



## **SERPENT activities at VUJE, a.s.**

**Tomáš Chrebet**  
**Amine Bouhaddane**  
**František Čajko**  
**Michal Sečanský**  
**Radoslav Zajac**

**26-29 September 2016**

**6th International Serpent User Group  
Meeting at Milan**



# Outline

During the last year, SERPENT was used mainly in the following activities:

- Calculations of the ALLEGRO core in the frame of the ESNII+ project.
- Optimization of the ALLEGRO core.
- Calculations of the ALLEGRO pin in the frame of the VINCO project.
- Full-core VVER-440 pin power distribution calculation benchmark.

## ESNII+ project

The aim is to develop a broad strategic approach to advanced nuclear fission systems in support of the **European Sustainable Nuclear Industrial Initiative** (ESNII), to ensure efficient coordinated research for the safety of Generation IV nuclear installations.

Gas cooled fast reactor (GFR) presents one of the three European candidate fast reactor types

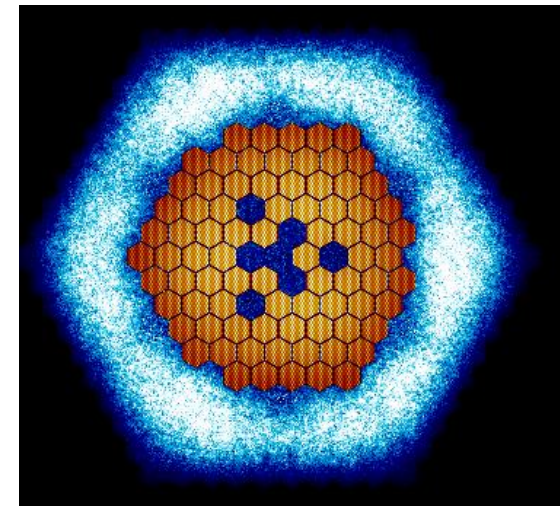
**ALLEGRO**: Gas Fast Reactor (GFR), **Potential Site**: Bohunice NPP, Slovakia

**ASTRID**: Advanced Sodium Technical Reactor for Industrial Demonstration of Sodium Fast Reactor (SFR), **Site**: Marcoule France

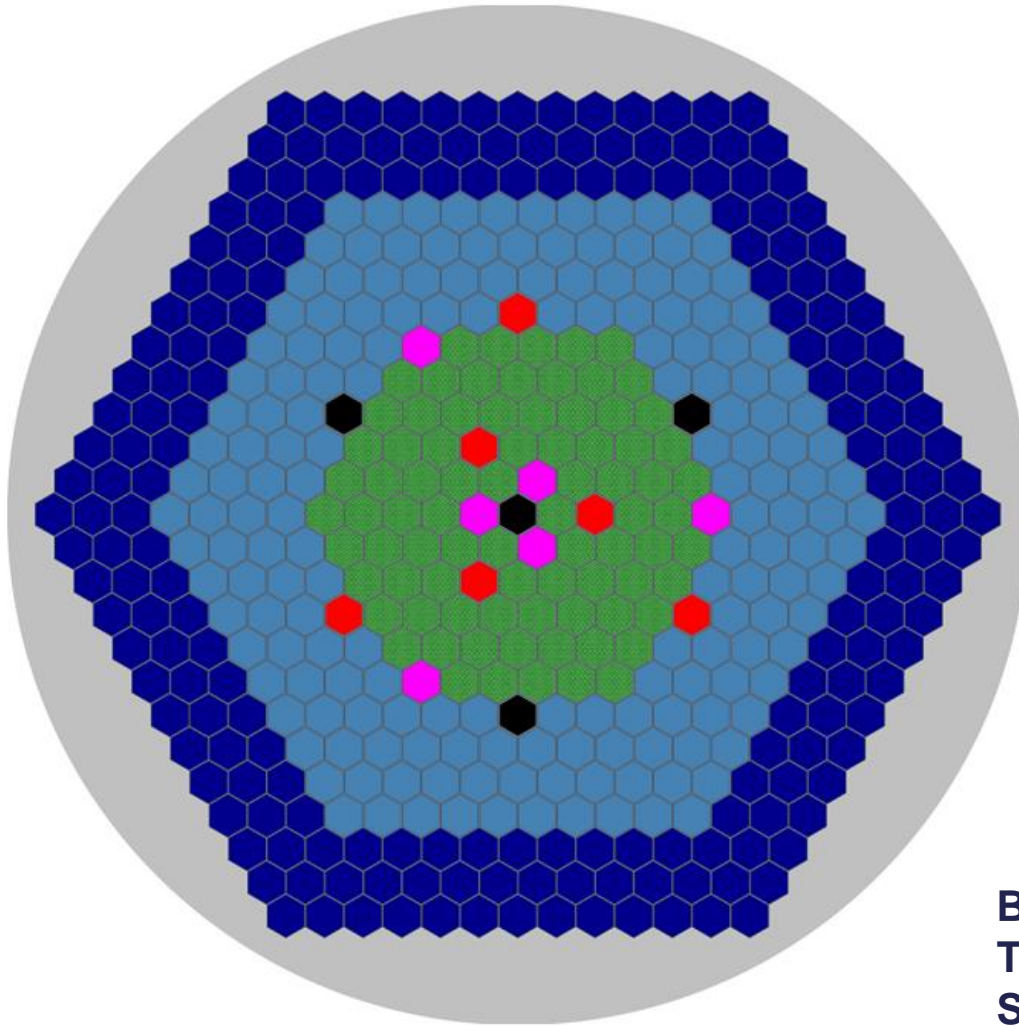
**ALFRED**: Advanced Lead Fast Reactor European Demonstrator of Lead Fast Reactor (LFR)  
**Potential Site**: Cerna Voda, Romania

## ALLEGRO

- concept of experimental Gas Cooled Fast Reactor (GFR)
- MOX fuel and carbide fuel
- cooled by helium under the pressure of 7 MPa
- two systems of control assemblies to control reactivity and to shutdown reactor: 6 CSD and 4 DSD rods using boron carbide (B<sub>4</sub>C) enriched to 70 % by B-10 isotope
- operating temperature of ALLEGRO reactor – 530°C for MOX core and 850°C for core loaded by ceramic fuel
- power of the ALLEGRO reactor will be 75MWth

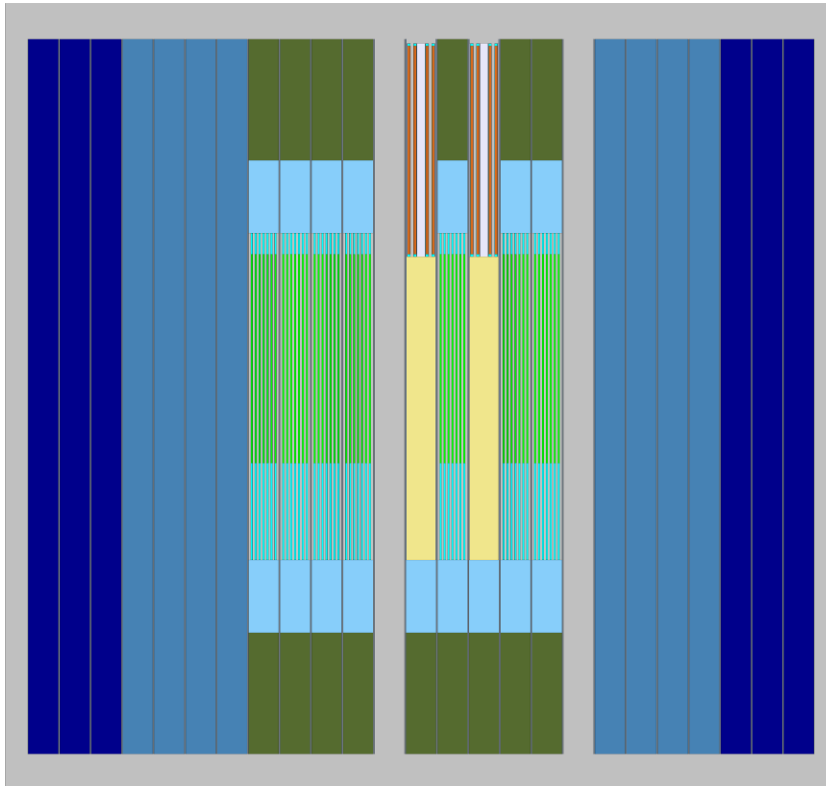


## ALLEGRO reactor MOXcore:

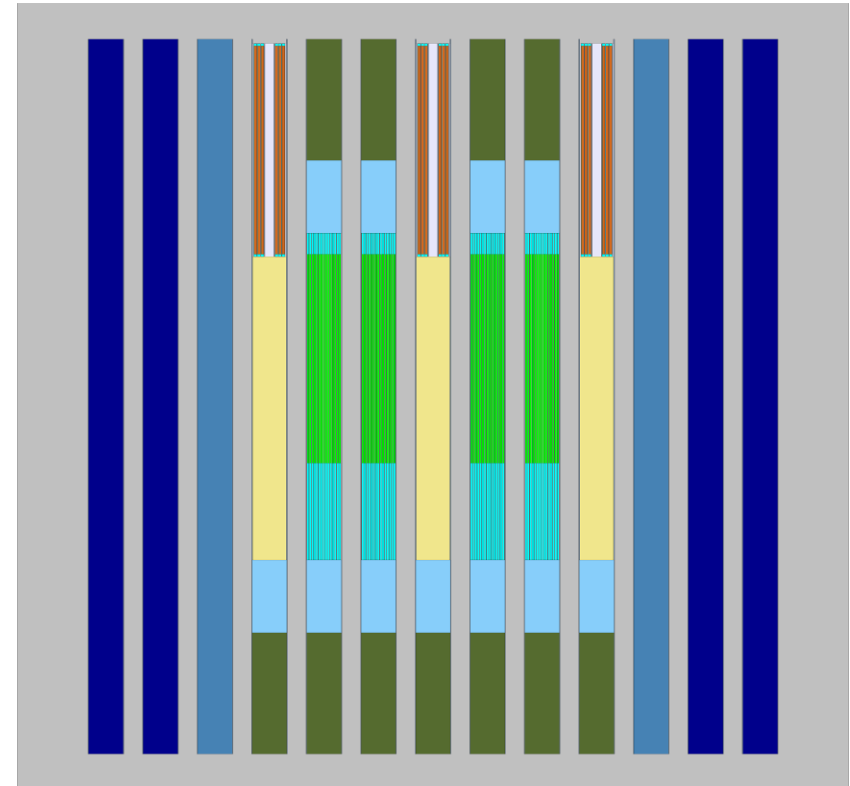


- 6 experimental assemblies
- 81 MOX fuel assemblies
- 6 Control and Shutdown Devices (CSD)
- 4 Diverse Shutdown Devices (DSD)
- 174 reflector assemblies
- 198 shielding assemblies

Background document:  
 TEMESVÁRI, E. (CER): ALLEGRO Core  
 Specification, ESNII plus, 15/10/2014, D6.6.1-2,  
 revision 0



**Plot of xz - cut (front view) of  
ALLEGRO MOX core model,  
 $y = 0$  cm**



**Plot of yz - cut (side view) of  
ALLEGRO MOX core model,  $x$   
 $= 0$  cm**

### Benchmark goals:

- k-effective
- CSD/DSD worth
- coefficients: Doppler (900 K, 1500 K)  
Fuel expansion (900 K, 1500 K)  
Void (3.5 MPa, 0.1 MPa)  
Diagrid expansion(+200 K, +400 K)

### Organizations:

EK-SP24 - Hungarian Academy of Sciences Centre For Energy Research (SERPENT 2.1.24, ENDF/B-VII.0)

PSI - Paul Scherrer Institut (ERANOS 2.2, JEFF3.1)

PSI-S - Paul Scherrer Institut (SERPENT 2.1.23, JEFF 3.1 )

NNL - National Nuclear Laboratory (ERANOS 2.0, ERALIB1)

