

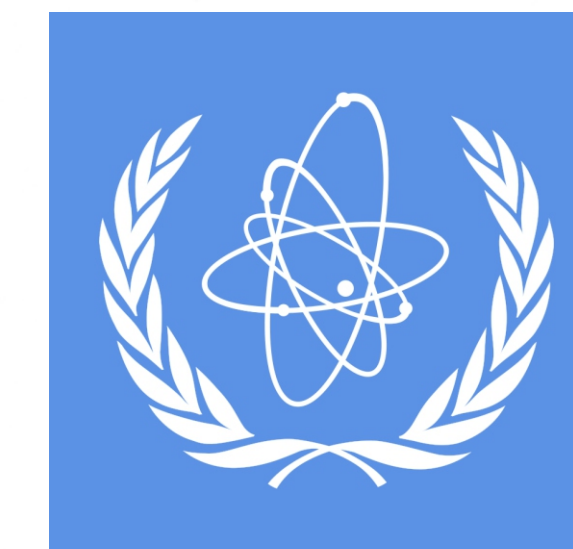
Evaluation of biases and experimental uncertainties of the fission rate profile measurements at the JSI TRIGA Mark II research reactor

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Motivation

- Validation experiment performed at the JSI TRIGA research reactor
- Measurements of fission rate axial profiles using miniature fission chambers
- Monte Carlo evaluation of experimental and computational biases and uncertainties
 - ▶ Analysis of effect of experimental instrumentation on reaction rate measurements
 - ▶ Assessment of the experimental uncertainty due to fuel material data errors
 - ▶ Study of the TRIGA fuel burn-up and the consequent computational bias

Fuel composition

- TRIGA fuel homogeneous mixture of 88 wt % ZrH and 12 wt % uranium with 20 % enrichment
- Average mass of uranium in fuel elements is 278 g and 236 g in fueled follower control rods
- **Experimental uncertainty:** fuel composition data uncertainty (mass of ²³⁵U and ²³⁸U)
- Fuel meat atomic density perturbed in Monte Carlo calculational model from ~ 0.9 % to 1.5 %
 - ▶ Relative fission rate differences small, mostly of the order of computational statistical uncertainty

Aluminium guide tubes

- FCs manipulated at reactor platform
- Aluminium guide tubes utilized for increased in-core positioning precision
- **Experimental bias:** water displacement (2 mm Al) effect on neutron spectrum
- Tubes induce a reduction in neutron thermalization resulting in a local increase of number of fast neutrons
 - ▶ Rate of ²³⁵U fissions is lowered, max. decrease in FC signal ~ 13 %

Fission rate ratio profile - Al tubes bias [%]

