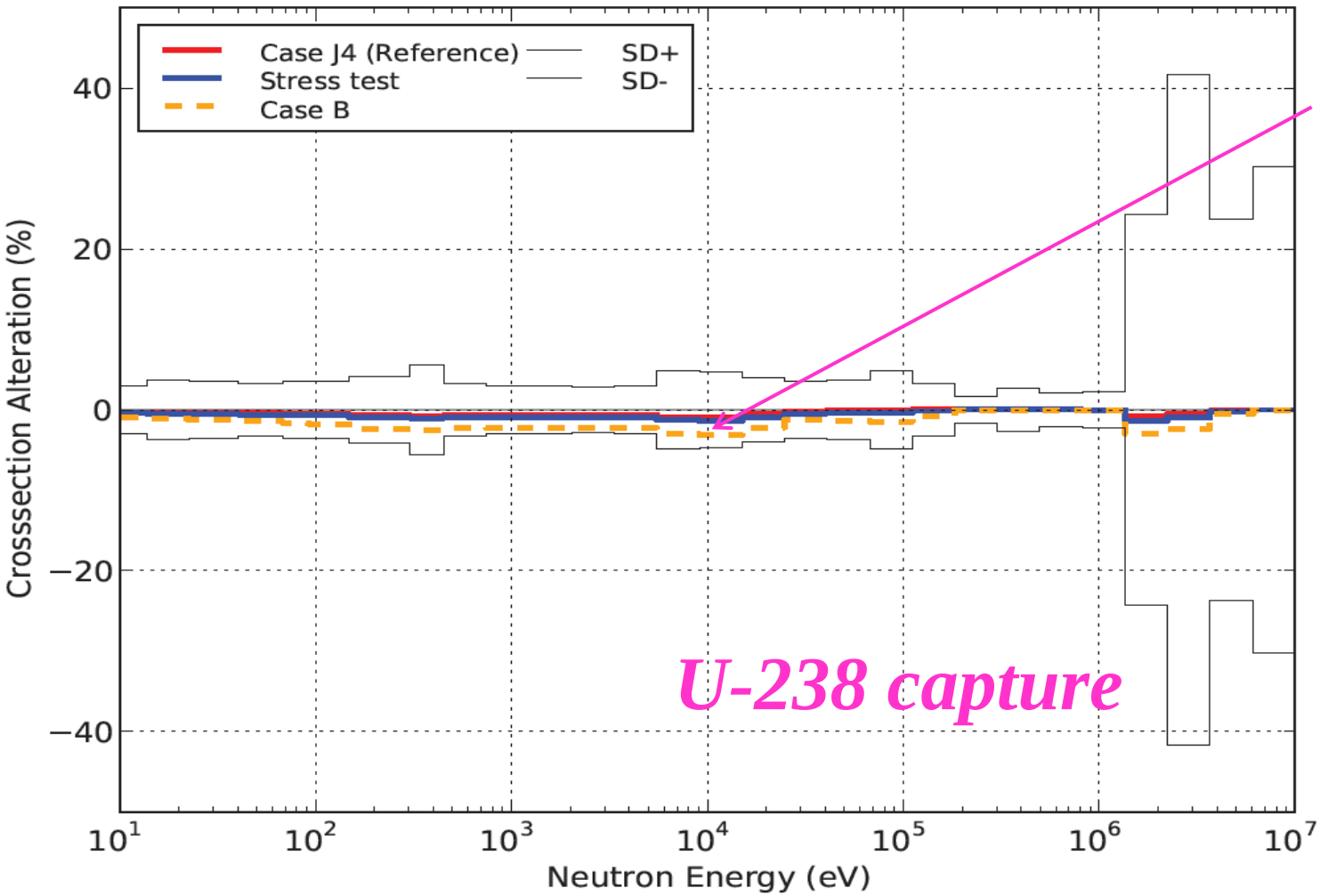
** Blank elements show the C/Es predicted with sensitivity, not included in the adjustment.*

