PAUL SCHERRER INSTITUT

PSI

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Use of SNF for PIE validation and criticality calculations

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Summary

- The CMSYS database and CS_2M method
- Validating SNF with PIE data: the U1 example
- Using SNF for criticality of canister
- Conclusion

- CS_2M: CASMO – SIMULATE – SNF – MCNP
  Systematic and consistent neutronic approach for Spent Nuclear Fuel, from power plants to long-term repository

- Goal: Spent Nuclear Fuel assessment (content) taking into account their irradiation life and cooling in a realistic way

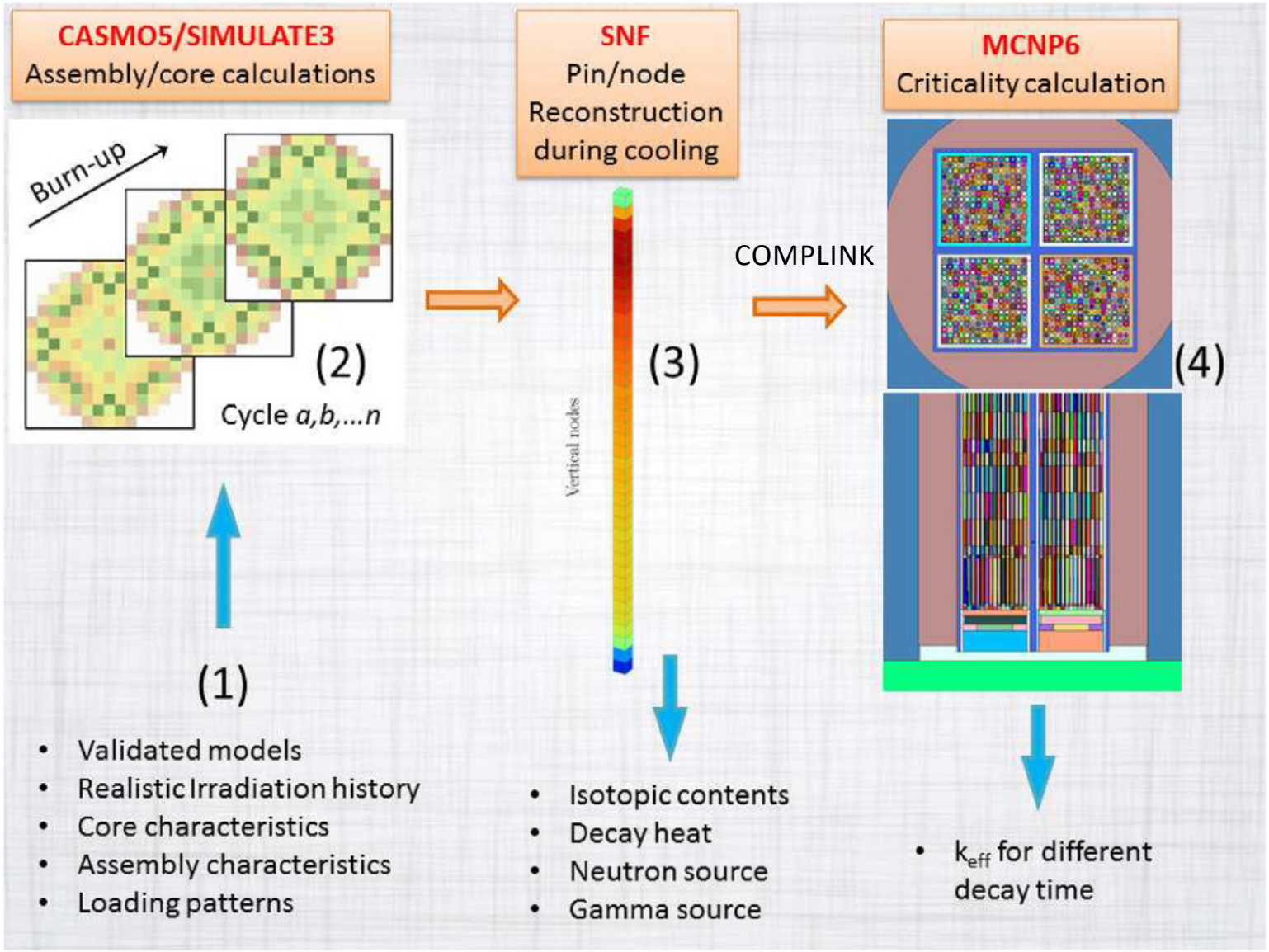
- Solid ground: Large amount of information + experience is already at the LRT
  - Fuel history from utilities (>40 years of operation)
  - State-of-the-art tools (CASMO + SIMULATE + Monte Carlo)
  - Validated models (CMSYS for the 5 Swiss reactors) + SNF (spent nuclear fuel code)
  - Nuclear data control
  - Applied for Spent Fuel knowledge (source term, canister, criticality…)

