Benchmark calculations for reflector effect in fast cores by using the latest evaluated nuclear data libraries

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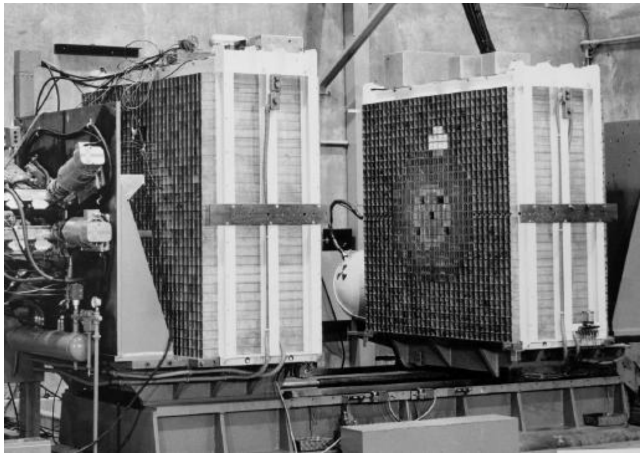
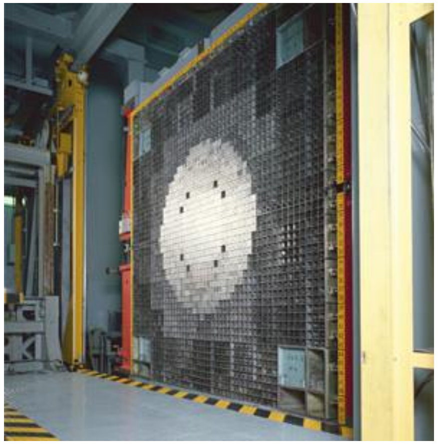
Outline

- Introduction
- Specification of benchmark cores
  (two ZPR cores, two FCA cores)
- Benchmark tests
- Sensitivity analyses
- Conclusion

ZPR-3



FCA



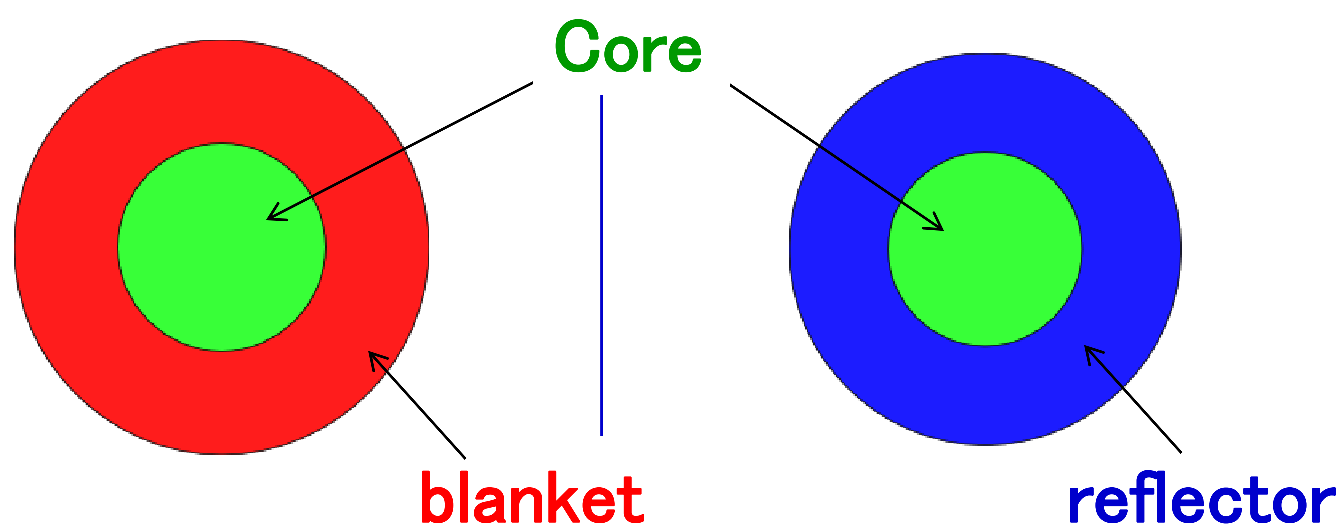
Introduction

- ✓ Impact of scattering angular distributions and scattering cross sections on k_{eff} values has been recently pointed out for small fast reactor cores with reflector.

- ✓ In WPEC of OECD/NEA, the subgroup 35 has been proposed for scattering angular distribution in the fast energy.

⇒ Benchmark calculations for **reflector effects** in fast cores by using the latest evaluated nuclear data libraries, JENDL-4.0(J40), ENDF/B-VII.1(E71), JEFF-3.1.2 (F312)

Specification of benchmark cores (ZPR)

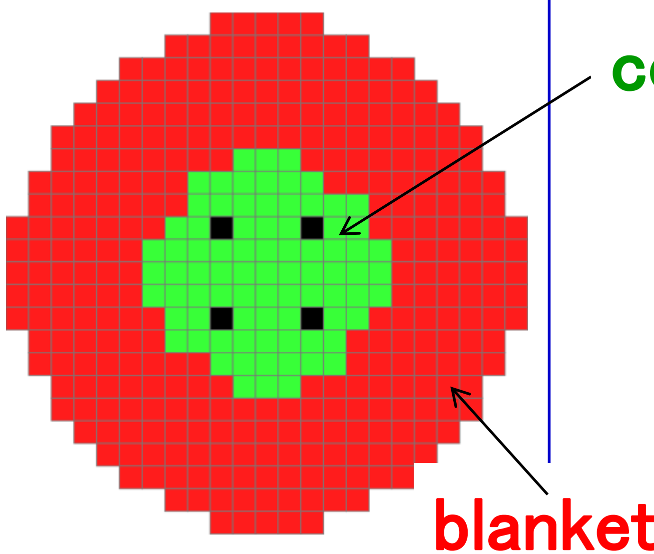
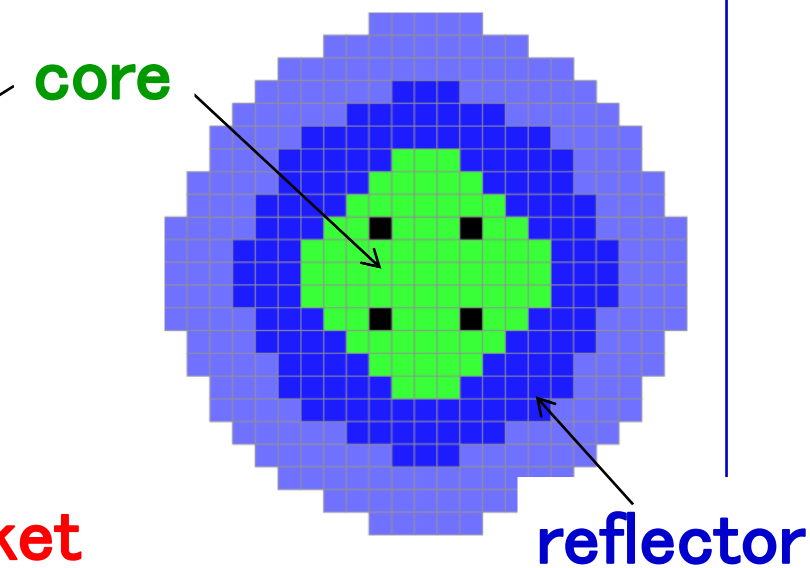
Core	ZPR-3/53	ZPR-3/54
Fuel region	Pu + Depleted U (Pu:40wt%)	
Radius	34.36 cm	32.08 cm
Radial region Thickness	Depleted U Blanket 34.14 cm	Iron Reflector 32.61 cm
Cross-sectional view RZ model ICSBEP		

Specification of benchmark cores (ZPR)

(atomic density × 10^{22}/cc)

Nuclide	ZPR-3/53 (Blanket)	ZPR-3/54 (Iron reflector)
U-235	0.008	—
U-238	3.993	—
C	0.001	0.056
Si	0.006	0.006
Cr	0.111	0.114
Mn	0.004	0.055
Fe	0.452	7.471
Ni	0.045	0.046

Specification of benchmark cores (FCA)

Core	FCA X-1	FCA X-2
Fuel region	Pu + Low enriched U (Pu:28wt% / ^{235}U:12wt%)	
Radius (cm)	28.71 cm	28.03 cm
Radial region Thickness	Depleted U Blanket 33.03 cm	SS+Na Reflector 33.71 cm
Cross-sectional view XYZ as-built model		

Specification of benchmark cores (FCA)

(atomic density × 10^{22}/cc)

