Sensitivity and uncertainty analysis for a combined depletion and criticality calculation chain of a BWR fuel assembly

F. Sommer, V. Hannstein, ANS NCSD
12.09.2017

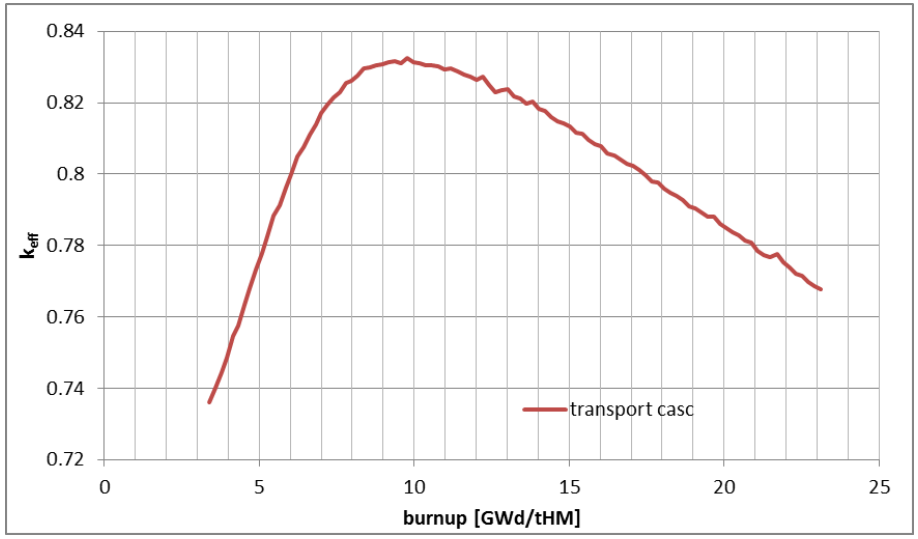
Content

- Motivation
- Calculation chain
  - Irradiation model
  - Depletion calculation
  - Criticality calculation
- Results
- Summary and Conclusion

BWR – Motivation

- BWR characteristics
  - Radial and axial heterogeneous conditions:
    - Symmetries
    - part length fuel rods
    - Enrichment
    - Moderator density (void)
      →variable spectrum
  - Gadolinium fuel rods (strong neutron absorber)
    → reactivity peak
    around ~ 10 GWd/tHM

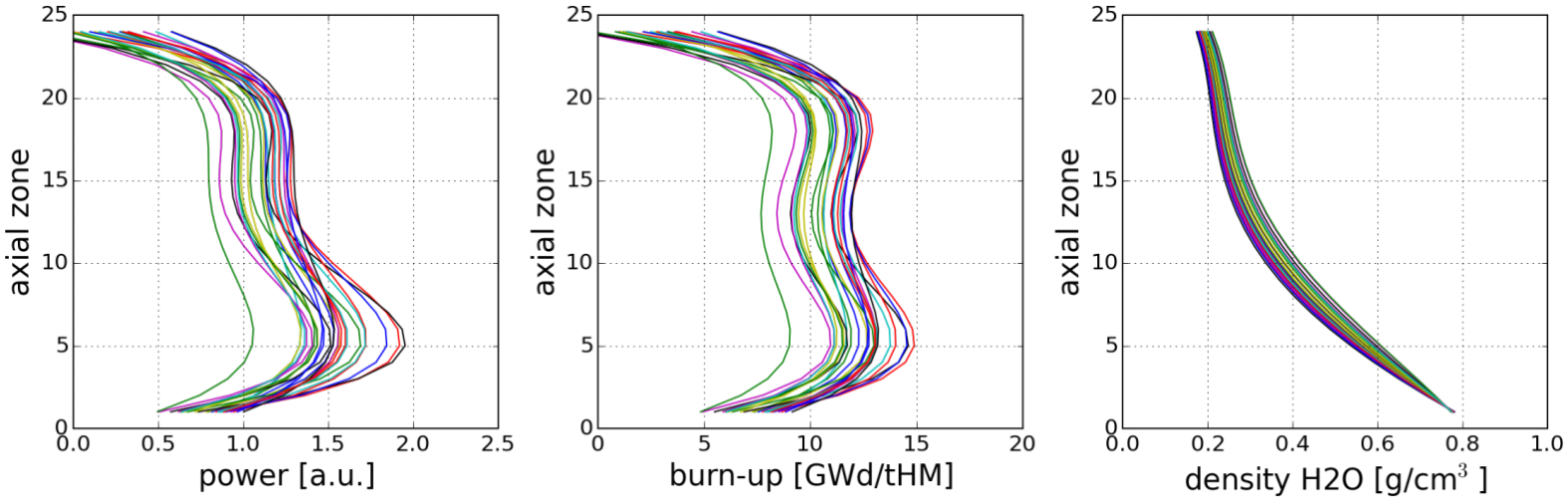
http://www.westinghousenuclear.com/About/News/Features/View/ArticleId/21/SVEA-96-Optima-3



