IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

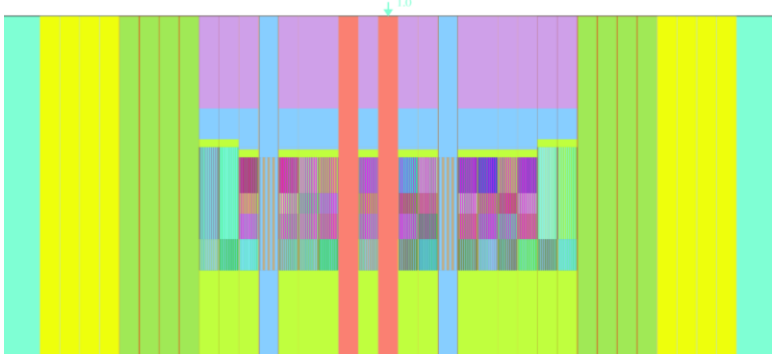
Faire avancer la sûreté nucléaire

Preliminary studies for ASTRID-like SFR implementation in the CLASS code

2nd Technical Workshop on Fuel Cycle Simulation

July 19th – 21st 2017

Columbia, South Carolina U.S.A.



Neutronics and Criticality Safety Department

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Outline

Objectives

Simulation tools

Geometry modeling

Preliminary results

- Static calculations
- Depletion calculations

Conclusion & Perspective

Objectives

Long term objectives

- **Scenario simulations** (integrating ASTRID-like SFR) → CLASS code
- Estimation of the accuracy associated with Physic models
  - *Fuel production & evolution*
- **Databank** (K_{eff} , Flux, XS): many depletion calculations

Core Library for Advanced Scenario Simulation

Medium term objectives

- Many full core calculations: **static & depletion simulations**
- ASTRID-like SFR: 2 types of axially heterogeneous assembly
  - *Huge cost in term of CPU time & memory resources*

Short term objectives

- **Assembly calculations**: full core preparation → **tools & methods**
- Accuracy & CPU time optimization
  - *Methods used for full core calculations*

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  - *Methods to be used for full core calculations*

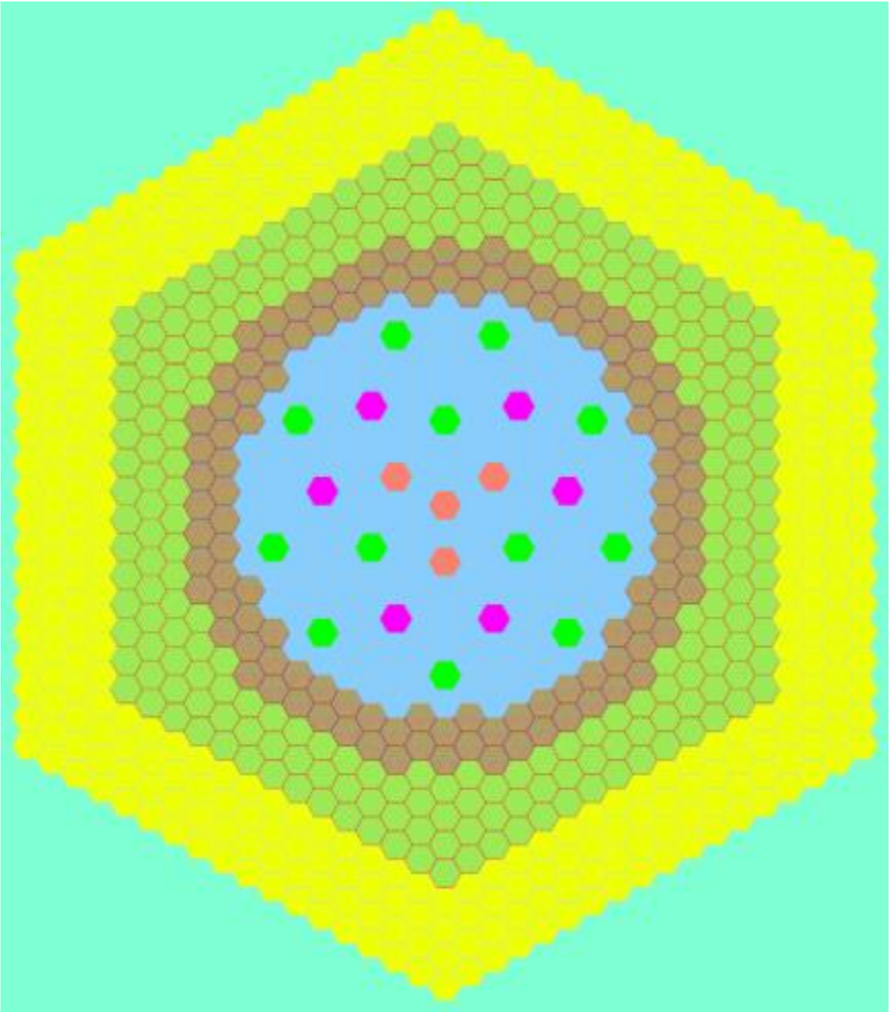
Simulation tools

- **Monte-Carlo calculations:** MORET 5.D.1 Beta
  - Criticality code
  - Soon available at OECD
- **Depletion calculations:** VESTA 2.2 Beta
  - Thin multigroup calculation (43 000 groups)
  - Version 2.1.5 available at OECD
- **Nuclear data:** JEFF.3.1
- **Parametrical calculations launching:** Prométhée
  - Parallel distribution of calculations
  - Algorithms for advanced engineering based on R language
- **Post-processing:** R scripts
  - (Library plotly, rCharts, devtools)

Geometry modeling

With the MORET code

- 2 types of hexagonal assembly
  - External: 1 fissile area, 1 fertile area
  - Internal: 2 fissile areas, 2 fertile areas
  - Depletion: 1 fuel / zone / assembly
  - 217 identical fuel pins per assembly
  - Helicoidally spacer wires: not modelled
  - Semi-infinite calculation