Nuclide	FCA X-1 (Blanket)	FCA X-2 (SS+Na Reflector)
U-235	0.008	—
U-238	4.020	—
Na	—	0.574
C	—	0.016
Cr	0.181	1.159
Mn	0.012	0.063
Fe	0.647	4.022
Ni	0.079	0.511

Benchmark tests

Benchmark Models for k_{eff} values

ZPR cores : **RZ models** given in ICSBEP handbook

Uncertainties in k_{eff} are up to 0.27%Δk/k

(Correction factors in ICSBEP are adopted for transformation of k_{eff} from RZ models to as-built ones)

FCA cores : **As-built models** with heterogeneous cell structure in 3-dimensional geometry

Uncertainties in k_{eff} are less than 0.1%Δk/k

Code: Continuous energy Monte Carlo code MVP

Statistical uncertainties are less than 0.01%Δk/k

Benchmark tests

Assumption

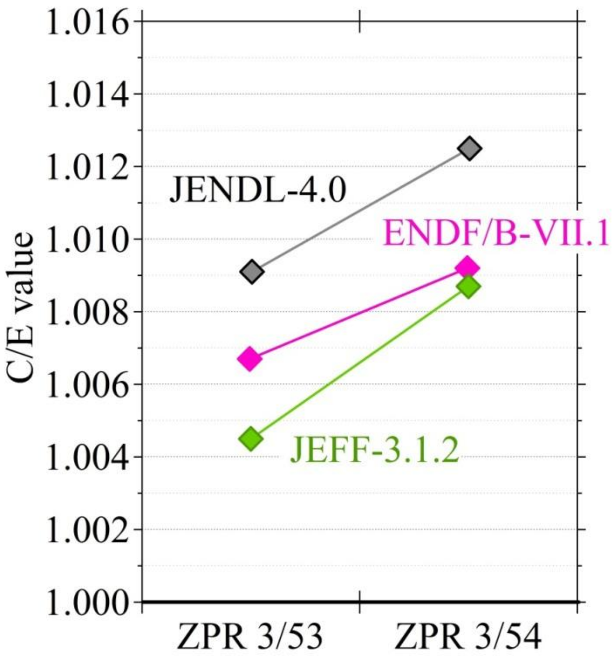
1. Since fuel components are the same between core with blanket and that with reflector, uncertainty in replacement reactivity from blanket to reflector can be assumed to be much less than that in k_{eff} values.

2. For ZPR tests, we assume that correction factors given for ENDF library in ICSBEP can be applied for calculations by all libraries.

Available to test replacement reactivity

- ZPR: U-238 blanket ⇒ Iron reflector
- FCA: U-238 blanket ⇒ SS and Na reflector

Benchmark tests (C/E values for ZPR cores)

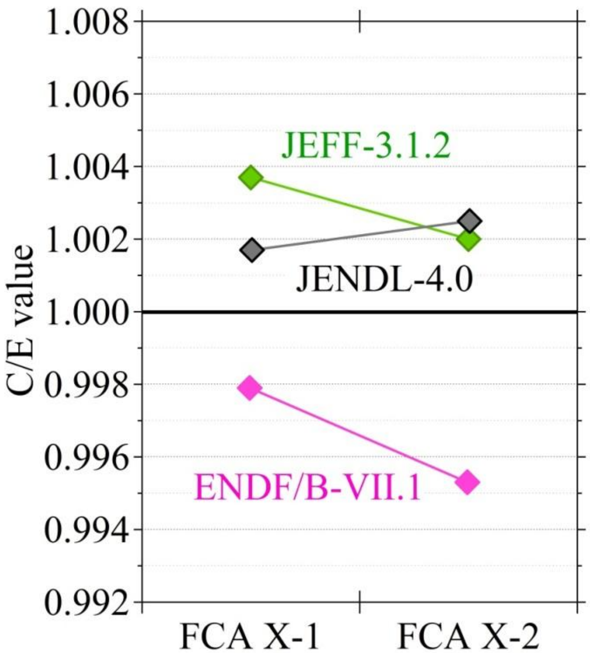


libraries	ZPR -3/53	ZPR -3/54	Difference*
JENDL-4.0	1.0091	1.0125	0.34%
ENDF/B-VII.1	1.0067	1.0092	0.25%
JEFF-3.1.2	1.0045	1.0087	0.42%

* Difference of C/E between ZPR-3/53 and -3/54

C/E values by all libraries commonly increase by replacing ZPR-3/53 with -3/54, which means **overestimations of replacement reactivity from blanket to iron reflector.**

Benchmark tests (C/E values for FCA cores)



libraries	FCA X-1	FCA X-2	Difference*
JENDL-4.0	1.0017	1.0025	0.08%
ENDF/B-VII.1	0.9979	0.9953	-0.26%
JEFF-3.1.2	1.0037	1.0020	-0.17%

* Difference of C/E between FCA X-1 and X-2

By JENDL-4.0, stable tendency of C/E values by replacing FCA X-1 with X-2 means that **replacement reactivity from blanket to SS and Na reflector agrees with experimental value.**

The other libraries underestimate the replacement reactivity.

Sensitivity analyses

Code: Generalized perturbation code SAGEP based on diffusion theory

Sensitivity coefficients based on JENDL−4.0

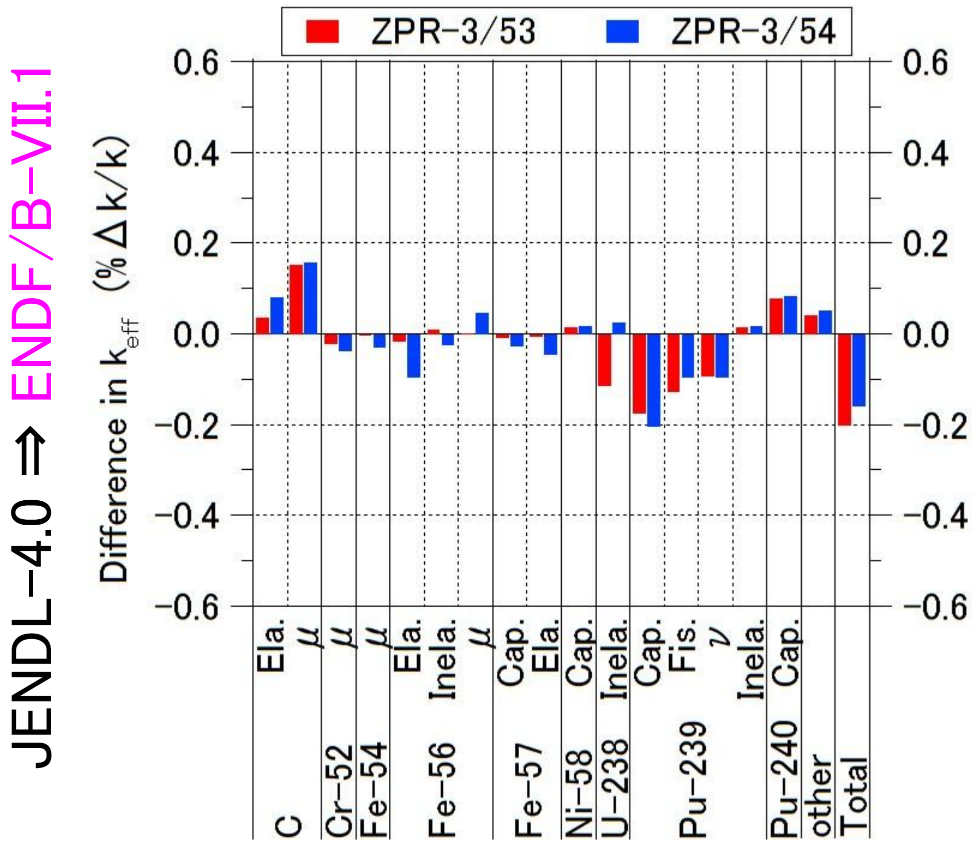
$$S_{m,x,g} = \left(\frac{dk/k}{d\sigma_{m,x,g}/\sigma_{m,x,g}}\right)_{\boldsymbol{J40}}$$

Here, x, m and g denote reaction type, nuclide and energy group, respectively.

