Nuclear data sensitivity analyses @ SCK CEN

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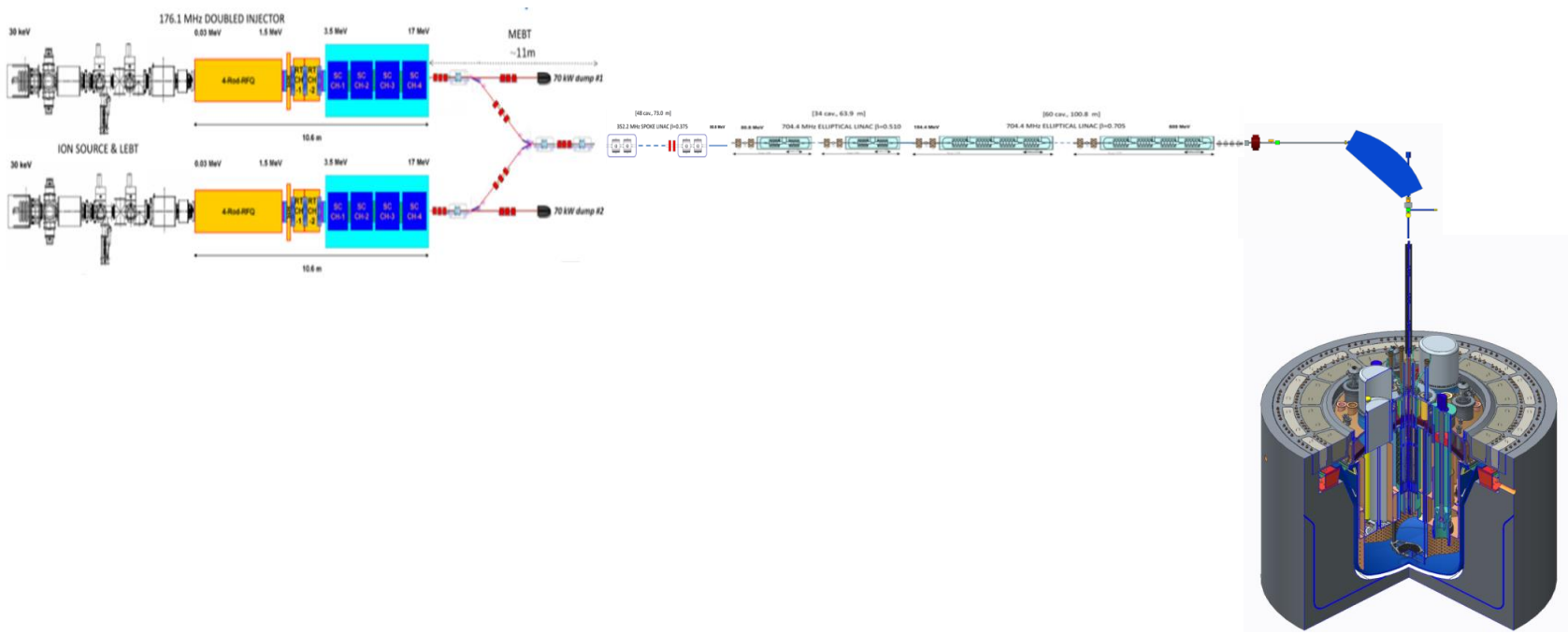
Introduction

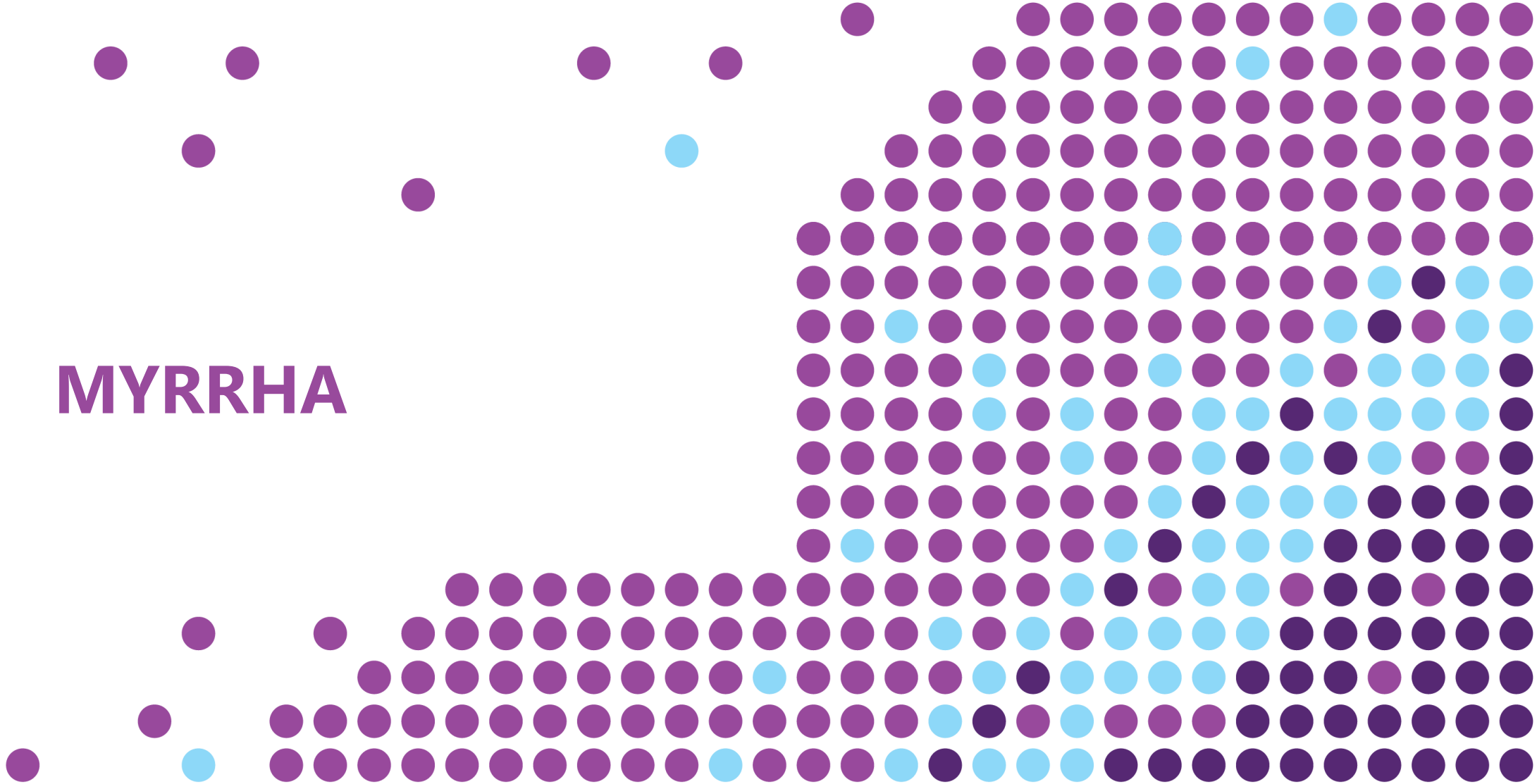
- **Sensitivity analyses focused on our applications**

