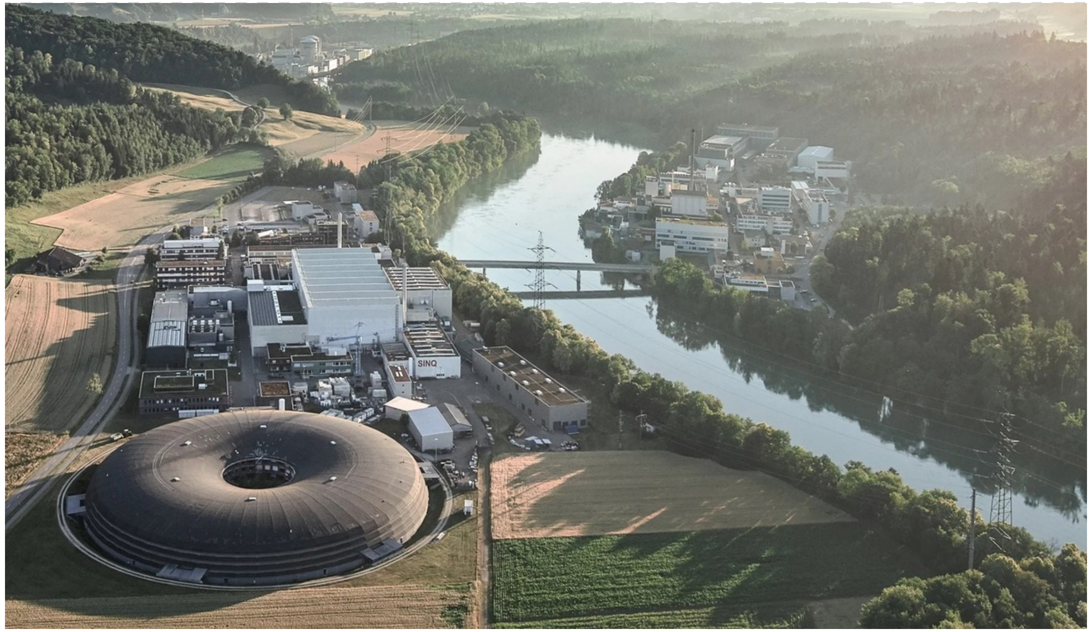
PSI Center for Nuclear Engineering and Sciences



Realistic reactivity calculations and uncertainties

D. Rochman

INDEN meeting on actinide evaluations, IAEA, Vienna, December 9, 2024

Summary

- Reactivity (k_∞ or k_{eff} as a function of burnup)
  - Simplified versus realistic calculations
  - Pincell
  - Assembly
  - Impact of nuclear data

- Example of BWR core

- Future: HALEU fuel

2D model for a PWR Fuel pin

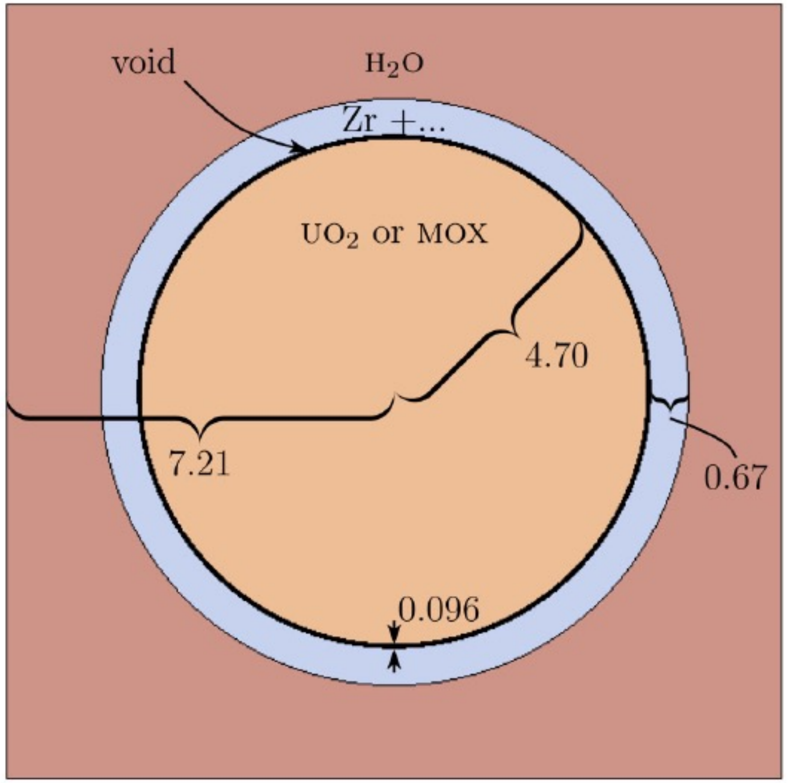


Fig. 1. The geometry of the pin cell model used in Serpent. The fuel, either UO_2 or MOX, is surrounded by concentric annular rings with a void and Zircaloy clad. The rest of the square is filled with water, and all sides are subject to reflecting boundary conditions. All distances are in millimeters.

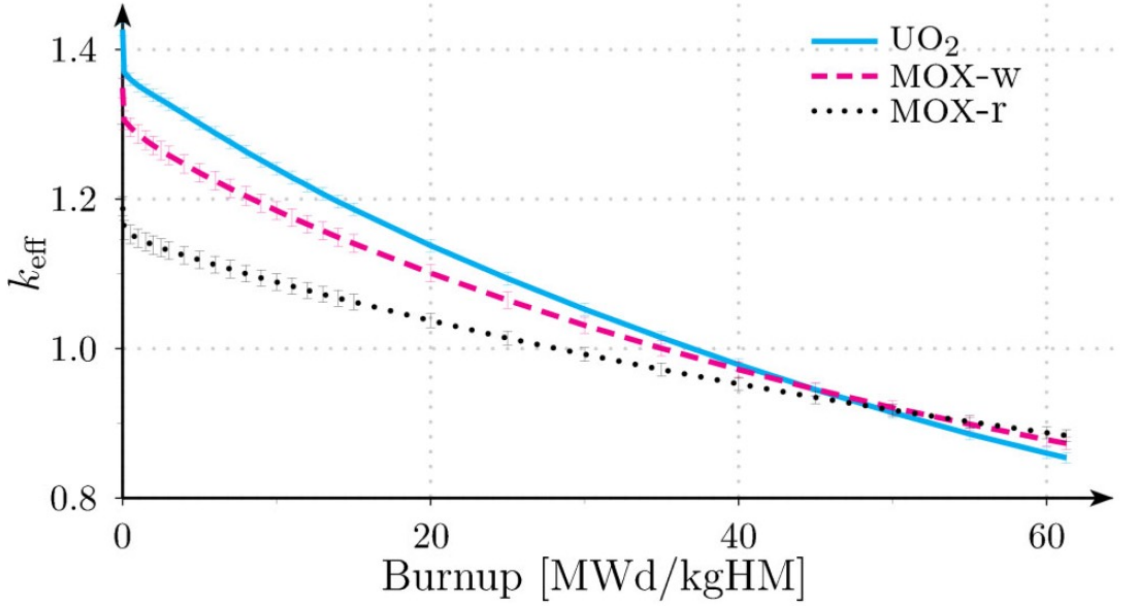
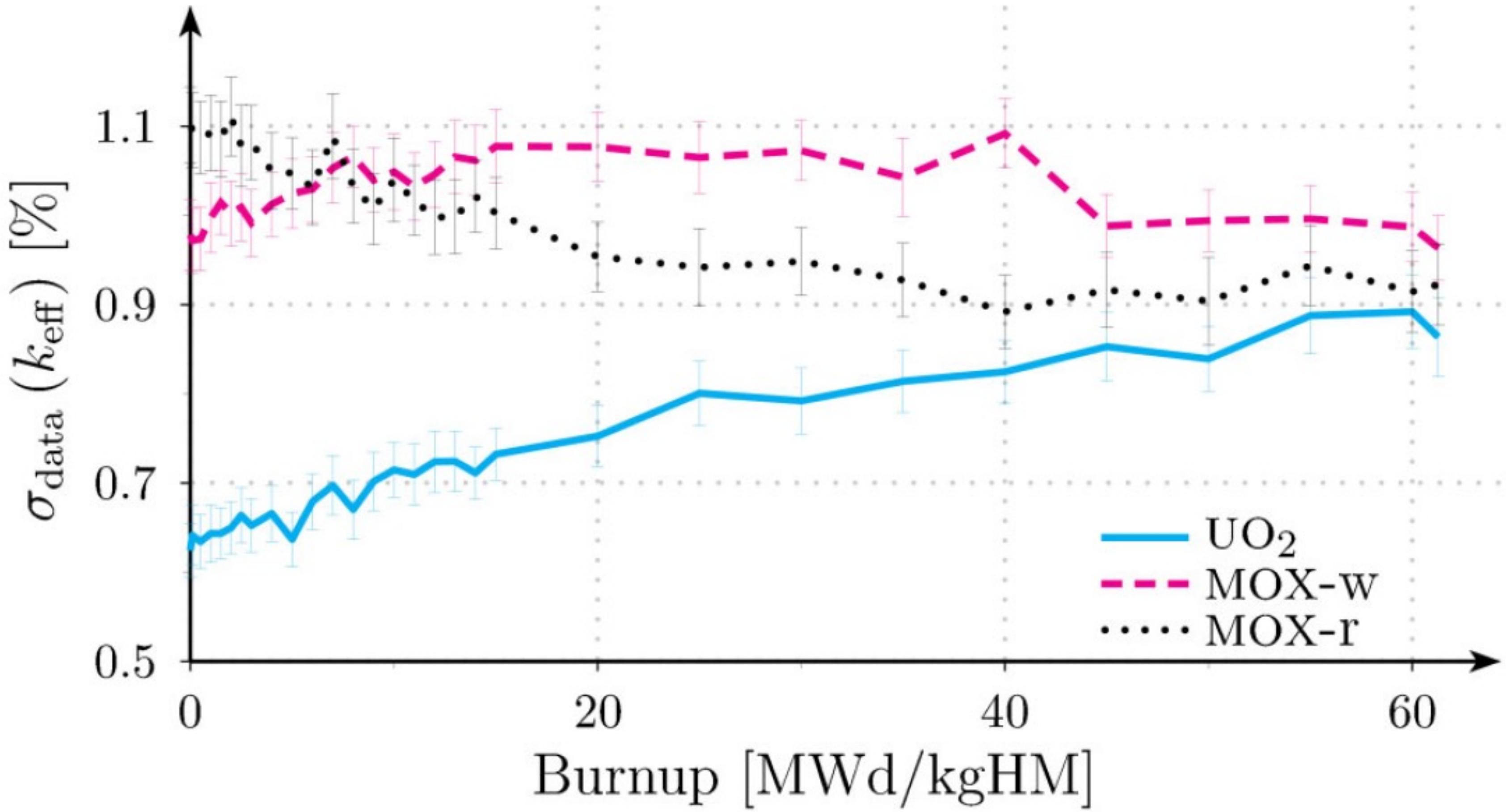