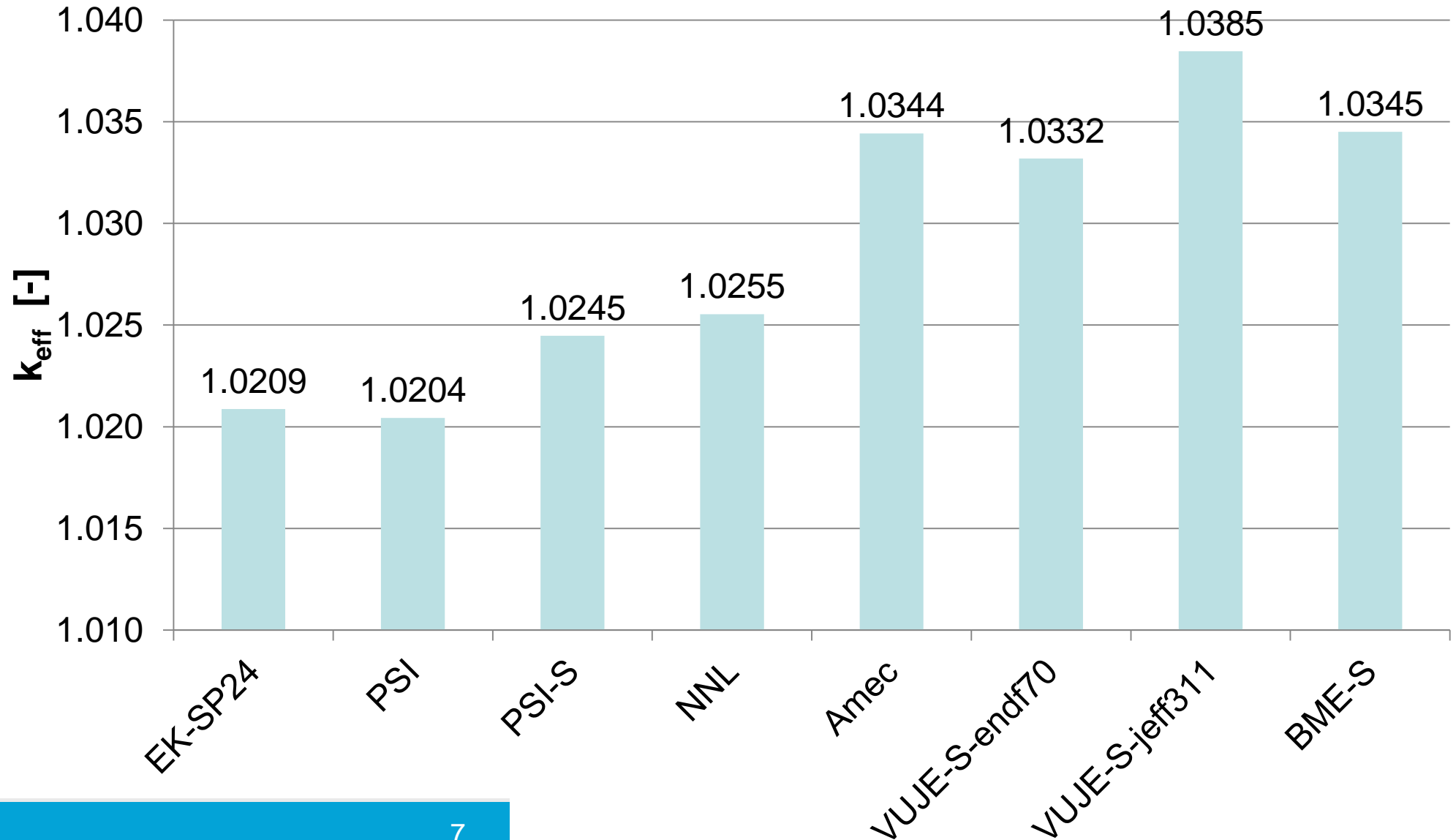
AmecFW - Amec Foster Wheeler (ECCO, JEFF3.1.2 )

VUJE-S endf70 - VUJE, a.s. (SERPENT 2.1.21, ENDF/B –VII.0)

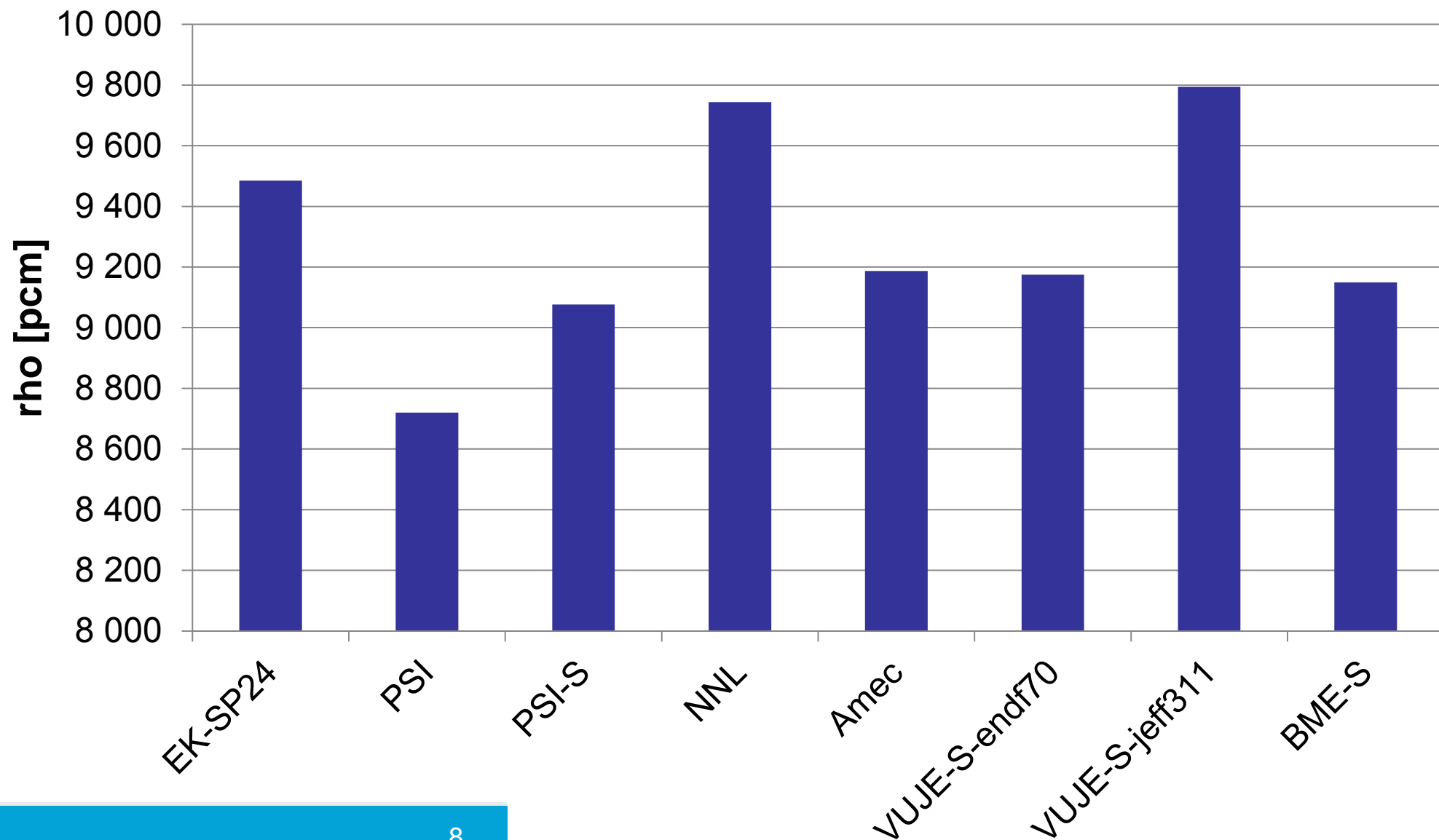
VUJE-S jeff311- VUJE, a.s. (SERPENT 2.1.21, JEFF 3.1.1)

BME-KIKO - Hungarian Academy of Sciences Centre For Energy Research (KIKO, JEFF3.1)

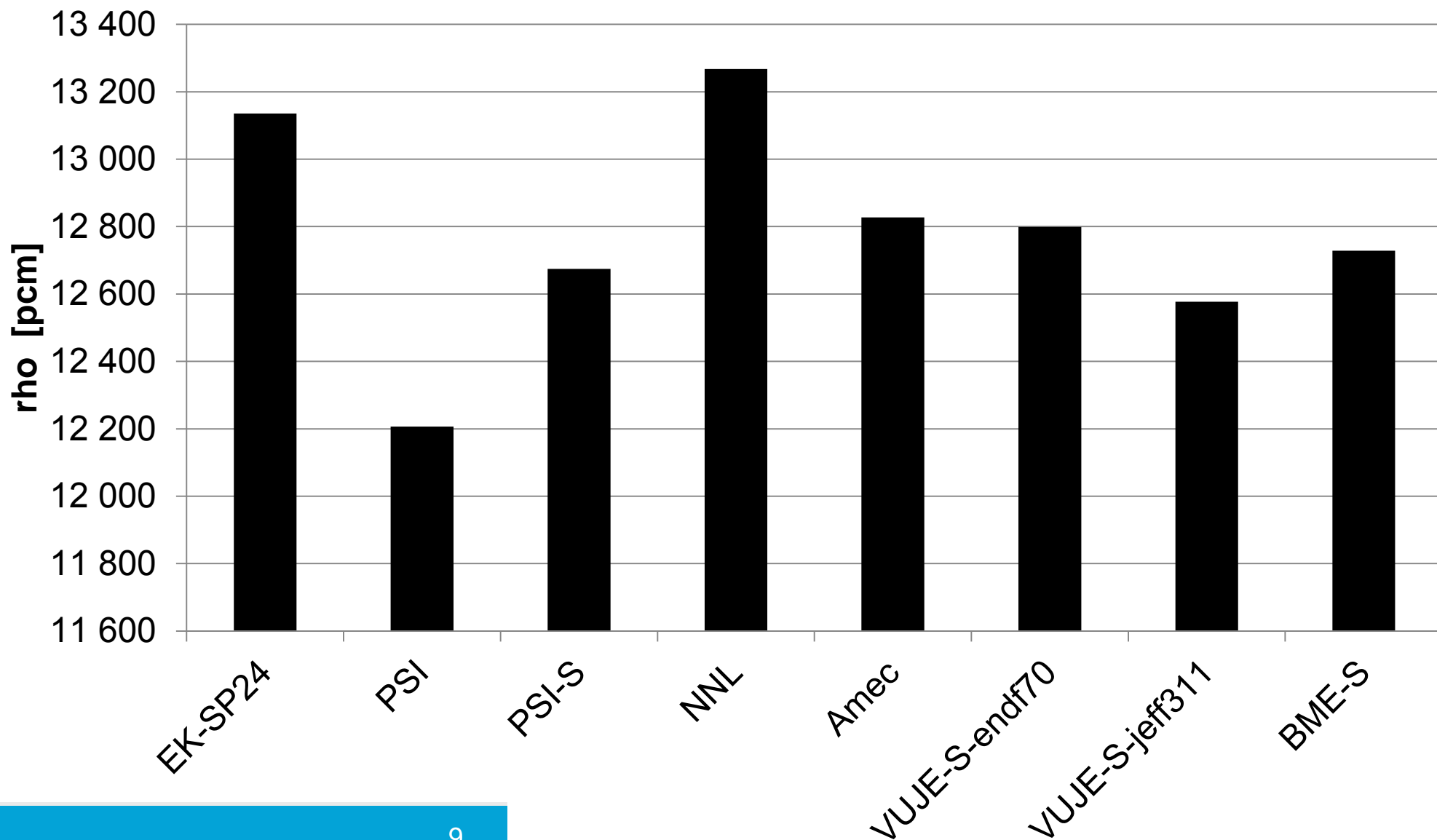
## Effective multiplication factors



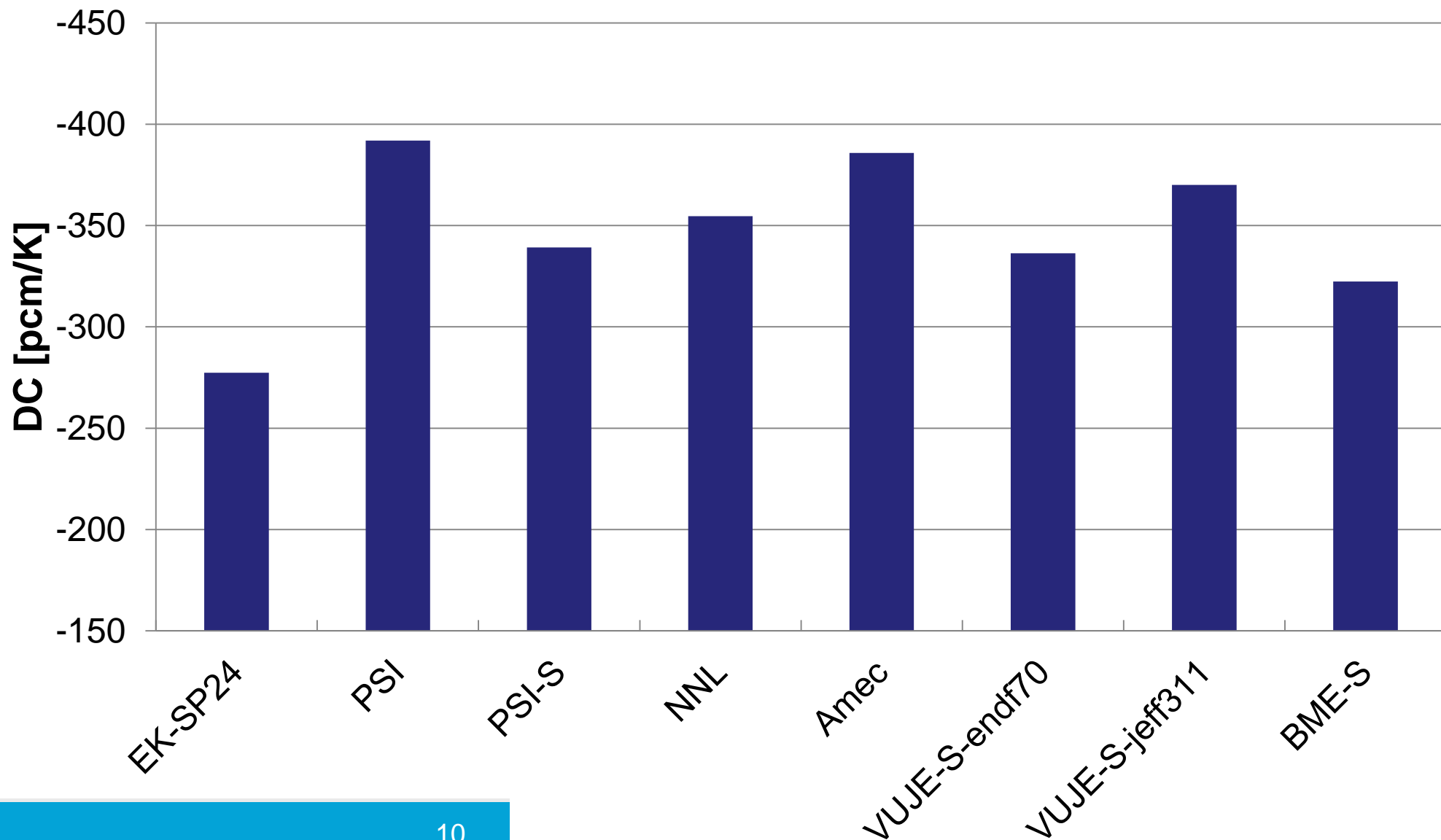
# Total CSD reactivity worth [pcm]