- Method: only “connecting the dots” (or linking the above)

- Output: consistent (from the same source) loading curves + decay heat + radiotoxicity + fuel content for all Swiss nuclear fuels (12 000 assemblies and for each segment)

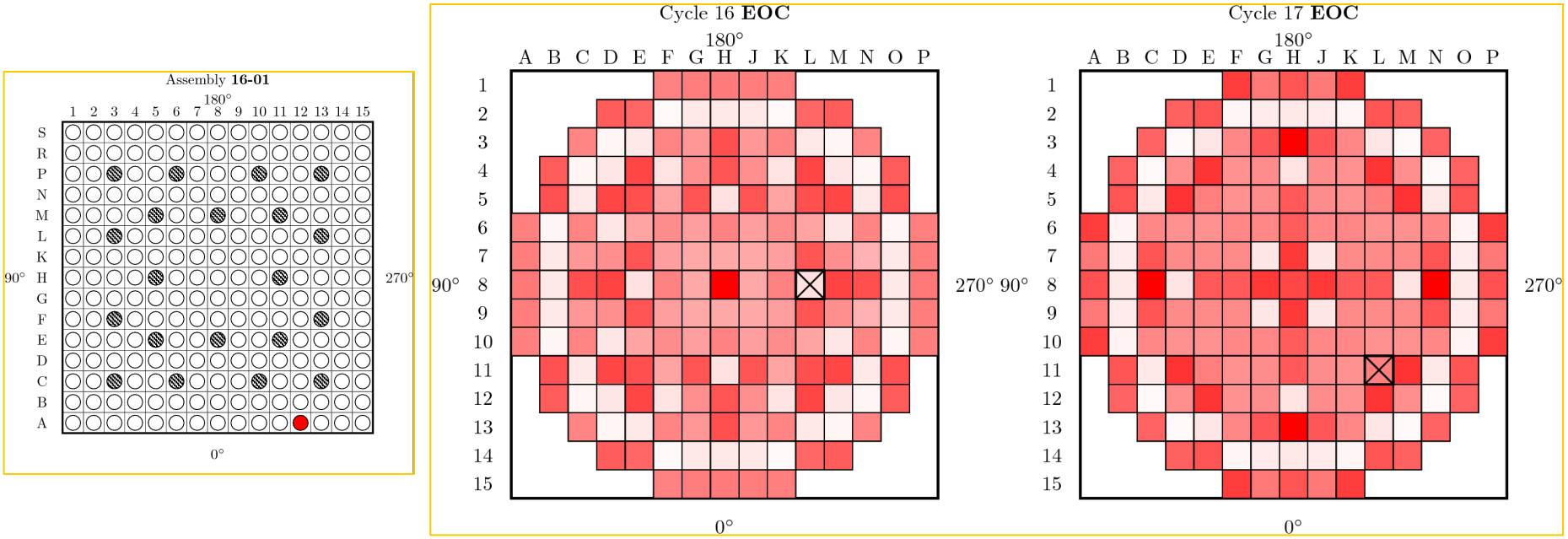
CS_2M: Just linking existing tools

- Based on core licensing information



SNF validation: Experimental knowledge on U1

- U1 sample (also known as UR7) is one of the 13 LWR-PROTEUS Phase II samples, analyzed for PIE isotopic contents
- It comes from the assembly 16-01 irradiated at Gösgen during 2 cycles (680 days):
  - Cycle 16: (343 days) - Shutdown time: 28 days Cycle 17: (337 days)

