On Prediction Accuracy of Neutronics Parameters of Accelerator-Driven System

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Background

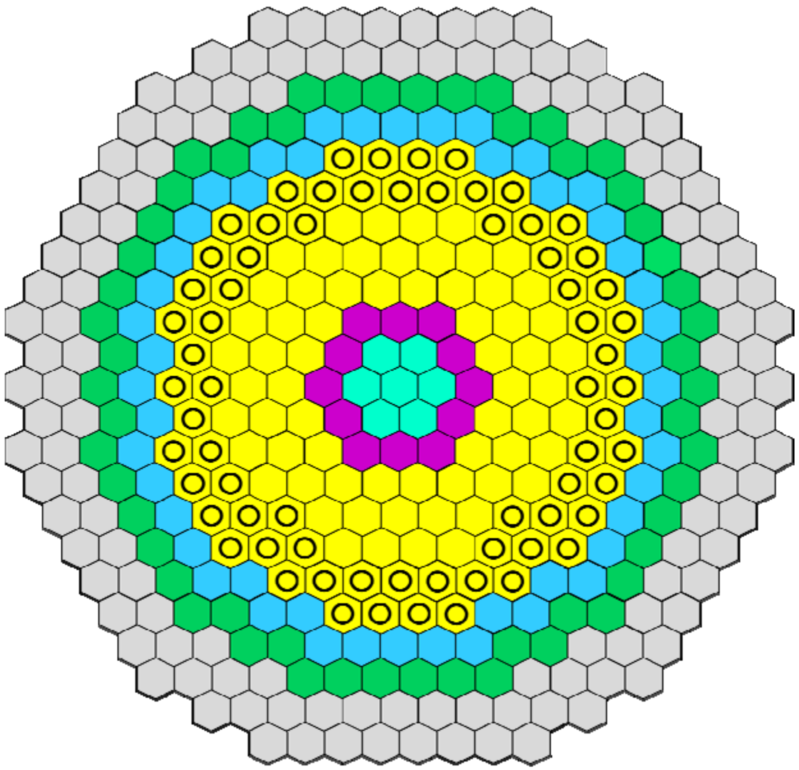
- An accelerator-driven system (ADS) can be an efficient burner of minor actinoid nuclides, such as neptunium and americium.

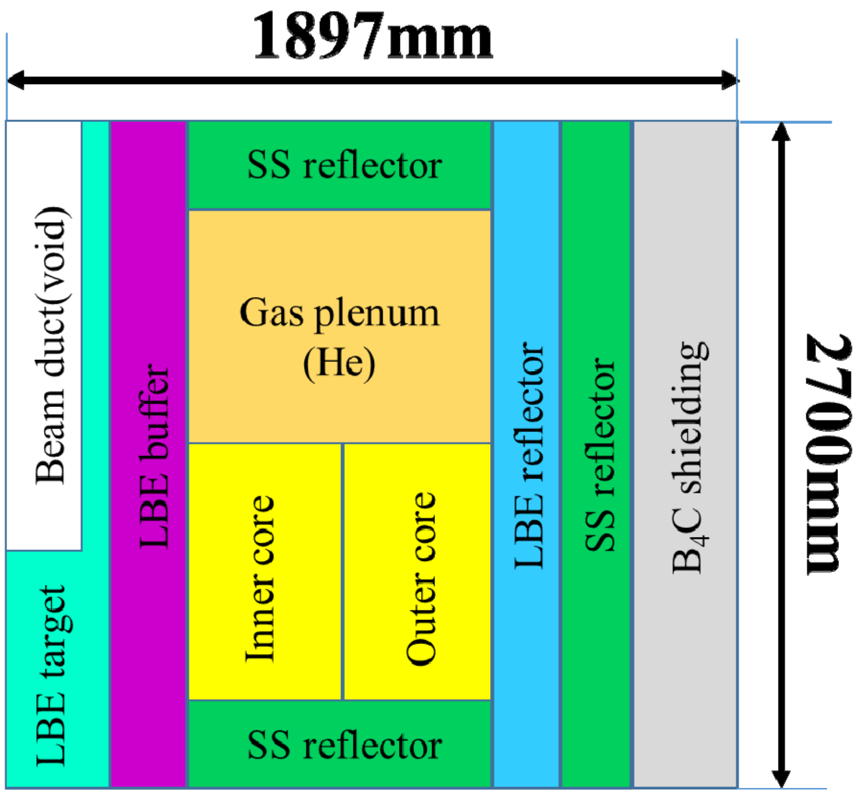
- Reliability of nuclear data used in core design calculations is one of major technical issues in the ADS development.

- Quantification and reduction of nuclear data-induced uncertainties of the ADS neutronics parameters are important.

JAEA-designed ADS

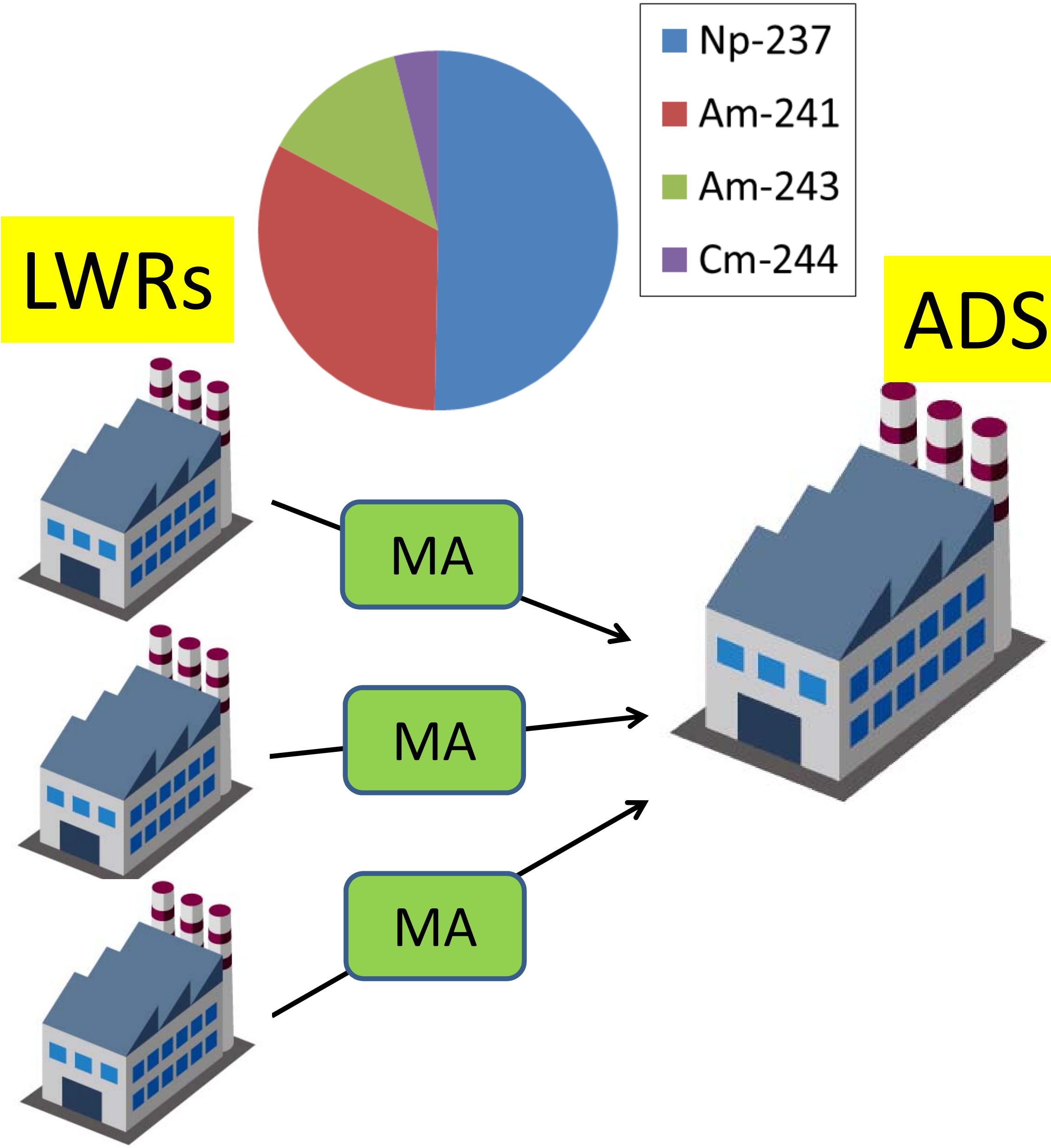
We consider the JAEA-designed lead-bismuth eutectic (LBE)-cooed ADS throughout this study.