- **Applications**
  - MYRRHA
  - VENUS-F
  - SFC

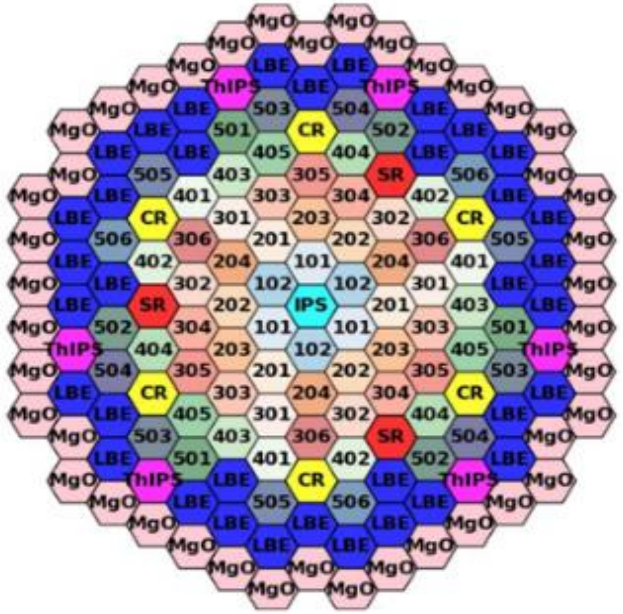
- **Codes**
  - Serpent 2
  - MCNP6
  - **SANDY**
  - NDaST



MYRRHA



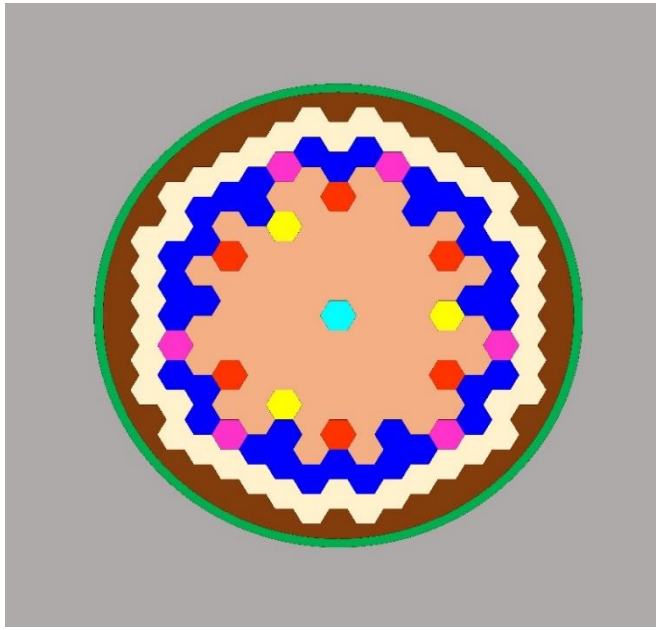
Homogenized critical configuration model

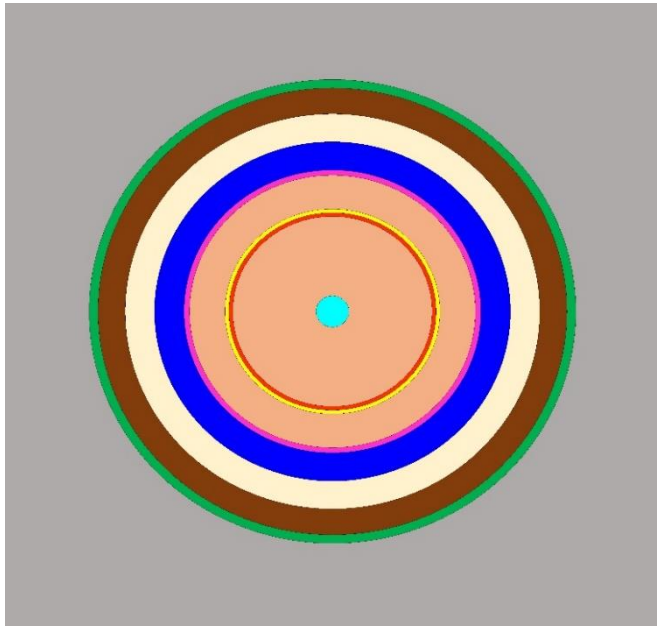


Heterogeneous model (MCNP + Serpent + OpenMC)

Homogeneous model (MCNP + OpenMC + Serpent)

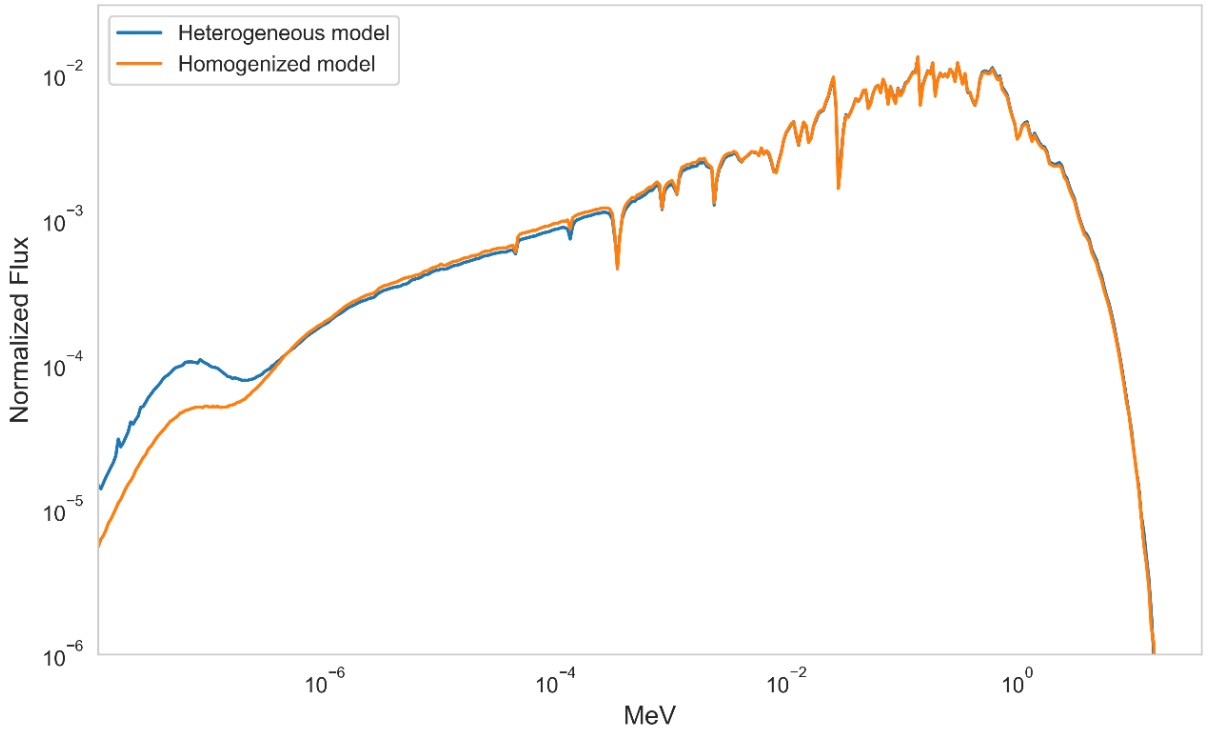
RZ model (Serpent)