Calculation chain – Irradiation model

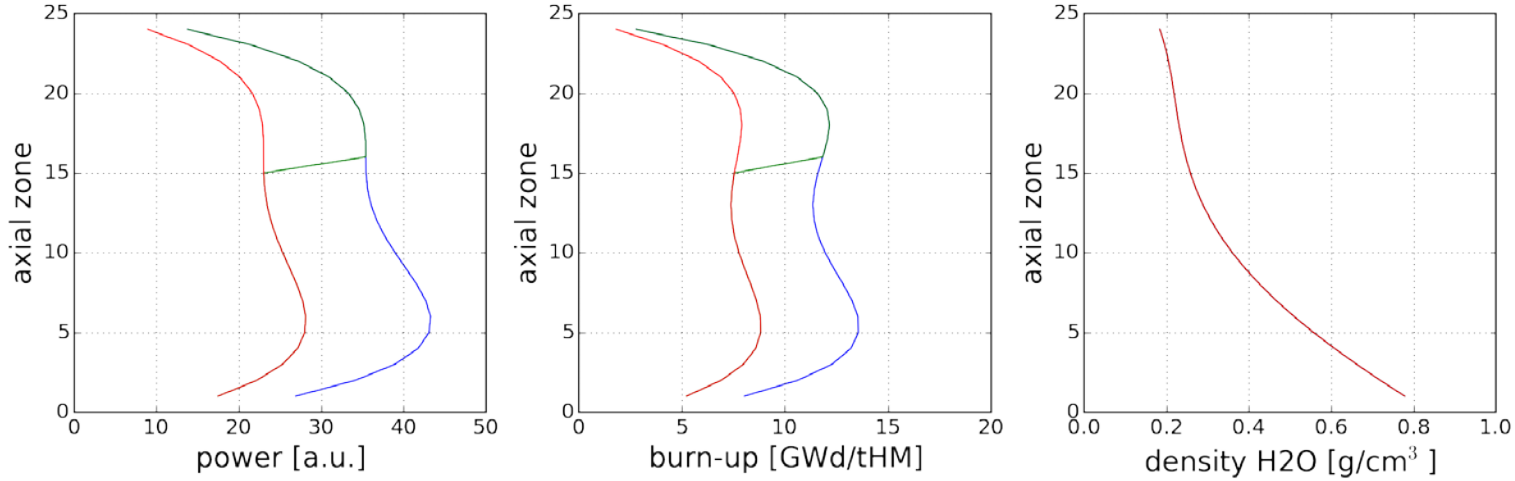
- Calculations chain:
  1D irradiation model – 2D depletion calculation – 3D criticality calculation

- Simplified, physically consistent model of typical axial profiles of BWR (24 zones)
  Power - burnup - moderator density
- Fit of core follow calculations with 4th order polynomials with coupled coefficients
- 5 cycles, each about 300 d, downtime = 60 d, decay period = 5 y
- Sampling of 2 independent coefficients (250 samples)
- Sensitivity and uncertainty analysis of k_{eff} in 3D transport cask on varied parameter
- cycle 1:



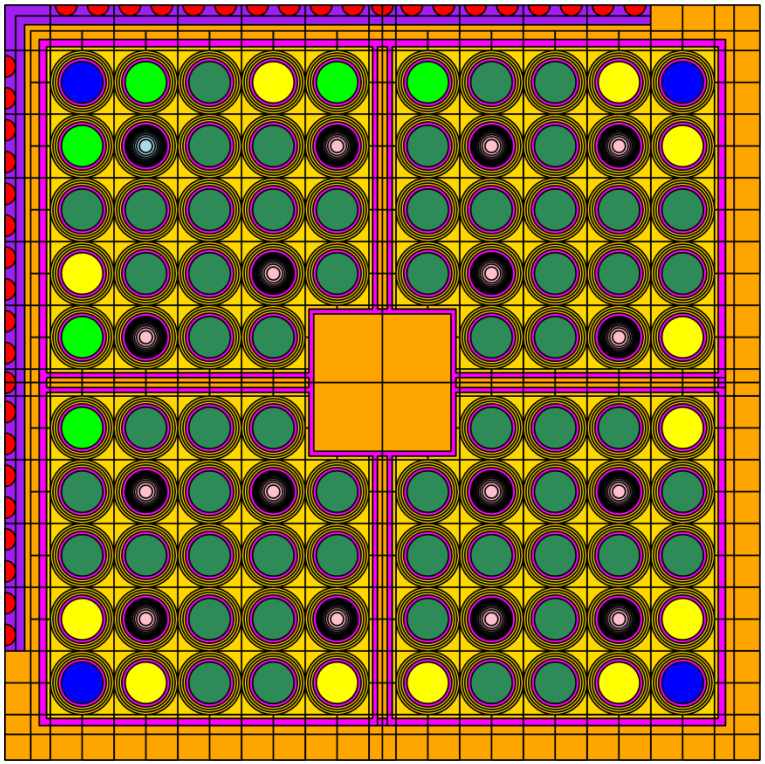
Calculation chain – Irradiation model

- Simplified use of control blades:
  - reduction of power and burnup by 35 % in zones with inserted control blade
  - Neutron absorption and modified spectrum by control blade in depletion model



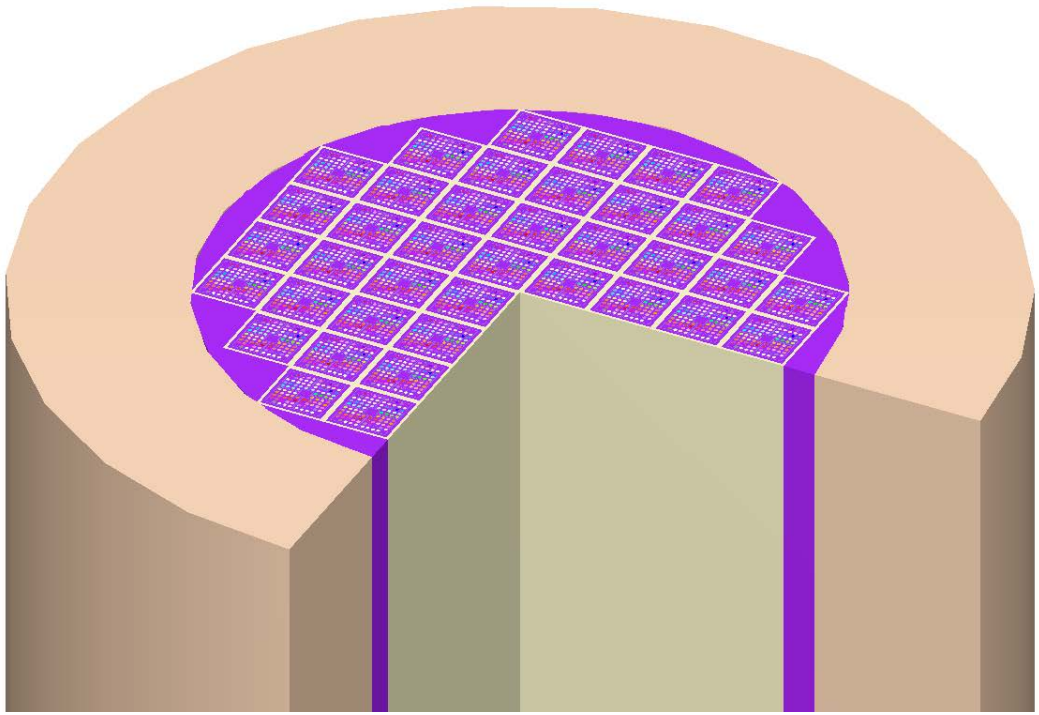
Calculation chain – Depletion model

- Generic BWR FA, 10x10, diagonal symmetry
- 12 part length FRs (1/3, 2/3), varying enrichment
- 4 x 4 Gd-fuel rods
- Possibility of ¼ control blade (B_4C)
- 24 axial zones with equal height calculated separately
- 250 samples for SU-investigation
  - 6000 depletion calculations
- Depletion code:
  - HELIOS 1.12 (Studsvik)
  - deterministic 2D latice code
    (fast calculation for MC sampling)