Fig. 3. $k_{\text{eff}} = k_\infty$ as a function of burnup for the three fuel types. The large deviations from 1 are explained by the simplified model: no leakage, infinite grid of pin cells (with the same burnup), and no control mechanisms. The uncertainty bars represent the data uncertainty $\sigma_{data}(k_{eff})$; the statistical uncertainty is negligible in comparison.

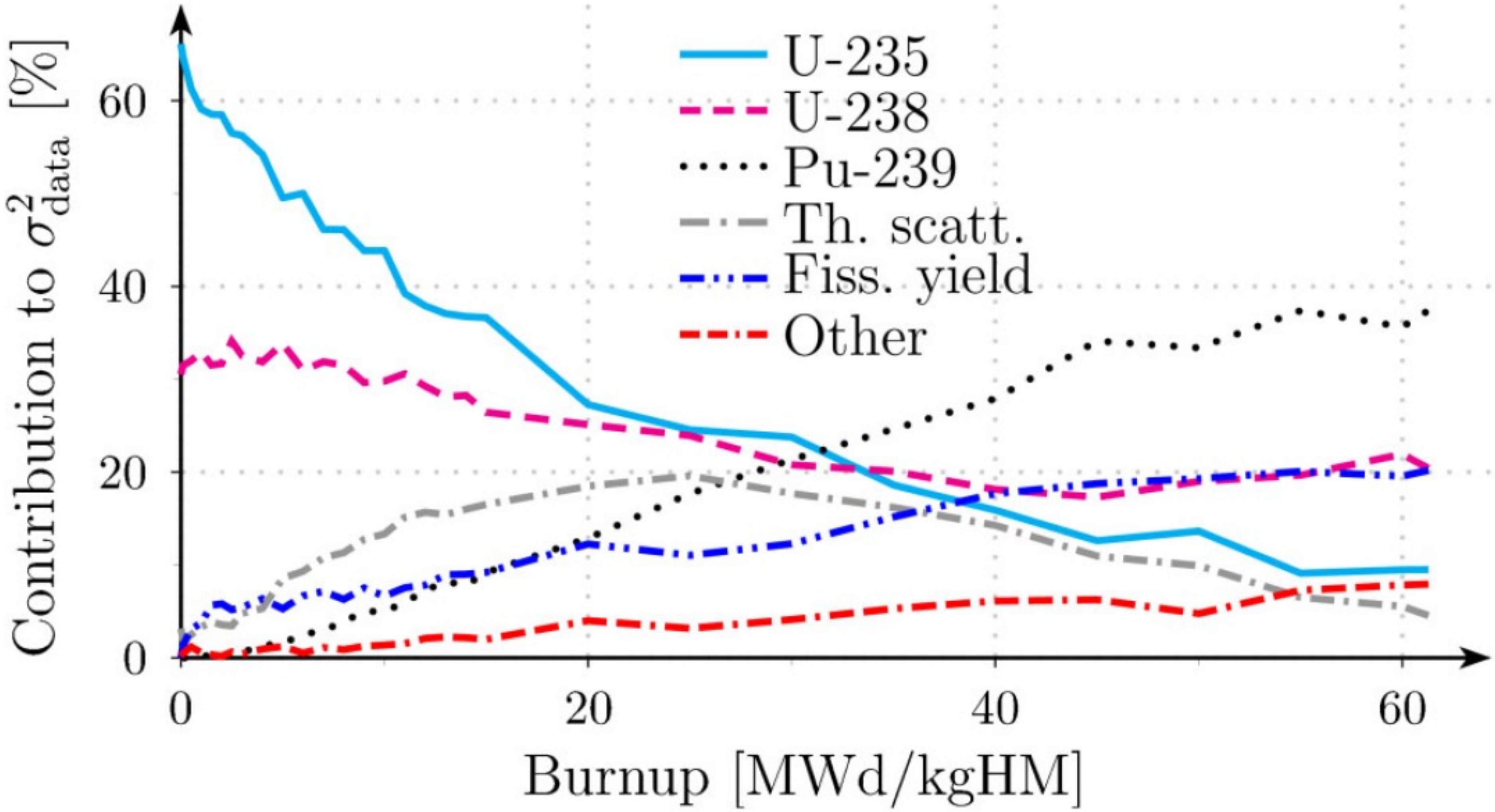
2D model for a PWR Fuel pin

- Total uncertainties due to nuclear data