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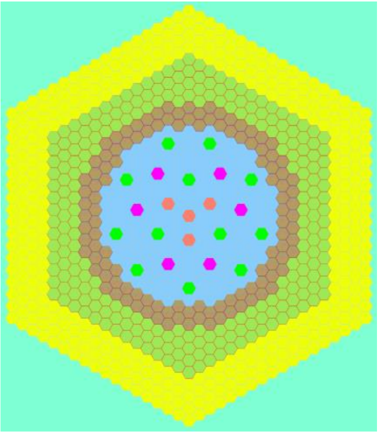
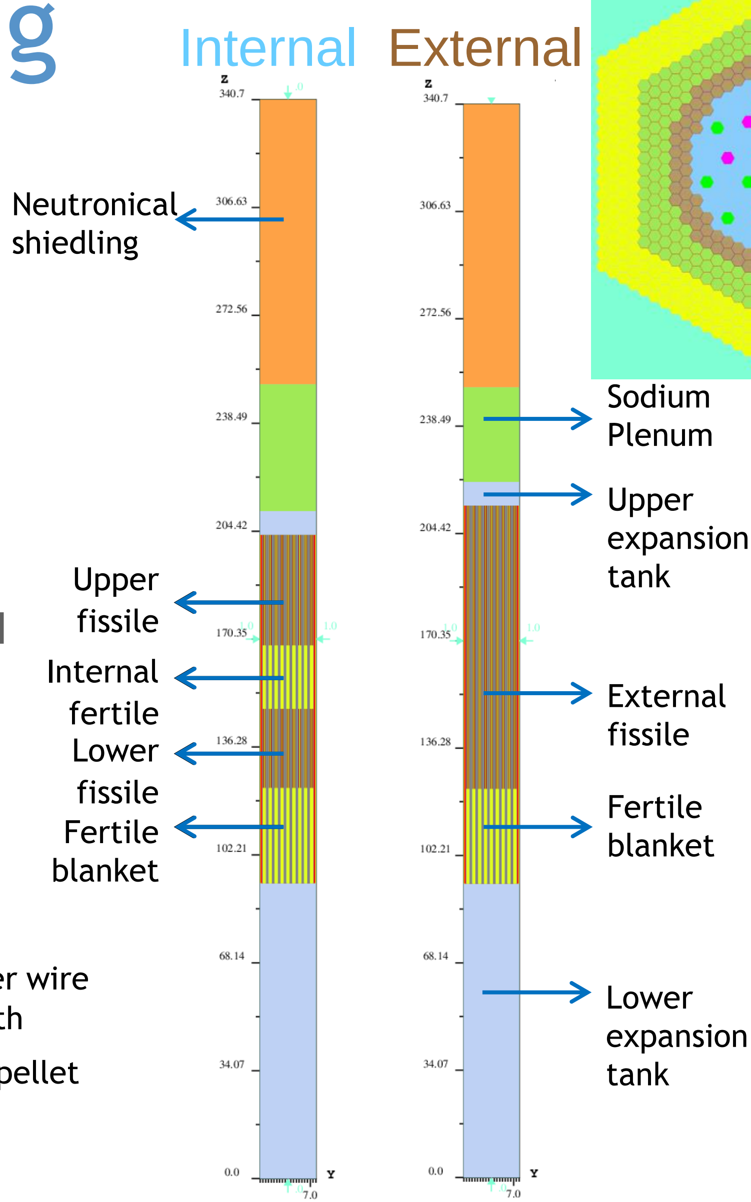
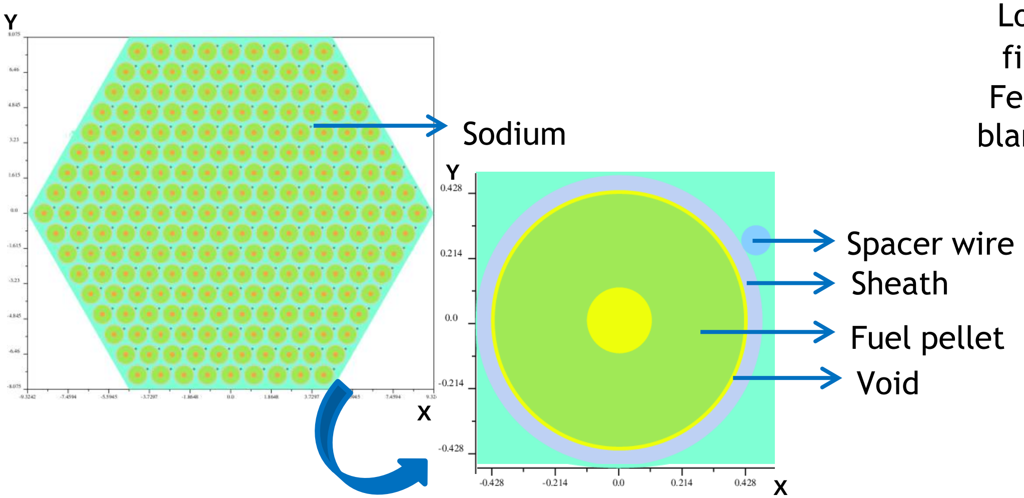