⇒ **To adjust the extra core, ZPR-6/10, many contributions are needed, that is, Fe-56 capture and elastic, and Pu-239 capture.**

⇒ **The core of Stress test, ZPR-9/34, partly helps to adjust ZPR-6/10.**

Change of Cross-sections (1/5)

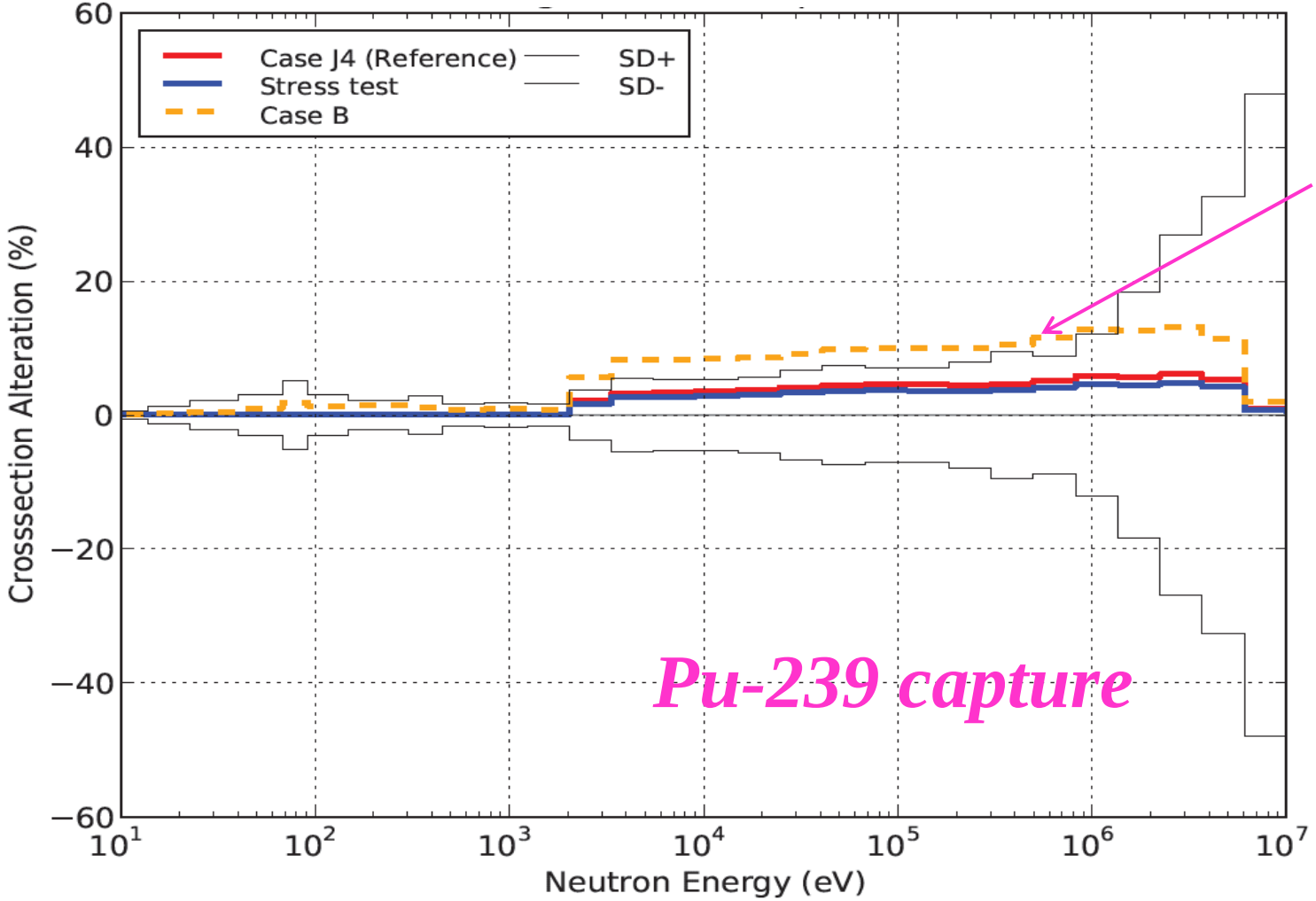
U-238: capture



In Case B, U-238 capture is decreased to cancel the positive keff effect of Pu-239 capture decrease in JOYO Mk-I and other cores (ZPR-6/7, ZPPR-9). This affects the C/Es of C28/F25, but the changes are within the experimental errors.