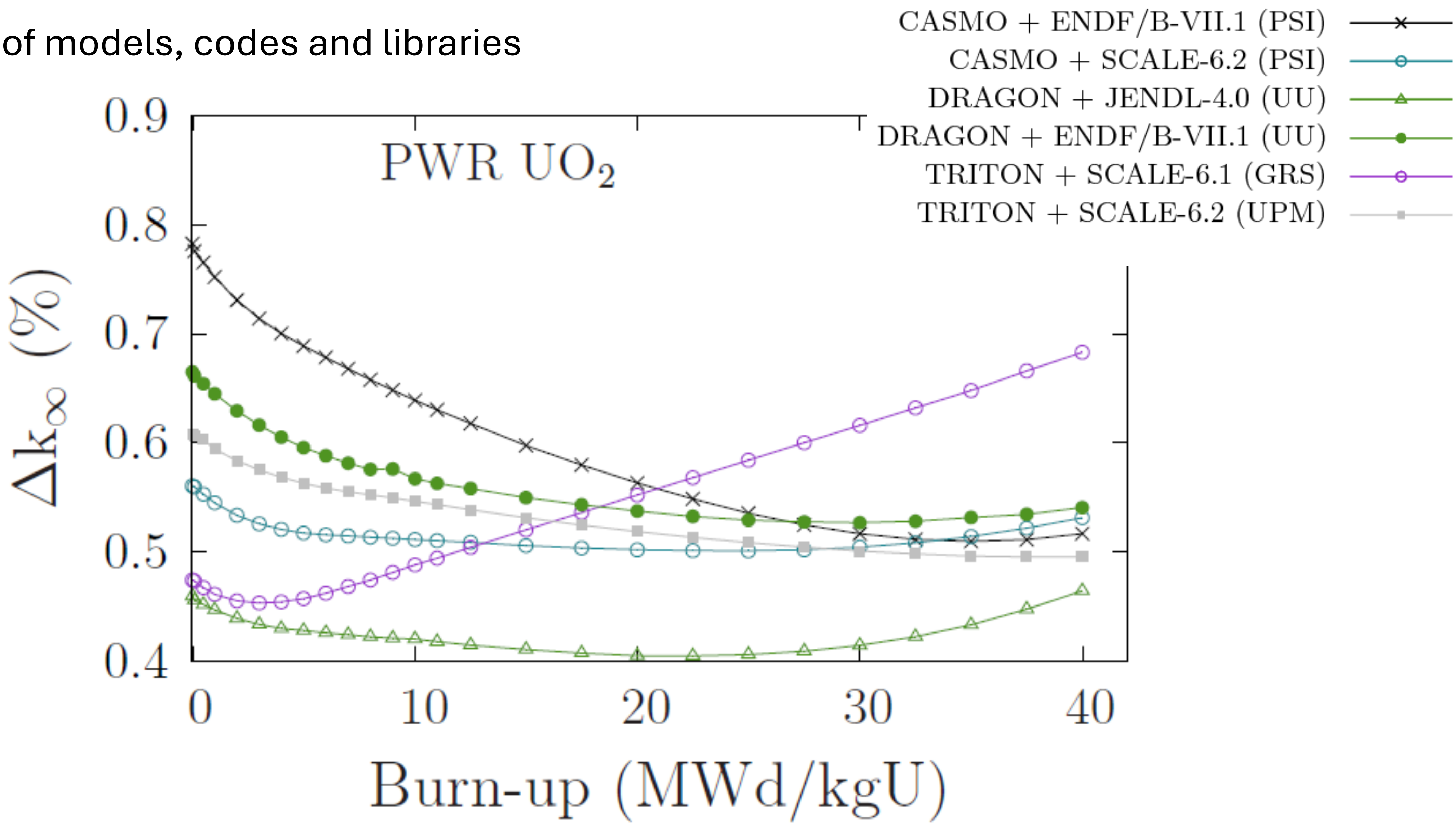
2D model for a PWR Fuel pin

- Contribution of nuclear data



2D model for a PWR Fuel pin

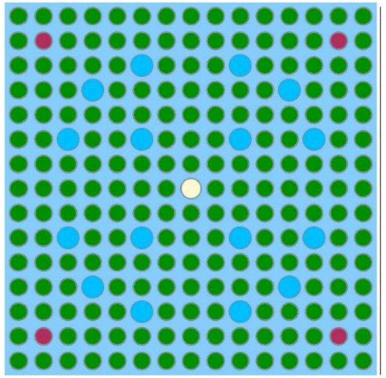
- Effect of models, codes and libraries



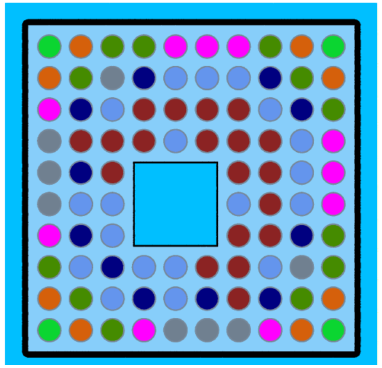
2D models for PWR or BWR assembly

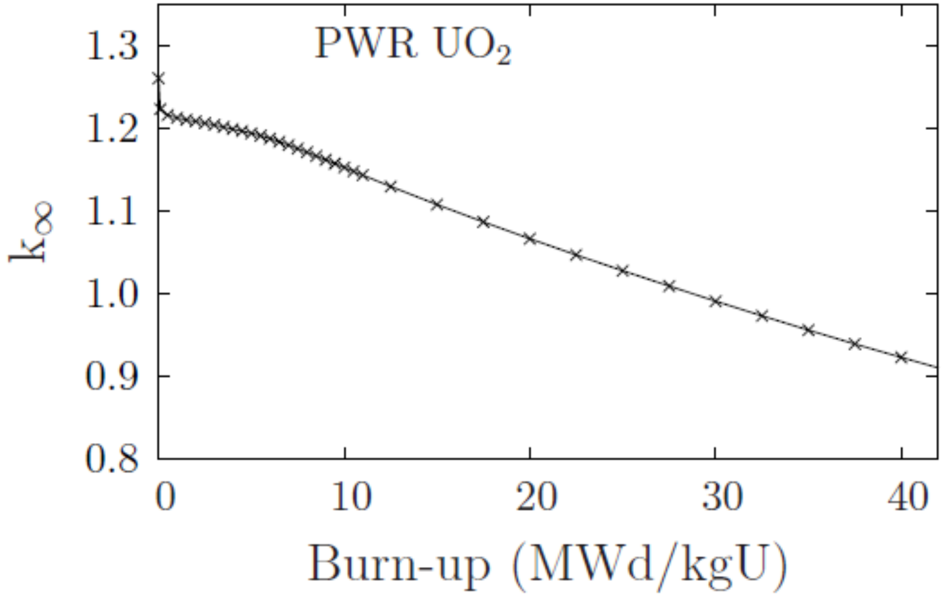
- More realistic: assembly cases

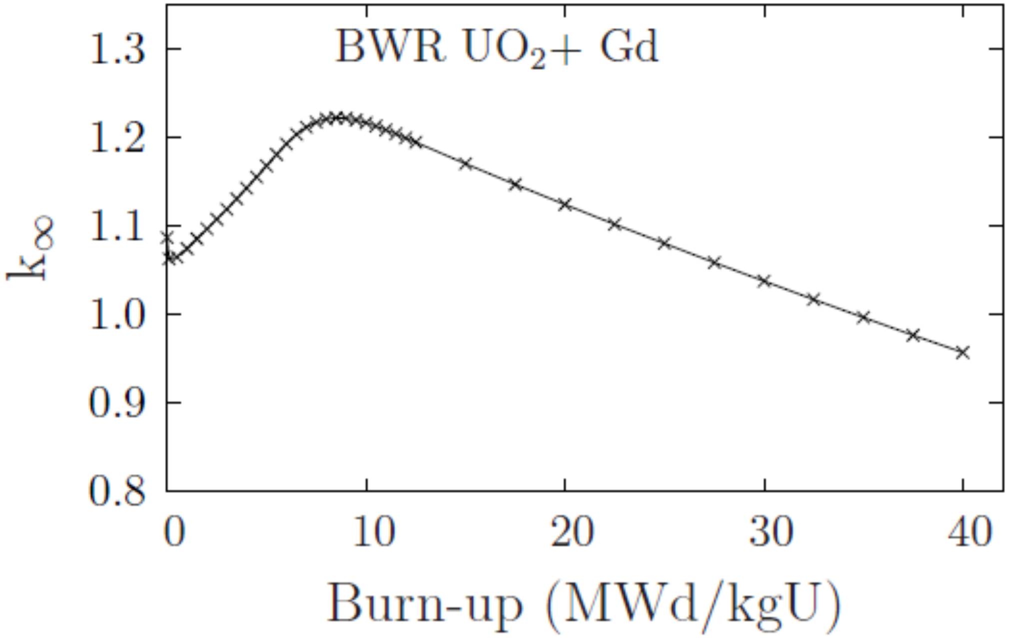
PWR UO_2



BWR UO_2+ Gd



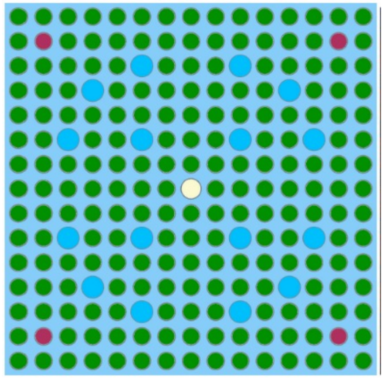