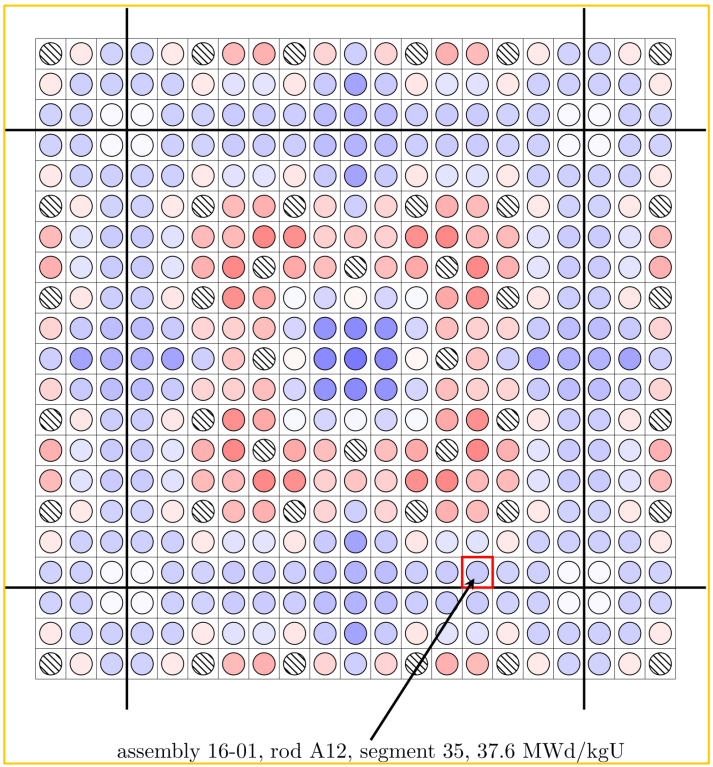


Location of the assembly 16-01 containing the U1 sample, for cycle 16 and 17. The position of the assembly 16-01 is indicated by a cross. The colours are proportional to the assembly burnup obtained from SIMULATE-3 at the end of cycle (EOC).

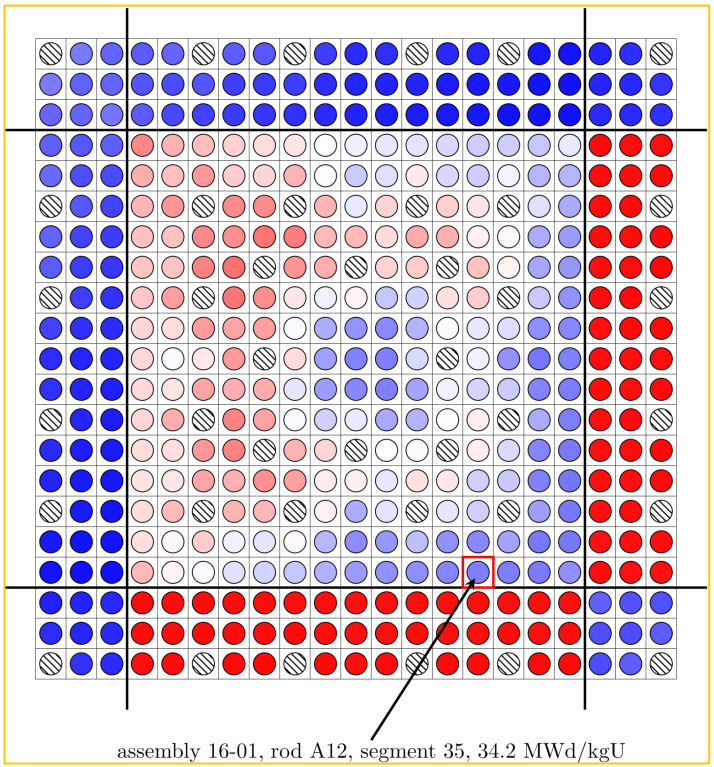
- This work is performed in collaboration with M. Seidl and J. Basualdo from PreussenElektra

CS_2M: advantage of fuel core vs. single assembly

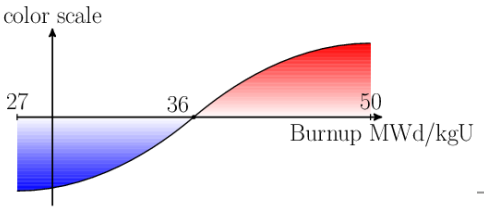
- With CS_2M, CASMO and SIMULATE are combined for pin/segment calculations
  - realistic irradiation history is considered + account for neighboring assemblies.
  - This is a major advantage compared "single assembly calculation" (only lattice code)



