Evaluation of postfission properties of uranium isotopes using hybrid method combining Langevin and statistical models†

S. Tanaka,*1 N. Nishimura,*2,*1 F. Minato,*3,*1 and Y. Aritomo*4

Nucleosynthesis by the rapid neutron capture process, called the r-process, represents the cosmic origin of elements heavier than iron group. Although several astrophysical scenarios have been proposed for the r-process, its mechanism is incompletely understood. One of the major reasons is the significan uncertainty in the fission properties of highly neutron-rich nuclei. Nuclear fission plays a key role in this context, because it facilitates matter recycling during neutron irradiation and ifluences the abundance distribution of r-process elements. Precisely understanding nuclear fission holds critical importance in experimental and theoretical nuclear physics, astrophysics, and industrial applications. However, experimental data on nuclear fission are unavailable for neutron-rich nuclei owing to complexities.

In this work, we aimed to quantitatively explore the nuclear decay processes following fission. The main purpose was to establish a calculation method with improved experimental reproducibility. To achieve this objective, we employed the Langevin equations to investigate fission based on a dynamical model, which is widely used in low-energy fission studies.[1] By combining the Langevin calculations with the width fluctuation-corrected Hauser-Feshbach statistical model implemented in CCONE,[2] we calculated independent yields and prompt neutron emissions. We smoothly combined these two methods using the universal charge distribution based on the unchanged charge distribution assumption and energy conservation determined by an anisothermal model.[3] This approach allows calculating a sequance of fission dynamics and postfission decay phases, including prompt neutron emissions.

We successfully reproduced the experimental data of primary-fission yields, total kinetic energy, independent-fission yields, and prompt neutron emissions for a neutron-induced fission of ^{235}U. The calculated prompt neutron emission multiplicity is shown in Fig. 1; it reproduces the sawtooth structure shown by experiment data.[4–6] From this calculation result, the mean number of prompt neutron emissions by one fission event is $\langle n \rangle = 2.574$, which is in good agreement with the experimental result of $\langle n \rangle = 2.413$.[5] We elucidated the physical mechanism of the characteristic features observed in previous experiments, such as shell properties, using our method. Additionally, we applied our calculation to two highly neutron-rich uranium isotopes, *i.e.*, ^{250}U and ^{255}U, which have not been experimentally confirmed but are important for r-process nucleosynthesis. Previous theoretical results indicate that ^{250}U exhibits a mass-asymmetric multiple-peak fission yield, whereas the neutron-rich ^{255}U shows a single peak owing to mass-symmetric fission. Our method predicted postneutron emission fragments, where ^{250}U showed a stronger neutron emissivity than ^{255}U. Our framework demonstrates high experimental reproducibility, revealing significant differences in the number of emitted neutrons after fission of neutron-rich uranium depending on the distribution of fission variables.

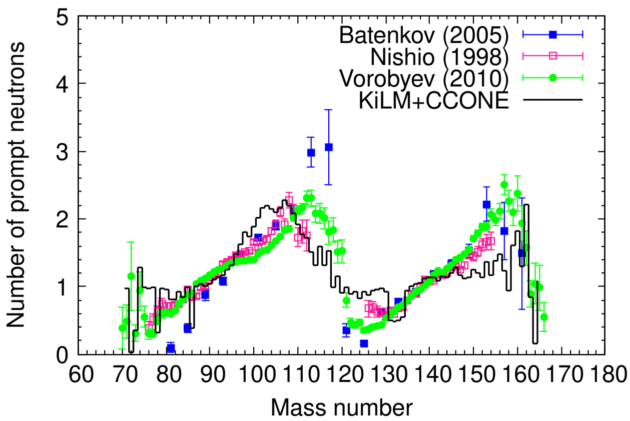

Fig. 1. Prompt neutrons multiplicities of thermal neutron-induced fission for ^{235}U. Numerical data shown using solid line (KiLM + CCONE) as function of fragment mass number are compared with evaluated data.[4–6]

References

1) S. Tanaka *et al.*, Phys. Rev. C **100**, 064605 (2019).
2) O. Iwamoto *et al.*, Nucl. Data Sheets **131**, 159 (2016).
3) T. Kawano *et al.*, Nucl. Phys. A **913**, 51 (2013).
4) O. A. Batenkov *et al.*, AIP Conf. Proc. **796**, 1003 (2005).
5) K. Nishio *et al.*, Nucl. Phys. A **632**, 540 (1998).
6) A. S. Vorobyev *et al.*, EPJ Web Conf. **8**, 03004 (2010).
7) O. Iwamoto *et al.*, J. Nucl. Sci. Technol. **60**, 1 (2023).

† Condensed from the article in Phys. Rev. C **108**, 054607 (2023)

*1 RIKEN Nishina Center
*2 RIKEN Astrophysical Big Bang Laboratory
*3 Department of Physics, Kyushu University
*4 Faculty of Science and Enginnering, Kindai University

DOI:10.34448/RIKEN.APR.57-191