Preliminary results

Static calculations: internal assembly

Experimental plan

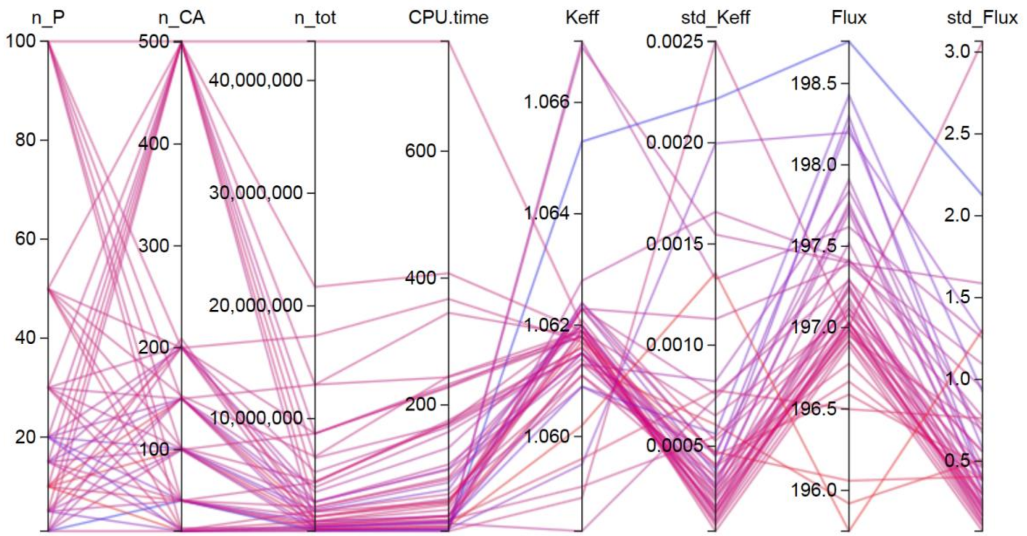
Simulation parameters

- 10 inactive cycles *(choice)*
- Active cycles
  → [20 , 50 , 100 , 150 , 200 , 500]
- Number of source particles per zone
  → [1 , 5 , 10 , 15 , 20 , 30 , 50 , 100]

Number of particles

$$N_p \times N_{ca} \times N_{pins} \times N_{zones}$$

Parallel plot of the simulations



A priori selected criteria

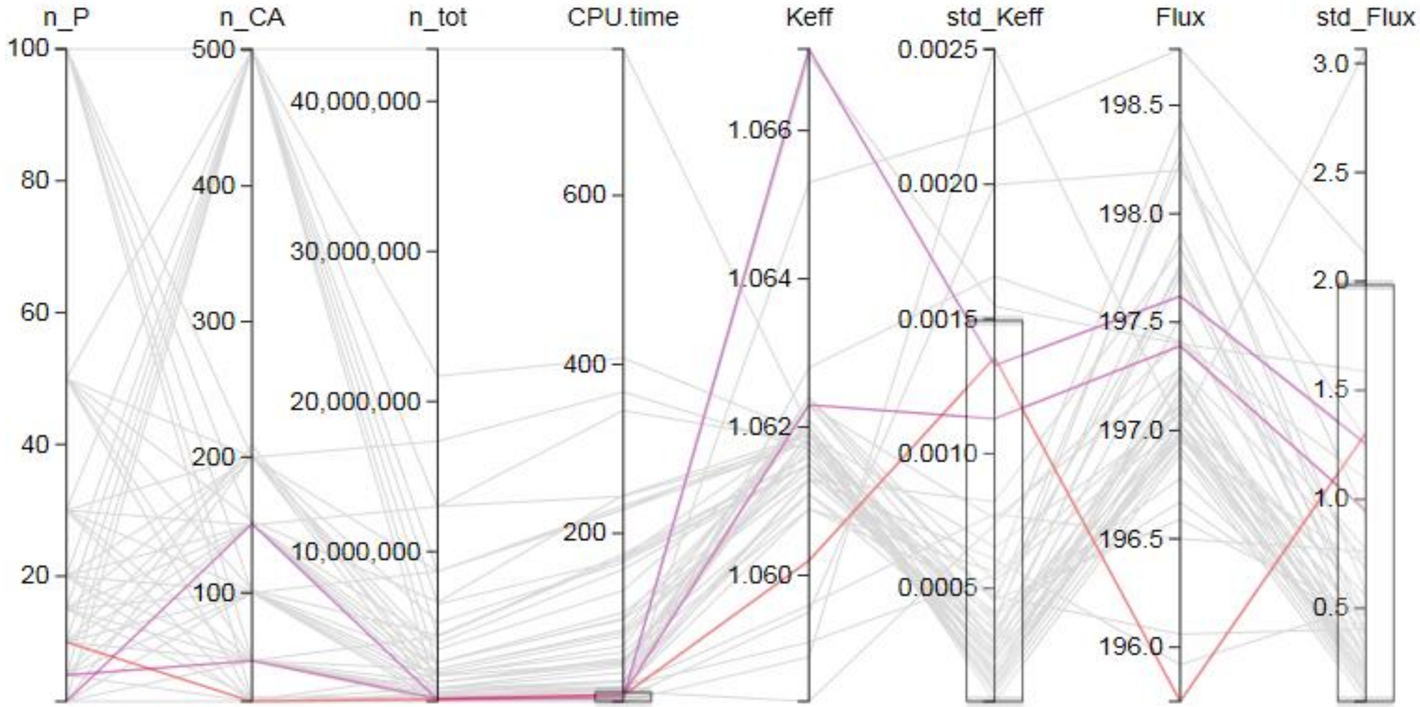
- CPU time < 10 min
- Uncertainty on K_{eff} ~ 1.5‰
- Uncertainty on Flux ~ 1%