CASMO

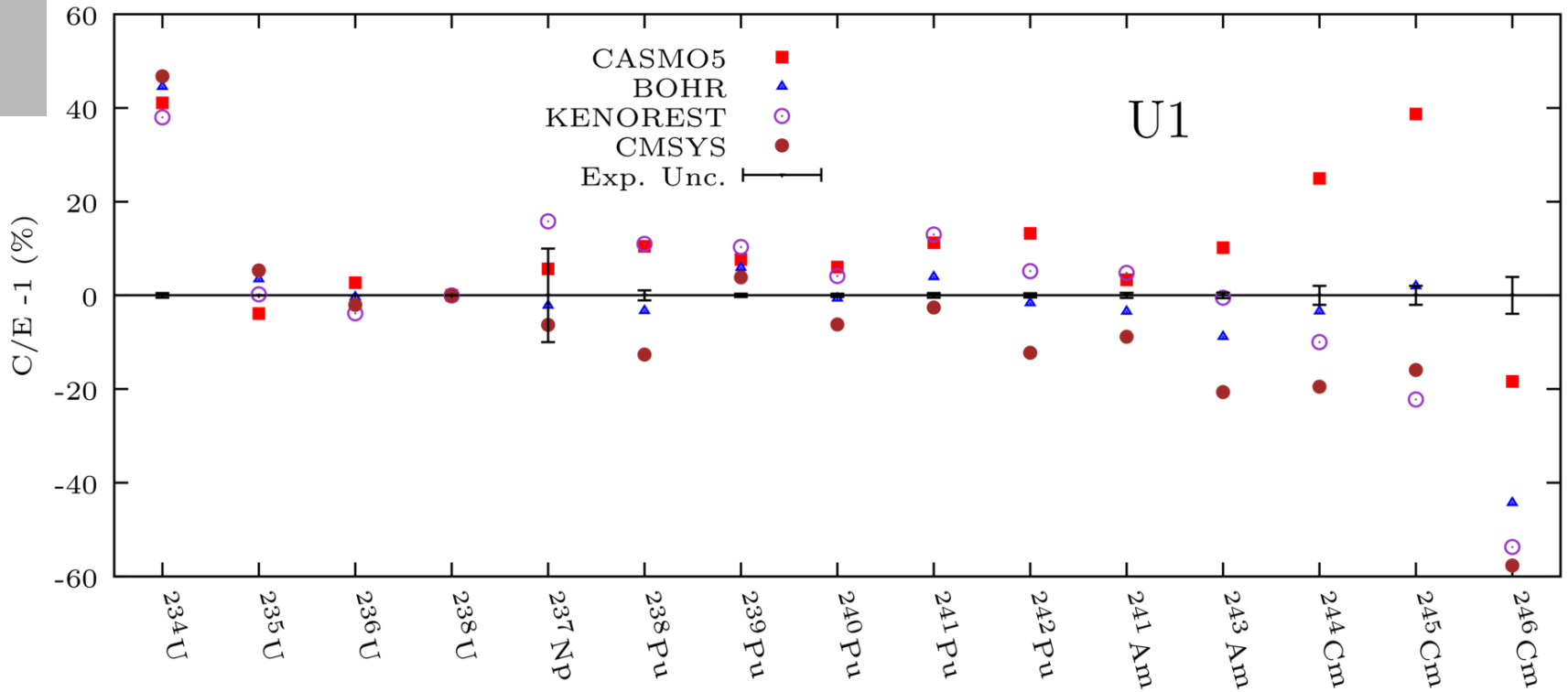


CS_2M



New SNF calculations for U1

- U1 calculation validation for PIE (Better C/E, different sample burnup)