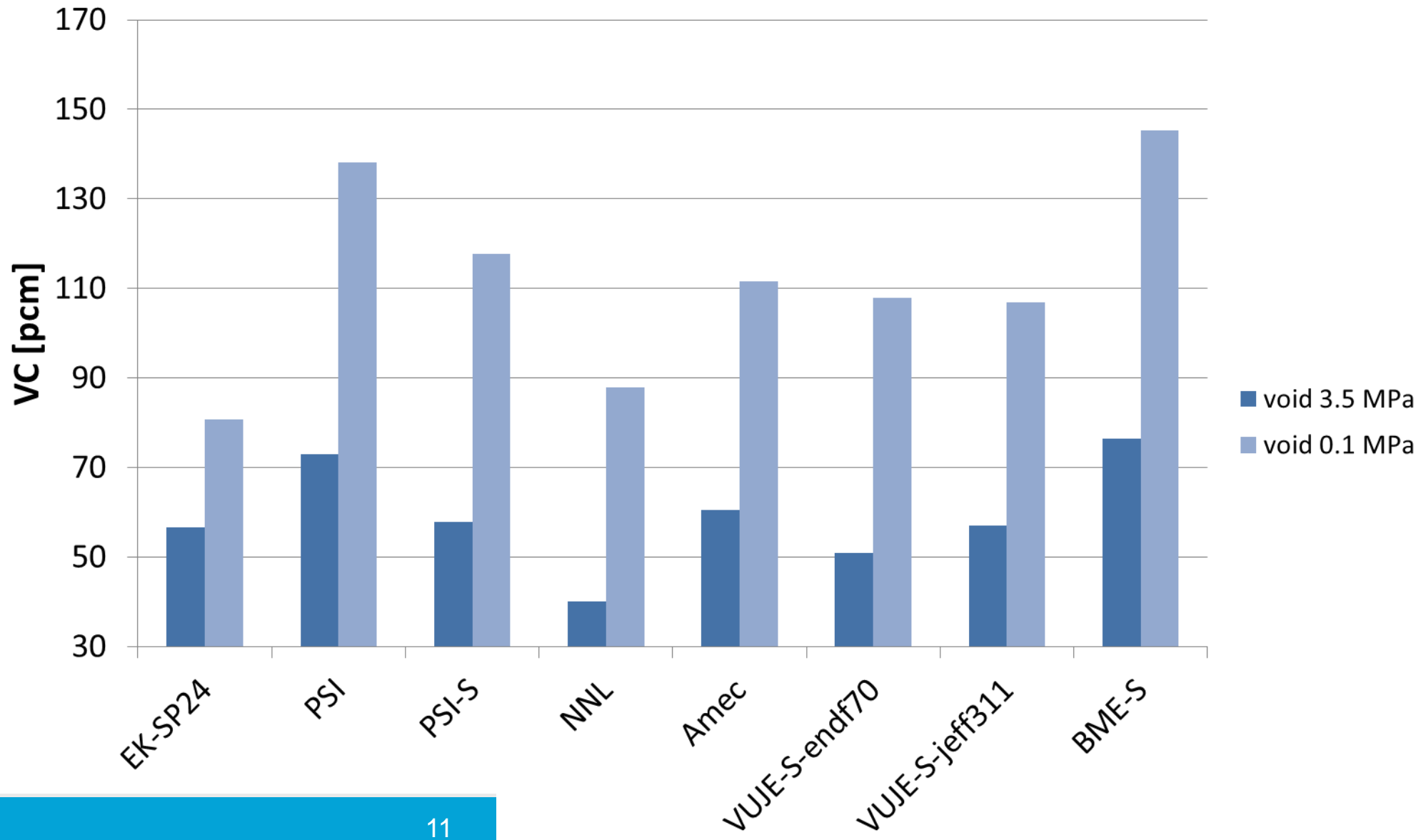
## CSD+DSD worth (Scram)