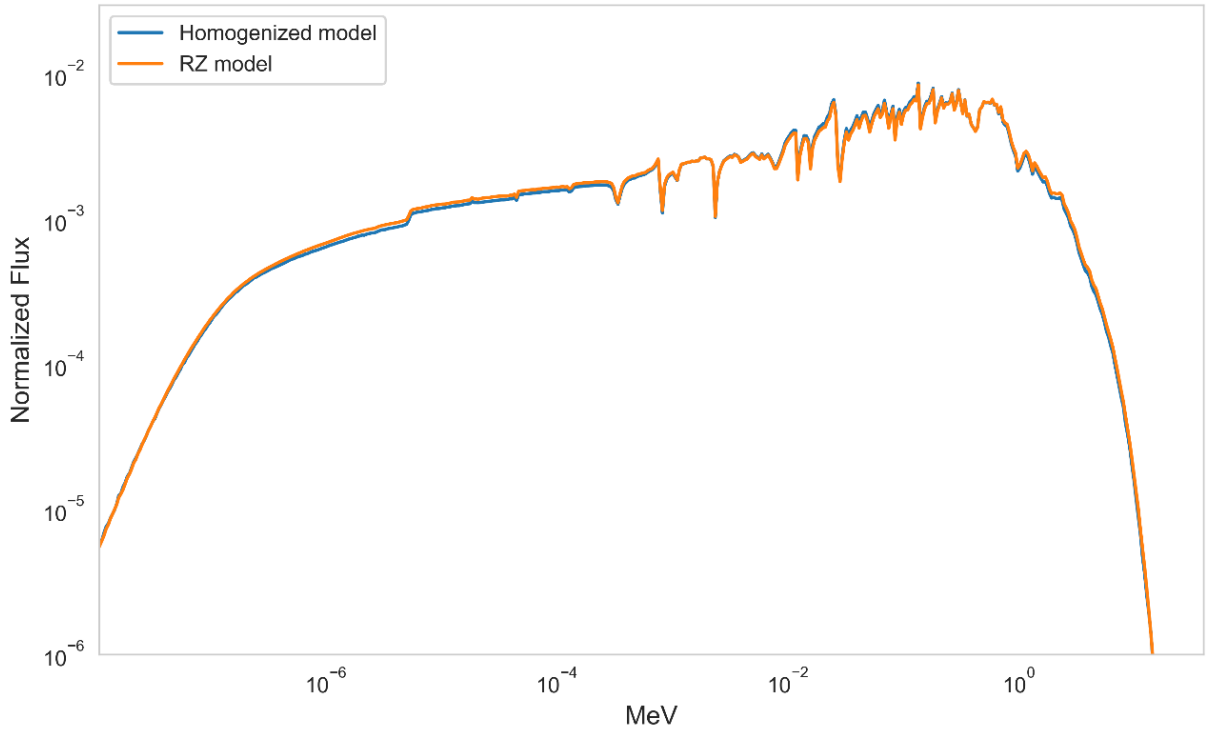




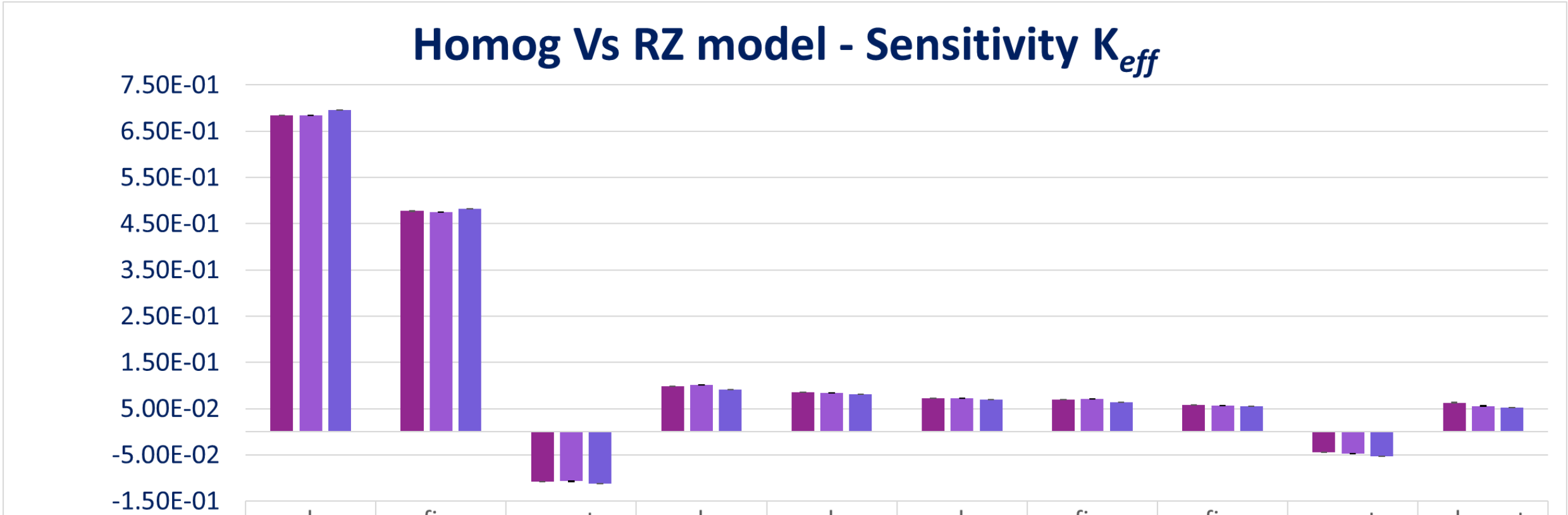
Homogenized critical configuration model

Model	k_{eff}	β_{eff}	Λ_{eff}
Heterogeneous	1.01512 ± 0.00029	358 ± 70 pcm	657 ± 52 ns
Homogeneous	1.01556 ± 0.00001	337 ± 1 pcm	685 ± 21 ns
RZ	1.01562 ± 0.00001	337 ± 1 pcm	649 ± 13 ns



