

# Similarity of the PMM-2 critical experiments and criticality safety cases based on the $k_{\text{eff}}$ sensitivity analysis

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*IRSN Laboratory of Neutronics*

*Mariya Brovchenko, PhD  
Nicolas Arphant*

 **ANS** Winter Meeting & Expo

# Content

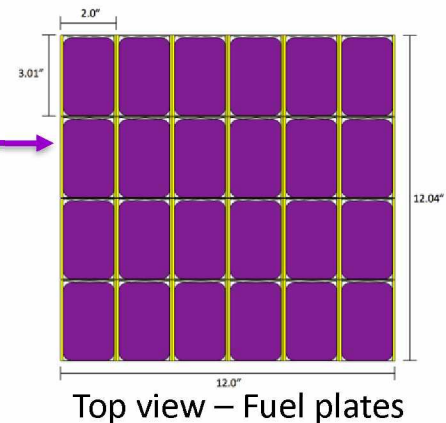
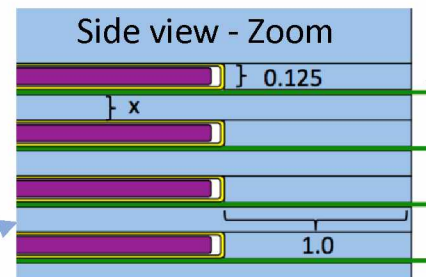
- TEX designs and experiments
- Application cases
- Similarity coefficients  $C_k$
- Shared sensitivity ratio (SSR)
- Conclusion and Prospects



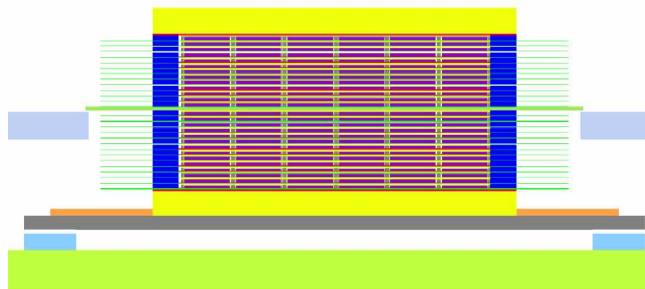
# TEX designs and experiments

# TEX-Pu experiments

- 5 baseline TEX (Thermal Epithermal eXperiments) published in ICSBEP Handbook 2020 (PMM002)
- Polyethylene moderator and reflector with varying thicknesses
- Plutonium metallic plates



PLANET machine at NCERC



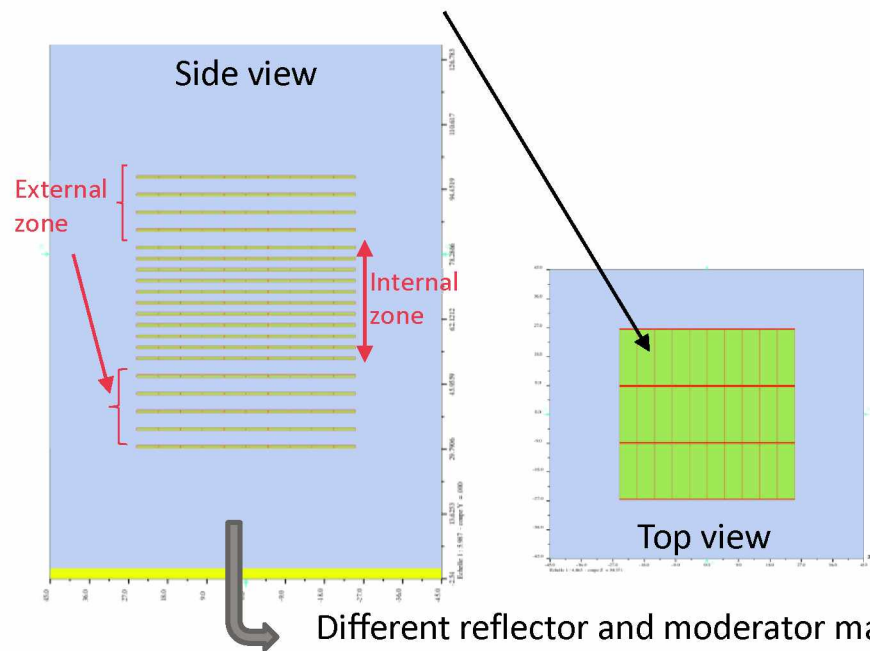
The experiment 1 of the PMM-2 series modelled with code MORET5.