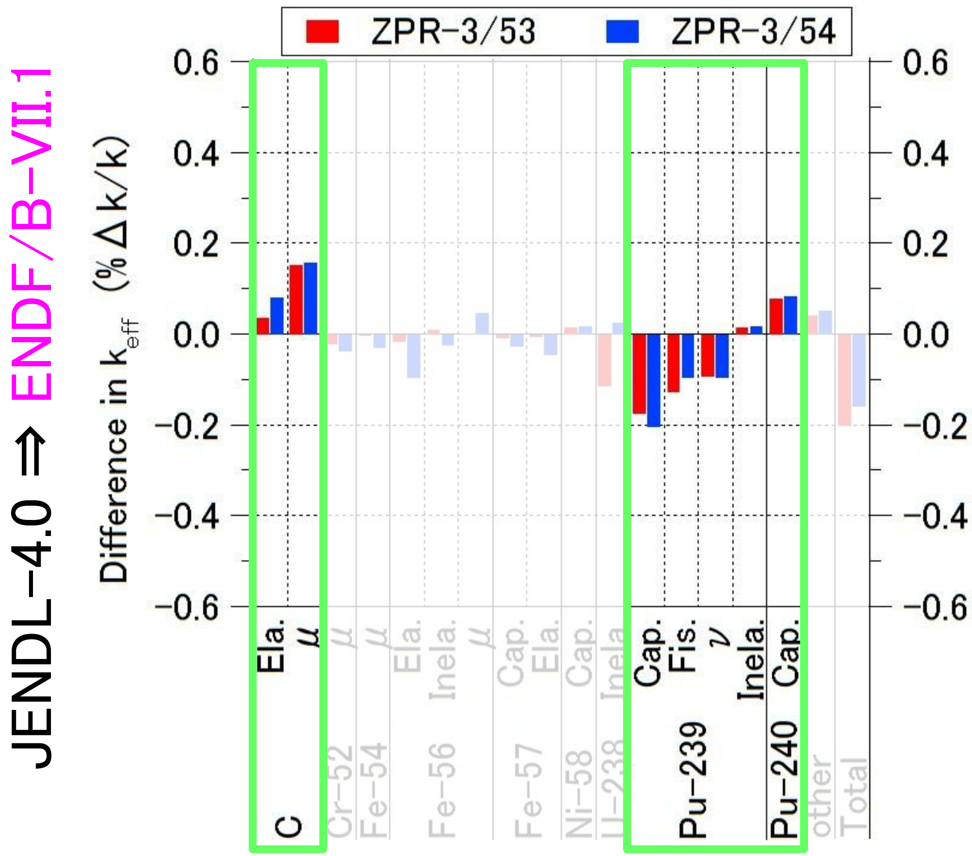
Differences in k_{eff} from JENDL−4.0 to other libraries

$$\left(\frac{dk_{eff}}{k_{eff}}\right)_{\boldsymbol{J40\rightarrow other}} = \sum_{m,x}\sum_{g} S_{m,x,g}\frac{\sigma_{m,x,g,\boldsymbol{other}} - \sigma_{m,x,g,\boldsymbol{J40}}}{\sigma_{m,x,g,\boldsymbol{J40}}}$$

Sensitivity analyses (ZPR cores)



Sensitivity analyses (ZPR cores)



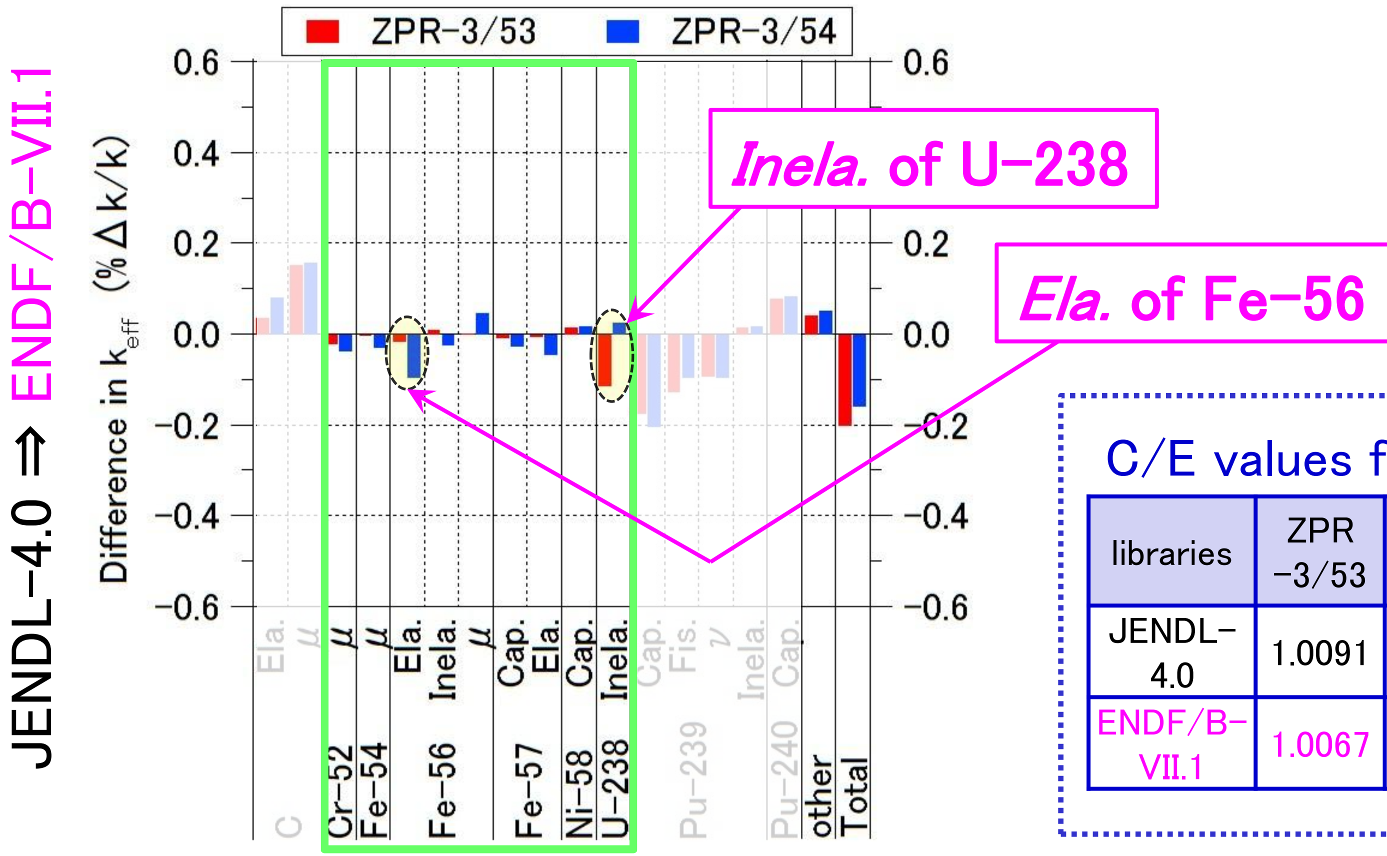
Since fuel regions of the ZPR cores include **Pu and C** in common, their sensitivities and contributions are similar.

C/E values for ZPR cores

libraries	ZPR −3/53	ZPR −3/54	Difference
JENDL−4.0	1.0091	1.0125	0.34%
ENDF/B−VII.1	1.0067	1.0092	0.25%

Replacement reactivity from blanket to iron reflector is affected mainly by other nuclides such as **U−238 and Fe**, and **these overestimations of replacement reactivity are mainly due to U−238 and Fe.**

Sensitivity analyses (ZPR cores)