Change of Cross-sections (2/5)

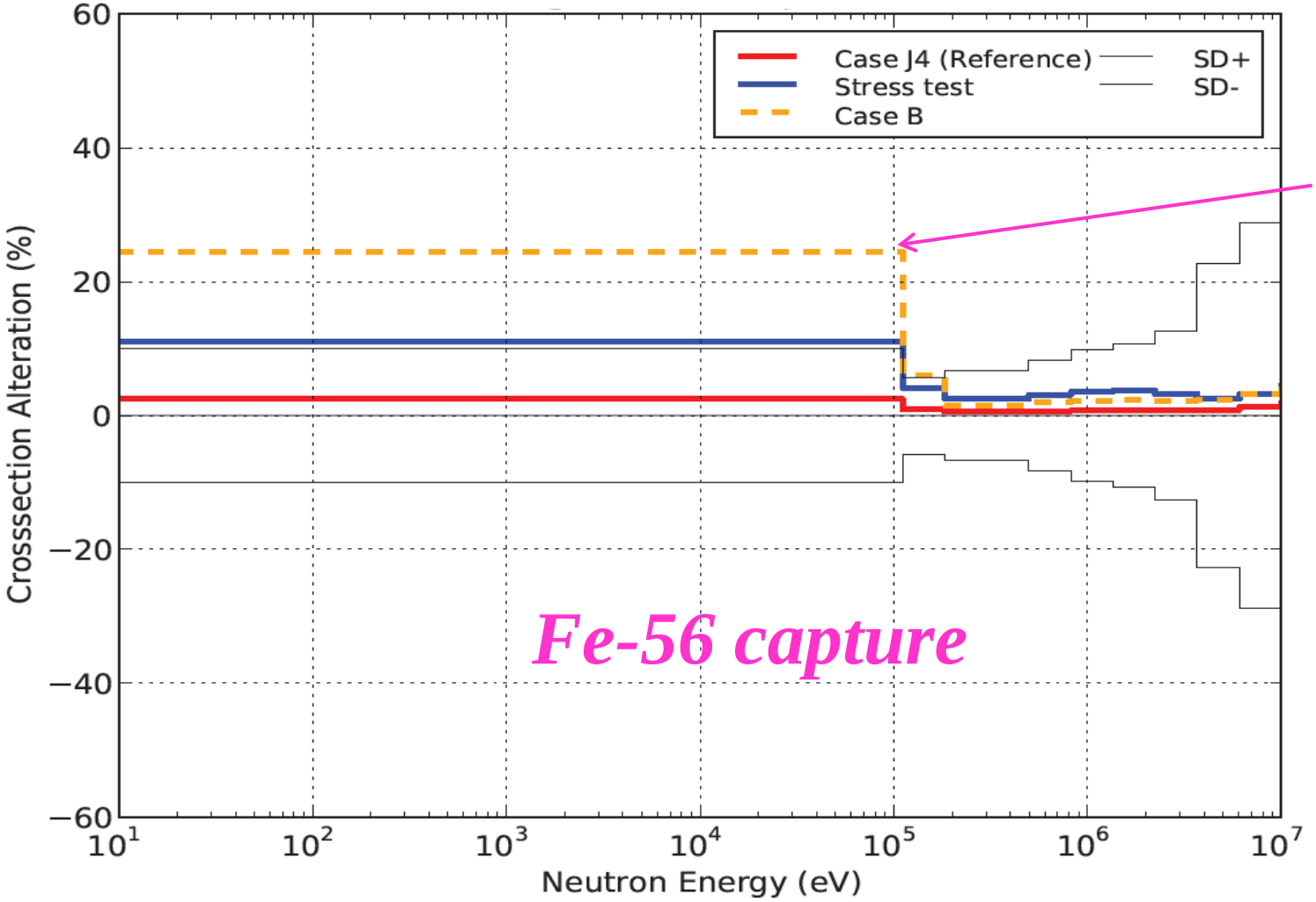
Pu-239: capture



In Case B, Pu-239 capture is largely increased to adjust keff of ZPR-6/10. This cross-section change exceeds the STD of JENDL-4.0 covariance.

Change of Cross-sections (3/5)

