Study of change in neutron-skin thickness in the spontaneous fission of U isotopes

Manpreet Kaur[1],* D. Choudhury[1], and S.K. Patra[2]
[1]Department of Physics, Indian Institute of Technology Ropar, Rupnagar - 140001 and
[2]Department of Physics, Siksha 'O' Anusandhan, Bhubaneswar-751030

Introduction

Exploration of different decay modes of nuclei such as alpha decay, cluster radioactivity, fission, etc. unravel the underlying nuclear structure information. Among these different decays, the spontaneous fission (SF) is of interest being a significant decay mode for nuclei heavier than Th. It plays a crucial role in determining the stability of heavy nuclei and subsequently influences the limit on the number of new elements that can exist. Additionally, studying SF offers insights into the fission process without external excitation energy, making it a valuable tool for exploring the role of shell effects and subtle changes in the nuclear structure of both the fissioning nucleus and the fission fragments [1].

The neutron-skin thickness of atomic nuclei is a fundamental property of nuclear structure. It is correlated with the slope of the symmetry energy, which is further linked to the pressure of neutron matter at the saturation density [2]. Besides, the neutron-skin thickness exhibits correlation with the electric dipole polarizability, the isoscalar giant dipole resonance, and the pygmy resonances [3]. In the present work, we intend to investigate any possible effect of neutron-skin thickness in the spontaneous fission, which is dominated by the shell effects and the released energy. For this, we analyze the change in the neutron-skin thickness from parent nucleus to the fission fragments in the SF of even-even isotopes of $^{234-244}U$ nuclei. Here, we use the relativistic mean field (RMF) model [4] to determine the neutron-skin thickness of U nuclei. The probability of formation of different probable fission fragments has been calculated within the preformed cluster-decay model (PCM) [5].

*Electronic address: manpreetphys@gmail.com

Formalism

The RMF model based Lagrangian with the IOPB-I parameter set [4] is used in the present work. From the relativistic Lagrangian, the field equations for the nucleons and mesons are obtained. These equations are solved by expanding the Dirac spinors and the boson fields in a deformed harmonic oscillator basis with an initial deformation. The set of coupled equations is solved numerically by a self-consistent iteration method to obtain the nuclear density, root mean square radii, etc.

The PCM [5] uses the collective coordinates of mass asymmetry (η) and charge asymmetry based on the quantum mechanical fragmentation theory. The cluster preformation probability P_0, which refers to η-motion, is given by

$$P_0(A_i) = \mid \psi(\eta(A_i)) \mid^2 \frac{2}{A}\sqrt{B_{\eta\eta}}$$

It is obtained as the solution of Schrödinger equation in η co-ordinate. Here, $B_{\eta\eta}$ is the hydrodynamical mass parameter [6].

Results and discussion

Fig. 1 shows the change in the neutron-skin thickness from the parent nuclei to the fission fragment (δ_n) in the SF of even-even $^{234-244}U$ nuclei. We have chosen some of the more probable fission fragments in the spontaneous fission. Fig. 1(a) shows taht in the case of ^{234}U, the δ_n is minimum for the fissioning channel ^{100}Zr+^{134}Te, compared to other fission fragments ^{102}Mo+^{132}Sn and ^{104}Mo+^{130}Sn. Similarly, in the decay of ^{236}U and ^{238}U nuclei, ^{102}Zr+^{134}Te and ^{104}Zr+^{134}Te fission fragments are accompanied by the least change in the δ_n. Fig. 1(b) displays that for the ^{108}Mo+^{132}Sn,