} Values on full assembly

Same parameters for both assembly

Static calculations: internal assembly

Parallel plot of the simulations



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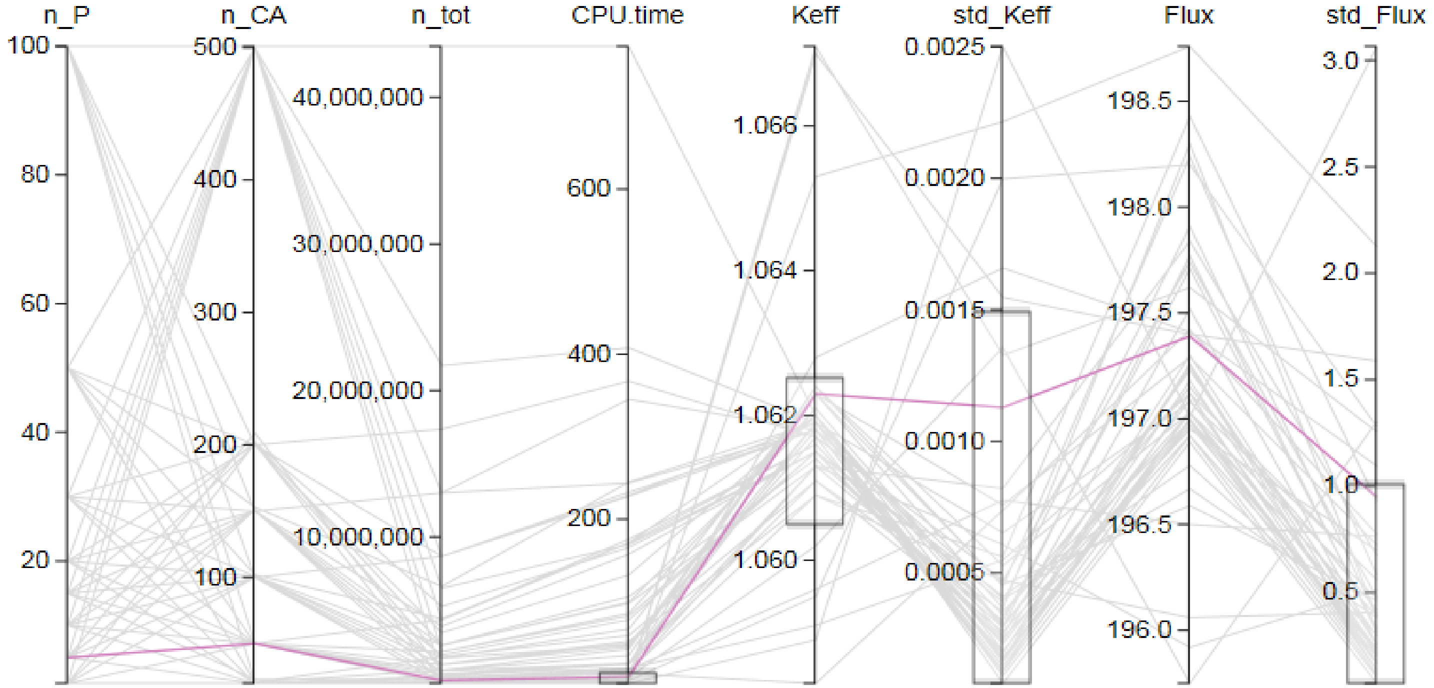

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} Values on full assembly

Selected parameters:
50 active cycles

Internal:	**External:**
4340 part/cycle	2170 part/cycle
9.03 min	2.35 min

Depletion calculations: internal assembly

Experimental plan

Simulation data

- Burnup: 110 GWd/t
- Mean power: 5.12 MWth
- Irradiation time: 2817 d

Modelling parameters

- Number of timesteps

→ [1, 4, 6, 8, 10, 15, 25, 50, 75, 100]

- Propagation of statistical Monte-Carlo uncertainty (random seed)

→ 50 seeds *[1000: 246000]*

Quantity of interest

- Reaction: Fission, Capture, (n,2n)
- Isotope: ^{238}U, ^{239}Pu, ^{237}Np, ^{243}Cm, …
- K_{eff} & associated uncertainty, Flux & Power, XS, Composition

Depletion calculations: internal assembly

↗ Experimental plan

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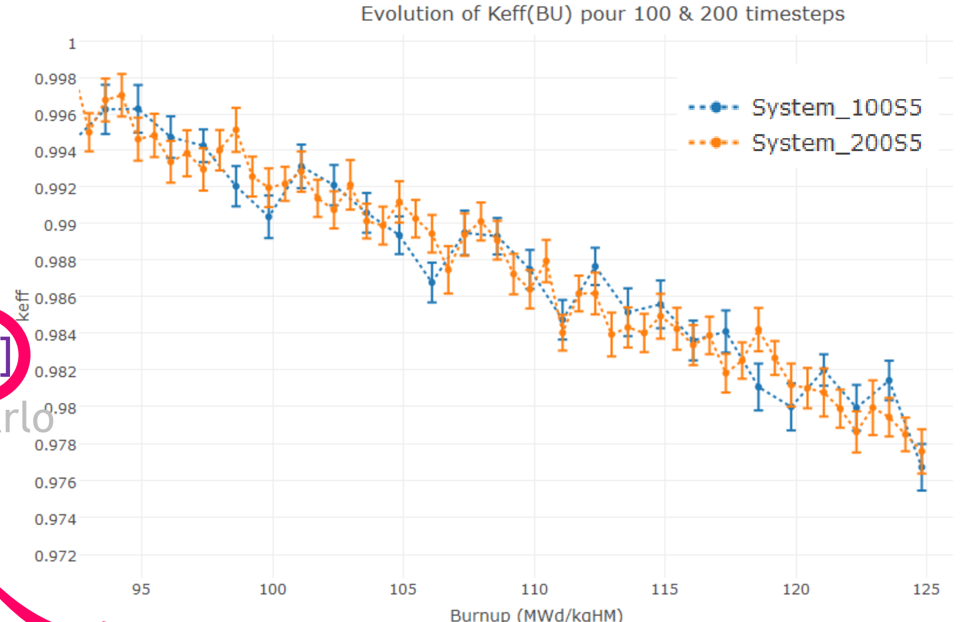
↗ Reference calculation for timesteps impact

