IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Preliminary design of the TEX-MOX using optimization algorithms

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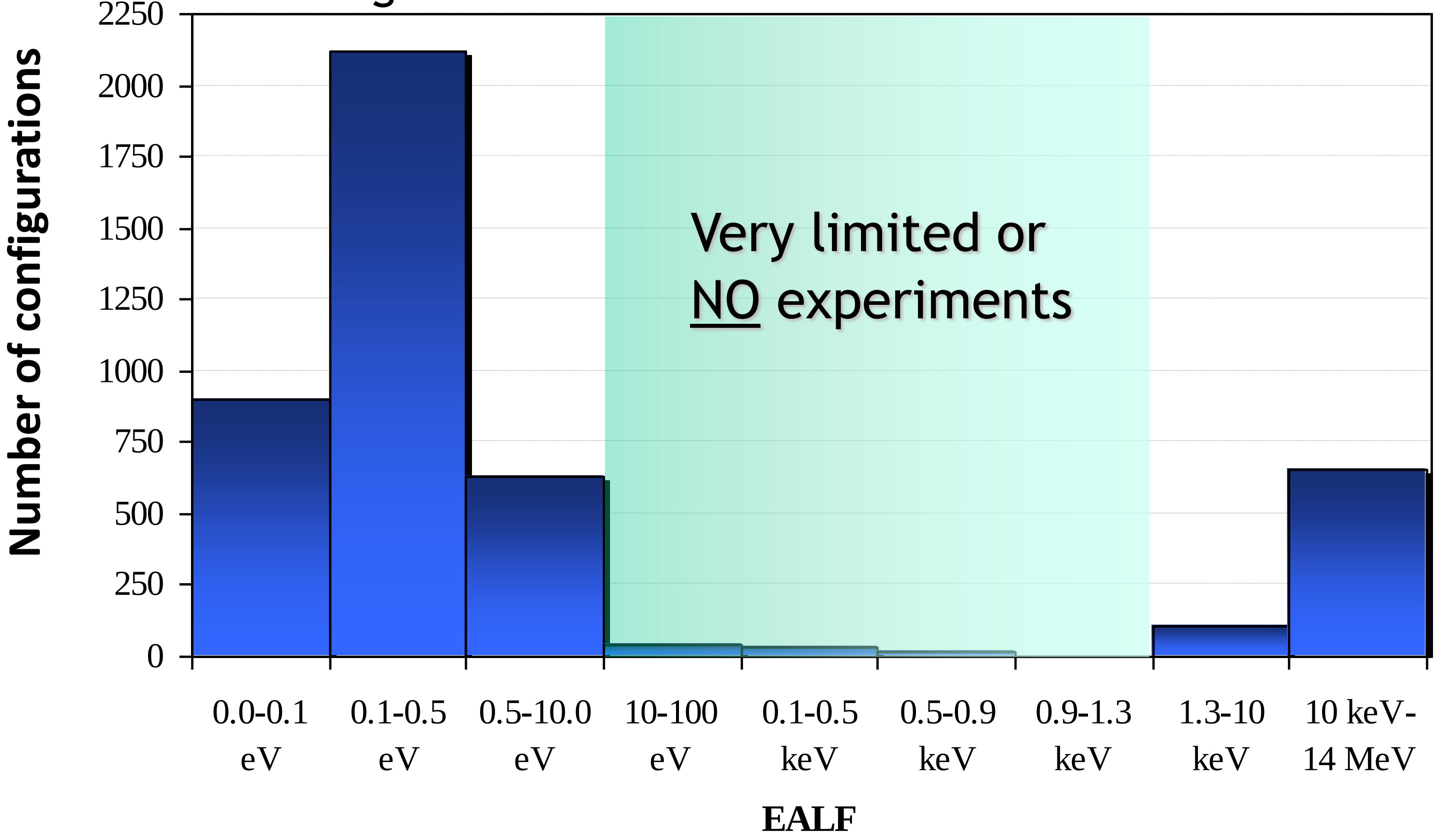
Critical benchmarks need

Established international criticality safety data need for thermal, epithermal and intermediate energy range critical benchmarks

Existing benchmarks in the ICSBEP* Handbook



* International Criticality Safety Benchmark Evaluation Project

TEX (Thermal/Epithermal eXperiments) program

NEED:

Intermediate spectrum experiments

Consensus prioritization of nuclear data needs (in order):

^{239}Pu, ^{240}Pu, ^{238}U, ^{235}U, Temperature variations, Water density variations, Steel, Lead (reflection), **Hafnium**, **Tantalum**, Tungsten, Nickel, Molybdenum, Chromium, Manganese, Copper, Vanadium, Titanium, and Concrete (reflection, characterization, and water content)

Integral experiment requests:

- TEX-Ta
- TEX-Hf

LLNL leader

- **TEX-MOX** — *IRSN leader*
- TEX-Fe
- TEX-U233

TEX-MOX experiments goal:

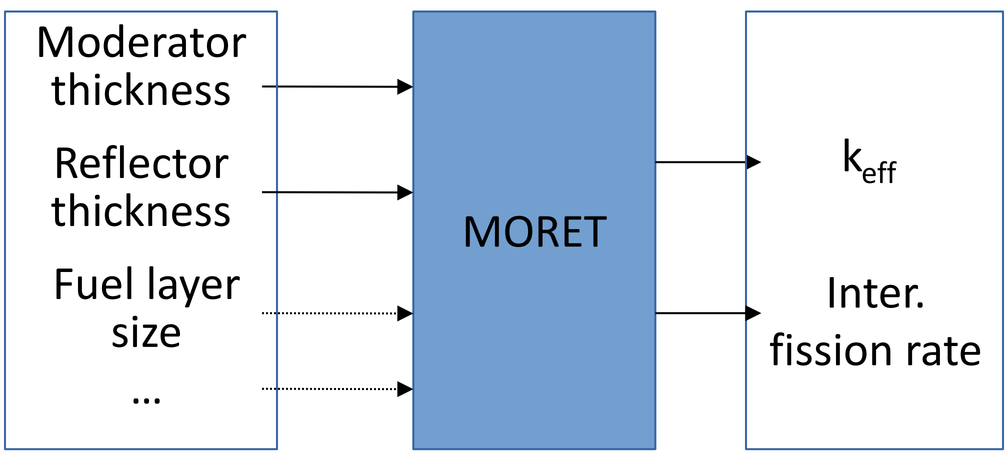
Represent as close as possible **low moderated MOX powder mixtures** with heterogeneous plates configurations based on **existing fuel plates**

Critical experiment design optimization

- PROMETHEE developed at IRSN
- Launcher-parametrizer tool using several codes (SCALE, MORET,…)
- Embeds ECEGO, an optimization algorithm

> It allows **maximizing an output value** (sensitivities to nuclear data, fission rate,…) while keeping parameters of interest (k_{eff}, pitch,…) **comprised in a given interval**

- Considers the criticality (numerical) model



- Searches for a **design point:**

- Critical k_{eff}

&

- Highest fission rate in intermediate spectrum

Why optimization algorithm ?

