OAK RIDGE National Laboratory

Preliminary SCALE Results for the OECD/NEA Benchmark for Uncertainty Analysis in Modeling of SFRs

Friederike Bostelmann, Bradley T. Rearden

Reactor and Nuclear Systems Division

Oak Ridge National Laboratory

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

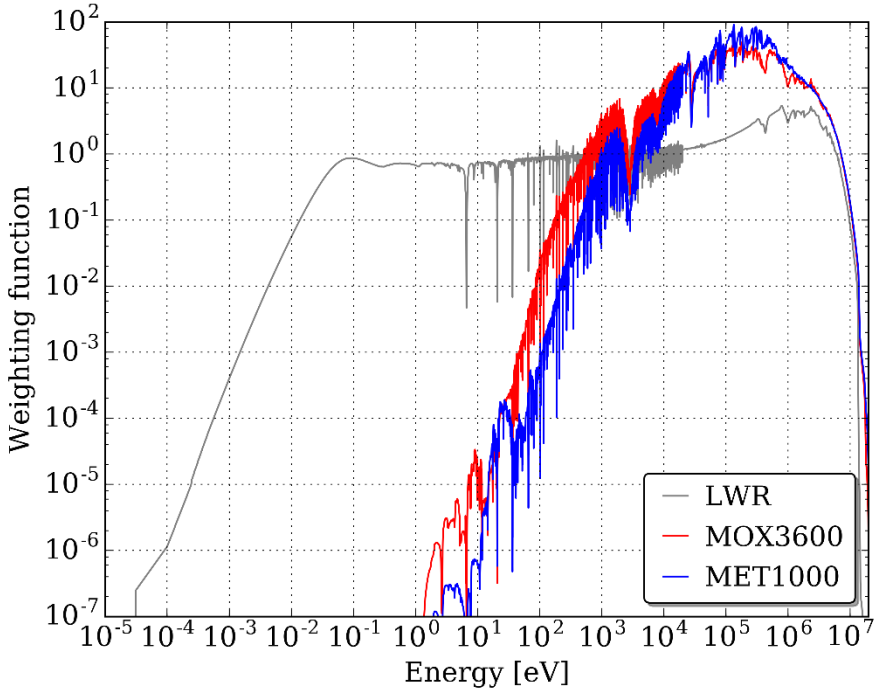
2nd SCALE Users' Group Workshop,
August 27-29, 2018, ORNL

Introduction

- In the United States, interest is growing in advancing modeling and simulation capabilities for advanced reactor systems
- The SCALE 6.2.3 code package offers a number of transport sequences and different methods for uncertainty and sensitivity analyses
- SCALE is part of the US Nuclear Regulatory Commission (NRC) licensing path that will soon be confronted with advanced reactor systems
- As part of ongoing activities for advanced reactor systems, calculations for the sub-exercises of the UAM-SFR are performed using a variety of SCALE modules

Introduction

- With SCALE 6.2, only multigroup libraries optimized for thermal systems are shipped
- Preparation of sodium-cooled fast reactor (SFR) calculations using AMPX (shipped with SCALE 6.2)* include:
  - Generation of a new 302-group cross section with appropriate weighting spectrum and a group structure optimized for fast spectrum systems
  - Corresponding 302-group covariance library



Neutron flux of a typical light water reactor (LWR) pin cell and SFR assemblies [1]

[1] F. Bostelmann, W. Zwermann, A. Pautz, "SCALE Covariance Libraries For Sodium-Cooled Fast Reactor Systems," Proc. PHYSOR 2018, Cancun, Mexico, April 22-26, 2018

*The major part of the library generation has been performed while affiliated with GRS in cooperation with ORNL.

Applied SCALE modules

TSUNAMI-2D

- Linear perturbation theory
- Transport solver NEWT
- 302g ENDF 7.1 XS data
- 302g SCALE 6.2 covariance data (mainly ENDF 7.1)

CE TSUNAMI

- Linear perturbation theory
- Transport solver KENO-VI
- CE ENDF 7.1 XS data
- 302g SCALE 6.2 covariance data (mainly ENDF 7.1)
- Eigenvalue uncertainties - CLUTCH
- GPT responses - GEAR (CLUTCH+IFP)

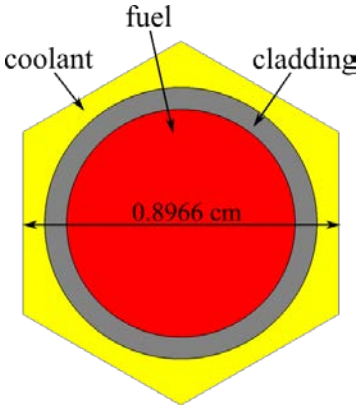
SAMPLER

- Random sampling approach
- Monte Carlo code KENO-VI
- 302g ENDF 7.1 XS data
- XS samples based on 302g SCALE 6.2 covariance data (mainly ENDF 7.1)

Ex. I-1: Pin cells

Eigenvalues and uncertainties

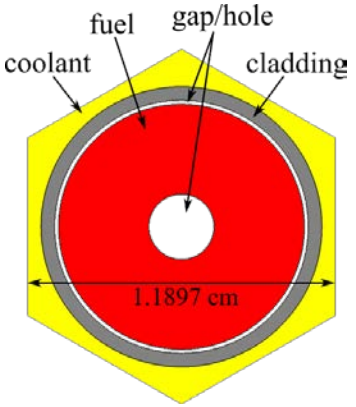
	MET1000		MOX3600	
	k_{inf}	$\Delta k_{inf}/k_{inf}$	k_{inf}	$\Delta k_{inf}/k_{inf}$
TSUNAMI-2D	1.3585	1.52%	1.1924	1.69%
CE TSUNAMI	1.3588(2)	1.52(2)%	1.1920(3)	1.71(1)%