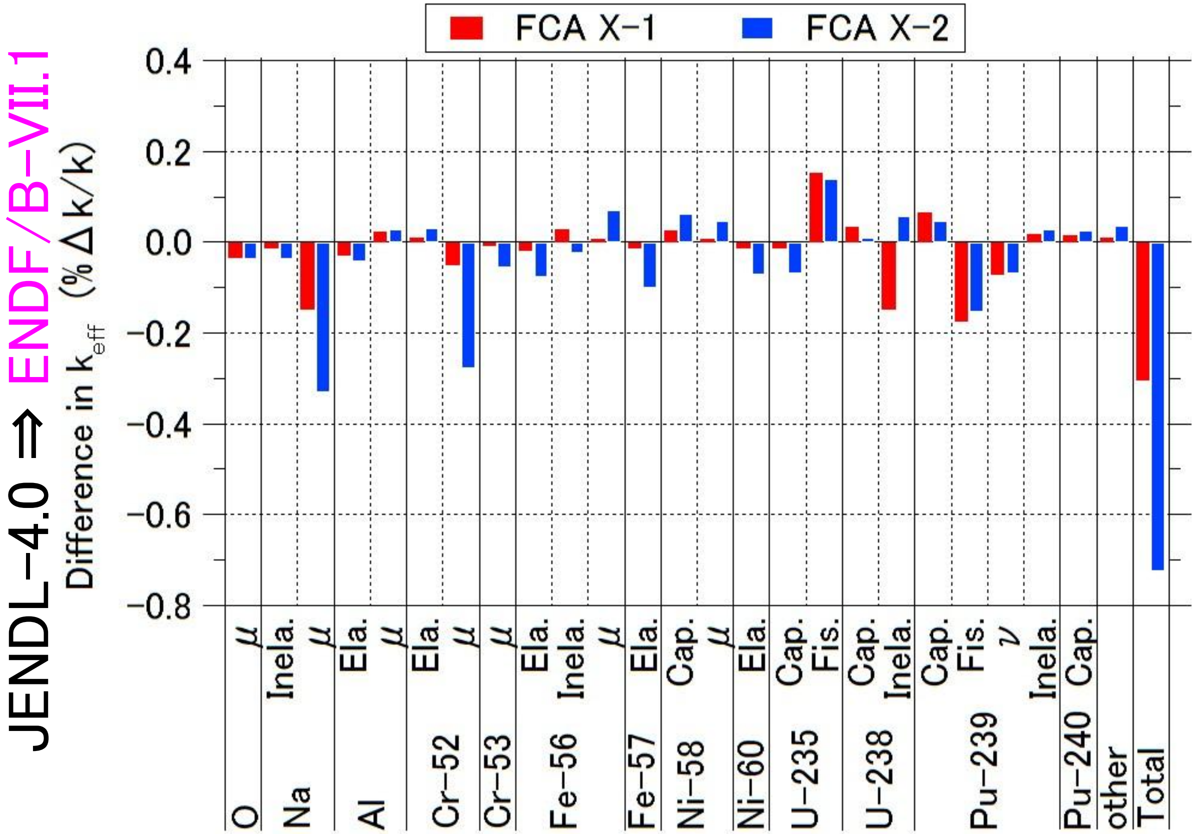


C/E values for ZPR cores

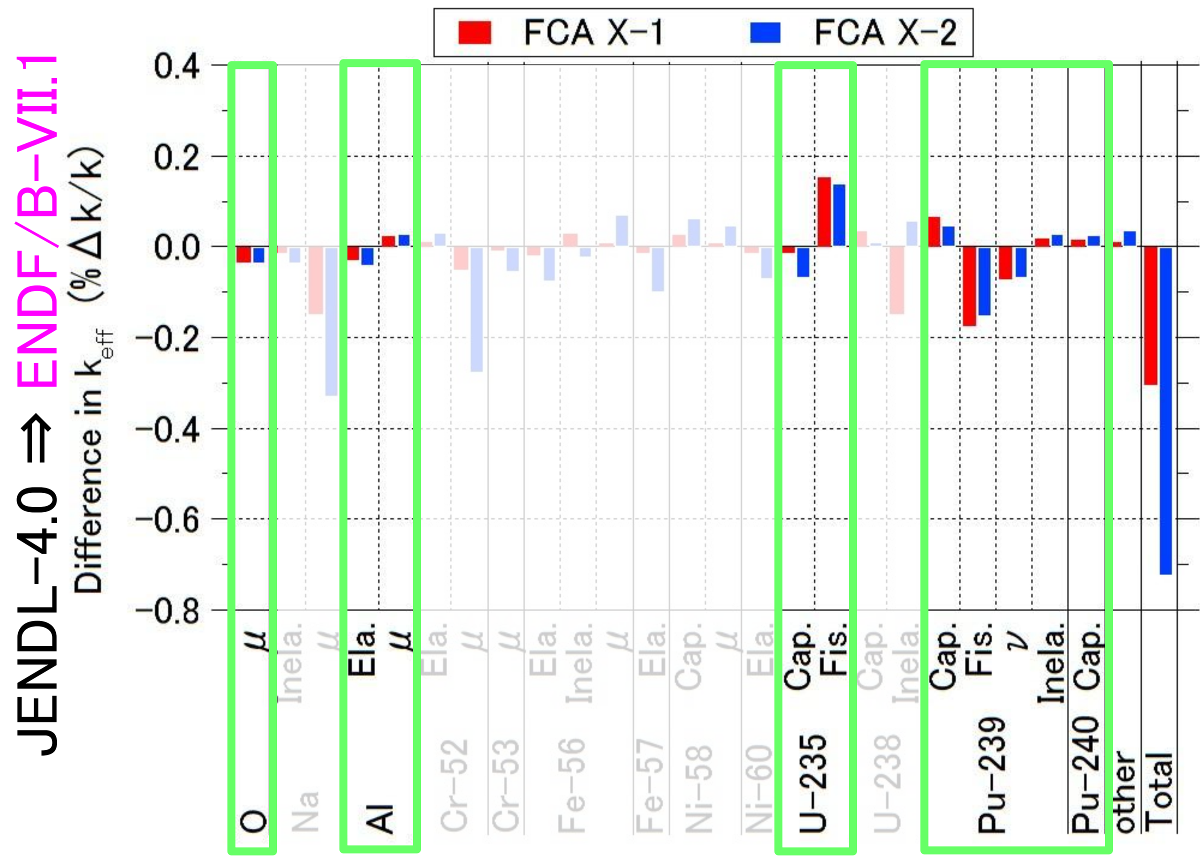
libraries	ZPR −3/53	ZPR −3/54	Difference
JENDL−4.0	1.0091	1.0125	0.34%
ENDF/B−VII.1	1.0067	1.0092	0.25%

Although inelastic of U−238 and elastic of Fe−56 have different contributions, they cancel out in total difference. Therefore, these libraries have a similar tendency of C/E.

Sensitivity analyses (FCA cores)



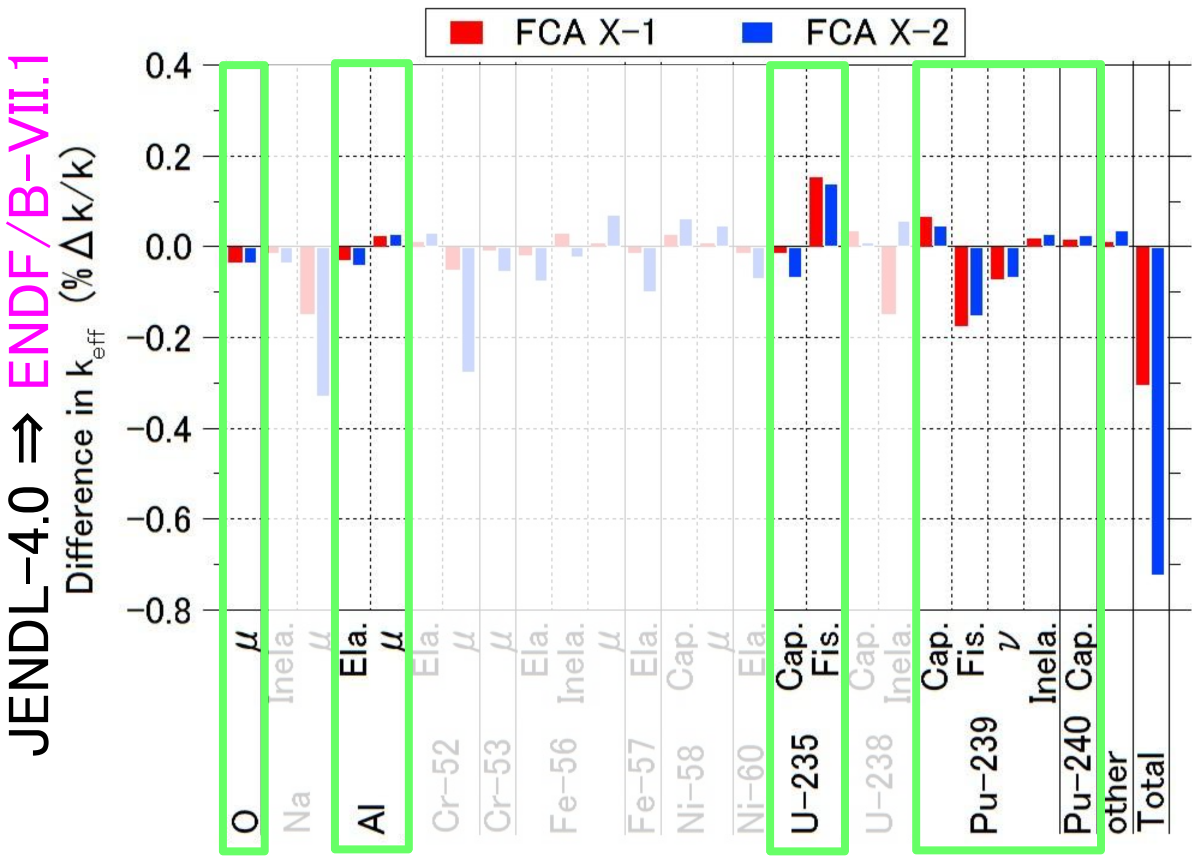
Sensitivity analyses (FCA cores)



Since fuel regions of FCA X-1 and X-2 include **O, Al, U-235 and Pu** in common, their sensitivities and contributions are similar.