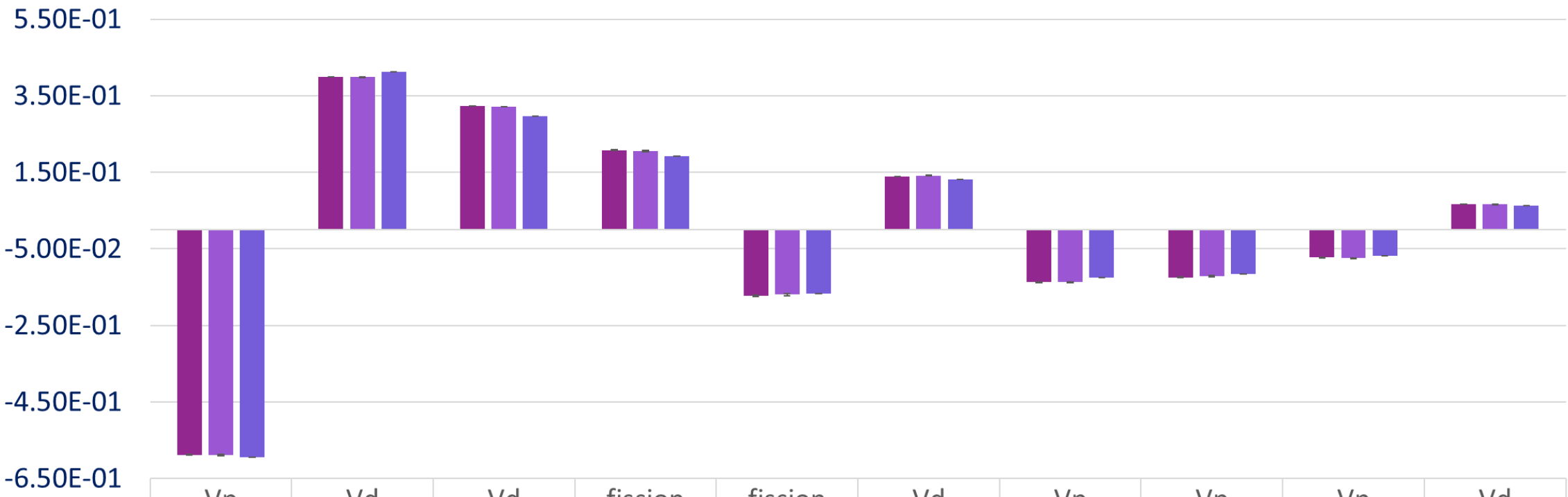


Sensitivity analysis – model comparison



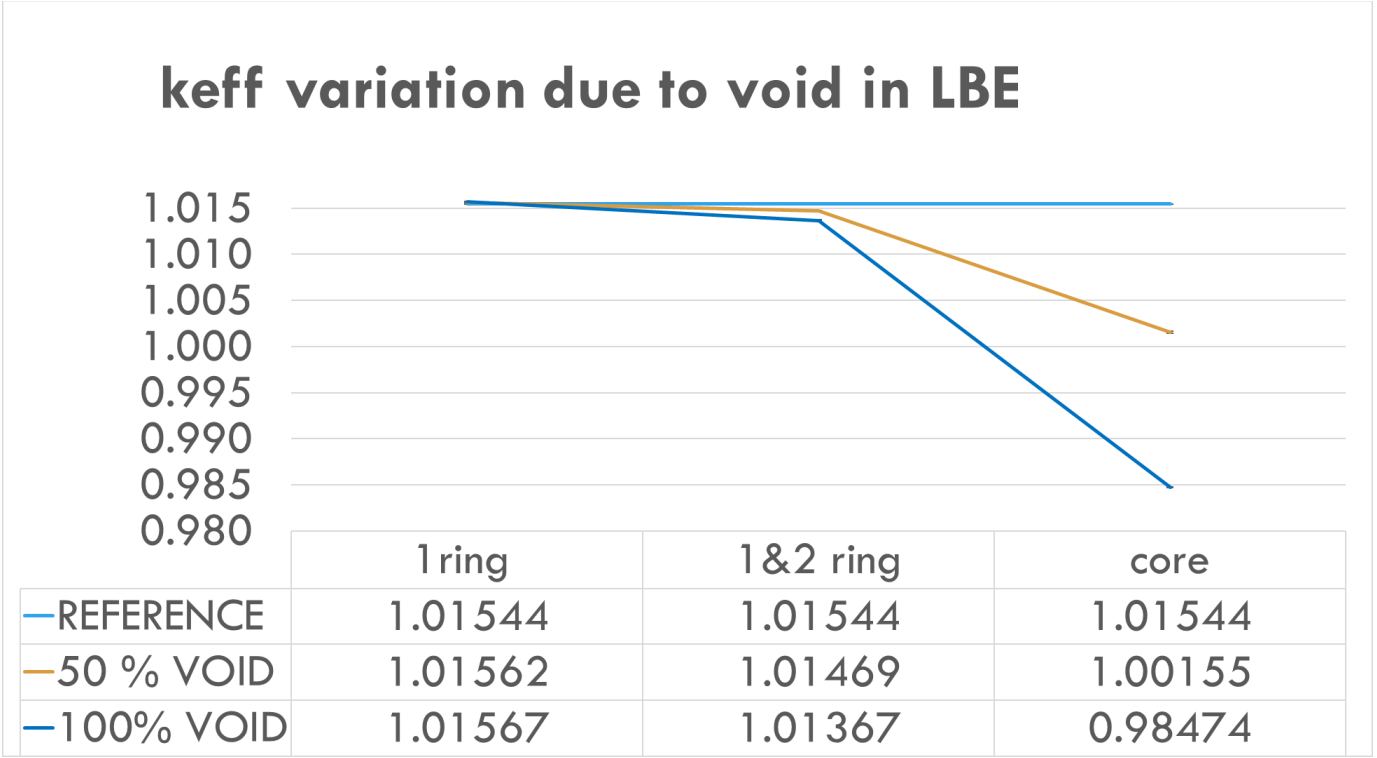
	nubar 239Pu ν	fiss 239Pu (n,f)	capt 238U (n,γ)	nubar 241Pu ν	nubar 240Pu ν	nubar 238U ν	fiss 241Pu (n,f)	fiss 240Pu (n,f)	capt 239Pu (n,γ)	ela scat 209Bi (n,n)
HOMOG	6.85E-01	4.77E-01	-1.08E-01	9.89E-02	8.49E-02	7.22E-02	7.00E-02	5.76E-02	-4.41E-02	6.29E-02
RZ	6.84E-01	4.75E-01	-1.07E-01	1.01E-01	8.37E-02	7.19E-02	7.11E-02	5.68E-02	-4.75E-02	5.57E-02
CHANDA v 1.6	6.96E-01	4.82E-01	-1.12E-01	9.10E-02	8.10E-02	7.00E-02	6.40E-02	5.50E-02	-5.30E-02	5.20E-02

Sensitivity analysis – model comparison

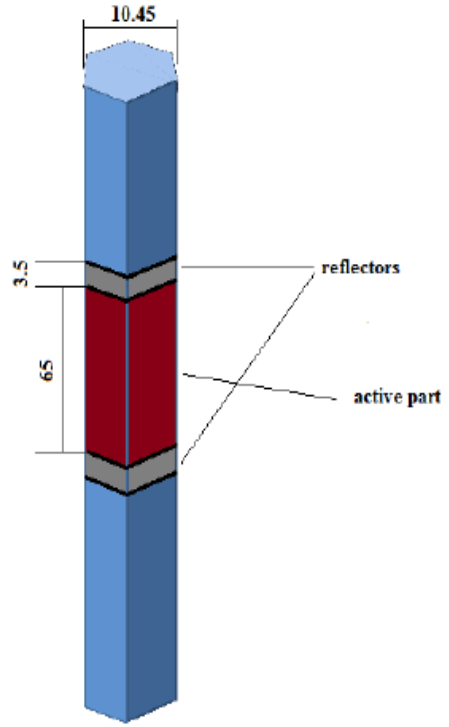


	Vp Pu_239	Vd Pu_239	Vd U_238	fission U_238	fission Pu_239	Vd Pu_241	Vp U_238	Vp Pu_240	Vp Pu_241	Vd Pu_240
HOMOG	-5.88E-01	3.99E-01	3.23E-01	2.08E-01	-1.73E-01	1.39E-01	-1.37E-01	-1.25E-01	-7.26E-02	6.64E-02
RZ	-5.89E-01	3.99E-01	3.21E-01	2.06E-01	-1.70E-01	1.41E-01	-1.38E-01	-1.21E-01	-7.49E-02	6.57E-02
CHANDA v 1.6	-5.94E-01	4.13E-01	2.97E-01	1.92E-01	-1.67E-01	1.31E-01	-1.26E-01	-1.16E-01	-6.80E-02	6.30E-02