MET1000

CE TSUNAMI: Top 3 contributors

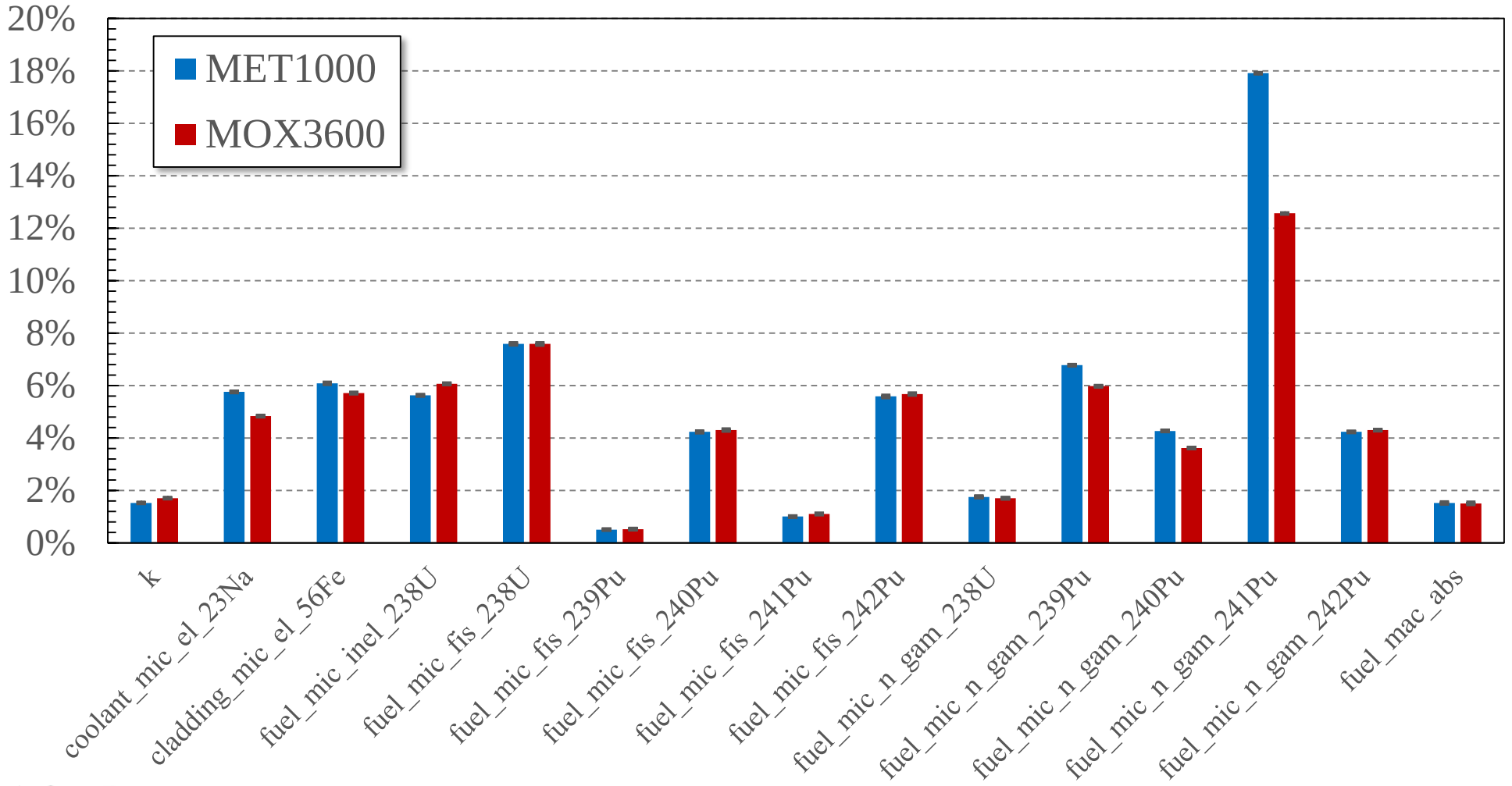
MET1000		MOX3600	
	$\Delta k_{inf}/k_{inf}$		$\Delta k_{inf}/k_{inf}$
U-238 inel.	1.35%	U-238 inel.	1.56%
Na-23 el.	0.28%	U-238 cap.	0.31%
U-238 cap.	0.23%	Pu-239 cap.	0.25%

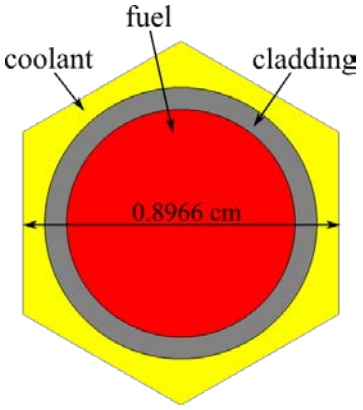


MOX3600

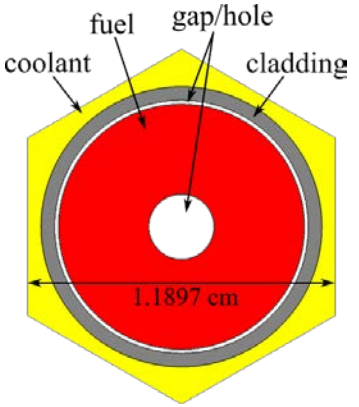
Ex. I-1: Pin cells

k-inf and 1-group xs uncertainties





MET1000

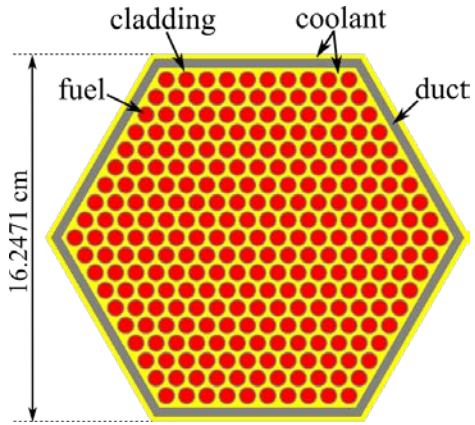


MOX3600

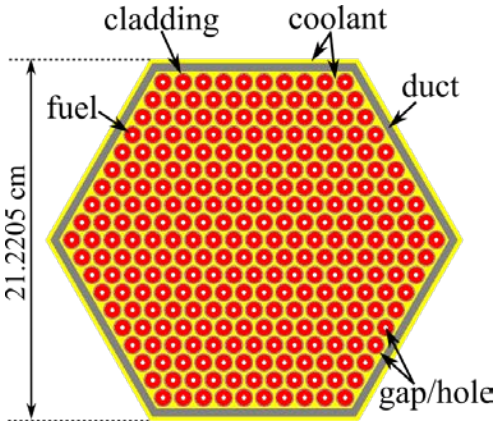
Ex. I-2: Fuel assemblies

CE TSUNAMI: nominal values and uncertainties

	MET1000		MOX3600	
	nominal	uncertainty	nominal	uncertainty
Eigenvalue	1.2800(1)	1.41(1)%	1.1467(1)	1.52(1)%
Doppler	-338(13) pcm	6.3(5)%	-781(21) pcm	5.2(3)%
Na-void	5895(9) pcm	5.47(1)%	2945(10) pcm	5.57(1)%