Replacement reactivity from blanket to SS and Na reflector is affected mainly by other nuclides such as **Na, Cr, Ni, Fe and U-238**.

Sensitivity analyses (FCA cores)



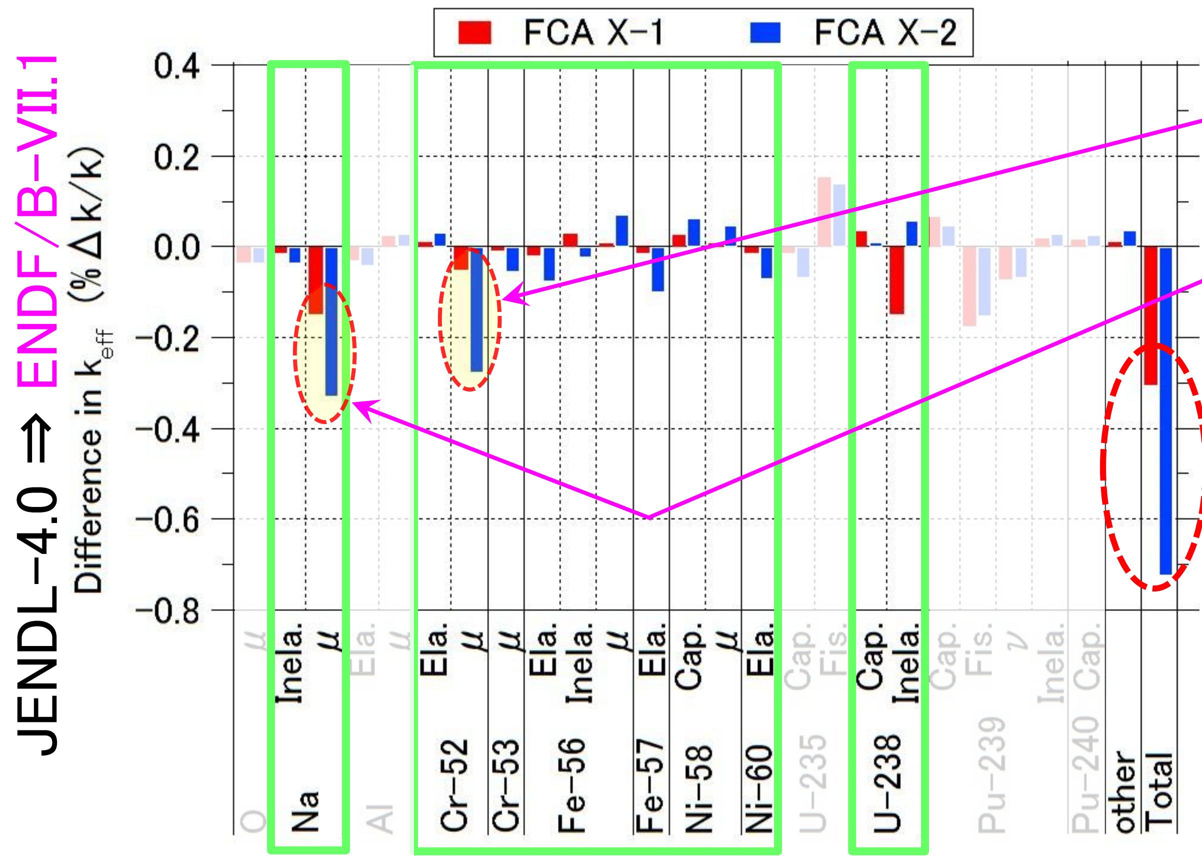
ZRP results show overestimation of replacement reactivity from blanket to iron due to U-238 and iron.

C/E values for FCA cores

libraries	ZPR -3/53	ZPR -3/54	Difference
JENDL-4.0	1.0017	1.0025	**0.08%**
ENDF/B-VII.1	0.9979	0.9953	-0.26%

From FCA and ZPR results, good agreement by JENDL-4.0 is caused by **underestimation of replacement reactivity due to Na, Cr and Ni** which offsets **overestimation due to U-238 and Fe**.

Sensitivity analyses (FCA cores)

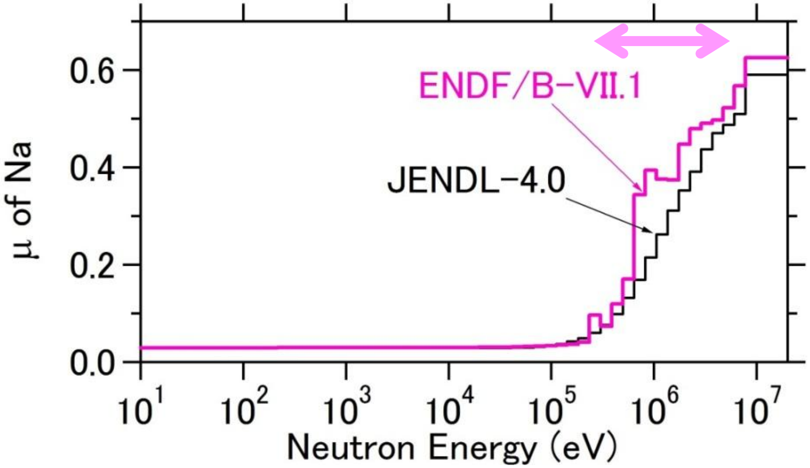


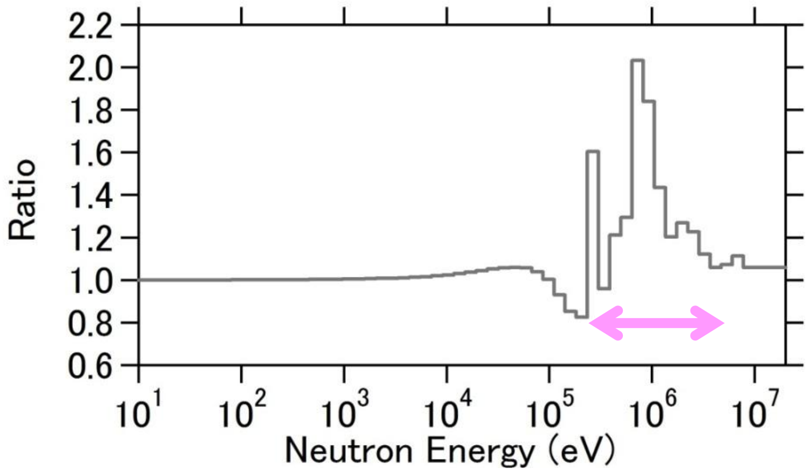
C/E values for FCA cores

libraries	ZPR -3/53	ZPR -3/54	Difference
JENDL-4.0	1.0017	1.0025	0.08%
ENDF/B-VII.1	0.9979	0.9953	**-0.26%**

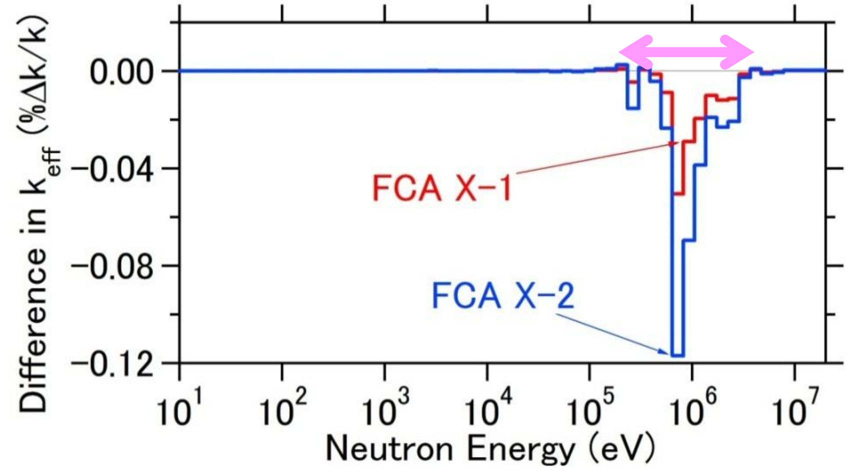
Total difference between ENDF/B-VII.1 and JENDL-4.0 increases negatively by replacing FCA X-1 with X-2, which **is caused by negative contributions of μ of Na and Cr-52.** Therefore, this leads to underestimation by ENDF/B-VII.1.

