TECHNISCHE UNIVERSITÄT DRESDEN

Transients at the nuclear training and research reactor AKR-2: Experiments and time-dependent simulations with Monte Carlo Code Serpent

J. J. Gómez Rodriguez (juan.gomezrodriguez@tu-dresden.de), A. Knospe, M. Viebach, C. Lange, A. Hurtado

1. Background, goal, and outline

Transients at nuclear reactors have historically been simulated using deterministic computer codes. In contrast, Monte Carlo (MC) simulations are typically reserved for static analyses. However, with the time-dependent capabilities of the Serpent MC code [1], transients at the AKR-2 zero-power reactor at the Technical University of Dresden, Germany can be investigated, which is the objective of the work presented here.

Eight different experimental transients were studied:

- i) Individual rod drops
- ii) Rods slow insertion
- iii) Simultaneous rod drop of all control rods
- iv) Reactor shutdown

This study represents the first time-dependent MC simulation study, performed in the context of the NAUTILUS project [2], and provides essential insights into the required experimental detection equipment contributing to the ongoing efforts to validate the MC model of the AKR-2.

2. The AKR-2 Reactor and Serpent MC Model

The nuclear training and research reactor AKR-2 is a thermal zero-power reactor with a cylindrical core made of a homogeneous mixture of polyethylene and enriched uranium. The core consists of two separable sections and is surrounded by a graphite reflector, within the three control rods move. There are four experimental channels, and four fixed detectors are installed outside of the reflector region. Additionally, other detectors can be inserted into the experimental channels. Finally, the reflector is surrounded by paraffin and concrete for gamma and neutron shielding (see Fig. 1).

Fuel enrichment (U-235)	19.62 %
Reactor core size	27.7 cm height, 25.0 cm diameter
Operational power	0 – 2 W
Control rods material	Cadmium
Fixed detectors	Fission chambers (3) Ionization chamber (1)
Additional detectors	He-3 proportional counters (2)

Table 1. Details about the AKR-2 reactor.