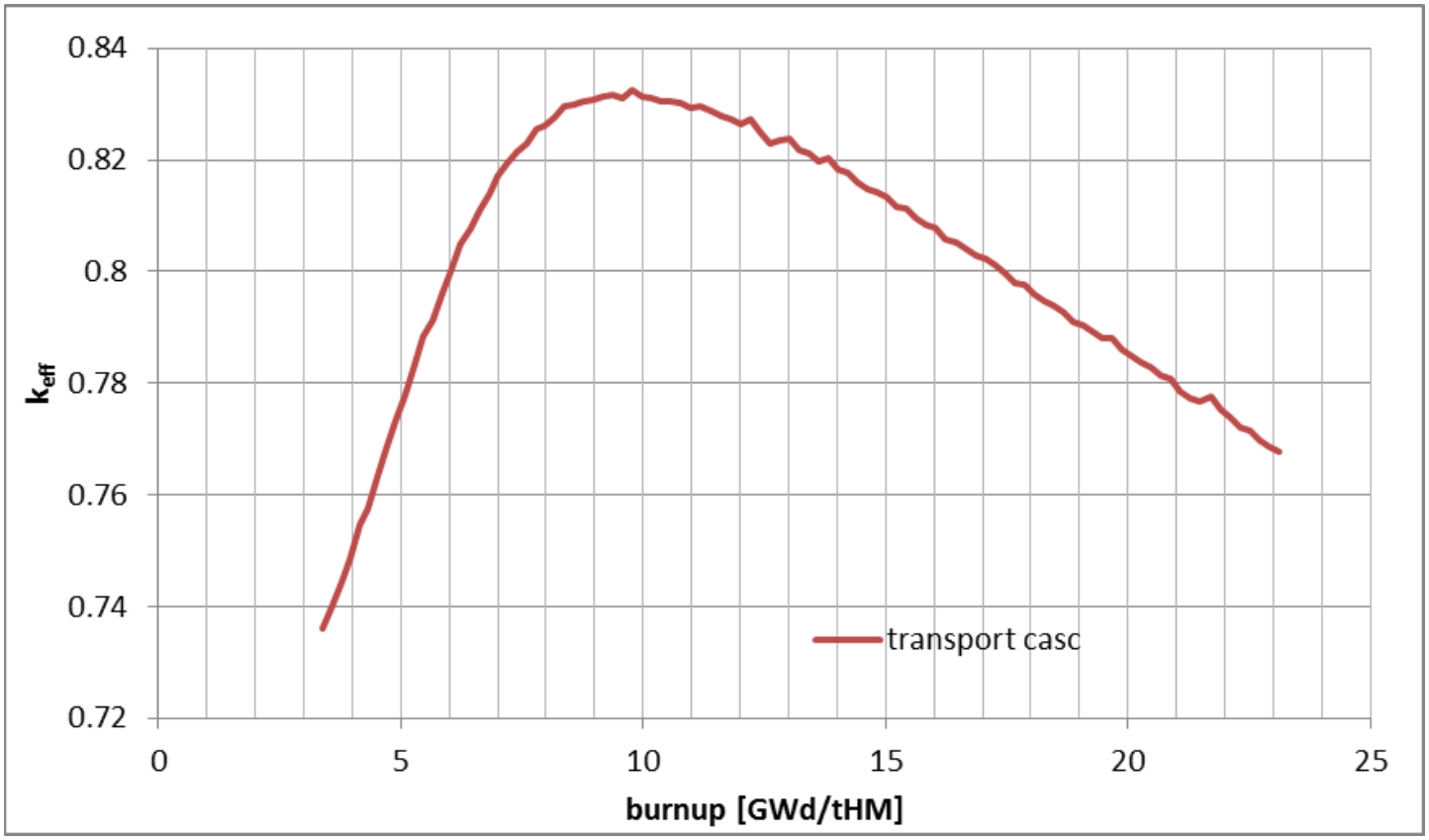
Calculation chain – Criticality model

- Generic transport cask with 52 equal FA
- Flooded with water for criticality calculations
- Nuclear densities of 24 axial zones combined in one 3D criticality model
- 51 thousand nuclides per sample, in total 12.8 Mio nuclides
- Criticality code:
  - KENO-Va (SCALE 6.2.1)
  - ENDF/B-VII library
  - $\sigma_{MC} = 5*10^{-4}$