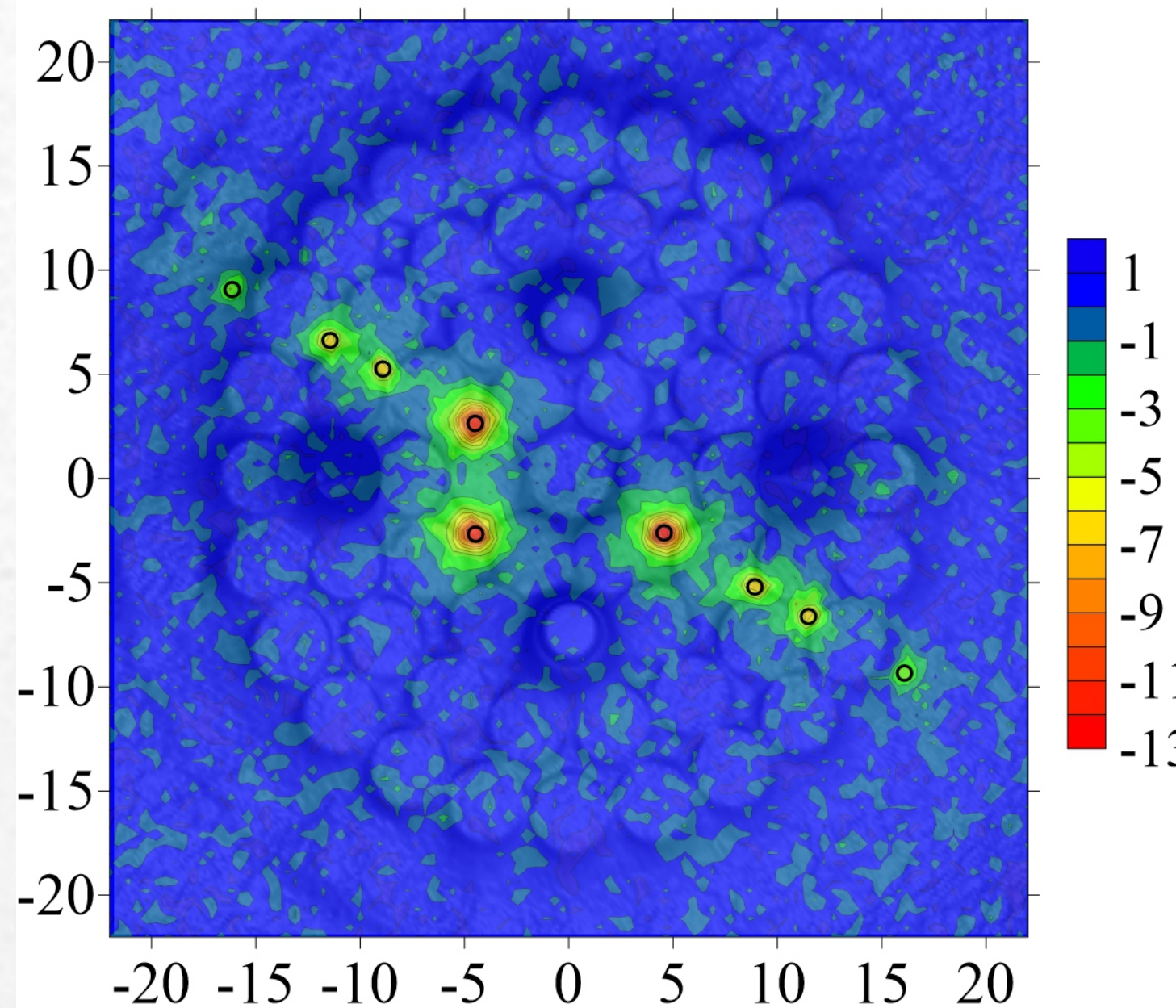


Figure 4: Profile of the relative difference in fission rates with Al guide tubes inserted and withdrawn from the reactor core.