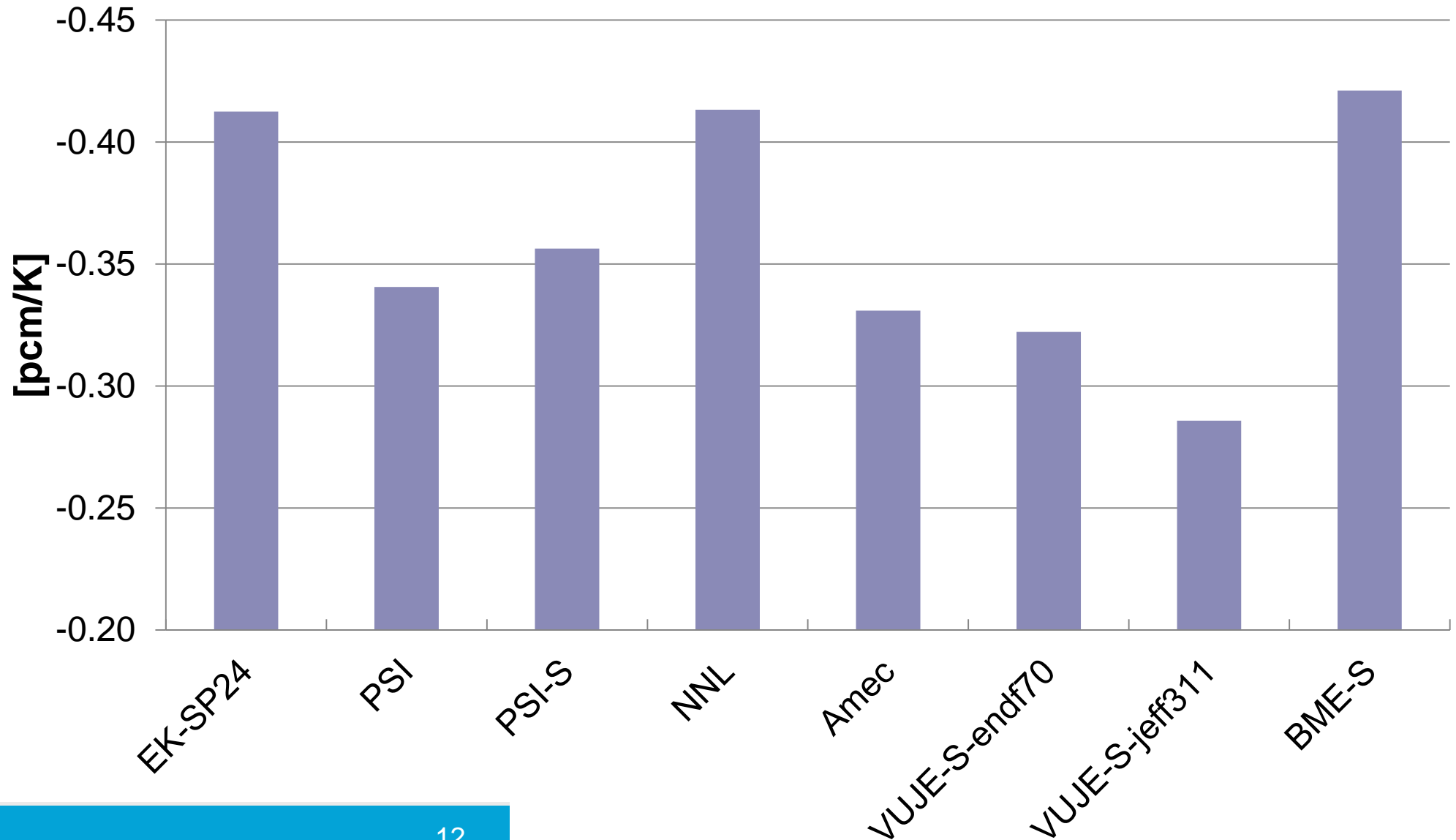
## Doppler coefficient



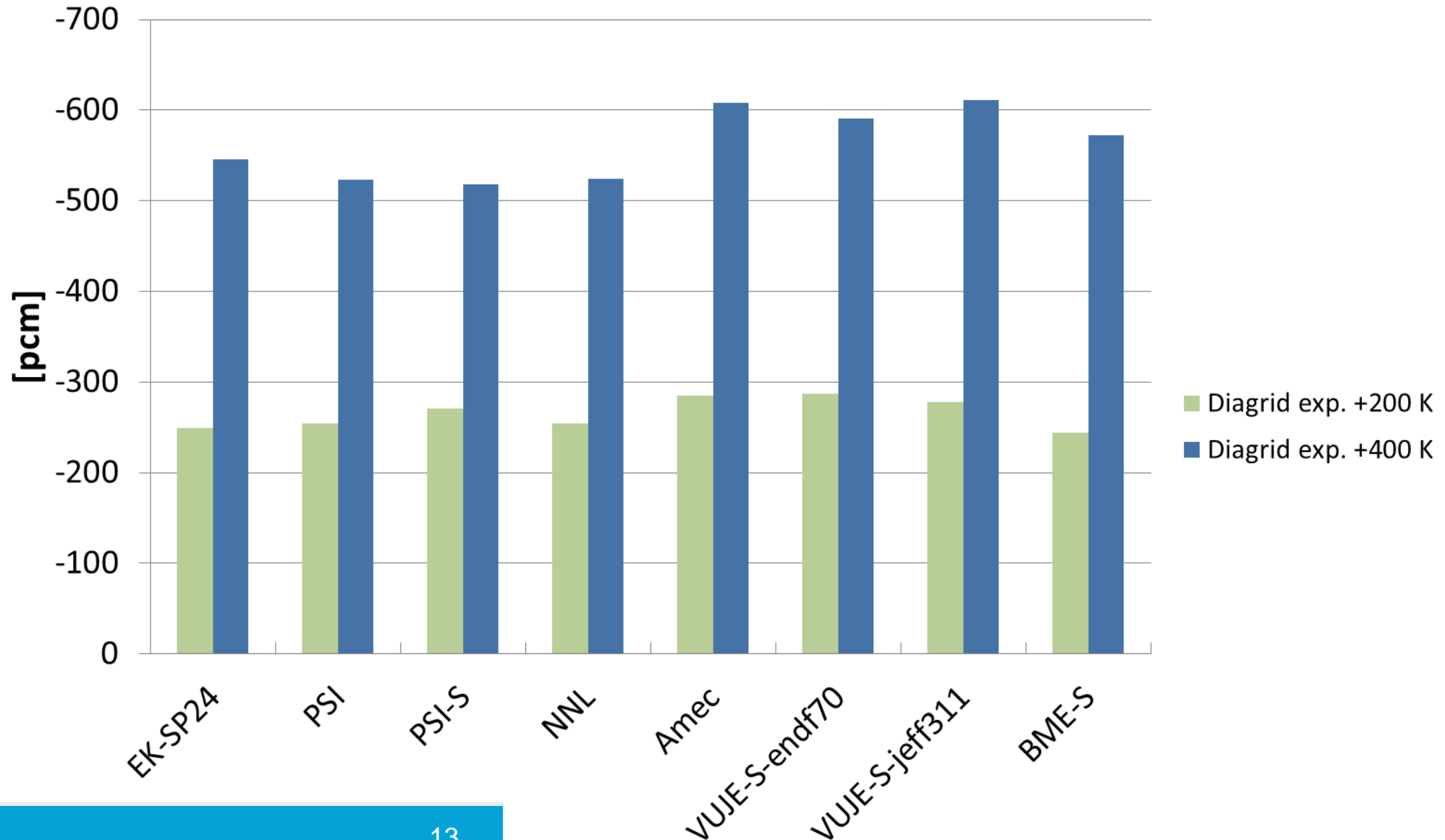
**VOID**



# Fuel expansion coefficient



**Diagrid expansion reactivity increase**



## Results of ESNII+ ALLEGRO whole core benchmark:

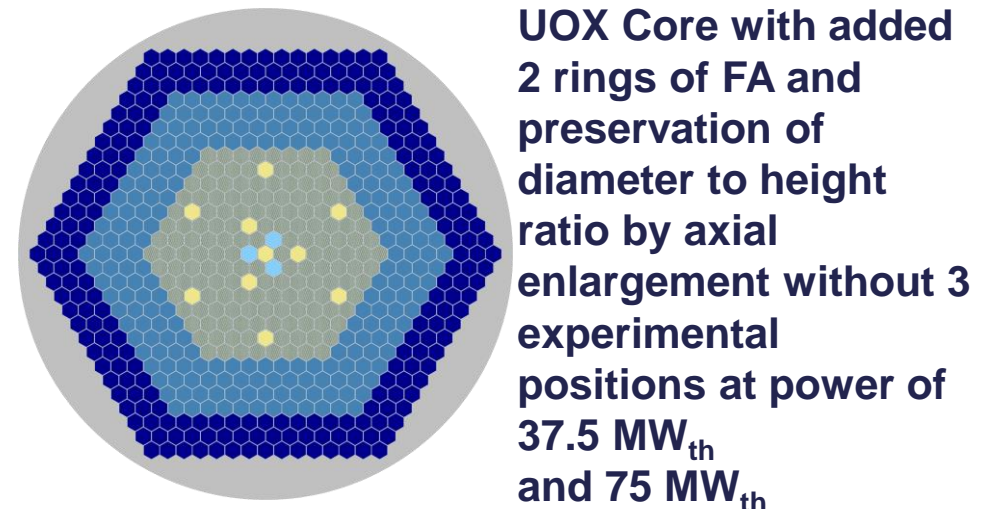
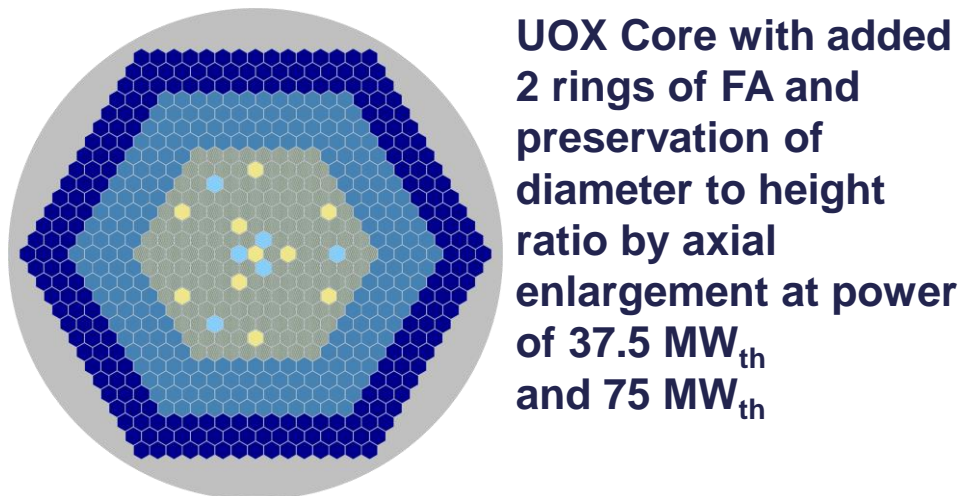
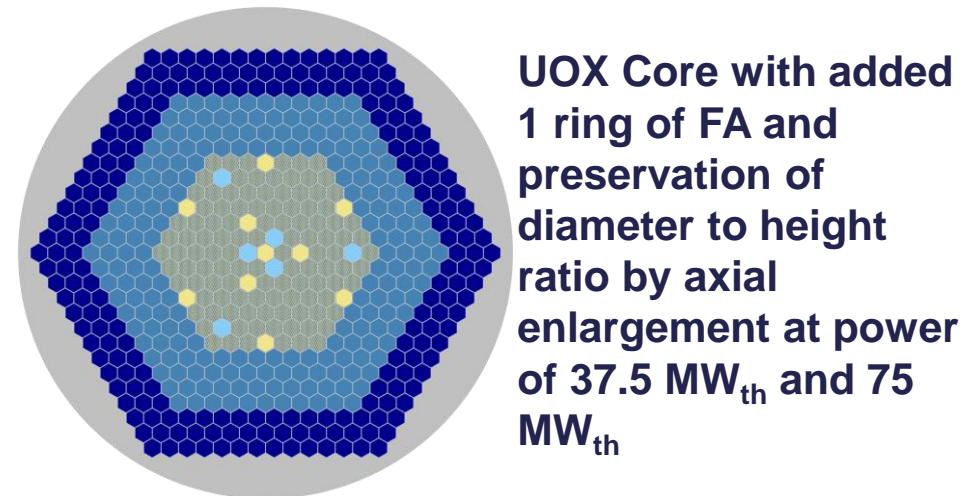
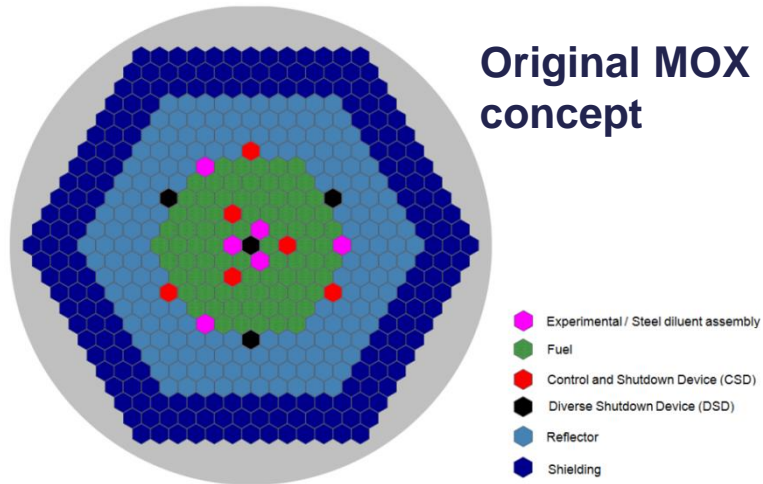
The obtained deviations characterize the user effects, the modeling uncertainties and the influence of the nuclear data differences altogether, without the possibility of their separation because of the complexity of the benchmark problem.

To identify the reasons of the deviations a step by step procedure is necessary by starting from simple problems (homogenous material, Wigner-Seitz cell in asymptotic approach, SA in asymptotic approach, etc.).

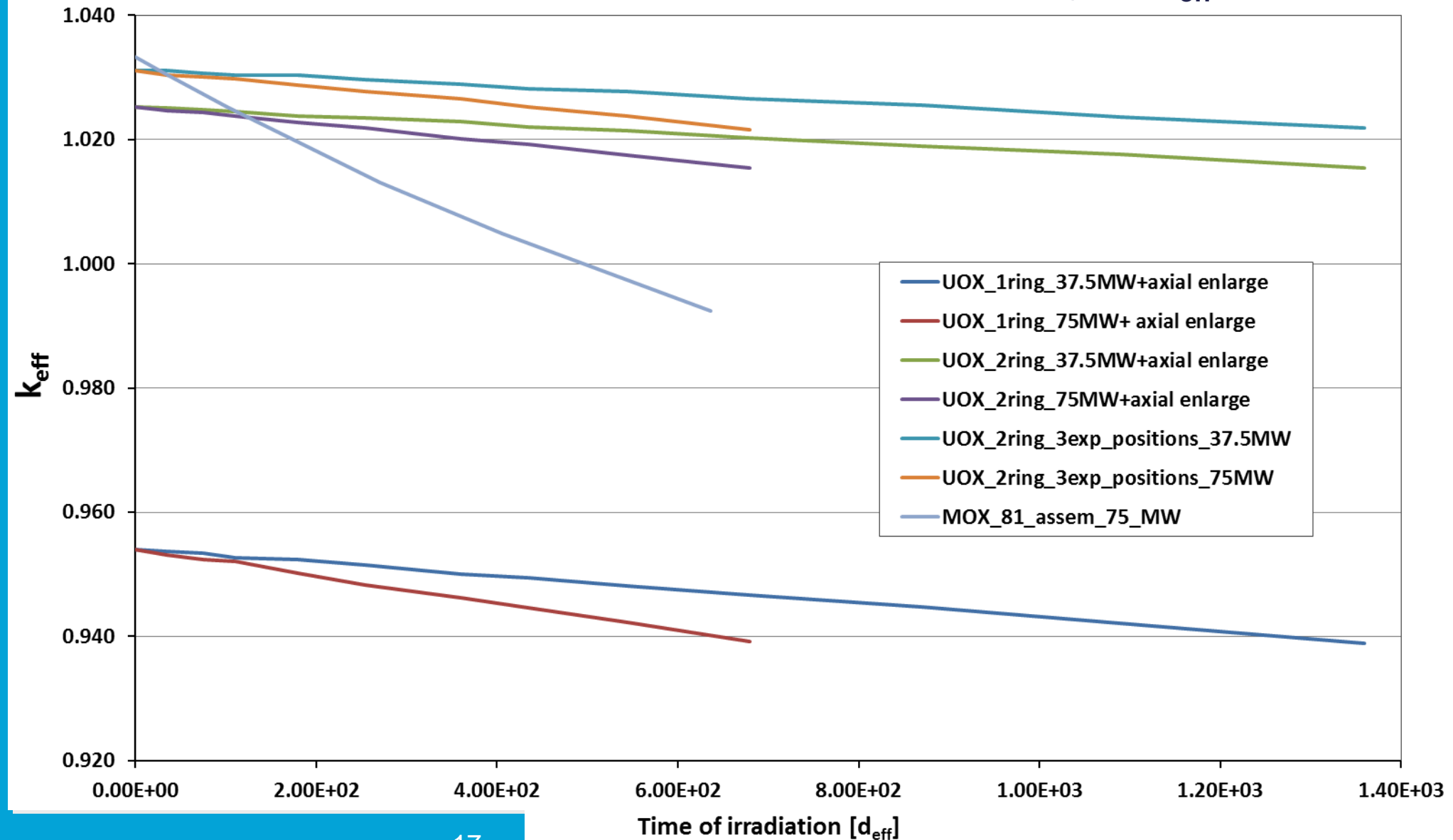
## Optimization of the ALLEGRO core.

- Replacement of the ALLEGRO MOX core by UOX core with max. 20% enriched uranium, would bring much easier fuel supply and both non-proliferation and qualification issues would be much simpler.
- The oxide driver core must be designed to deliver adequate conditions in terms of neutron flux, neutron spectrum, dpa and temperature.
- Aim of this activity was investigation of the ALLEGRO UOX core feasibility options.

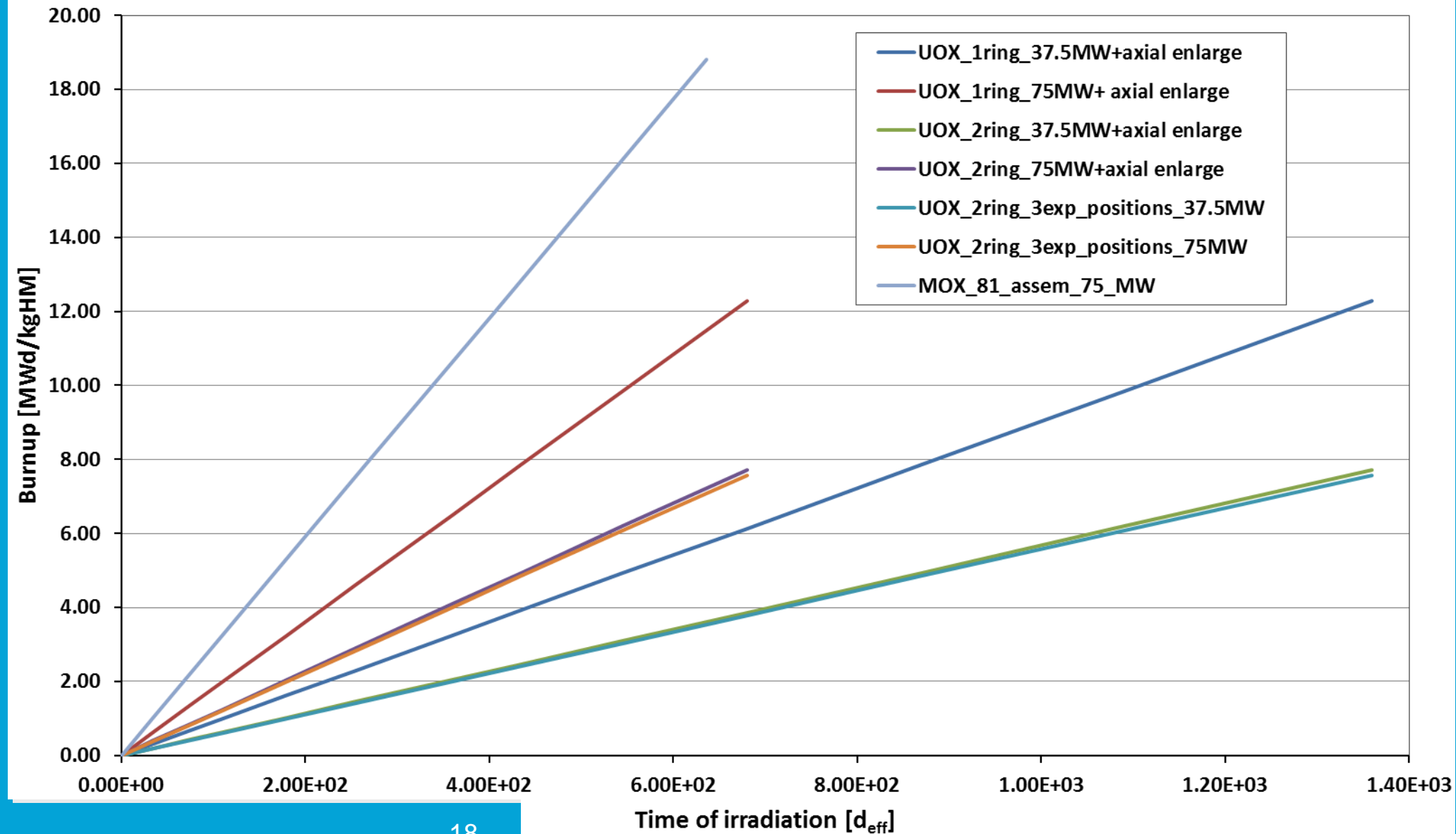
## Design scenarios to explore the feasibility of an ALLEGRO UOX core:



# Irradiation time dependency of $k_{eff}$



## Irradiation time dependency of burnup



## **ALLEGRO core optimisation conclusions**

- **Enlargement of the UOX core by one fuel ring is insufficient compared to the original MOX core – low value of  $k_{\text{eff}}$ ,  $k_{\text{eff}} < 1$**
- **Enlargement by two UOX rings results to equalisation of reactivity reserve in comparison to the MOX core**
- **Irradiation abilities of enlarged UOX core are at least two times worse than of MOX core**

## VINCO project

**The main objective is to conduct a variety of capacity building activities aiming at strengthening the coordinating role of the “V4G4 CoE” and supporting its member organizations.**

**Participants: MTA EK (Hungary), UJV (Czech Republic), VUJE (Slovakia), NCBJ (Poland), CEA (France), CVR (Czech Republic)**

As was mentioned in the results of ALLEGRO ESNII+ to minimize the user effects, the most simple heterogeneous unit of the reactor, a pin surrounded by the hexagonal cell needs to be calculated. (Calculation of the assembly would raise the very similar modeling problems.)

## VINCO benchmark

2D one fuel pin, reflective boundary condition

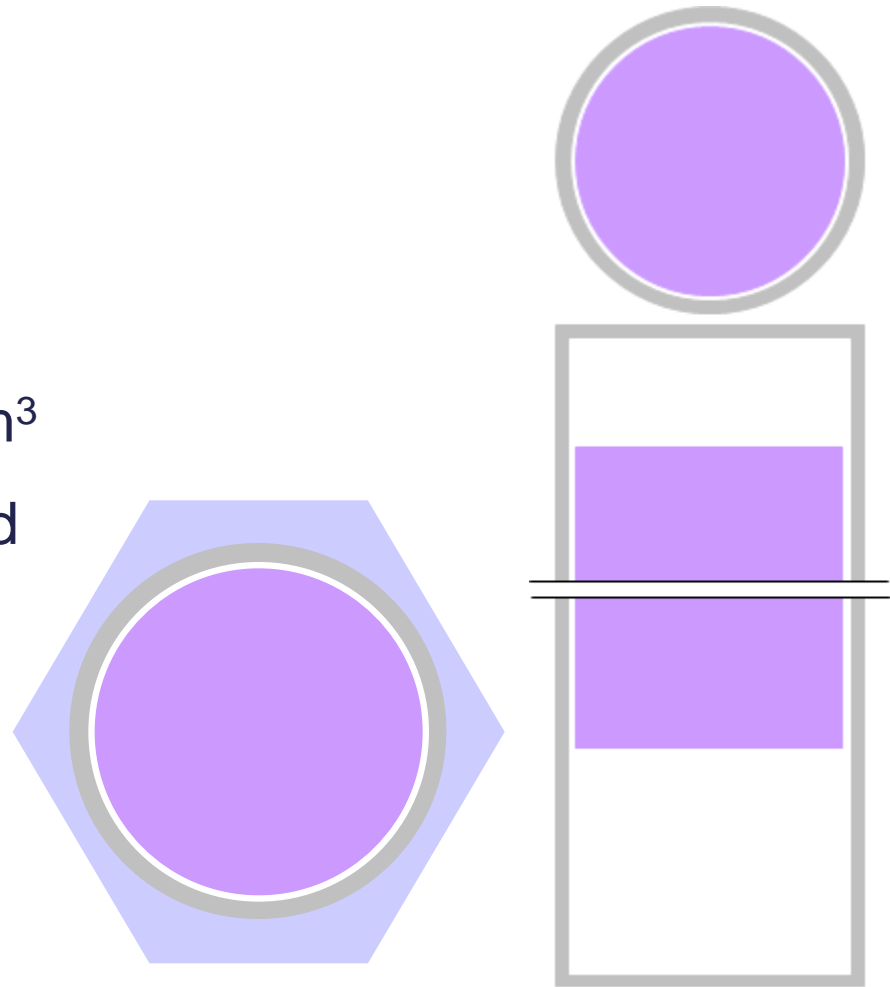
fuel: MOX and UOX

burnup is to be followed up to 75 MWd/kgU at power density 50 W/cm<sup>3</sup>

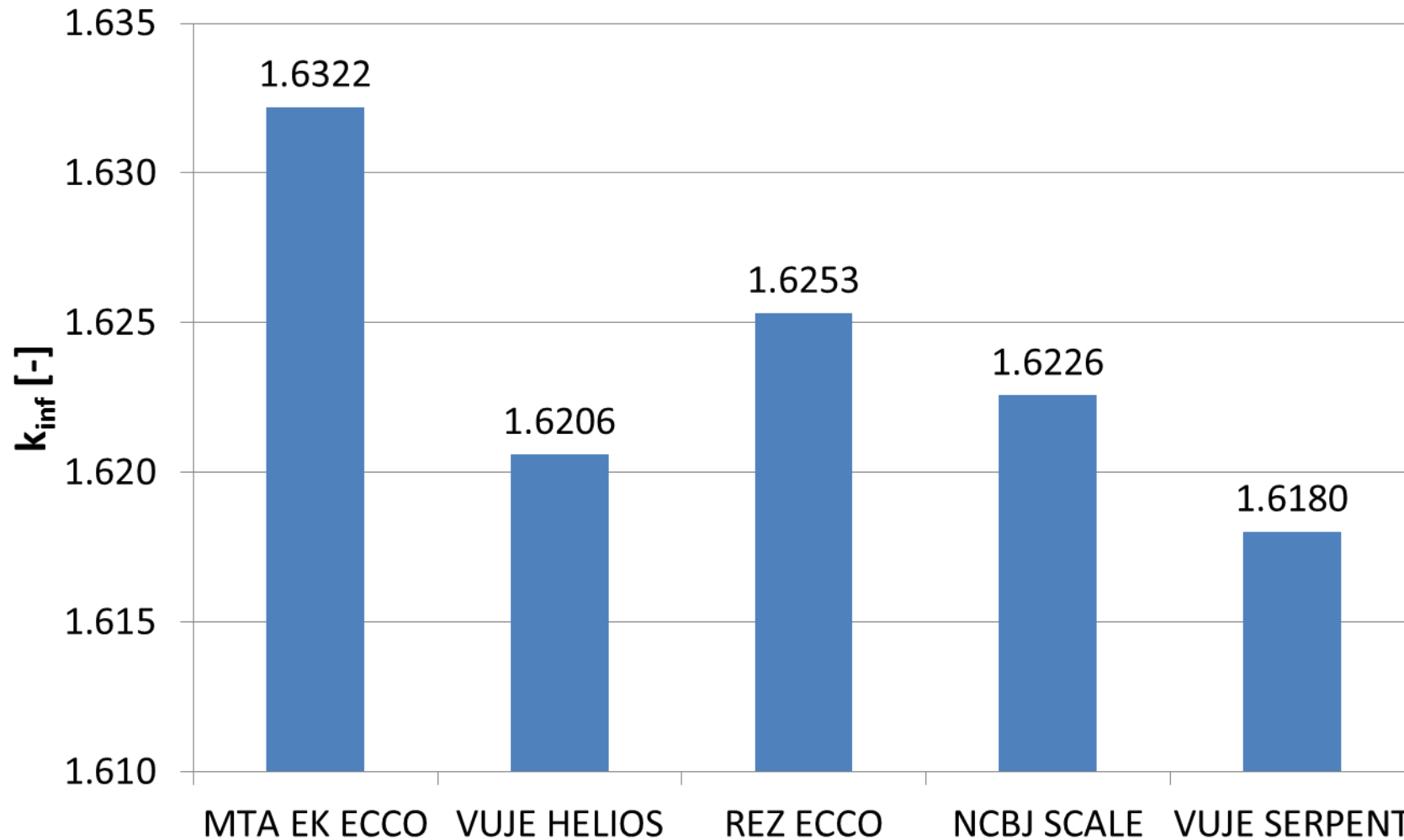
Calculation of  $k_{eff}$  is defined by fixed buckling.

Branches:

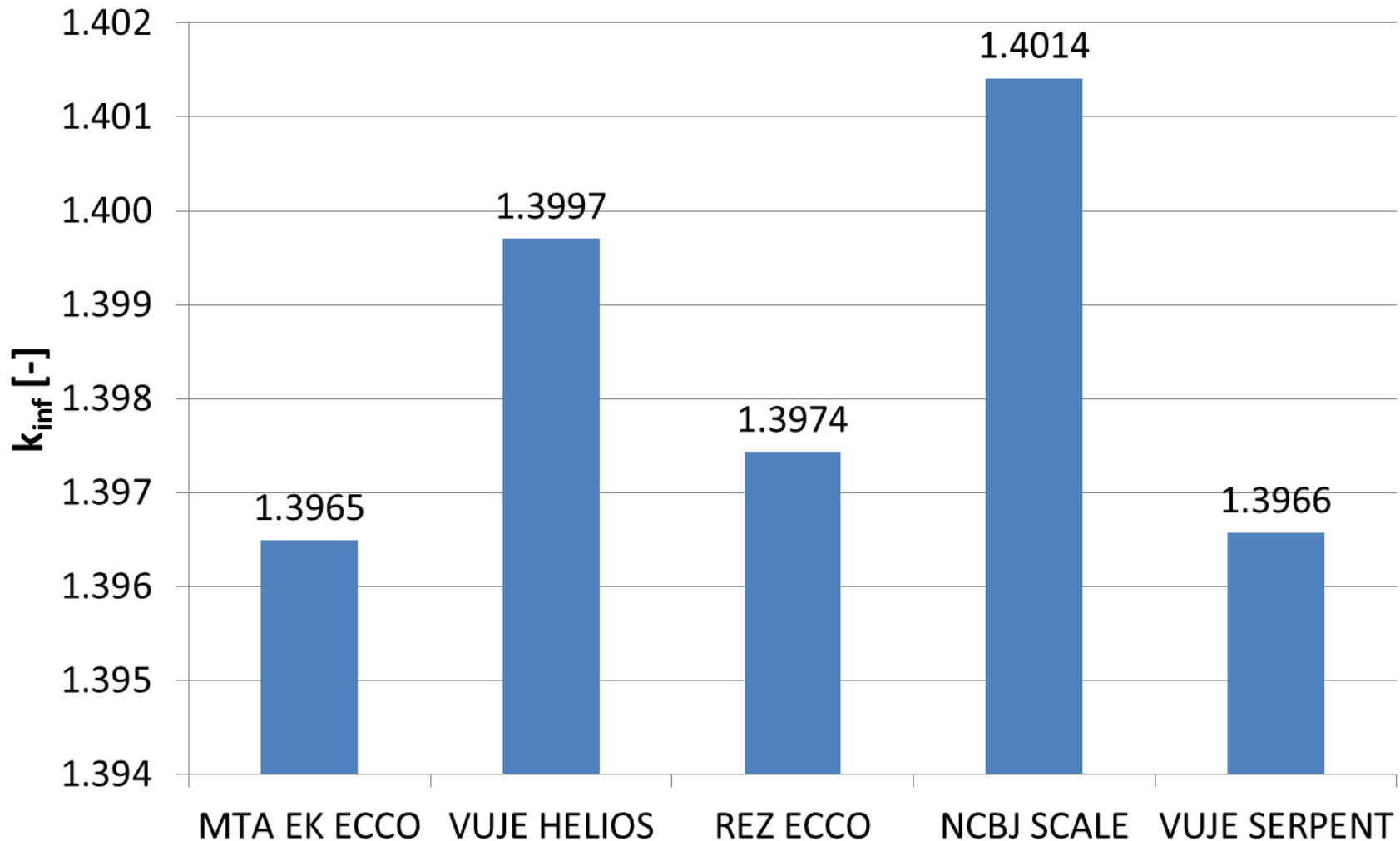
- change of fuel temperature
- change of pin diameter and fuel density
- change of coolant density