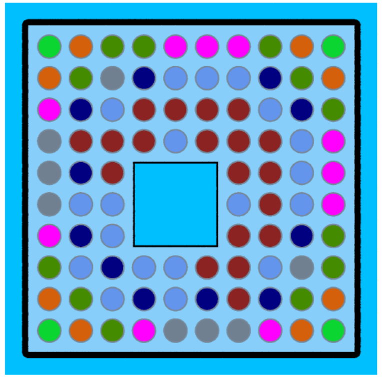
2D models for PWR or BWR assembly

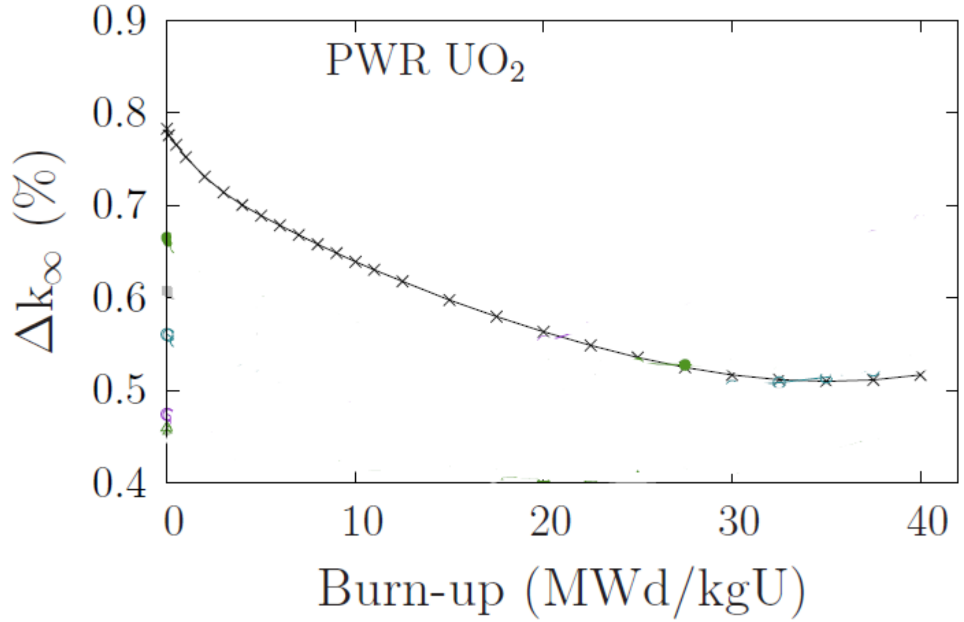
- More realistic: assembly cases

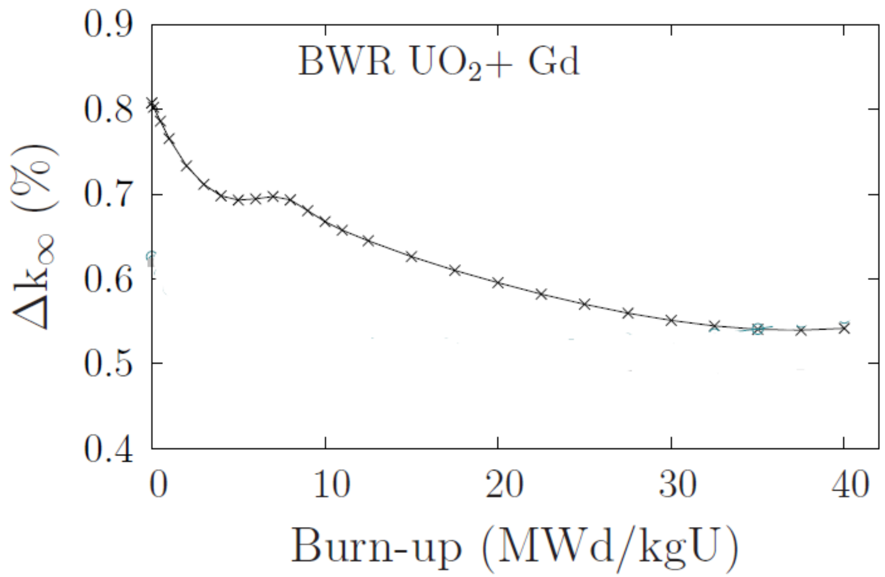
PWR UO_2



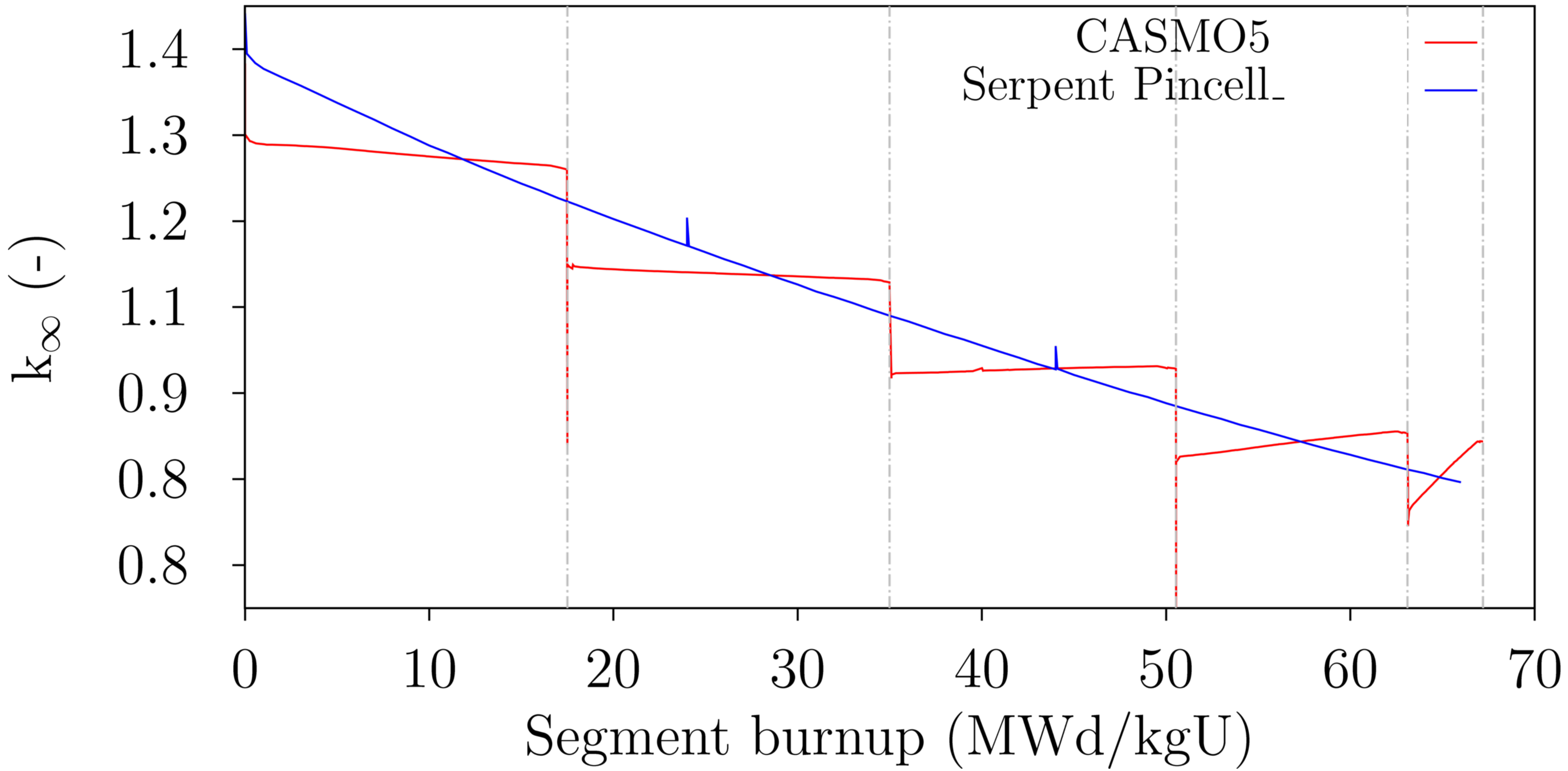
BWR UO_2+ Gd





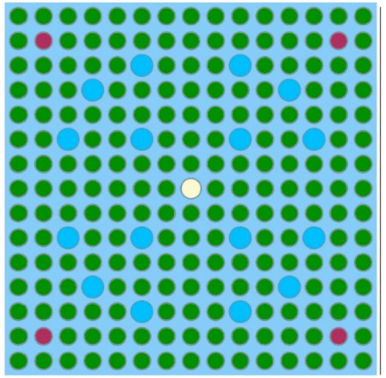


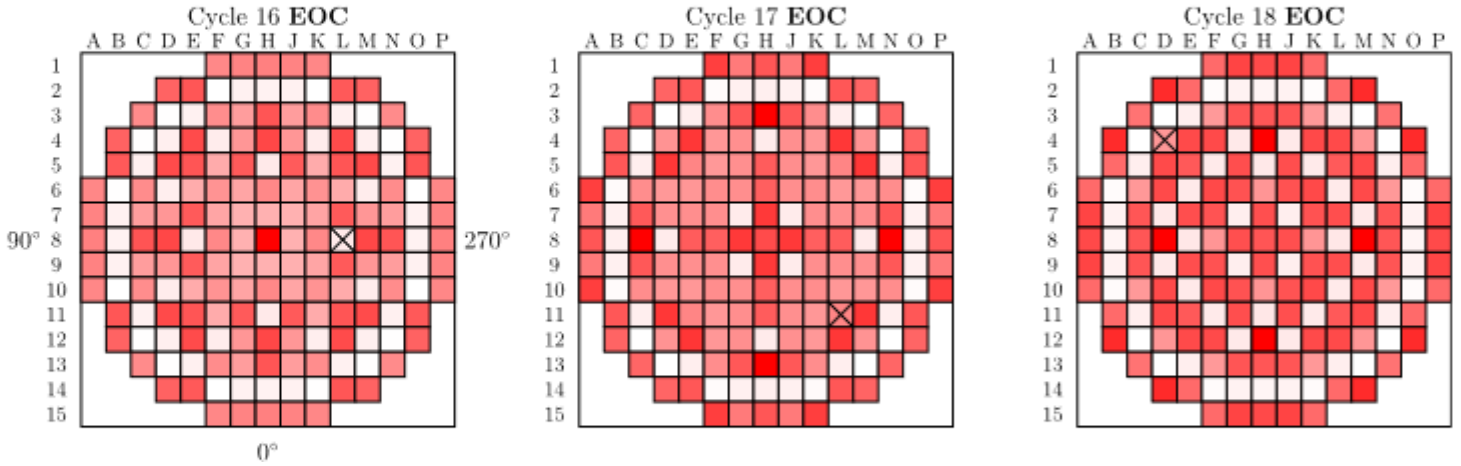
- Simplified versus realistic calculations

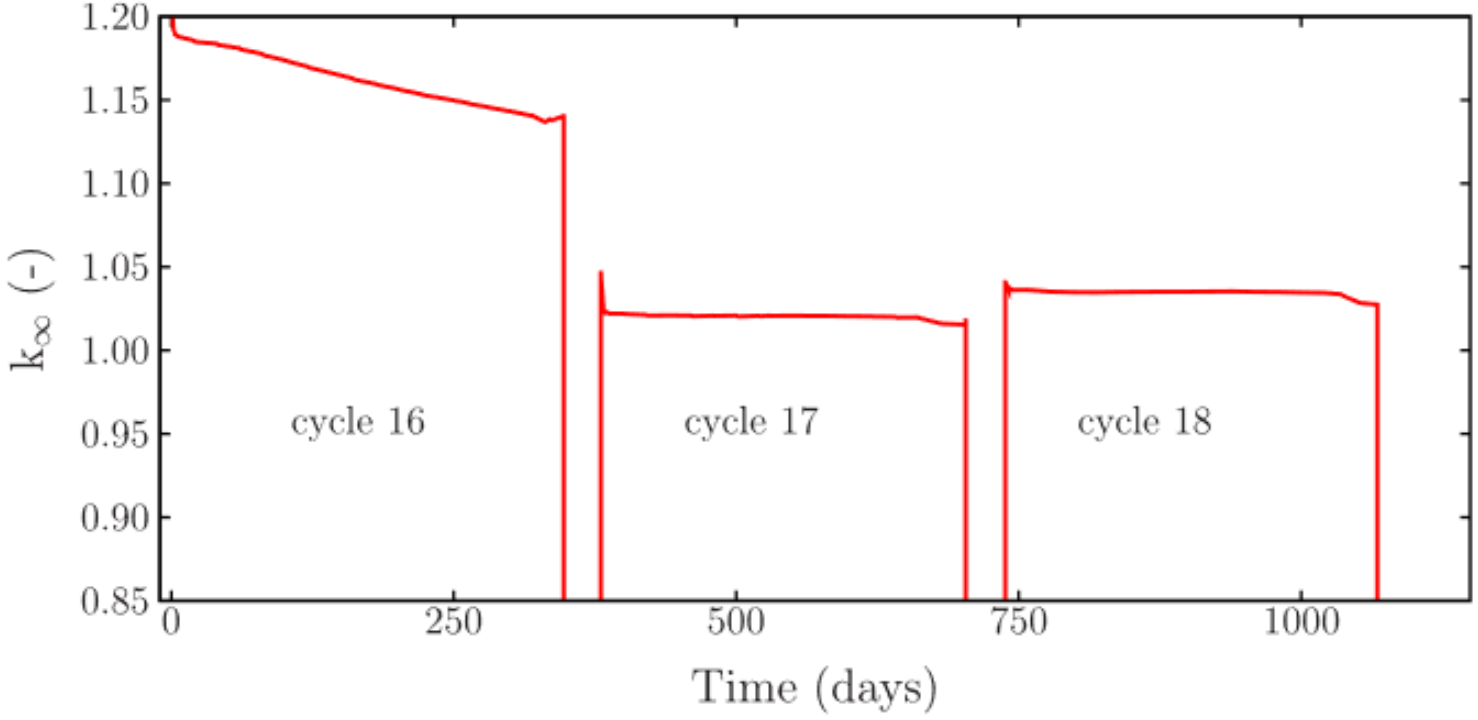


2D models for PWR (3 cycles)