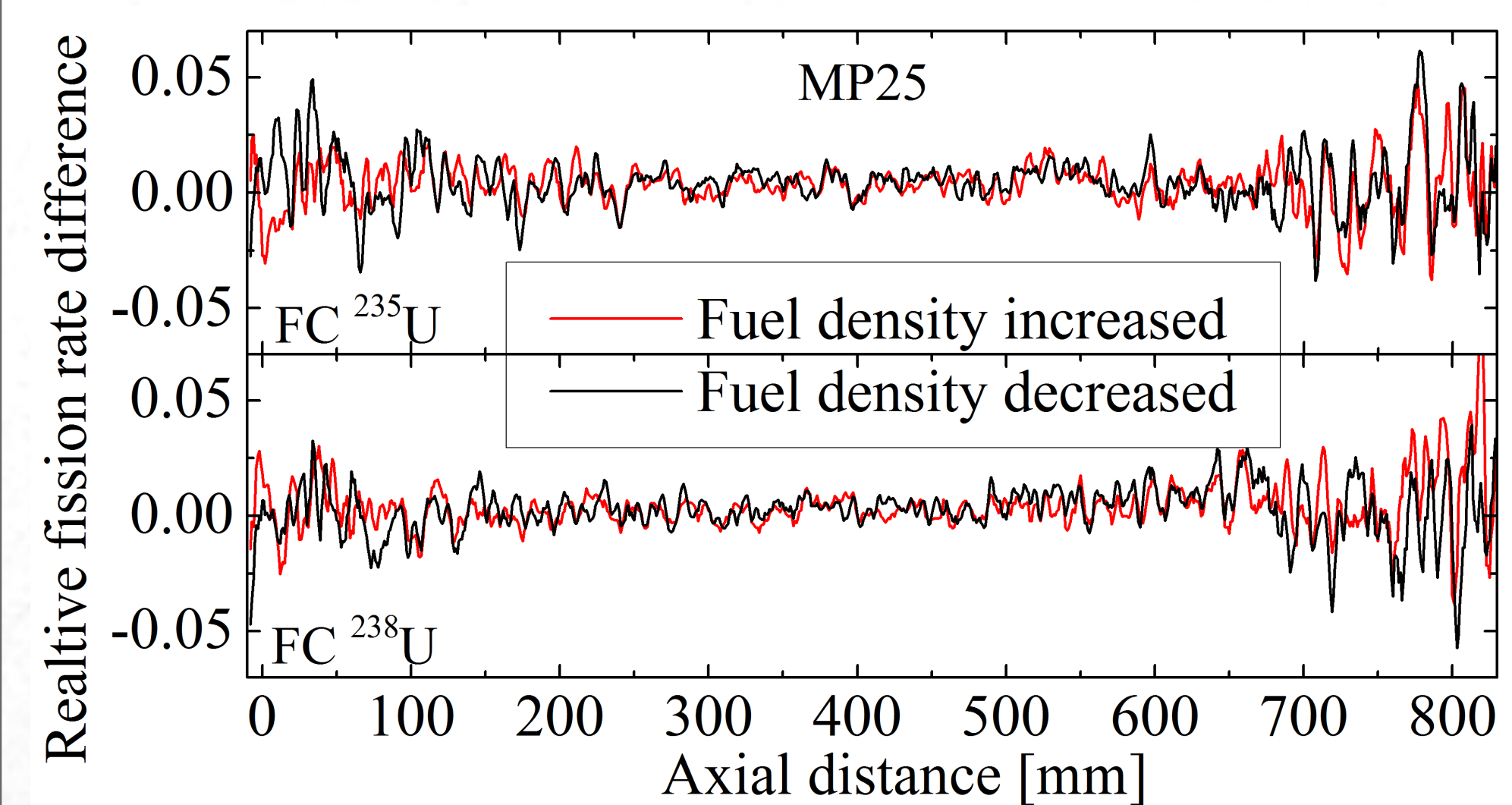


Figure 5: Relative difference between fission rate axial profiles calculated with the reference model and the model exhibiting perturbed fuel density.

Fuel burn-up

- Low average burnup of fuel (< 5 MWd) - reference Monte Carlo model with fresh fuel
- **Computational bias:** fuel burnup effect on core neutron spectrum and FC response
- After 20 years of operation the average burnup of a fuel element is ~ 2.2 MWd, which equals 25 days of operation at full steady-state power of 250 kW
- In-house developed TRIGLAV software used to calculate individual burnup of 56 fuel elements
- 15 core radial groups depending on burnup levels, varying from 0.7 MWd (edge) to 4.9 MWd (center)
- Isotopic composition calculated using ORIGEN 2 computer code with PWR libraries [3]
- 10 axial burnup slices included in Monte Carlo model taking into account flux axial distribution