Difference of μ of Na between J40 and E71





μ of Na around 1MeV in E71 is two times larger than that in J40

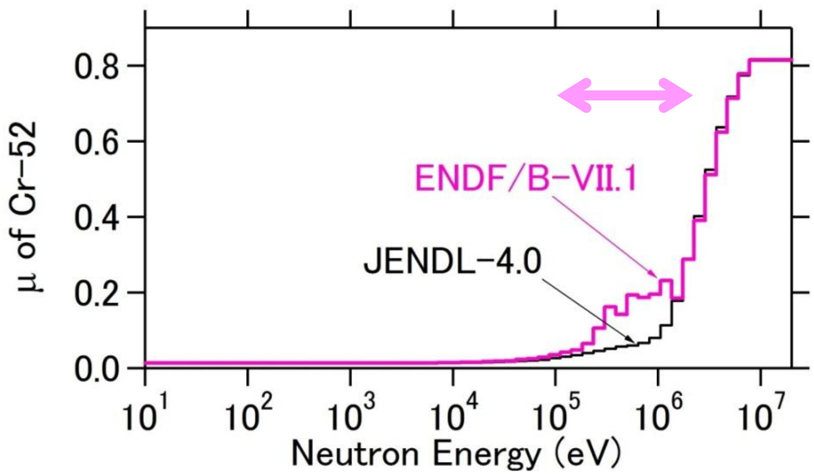


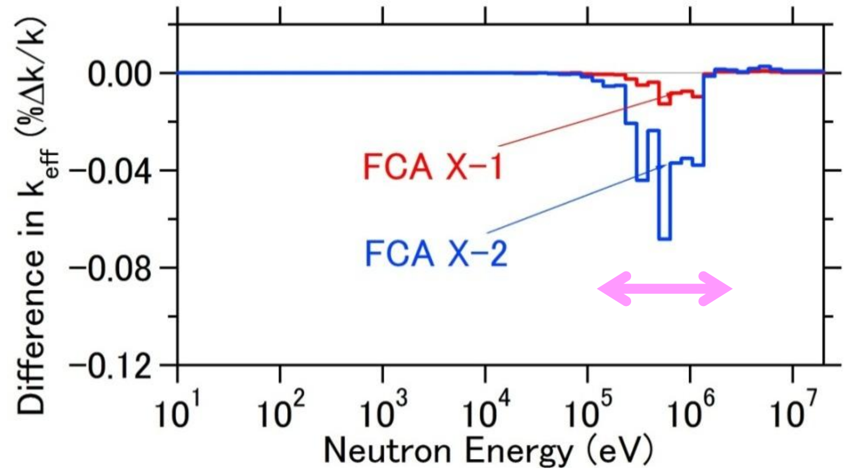
FCA X−1	FCA X−2
−0.15%	−0.33%

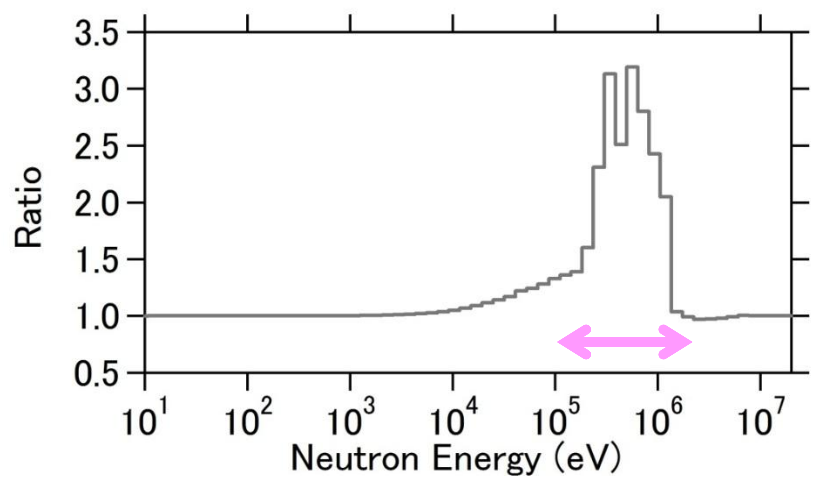
−0.18%

μ of Na contributes totally to difference by −0.18%Δk/k

Difference of μ of Cr−52 between J40 and E71







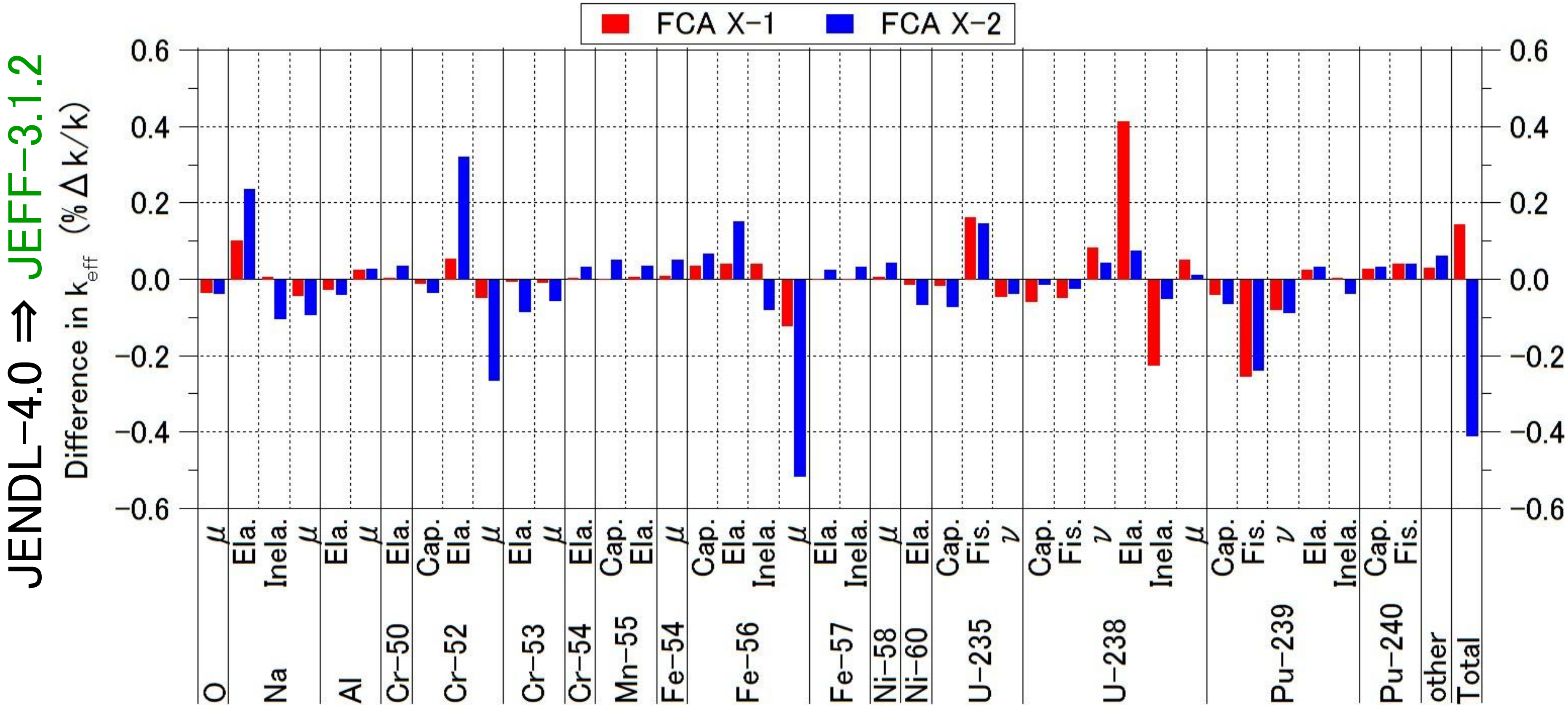
FCA X−1	FCA X−2
−0.05%	−0.28%

−0.23%