PWR UO_2

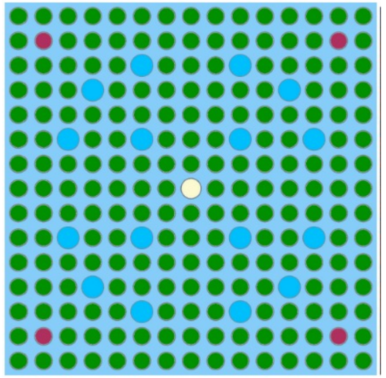


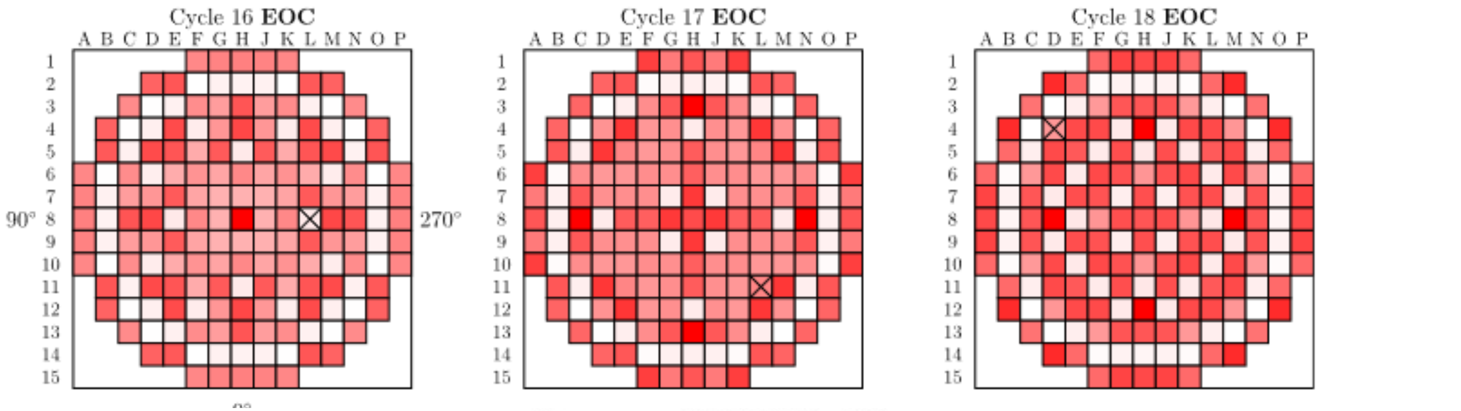


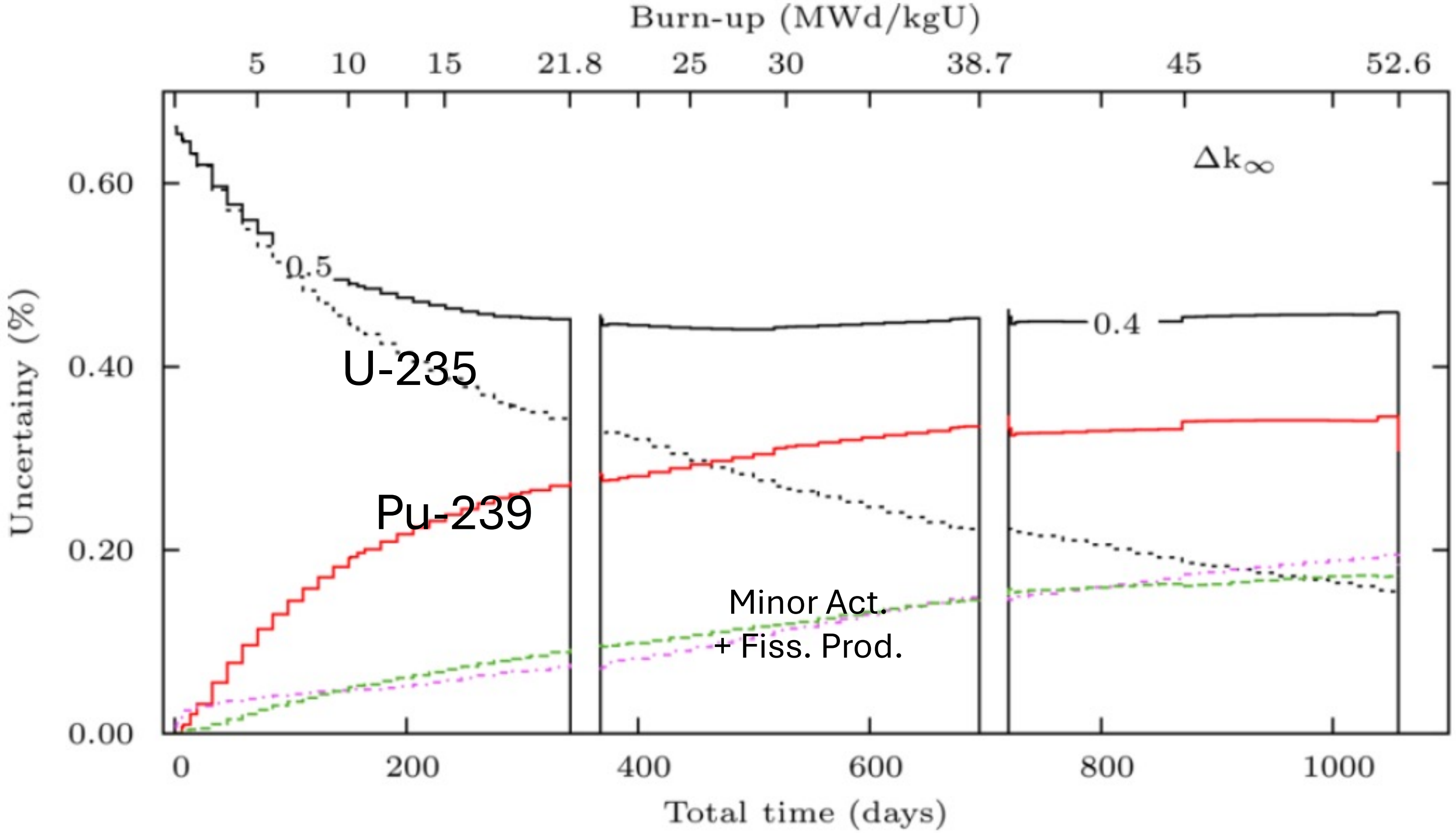


2D models for PWR (3 cycles)

PWR UO_2







2D models for PWR (3 cycles)

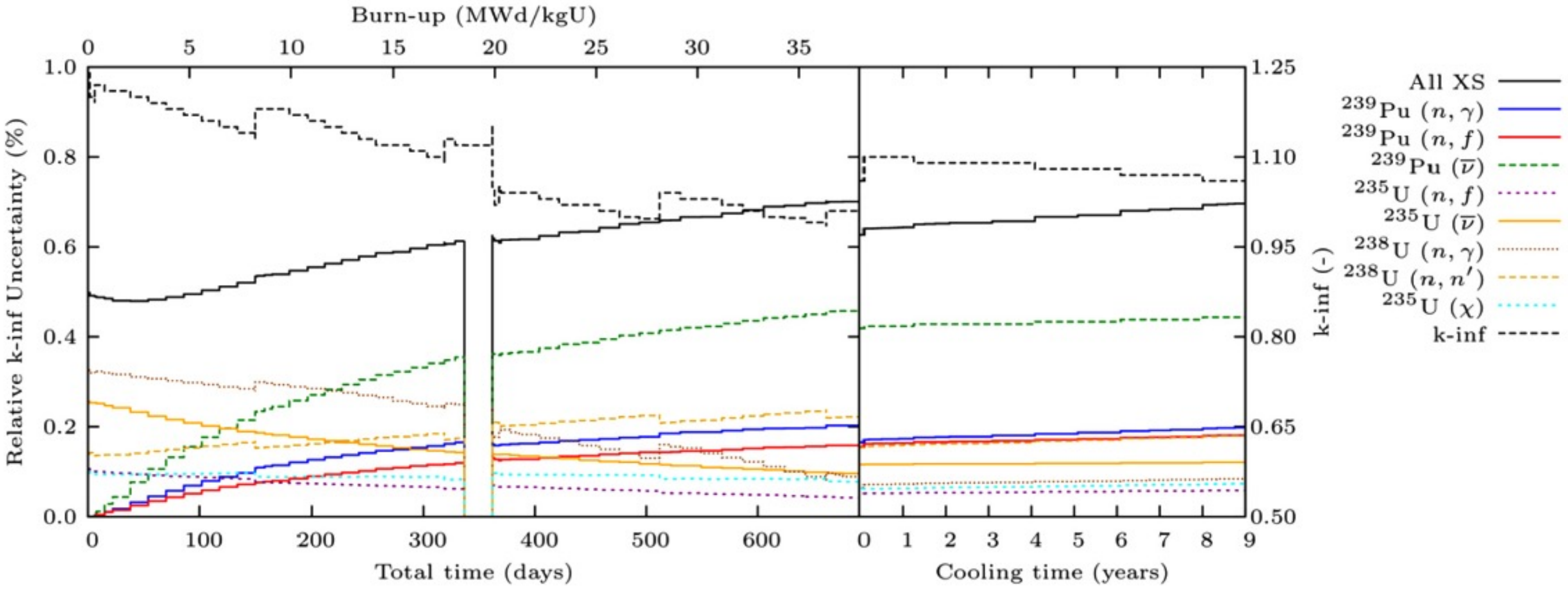


Fig. 3. Relative uncertainty on k-infinity (U1 sample) due to cross-sections, $\bar{\nu}$) (total neutron multiplicity) and χ (fission spectra). The VCM are taken from SCALE-6.0.