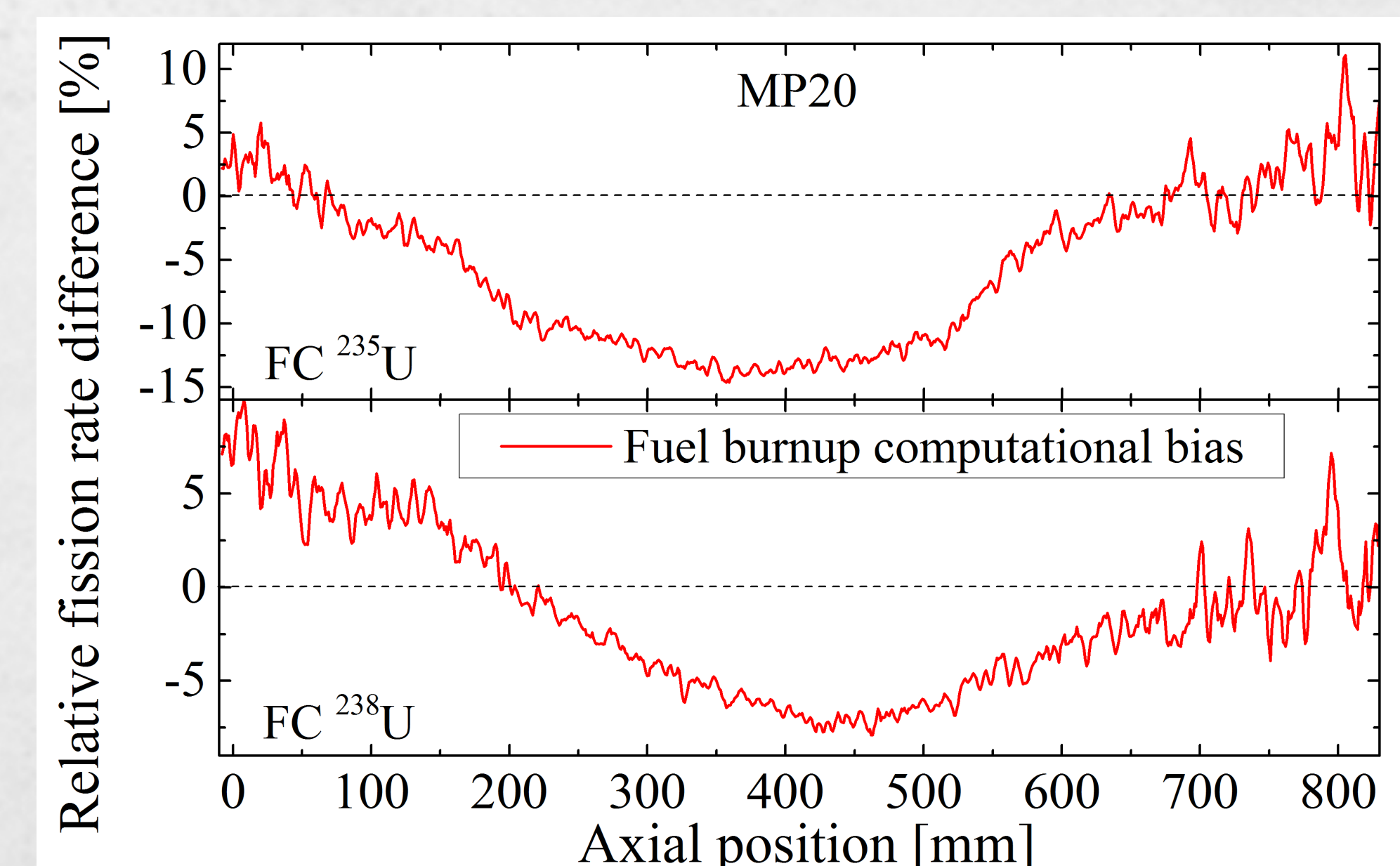


Figure 7: Relative difference between fission rate axial profiles calculated with the TRIGA Monte Carlo model with burnt-up fuel and fresh fuel.