MET1000



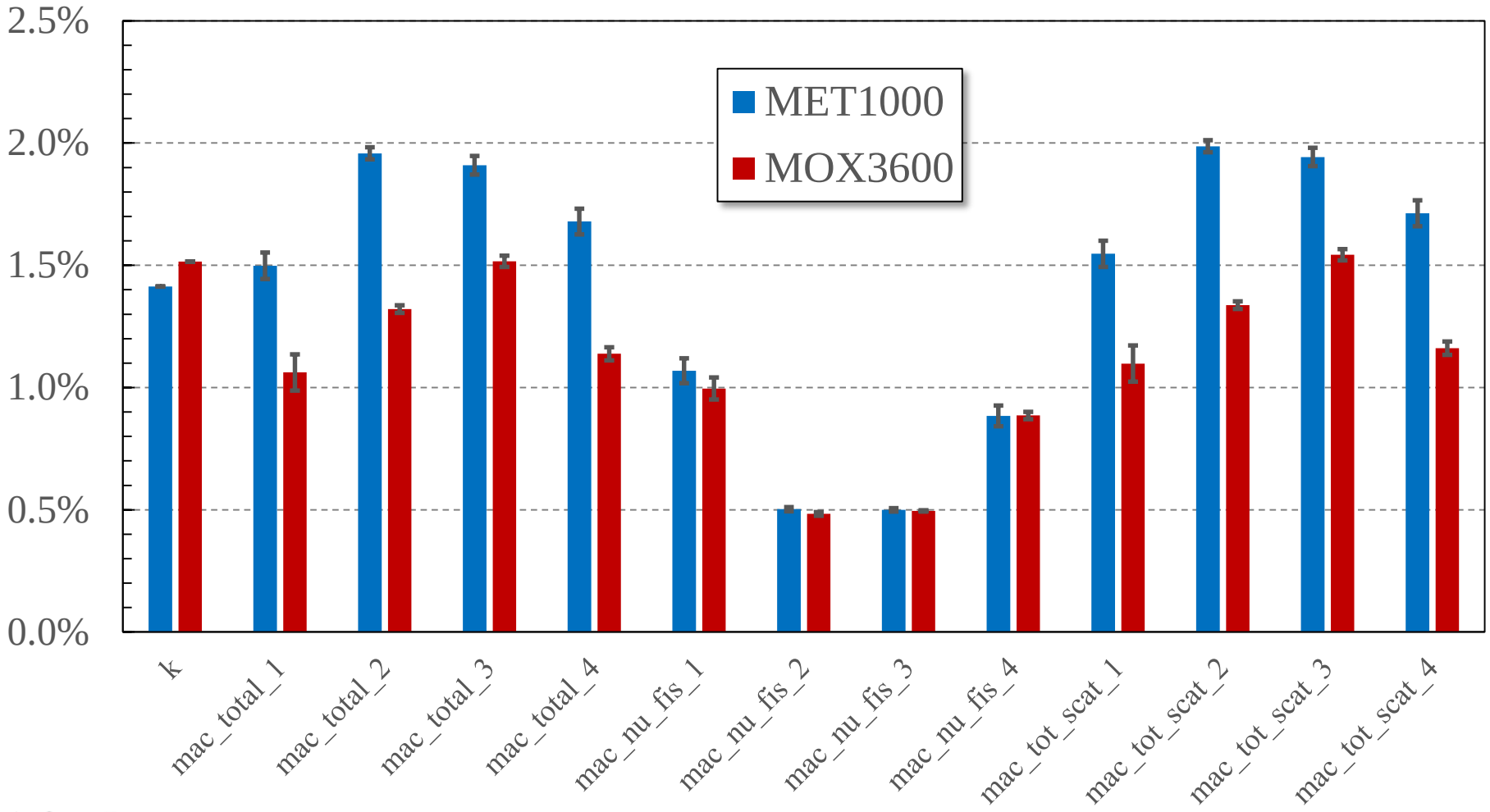
MOX3600

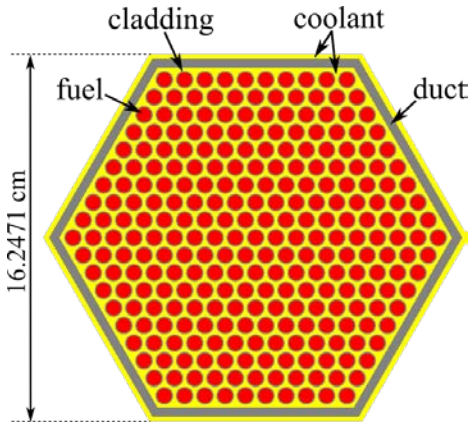
CE TSUNAMI: Top 3 contributors

MET1000			MOX3600		
Eigenvalue	Doppler	Navoid	Eigenvalue	Doppler	Na-void
U-238 inel.	U-238 inel.	Na-23 el.	U-238 inel.	U-238 inel.	Na-23 el.
Na-23 el.	Na-23 el.	Na-23 inel.	U-238 cap.	O-16 el.	Na-23 inel.
Fe-56 el.	Pu-239 inel.	U-238 inel.	Pu-239 cap.	Pu-239 cap.	U-238 inel.

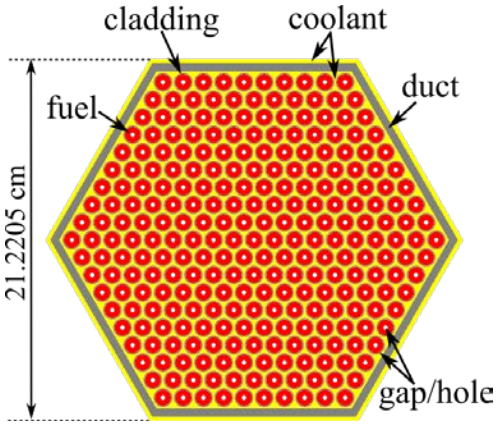
Ex. I-2: Fuel assemblies

k-inf and 4-group macro xs uncertainties





MET1000



MOX3600

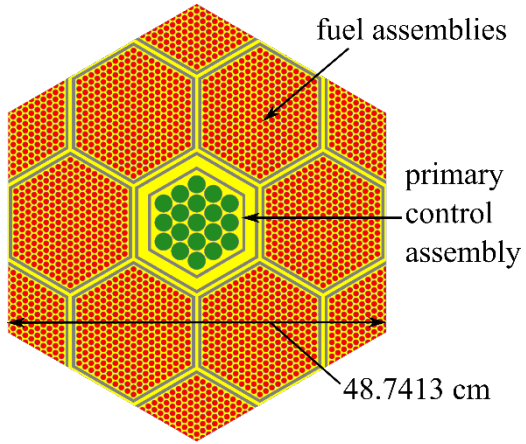
Ex. I-3: Super-cells

CE TSUNAMI: nominal values and uncertainties

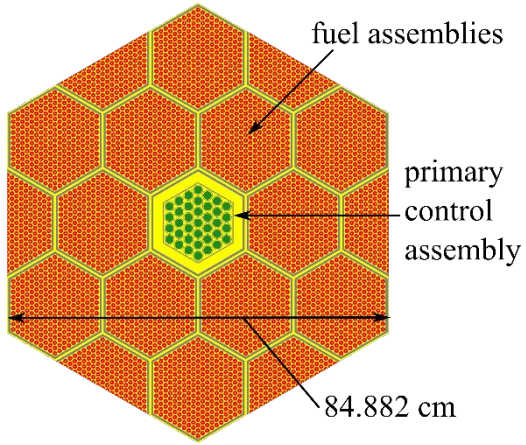
	MET1000		MOX3600	
	nominal	uncertainty	nominal	uncertainty
Eigenvalue	1.0841(1)	1.49(1)%	1.0771(1)	1.52(1)%
CR worth	12081(11) pcm	2.81(1)%	4973(11) pcm	2.67(1)%