Sensitivity analysis – void coefficient



	1 ring	1&2 ring	core
REFERENCE	1.01544	1.01544	1.01544
50 % VOID	1.01562	1.01469	1.00155
100% VOID	1.01567	1.01367	0.98474



Small size

Reactivity decreases fast

Leakages predominate

Negative reactivity feedback coefficient

Sensitivity analysis – void coefficient

Isotope	XS	ISC (0% VOID)	std_dev 0% (%)	ISC (100% VOID)	std_dev 100% (%)	Δp [pcm]	$S_{\rho_{1\to2,\alpha}}$	$std_{\rho_{1\to2,\alpha}}$ (%)
^{239}Pu	nubar prompt	6.816E-01	0.19%	6.668E-01	0.04%	-598.803	-1.950E-01	21.03%
^{239}Pu	fission	4.728E-01	0.39%	4.701E-01	0.07%	-1173.501	-3.822E-01	15.70%
^{238}U	capture	-1.068E-01	0.96%	-9.656E-02	0.18%	-715.550	-2.330E-01	13.94%
^{241}Pu	nubar prompt	9.898E-02	0.90%	9.532E-02	0.17%	67.148	2.187E-02	131.45%
^{240}Pu	nubar prompt	8.553E-02	0.91%	8.914E-02	0.15%	-629.147	-2.049E-01	12.53%
^{238}U	nubar prompt	7.123E-02	0.99%	8.495E-02	0.16%	-1612.153	-5.250E-01	4.62%
^{241}Pu	fission	7.070E-02	1.40%	6.801E-02	0.23%	56.831	1.851E-02	172.53%
^{240}Pu	fission	5.855E-02	1.50%	6.180E-02	0.24%	-509.278	-1.659E-01	17.41%
^{239}Pu	capture	-4.432E-02	1.50%	-4.165E-02	0.27%	-135.601	-4.416E-02	48.49%
^{238}U	fission	4.371E-02	1.90%	5.431E-02	0.30%	-1209.936	-3.941E-01	7.13%

Sensitivity analysis – Doppler coefficient

SENSITIVITIES (%/%)					
ISOTOPE	**XS**	**ISC (800 K)**	**std err (800 K)**	**$ISC_{doppler}$ (1100 K)**	**std err (1100 K)**
^{239}**Pu**	(n,f)	$4.773 \cdot 10^{-1}$	0.069%	$7.242 \cdot 10^{-3}$	1.300%
^{238}**U**	(n,γ)	$-1.081 \cdot 10^{-1}$	0.160%	$-9.564 \cdot 10^{-3}$	0.480%
^{239}**Pu**	(n,γ)	$-4.414 \cdot 10^{-2}$	0.270%	$-5.560 \cdot 10^{-3}$	1.300%

$$\alpha_{doppler} = \frac{ISC \cdot keff \cdot 10^5 \cdot T_{fuel}}{\Delta T}$$

Source: Heddy Barale, "Application of the SERPENT2 code to neutronic analyses of the MYRRHA core : a sensitivity approach," 2020.

Isotope	Cross section	Doppler coeff (pcm)
^{238}**U**	(n,γ)	-3561
^{239}**Pu**	(n,f)	2697
	(n,γ)	-2070

Sensitivity analysis – Power Peaking Factors

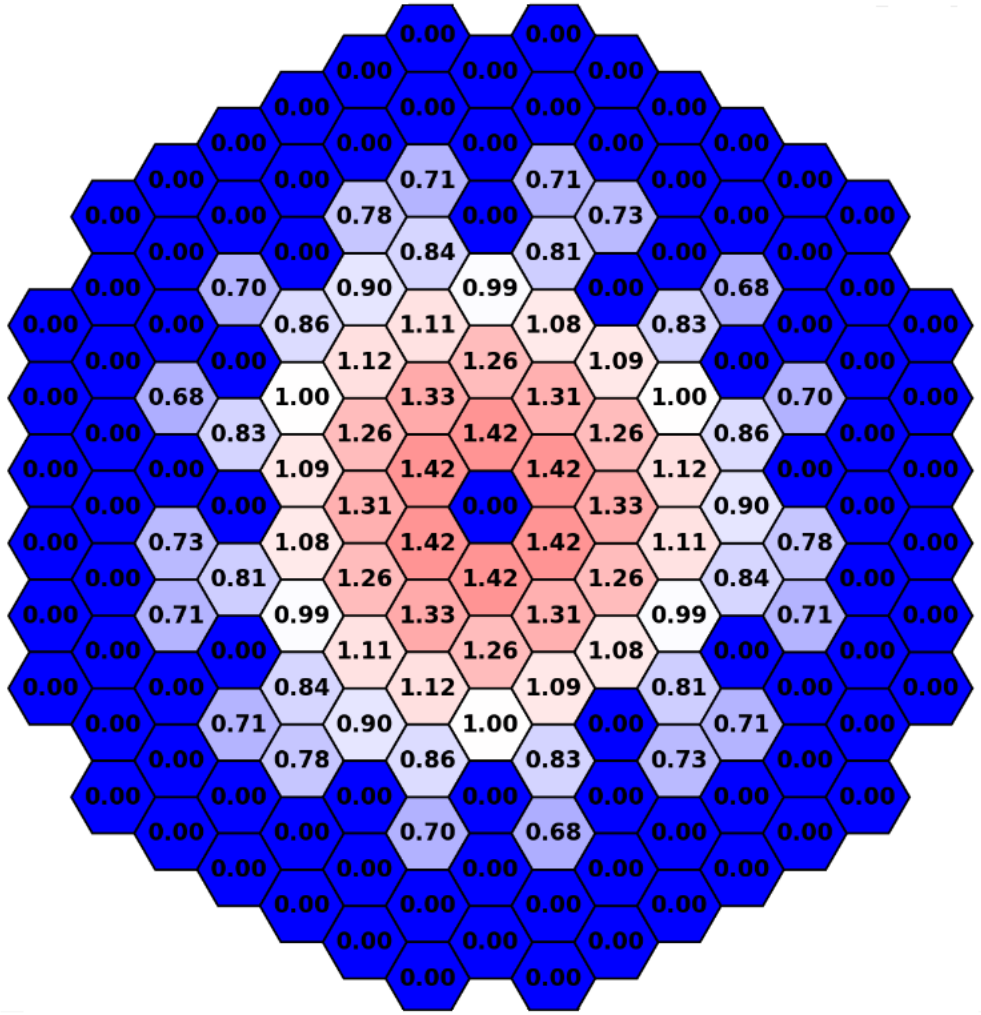
$$P_{max} = \frac{V_{core}\langle \Sigma_p \emptyset \rangle_{max}}{V_{max}\langle \Sigma_p \emptyset \rangle}$$