How to find this **optimal design point** ?

- True practical constraints:
  - more than 2 input parameters (say 5)
  - non-linear I/O behavior
  - 20' cpu per calculation

⇒ Building the whole response surfaces for 5 parameters requires:
10 [pt/dim] ^ **5** [dim] * **20** ['cpu] = **1400** days.cpu

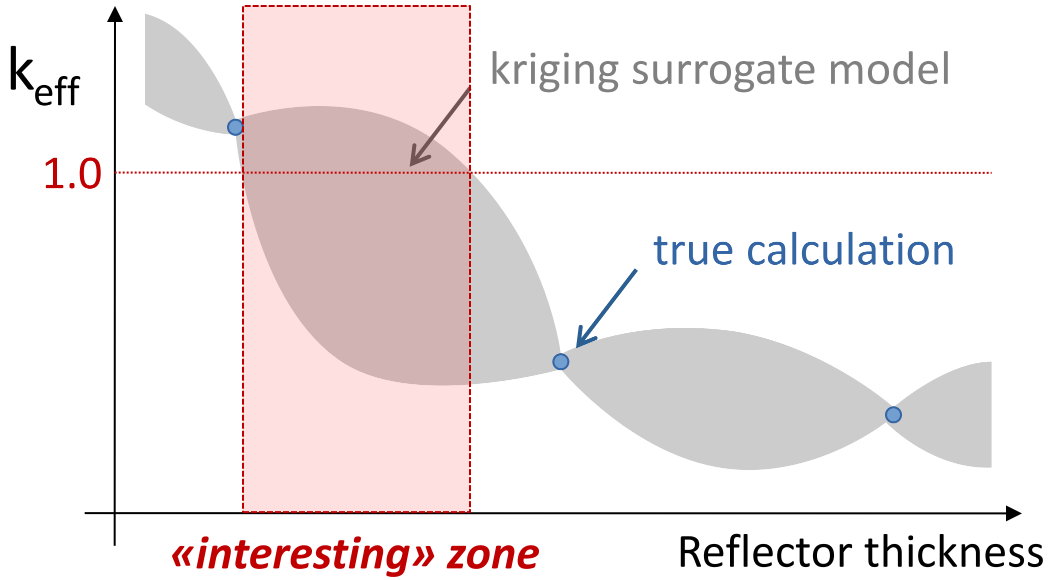
⇒ Build a *good* response surface surrogate (**kriging**)
Good means "refined in interesting zones"

Model based on kriging

- "Kriging"

  = interpolate few calculations to get a **response surface**

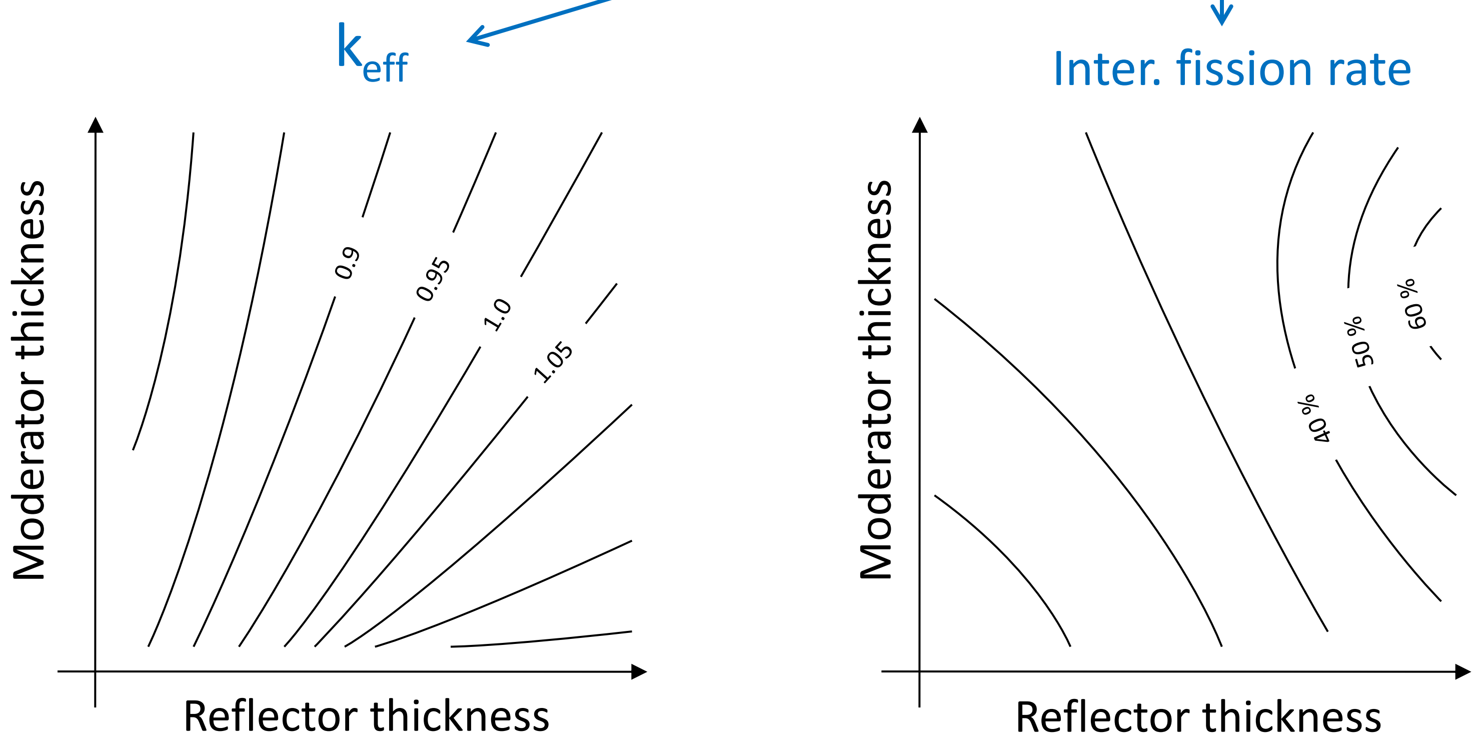
  … *with **uncertainty***



- ECEGO algorithm
  - **iteratively** enriches the calculations list, in order to converge toward the best possible design point
  - reaches convergence with ~1000 points = **5** days.cpu

ECEGO optimization algorithm

- Model can be seen as a response surface for each output here just considering 2 input parameters:
  - ➢ *moderator thickness* and *reflector thickness*