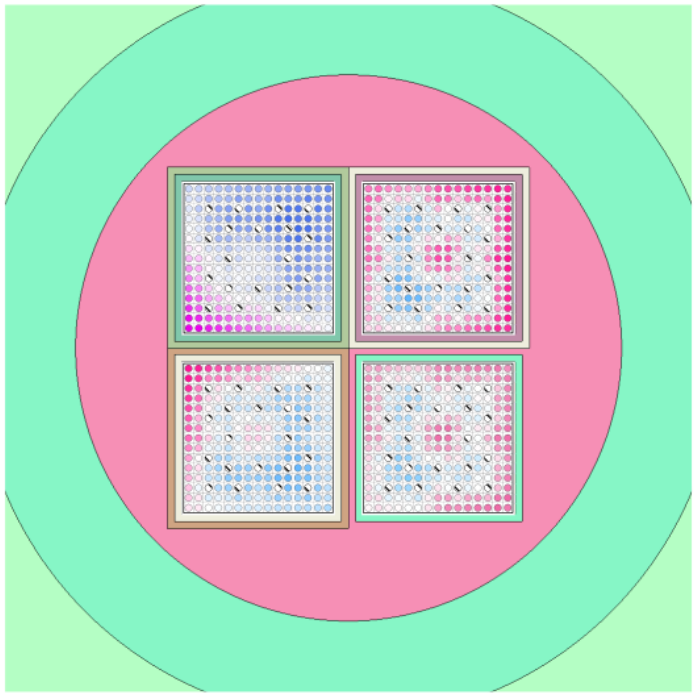


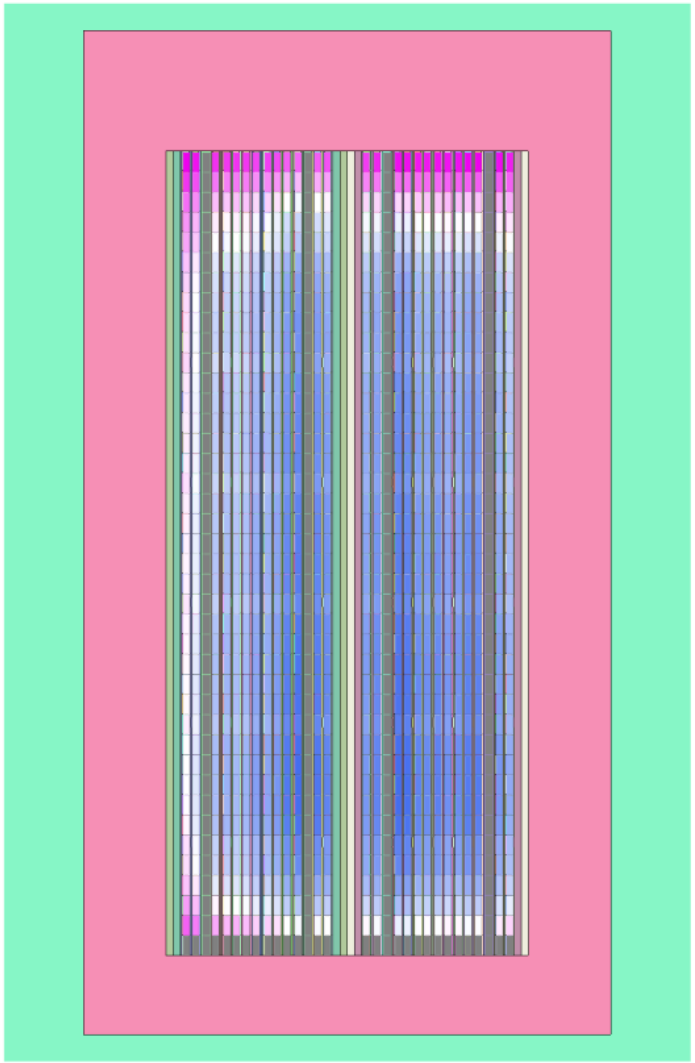
- CMSYS U1 burnup: 34.2 MWd/kgU, average C/E-1= +1.5 %
- CASMO5 U1 burnup: 37.6 MWd/kgU average C/E-1= +16.8 %
- BOHR U1 burnup: 35.8 ± 1.8 MWd/kgU average C/E-1= +7.6 %
- KENOREST U1 burnup: 35.9 MWd/kgU average C/E-1= +10.3 %