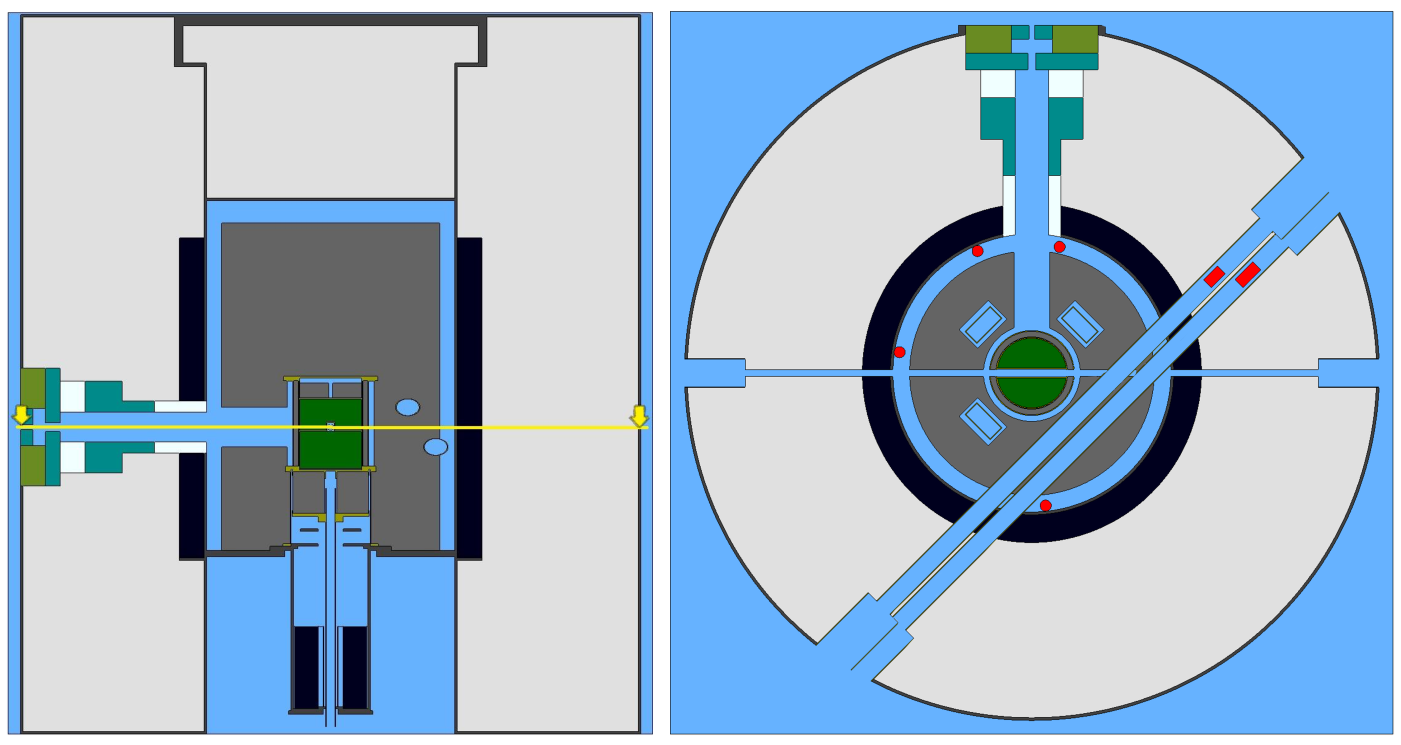

Fig 1. Lateral (left) and top (right) view of the AKR-2 reactor model and detectors' position (in red).

3. Experimental and simulation details

The rods at the AKR-2 can be dropped individually, jointly or with the drop of the lower core half during shutdown. Prior to all transients, the reactor was initially critical at a power of 2.2 W. Measurements were taken using the fixed installed detectors and two He-3 proportional counters inserted in channels 3-4 and 5-6. The drop times for rods 1, 2, and 3, as well as the lower core half, are displayed in Table 2.

In simulations, the first step of the time-dependent simulations was to perform a static criticality calculation (see also Ref. [3]). Then, dynamic simulations were conducted. During these simulations, the core and rods position were updated at equal-time intervals. Rod and core drops were modelled using constant acceleration translations, while driven insertion were modelled using constant-speed translations. In this study, shutdown was simulated for 5 s, all-rods drop for 25 s, and individual drops for 85 s.

Experiment	Lower core half	Rod 1	Rod 2	Rod 3
Rapid insertion	~ 250 ms	~ 630 ms	~ 600 ms	~ 600 ms
Slow insertion	N/A	84 s	94 s	83 s

Table 2. Drop time of control and shutdown devices at AKR-2 during rapid and slow insertion.