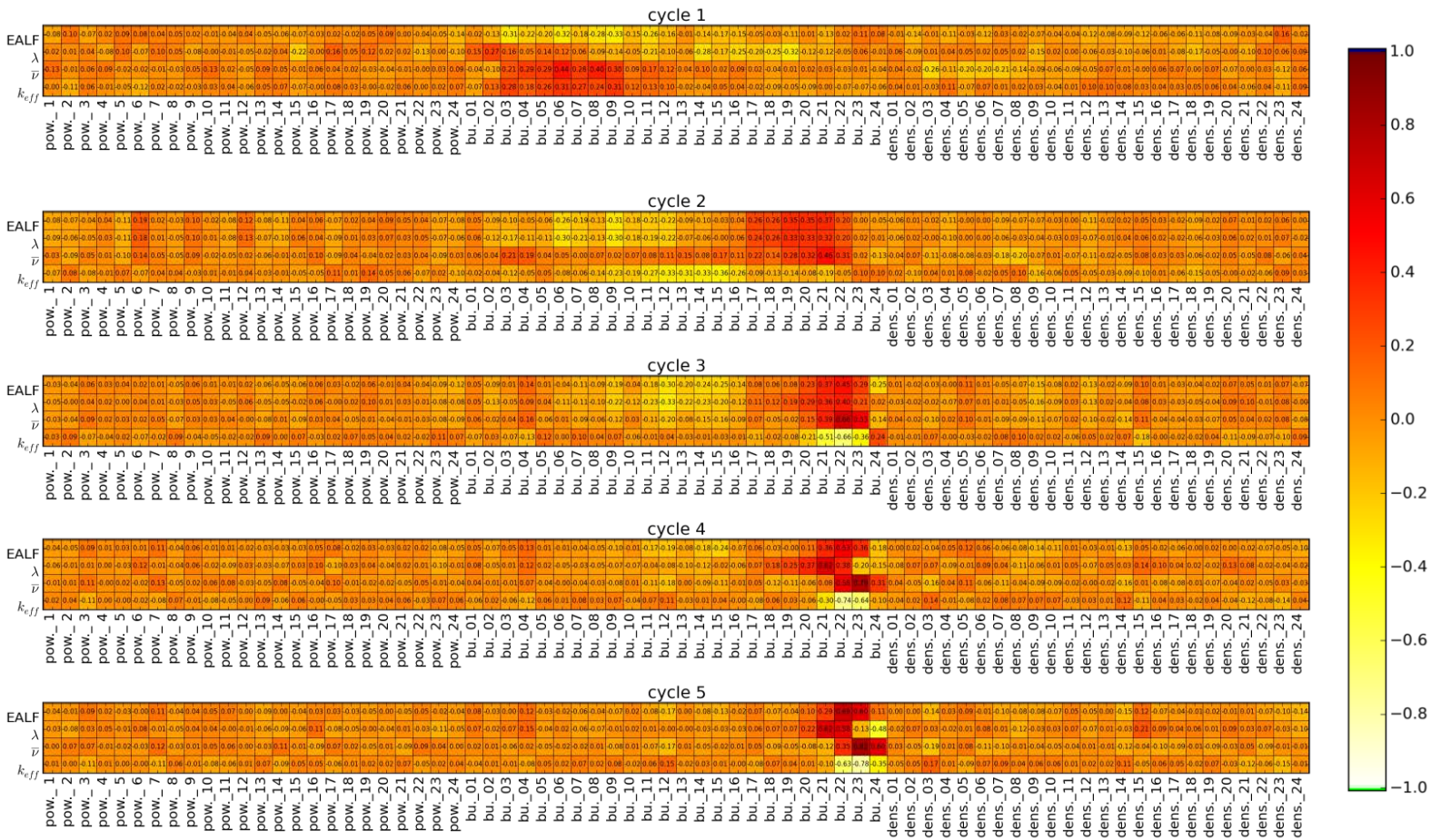
Results – Finding the burnup peak

- k_{eff} in flooded transport cask
- 1 cycle, constant power and void
- Increase of constant term of burnup profile
- Peak at 9.78 GWd/tHM, k_{eff} = 0,8326