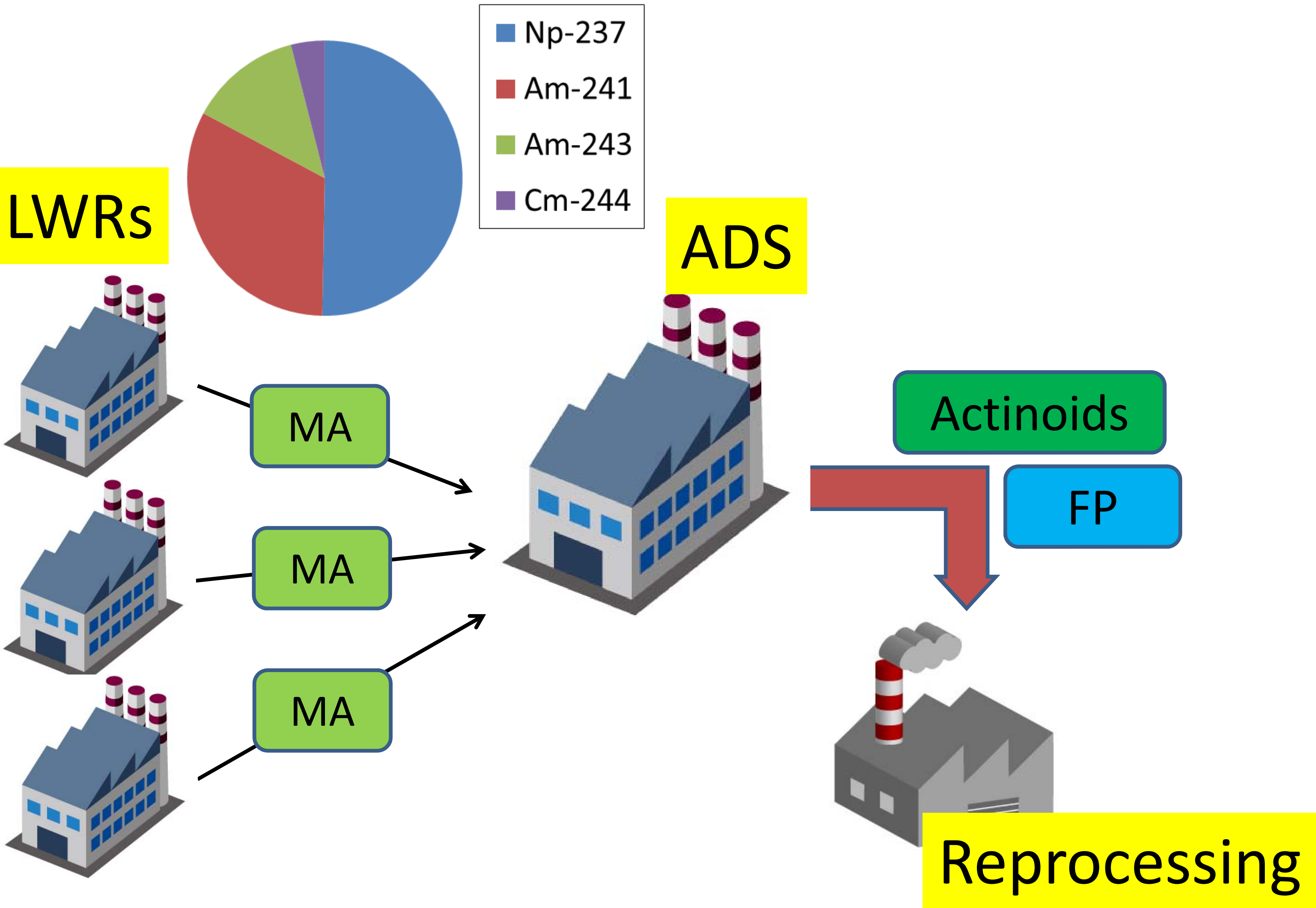


- Core thermal power : 800 MW
- Burnup period : 600 effective full power days

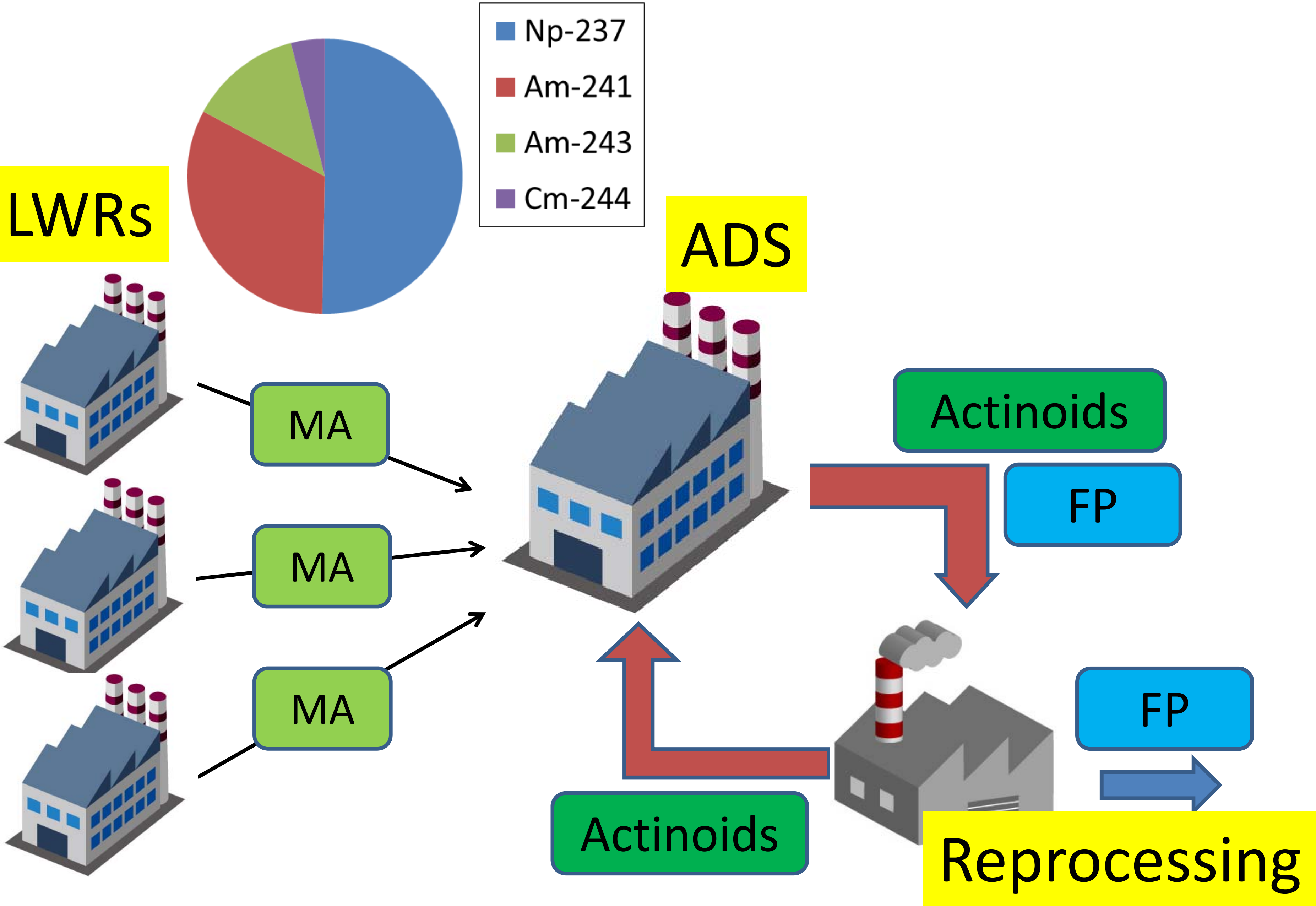
ADS fuel cycle



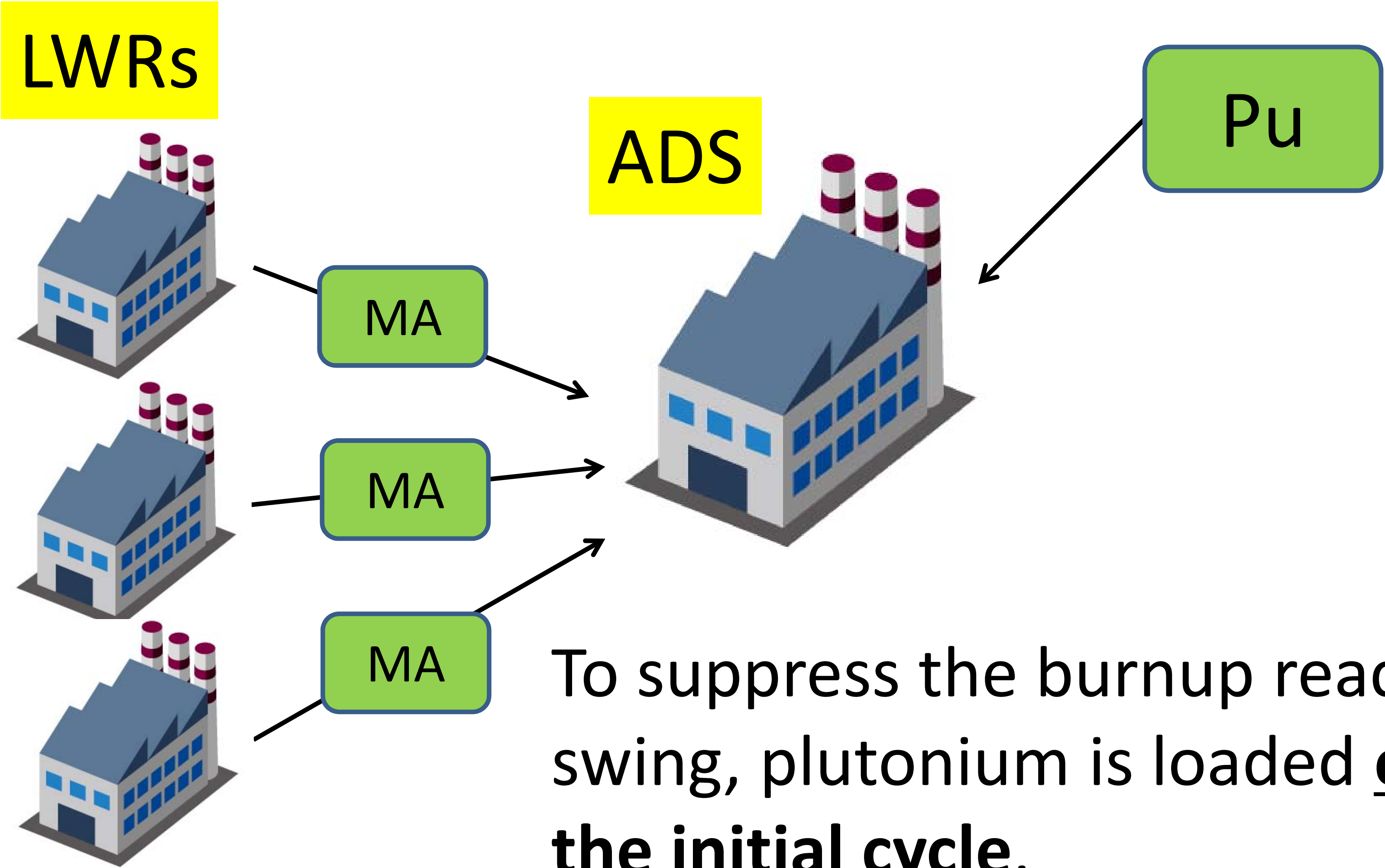
ADS fuel cycle



ADS fuel cycle



ADS fuel cycle



To suppress the burnup reactivity swing, plutonium is loaded **only at the initial cycle**.

Numerical calculations with CBZ

- All the calculations are carried out with a code system CBZ, which is under development at Hokkaido Univ.

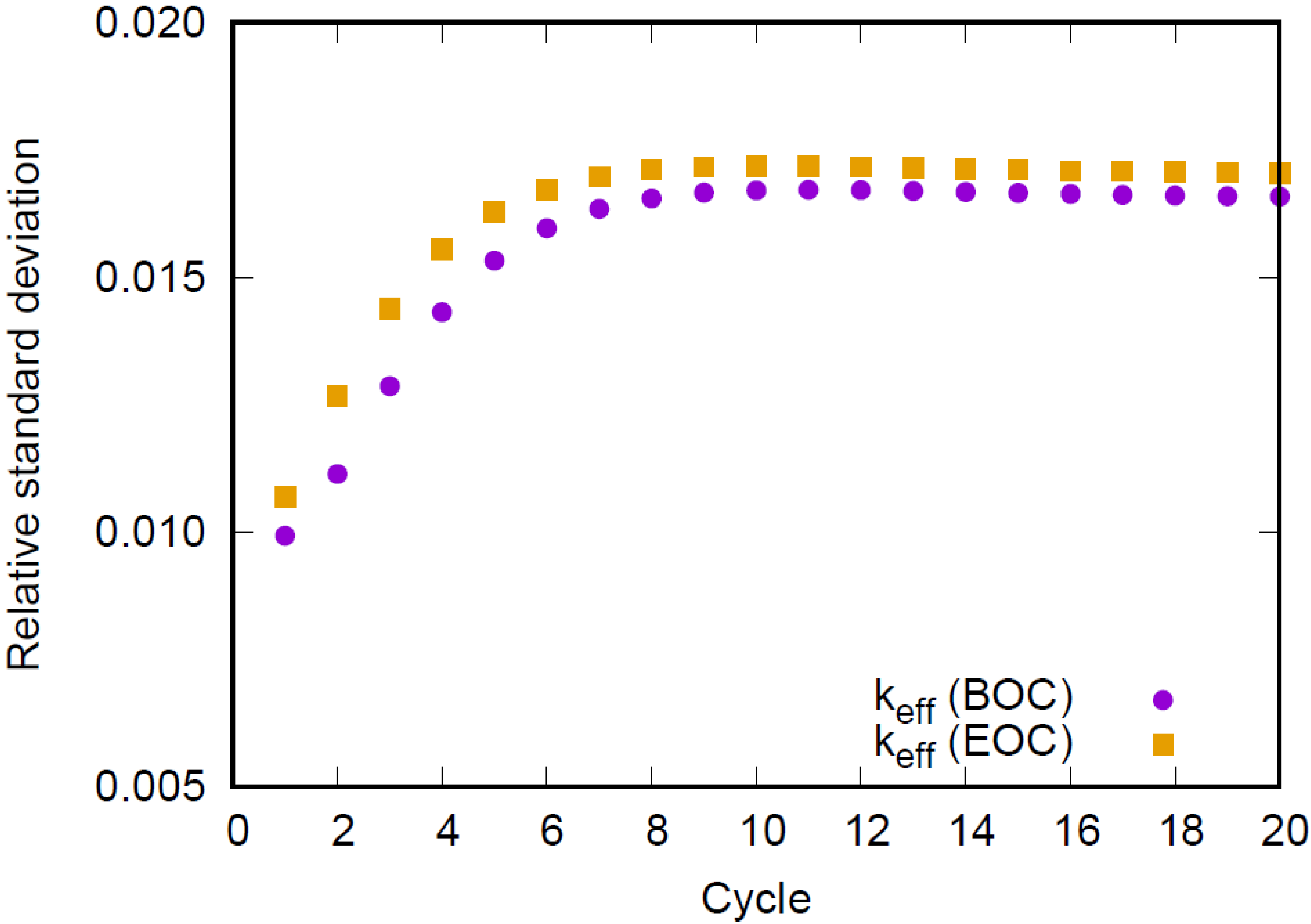
- Sensitivities of neutronics parameters with respect to the nuclear data are calculated with the (generalized) perturbation theory to perform uncertainty propagation calculations.

Burnup cycle-dependent uncertainty calculation

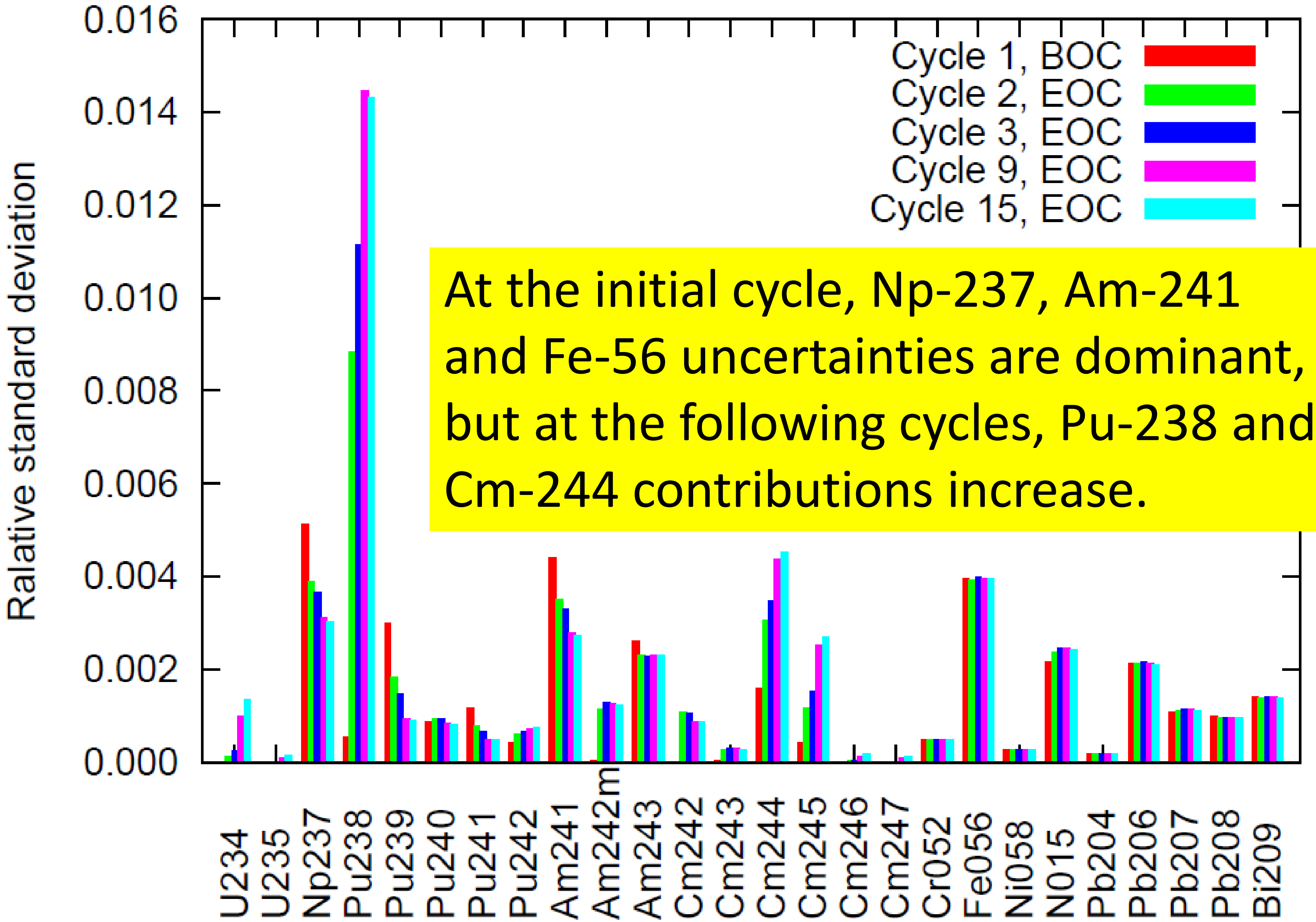
- Burnup cycle-dependent nuclear data-induced uncertainties of the ADS neutronics parameters, k_{eff}, β_{eff} and coolant void reactivity, are calculated.
- Covariance data given in JENDL-4.0 is used.

Details can be found in our paper published in *Journal of Nuclear Science and Technology* in 2016.