ECEGO optimization algorithm

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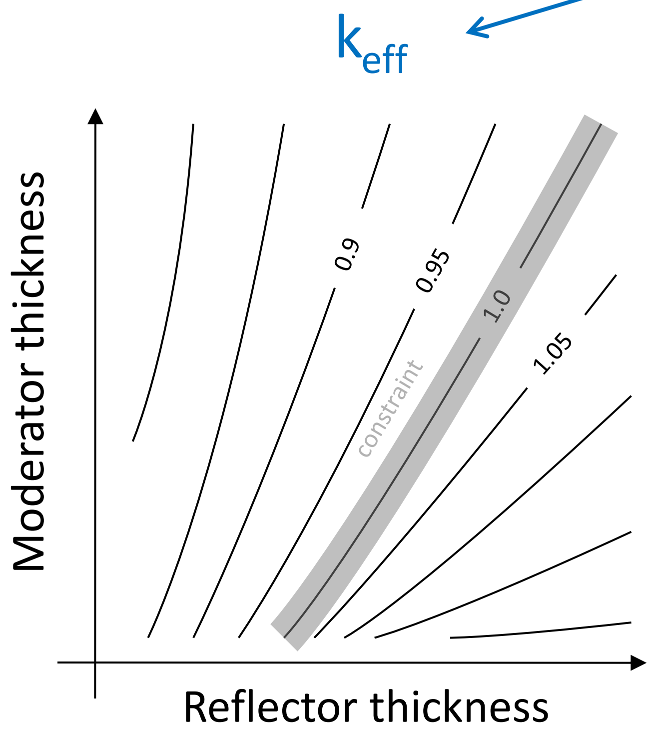
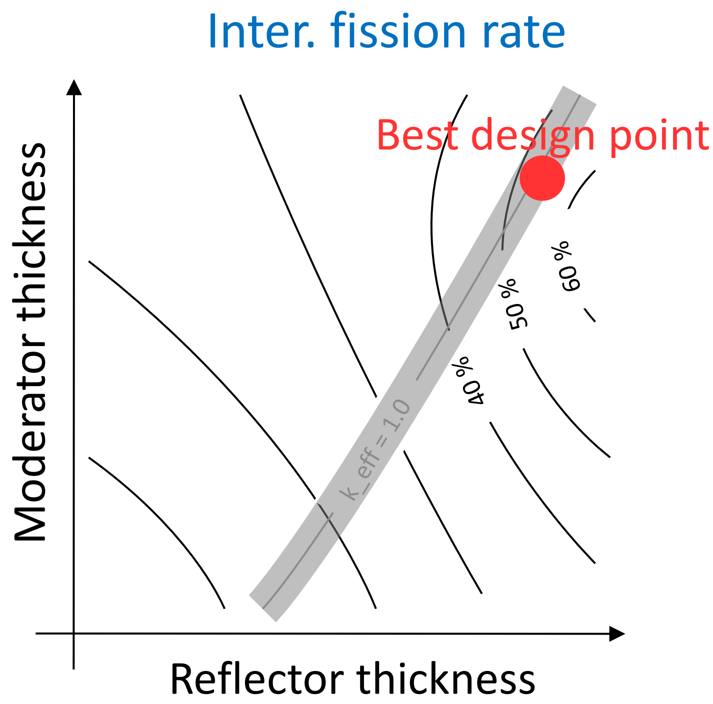




Optimization of TEX-MOX configurations

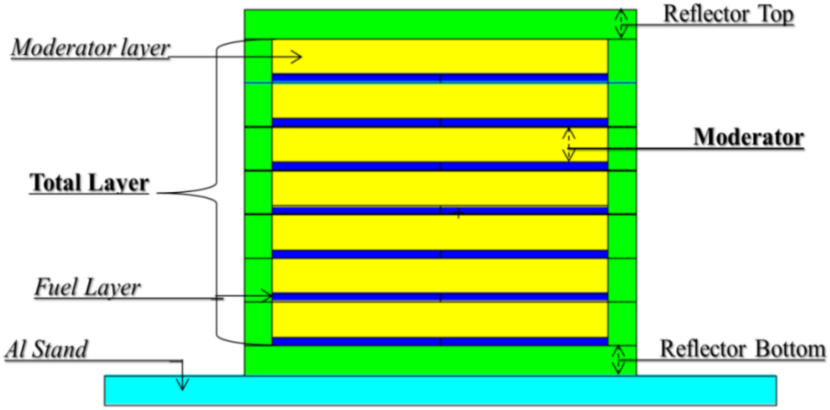
<u>Experimental constraints:</u>

- Materials allowed in PLANET/COMET
- Number of fuel plates (PUMN)
- Max size in PLANET machine

<u>Model simplification for optimization:</u>

- Fuel plates considered as continuous medium

First model:



<u>Varied parameters:</u>

- Reflector thickness
- Moderator thickness
- Fuel area for one layer
- Number of layers

Maximize the Intermediate fission rate
&
Configurations are critical

If results unsatisfying → Release constraints/Add parameters

Optimization of TEX-MOX configurations

<u>Experimental constraints:</u>

- Materials allowed in PLANET/COMET
- Number of fuel plates (PUMN)
- Max size in PLANET machine

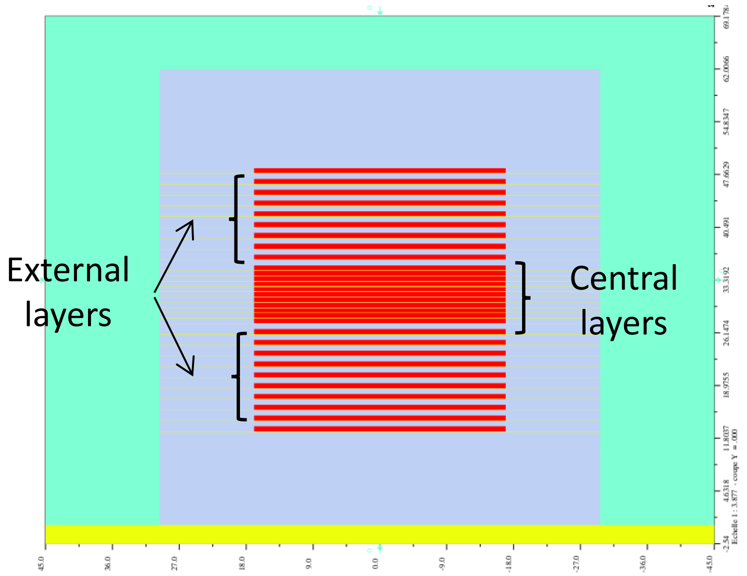
<u>Model simplification for optimization:</u>

- Fuel plates considered as continuous medium

<u>Varied parameters:</u>

- Reflector thickness
- Moderator thickness central layers
- Moderator thickness external layers
- Fuel area for one layer
- Number of central layers
- Number of external layers

Second model:



Maximize the Intermediate fission rate
&
Configurations are critical

If results unsatisfying ⇒ Release constraints/Add parameters

Results analysis

Projection of the kriging model for each input parameter

Red line = model of the value of interest (k_{eff} or fission rate)

