Research Group for Heavy Element Nuclear Science

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Determining the limits of stability of heaviest nuclei is the most interesting and challenging topics, and the relevant problem, i.e., nuclear fission is the core subject in nuclear physics program of our group. Our experiments also include nuclear structure studies of broad range of nuclides, in addition to super-heavy nuclei. The heavy elements open a unique opportunity for studies of relativistic effects in chemistry and atomic physics. For the chemical properties of the heaviest elements, many experimental approaches are promoted to determine the energy and orbitals of the valence electrons.

In the chemistry program in FY2019, the formation of $NbOCl_3$ and $TaOCl_3$ and their adsorption behaviour on quartz surfaces were explored by applying an isothermal gas-chromatographic method for the basic study of dubnium (Db, element 105) [1,2]. The future studies with $DbOCl_3$ under the same experimental conditions will quantify the volatility trend in Group-5 elements.

In this report, we present two results of fission studies, i.e., the effects of neutron emission from compound nucleus on the fission-fragment mass distribution (FFMD) and the measurement of high-energy prompt fission γ-ray spectrum (PFGS) in the fission of ^{235}U induced by a thermal neutron, $^{235}\mathrm{U}(n_{\mathrm{th}},f)$.

Effects of multichance fission on isotope dependence of FFMD at high energies

In our recent study [3] on the measurement of FFMDs using multinucleon transfer reactions, we reached a conclusion that the mass-asymmetric shape of the FFMD remaining at high-excitation energies is due to the multichance fission (MCF), i.e., fission after evaporation of neutrons. As excitation energy is successively lowered by multiple neutron emission, fission from higher-order fission chances tends to have a pronounced double-humped shape in FFMD due to revival of the shell effects responsible for mass asymmetry.

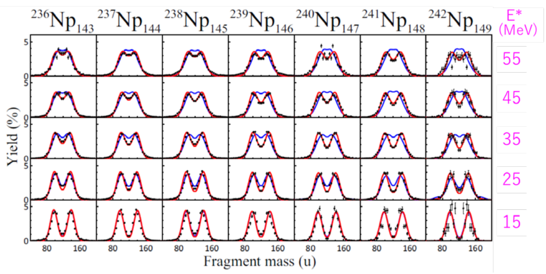

Fig.1 Fission-fragment mass distribution for neptunium isotopes (black dot with error bars). Initial excitation energy of the compound nucleus E^* is shown at the right-hand side. Solid curves are the Langevin calculations (see text).

We extended the measurement to obtain data for a wide set of nuclides. For example, FFMDs of neptunium isotopes are shown in Fig.1. We also carried out a calculation using the Langevin approaches [4]. The blue curves are the results which do not take into account the MCF. Large deviation is evident at the excitation energies $E^* \geq 35$ MeV. The results after invoking the MCF nicely reproduce all the data, showing double-peak structure even at the highest energies. Looking at exact detail, the experimental FFMDs clearly show the dependence on the isotope for $E^* > 30$ MeV, exhibiting deeper peak-to-valley ratio toward heavier isotopes. A larger number of evaporated neutrons for heavier isotopes accounts for these trends.

Effects of the nuclear structure of fission fragments on the high-energy prompt fission γ-rayspectrum in $^{235}\mathrm{U}(n_{\mathrm{th}},f)$

We have measured the PFGS in $^{235}\mathrm{U}(n_{\mathrm{th}},f)$ by significantly extending the high-energy limit of E^* to about 20 MeV, in contrast to ~ 7 MeV in literature (see Fig.2) [5]. This was achieved by the high-efficiency setup consisting of large volume $LaBr_3$(Ce) scintillators and compact fission-fragment detectors.

We compared our data with a statistical Hauser-Feshbach model calculation to find the origin of high-energy γ-rays. Here, we adopted a fission model which can reproduce experimental data on the average properties of neutron and γ-ray emissions in order to calculate the initial excitation-energy and spin distributions of primary fission fragments (FFs) [3]. The solid curve in Fig. 2 is the results of the calculation, where available experimental data on low-lying nuclear levels of the FFs are used.

In this analysis we found that dominant contributions to the spectrum at $E_\gamma > 10$ MeV are given only by specific FFs, such as ^{86}Br, ^{102,103}Nb , and ^{109}Tc , known as having low-lying high-spin states which open the γ-ray transition from high-energy and high-spin states of primary FFs. Significant underestimation of the spectrum at $E_\gamma > 14$ MeV suggests the presence of neutron-rich nuclei whose low-lying high-spin states are not found yet.

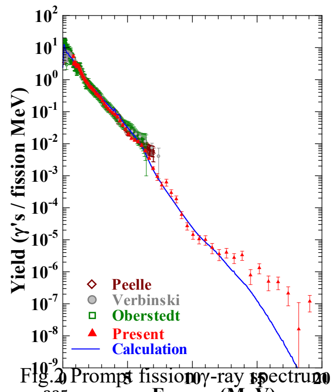

Fig.2 Prompt fission γ-ray spectrum in $^{235}\mathrm{U}(n_{\mathrm{th}},f)$.

References

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