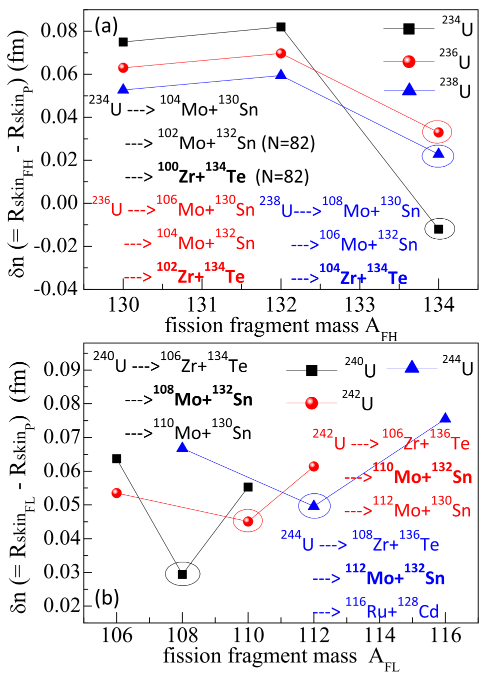

FIG. 1: Change in the neutron-skin thickness from parent nuclei to either of the fission fragment (δn) as a function of fission fragment mass in the decay of (a)$^{234,236,238}U$ (b)$^{240,242,244}U$. The fission fragments for which the δn is minimal are encircled.

^{110}Mo+^{132}Sn, and ^{112}Mo+^{132}Sn (shown encircled) fission fragments in the spontaneous decay of ^{240}U, ^{242}U and ^{244}U, respectively, there is a minimal change in the δ_n.

Further, the preformation probability of the different fission fragments in the decay of even-even isotopes of $^{234-244}$U is shown in Fig. 2. In the case of ^{234,236}U (see Fig. 2(a)), the maxima in the preformation profile corresponds to ^{134}Te (N = 82) (with complimentary fission fragment) instead of ^{132}Sn , which is doubly magic with Z = 50 and N = 82. On the other hand, in the case of ^{240,242,244}U, the ^{132}Sn with the complimentary fission fragment is the most probable. It is interesting to note that the fission fragment for which the change in neutron-skin thickness δ_n is minimal corresponds to the fission fragment having the highest P_0 value. It portrays that in addition to shell effects the change in the neutron-skin thickness also affects the spontaneous decay of U isotopes. It also suggests a correlation

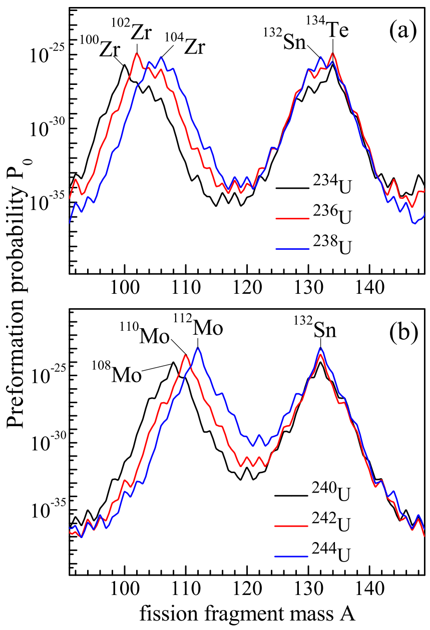

FIG. 2: Probability of preformation (P_0) of different fission fragments in the spontaneous decay of (a)$^{234,236,238}U$ (b)$^{240,242,244}U$ nuclei.

between the change in the neutron-skin thickness δ_n and preformation probability P_0 in spontaneous fission. Further, to explore the effect of the change in the neutron-skin thickness upon the spontaneous decay half-lives is under progress. Detailed results will be presented during the symposium.

Acknowledgment

M.K. acknowledges the support of SERB, New Delhi for NPDF vide no. PDF/2021/003191. D.C. acknowledges the support from the SERB-DST India under CRG (CRG/2022/005439).

References

[1] G. N. Flerov, K. A. Petrzhak, PR **58**, 89 (1940); PR **92**, 907 (1953).
[2] M. Kaur, S. K. Patra, P. K. Raina, JPG: NPP **51**, 065108 (2024); X. Roca-Mazza, PRL **106**, 252501 (2011).
[3] A. Carbone et al., PRC **81**, 041301(R) (2010); PRC **77**, 061304(R) (2008).
[4] B. Kumar, S. K. Patra, B. K. Agrawal, PRC **97**, 045806 (2018); M. Kaur et al., NPA **1000**, 121871 (2020).
[5] S. K. Arun et al., PRC **79**, 064616 (2009).
[6] H. Kröger, W. Scheid, JPG **6**, L85 (1980).