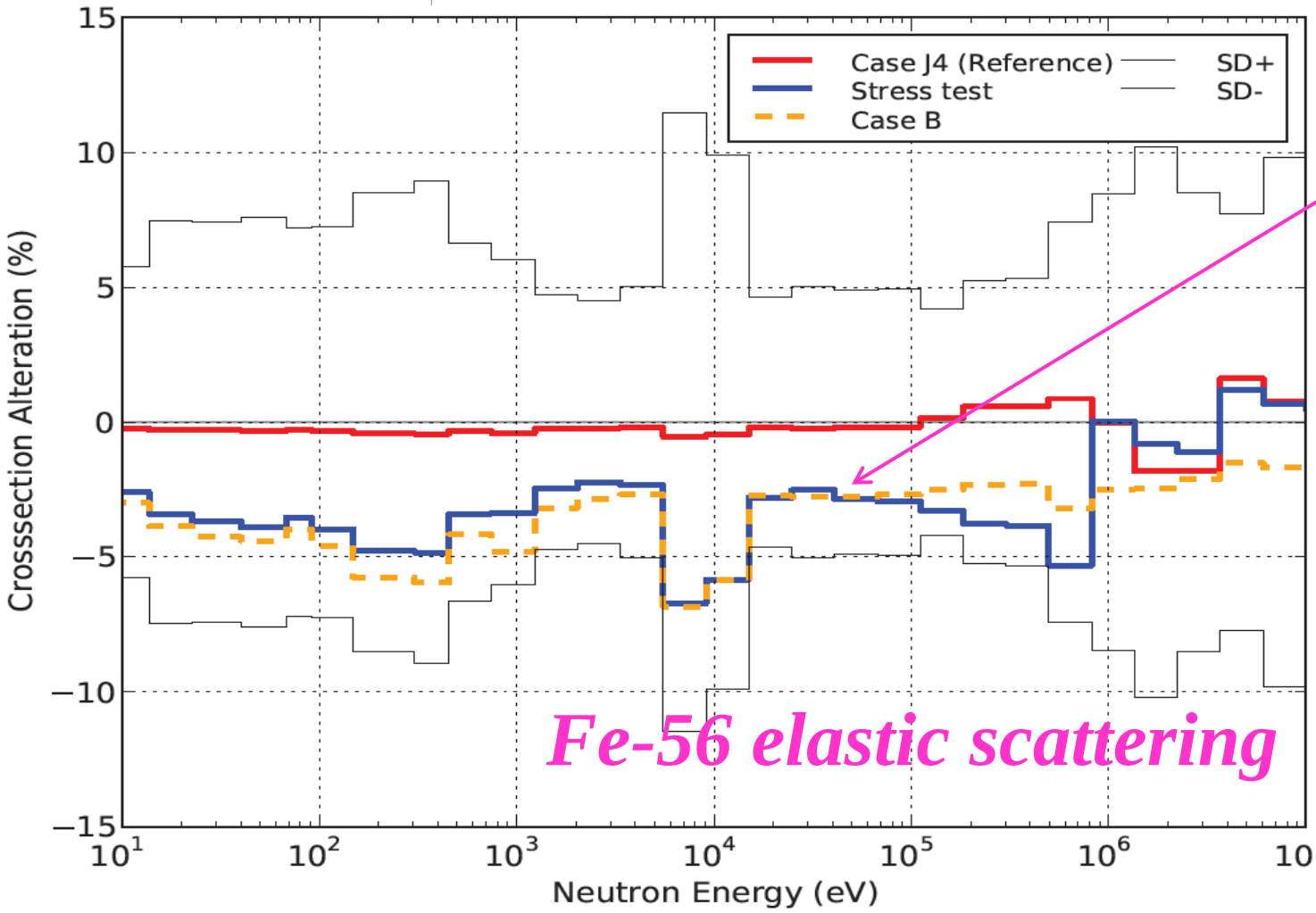
Fe-56: capture



In Case B, Fe-56 capture is largely increased to adjust the overprediction of ZPR-6/10 keff. This cross-section change exceeds the STD of JENDL-4.0 covariance more than twice. Apparently, this change will not be acceptable from the nuclear-data evaluation viewpoint.

Change of Cross-sections (4/5)