2D models for PWR (3 cycles)

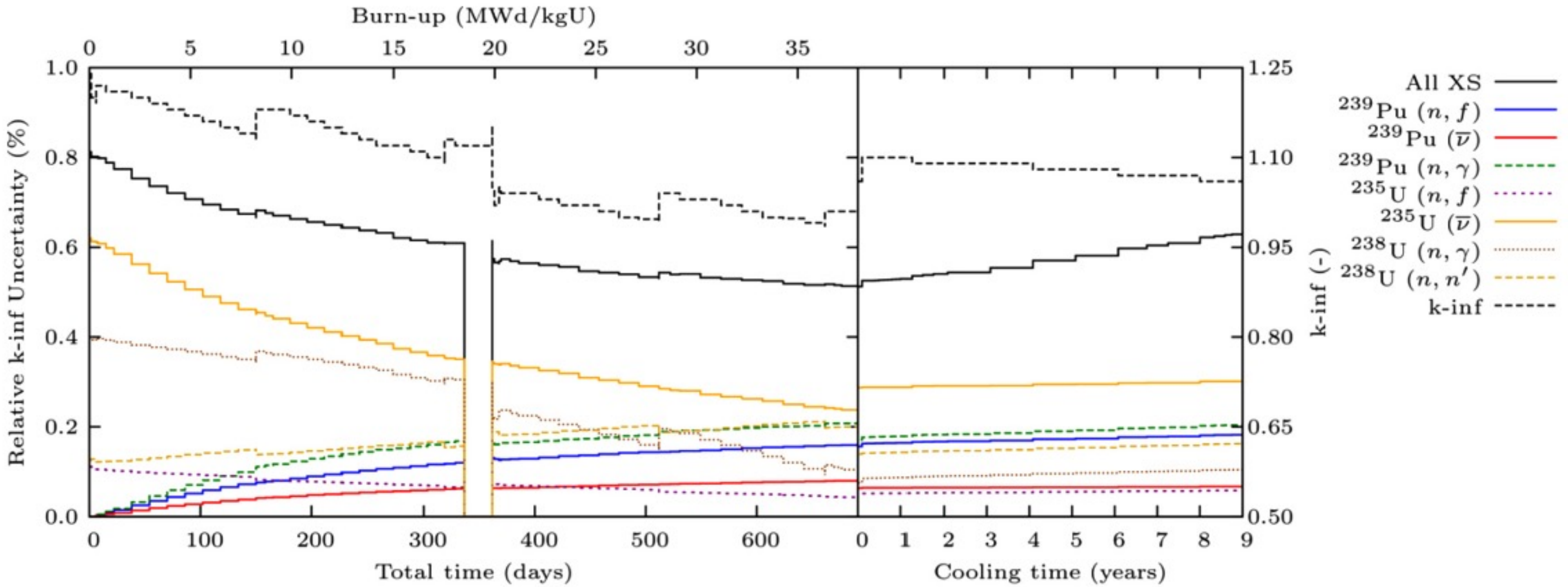


Fig. 4. Relative uncertainty on k-infinity (U1 sample) due to cross-sections, ν and χ (VCM from ENDF/B-VII.1).

2D models for PWR (3 cycles)

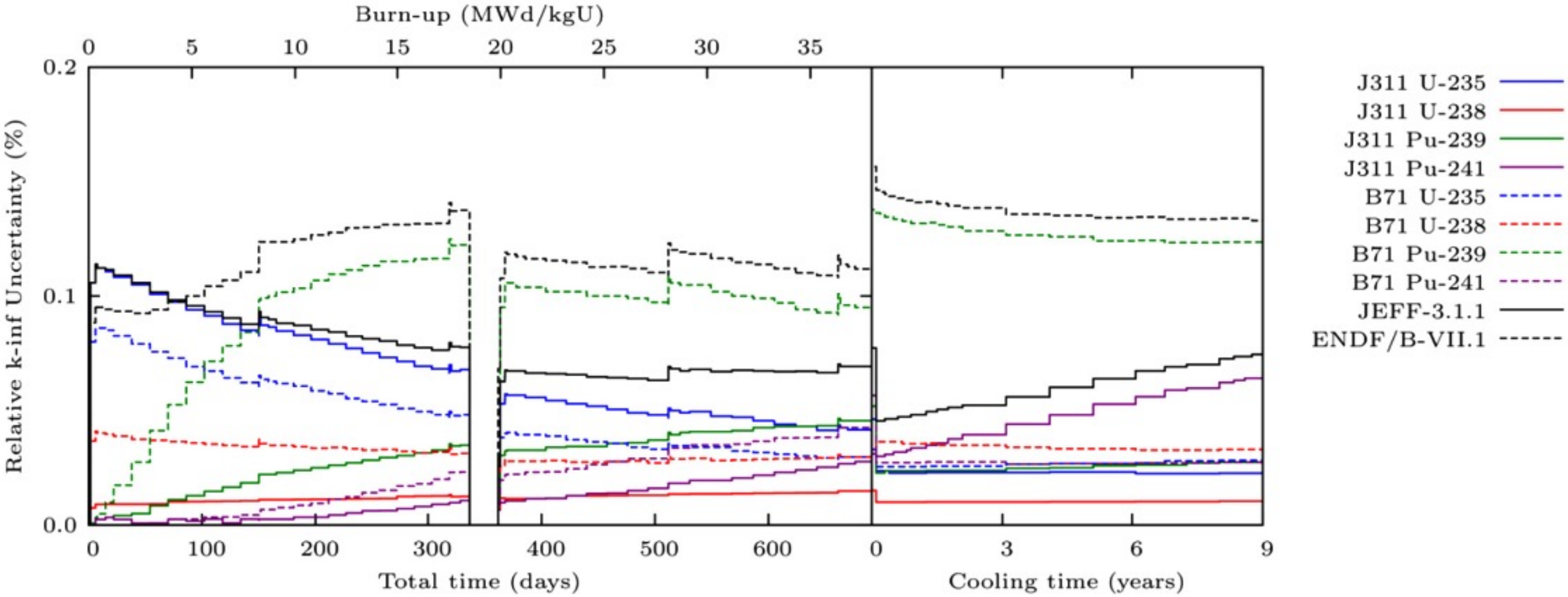
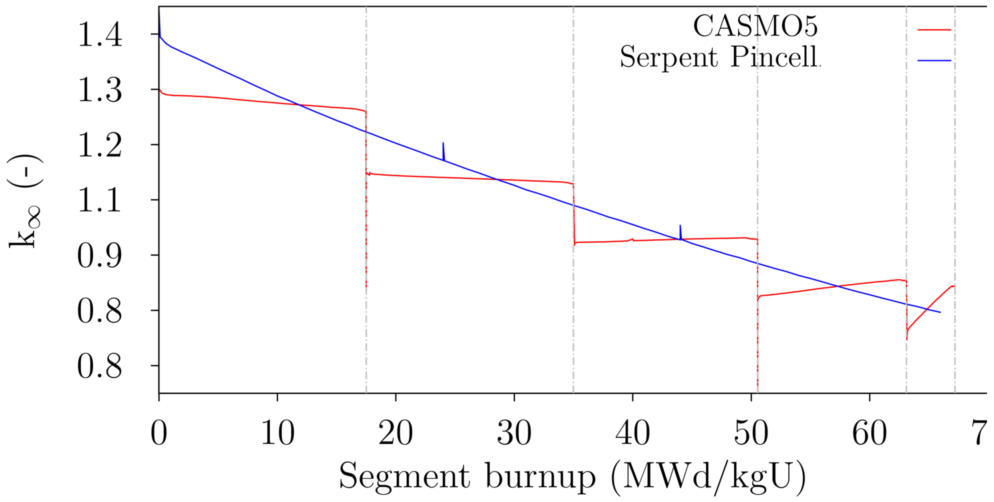
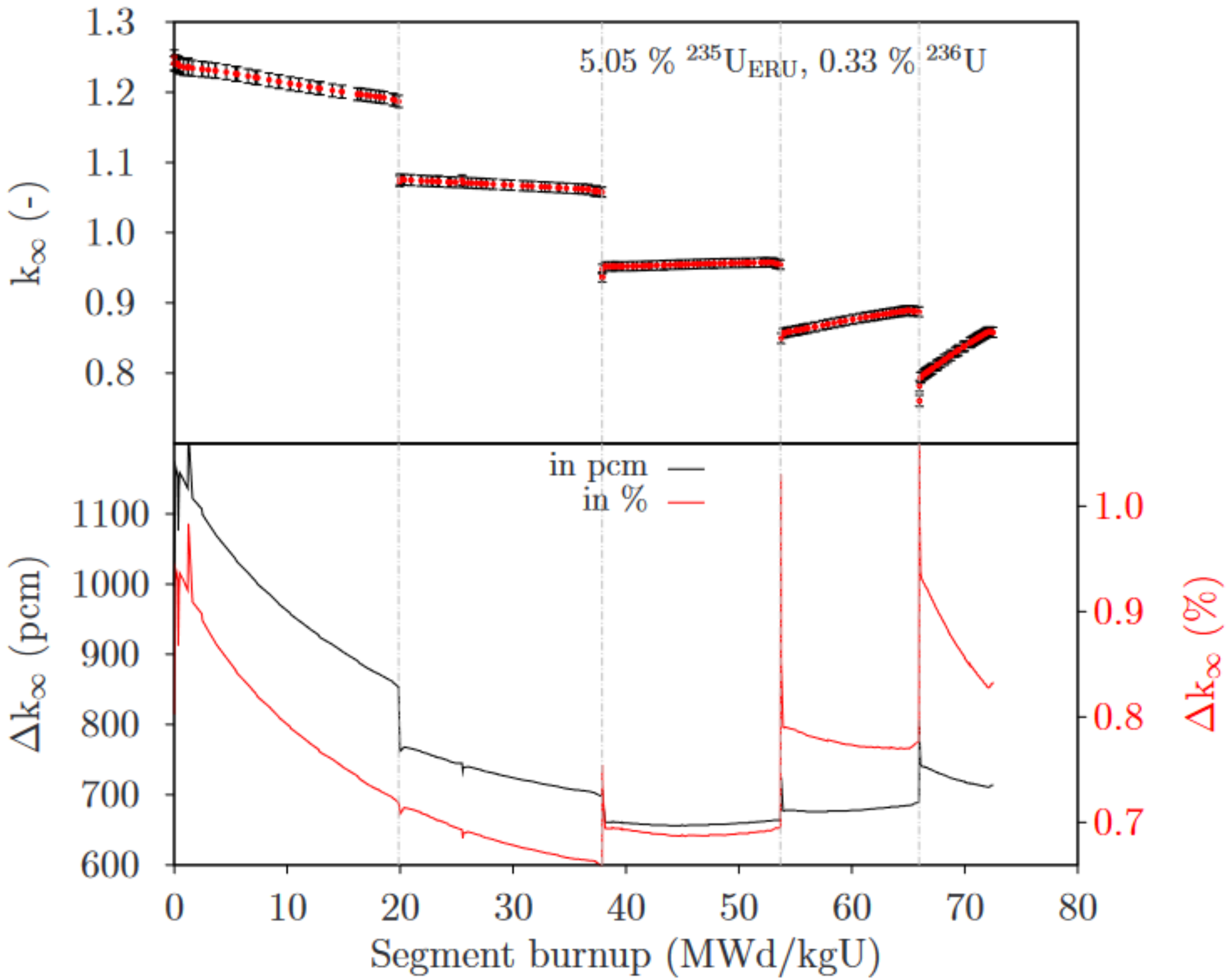