# TEX-MOX designs

■ PUMN plates (Pu-U-Mo-NUMEC):

Pu (wt% of U+Pu)	U235 (%wt of U)	Pu240 (%w of Pu)
28.8	0.2	11.6

■ Multi-parametric design optimization (*Proceedings ANS Winter Meeting 2016*)



5 selected configurations:

Name	Mod + Reflector material	Neutron spectrum
TEX-MOX case 1	Al <sub>2</sub> O <sub>3</sub>	FAST-max
TEX-MOX case 2	Al <sub>2</sub> O <sub>3</sub>	INTER
TEX-MOX case 3	PE	FAST
TEX-MOX case 4	PE	INTER
TEX-MOX case 5	PE	THERM

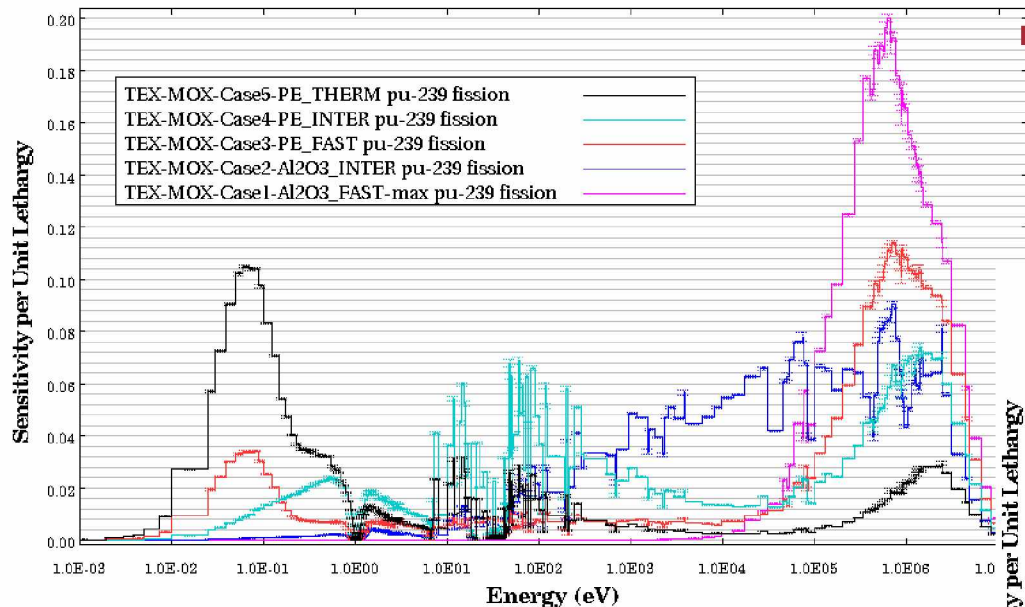
Different reflector and moderator materials tested (graphite, borated polyethylene,... )  
 This work: configurations only with Al<sub>2</sub>O<sub>3</sub> and polyethylene

## TEX-MOX preliminary designs with Al<sub>2</sub>O<sub>3</sub> and PE

	TEX-MOX case 1	TEX-MOX case 2	TEX-MOX case 3	TEX-MOX case 4	TEX-MOX case 5
	FAST-MAX-Al2O3	INTER-Al2O3	PE-28%-FAST	PE-28%-INTER	PE-28%-THERM
Number of fuel layers (extern - intern)	28	20 (2x5 – 10)	15	30 (2x10 – 10)	20
Moderator thickness (cm) extern – intern	0.001 <sup>1</sup>	3.69 - 2.04	0.001 <sup>1</sup>	0.36 – 0.39	3
Reflector thickness (cm)	0.01	18.65	22	0.448	0.001 <sup>1</sup>
Aluminum plate thickness (cm)	0.0254	0.0254	0.0254	0.8245	3
Fuel layer dimensions (cm x cm)	45.2 x 45.72	50.23 x 53.34	45.20 x 45.72	46.58 x 46.58	45.20 x 45.72
Height/Width ratio of the fissile stack	0.45	1.36	0.34	1.21	1.6
Estimated decay power (W)	750	560	350	680	460
EALF (keV)	797	24	3.88	2.42	2.31 E-3
Thermal fission rate (%)	0.0%	1.5%	26.8%	12.4%	<b>68.9%</b>
Intermediate fission rate (%)	6.4%	<b>56.8%</b>	17.1%	<b>49.5%</b>	17.6%
Fast fission rate (%)	<b>93.6%</b>	41.7%	<b>56.1%</b>	38.1%	13.5%
$k_{\text{eff}}$	1.01134 +/- 15 pcm	1.01238 +/- 15 pcm	1.01029 +/- 15 pcm	1.01062 +/- 15 pcm	1.00969 +/- 15 pcm