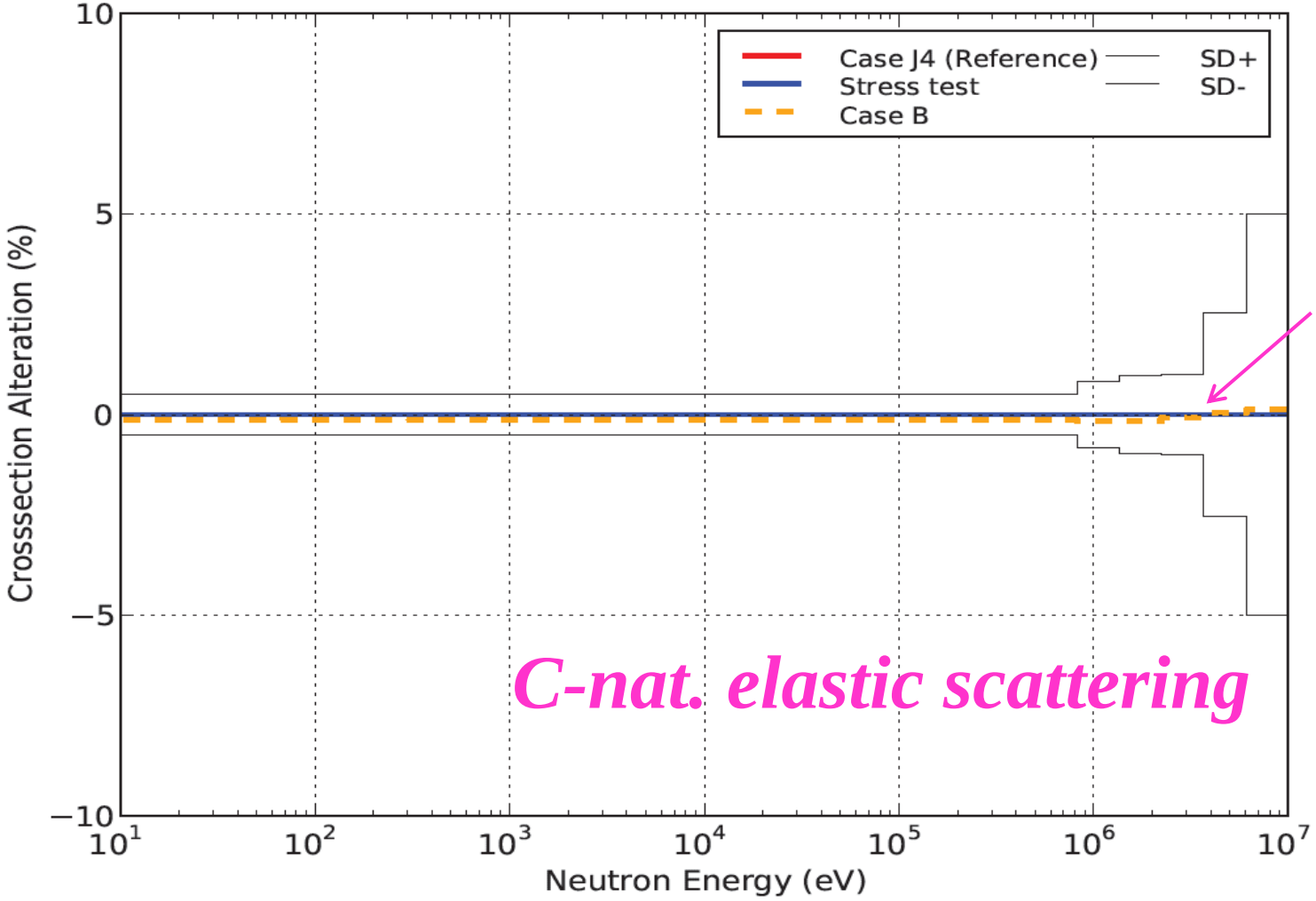
Fe-56: elastic scattering



In Stress test and Case B, Fe-56 elastic is decreased to adjust keffs of Fe or SS reflector cores, that is, ZPR-9/34, -3/54 and -6/10. This cross-section change is quite large, compared with Reference, but still within the STD of JENDL-4.0 covariance.