Results – Finding most important axial zones

- Variation of mean profiles of power, burnup and void of each axial zone individually by 10 % → unphysical conditions accepted, but influence of individual zones on k_{eff}



k_{eff}

0,793 ± 0,002

0,760 ± 0,002

0,724 ± 0,0025

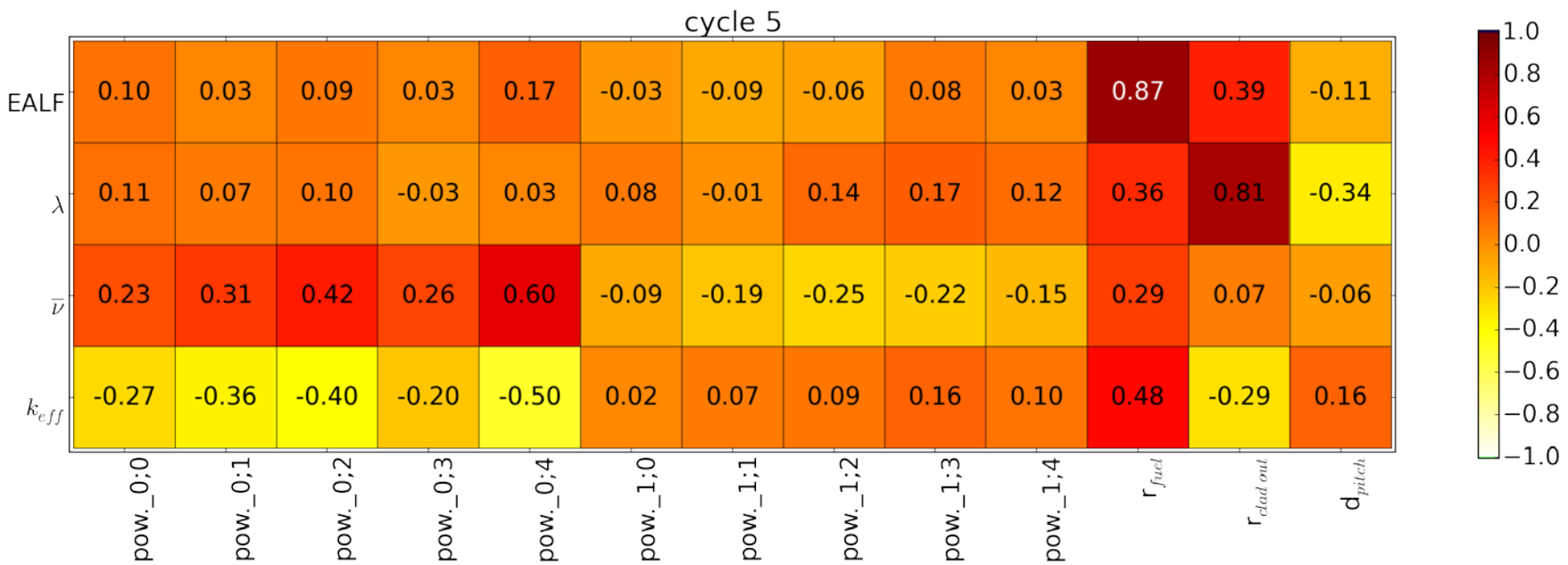
0,699 ± 0,006

0,666 ± 0,008

Results – Irradiation model including geometric variations

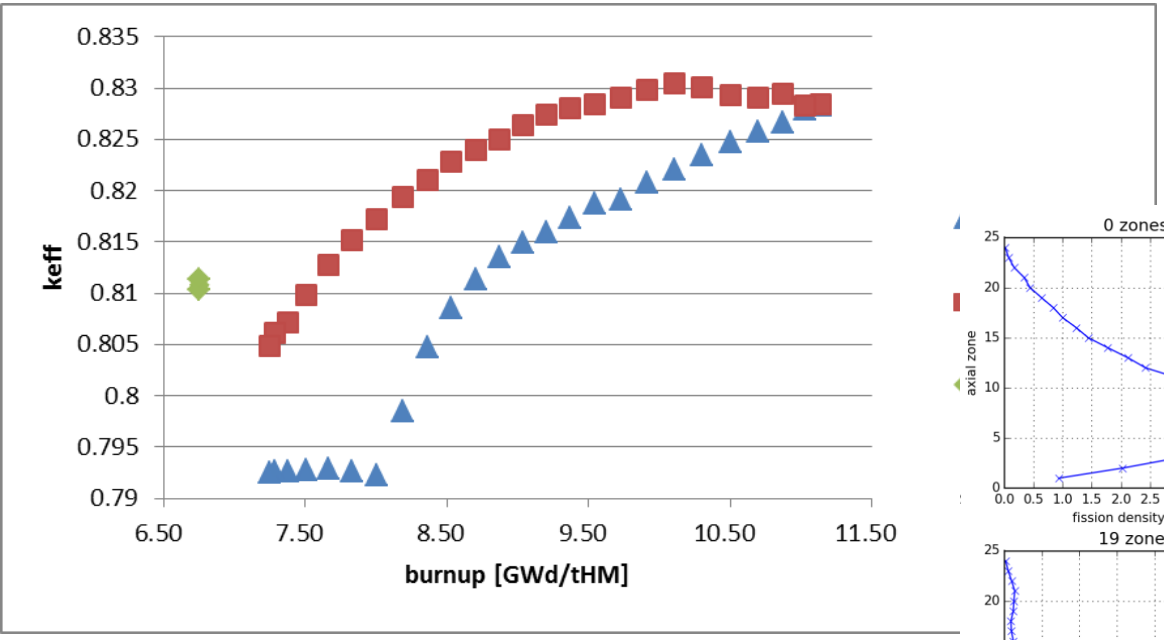
- Application of irradiation model

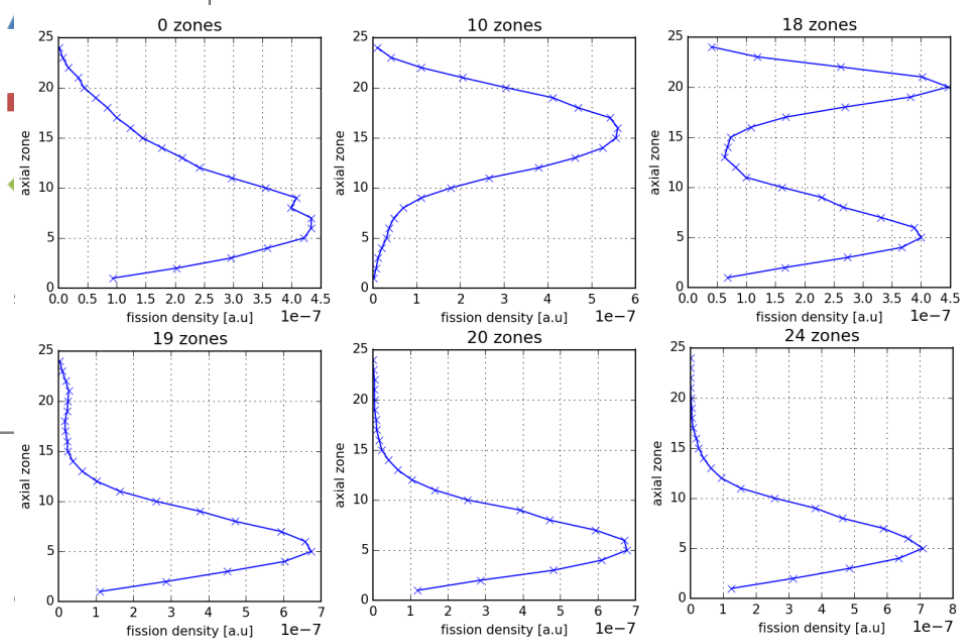