CE TSUNAMI: Top 3 contributors

MET1000		MOX3600	
Eigenvalue	CR worth	Eigenvalue	CR worth
U-238 inel.	U-238 inel.	U-238 inel.	U-238 inel.
Fe-56 inel.	Fe-56 inel.	U-238 cap.	Na-23 el.
Na-23 el.	Na-23 el.	Pu-239 cap.	U-238 chi



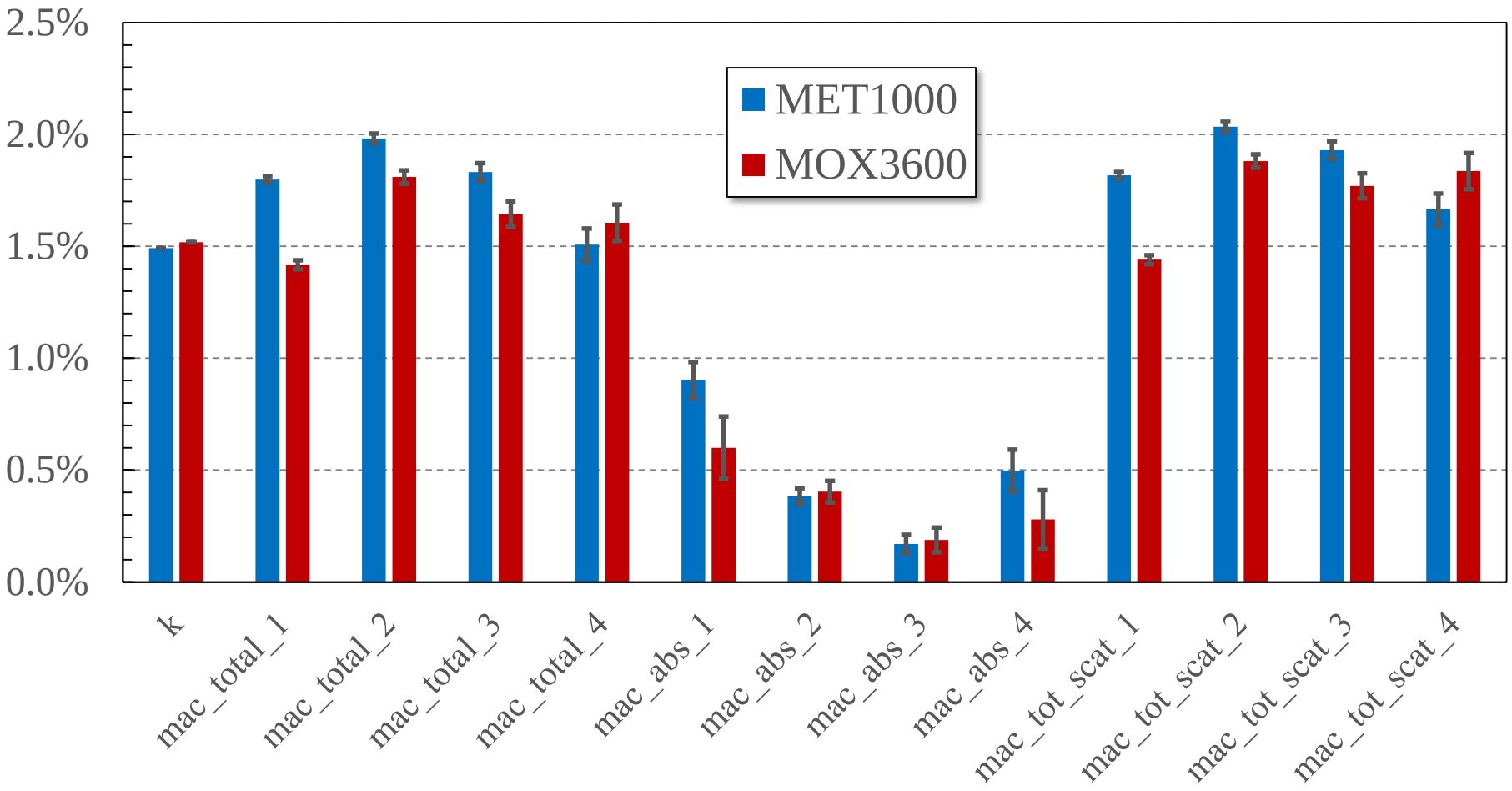
MET1000

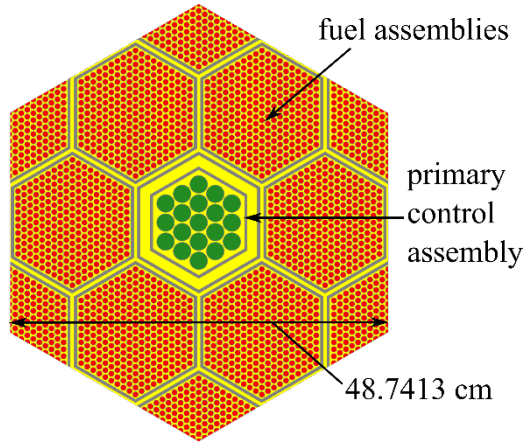


MOX3600

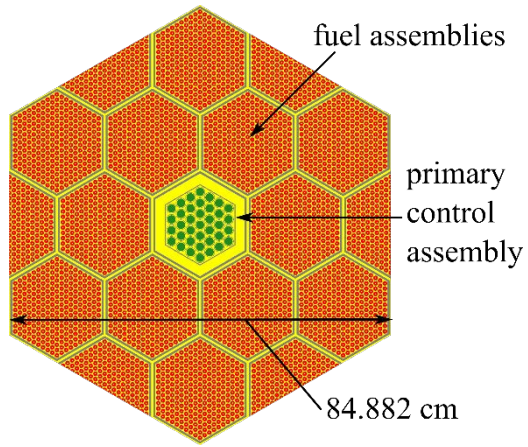
Ex. I-3: Super-cells

k-inf and 4-group macro xs uncertainties of central absorber assembly





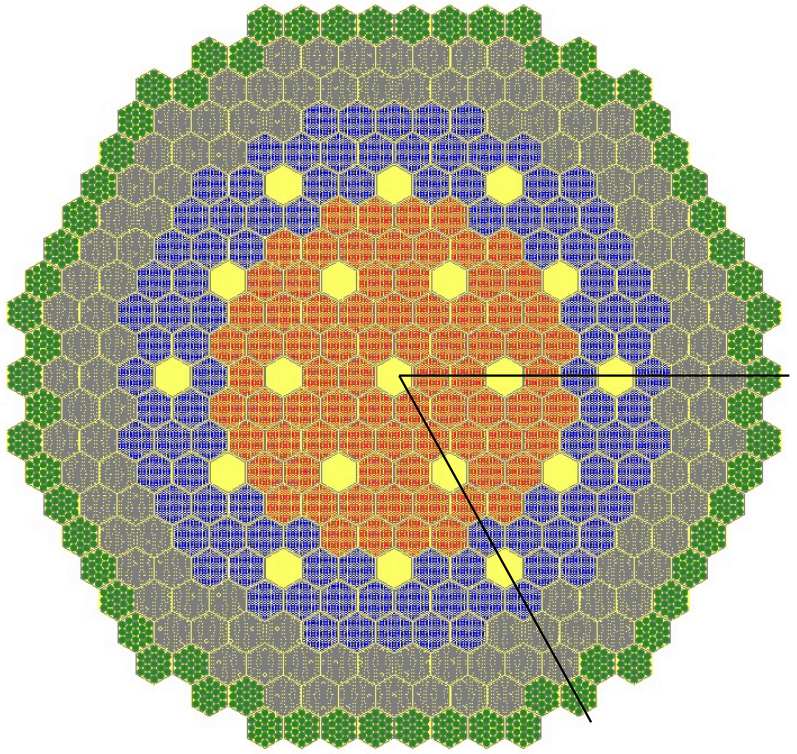