Uncertainty of k_{eff}

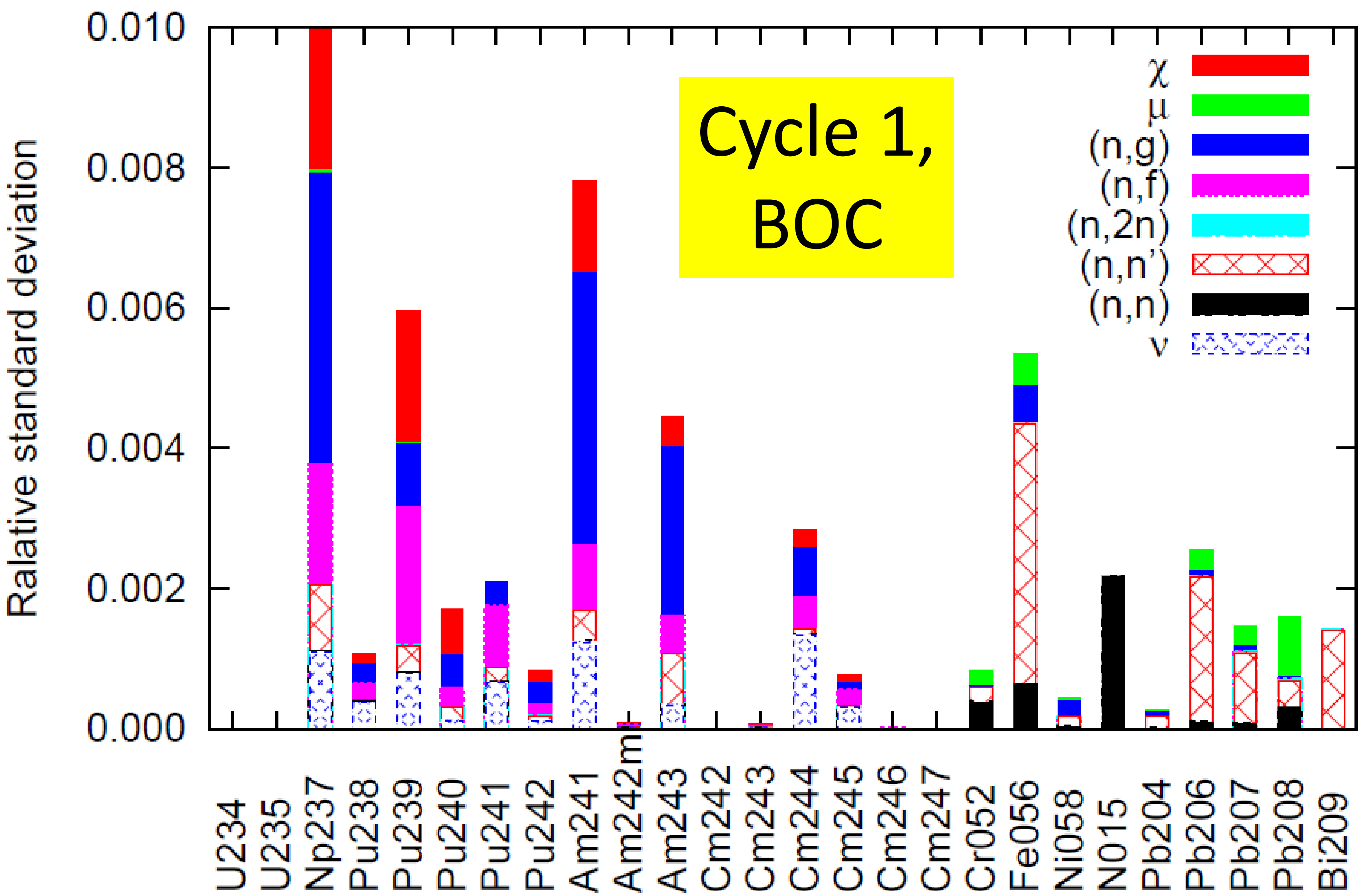


Uncertainty of k_{eff}

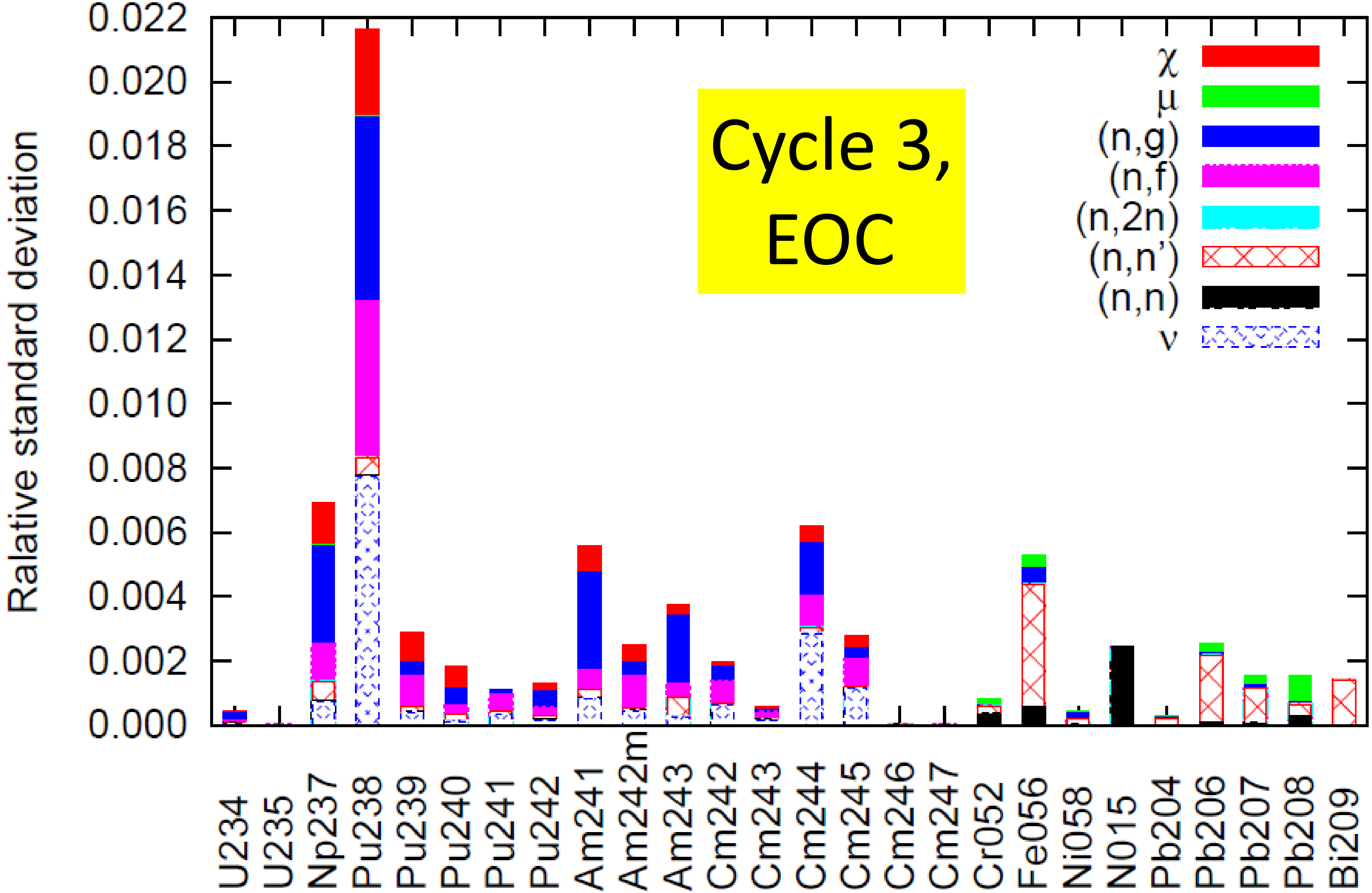


At the initial cycle, Np-237, Am-241 and Fe-56 uncertainties are dominant, but at the following cycles, Pu-238 and Cm-244 contributions increase.