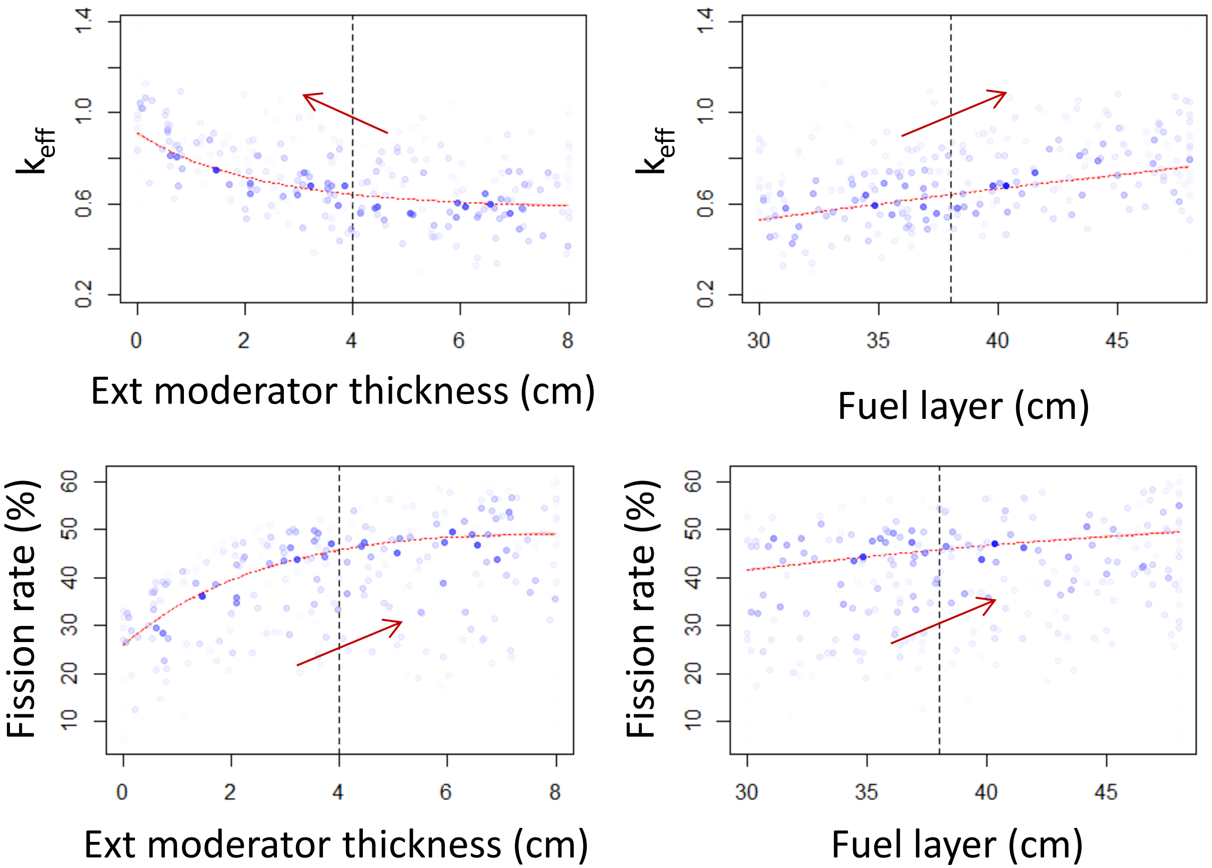
Blue point = true calculation

Moderator thickness

- Opposite impact
- Trade-off value

Fuel layer dimension

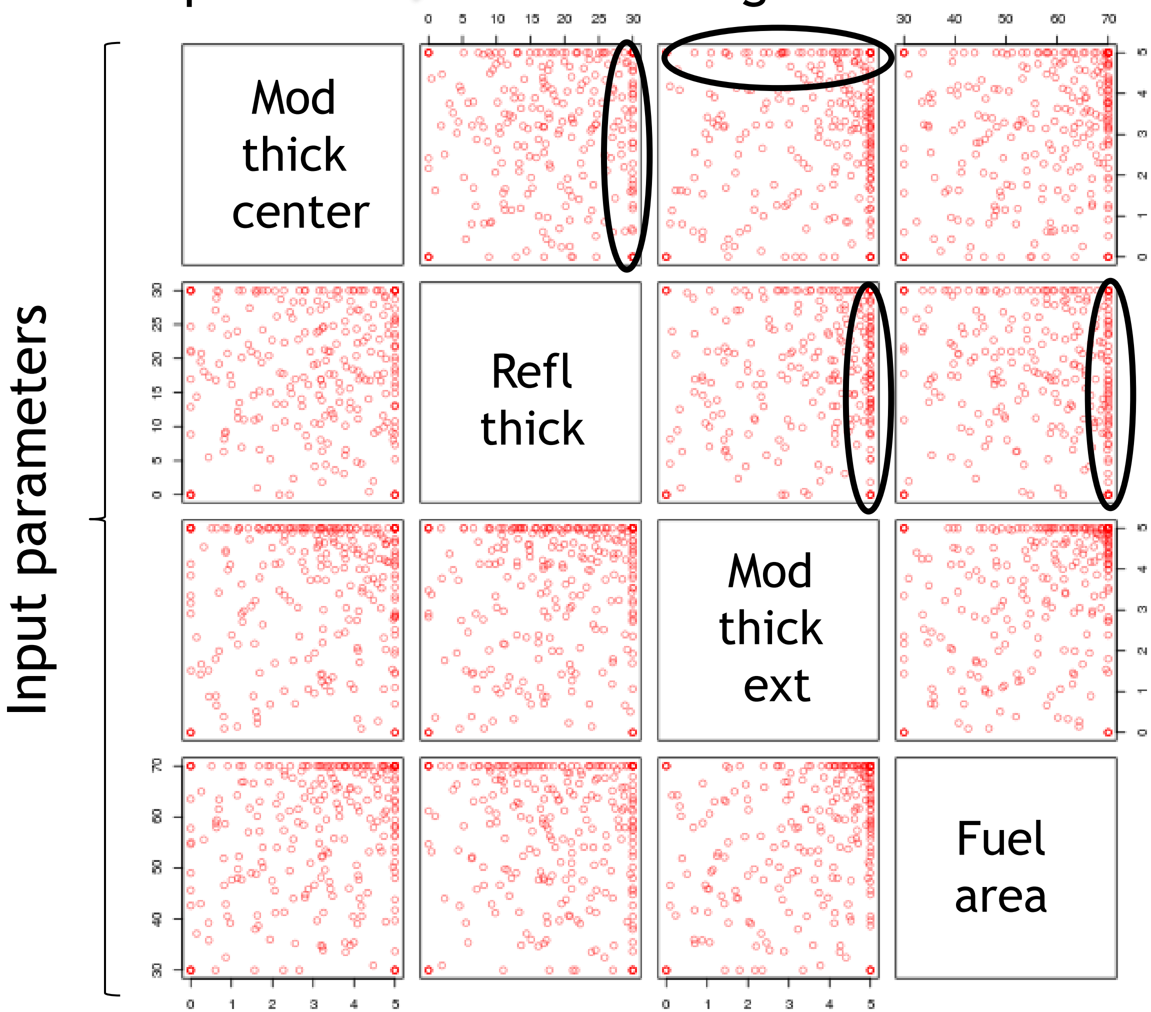
- Positive impact on both parameters
- Experimental constraints limits the max. value



Results analysis

Each red point = calculation

More points ⇨ « interesting » area



- Interesting areas at the **limits** of the input parameters
- Reconsider **fixed (experimental) constraints**