Fission rate measurements

- Two miniature watertight fission chambers developed and manufactured by CEA Cadarache [1]
- Stainless steel cylinder with a 3 mm diameter
- Fissionable material deposited in active part (4 mm)
- One chamber with coating composed mainly of ²³⁵U (98.490 %) and the other of ²³⁸U (99.964 %)

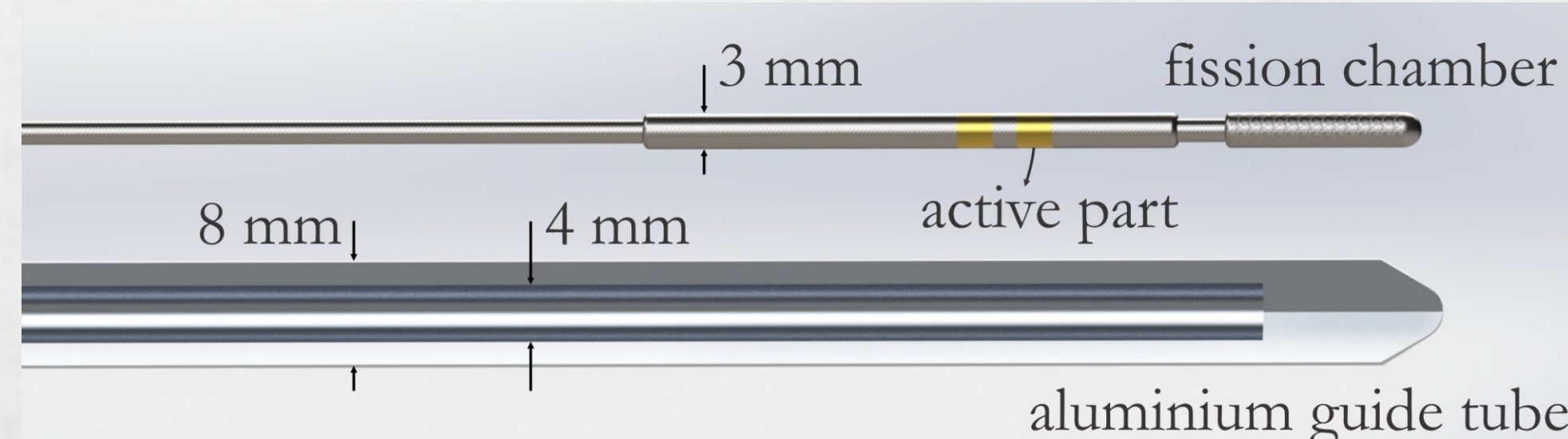


Figure 2: Fission chamber and a cut view of the aluminium guide tube for in-core insertion.

- Monte Carlo calculations of fission rate profiles using a detailed geometric model of the reactor [2]