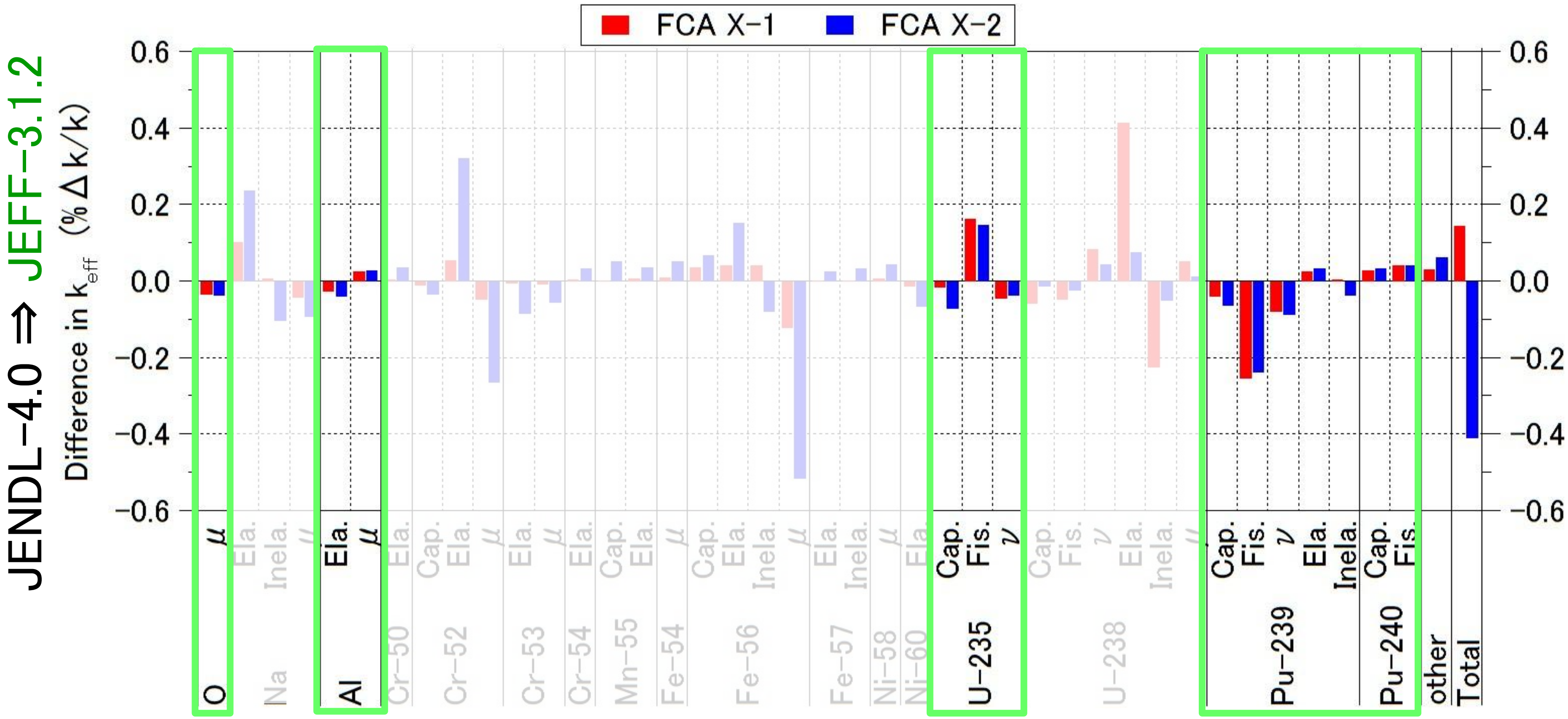
μ of Cr−52 contributes totally to difference by −0.23%Δk/k

μ of Cr−52 from few 100 MeV to 1GeV in E71 is three times larger than that in J40

Sensitivity analyses (FCA cores)

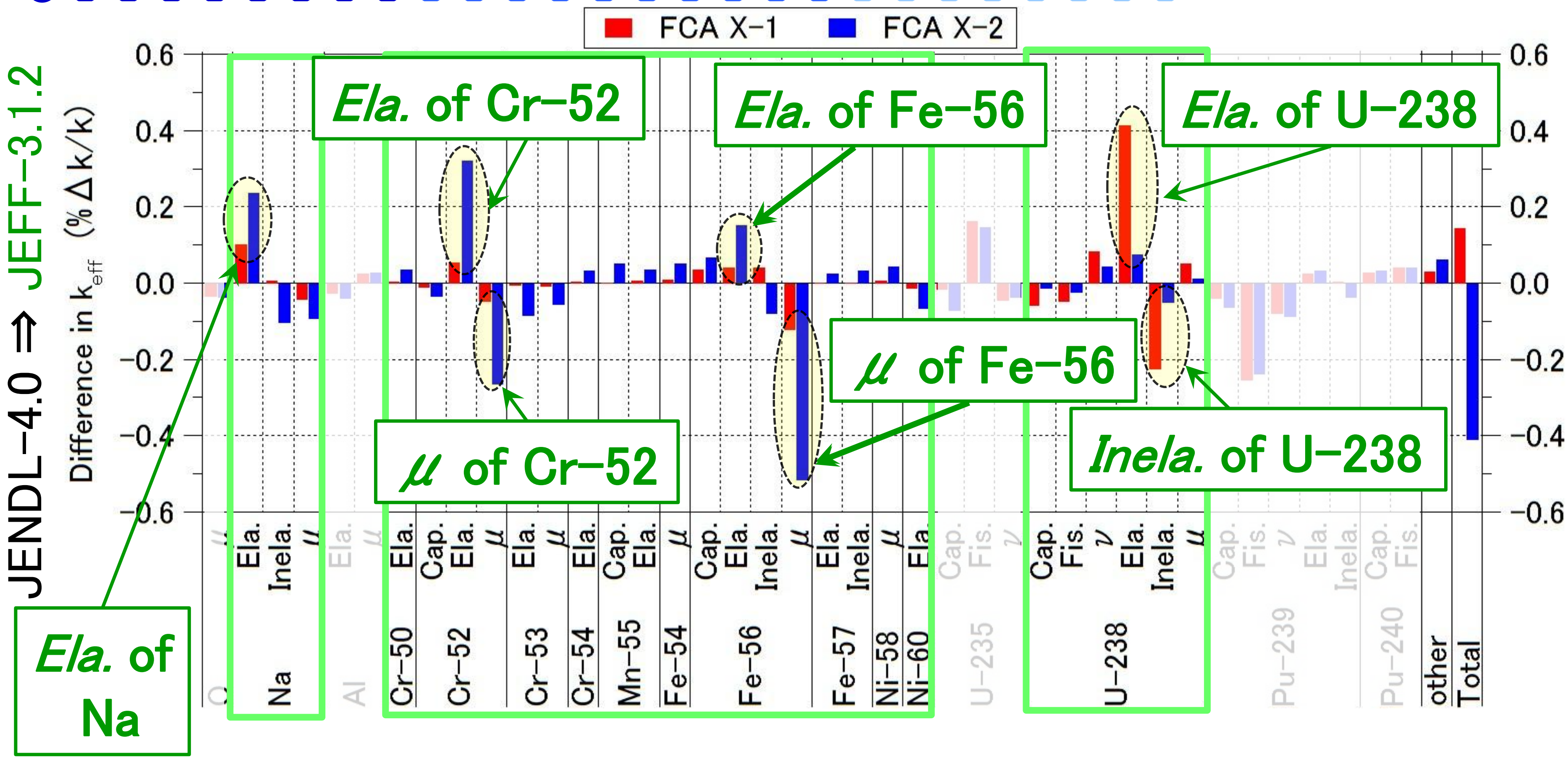


Sensitivity analyses (FCA cores)



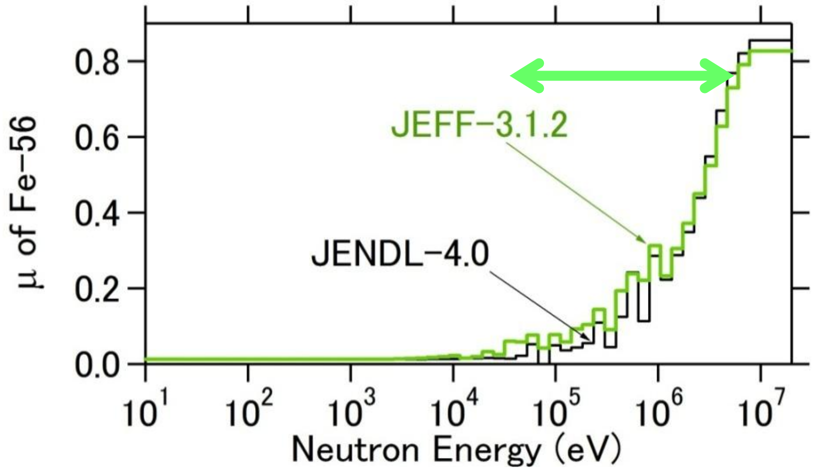
Since fuel regions of FCA X-1 and X-2 include **O, Al, U-235 and Pu** in common, their sensitivities and contributions are similar.