- k_{eff} has negative correlation with pow_0 → burnup directly coupled to power
- Last cycle has maximum impact
- pow_1 negligible correlation
- Fuel radius and outer cladding radius also impact k_{eff}



Results – Irradiation model including control blade model

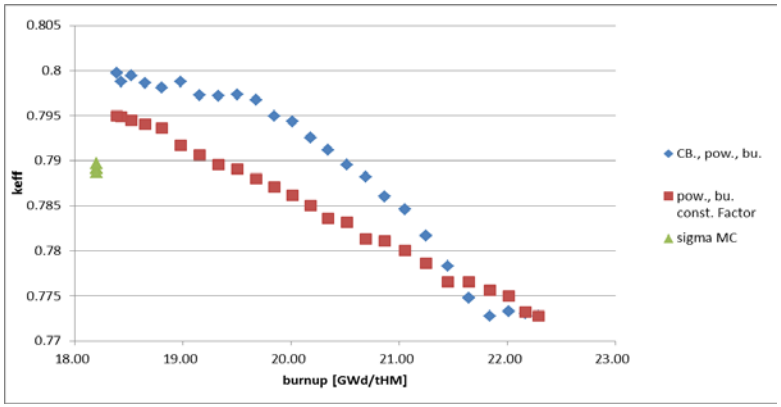
- One cycle, control blade inserted from below
- Reduction of k_{eff} with insertion of CB up to zone 18 (blue curve)
- No change with further insertion – explainable with peak of fission density
- Homogeneous reduction of power and burnup as comparison (blue curve)
  - neglect of CB conservative