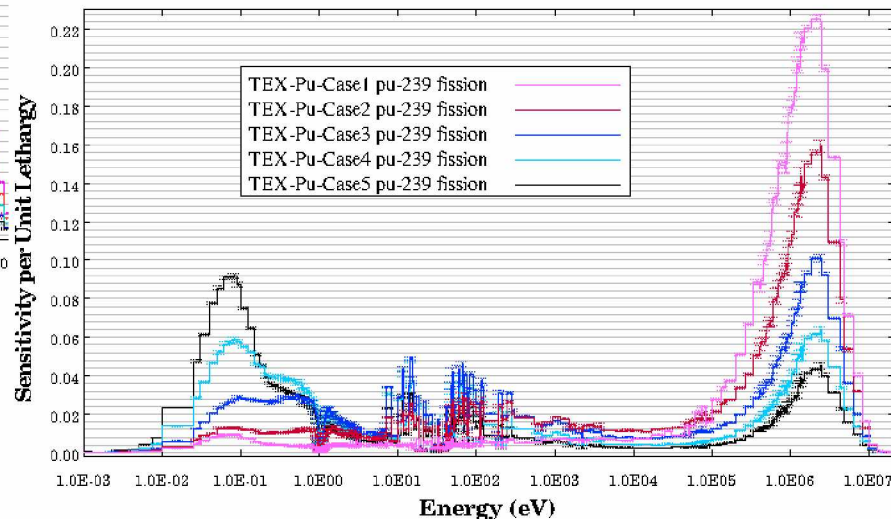
<sup>1</sup> It corresponds to the minimal value available in the optimization calculation, and will be considered as 0.

# Varying spectrum – $k_{\text{eff}}$ sensitivities



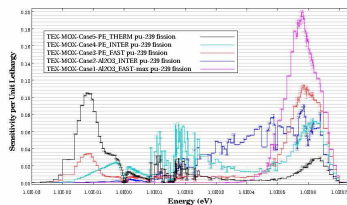
More variability of the neutron spectrum

## TEX-Pu (PMM2) experiments

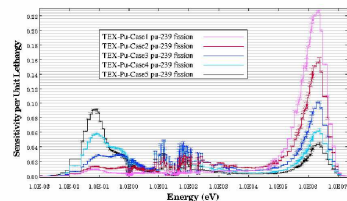


## TEX-MOX selected cases

# Aim of the work ?



TEX-MOX



TEX-Pu

*What is the (potential) interest in these experiments for the ND validation in regards to an application case ?*

*Which are more useful ?*

Analysis of different similarity indicators

Existing experimental benchmarks

« Real » application cases





# Application cases

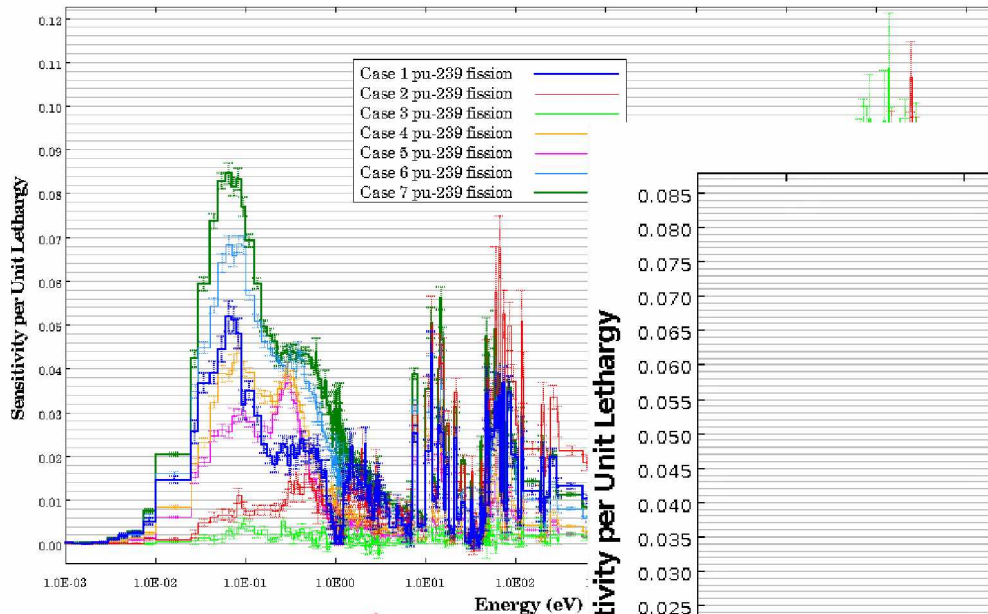
## Application cases description

7 cases were selected involving  $\text{PuO}_2$  or  $\text{PuO}_2$  with  $\text{UO}_2$  where intermediate energy range plays a role