MET1000



MOX3600

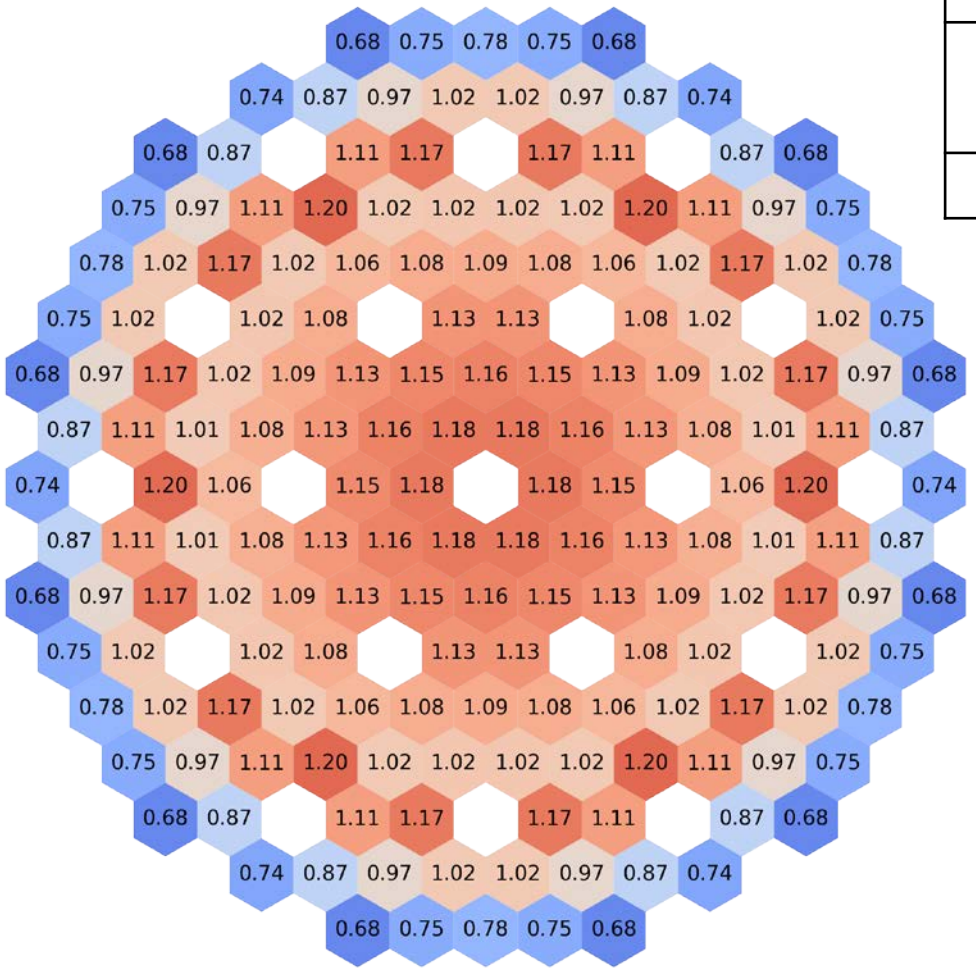
Ex.I-4: MET1000 full core

- Step 1: Criticality calculations using KENO-VI
  - Model of only $^1/_6$ core
  - Reach convergence of assembly-averaged power
    - 4×10^8 neutron histories in CE calculation
    - 1×10^9 neutron histories for 302g calculation
  - Comparison of multigroup (MG) to continuous energy (CE) calculation to assure that effects due to 1D self-shielding in infinite lattice are negligible