Change of Cross-sections (5/5)

C-nat.: elastic scattering



Although C-nat. has large sensitivity to extra cores in Case B, that is, ZPR-3/53, -3/54 and -6/10, the cross-section hardly changes due to the small STD of COMMARA-2.0.

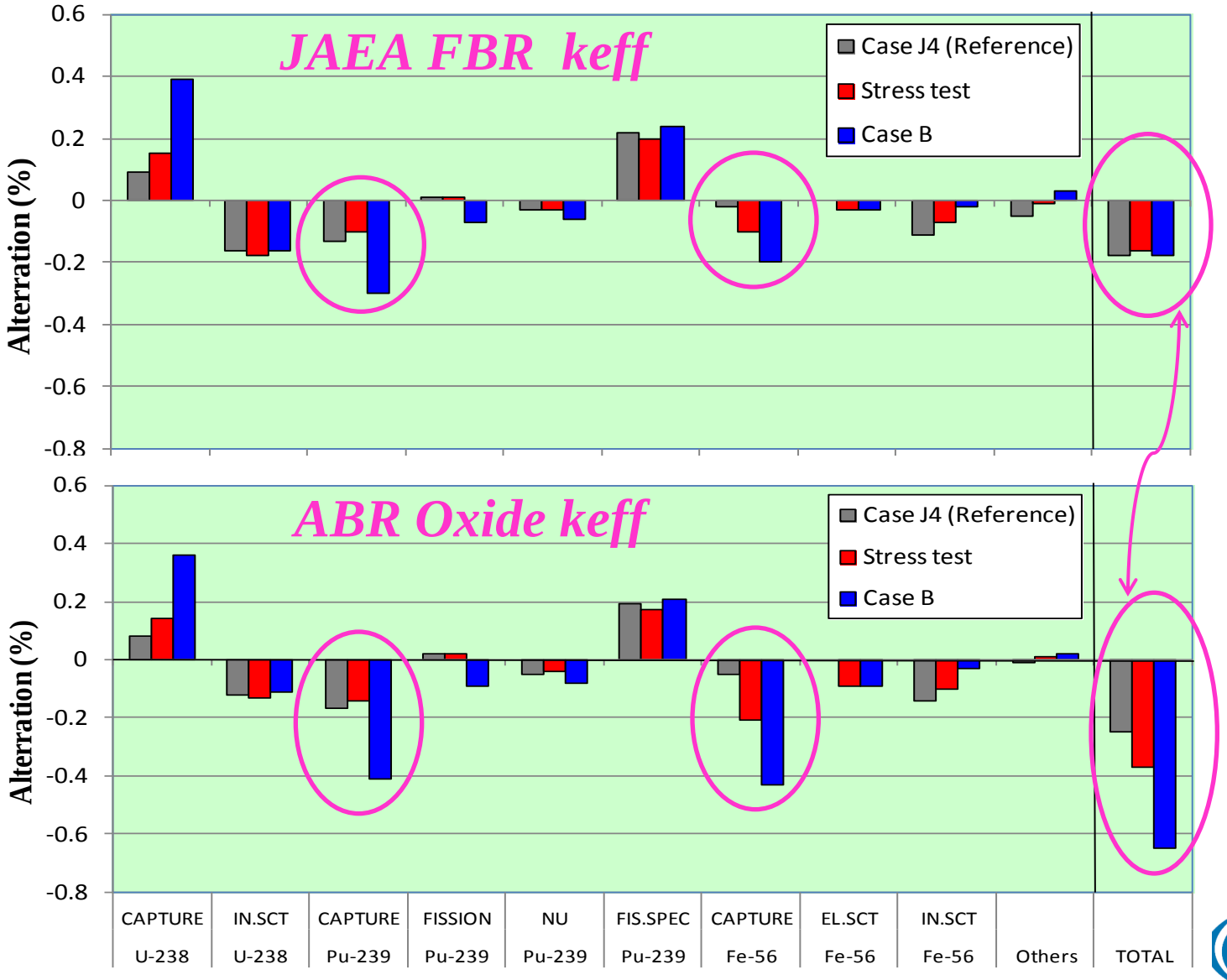
Effects for Target Core Criticality (keff)