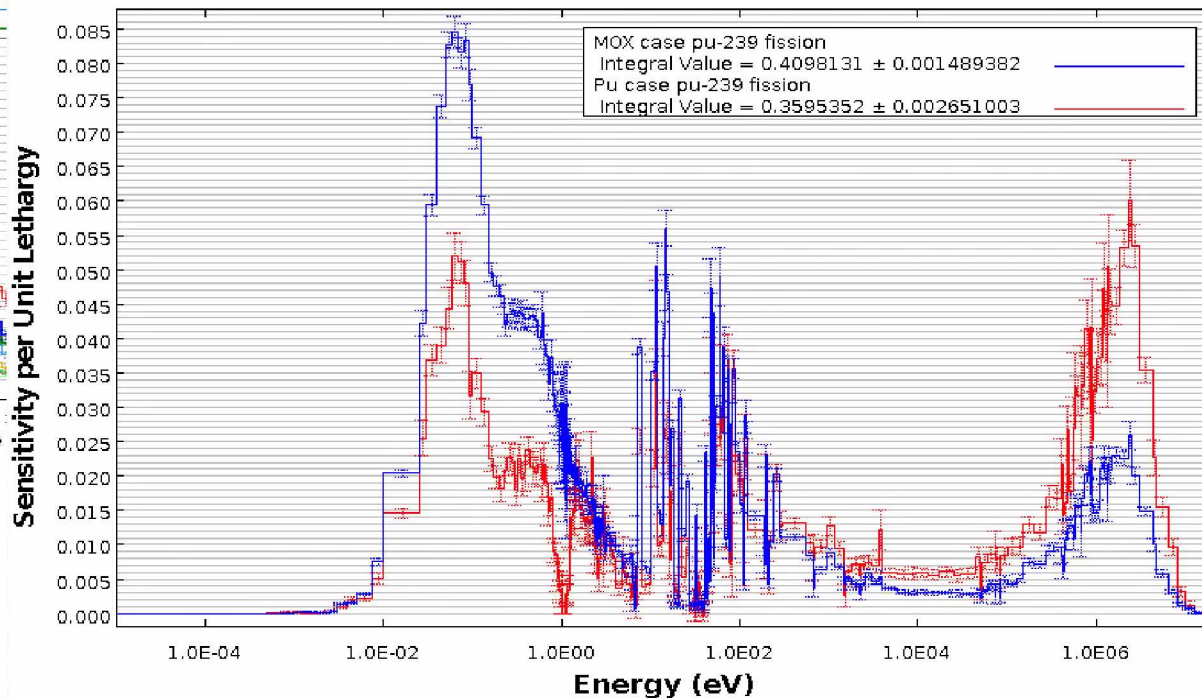
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
	PuO <sub>2</sub> powder interim storage	PuO <sub>2</sub> powder cask	UPuO <sub>2</sub> powder cask	UPuO <sub>2</sub> storage	UPuO <sub>2</sub> storage	UPuO <sub>2</sub> storage	UPuO <sub>2</sub> storage
<b>Pu/(U+Pu) (%wt)</b>	100	100	37	30	20	30	30
<b><sup>240</sup>Pu/ Pu<sub>tot</sub> (%wt)</b>	17	17	17	0	0	0	0
<b><sup>235</sup>U/U<sub>tot</sub> (%wt)</b>	-	-	70	> 90	> 90	20	0.7
<b>Thermal fission rate (%)</b>	42	10	6	63	64	62	63
<b>Intermediate fission rate (%)</b>	37	53	21	31	31	30	27
<b>Fast fission rate (%)</b>	22	36	73	6	5	8	10