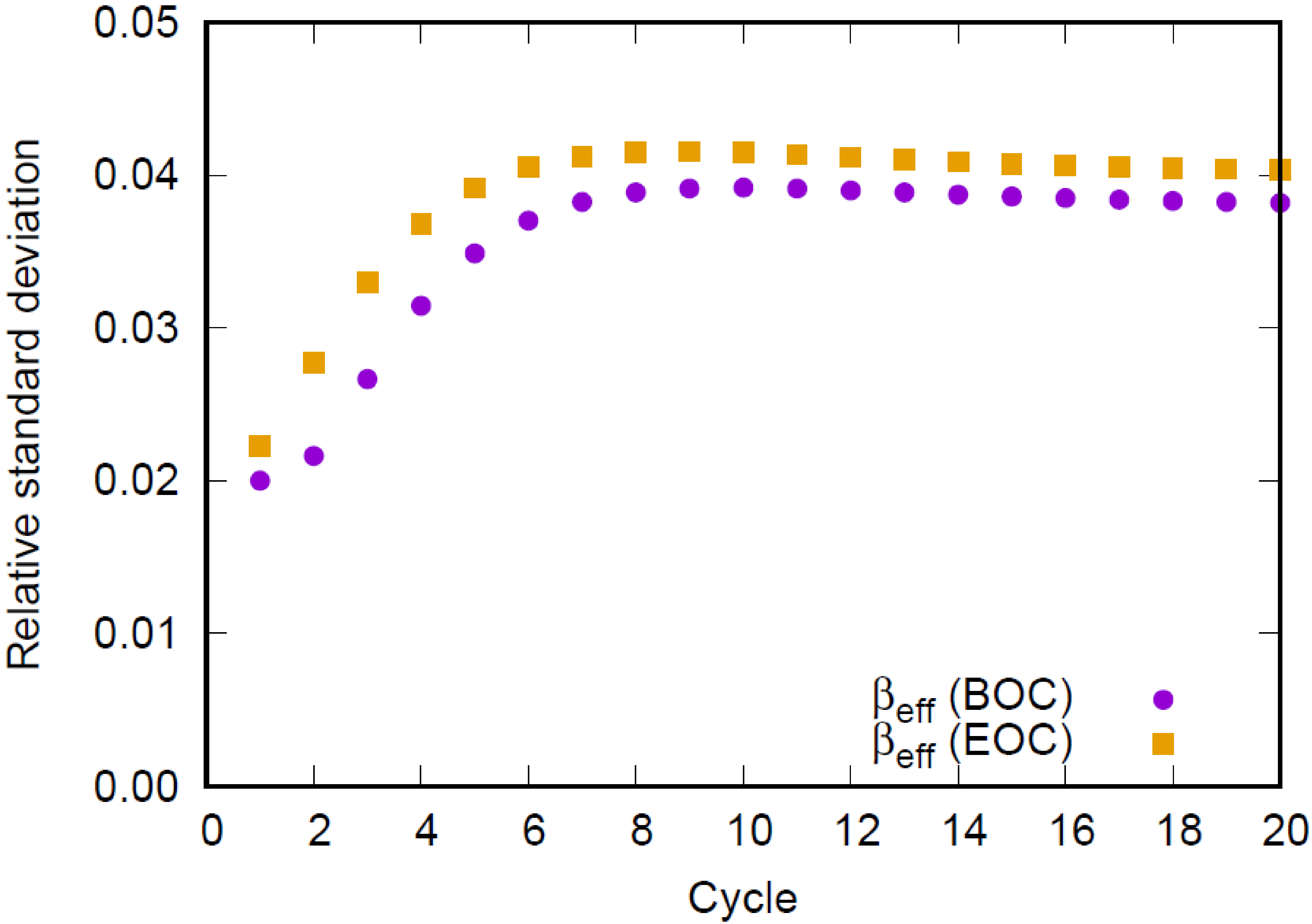
Uncertainty of k_{eff}



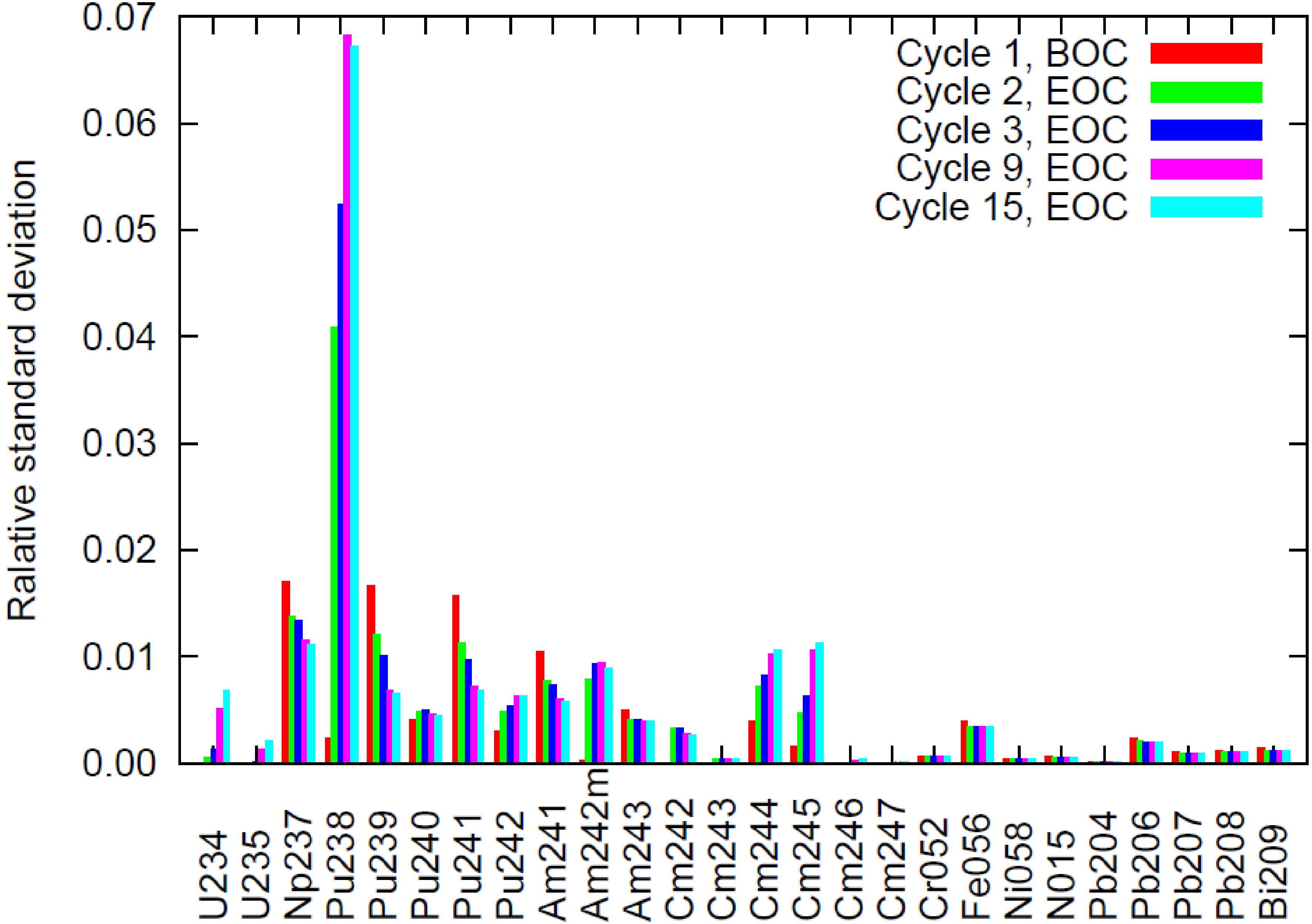
Uncertainty of k_{eff}



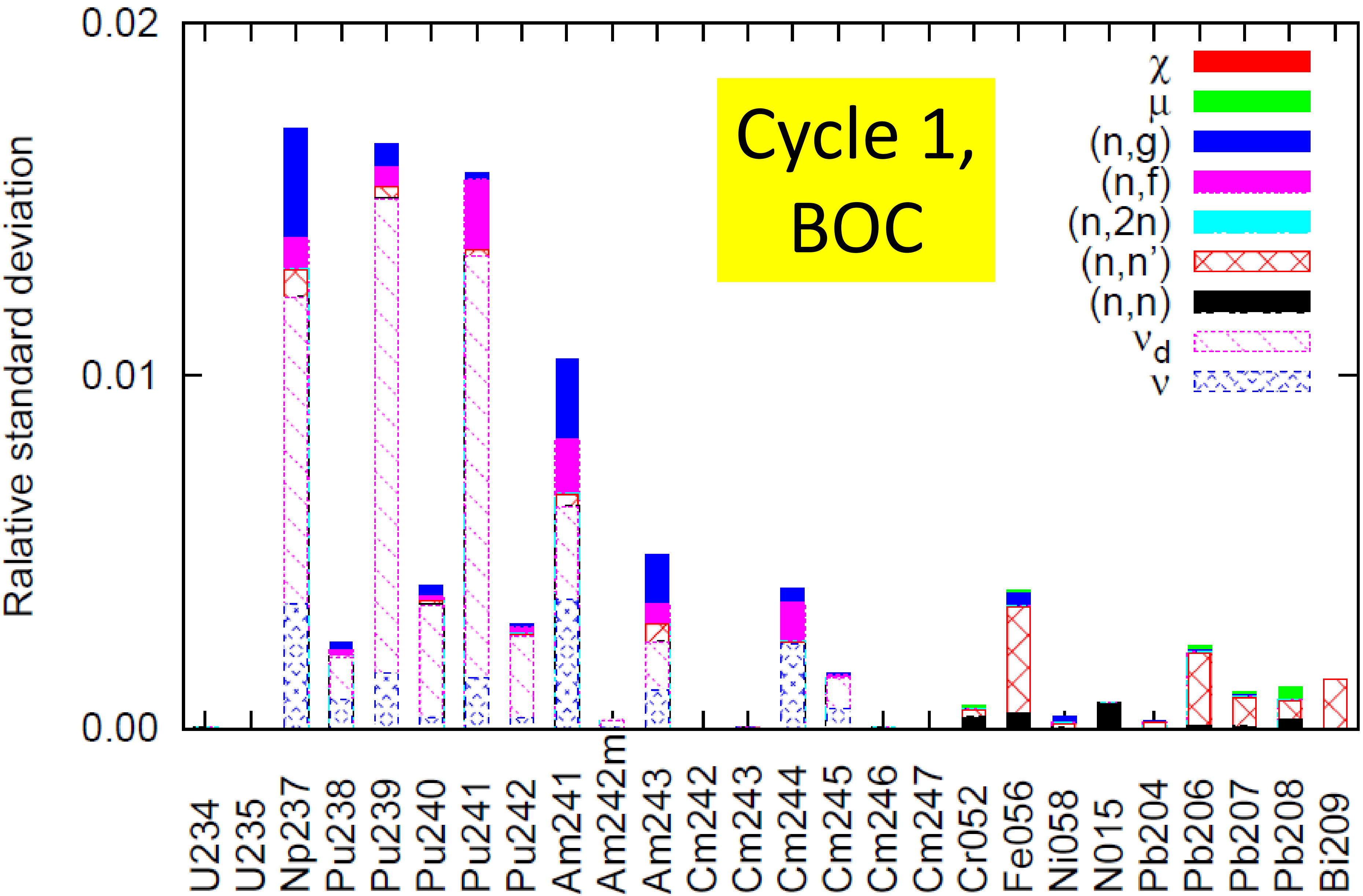
Uncertainty of β_{eff}



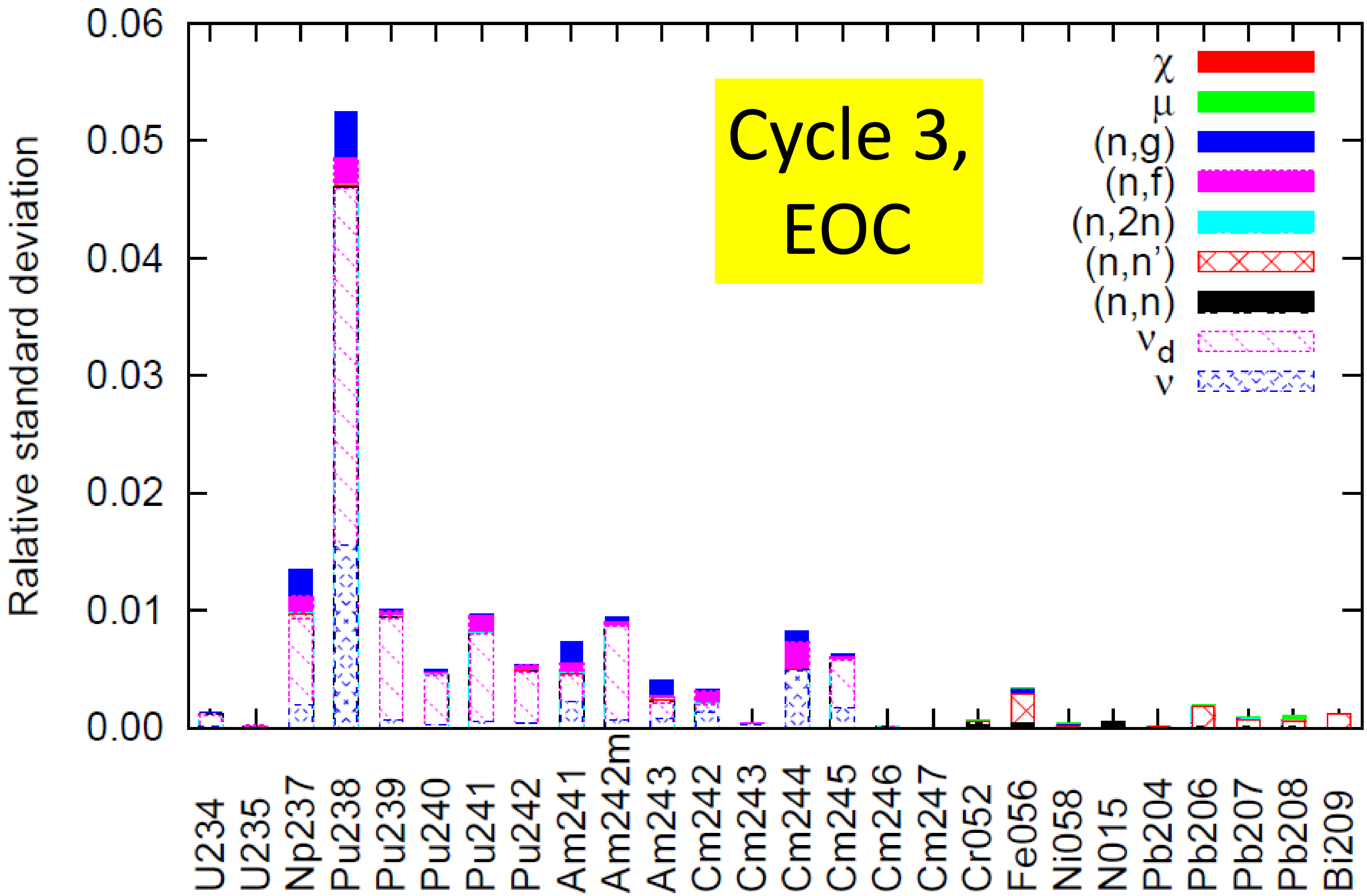
Uncertainty of β_{eff}



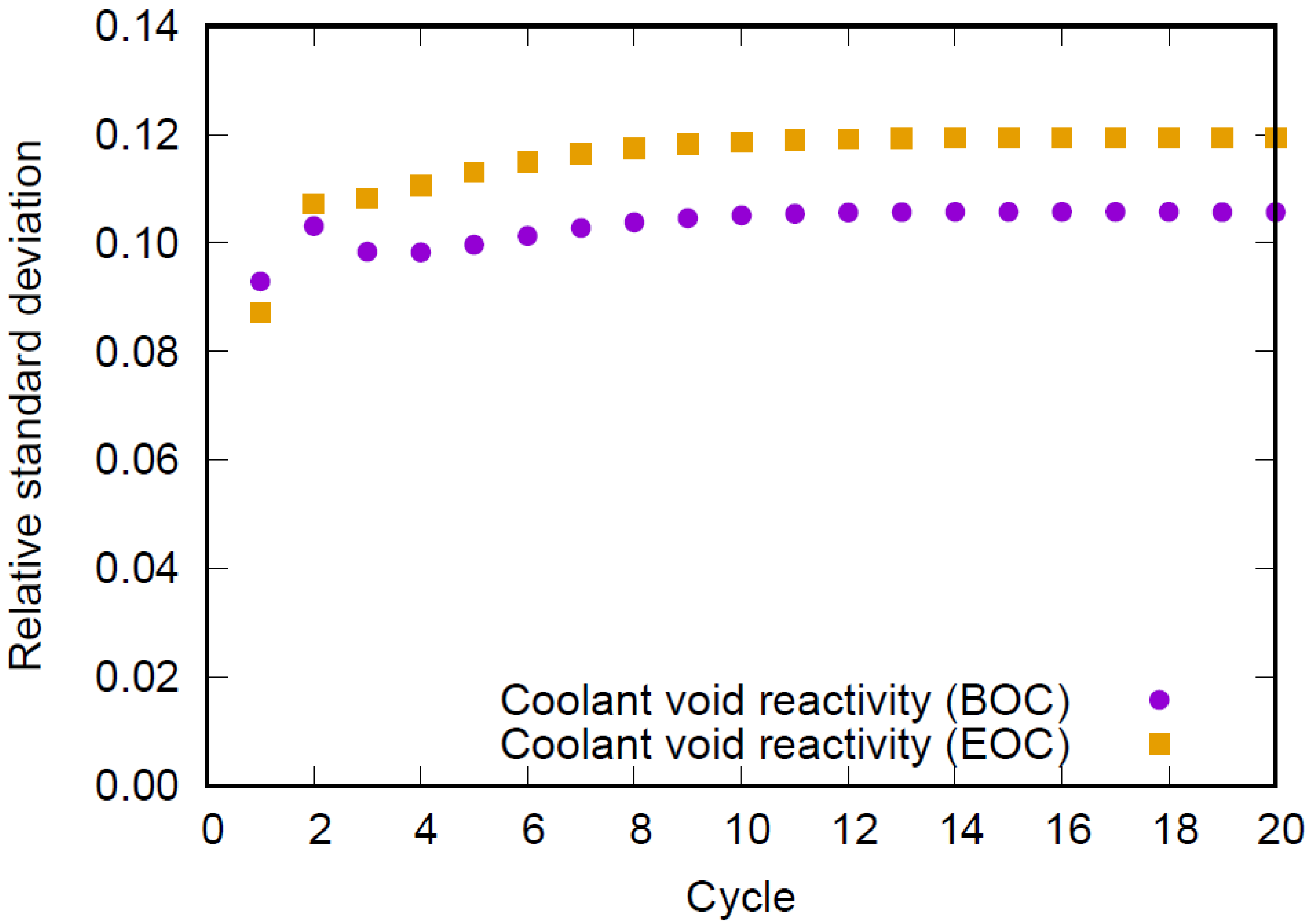
Uncertainty of β_{eff}



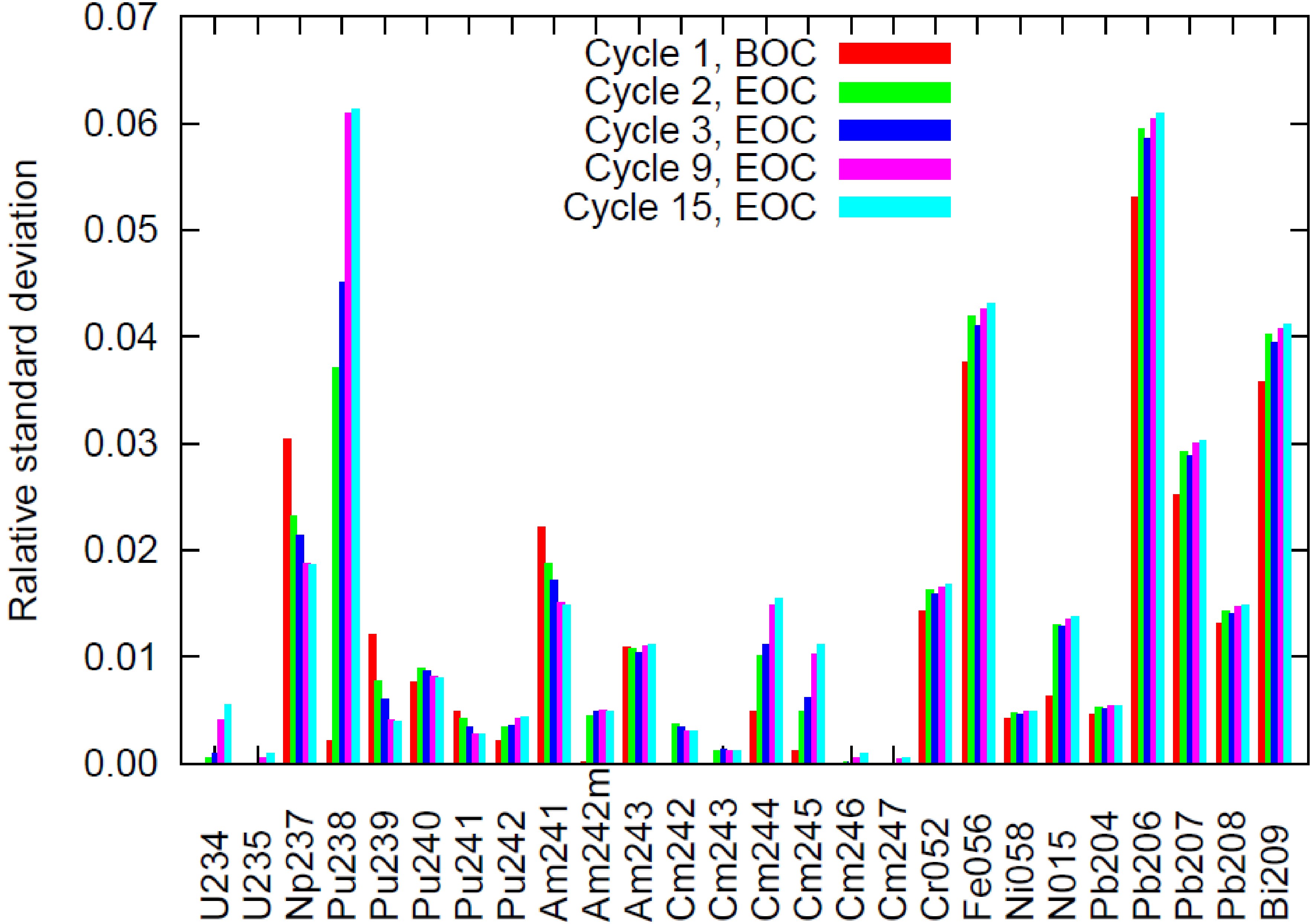
Uncertainty of β_{eff}



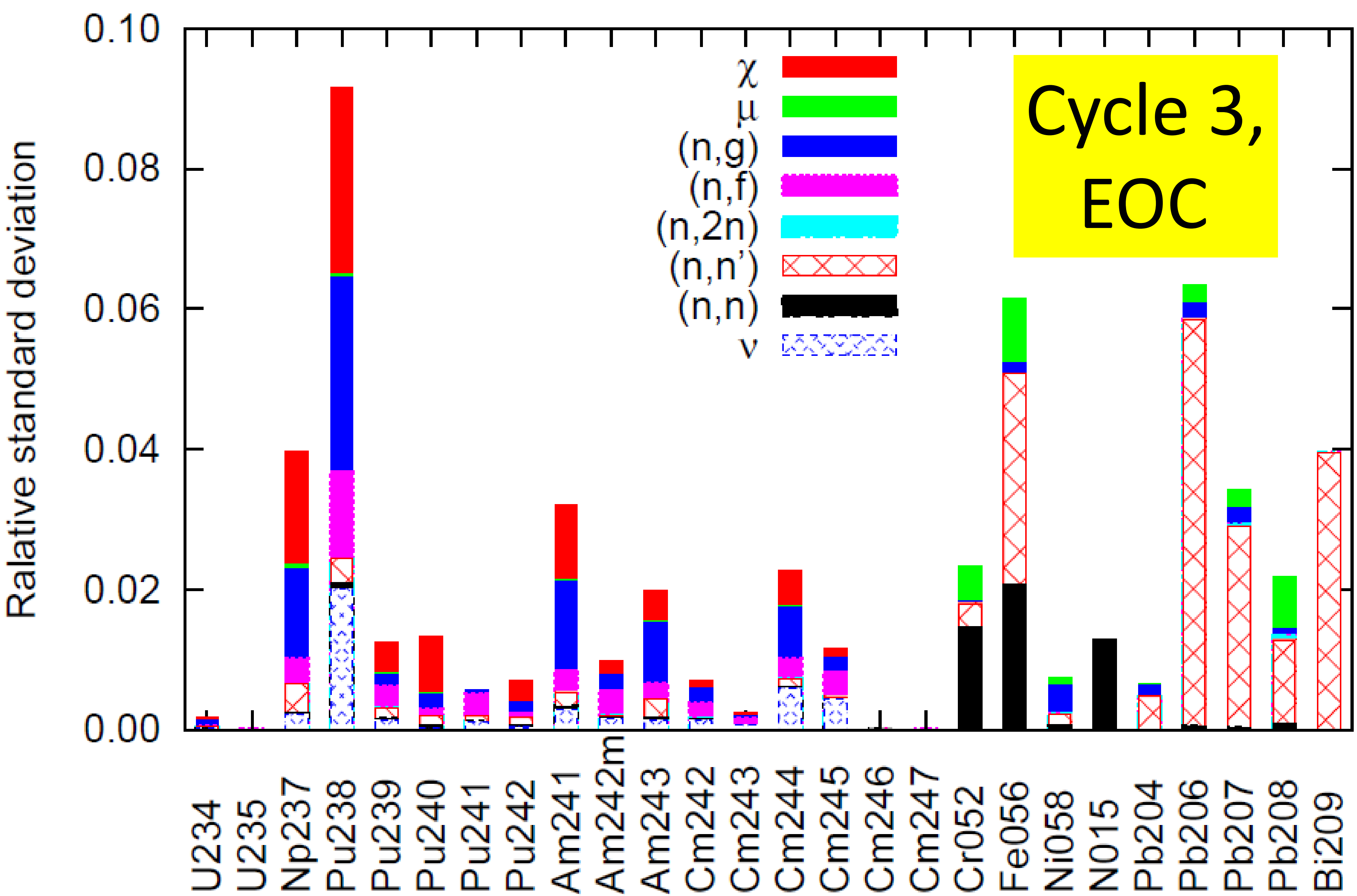
Uncertainty of coolant void reactivity



Uncertainty of coolant void reactivity



Uncertainty of coolant void reactivity

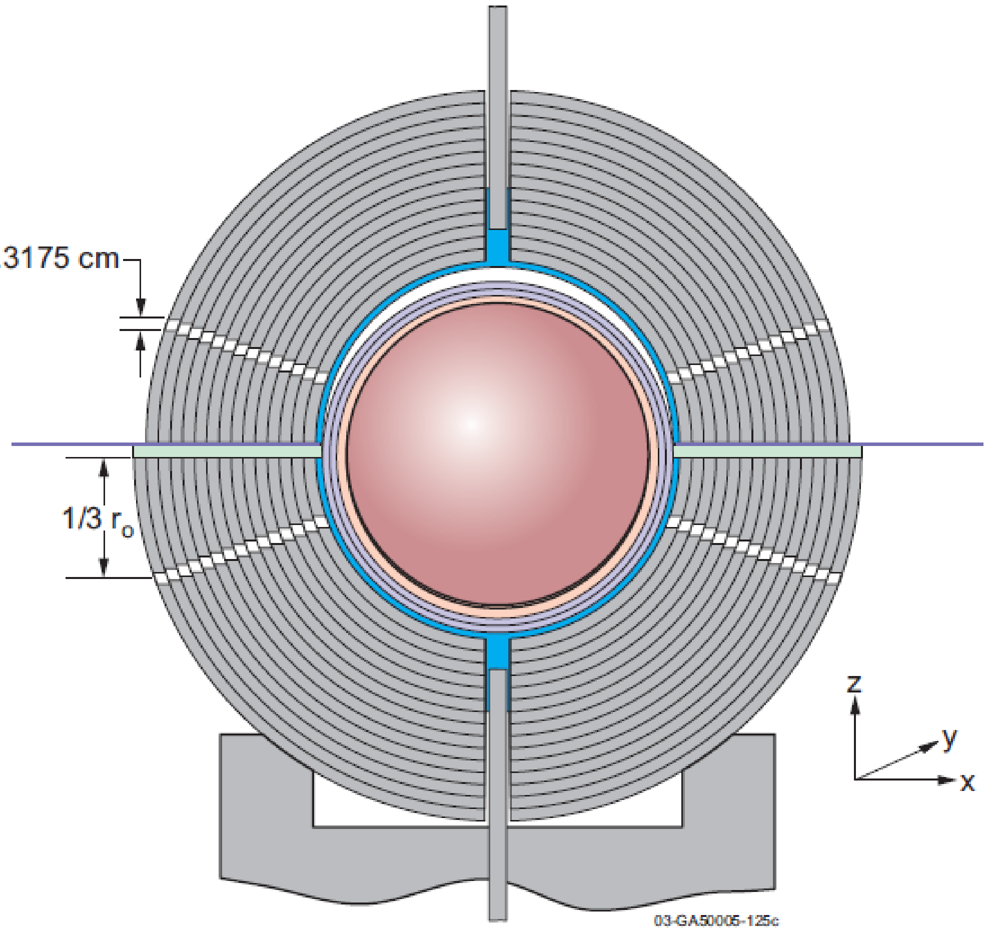


The next step

- To reduce these nuclear data-induced uncertainties, integral data can be efficiently utilized.
- The nuclear data adjustment method is a powerful tool for this purpose.