Core	Change of keff by adjustment		
	Case J4 (Reference)	Stress test	Case B
JAEA FBR	-0.18 %Δk	-0.16 %Δk	-0.18 %Δk
ABR Oxide	-0.25 %Δk	-0.37 %Δk	-0.65 %Δk
ABR Metal	-0.22 %Δk	-0.40 %Δk	-0.55 %Δk

⇒ **To JAEA FBR, there are no effects with adjustment cases, on the other hand, to ABR Oxide core, the core of Stress test, ZPR-9/34, affect its keffby 100pcm, but Case B changes by 400 pcm, compared with Reference case J4.**

Contribution to keff Change of Target Cores

JAEA FBR vs. ABR Oxide



The differences of keff changes between JAEA FBR and ABR Oxide cores among adjustment cases caused by the differences of sensitivity to Pu-239 and Fe-56 captures.

Concluding Remarks

1. **In Stress test, the overestimation to keff of ZPR-9/34 (+1,400pcm) was successfully adjusted with no harm to the standard 20 integral data and the nuclear data based on JENDL-4.**

   → ***It is judged that "Stress test" of the SG33 adjustment exercise was passed to demonstrate its robustness.***

2. **In the extreme Case B (+3,400pcm), some cross-sections were changed unacceptably exceeding their STD ranges, though the all C/E values seemed to be successfully adjusted at a glance.**

   → ***It is necessary to eliminate some abnormal integral data in the adjustment procedure. A proposal of the measure is that the ratio of*** $|C/E-1|$ ***to the total error (=*** $\sqrt{GMG^t+Ve+Vm}$ ***), must be less than 1.5 ~ 2.***

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 $GMG^t \ll Ve+Vm$, $T' \fallingdotseq T_0$ and $GM'G^t \fallingdotseq GMG^t$

✓If $GMG^t \gg Ve+Vm$, $GM'G^t \fallingdotseq Ve+Vm$

✓If $GMG^t \fallingdotseq Ve+Vm$, $GM'G^t \fallingdotseq 1/2 \times GMG^t$

- 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
M : Covariance before adjustment
Re : Measured values of integral experiments
Rc : Analytical values of integral experiments
Ve : Experimental errors of integral experiments
Vm : Analytical modeling errors of integral experiments
G : Sensitivity coefficients, $(dR/R)/(d\sigma/\sigma)$