$$S_{P_{max}} = \frac{\sigma}{P_{max}} \frac{dP_{max}}{d\sigma} = \frac{\sigma}{P_{max}} \left\{ \frac{\partial P_{max}}{\partial \sigma} - \langle \Psi^*, \left(\frac{\partial A}{\partial \sigma} - \frac{1}{k} \frac{\partial F}{\partial \sigma} \right) \emptyset \rangle \right\}$$
$$= \left\{ S_{P_{max,D}} - S_{P_{max,I}} \right\}$$

$$S_{P_{max,D}} = \frac{\sigma}{P_{max}} \left(\frac{\left(\langle \Sigma_p \emptyset \rangle_{max} \right)_{i,g}}{\langle \Sigma_p \emptyset \rangle_{max}} - \frac{\left(\langle \Sigma_p \emptyset \rangle \right)_{i,g,d}}{\langle \Sigma_p \emptyset \rangle} \right)$$

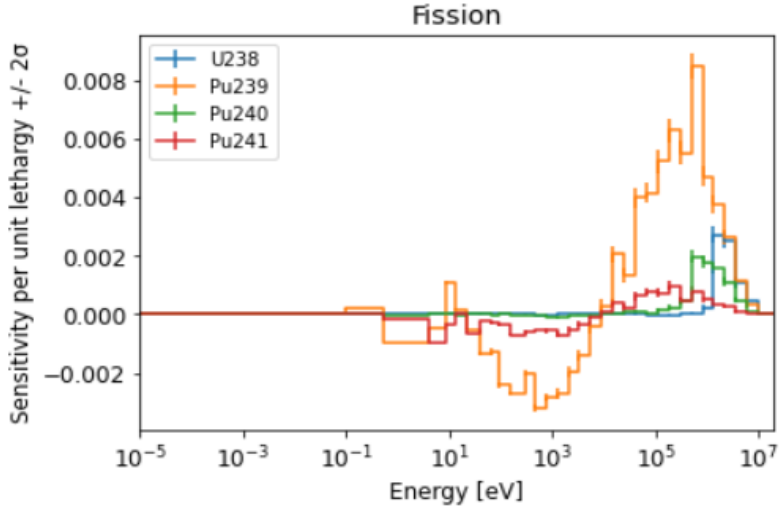
i=isotope
g=energy group
d=reactor domain

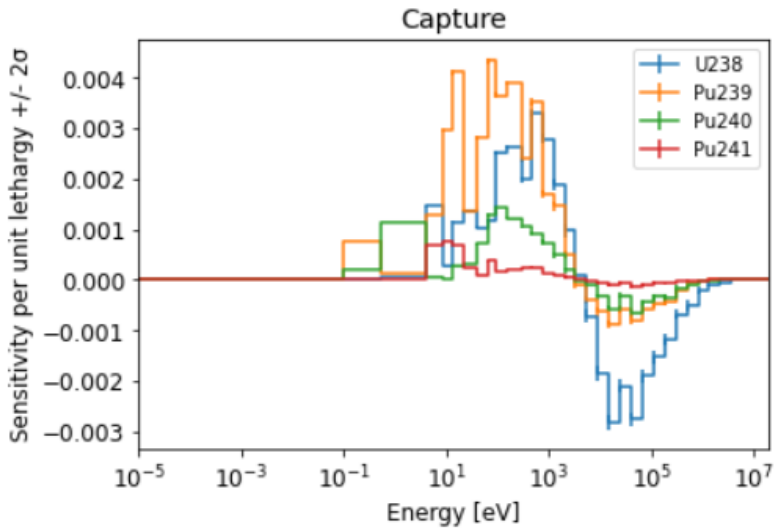
0

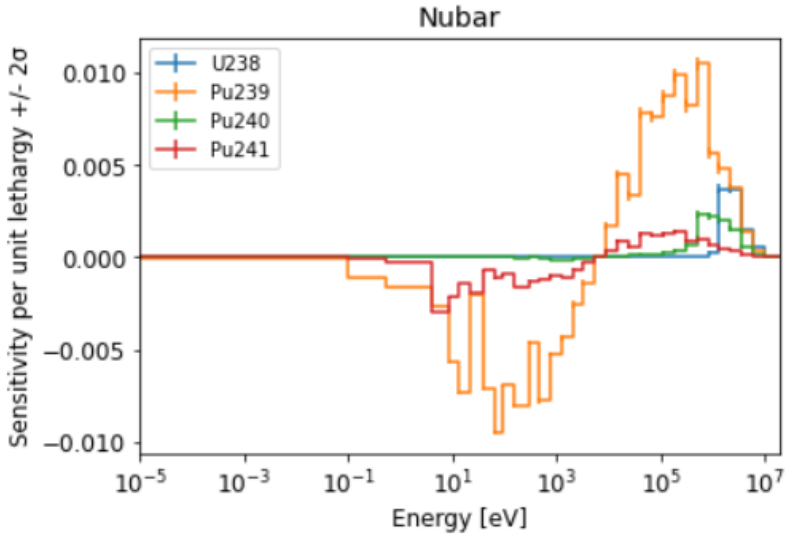


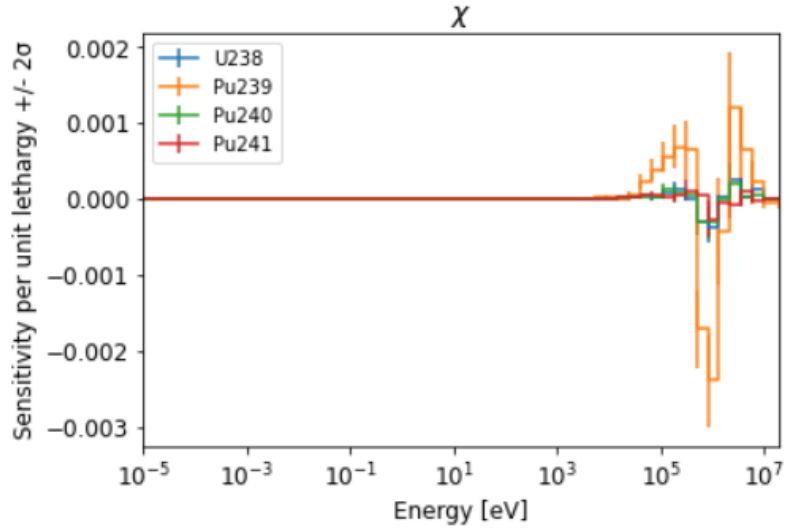
Source: M. Salvatores and R. Jacqmin, *Uncertainty and target accuracy assessment for innovative systems using recent covariance data evaluations*, vol. 26, no. NEA/WPEC-26. 2008.