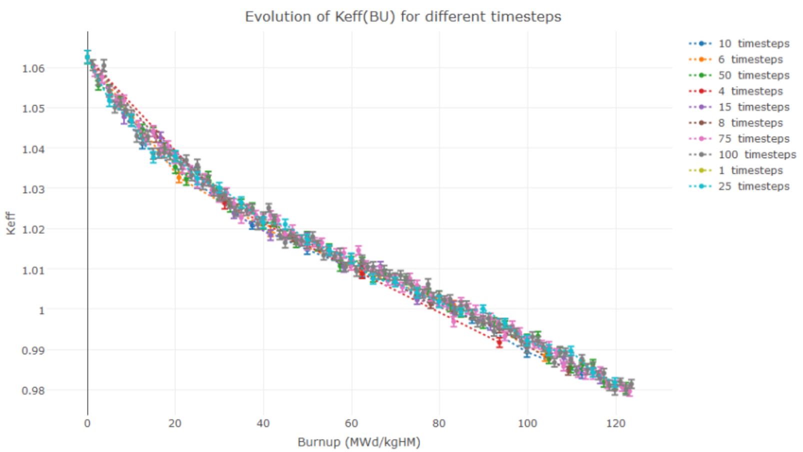


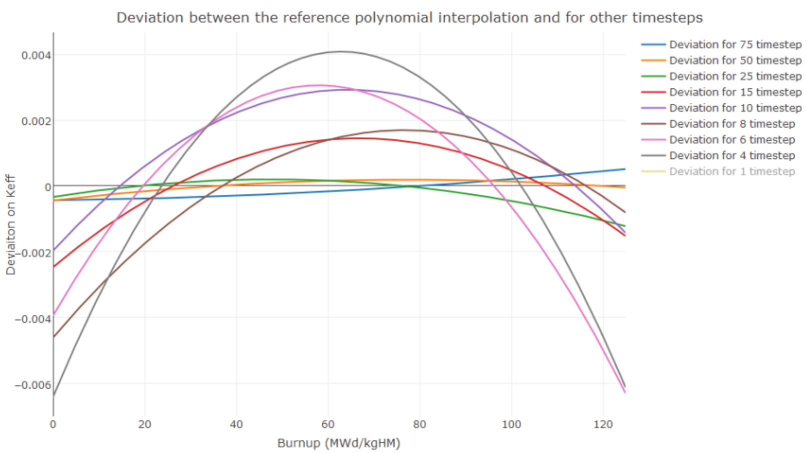
100 timesteps:
reference calculation to estimate differences due to the number of timesteps

