Effect of collective enhancement in level density in the fission of pre-actinides

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Fission fragment angular distributions for three reactions, ^{19}F + ^{182}W, ^{19}F + ^{187}Re, and ^{19}F + ^{193}Ir, are measured in the laboratory energy range of 82–120 MeV. Extracted fission cross sections of the present systems as well as those of three others from literature (^{19}F + ^{192}Os, ^{19}F + ^{194}Pt, and ^{19}F + ^{197}Au) are compared with the predictions of a statistical model which takes into account the effects of shell, orientation degree of freedom, and collective enhancement in level density (CELD). In all the cases, the standard statistical model predictions overestimate the measured fission cross section, indicating the presence of some amount of dynamical effects in the exit channel. A dissipation strength of 2×10^{21} s^{-1} is found to be sufficient to reproduce the data of all the reactions. No scaling of fission barrier height to fit the data is required.

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I. INTRODUCTION

The fission cross section of heavy-ion-induced fusion reactions, leading to compound nuclei (CN) in the pre-actinide region, is the outcome of competing decay mechanisms of fission and (mostly) neutron evaporation and hence is a sensitive tool for studying the fission process. A reduction in fission barrier height, or fission enhancement, is usually required in the standard statistical model (SM) calculations in order to reproduce the experimental fission (σ_{fis}) or evaporation residue (ER) (σ_{ER}) cross sections [1–7]. This, however, is in contrast with the fission hindrance found necessary to explain the multiplicity of prescission neutrons (ν_{pre}) in similar reactions [8–14]. This clearly calls for further experimental and theoretical investigations.

In the present work, we investigate the de-excitation of six pre-actinide CN, viz., $^{201}_{83}$Bi, $^{206}_{84}$Po, $^{211}_{85}$At, $^{212}_{86}$Rn, $^{213}_{87}$Fr, and $^{216}_{88}$Ra formed by ^{19}F-induced reactions. Fission fragment (FF) angular distributions and σ_{fis} of the three reactions (^{19}F + ^{182}W, ^{19}F + ^{187}Re, and ^{19}F + ^{193}Ir forming the CN $^{201}_{83}$Bi, $^{206}_{84}$Po, and $^{212}_{86}$Rn, respectively) are measured presently. The σ_{fis} of the other three reactions (^{19}F + ^{192}Os, ^{19}F + ^{194}Pt, and ^{19}F + ^{197}Au forming the CN $^{211}_{85}$At, $^{213}_{87}$Fr, and $^{216}_{88}$Ra, respectively) are taken from the literature [15–20] and included here for analysis.

II. EXPERIMENTAL DETAILS

A ^{19}F beam, in the laboratory energy (E_{lab}) range of 82–120 MeV, from the 15UD Pelletron accelerator of IUAC, New Delhi, is bombarded onto three isotopically enriched targets ^{182}W (70 μg/cm^2), ^{187}Re (60 μg/cm^2), and ^{193}Ir (80 μg/cm^2) with ~25 μg/cm^2 thick $^{\mathrm{nat}}$C backing. FFs are detected by nine hybrid telescope (E-ΔE) detectors [21], mounted on the rotatable arms of the general purpose scattering chamber (GPSC), with large angular coverage $\theta_{\mathrm{lab}} = 41$–$170^\circ$. Each telescope consists of an ionization chamber (IC) followed by a silicon detector (E). The isobutane gas pressure at each ΔE is kept at 68 mbar. Two passivated implanted planar silicon detectors are mounted at a laboratory angle (θ_{lab}) of 10° with respect to the beam direction, in the horizontal plane, for monitoring the beam and absolute normalization of cross sections. The schematic of the experimental set up and other details can be found elsewhere [22].

III. RESULTS

FFs are unambiguously distinguished from the other reaction products based on energy loss and residual energy. Measured angular distributions are transformed to the center-of-mass (c.m.) frame of reference by assuming symmetric mass division and using the Viola systematics [23] for FF kinetic energies. The FF angular distributions in the c.m. frame of reference, $\frac{d\sigma_{\mathrm{fis}}}{d\Omega}(\theta_{\mathrm{c.m.}})$ thus obtained, are fitted by the exact theoretical expression for the angular distribution function $[W(\theta_{\mathrm{c.m.}})]$ as described in Ref. [22]. Figure 1 shows the experimental FF angular distributions along with the fitted curves for ^{19}F + ^{182}W. Experimental angular anisotropy (A_{exp}) is obtained from the ratio $\frac{W(180^\circ)}{W(90^\circ)}$.

The reliability of the capture ℓ distribution used in our subsequent analysis is verified by reproducing the experimental capture excitation functions of ^{19}F + ^{182}W, ^{19}F + ^{192}Os, ^{19}F + ^{194}Pt, and ^{19}F + ^{197}Au reactions (Fig. 2). The data are fitted by the coupled-channels code CCFULL [25]. The deformation parameters used in coupled-channels calculation are taken from standard tables [26–28]. For each odd-mass target, deformation parameters and energy of the first 2^+ excited state are approximated by averaging the corresponding values in neighboring even-even nuclei. The low-lying inelastic states of ^{19}F are also included in the calculation. Potential parameters, i.e., depth V_0, radius r_0, and diffuseness a, are obtained

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