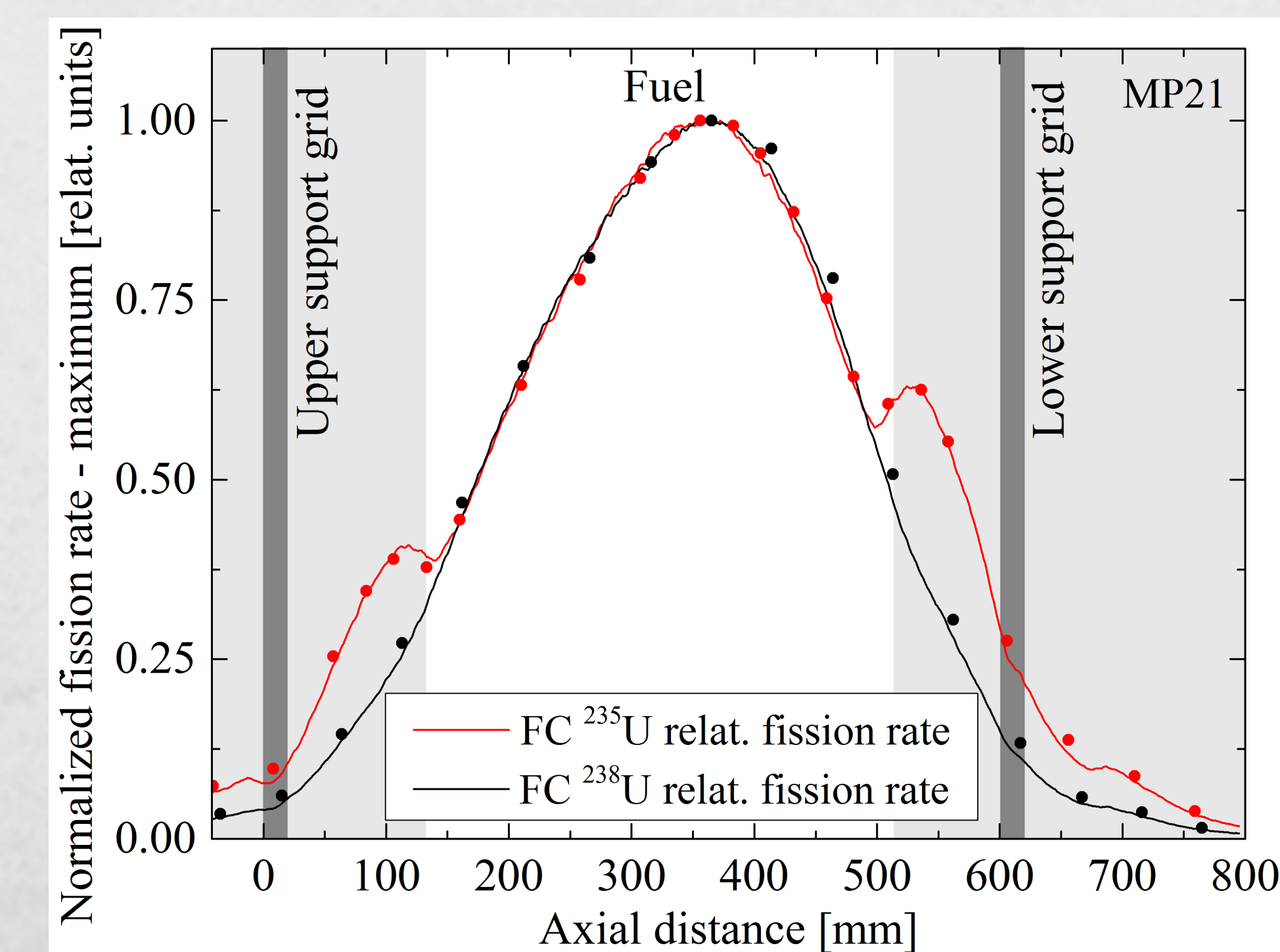
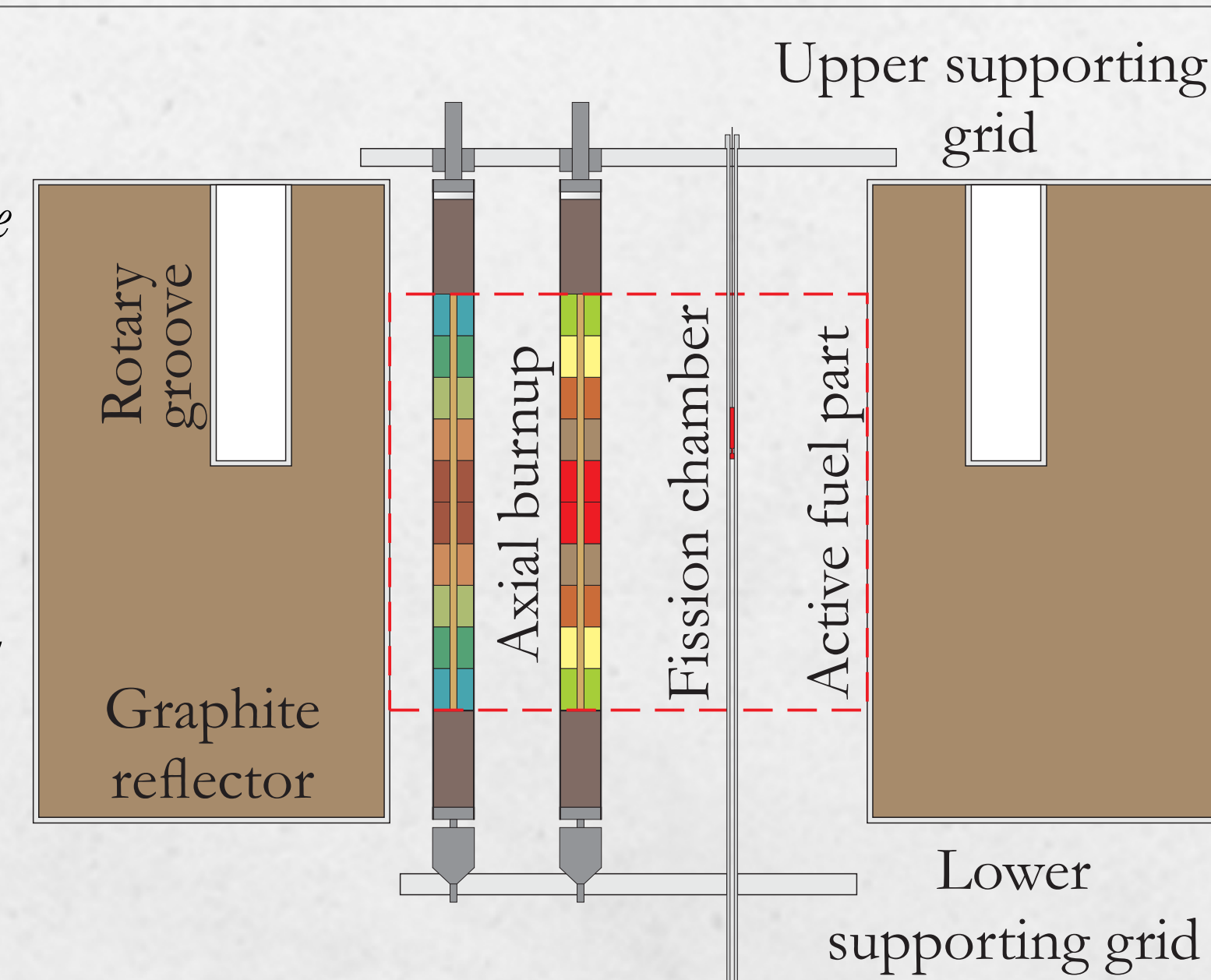