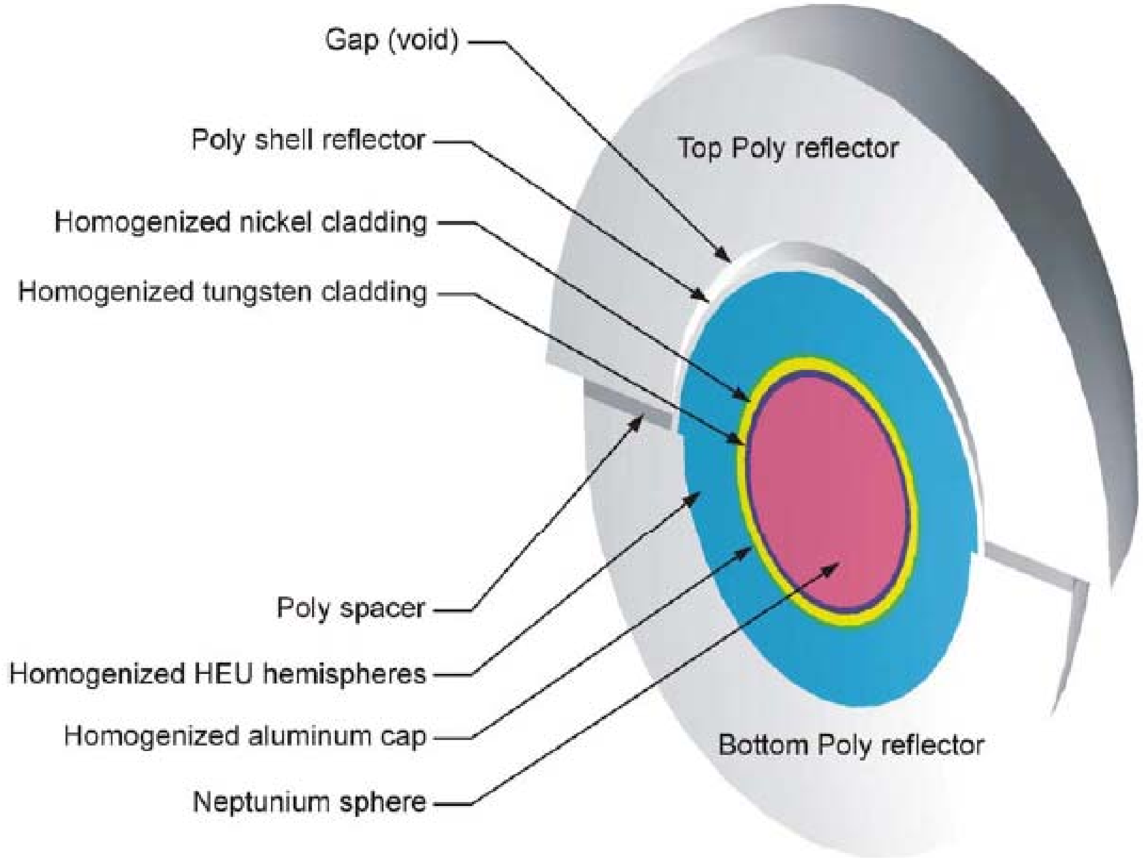
How useful are the presently available integral data for uncertainty reduction of the ADS parameters?

SPEC-MET-FAST-008



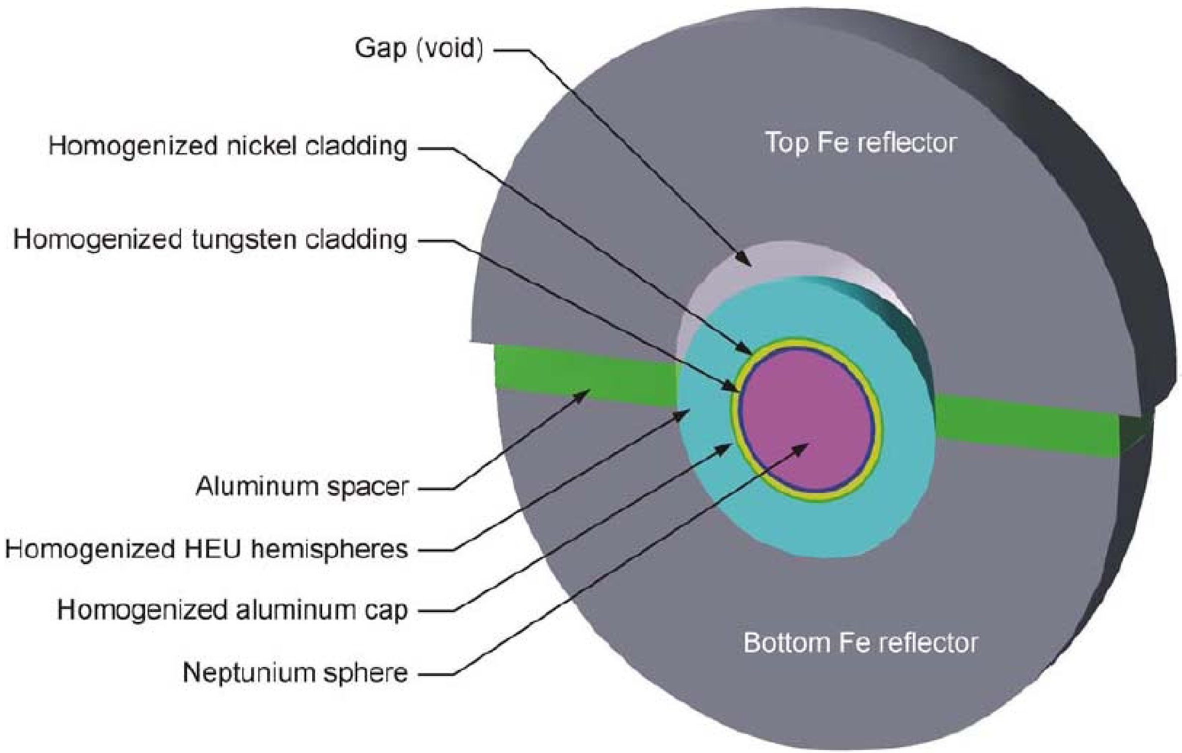
Np sphere surrounded by HEU drivers

SPEC-MET-FAST-011



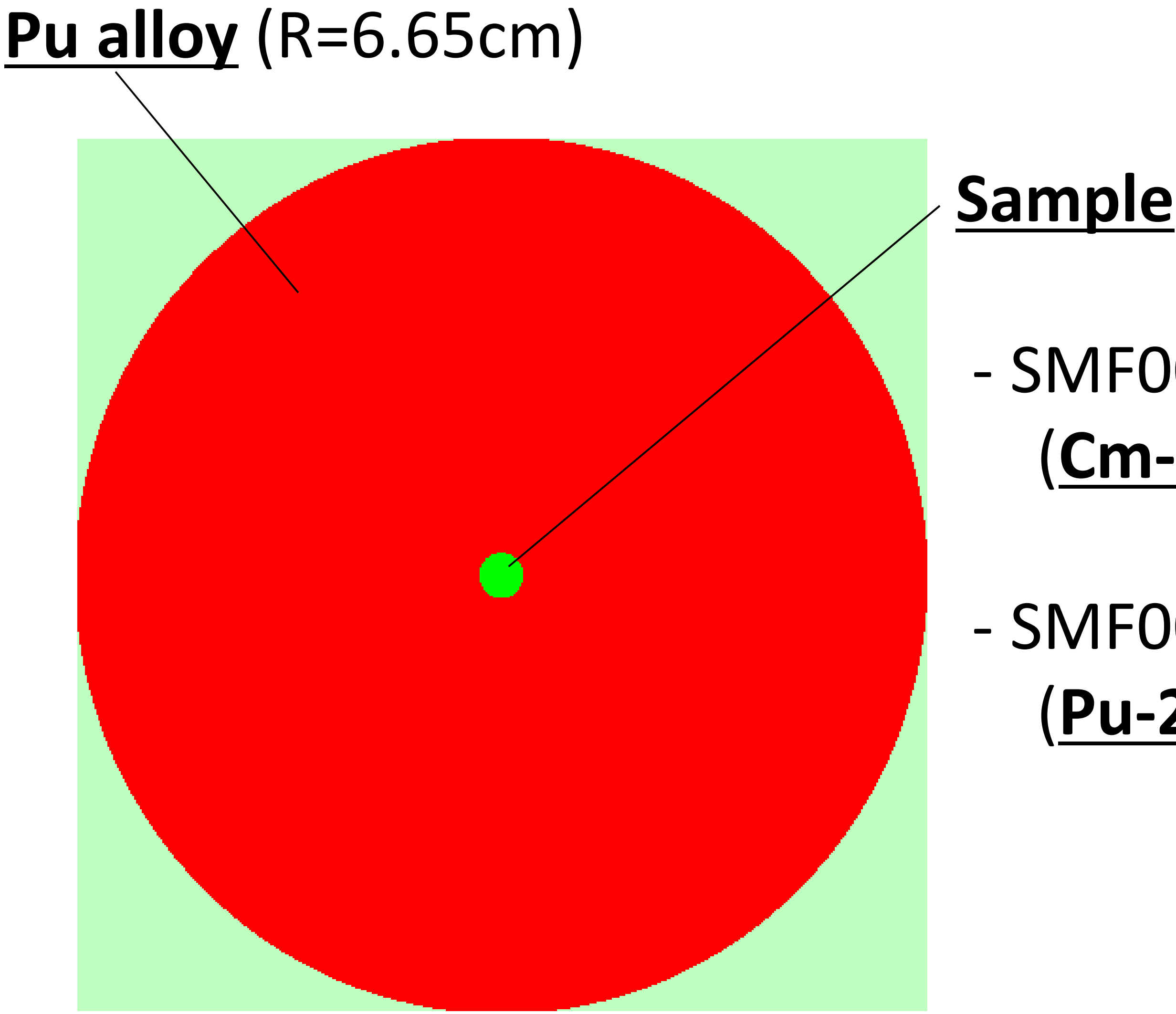
Np sphere surrounded by HEU drivers
with Polyethylene reflector

SPEC-MET-FAST-014



Np sphere surrounded by HEU drivers with iron reflector

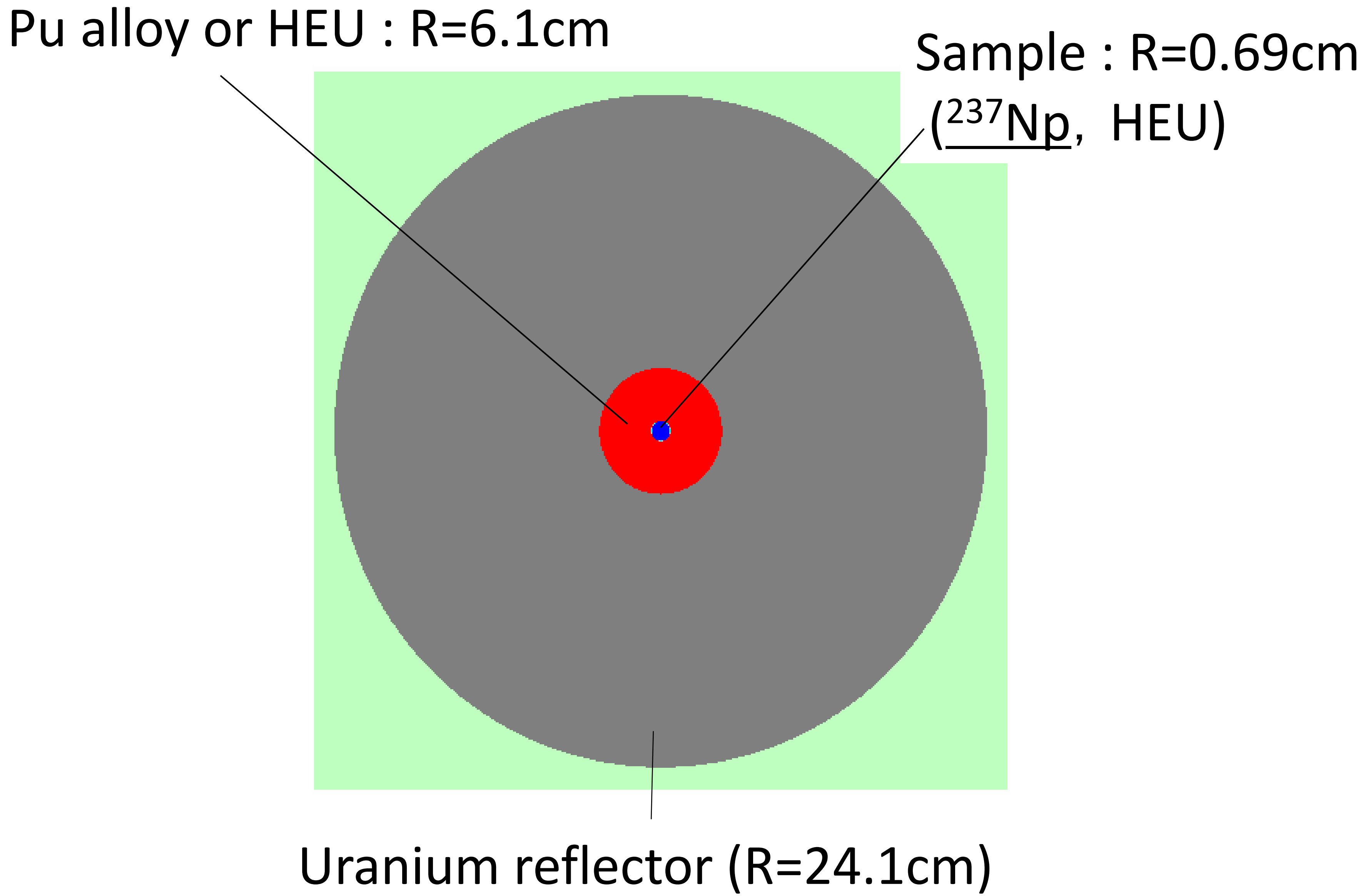
SPEC-MET-FAST-001, -002 : Sample reactivity worth



- SMF001 : R = 0.31cm
  (**Cm-244**, U-235, Pu-239)

- SMF002 : R = 0.65cm
  (**Pu-238**, Pu-239)