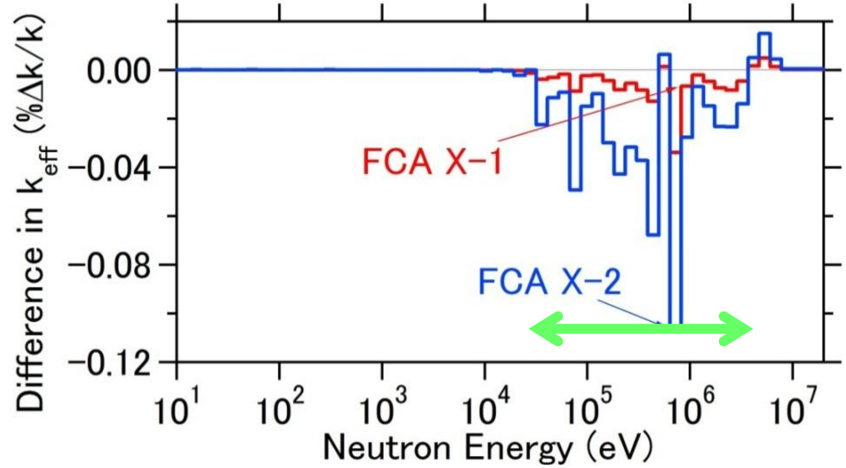
Sensitivity analyses (FCA cores)

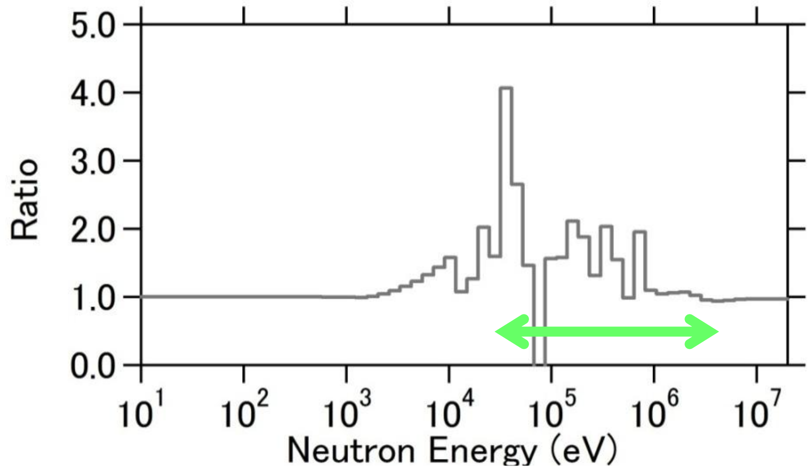


Total difference between JEFF-3.1.2 and JENDL-4.0 is due to many nuclides and reactions such as **μ of Fe-56 and Cr-52, elastic of Cr-52 and U-238.**

Difference of μ of Fe−56 between J40 and F312







FCA X−1	FCA X−2
−0.12%	**−0.52%**

−0.40%

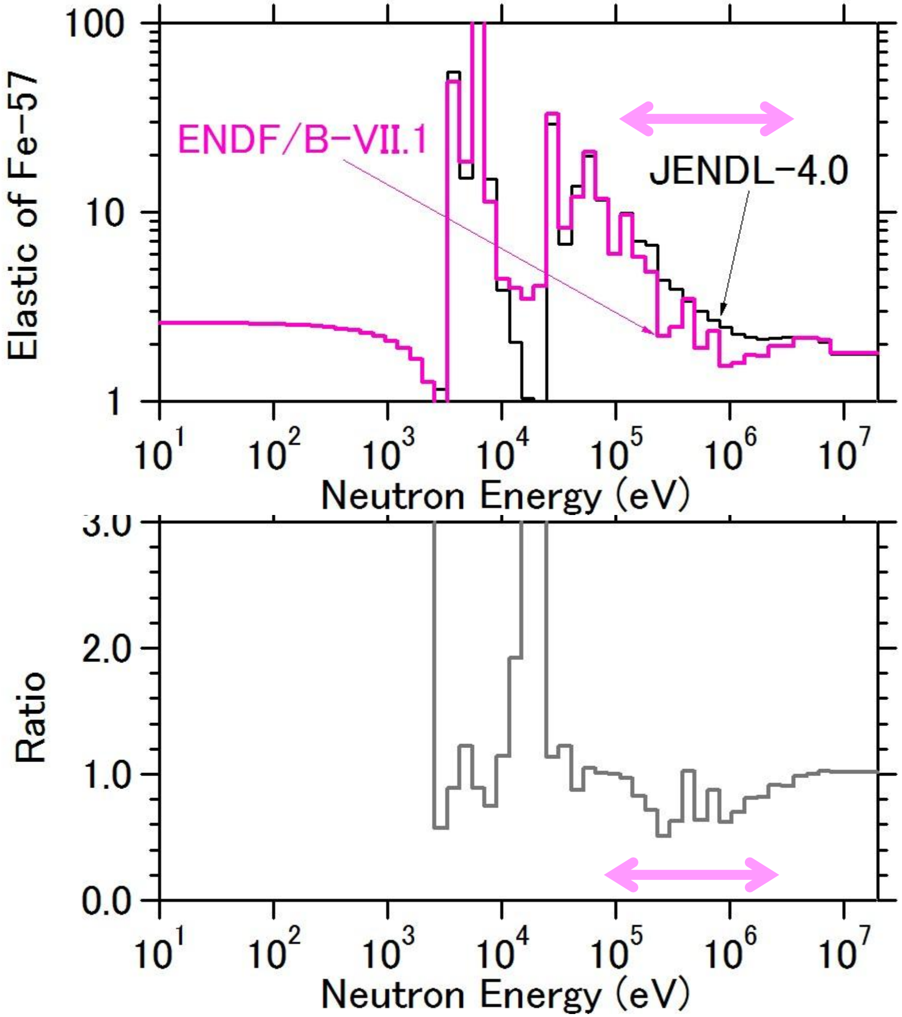
μ of Fe−56 in the wide region
in F312 is larger than that in J40

Conclusions

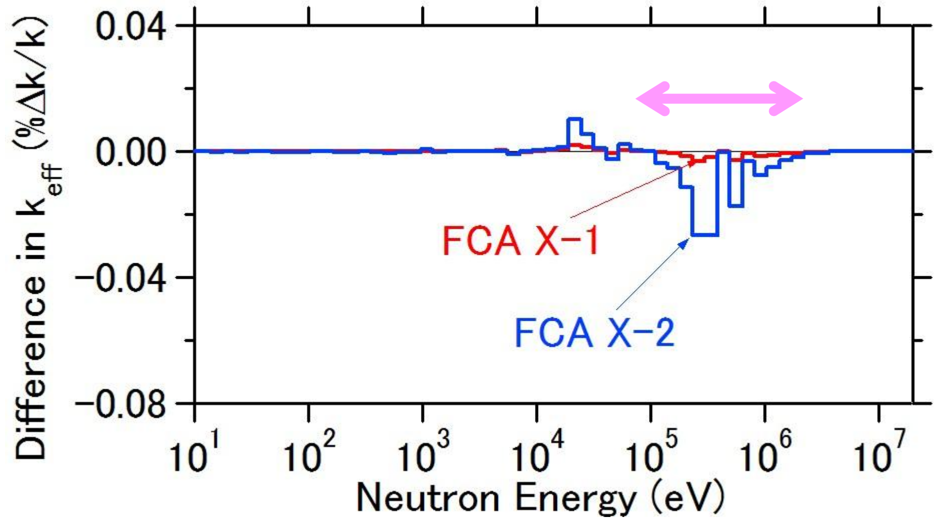
- From the ZPR results, all libraries commonly overestimate replacement reactivity from blanket to iron reflector and this is mainly due to U-238 and Fe.
- The replacement reactivity from blanket to SS and Na reflector is better evaluated by JENDL-4.0 than by the other libraries.
  - The good agreement by JENDL-4.0 is caused by the offset of the underestimation due to Na, Cr and Ni and the overestimation due to U-238 and Fe.
  - The underestimation by ENDF/B-VII.1 is caused by the negative contributions of the μ of Cr-52 and Na much larger than JENDL-4.0.
- The difference between JEFF-3.1.2 and JENDL-4.0 is due to many nuclides and reactions, and therefore, the physical mechanism seems too complicated to clearly understand.

END

Difference of *Ela.* of Fe-57 between E71 and J40



FCA cores



FCA X-1	FCA X-2
−0.01%	−0.10%

−0.09%