3–1 Capturing Various Nuclear Splits in Fission

— Toward the Reduction of Radiotoxicity of Nuclear Waste —

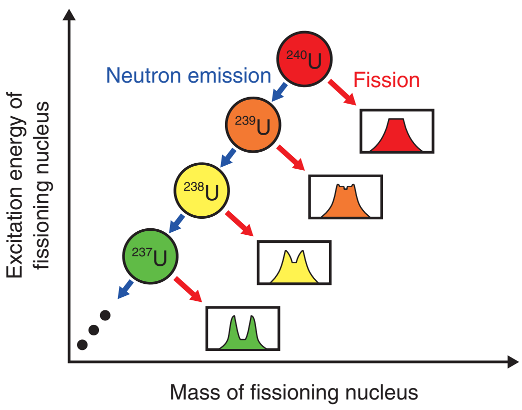

Fig.3-2 Competition between fission and neutron emission
A highly excited ^{240}U either decays via fission or produces a lower-excited ^{239}U via neutron emission. These competing processes continue until the excitation energy of the compound nucleus becomes sufficiently low. The observables in high-energy fission experiments are contributed by many nuclides that cannot be individually distinguished, which confuses the study of high-energy fission.

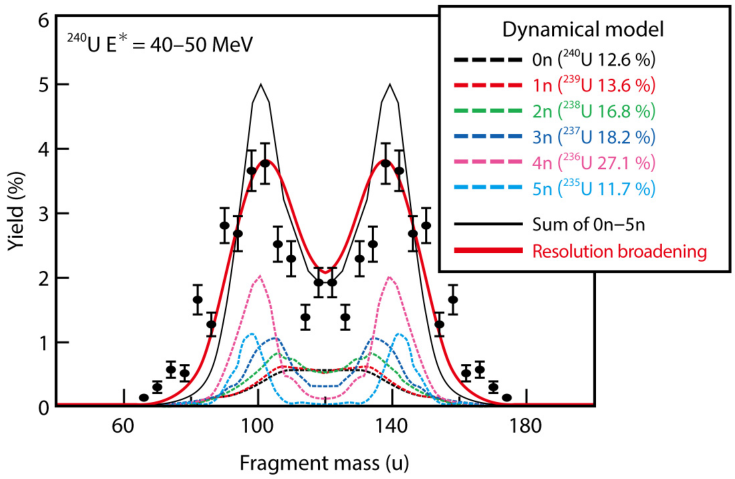

Fig.3-3 Nuclear splits in high-energy fission
The black plots show the observed nuclear splitting when a ^{240}U nucleus is produced in the excitation energy range of $E^* =$ 40–50 MeV. The spectrum is contributed by six $^{235\text{-}240}U$ nuclides produced by the emissions of 0–5 neutrons (dashed lines). These calculated fission fragment mass distributions (FFMDs) sum to the red curve, which well reproduces the experimental result.

The management of radioactive wastes, such as trans-uranium accumulating in light water reactors, is among the most urgent issues in the use of nuclear power. Some of these nuclides survive irradiation with thermal neutrons in the light water reactor but can decay via fission when bombarded with higher-energy neutrons. Under this circumstance, a fissioning nucleus has a higher excitation energy compared with a fissioning nucleus in a light water reactor. To develop a fission-based nuclear transmutation technology, fission at high excitation energies must be clearly understood.

Nuclear fission is a process of a nucleus deforming gradually and finally splits into two lighter nuclei. This process can be investigated by observing the mass balance between the two daughter fragments, the so-called fission fragment mass distribution (FFMD). However, observing the FFMDs of highly excited nuclei has been prevented by an experimental difficulty, as described later. Thus, the fission mechanism at high energies remains poorly understood.

Herein, we produced a multitude of nuclides from the $^{18}O + ^{238}U$ reaction at the JAEA tandem accelerator facility and obtained their FFMDs over a wide range of excitation energies. A nucleus with a high excitation energy decays either by fission or by neutron emission. The latter creates a different nucleus with a lower excitation energy than the initial nucleus. Fig.3-2 demonstrates the competition between fission and neutron emission for the initial ^{240}U nucleus produced with a high excitation energy. The experimentally observed FFMDs are contributed not only by the ^{240}U nucleus but also by lower-excited $^{239,\,238,\,237,\ldots}U$ nuclei. The contributions from each nuclide cannot be separated, leading to the aforementioned experimental difficulty.

In this study, we separated these contributions by combining a dynamical fission model with the neutron emission before fission. Fig.3-3 presents an example of the obtained results. The closed circles plot the FFMD of the initial highly excited nucleus ^{240}U. As shown by the dashed curve, this FFMD comprised the FFMDs of six nuclides. We present the first *pure* FFMD at high excitation energies, i.e., the FFMD of ^{240}U (black dashed curve in Fig.3-3), which will promote high-energy fission research. To further understand the fission mechanism, we are planning to conduct measurements of prompt fission neutrons together with FFMDs. Such studies will help the evaluation of as-yet unmeasured nuclear data and the development of fission-based nuclear transmutation technology.

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Reference

Hirose, K. et al., Role of Multichance Fission in the Description of Fission-Fragment Mass Distributions at High Energies, Physical Review Letters, vol.119, issue 22, 2017, p.222501-1–222501-6.