4. Results

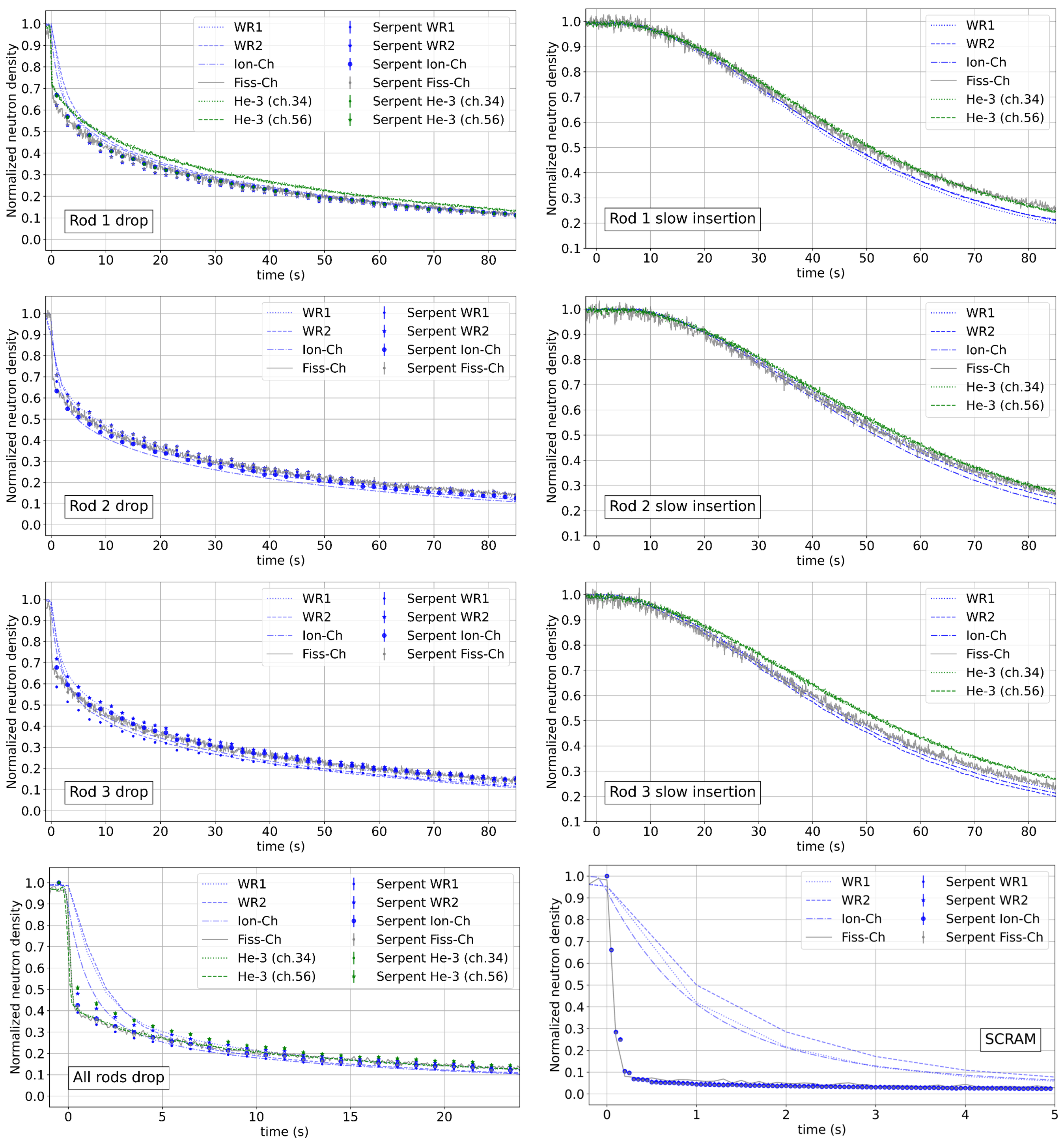

Fig 2. Rod 1 drop and insertion (top). Rod 2 (middle). Rod 3 (middle). All rods drop and SCRAM (bottom).

During the simulated time, the three rods' drop, all-rods drop, and reactor shutdown showed good agreement between simulated and experimental results. The He-3 detectors signals were not dead-time corrected, leading to deviations when compared with simulated results (see Fig. 2, rod 1 drop). Reactivity worth ρ of the rods was computed with their prompt drop (see Fig. 3). After shutdown, the model correctly predicted a 7 % reduction in neutron density. At the start of the transients, deviations arose due to electronics' transfer functions in 3 detectors.

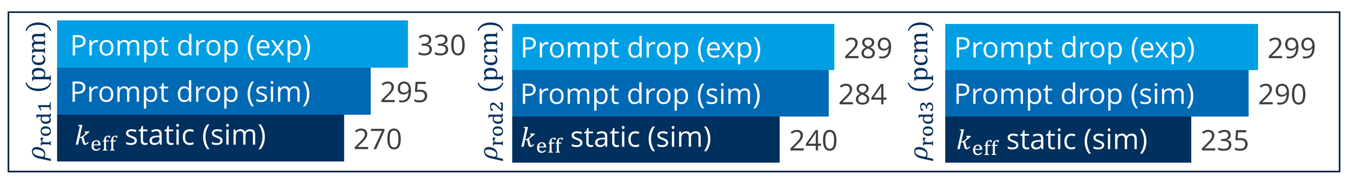

Fig 3. Reactivity worth of the control rods.

5. Summary and conclusions

The time-dependent evolution of neutron density during various transients at the AKR-2 reactor was successfully analyzed, yielding accurate results for rapid transients. The study highlighted the need to account for detector electronics' transfer functions during rod drops and reactor shutdowns. Slower transients and small reactivity insertions may require greater computational capabilities in the future. In summary, the MC code Serpent, along with the AKR-2 reactor MC model, enabled transient studies and showed good agreement with experimental data.

References

[1] Leppänen, J., *et al*. *Status of Serpent Monte Carlo code in 2024*. EPJ Nuclear Sci. Technol. **11**, 2025. **[2]** Viebach *et al*.: *NAUTILUS: A Project for the Development of Experimental Methods for Investigating Innovative Approaches to Nuclear Waste Management and to Nuclear Safety* (PHYSOR2024). **[3]** Fridman, E., & Huo, X. *Dynamic simulation of the CEFR control rod drop experiments with the Monte Carlo code Serpent*. Annals of Nuclear Energy **148**, 2020.

Acknowledgement

This work is part of the research project NAUTILUS funded by the German Federal Ministry of Education and Research (BMBF) under the reference number 02NUK079.

Member in the network of:

DRESDEN concept SCIENCE AND INNOVATION CAMPUS

SPONSORED BY THE Federal Ministry of Education and Research

NAUTILUS

Professur für Wasserstoff- und Kernenergietechnik

RRFM EUROPEAN RESEARCH REACTOR CONFERENCE

FKZ: 02NUK079