For this presentation: focus on 2 application cases

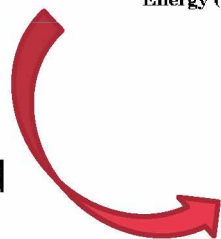
# Application cases



- Different fuels
- Both high sensitivity in the intermediate energies



2 cases selected





# Similarity coefficients $C_k$

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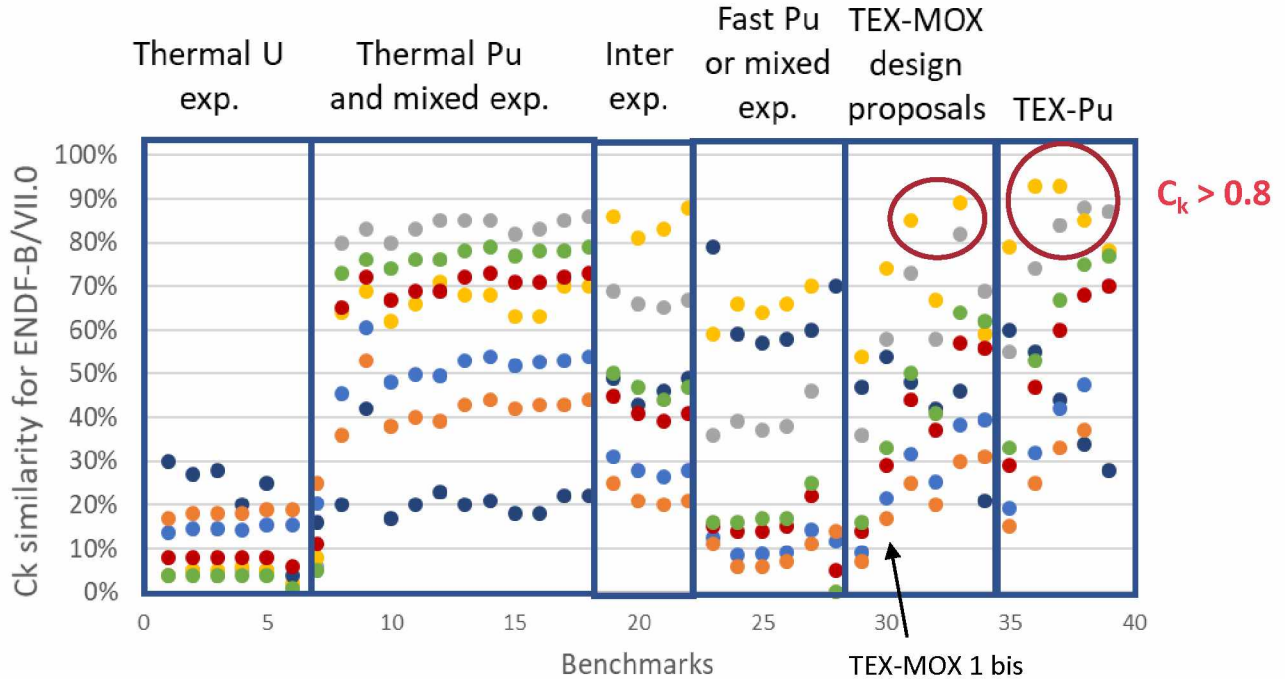
The  $C_k$  similarity coefficients between 7 application cases and a selection of experimental benchmarks or working designs proposals.

$$C_k = \frac{S_{exp}^T C_{\sigma} S_{app}}{\sqrt{S_{exp}^T C_{\sigma} S_{app}} \sqrt{S_{app}^T C_{\sigma} S_{app}}}$$

Calculated with TSURFER

$C_{\sigma}$  = covariance matrix ENDF/B-VII.0 in 44 groups provided with the SCALE code system