Configurations selection

Line = configuration

Column = parameter, constraint, information or result

⟹ Dynamic plot

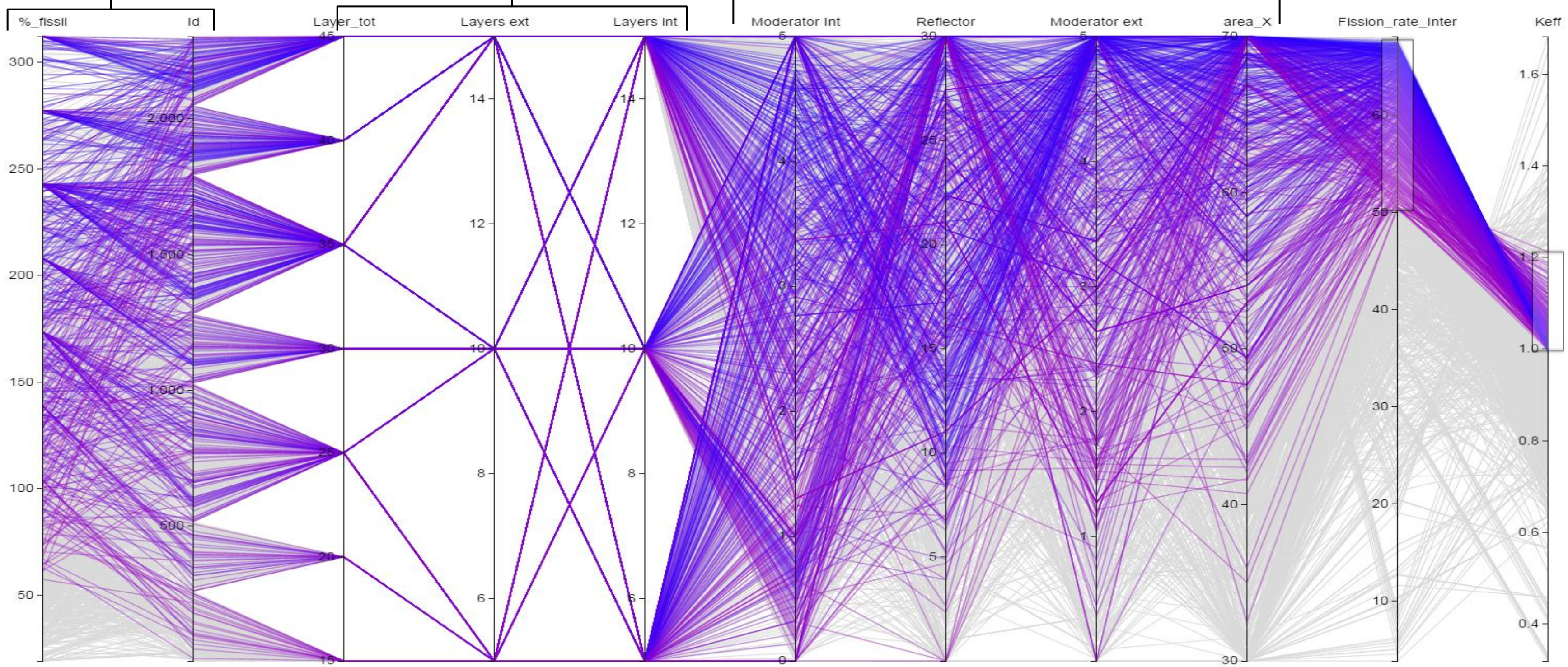
Value to maximize

Continuous parameters (adjusted by the algorithm)

Constraint

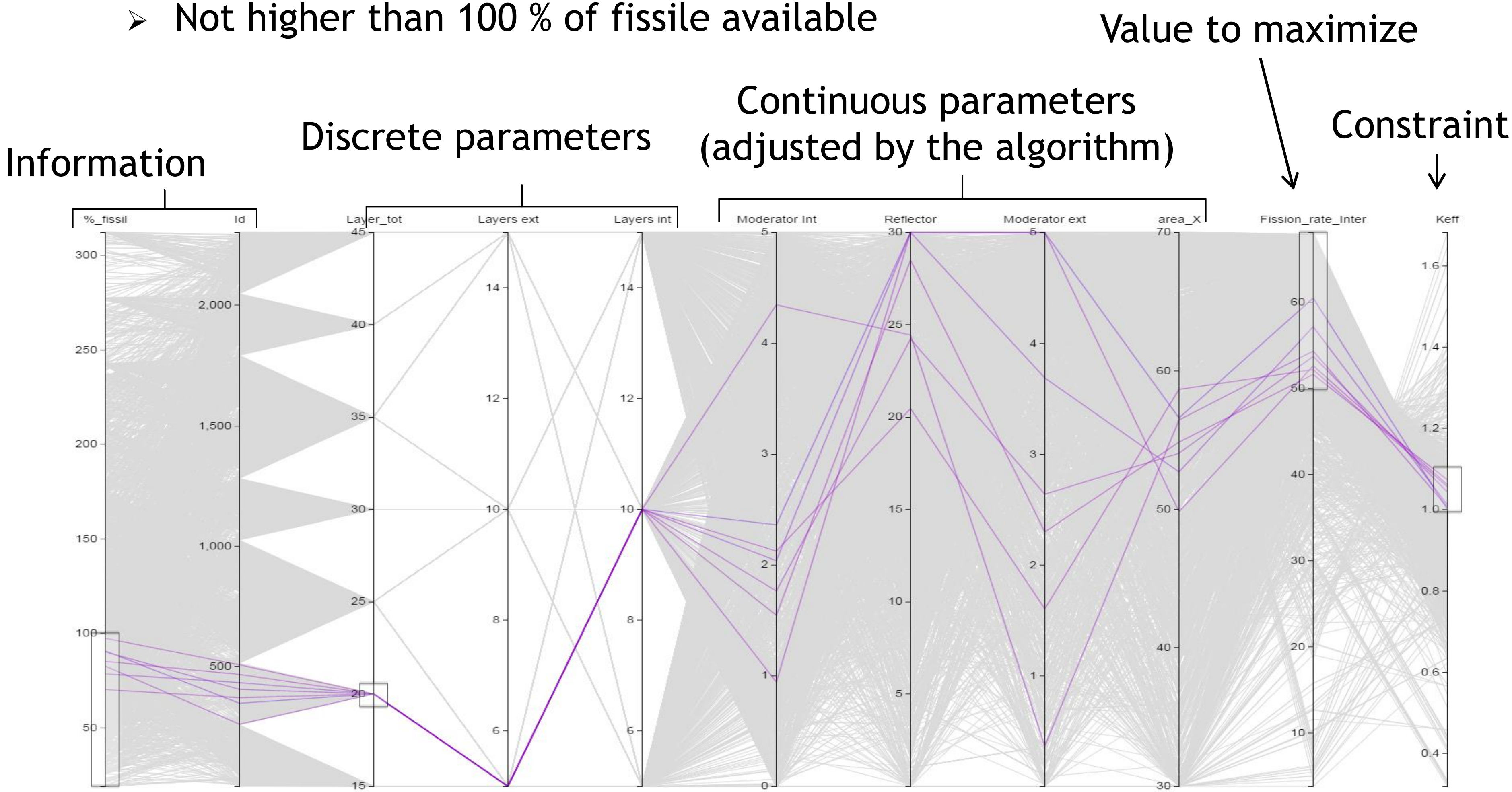
Discrete parameters

Information



Configurations selection

- 1.1 > k_{eff} > 1.0
- Intermediate fission rate > 50 %
- Not higher than 100 % of fissile available