Fig. 5. Relative uncertainty on k-infinity (U1 sample) due to fission yields (JEFF-3.1.1 and ENDF/B-VII.1) using GEF correlations with re-normalization.

2D models for PWR (5 cycles)





Example on k_{eff} for real BWR cycles

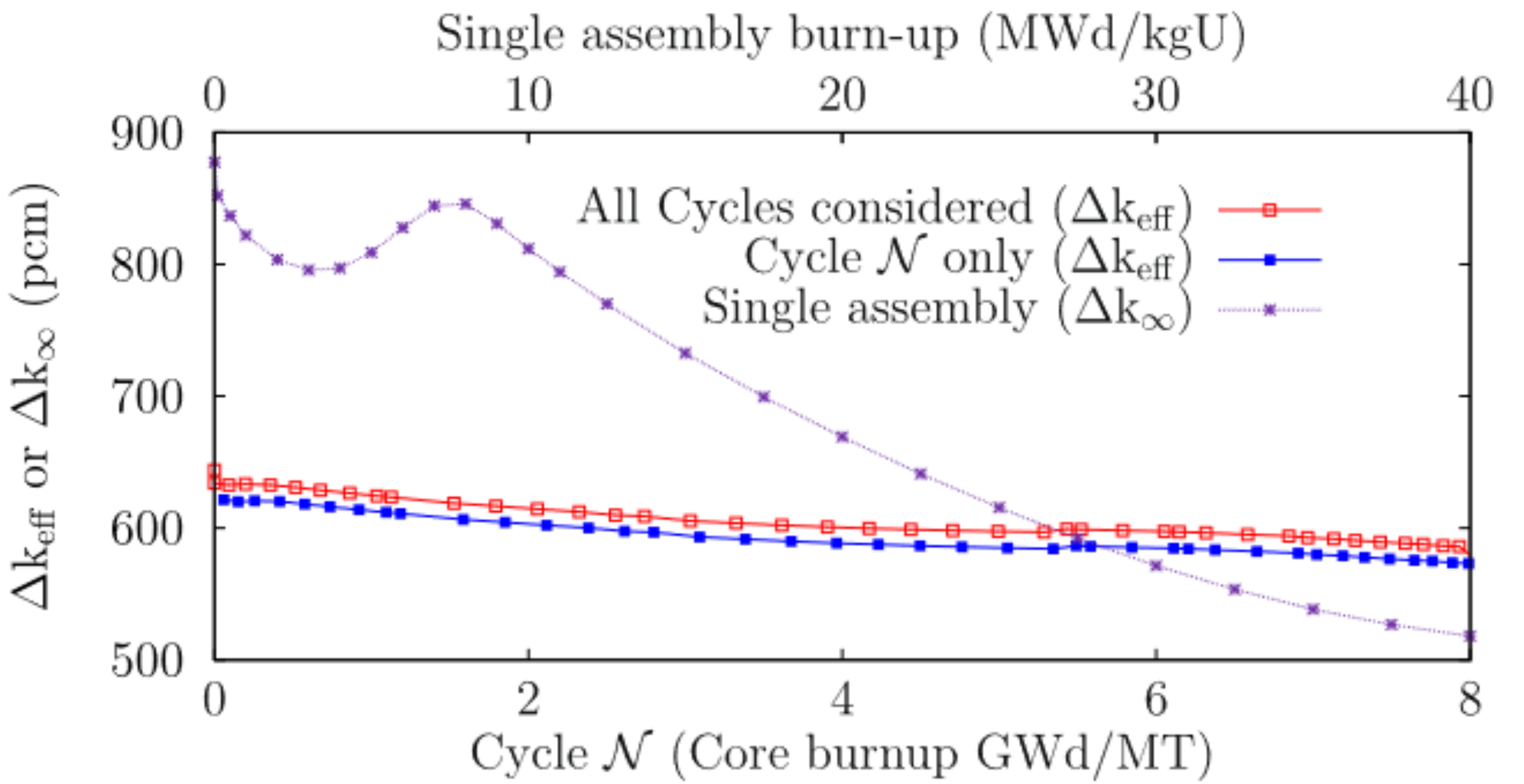
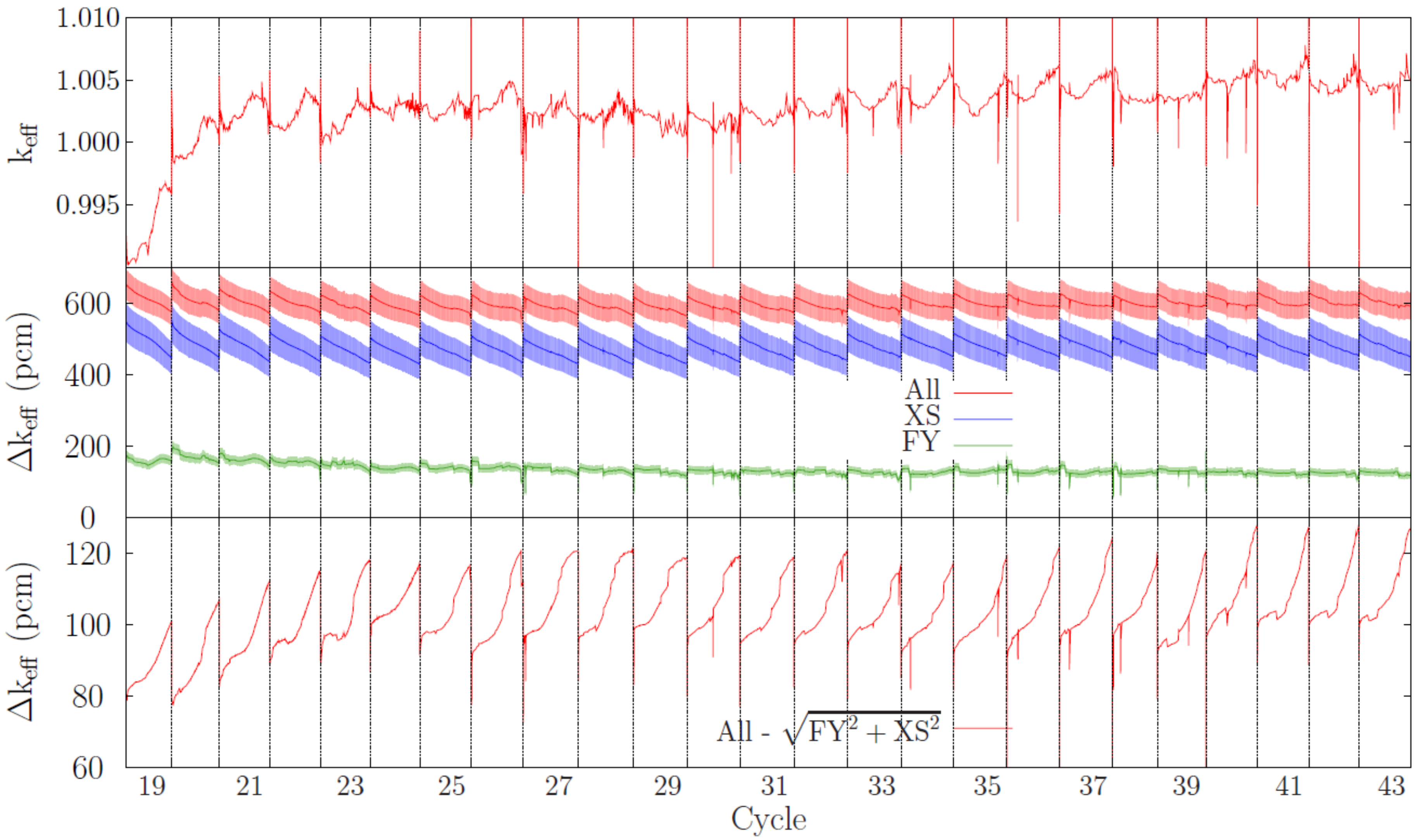