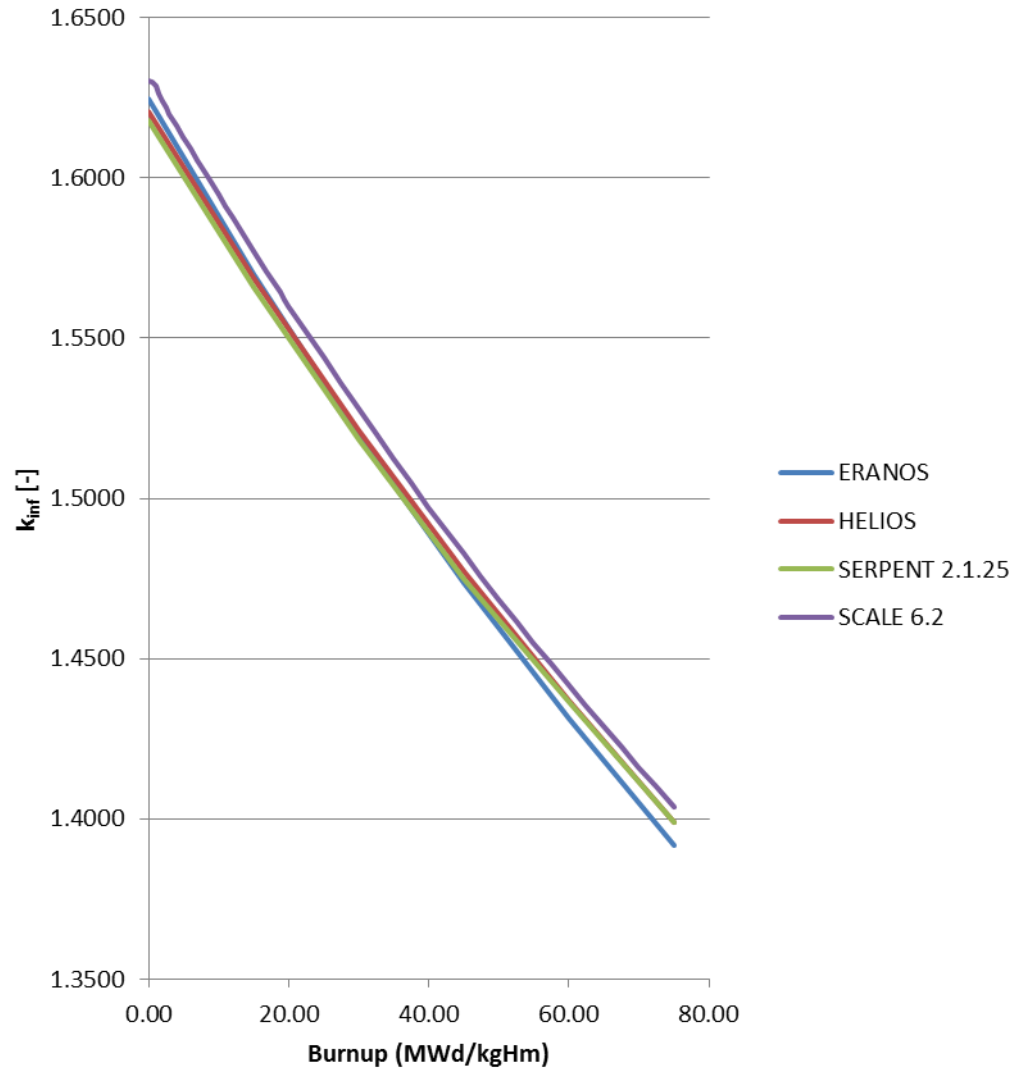
## Infinite multiplication factors at zero burn up for MOX



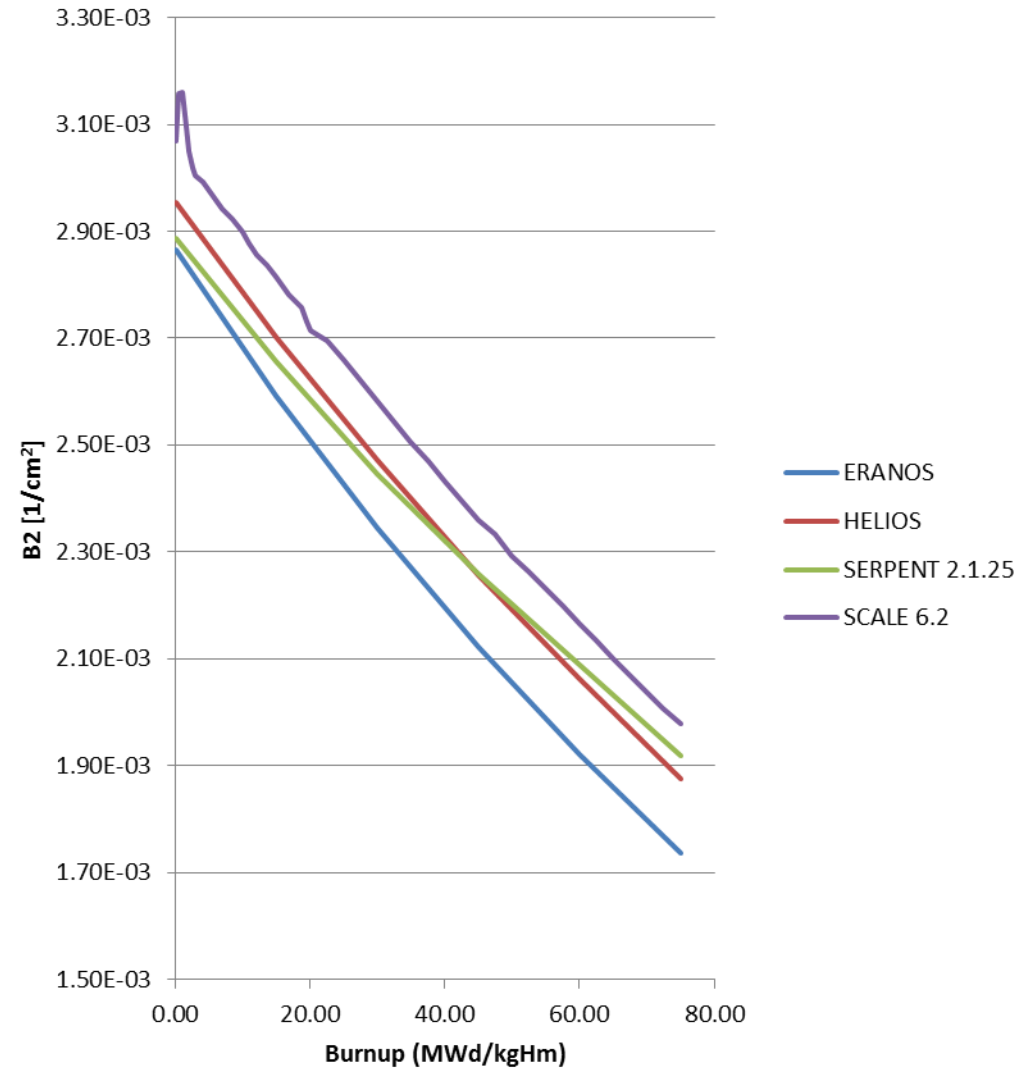
## Infinite multiplication factors at zero burn up for UOX



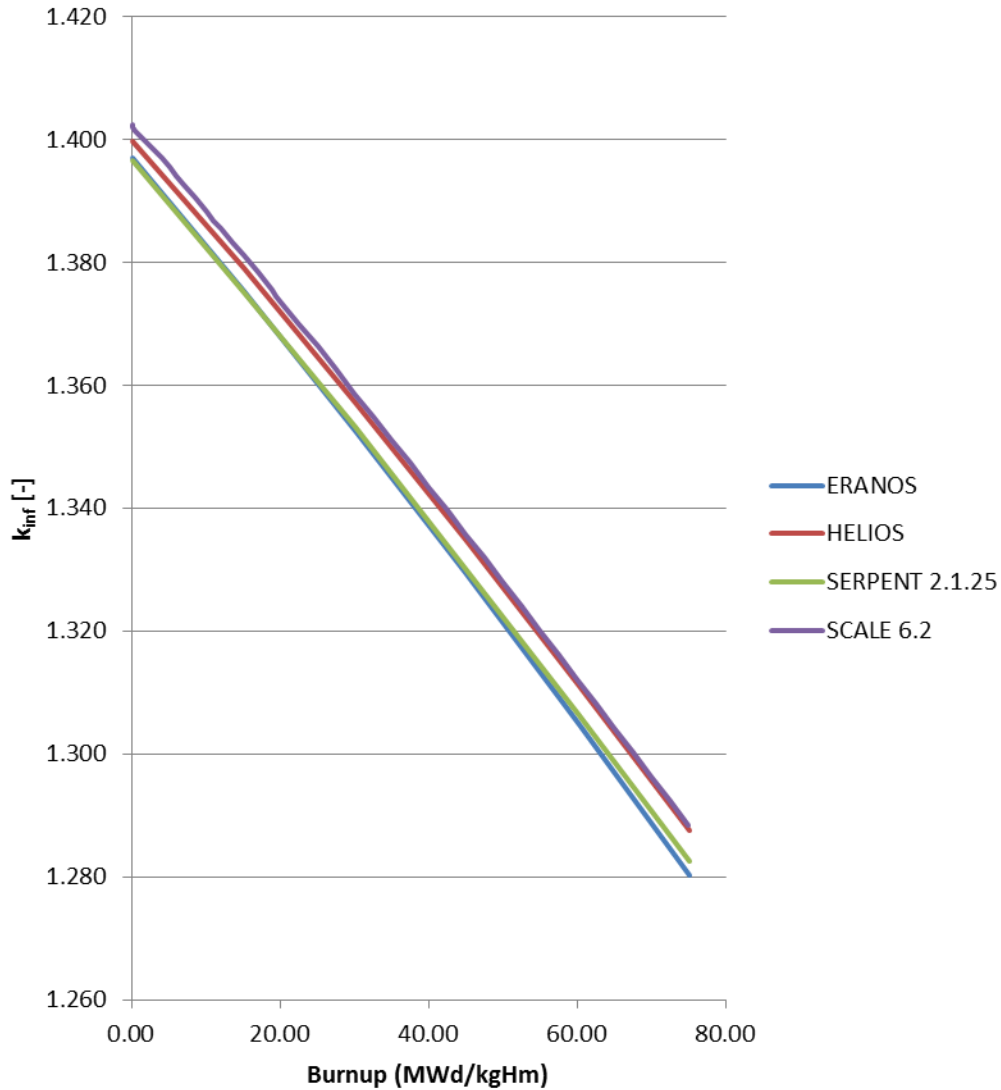
## Infinite multiplication coefficient MOX



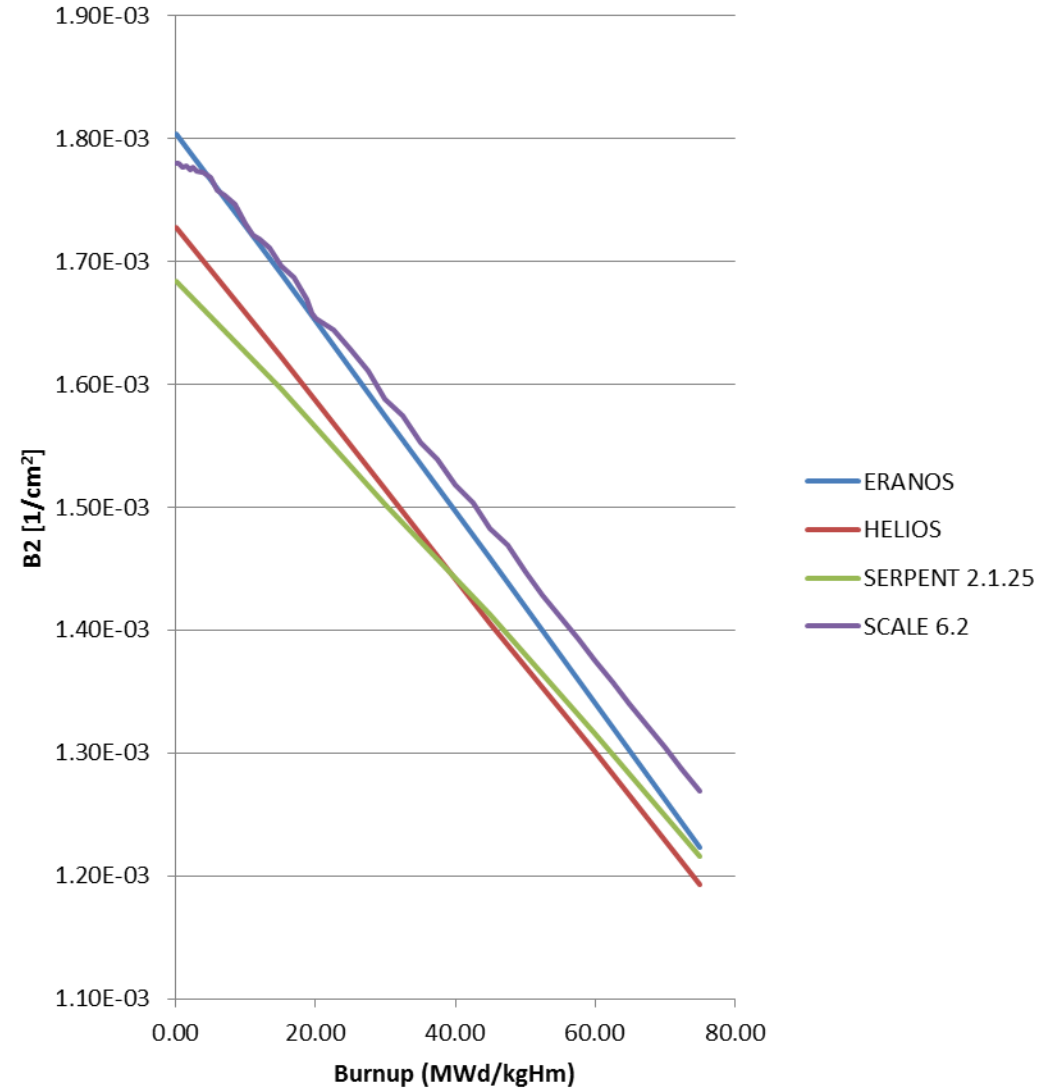
## Calculated buckling for MOX



## Infinite multiplication coefficient UOX



## Calculated buckling for UOX



## Conclusions of VINCO Project

- SERPENT code has no ability to fix buckling (B2) so  $k_{inf}$  values are shown only
- In case of MOX the SERPENT curve of buckling (B2) is crossing the others dependences significantly – the reason is unknown at present
- Now the second phase is running of benchmark focused on 2D MOX, UOX assembly analyses –  $k_{inf}$ , reactivity coefficients, kinetic parameters and group constants