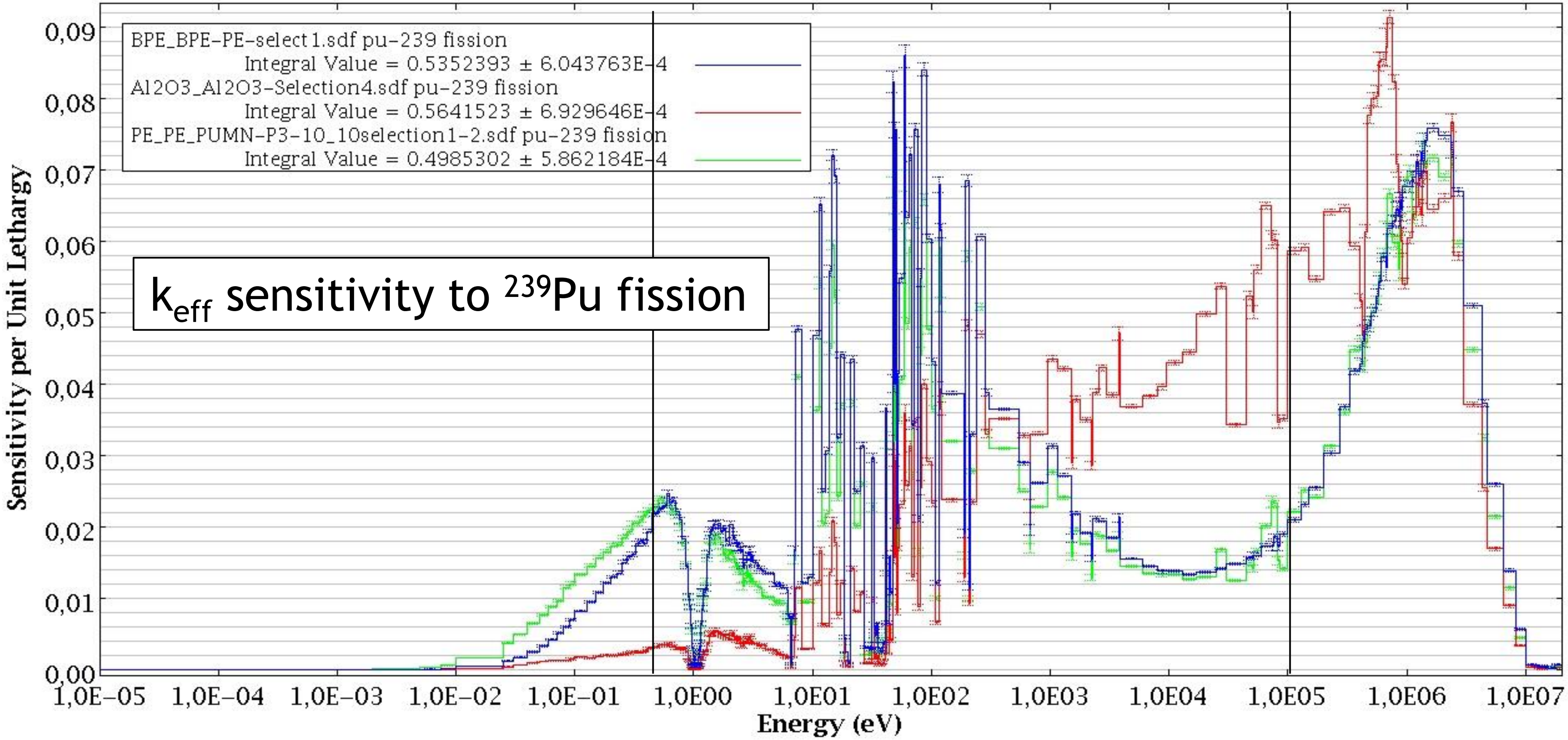


TEX-MOX configurations

Optimization tested with different materials

⇨ 3 materials (moderator & reflector) **satisfy** the requirements:

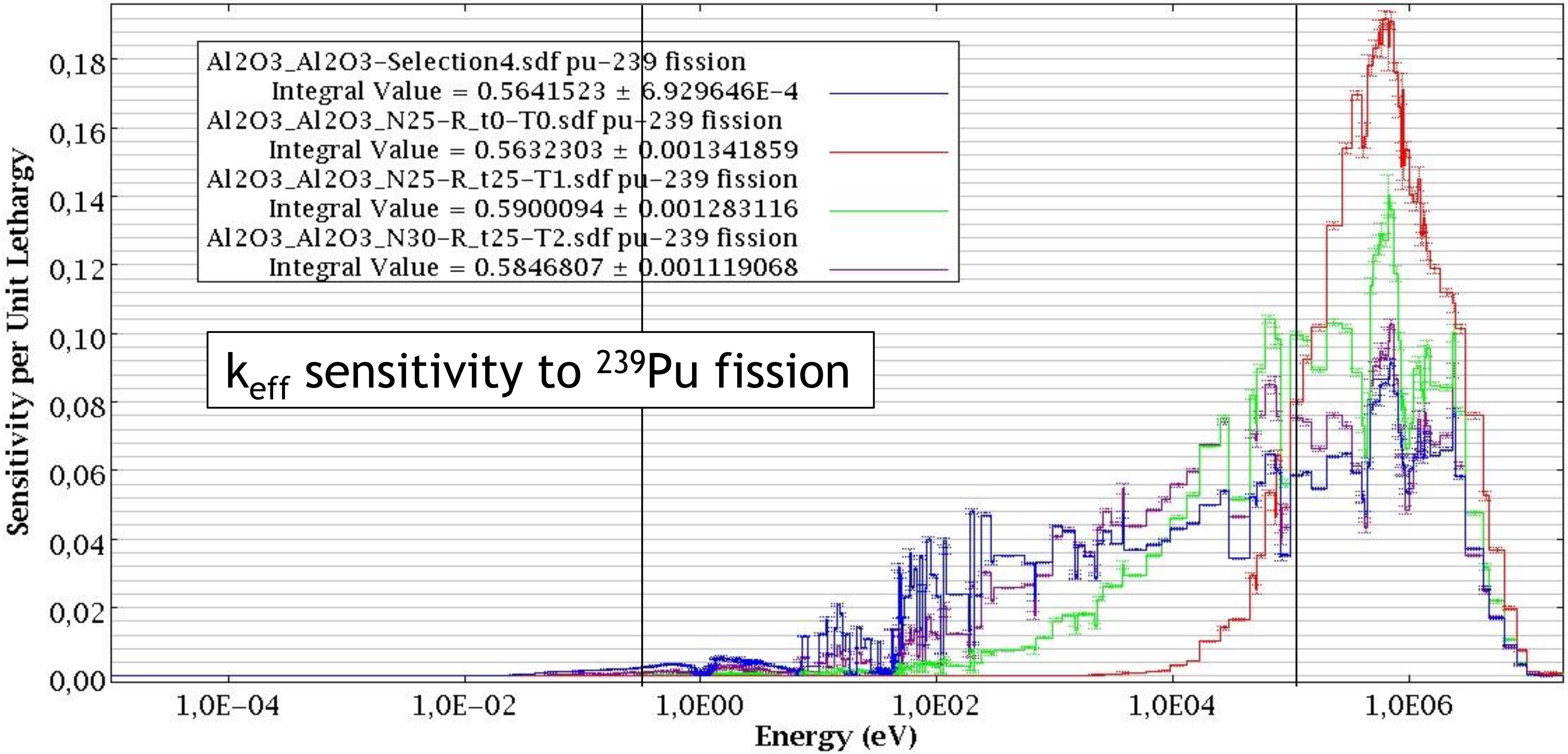
Borated Polyethylene, **Alumina**, **Polyethylene**