SPEC-MET-FAST-003 : Sample reactivity worth



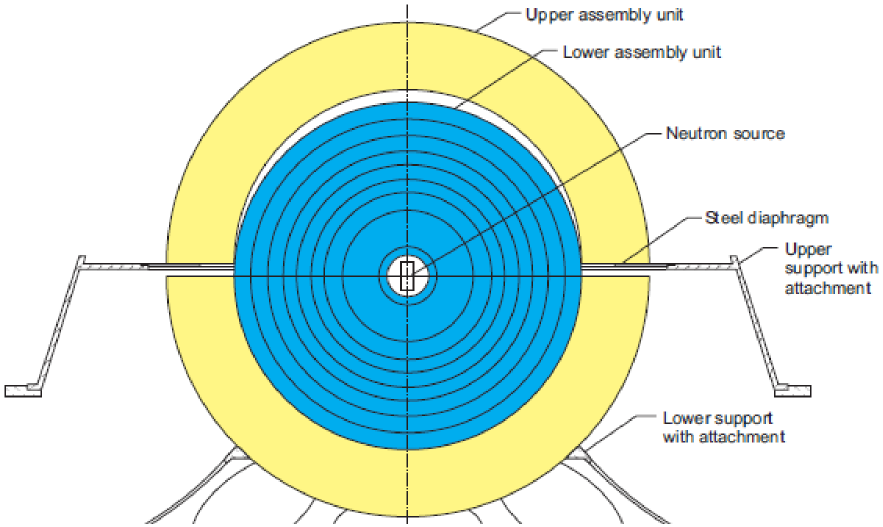
Fission reaction rate ratio in LANL assemblies

Assembly	Quantity	U238f/U235f	Np237f/U235f	U233f/U235f	Pu239f/U235f
Godiva (HMF001)	Calc	0.1579	0.8301	1.5687	1.3823
	Exp-B	0.1643 ±0.0018	0.8516±0.012		1.4152 ± 0.014
	Exp-A	0.1642 ±0.0018	0.837 ±0.013	1.59±0.03	1.402±0.025
	Calc/Exp	C/E=0.9610	C/E=0.9747	C/E=0.9866	C/E=0.9768
Jezebel (PMF001)	Calc	0.2085	0.9708	1.5561	1.4242
	Exp-B	0.2133 ±0.0023	0.9835 ±0.014		1.4609 ± 0.013
	Exp-A	0.2137 ±0.0023	0.962 ±0.016	1.578 ±0.027	1.448 ±0.029
	Calc/Exp	C/E=0.9775	C/E=0.9871	C/E=0.9861	C/E=0.9749
Jezebel-23 (UMF001)	Calc	0.2111	0.9970		
	Exp-B	0.2131 ±0.0026	0.9970 ±0.015		
	Exp-A	0.2131 ±0.0023	0.977 ±0.016		
	Calc/Exp	C/E=0.9906	C/E=1.000		
Flattop-25 (HMF028)	Calc	0.1438	0.7693	1.5674	1.3586
	Exp-B	0.1492 ±0.0016	0.7804 ±0.01	1.608 ±0.003	1.3847 ±0.012
	Exp-A	0.149 ±0.002	0.76 ±0.01	1.60 ±0.003	1.37 ±0.02
	Calc/Exp	C/E=0.9638	C/E=0.9858	C/E=0.9748	C/E=0.9812
Flattop-Pu (PMF006)	Calc	0.1767	0.8521		
	Exp-B	0.1799 ±0.002	0.8561 ±0.012		
	Exp-A	0.180 ±0.003	0.84 ±0.01		
	Calc/Exp	C/E=0.9822	C/E=0.9953		
Flattop-23 (UMF006)	Calc	0.1882	0.9128		
	Exp-B	0.1916 ±0.0021	0.9103 ±0.013		
	Exp-A	0.191 ±0.003	0.89 ±0.01		
	Calc/Exp	C/E=0.9823	C/E=1.0027		

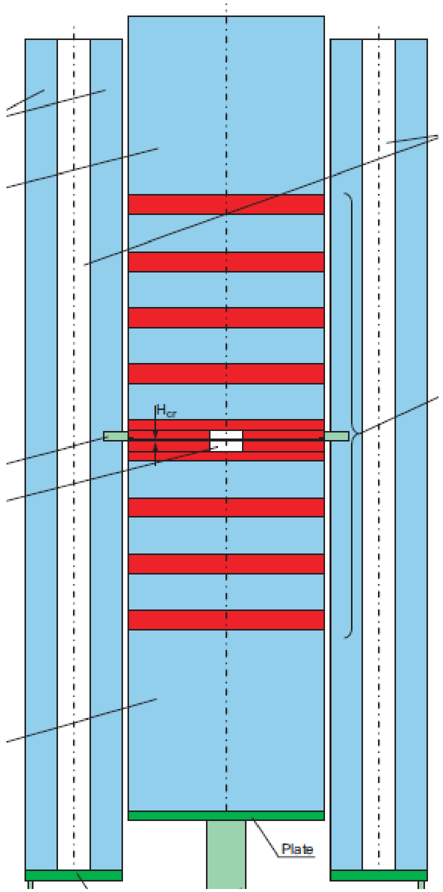
Nucl. Data Sheets, 112, p.2887 (2011).

Lead-related fast neutron systems

The following integral data related to lead are used: HMF-027, PMF-035, three assemblies in HMF-064.



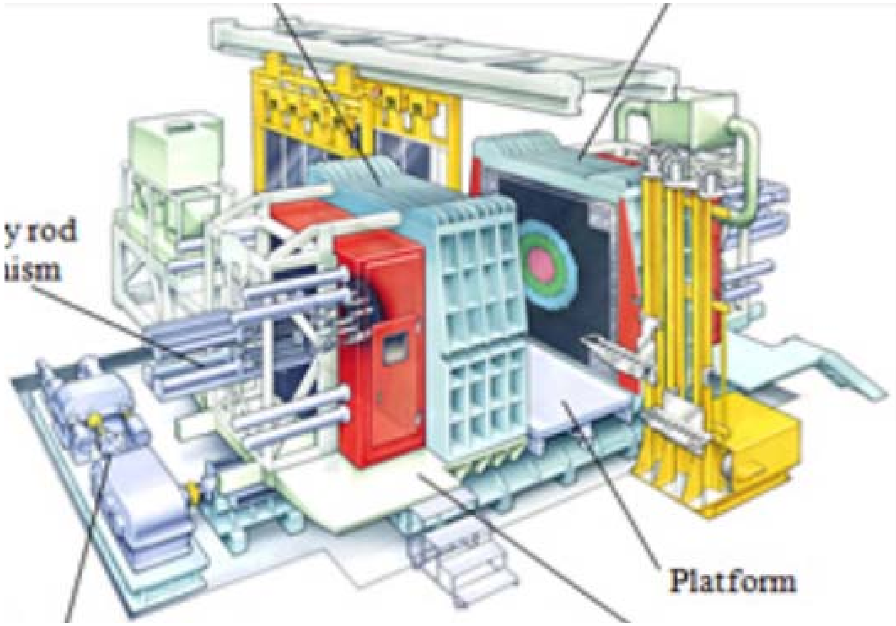
HMF-027

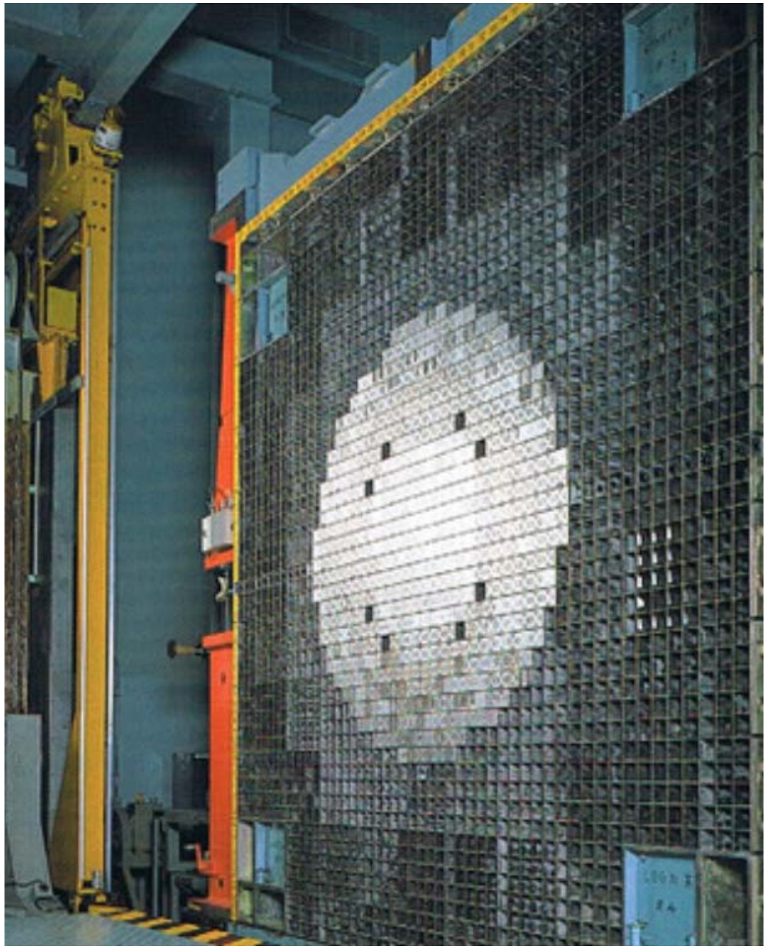


HMF-064-2

TRU fission reaction rate ratio measured at FCA IX

The fission reaction rate ratio of Np-237, Pu-238, -242, Am-241, -243 and Cm-244 against Pu-239 were measured at six assemblies of the FCA IX core.





Application of adjusted library to ADS calculation

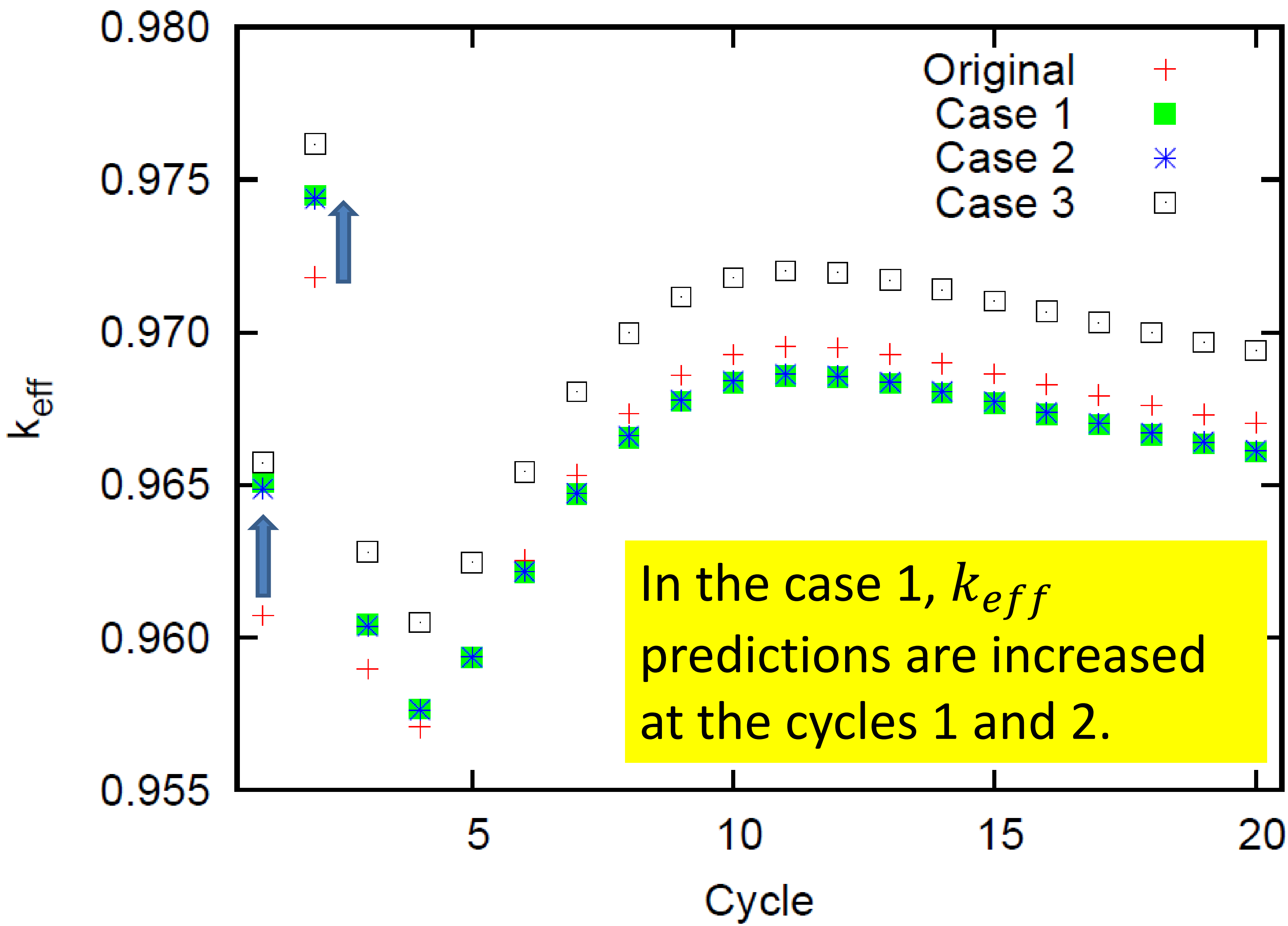
Three adjustment calculations are carried out:

- **<u>Case 1</u>**: k_{eff} of Np spheres, sample reactivity worth and fission reaction rate ratio at LANL assemblies (31 data in total).

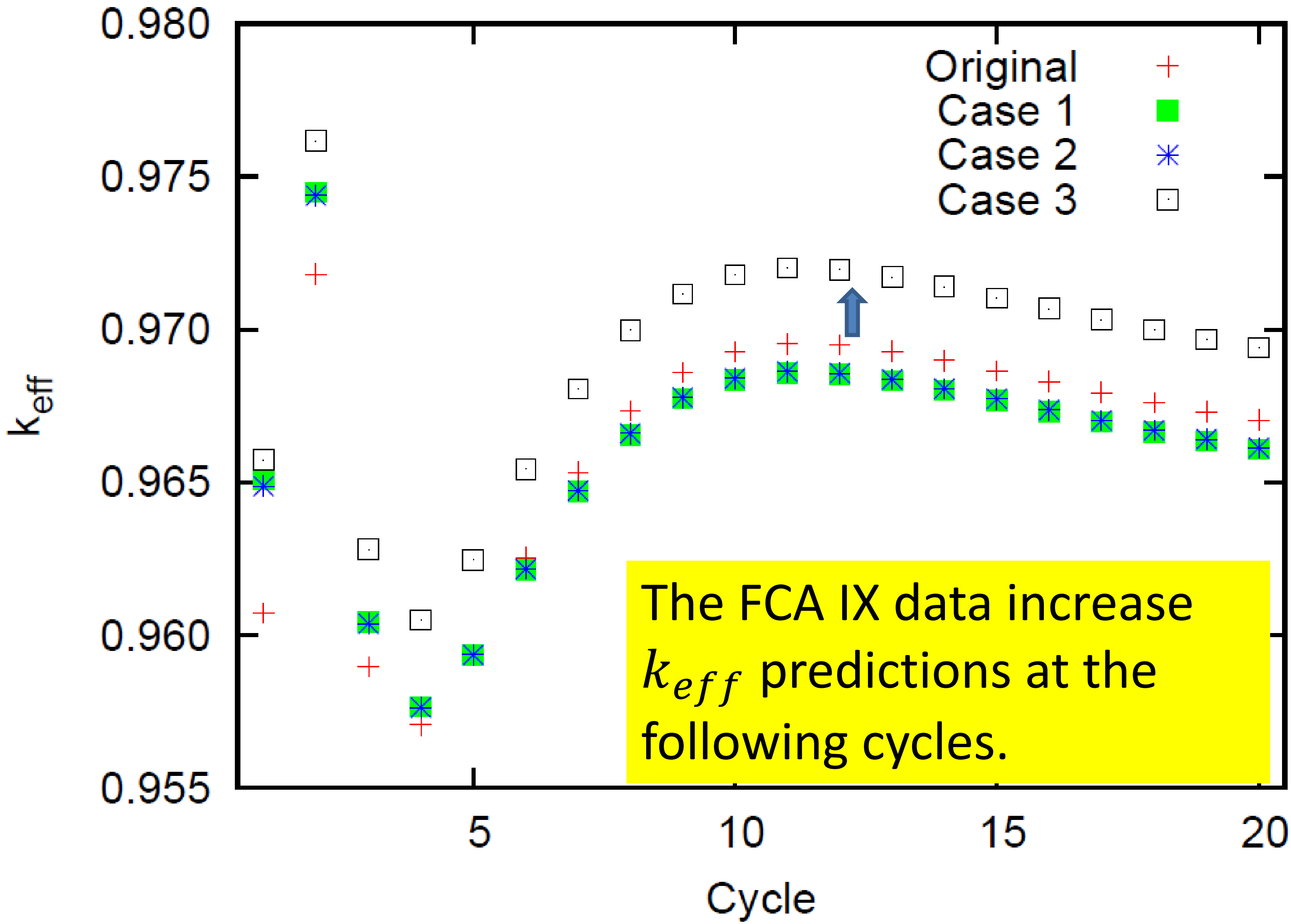
- **<u>Case 2</u>**: Case 1 plus k_{eff} of lead-related systems (38 data).