## Full-core VVER-440 pin power distribution calculation benchmark

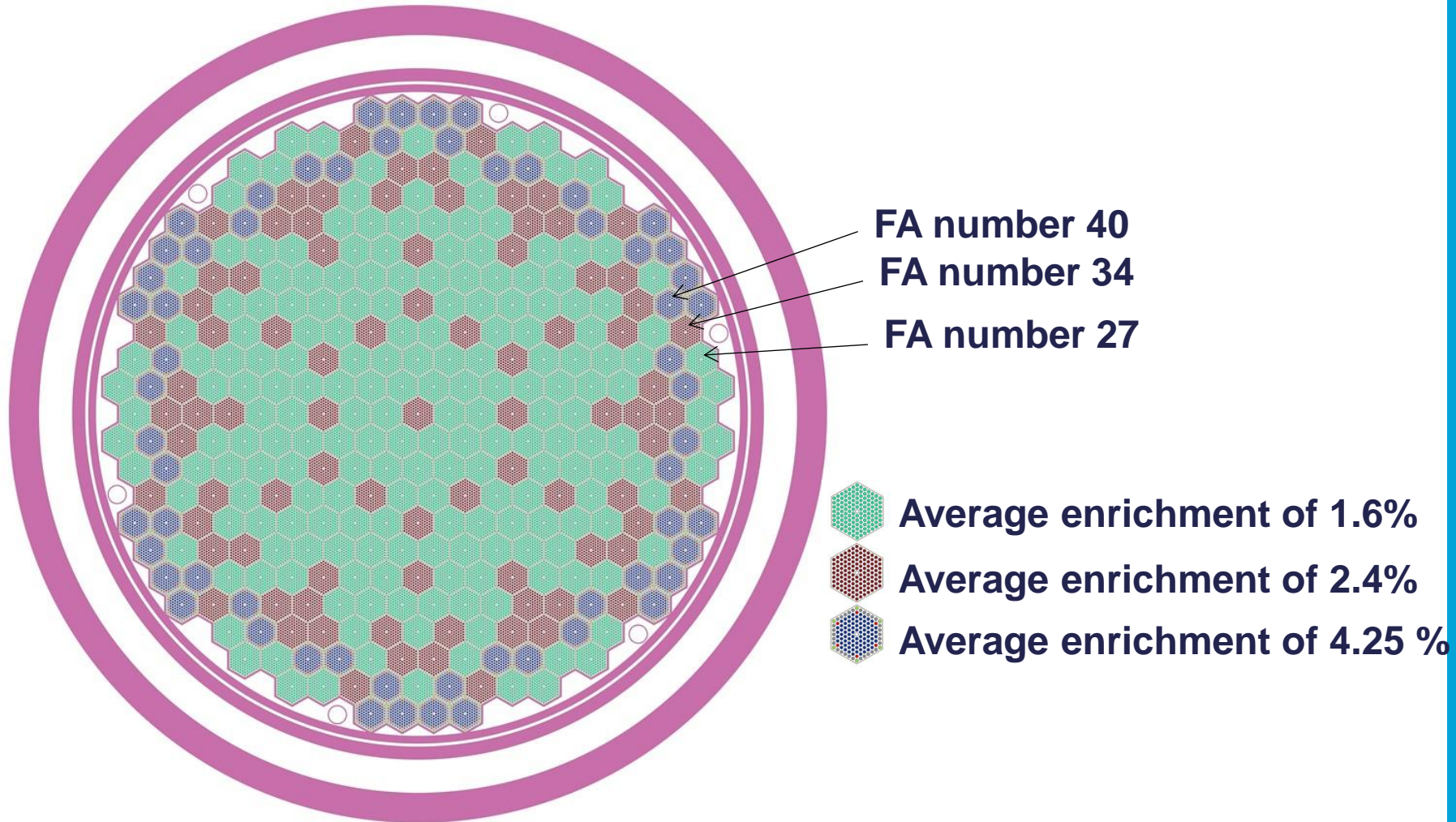
The 'Full-Core' benchmark is a 2D calculation benchmark based on the VVER-440 reactor core cold state geometry with taking into the account the geometry of explicit radial reflector.

The main task of this benchmark is to test the pin by pin power distribution in fuel assemblies that are placed mainly at the border of the VVER-440 core.

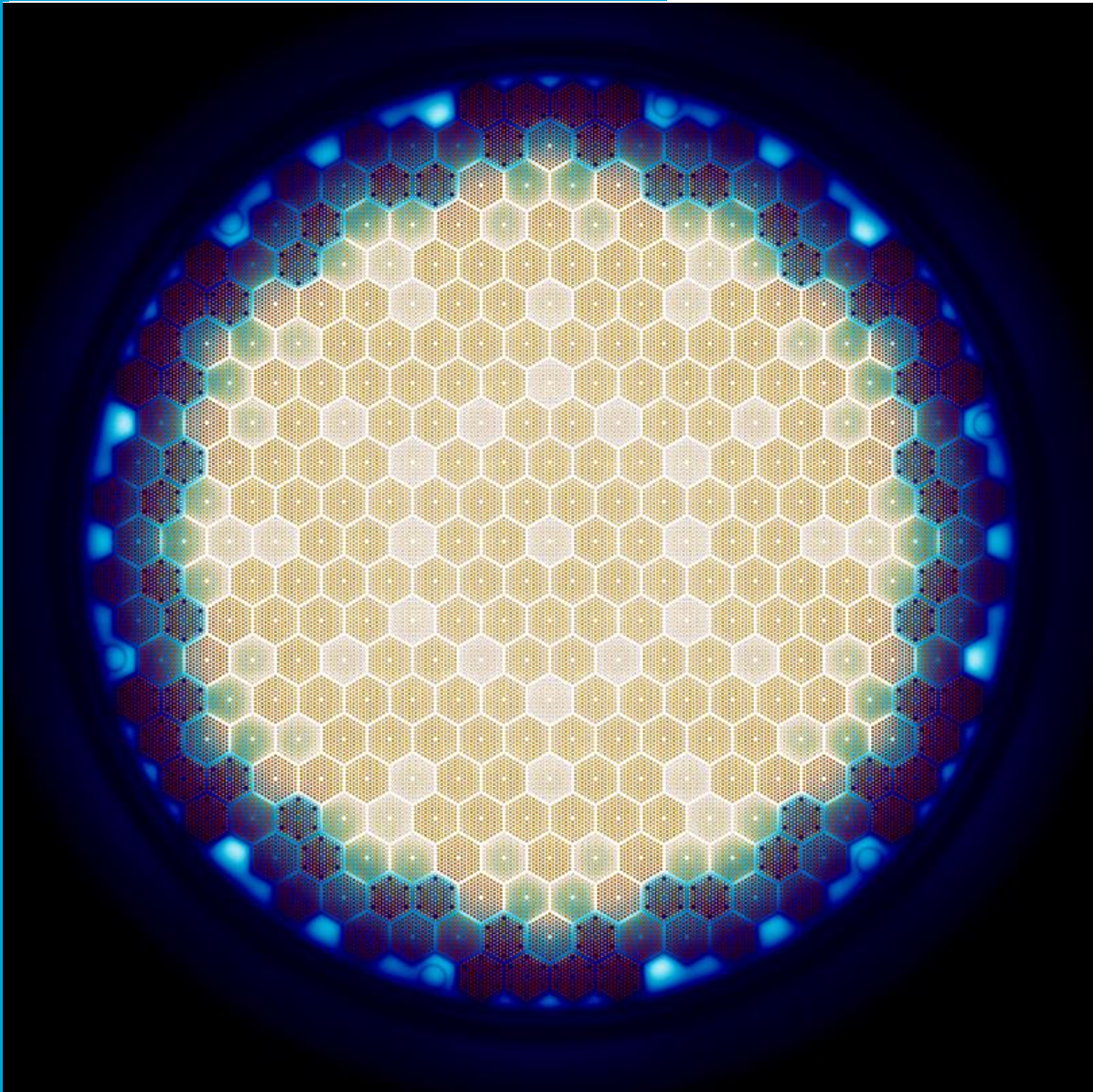
All necessary input data including material composition and dimension specification have been taken from [1]. The dimensions have been taken from the cold state geometry. Although the benchmark specification for temperature of FA's and moderator was 543.15 K we used the temperature 600 K.

*[1] V. Krýsl, P. Mikoláš, D. Sprinzl, J. Švarný: 'Full-Core' VVER-440 pin power distribution benchmark proposal. Proceedings of the AER Symposium 2011*

## Loading pattern of fresh FA at the Full-Core model



## Power distribution for the Full-Core model



Referential calculation by  
MCNP-4C code,  
ENDF/B-VI library,  
temperature 543.15 K,  
200 mil. nps and 200 000 n. per  
generation,