Spectrum modification

Optimization for intermediate configuration ⇨ **fixes** fuel layer dimensions

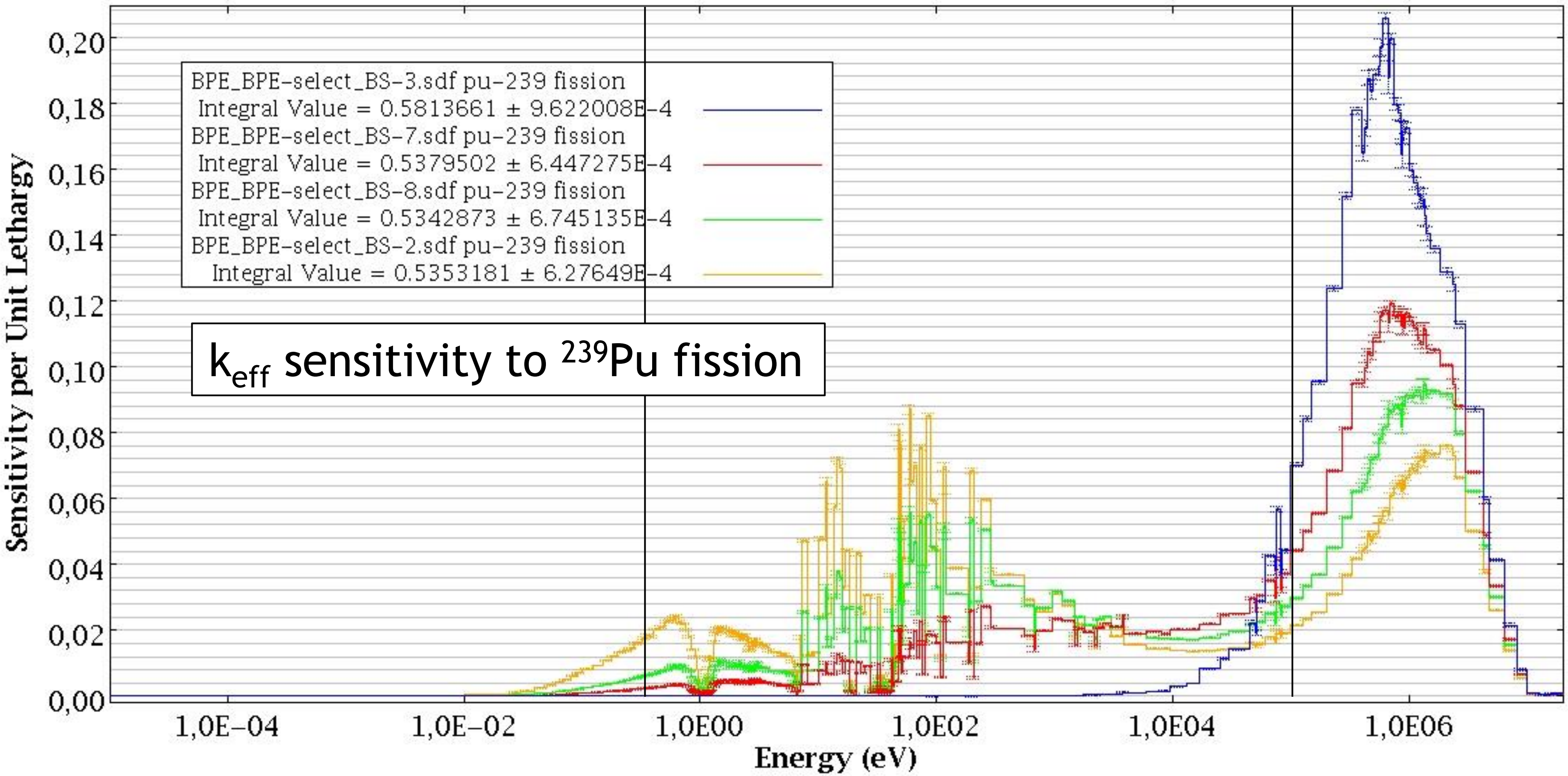
Al_2O_3 moderator thickness variation ⇨ spectrum modification