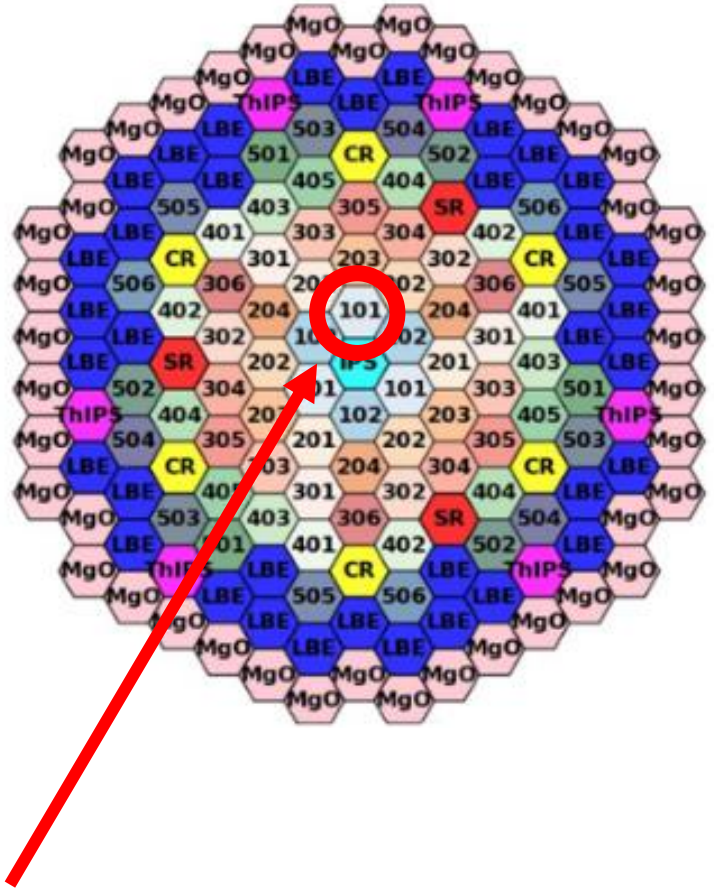
Sensitivity analysis – Power Peaking Factors









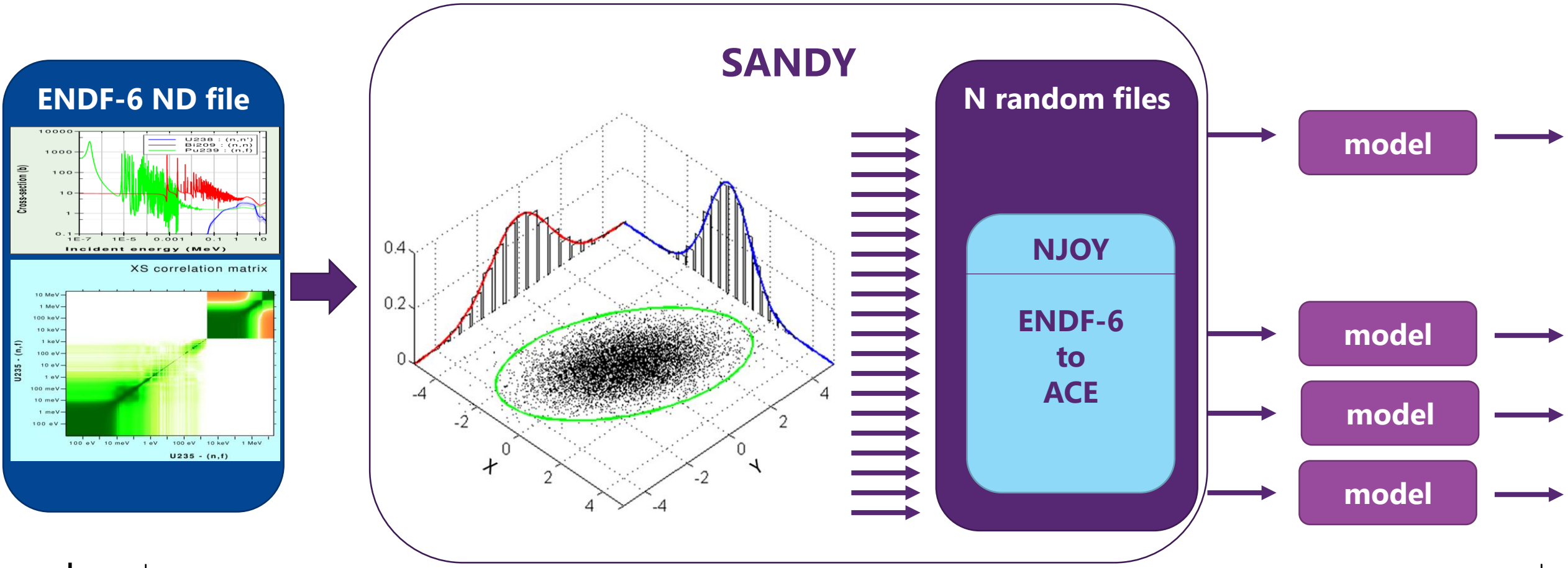


Sensitivity analysis by introducing a perturbation to the effective fission cross section of ^{235}U, ^{239}Pu, ^{240}Pu and ^{241}Pu in fuel batch 101 (highest power peaking value 1.42)

Fuel depletion

ND sampling with SANDY

Covariance-based sampling



Sensitivities

- **Local / global sensitivity analysis**
  - Perturbation coefficients
  - Energy/reaction-dependent sampling
  - Custom covariance matrix
  - Custom perturbations

$$\boldsymbol{x} \longrightarrow \mathcal{N}_{\boldsymbol{x}}(\boldsymbol{x}_0, \boldsymbol{\Sigma}_x)$$