Example of previous validation: ANE94(2016)603

CMSYS + CS_2M for canister filling

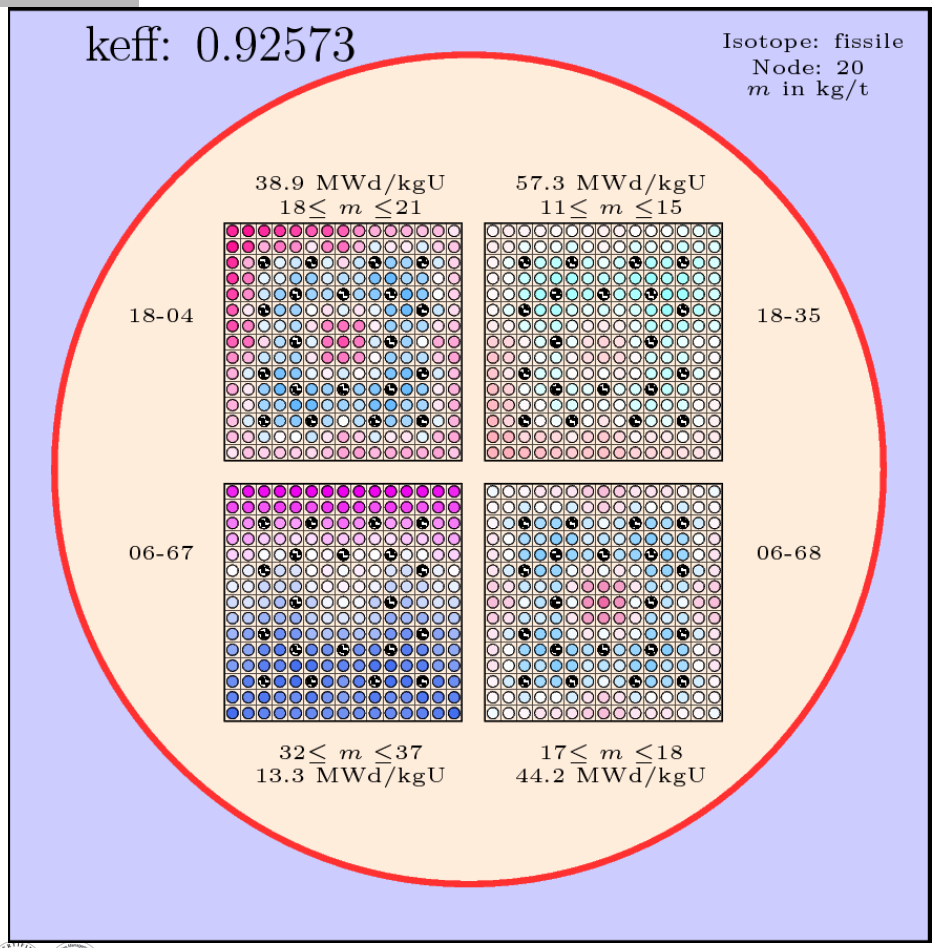
- SNF is applied for every assembly/pin/segment for the Gösgen assemblies
- A MCNP (SERPENT) pin-by-pin Monte Carlo model is built containing 9000 cells/assemblies with isotopic contents from SNF
- A canister with 4 assemblies is considered
- k_{eff} is calculated for various loadings

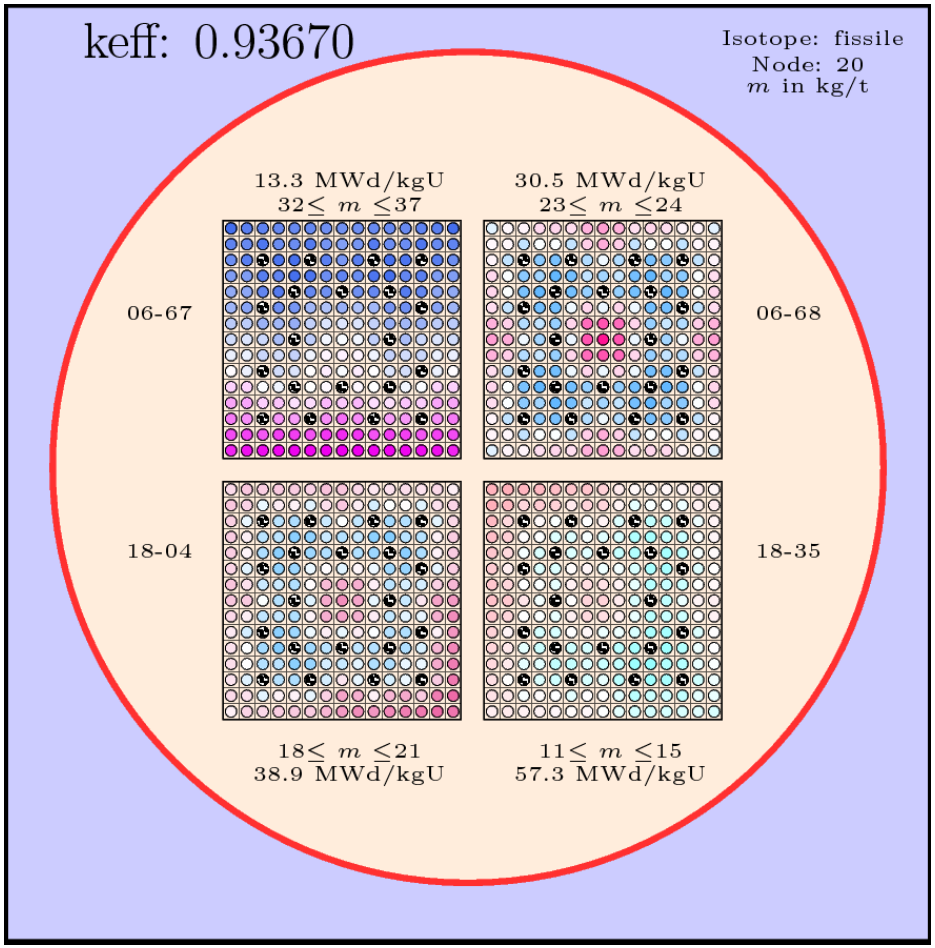




CMSYS + CS_2M for canister filling

- Due to the burnup gradient, relative positioning matters for k_{eff} (rotation, up side down)
- This impacts the calculation of safety limit for criticality
- Example: same assemblies in different order and up side down ("*gedanken experiment*")