✗ No thermal, no epithermal configurations ✓ Fast & intermediate spectrum

Spectrum modification

Borated PE moderator thickness variation ⇨ spectrum modification

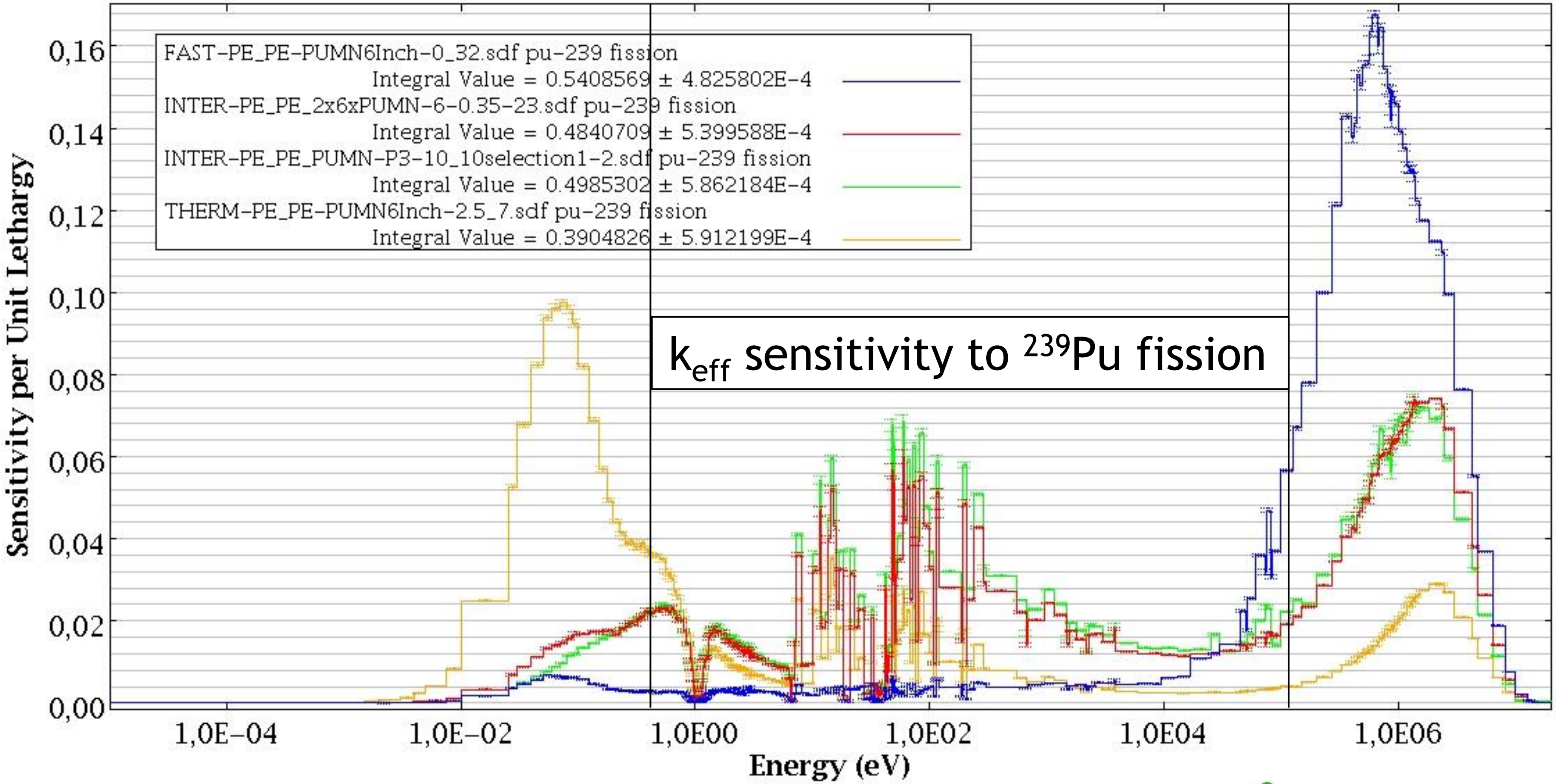


✗ No thermal configuration (boron capture)

✓ Resonances region, fast

Spectrum modification

PE moderator thickness variation ⇨ spectrum modification

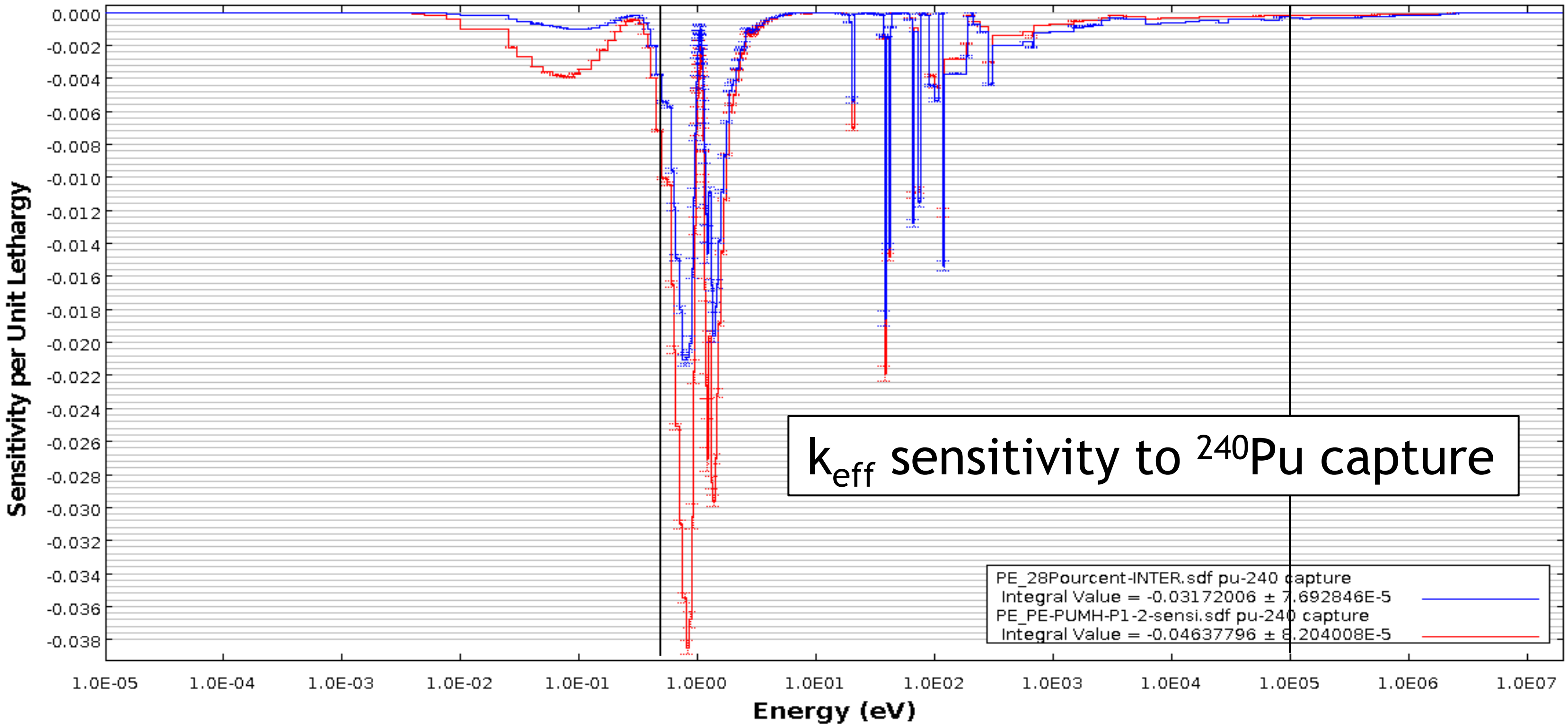


✗ Not best in intermediate (only 49.45% fission rate)

✓ Thermal, fast

Optimization on ^{240}Pu capture

- **PUMN** plates (12% ^{240}Pu) replaced by **PUMH** (26% ^{240}Pu) plates
- Optimized on the ^{240}Pu capture reaction rate in the intermediate energy range



- Use of PUMH plates & optimizing on ^{240}Pu capture allow increase sensitivity to ^{240}Pu capture

Conclusion & Perspectives

TEX-MOX experiments

- Goal: set of experiments with varying spectrum, varying Pu/(U+Pu) content, varying ^{240}Pu content
- CED-1 report in progress: overview of studied configurations, preliminary designs
- Comparison of sensitivity profiles to application case → representative ?
- Experimental uncertainties
- Final designs …

Critical experiments design optimization with PROMETHEE

- Allows rapidly finding interesting configurations ("trade-off" points)
- Especially interesting with many input parameters (here up to 7)
- Optimization algorithm based on 2 output parameters (k_{eff} + reaction rate in a given energy interval, …)

Thank you for your attention!