- **<u>Case 3</u>**: All (Case 2 plus fission reaction rate ratio at FCA-IX, 79 data).

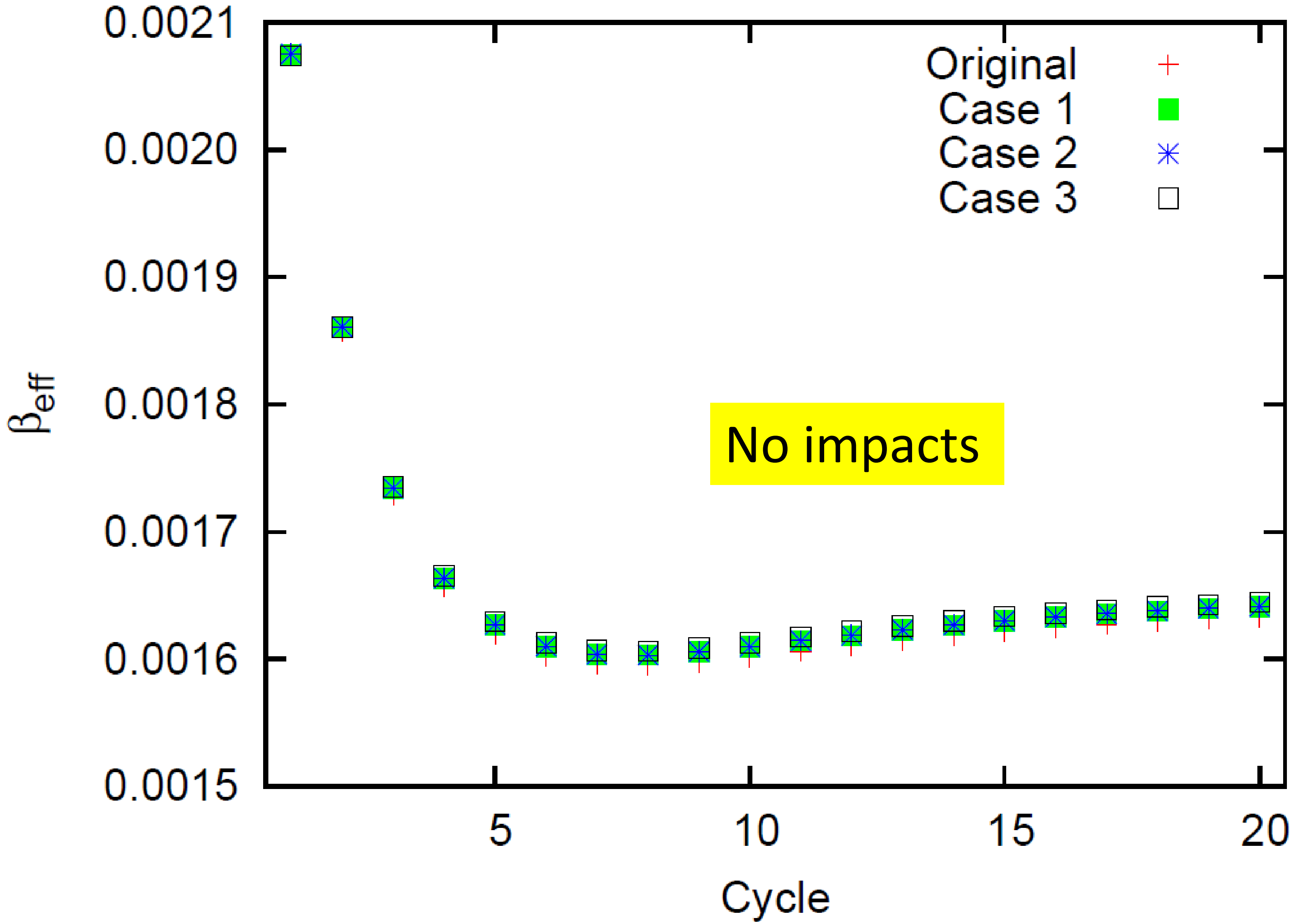
Results of k_{eff}



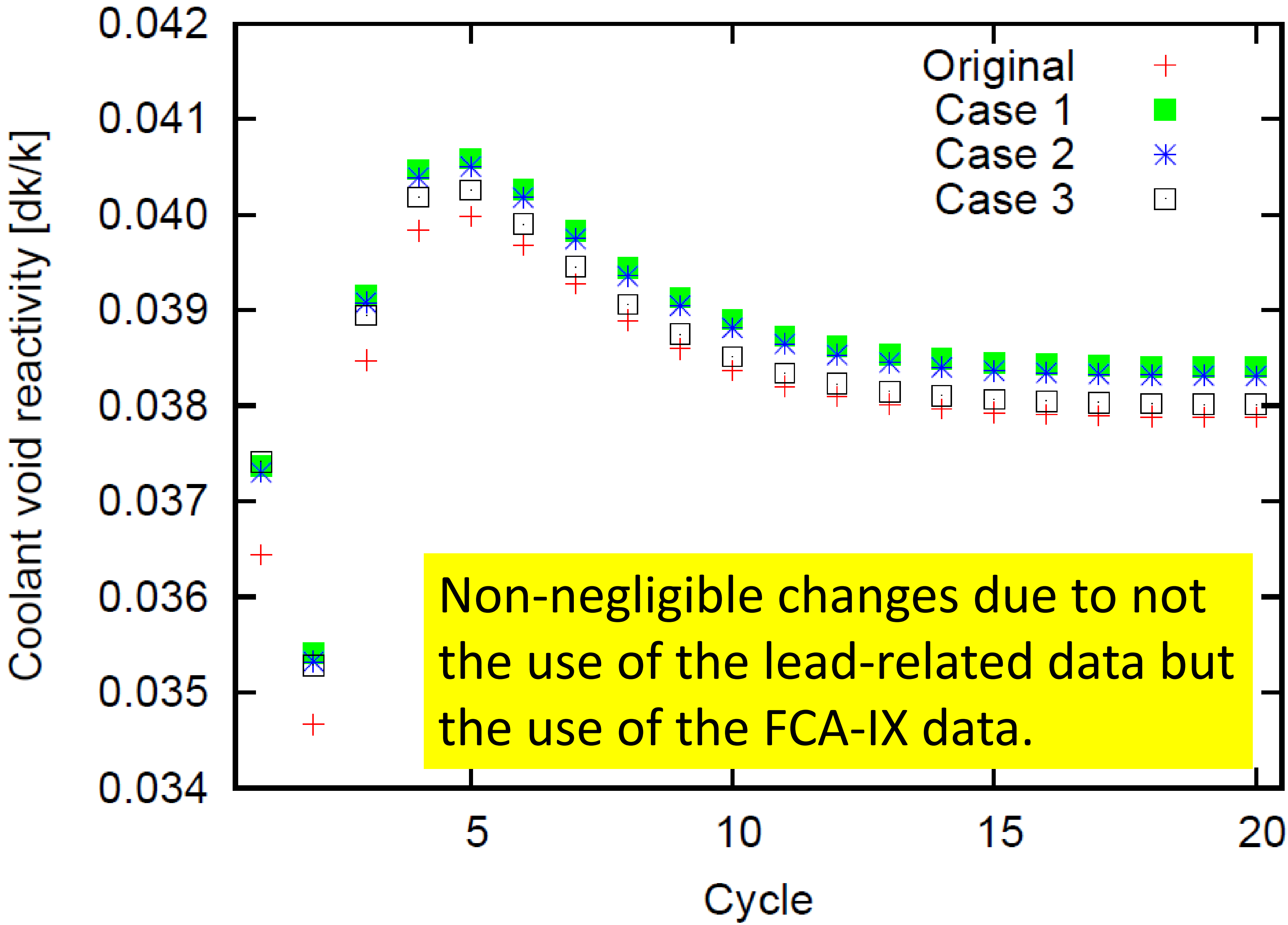
Results of k_{eff}



Results of β_{eff}

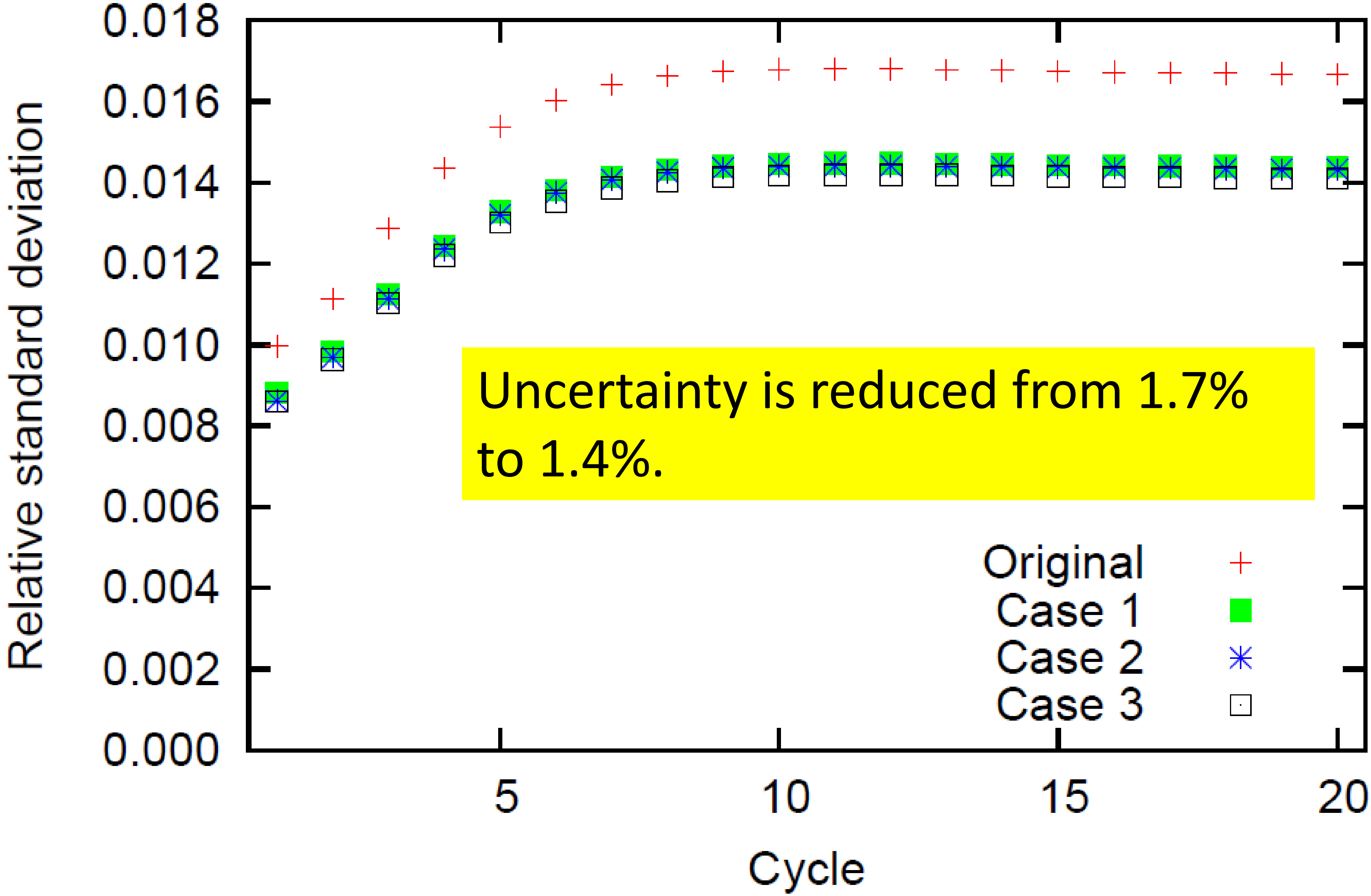


Results of coolant void reactivity

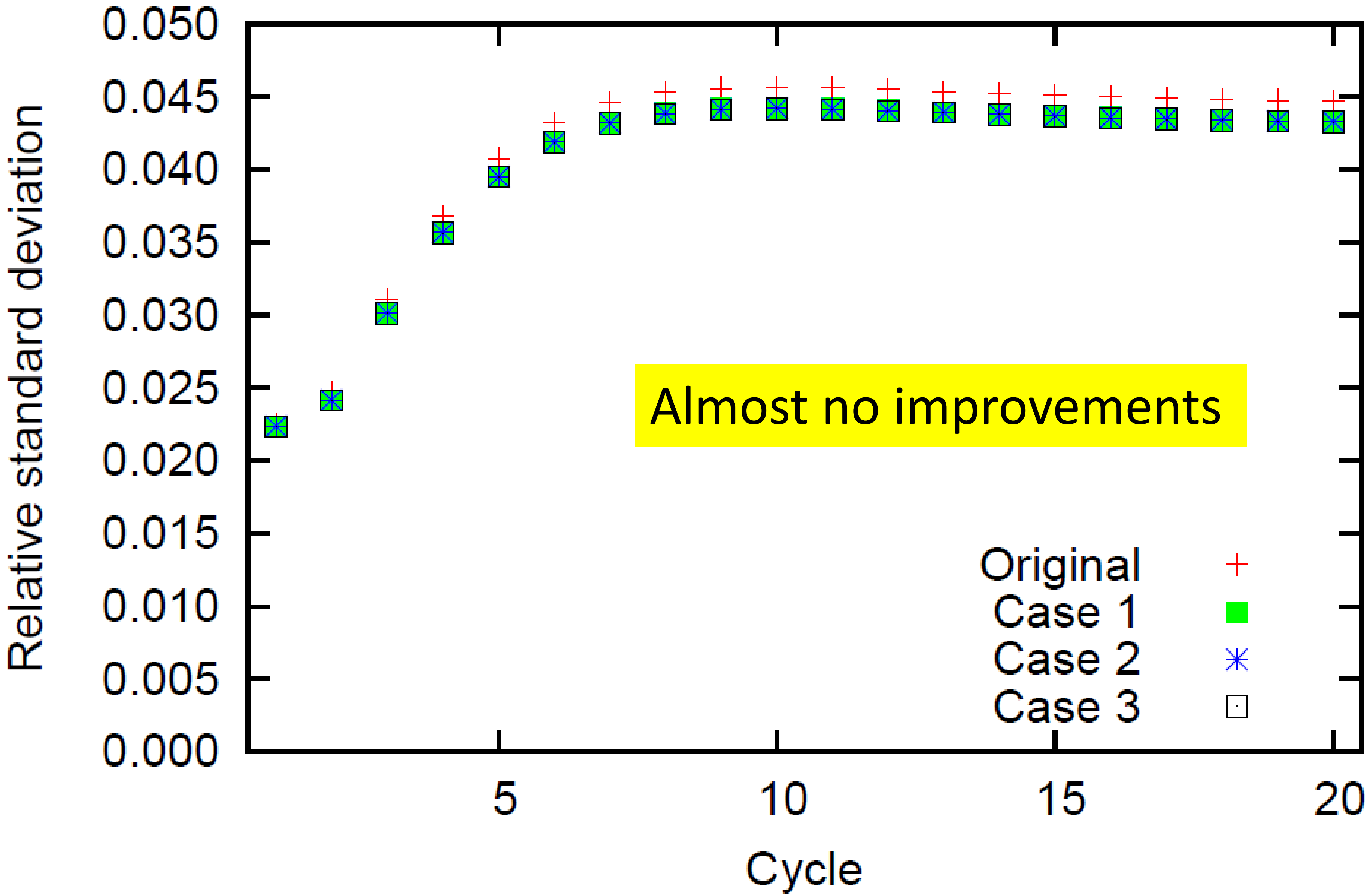


Non-negligible changes due to not the use of the lead-related data but the use of the FCA-IX data.