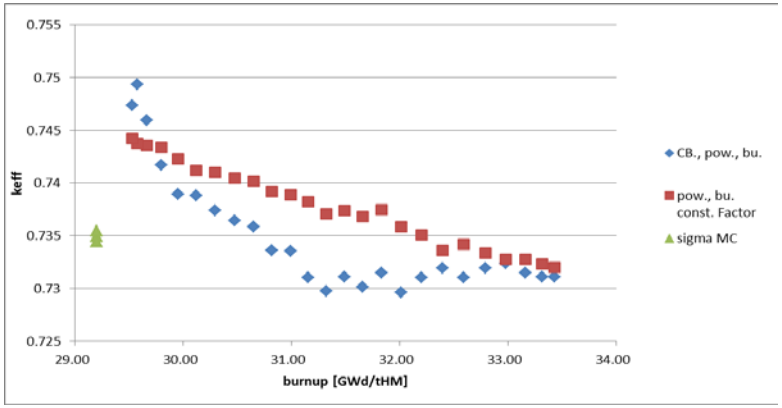


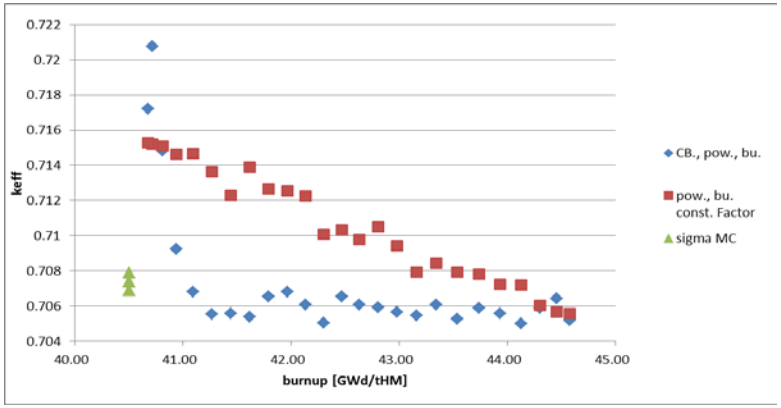


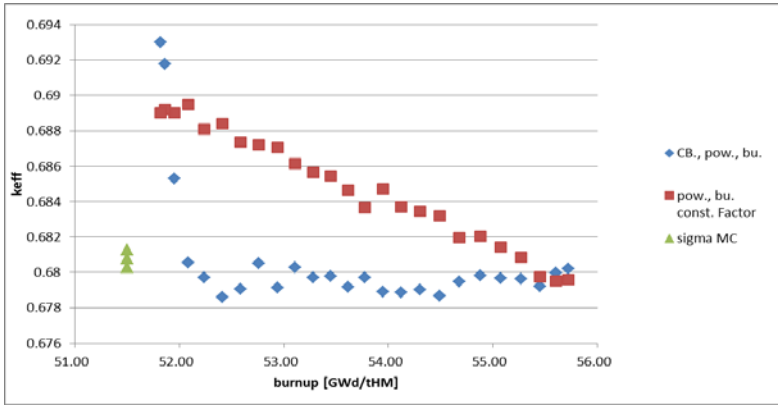
Irradiation model including control blade model – 2-5 cycles

- CB only inserted in the last cycle
- 2 Cycles: neglect of CB non-conservative
- 3 – 5 cycles: neglect of CB only non-conservative for insertion up to zone 23 or 24









Summary and conclusions

- Application of calculations chain:
  1D irradiation model – 2D depletion calculation – 3D criticality calculation

- With increasing burnup the region affecting k_{eff} migrates to the top three zones
  - Sensitivity study, fission density distribution

- Application of the irradiation model:
  - k_{eff} most sensitive on the constant term of the power of the last cycle (directly coupled to the burnup) and the fuel radius
  - Below and around the Gd-peak the neglect of CB is conservative
  - Above ~15 GWd/tHM CB might have to be considered due to a k_{eff} increase
    - with our used extreme CB scenarios

- We have shown the general feasibility of the chosen approach with generic models

- Next possible steps:
  - Coupling to thermohydraulic code or using actual core-follow data
  - Application to different fuel elements and transport cask designs, ideally based on data from manufacturers
  - Investigate more realistic CB histories

Thank you for your attention. Any questions?