$$k_{\text{eff}} = 1.09216 \quad \sigma = 4\text{E-}05$$

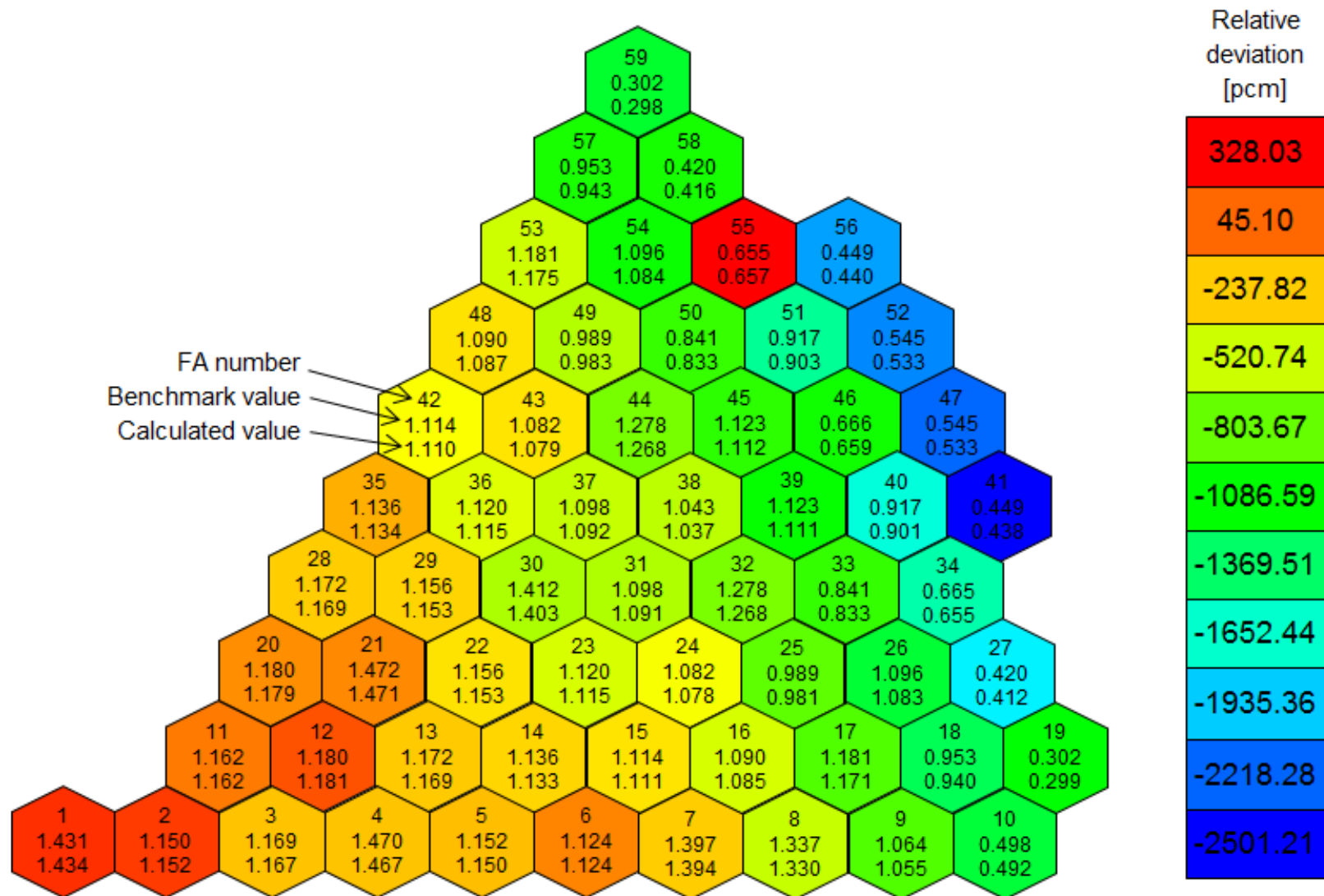
Serpent 2.1.25

3 500 000 n. per generation and 500  
active cycle,

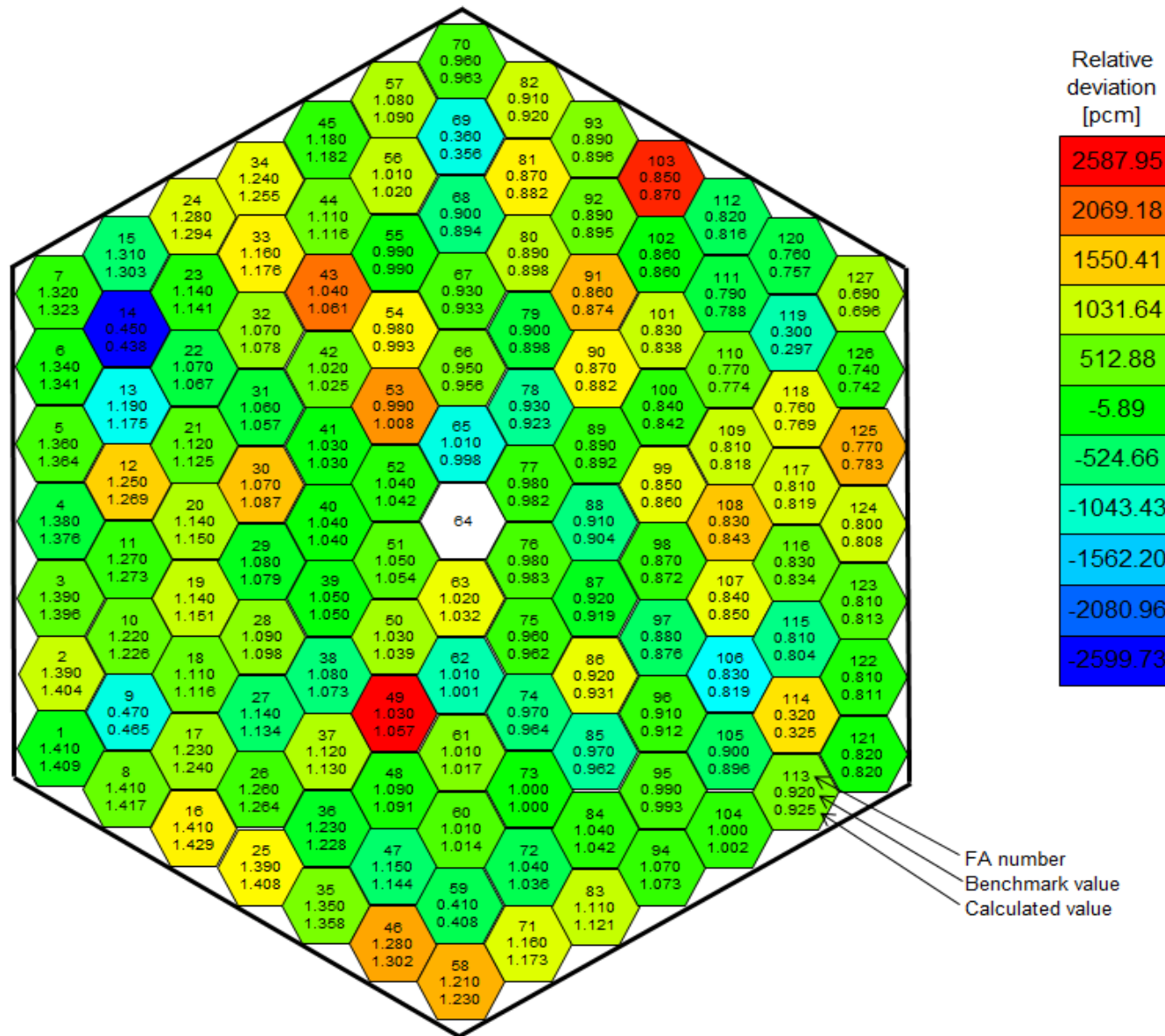
ENDF/B-VII.0 library,  
temperature 600 K,

$$k_{\text{eff}} = 1.08652\text{E}+00 \quad \sigma = 1.3\text{E-}05$$

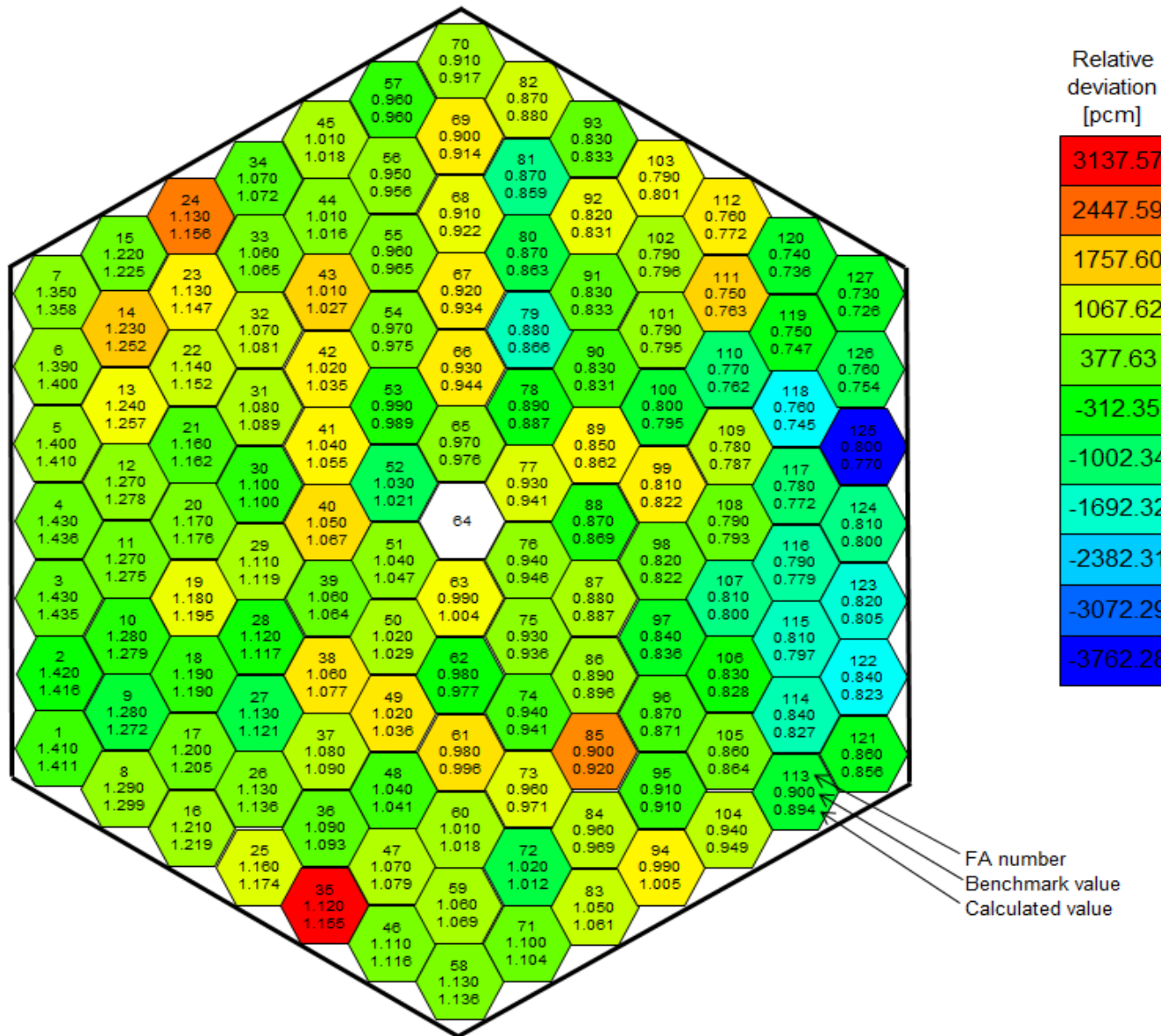
**In this presentation are shown  
the preliminary results of this  
benchmark only because the  
model and analysis are still  
under improvements**



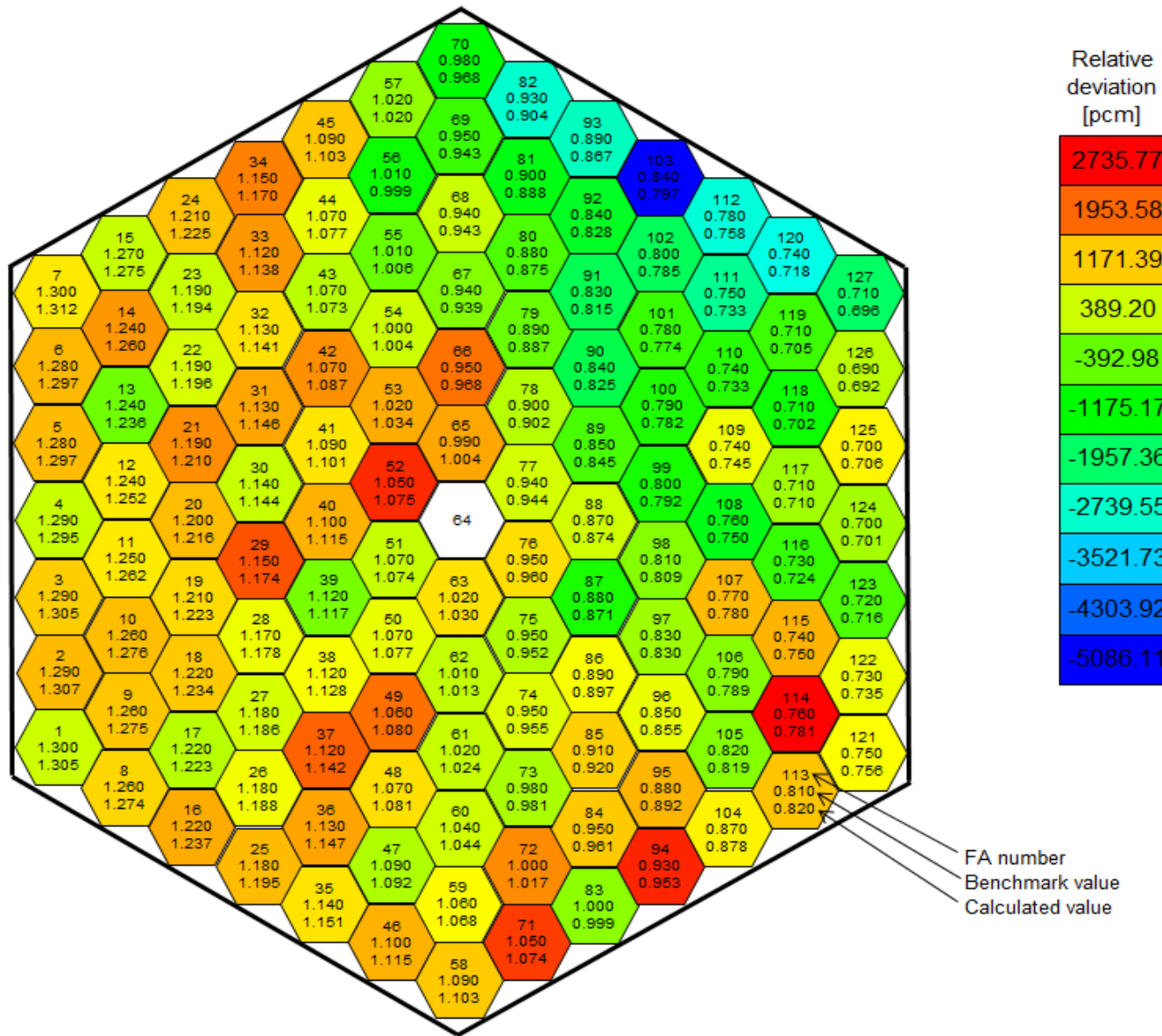
## Relative pin power distribution for FA no. 40 (4.25 %)



## Relative pin power distribution for FA no. 34 (2.4 %)



## Relative pin power distribution for FA no. 27 (1.6 %)



## Summary

**SERPENT code has been used at VUJE, a. s. for research activities only:**

- **ALLEGRO Project:**
  1. **ESNII+ Project**
  2. **ALLEGRO Core Optimisation**
  3. **VINCO Project**
- **Full-core VVER-440 pin power distribution calculation benchmark**

**Thank you  
for your attention**

**VUJE, a.s.**

**Okružná 5  
918 64 Trnava  
Slovak Republic**

[www.vuje.sk](http://www.vuje.sk)  
[tomas.chrebet@vuje.sk](mailto:tomas.chrebet@vuje.sk)