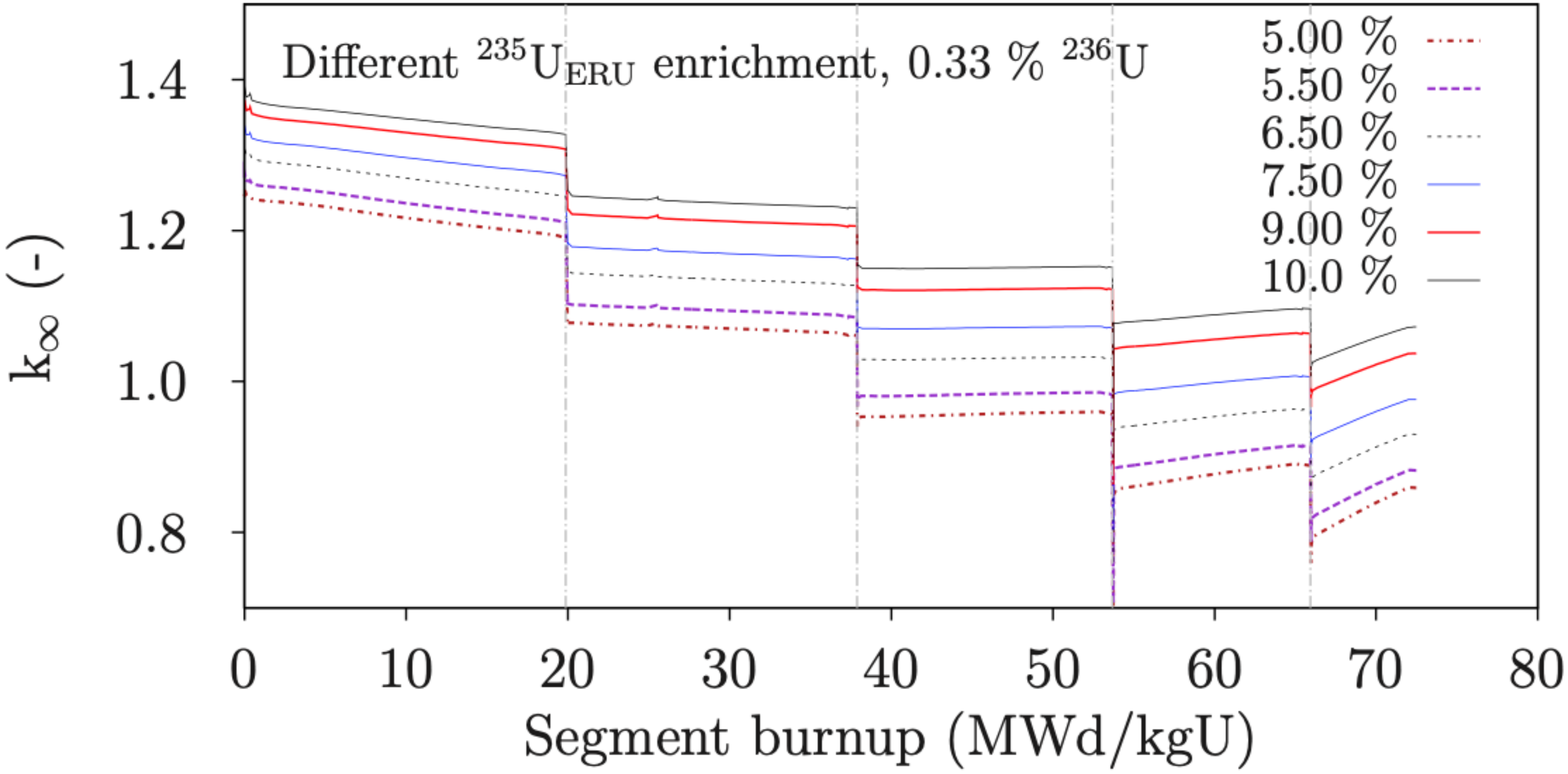
Fig. 4. Uncertainties for k_{eff} (full core) for cycle $\mathcal{N}$ and k_∞ for a single assembly from Ref. Rochman et al. (2017). For the full core (bottom X-scale), two cases are presented: with uncertainty propagation for cycle $\mathcal{N}$ only, and for also for all previous cycles.

Example on k_{eff} for real BWR cycles

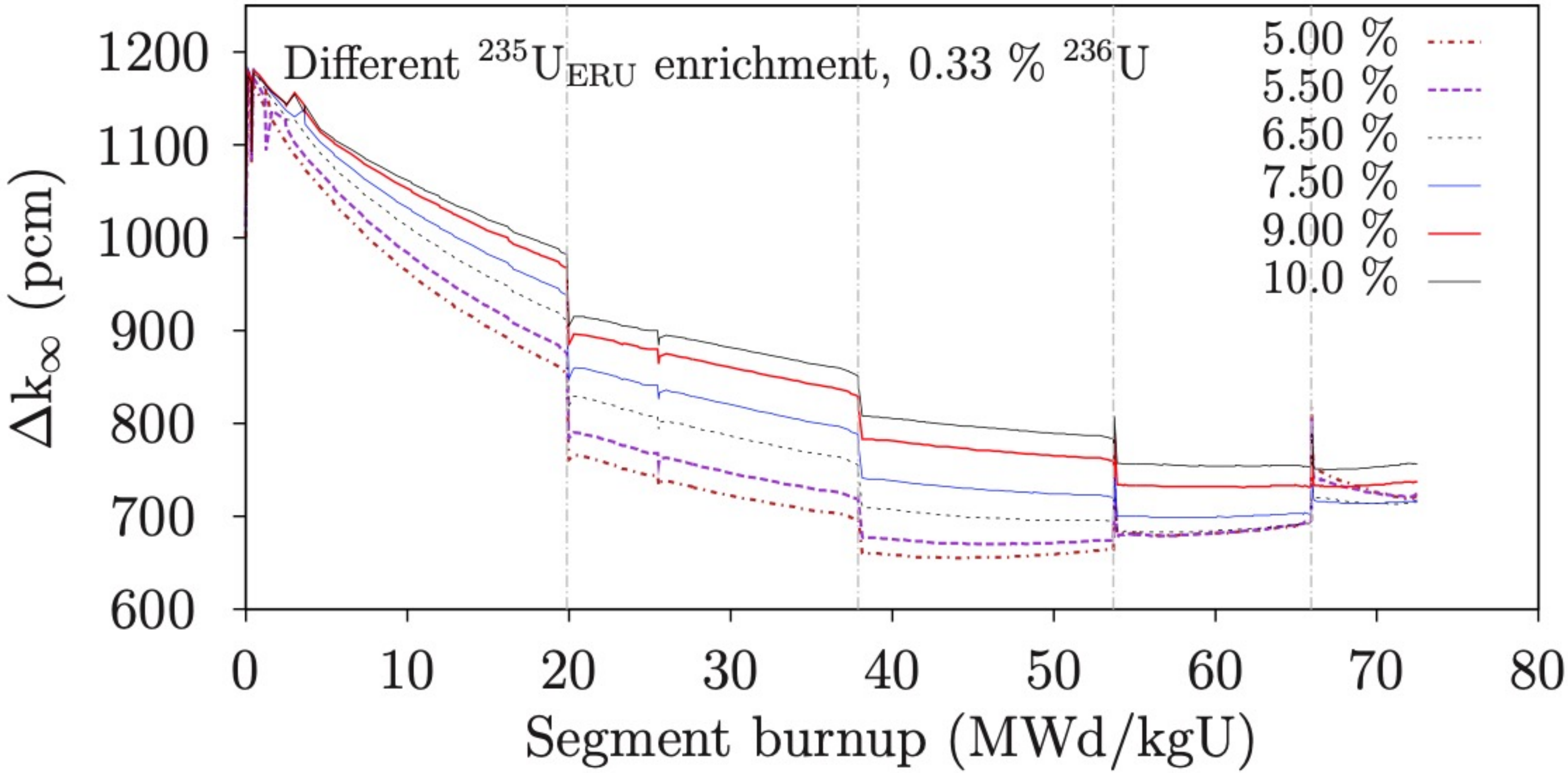


Going towards HALEU fuel

- HALEU fuel: to be used in SMR, space propulsion, PWR long cycles
- ^{235}U enrichment > 5 %
- Already in test in some PWRs.



Going towards HALEU fuel



Conclusion

- For testing nuclear data (and uncertainties):
  - Simplified reactivity calculation: ok to get an approximative answer
  - Realistic reactivity calculation: can change the k_{eff} trend and needs to be done.

- Into the future:
  - Check higher enrichments for PWRs
  - Different fuel for SMR and space propulsion

Many thanks

- References