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Study of fission timescale using dynamical model

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Introduction

The fission time scale measures the time required for the excited compound nucleus (CN) to reach the scission point from the ground state configuration [1]. Further, this study provides a deep understanding of the fission dynamics of CN. Conventionally, the fission time scales can be deduced from the measured pre-scission particle multiplicities, specifically neutrons [1–3]. These nuclear techniques indicate the short fission lifetimes within the range of $\sim 10^{-21}s$ to $10^{-20}s$ [1, 3]. However, fission time-scales also could be obtained using direct techniques such as crystal blocking technique and measurement of K-vacancy production sensitive to long lifetimes in the order of $10^{-18}s$ [4]. Given the wide range of fission time scales obtained from various approaches, we have applied the one-dimensional Langevin dynamical model [5] to comprehend the fission lifetime in [4]. We extended our previous study [4] to investigate the correlation between the lifetime of a nucleus and its mass number across a wide range of nuclei.

The model

A stochastic one-dimensional Langevin approach is utilised to study the complete dynamical evolution of an excited compound system. The details of the model can be found in [4,5]. In this work, the reduced friction parameter (β) is considered as a free parameter to fit the experimental neutron multiplicities. A huge number of Langevin trajectories 10^6 are considered to reduce the statistical uncertainties. For each event, fission dynamics is followed numerically up to 10^{-15} s with a time-step of 10^{-25} s. At each time step, the evaporation of light particle (n, p, α) and GDR $\gamma-$ray are sampled with the Monte Carlo technique. The Weiskopf statistical model is employed to calculate the widths for these evaporation channels. During the dynamical evolution, a Langevin trajectory is determined as a fission event when it reaches the scission configuration: $c_s = 0.3\ R_0$ (R_0 being the spherical nucleus radius). For each fission event, fission time is evaluated with associated neutron evaporation fission channels.

TABLE I: Details of the reactions.

CN	E^* (MeV)	ν_{pre} (Exp.)	ν_{pre} (Cal.)	β (MeV/$\hbar$)	Ref.
^{187}Ir	120.80	3.70±0.30	4.03	2	[1]
^{203}At	72.5	2.54±0.23	2.5989	5	[2]
^{243}Am	54.1	1.35±0.14	1.4312	0.5	[3]

Results and Discussion

The details of the reaction channels chosen for the present work are given in table I. In the 1D Langevin model, β values are adjusted for each reaction to reproduce the experimental pre-scission neutron multiplicity. Simultaneously, fission yields associated with each neutron evaporation are calculated. In Fig. 1, 2, and 3, the fission yield distributions (upper panel) for ^{187}Ir, ^{203}At and ^{243}Am are shown as a function of fission time. Three different kinds of distributions are observed. For the ^{187}Ir, the fission time distribution has a peak around 10^{-20} s with a small non-vanishing tail up to 10^{-16} s. Further, the (τ_f) (fission time) distribution for

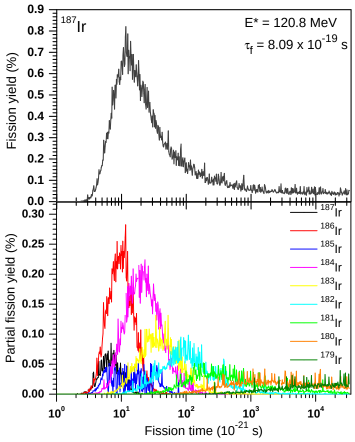

FIG. 1: Fission yield distribution (upper panel) and partial fission yield for neutron evaporation (lower panel) as a function of time for ^{187}Ir.

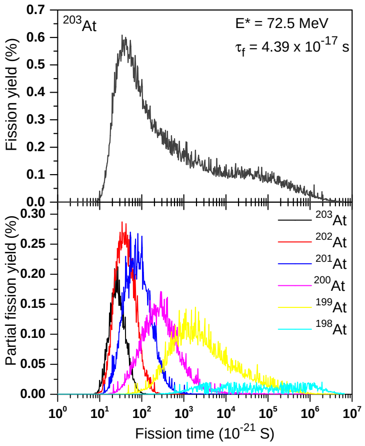

FIG. 2: Same as Fig. 1 for ^{203}At.

^{203}At has a broader width with a peak around 10^{-19} s and has a considerably longer bump - like tail up to maximum dynamical time. Conversely, ^{243}Am shows a broad peak with a shorter fission lifetime $\sim$ 10^{-20} s as it is heavy nucleus and highly fissile. Further, to understand the behaviour of (τ_f), the partial fission yields form each neutron evaporation for ^{187}Ir, ^{203}At and ^{243}Am is shown in Fig. 1,2 and 3 (lower panels). For ^{187}Ir, the partial yield of the first two neutron evaporation channels contributes to the peak around the 10^{-20} s. Because of the higher excitation energy of CN, the higher neutron evaporation channels have considerable yield, which is responsible for the non-vanishing tail in fission time distribution. For each neutron evaporation, the E^* around $8-10$MeV can be reduced from the initial E^* which makes the fission process slower. Further, it can influence the average fission timescale and also the shape of the time distribution curve. Hence, the average fission lifetime $\sim$ 10^{-19} s is obtained. The bump-like structure in fission time distribution for ^{203}At is mainly contributed by 4^{th} and 5^{th} neutron evaporation partial yields. In addition, the longer average τ_f of the order of $\sim 10^{-17}$ s is obtained. In contrast, the broad-peak structure for ^{243}Am is substantially contributed by 3^{rd} neutron evaporation gives very short (τ_f) $\sim 10^{-20}$ s.

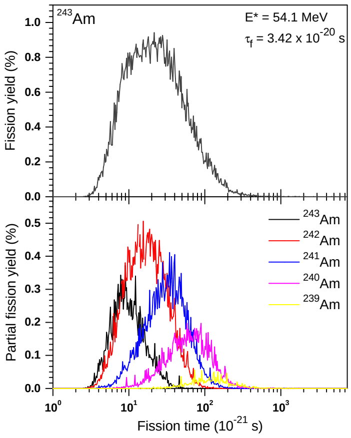

FIG. 3: Same as Fig. 1 for ^{243}Am

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