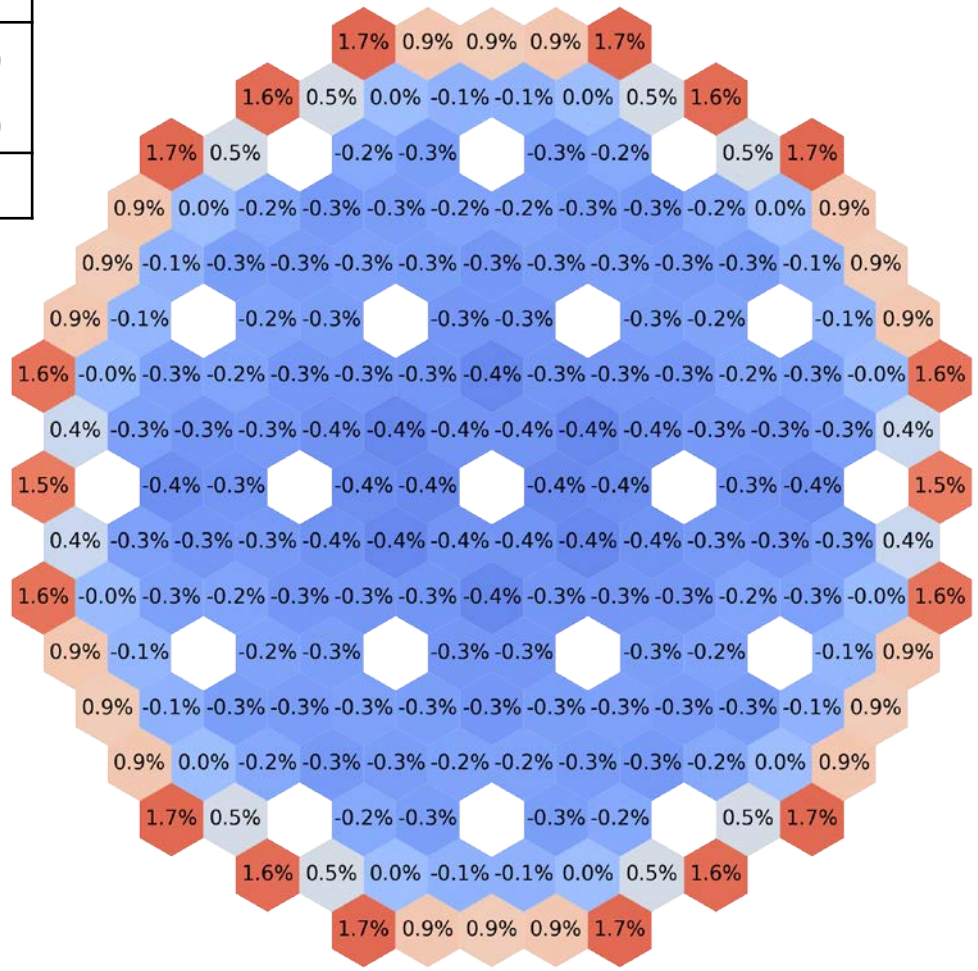


Ex.I-4: MET1000 full core

Code	k_{eff}
KENO-CE	1.01652(4)
KENO-MG	1.02175(2)
Δk_{eff} = 523 pcm	



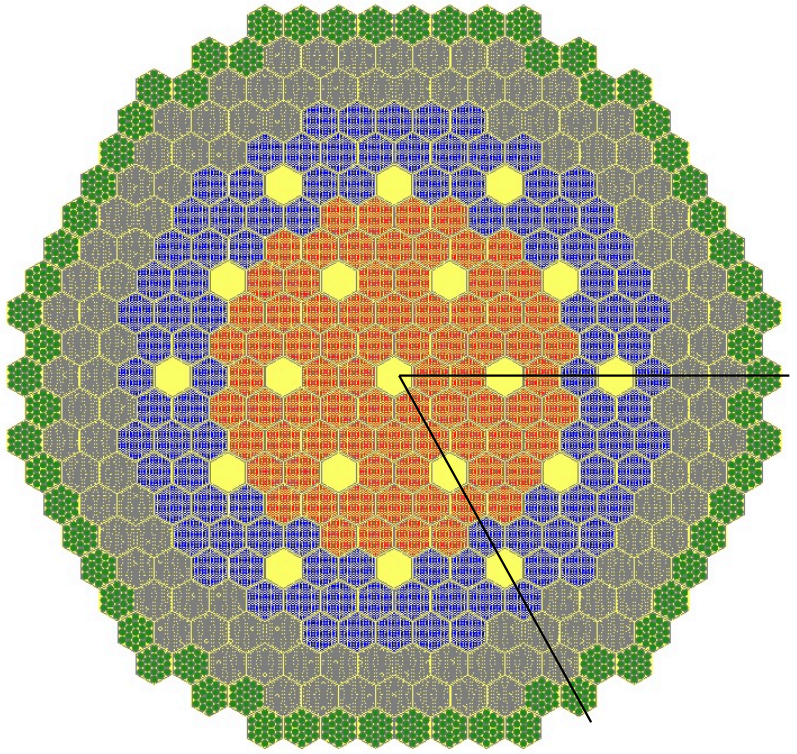
KENO-VI 302g assembly power map



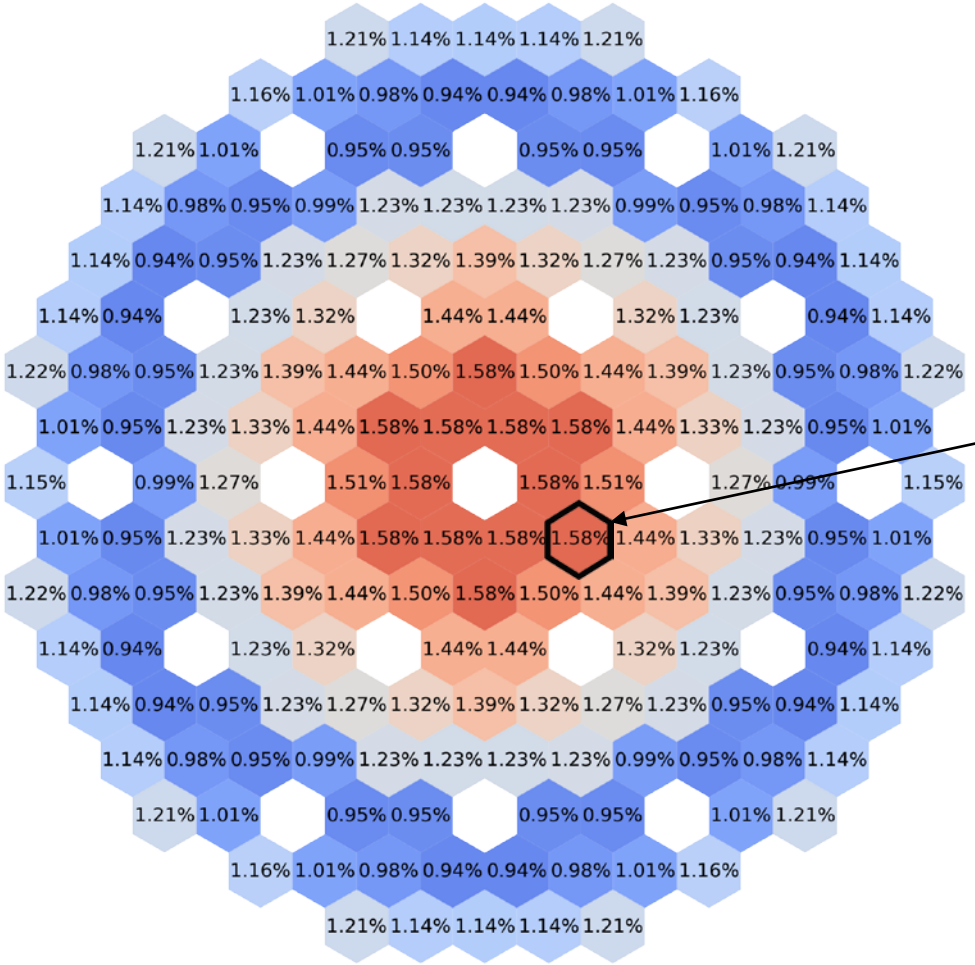
Relative difference between CE and 302g calculation

Ex.I-4: MET1000 full core

- Step 2: Uncertainty analysis
  - SAMPLER/KENO-VI calculations
    i. Generate cross section perturbations based on the 302g covariance library
    ii. Run KENO-VI model using perturbed 302g XS data; sample size 102 (planned: 350)
    iii. Determine mean values and standard deviations
  - CE TSUNAMI calculations for comparison of at least eigenvalue uncertainties
    - Challenge: Find correct settings (number of latent generations, grid for weighting function)
    - Direct perturbation calculations to confirm settings



Ex.I-4: MET1000 full core



SAMPLER/KENO-VI 302g assembly power map:
relative uncertainties due to nuclear data

Eigenvalue of full core

Code	k_{eff}	Uncertainty
CE TSUNAMI	1.01652(4)	1.149(1)%
KENO-MG	1.02175(3)	
SAMPLER/KENO-MG	1.02204	1.158%

Axial power distribution of Assembly 6

Layer	Power	Uncertainty
5	0.769	1.601%
4	1.031	1.645%
3	1.155	1.594%
2	1.107	1.598%
1	0.938	1.506%

This is the first set of results for the fuel assembly power distribution with a limited sample size.
→ Analysis to be completed.