S = sensitivities calculated with MORET

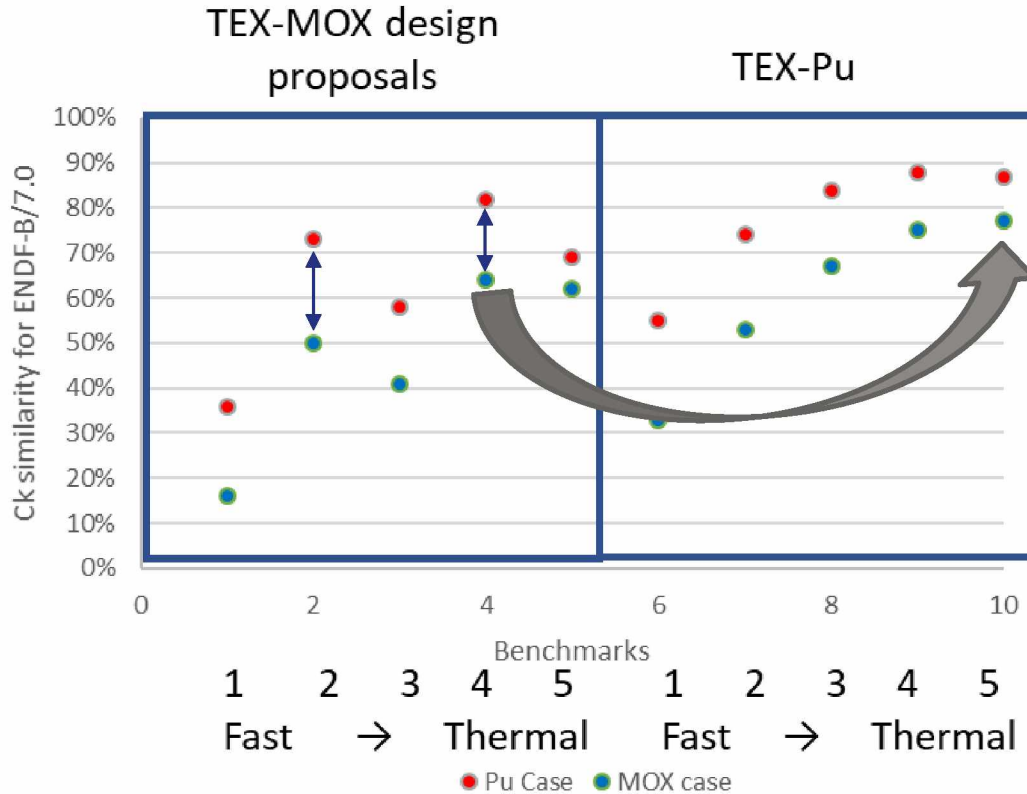


- All TEX-Pu cases high  $C_k$  for  $PuO_2$  appl. Cases
- TEX-MOX case 2 and 4 high  $C_k$  values for  $PuO_2$  appl. case

$PuO_2$  ← Case 1 Case 2 Case 3 Case 4 Case 5 Case 6 Case 7 →  $UPuO_2$

# Similarity coefficient $C_k$

Focus on 2 application cases  
Pu case (1) and MOX case (7)



*TEX-MOX: MOX case lower  $C_k$  then PU Case!*

→ MOX case has higher iron sensitivity  
→ “complicated” application case may use separated benchmarks:

- iron ND assimilation
- fuel ND assimilation

(possibly no  $C_k > 0.8$ )

*MOX application case has even higher  $C_k$  for TEX-Pu cases then for TEX-MOX designs !*

→  $C_k$  similarity coefficients contain the information about the covariance data which « ponderates » the importance of some cross sections



# Shared sensitivity ratio (SSR)

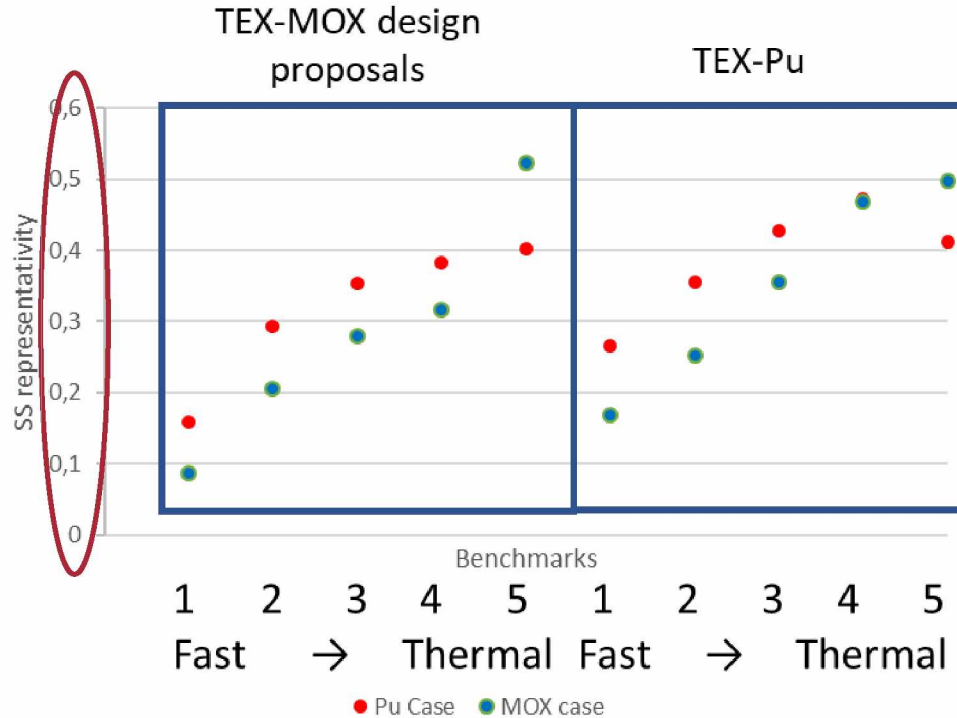
## Shared sensitivity ratio

New indice that does not take into account the covariance data, but focuses only on comparing the sensitivity profiles:

$$SS_{12} = \frac{\sum_{i,r} \sum_{Eg} \left\{ \begin{array}{l} \text{if } S_1^{i,r,Eg} S_2^{i,r,Eg} > 0 : \min(|S_1^{i,r,Eg}|, |S_2^{i,r,Eg}|) \\ \text{else : } 0 \end{array} \right.}{\sum_{i,r} \sum_{Eg} S_1^{i,r,Eg}}$$