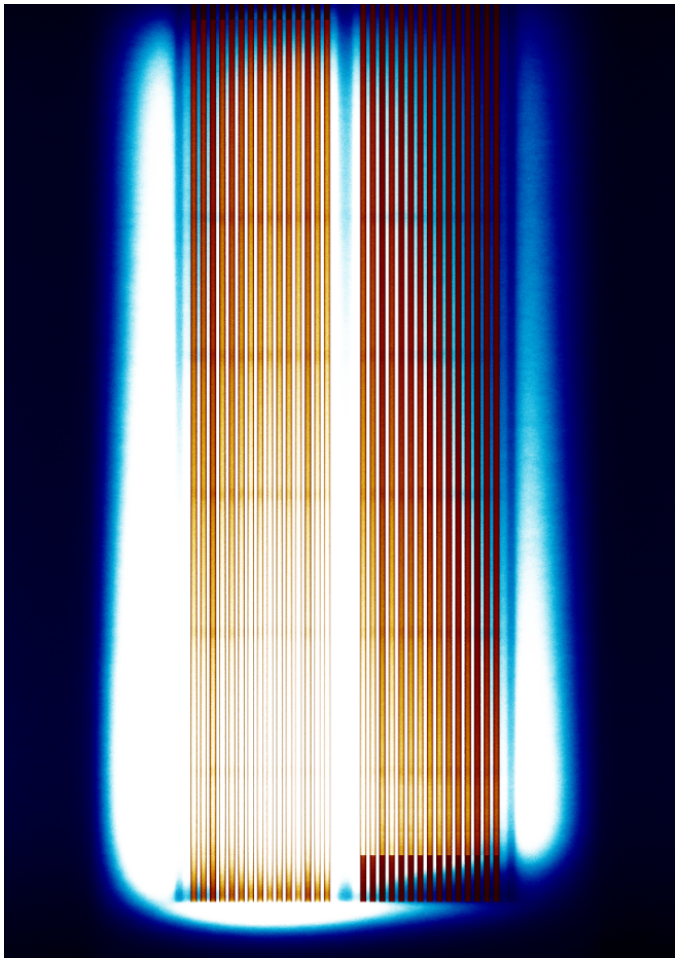




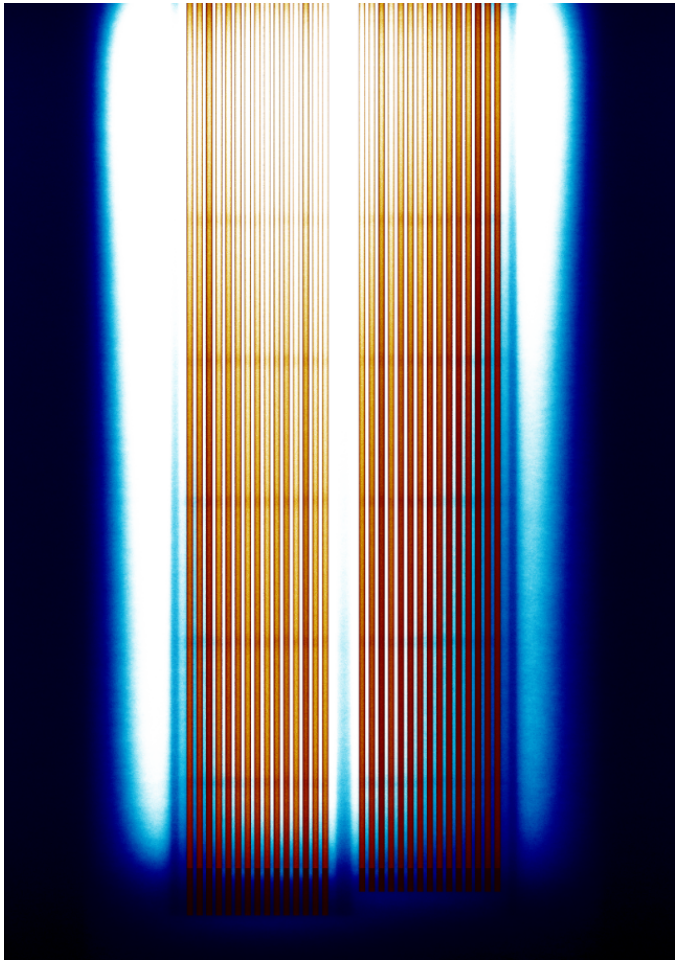
CMSYS + CS_2M for canister filling

- Such results can be obtained for all assemblies and canister loading, going into more reliable calculations and allowing optimization