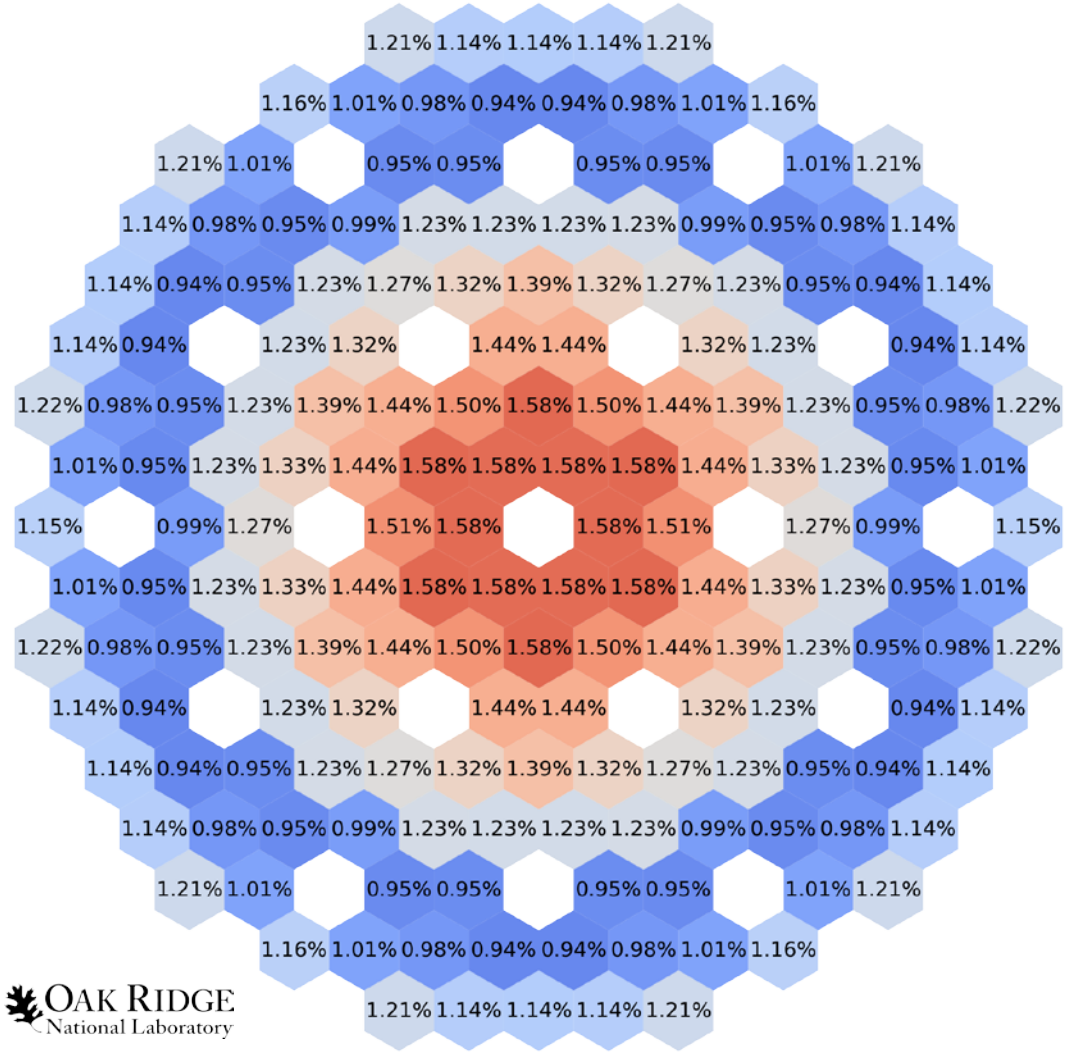
Next steps

- Completion of full core analyses
- Investigation of validation exercises for the neutronics exercises
- Long term: coupled neutronics/TH calculations

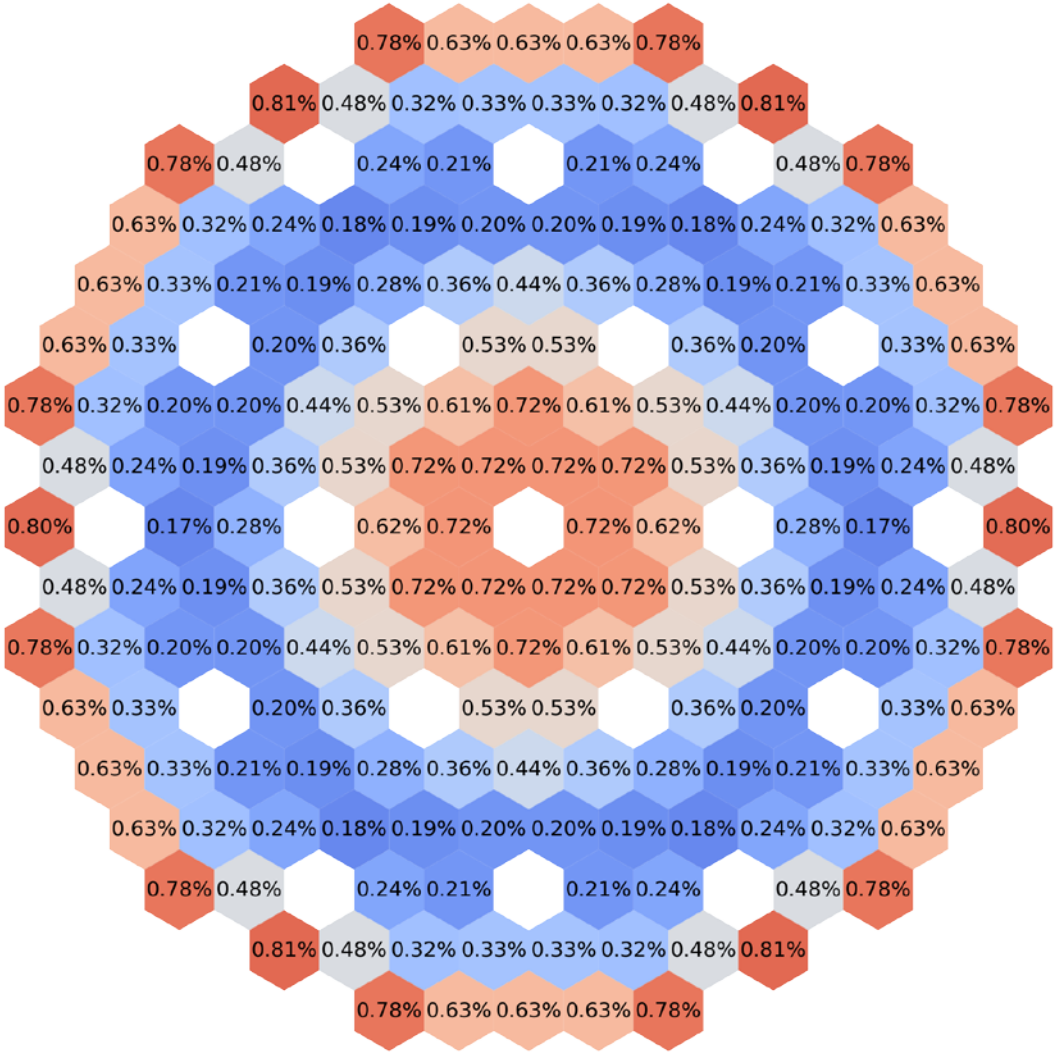
Backup

Ex.I-4: MET1000 full core – SAMPLER relative uncertainties due to nuclear data

(A) Run simulation with same settings, determine average of output:



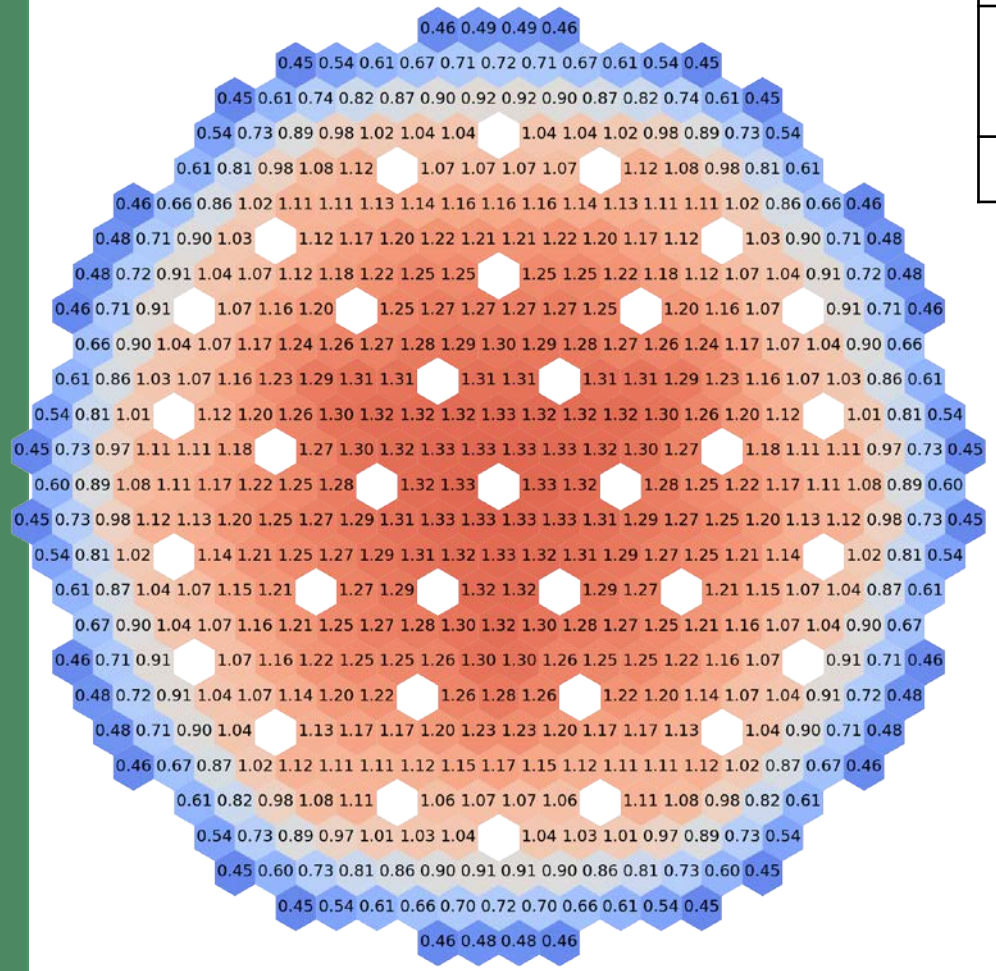
(B): Normalize power of each sample calculation to mean value, then determine average:



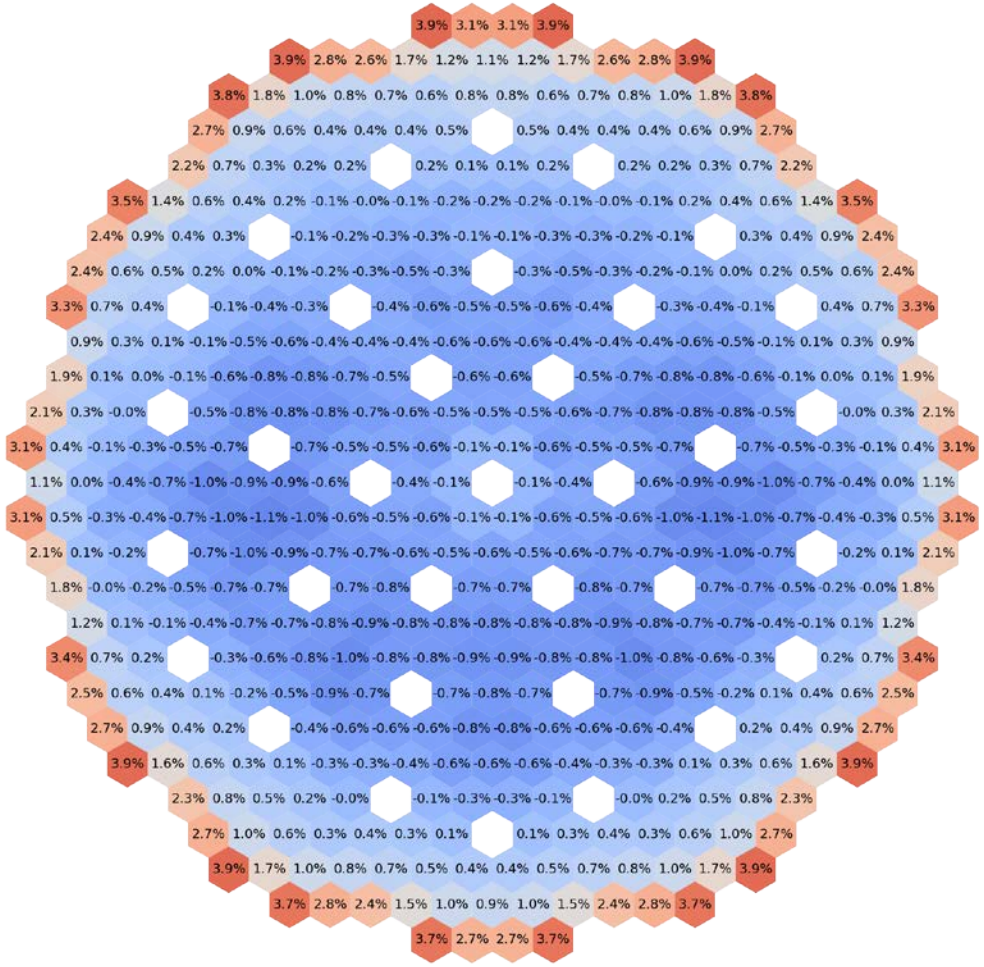
OAK RIDGE National Laboratory

Backup: Ex.I-4: MOX3600 full core

Code	k_{eff}
KENO-CE	1.01131(2)
KENO-MG	1.01518(3)
Δk_{eff} = 387 pcm	



KENO-VI 302g assembly power map



Relative difference between CE and 302g calculation

OAK RIDGE National Laboratory