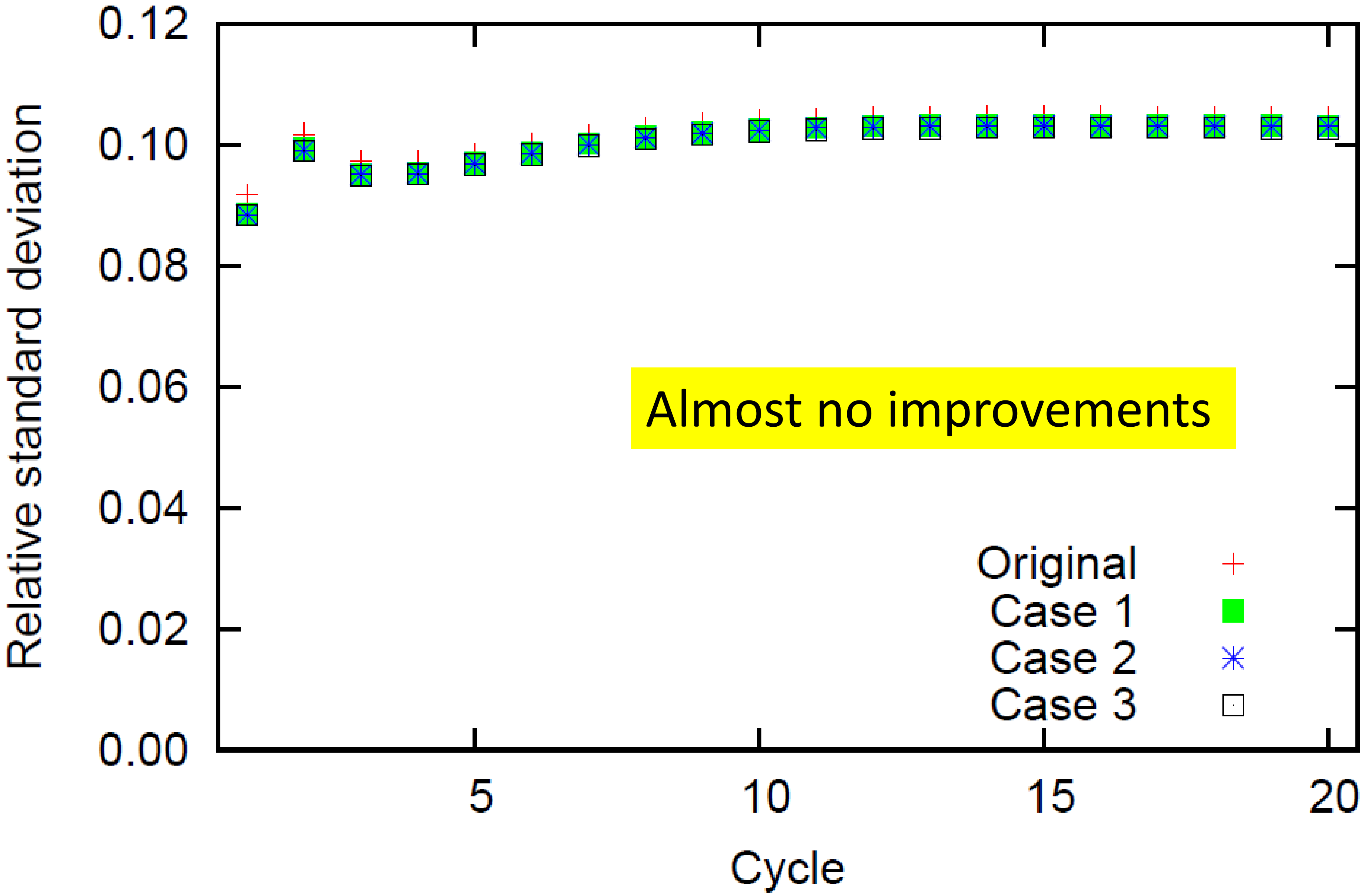
Uncertainties of k_{eff}



Uncertainties of β_{eff}



Uncertainties of coolant void reactivity



Conclusion and future perspective

- Uncertainty reduction by the nuclear data adjustment with the available integral data are restrictive and insignificant.
- Other integral data which are sensitive to **capture cross sections** are desired.
- On the uncertainty of β_{eff}, ν_d of Np-237 and Pu-238 are dominant contributors, but it is difficult to reduce these uncertainties with the integral data.
- To reduce the uncertainty of the coolant void reactivity, integral data sensitive to **inelastic scattering cross sections of lead** is desired.

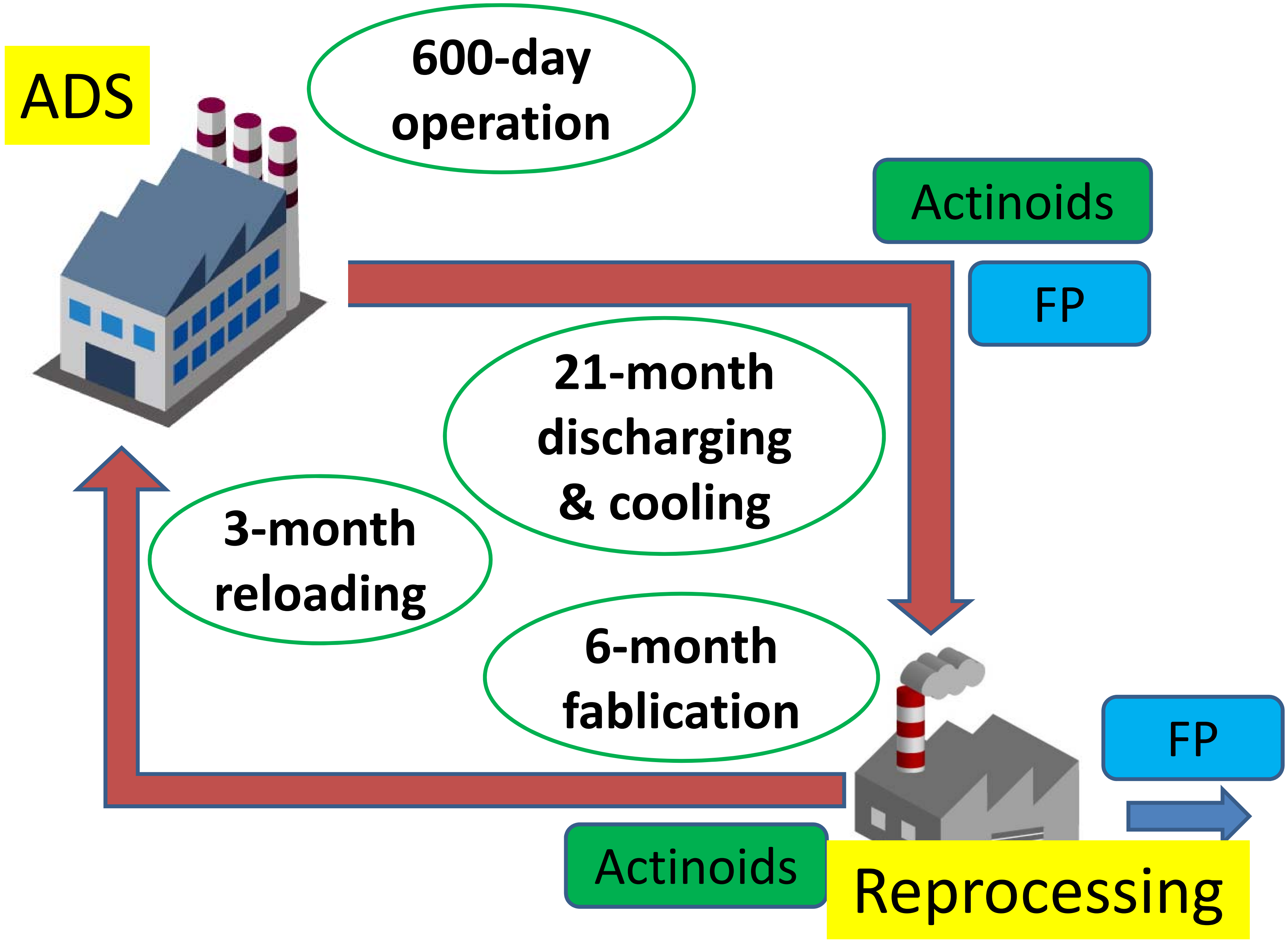
Conclusion and future perspective

- Uncertainty accumulated through fuel burnup should be considered for more accurate uncertainty quantification. New capability to consider this effect has recently implemented into CBZ.

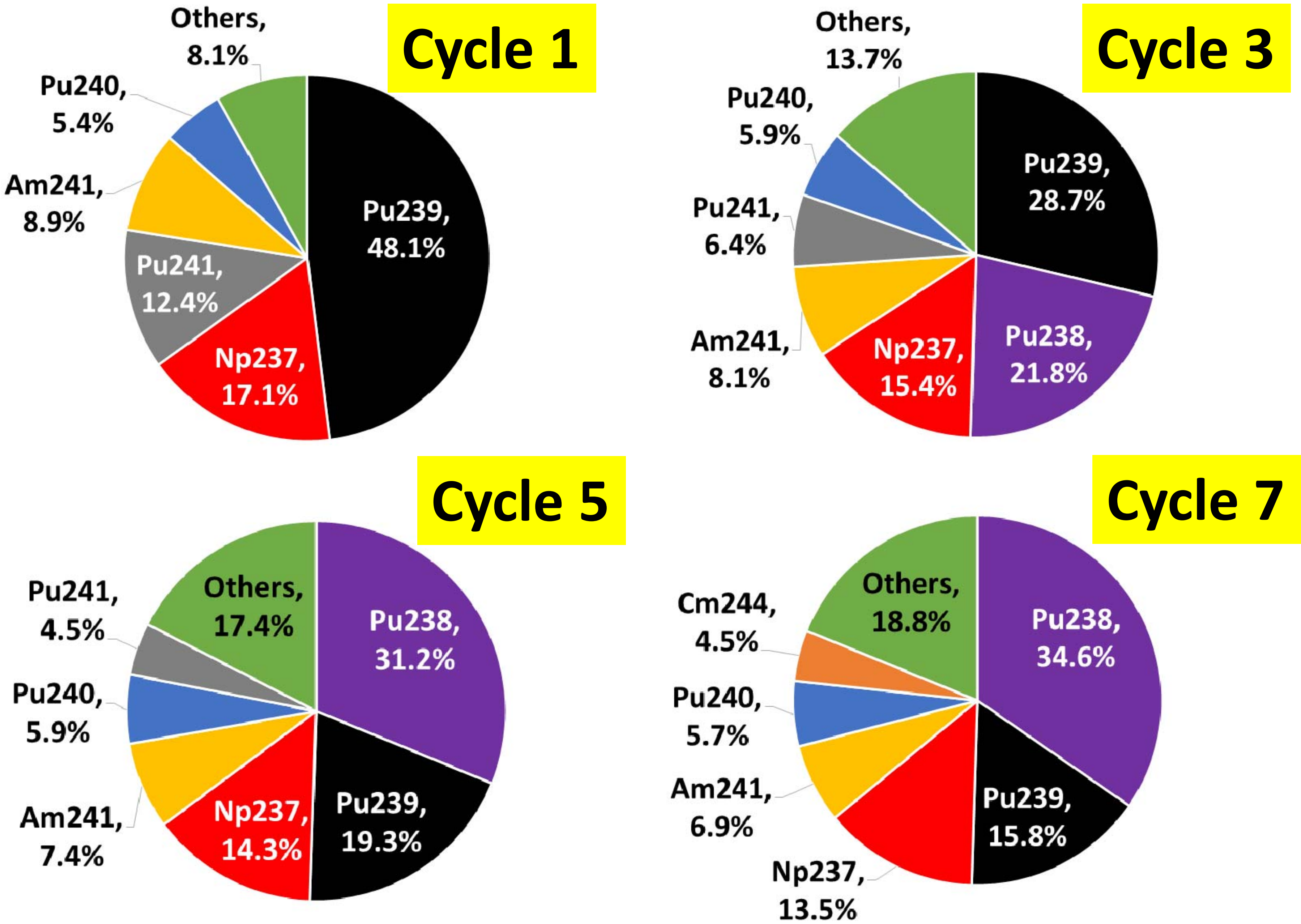
These will be presented at the next M&C conference, M&C 2017, in Jeju.

This work is supported under the project *Basic Research for Nuclear Transmutation Techniques by Accelerator-Driven System*, a Special Research Program funded by Chubu Electric Power Co., Inc.

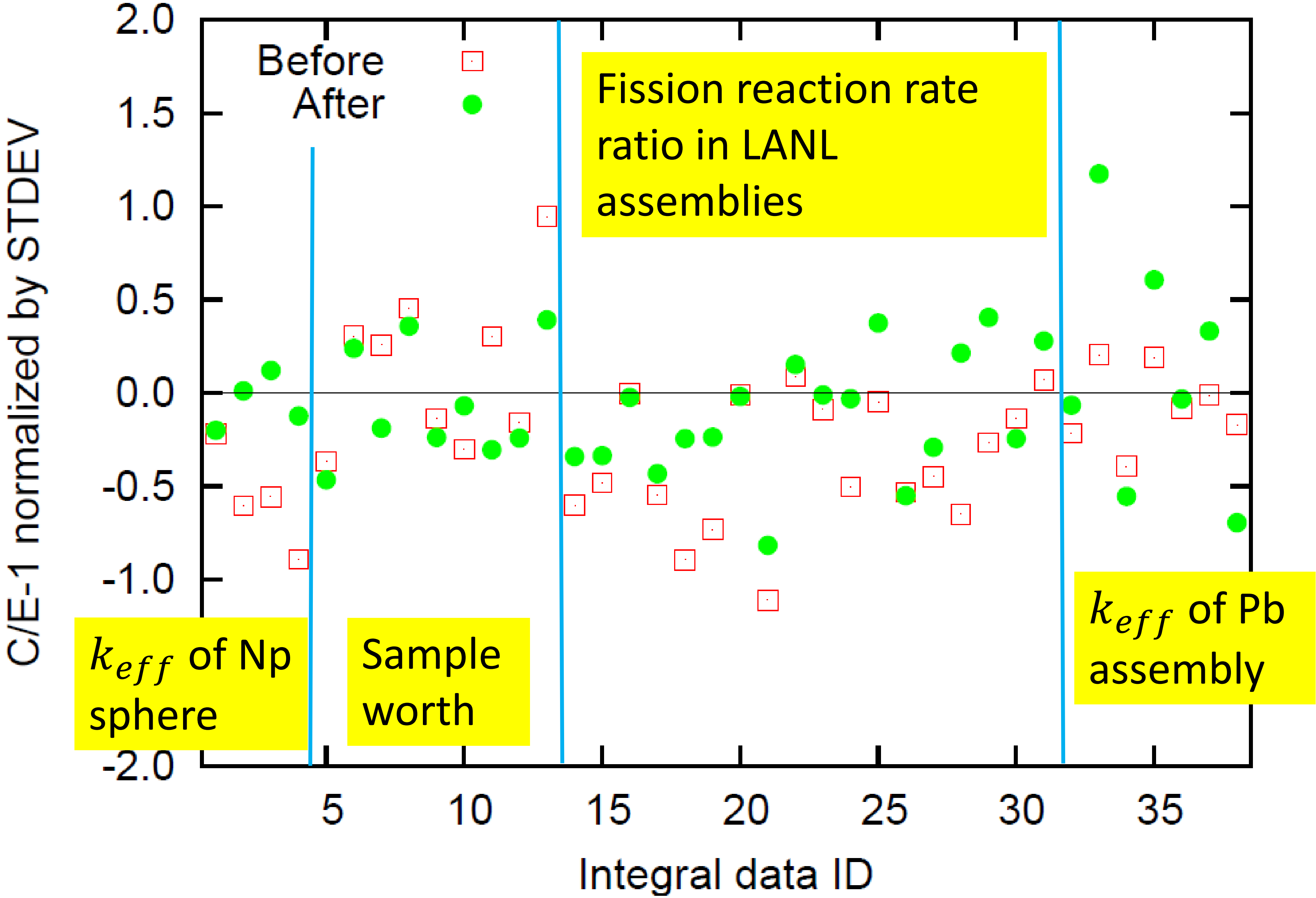
ADS fuel cycle



Nuclide-wise contribution to fission reactions



C/E values before and after adjustment



C/E values before and after adjustment