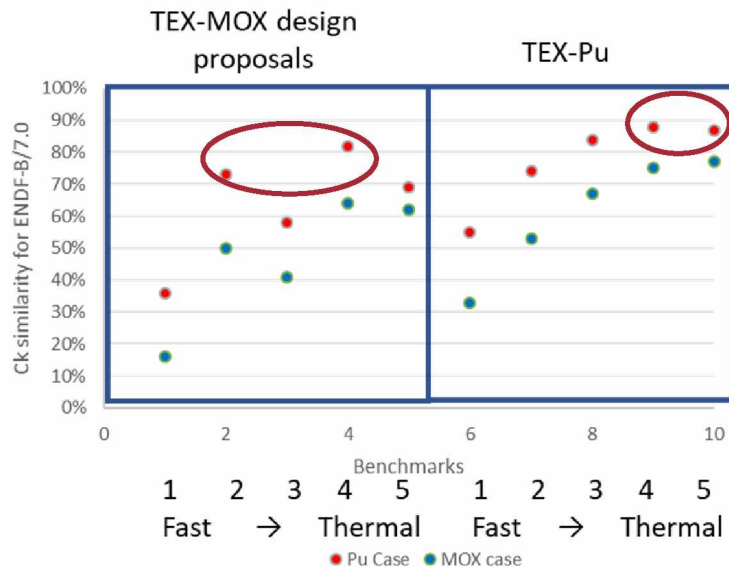
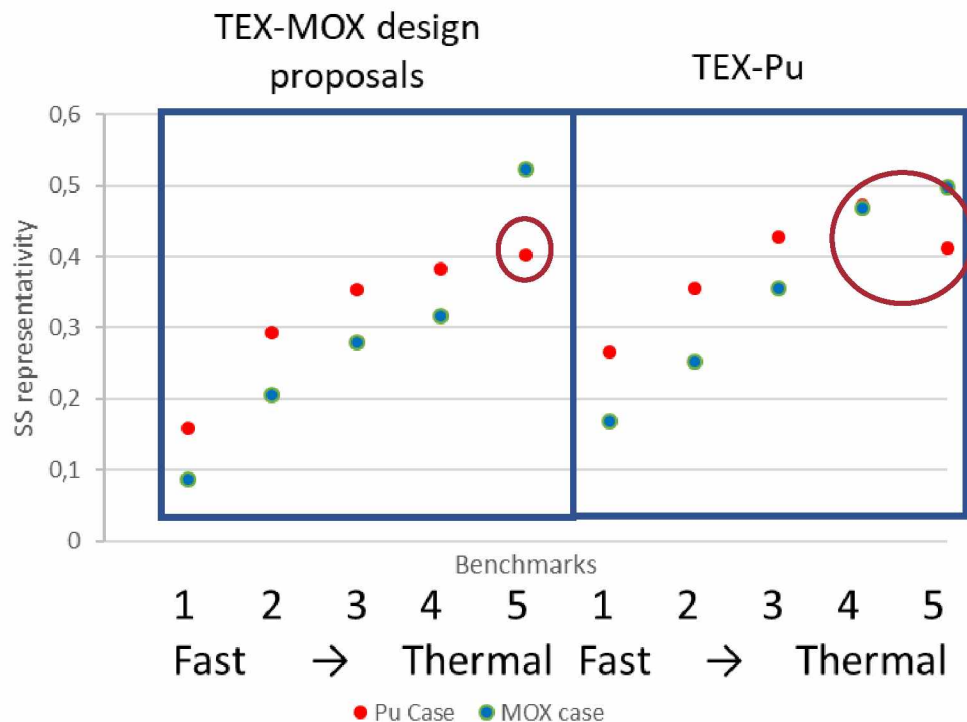


# Shared sensitivity ratio



- Absolute values in SS ratio are much lower than Ck's (max ~50%)
  - Other XS plays a role but have « small » covariances data
  - In this case probably iron 56 plays an important role
- Fe56 n,γ: Pu case -0.05, MOX case -0.14
- Different trends compared to Ck's