Depletion calculations: K_{eff} & Flux

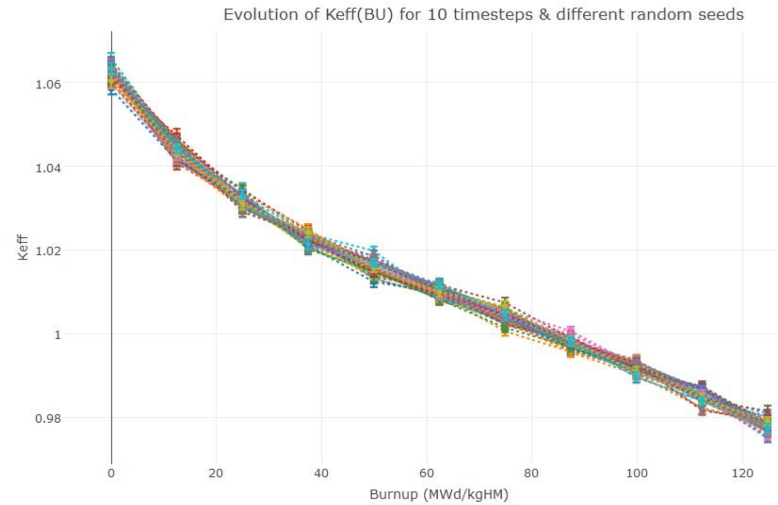
Example of K_{eff}

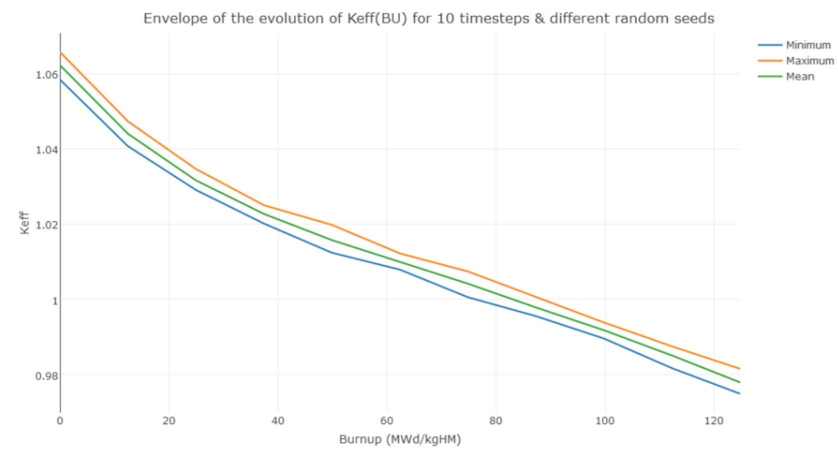
Impact of the timestep number





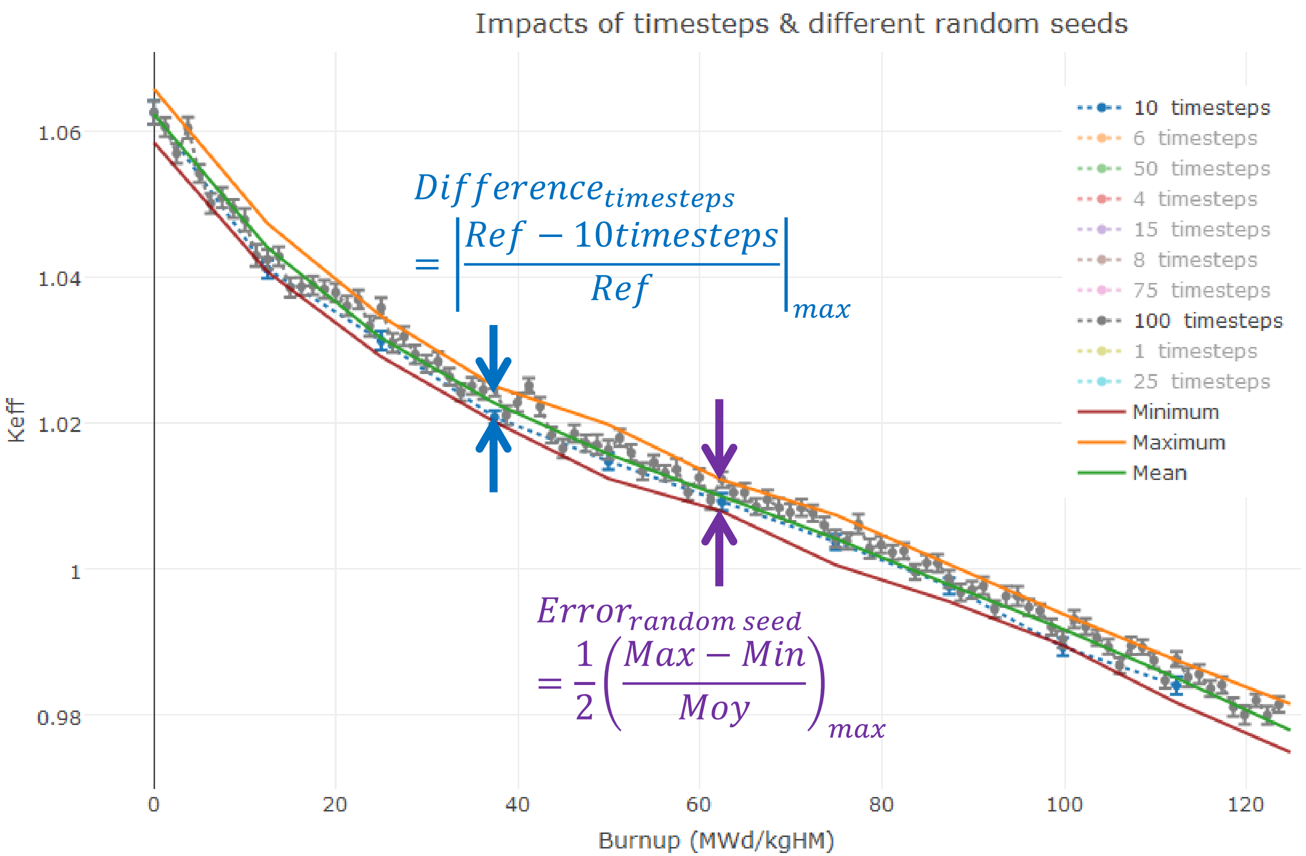
Impact of the random seed





Depletion calculations: K_{eff} & Flux

↗ Example of K_{eff}



10 timesteps:

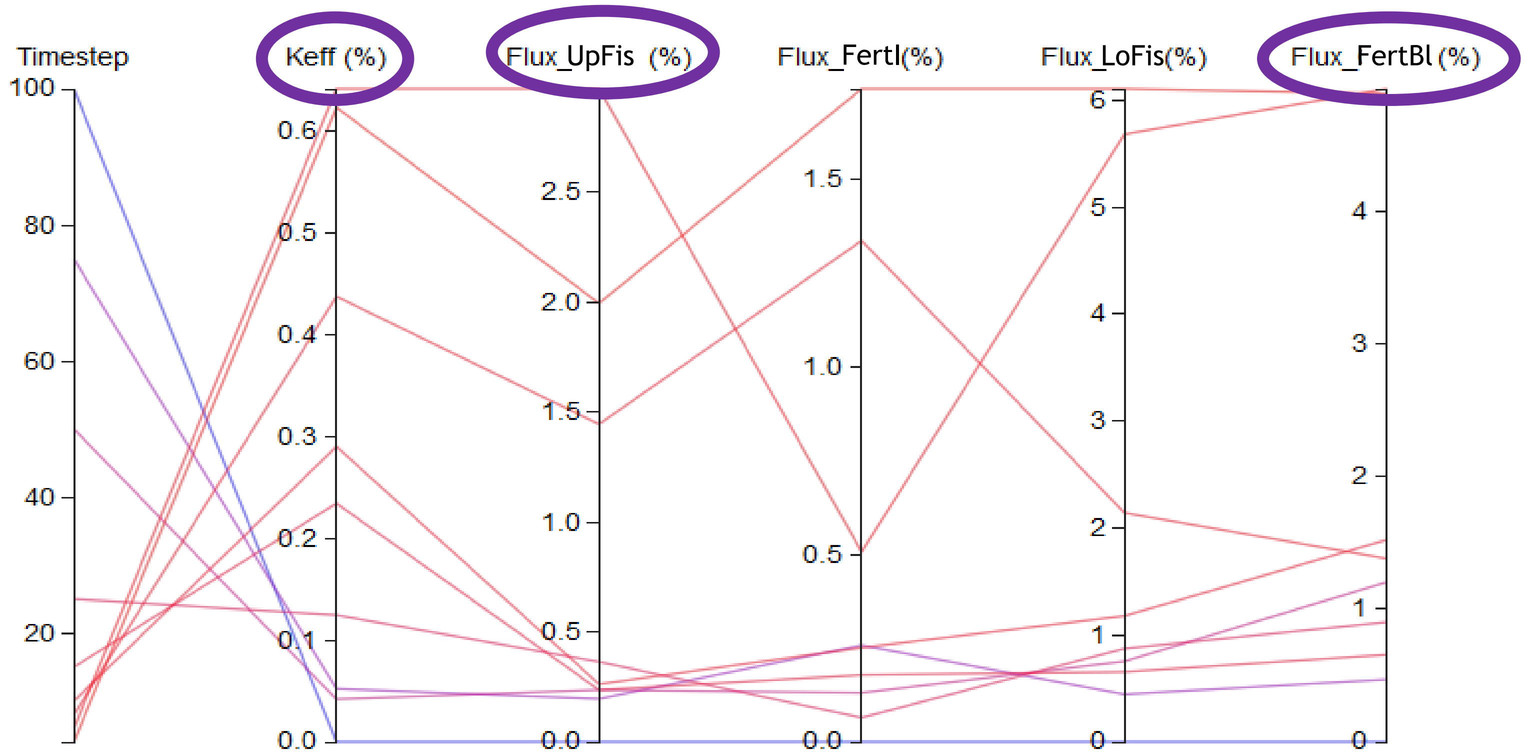
0.29% of relative difference compared to 100 timesteps