Figure 3: Normalized fission rate profiles for two fission chambers determined by measurements (dots) and Monte Carlo calculations (line).

- ▶ Relatively good agreement - evaluation of the experimental and computational uncertainties for final validation

Figure 6: Scheme of the Monte Carlo model of the TRIGA reactor core with axial levels of fuel burnup and fission chambers.



- ▶ Fuel burnup effects the axial shape of fission rate profiles as well as absolute rate values
- ▶ **FC fission rates are lower in the active part of fuel and relatively higher at the edges of the core**
- ▶ Relative discrepancies for ²³⁵U FC reach a max. of approximately - 15 % and - 7 % for ²³⁸U FC

Conclusion

- ▶ Aluminium guide tubes experimental bias - due to water dislocation the local neutron spectrum is affected resulting in its hardening and consequently lower FC response
- ▶ Fuel composition data experimental uncertainty - effect on fission rates is minor
- ▶ Fuel burnup computational bias - significantly effects the axial distribution and absolute values of fission rates with up to 15 % decrease in the active part of the fuel

References

- [1] GESLOT, B., et al., „Development and manufacturing of special fission chambers for in-core measurement requirements in nuclear reactors“, ANIMMA, 2009
- [2] Los Alamos National Laboratory, „MCNP6 User's Manual - Code Version 6.1.1 Beta“, LA-CP-14-00745, 2014
- [3] CROFF, A. G., et al., „ORIGEN2.2: Isotope Generation and Depletion Code, Matrix Exponential Method“, Oak Ridge National Laboratory, CCC-371, 2002