## Shared sensitivity ratio



- Pu appl. case:
  - Best TEX-Pu: case 4 for SS  
cases 4-5 for Ck
  - Best TEX-MOX: case 5 for SS  
cases 2 and 4 for Ck

**Interpretation: spectral effects in the covariance data**



# Conclusion and Prospects

# Conclusion

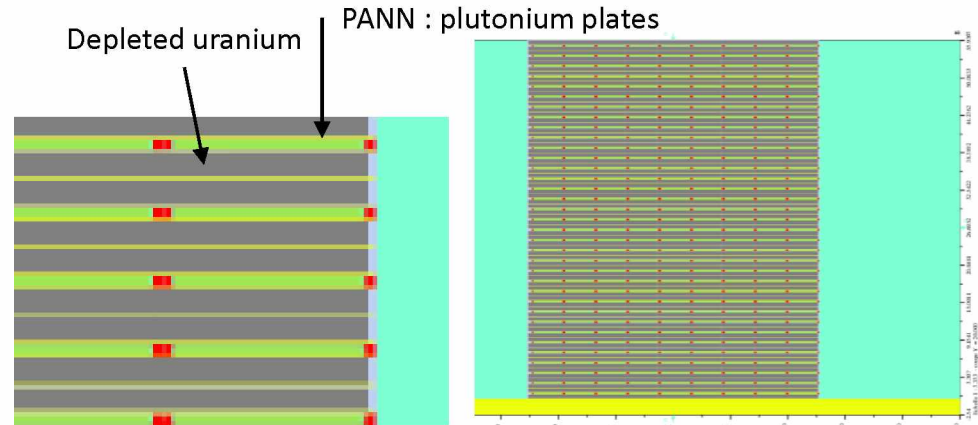
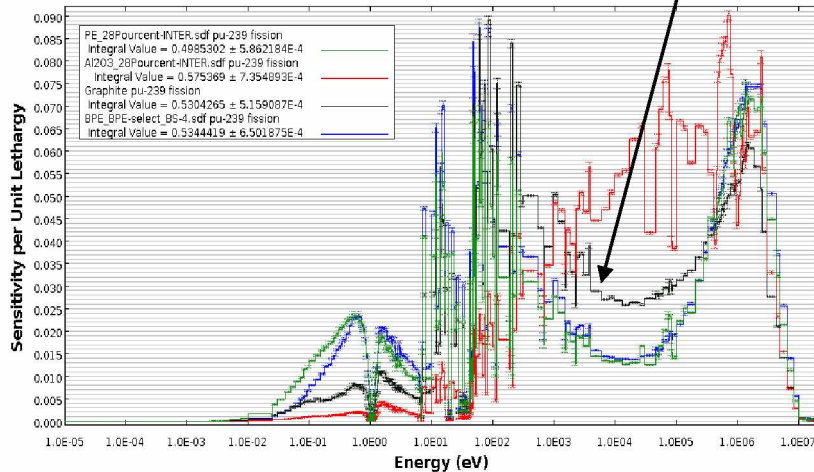
- The analysis of the experimental benchmarks using both  $C_k$  and SS ratios allows a better understanding of the physics behind, separating the effects of:
  - Similarity between an experiment and the application case
  - Similarity pondered by the covariance data,
    - which evolves with time, is questionable, is sometimes just missing ...
- For « complex » application cases, having  $C_k > 0.8$  will not always be possible, so it is not a redhibitory criteria
- Analysis of design proposals for TEX-MOX :
  - Configurations with  $Al_2O_3$  and PE both useful for targeted application cases
    - especially polyethylene (INTER + THERM) – SS ratio
    - $Al_2O_3$  more interesting in area with higher ND uncertainties ( $C_k$  index)

Name	Mod + Reflector material	Neutron spectrum
TEX-MOX case 1	Al2O3	FAST-max
TEX-MOX case 2	Al2O3	INTER
TEX-MOX case 3	PE	FAST
TEX-MOX case 4	PE	INTER
TEX-MOX case 5	PE	THERM

# Prospects

Due to possible experimental constraints (decay heat evacuation) with polyethylene moderator, the analysis of TEX-MOX designs proposals will be pursued including more designs (resulting from design optimization):

- Other materials and configurations: graphite, PE + aluminum, ...
- Other fuel plates: higher  $^{240}\text{Pu}$  content, separated plutonium and depleted uranium fuel plates



Fast 23% Pu TEX-MOX configuration with  $\text{UOD}_8$  plates in dark grey and PANN plates (cladding in red and fuel in green) with aluminum fins in yellow and  $\text{Al}_2\text{O}_3$  reflector in blue

*Thank you for your attention*