0.38% of relative error due to random seed

Depletion calculations: K_{eff} & Flux

Impact of the **timestep number**

- Maximal polynomial difference compared to the reference



- A priori selected criteria
  - Uncertainty on K_{eff} ~ 1.5‰
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Impact of the **timestep number**

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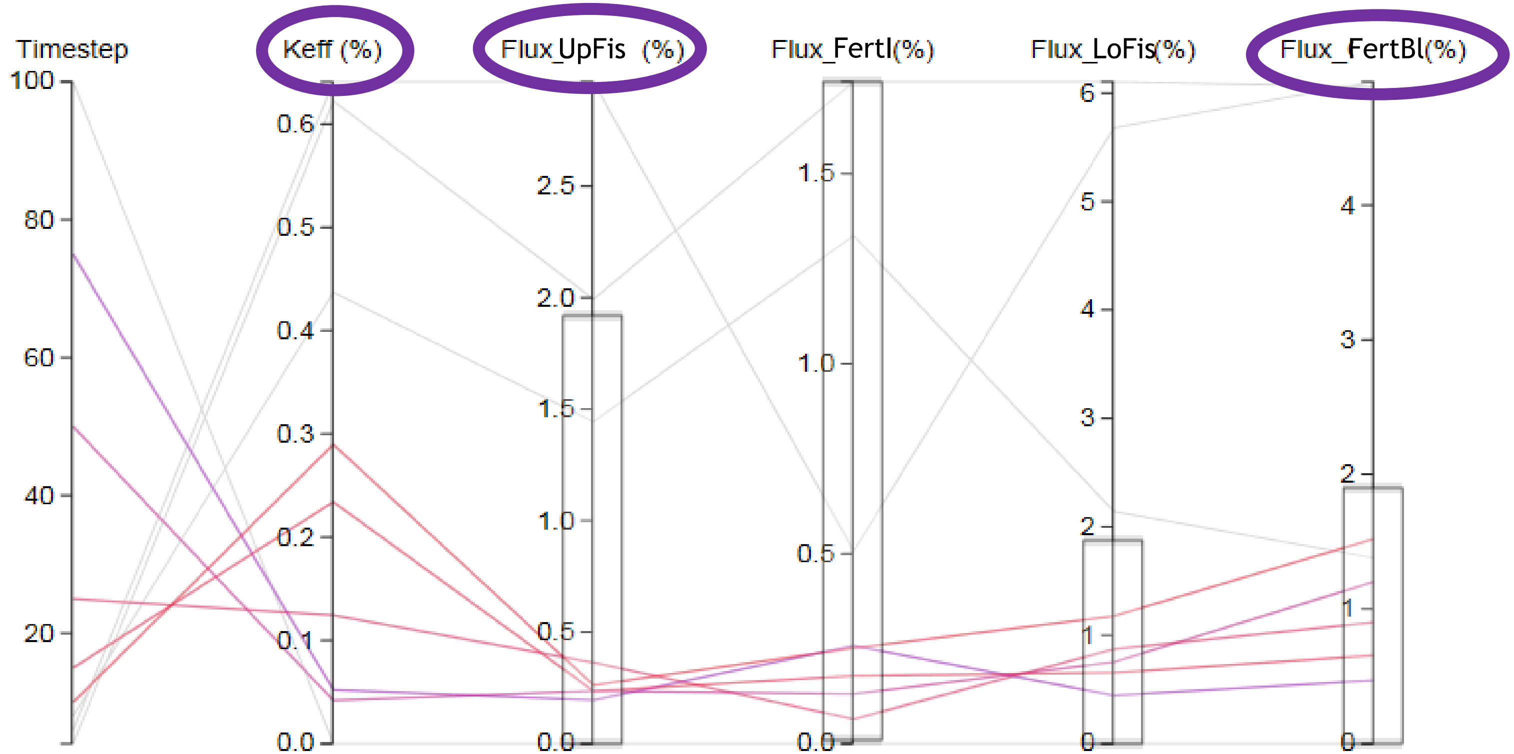