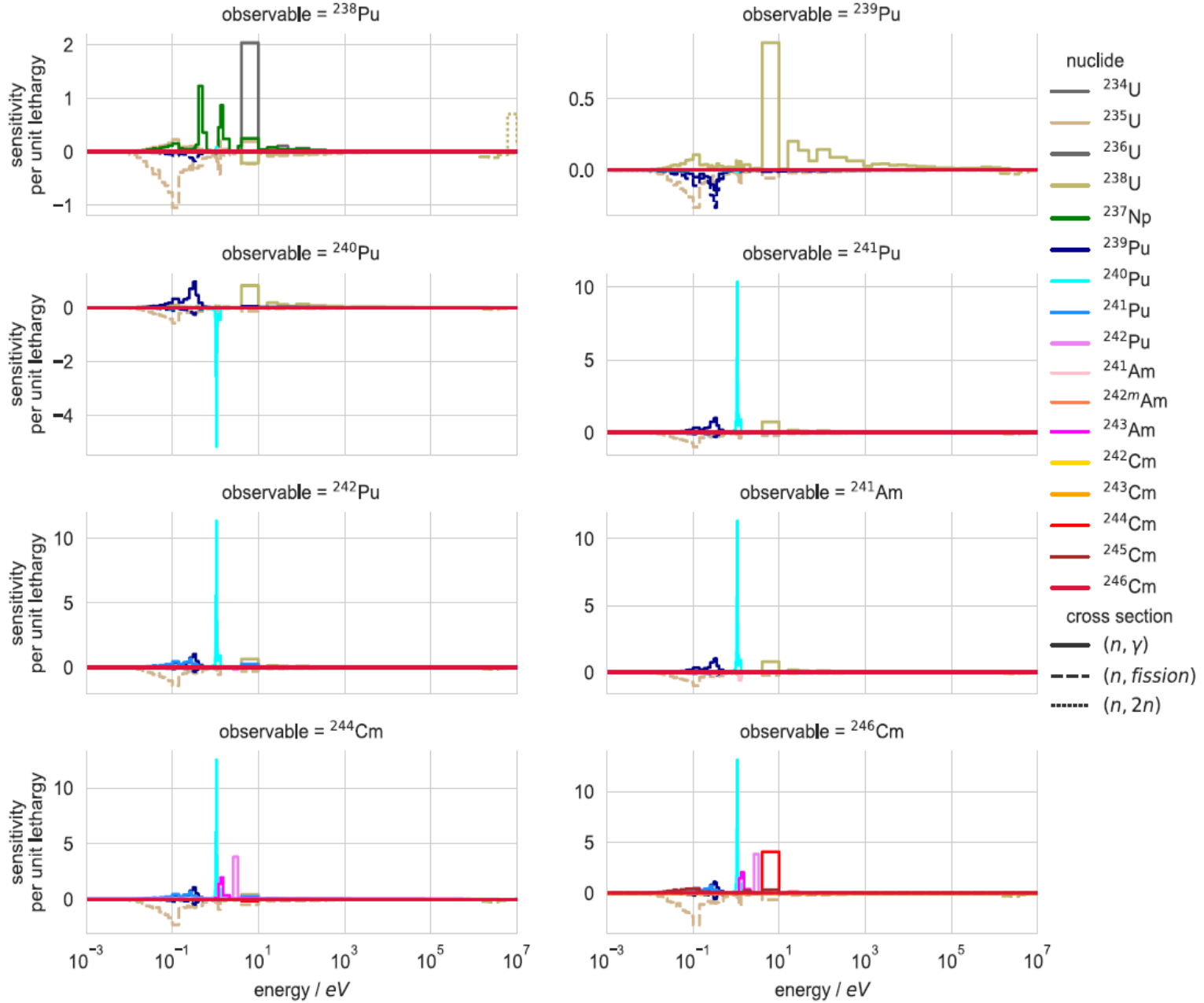
$$\begin{bmatrix} x_1^{(1)} & x_2^{(1)} & \dots & x_M^{(1)} \\ x_1^{(2)} & x_2^{(2)} & \dots & x_M^{(2)} \\ \vdots & \vdots & \ddots & \vdots \\ x_1^{(N)} & x_2^{(N)} & \dots & x_M^{(N)} \end{bmatrix} \rightarrow \boxed{\text{model}} \rightarrow \begin{bmatrix} y^{(1)} \\ y^{(2)} \\ \vdots \\ y^{(N)} \end{bmatrix}$$

$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{\beta} + \boldsymbol{\epsilon} \qquad \hat{\boldsymbol{\beta}} = \left(\boldsymbol{X}^T\boldsymbol{X}\right)^{-1}\boldsymbol{X}^T\boldsymbol{y}$$

Source: L. Fiorito *et al*. On the use of criticality and depletion benchmarks for verification of nuclear data. Annals of Nuclear Energy 161 (2021) 108415

Sensitivities

- 10 GWd/MTU



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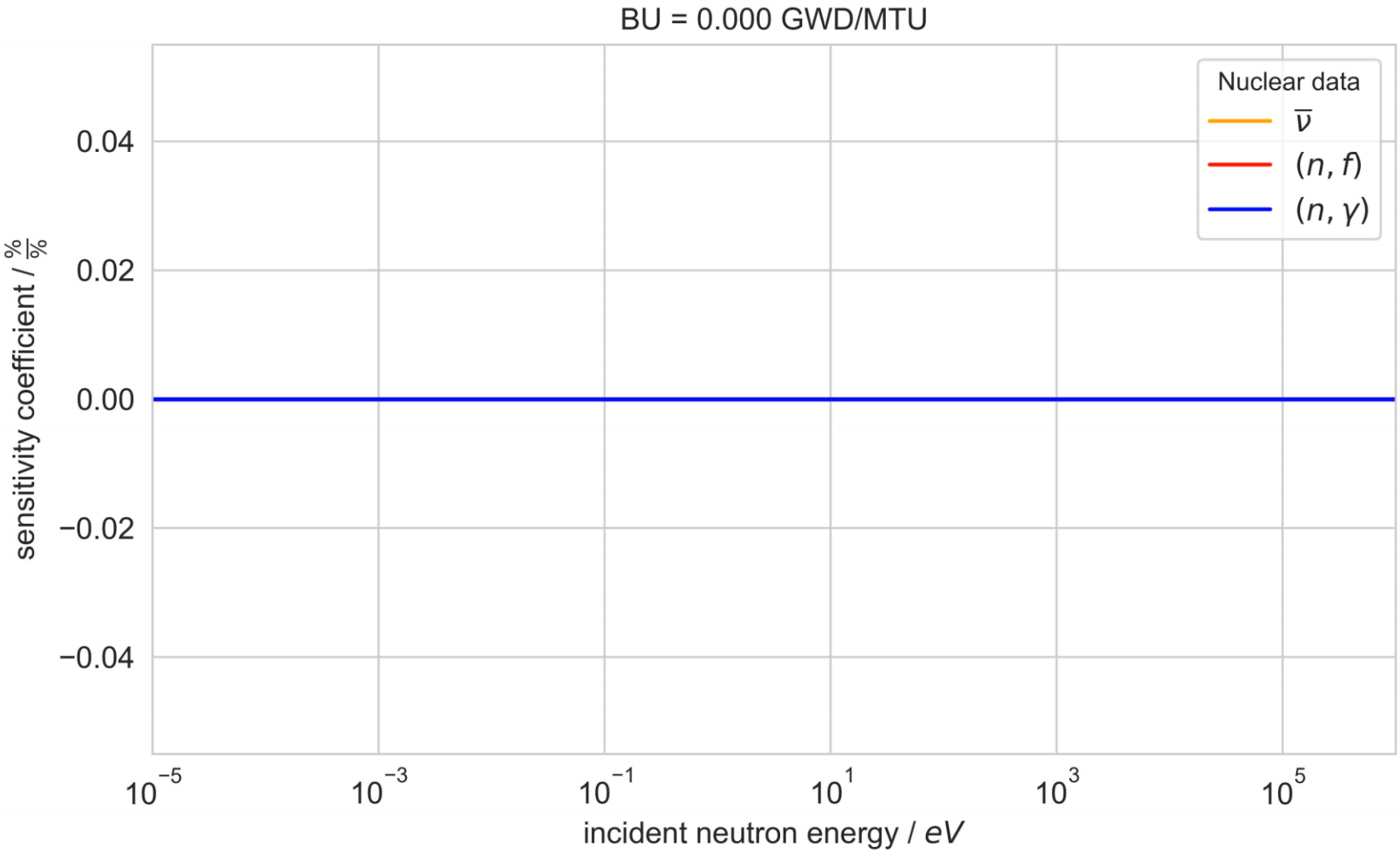
Sensitivities



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