keff= 0.92573

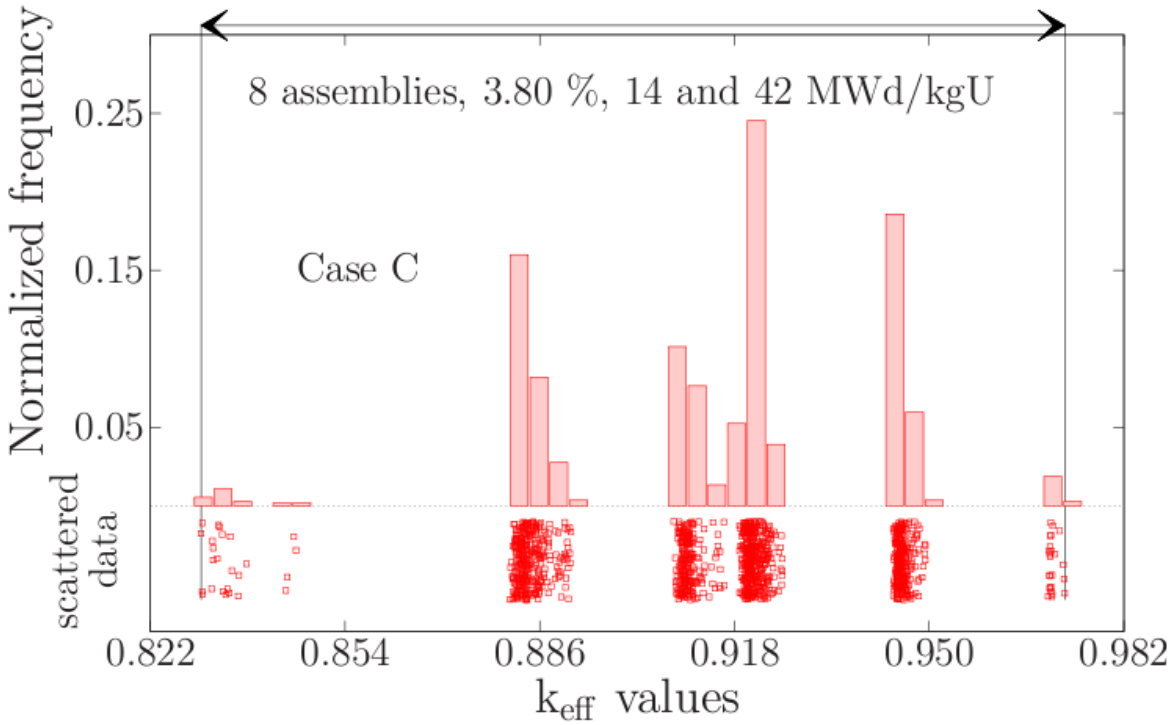


keff=0.93670



CMSYS + CS_2M for canister filling

- Open the possibility of mixed *vs.* homogeneous loading
- Example of application: 2 canisters with 4 assemblies in each. How to select the mixed loading to have keff < 0.95 ?



- More generally: How to efficiently load canisters with 4 different assemblies ?
  - How to search among the 12 000 assemblies considering boundary conditions (k_{eff},decay heat,…) ? ($\approx 10^{15}$ solutions)
  - Moving towards surrogate models.

Conclusion and wish list

- Our validated models + CASMO+ SIMULATE +SNF (CMSYS + CS_2M) allows to calculate (and later validate) spent fuel characteristics (content, source terms) and connect with various projects.
- SNF is one of our key tools (with CASMO/SIMULATE), at the basis of our work for core physics, spent fuel, and later links to transient and fuel behavior.

- <u>Wishes:</u>
- Need more validation (SNF for short or less short cooling times): decay heat and isotopic
- Need a better handling of output (hdf5 format ?)
- Need easier procedure for multi state point/pin/segment calculations

- More generally:
  1. More information would be welcome on the library processing
  2. We need a stronger and more reliable procedure for nuclear data uncertainty propagation (for SNF, but also CASMO and SIMULATE). An uncertainty method should be built in SNF, from ENDF files to core and fuel output.

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