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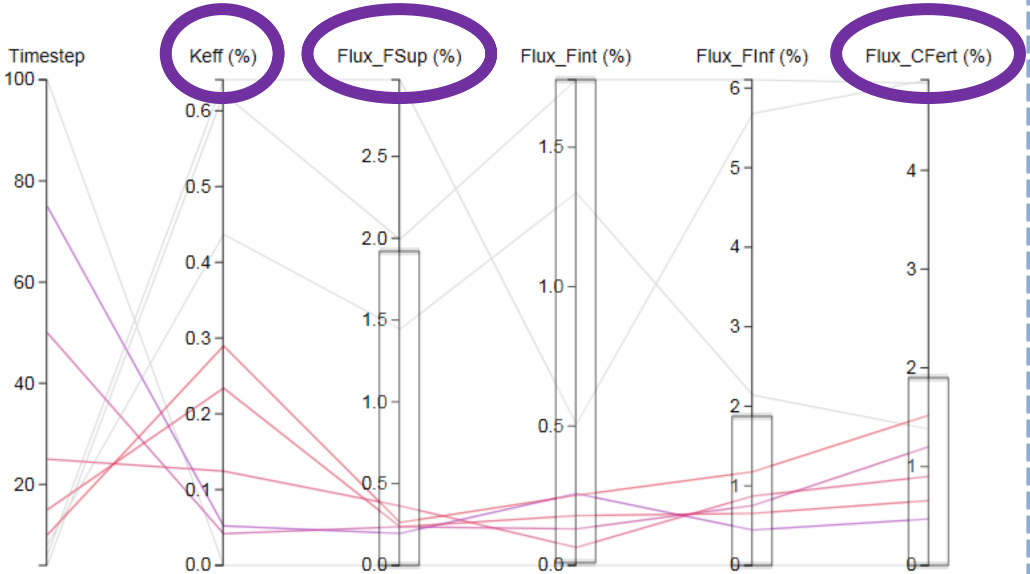
↗ Deviation due to **timestep number** variation



▌ A priori selected criteria

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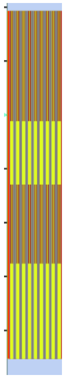
↗ Error due to the **random seed**

▌ Relative error for 10 timesteps



- 0.38% on the K_{eff}
- 2.25% on Flux, Upper Fissile zone
- 1.83% on Flux, Internal Fertile zone
- 2.94% on Flux, Lower Fissile zone
- 4.26% on Flux, Fertile Blanket

Depletion calculations: K_{eff} & Flux

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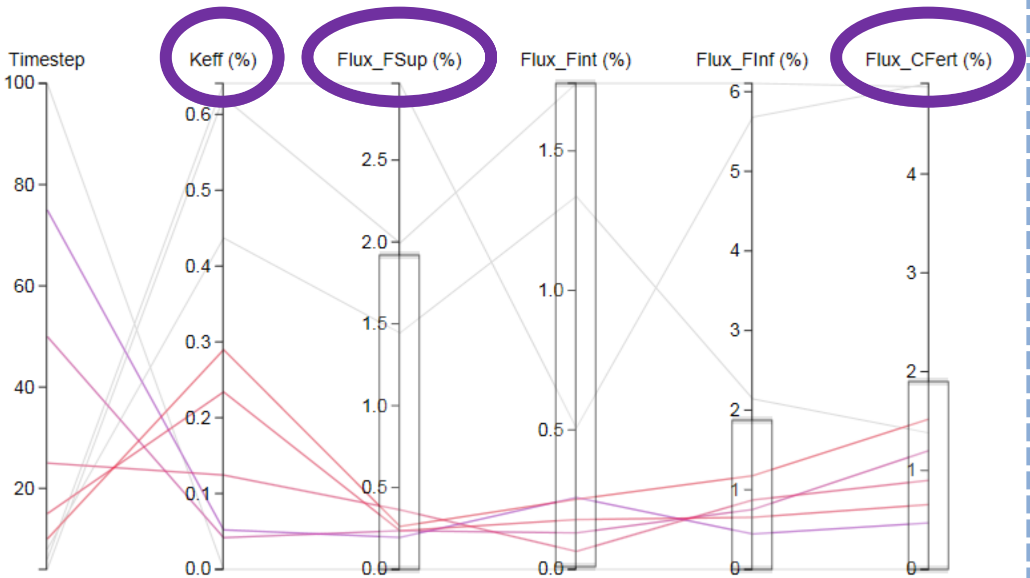
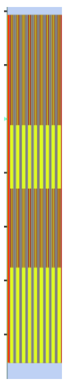


↗ Error due to the **random seed**



Relative error for 10 timesteps

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$$Error_{random\ seed} > Difference_{timesteps}$$

No visible gain for $timesteps \geq 10$
Caution of the difference estimation (random error dominates)
} Increase of the number of particle

Depletion calculations: XS & Composition

- Same method for other quantities of interest
  - Similar trends: no visible gain for $timesteps \geq 10$
  - $\boldsymbol{Error}_{random\ seed}$ generally superior than $\boldsymbol{Difference}_{timesteps}$

↗ Additional observation

Relative error due to the random seed for 10 timesteps

- XS

Isotope	Reaction	*Upper Fissile zone* MAX	*Fertile Blanket* MAX
^{238}U	Capture	0.69 %	1.71 %
^{239}Pu	Fission	0.27 %	2.07 %
^{237}Np	Capture	0.82 %	2.94 %
^{243}Cm	Fission	0.43 %	1.74 %

- Composition

Isotope	*Upper Fissile zone* EOC	*Fertile Blanket* EOC
^{238}U	0.11 %	0.08 %
^{239}Pu	0.13 %	0.77 %
^{237}Np	2.52 %	5.59 %
^{243}Cm	0.75 %	4.83 %

Less flux
→ less neutrons

Impact on the future full core reactor modelling

Isotopes absents at the beginning

Conclusion & perspective

Final objective

- Integration of **ASTRID-like SFR into CLASS code**
- Utilisation of physic models based on databanks
- Accuracy of model predictions → Errors associated with the quantities of interest

Objective of this preliminary study

- Development of **tools & methods** to estimate errors at each step of the databank generation

Conclusion & perspective of this preliminary study

- Might be sufficient to use a relatively low number of timesteps
- Increase of the statistical error with 10 timesteps during the depletion calculation
- Under-estimation of the number of neutrons during the static calculation
- **Trade-off between CPU time and number of neutron increase**

→ **Iteration of the method with more particle to confirm previous conclusion**

→ Estimation of error due to the random seed for 100 timesteps

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Thank you for your attention