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Evaporation channel as a tool to study fission dynamics

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Abstract

The dynamics of the fission process is expected to affect the evaporation residue cross section because of the fission hindrance due to the nuclear viscosity. Systems of intermediate fissility constitute a suitable environment for testing such hypothesis since they are characterized by evaporation residue cross sections comparable or larger than the fission ones. Observables related to emitted charged particles, due to their relatively high emission probability, can be used to put stringent constraints on models describing the excited nucleus decay and to recognize the effects of fission dynamics. In this work model simulations are compared with the experimental data collected via the $^{32}S + {}^{100}Mo$ reaction at $E_{lab} = 200$ MeV. Consequently we pointed out, exploring an extended set of evaporation channel observables, the limits of the statistical model and the large improvement obtained with a dynamical model. Moreover we stress the importance of using an apparatus covering a large fraction of 4π to extract observables. Finally, we discuss the opportunity to measure more sensitive observables by a new detection device in operation at LNL.

Keywords: ^{132}Ce; Fusion-evaporation; Fusion-fission; Statistical model; 3-D Langevin equations

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1. Introduction

Since the discovery of nuclear fission in 1939 [1,2], a large effort was devoted to provide a realistic description of this complex phenomenon originated by the interplay of macroscopic and microscopic degrees of freedom in a nucleus. With the advent of heavy-ion accelerators the study of fission was extended to a new variety of nuclei produced in few-nucleon direct transfer reactions [3,4] or in complete fusion reactions (as in recent works [5,6]). And more recently new detailed information has been obtained in a study on fissioning systems at high excitation energies and low angular momenta produced in inverse kinematics by means of spallation reactions [7]. Toward heavier mass region the quasi-fission process suddenly appears and becomes the main antagonist to the fusion and consequently to the formation of Superheavy elements (see the reviews [8,9]).

It is well established that fission is a slow process dominated by nuclear viscosity [10,11]. A very striking experimental evidence of this behavior is the excess of pre-scission light particles with respect to the predictions of the Statistical Model (SM), and its dependence on the excitation energy [12–14]. Phenomenological studies based on the SM predictions were carried out with the aim to estimate the fission delay time, and, in some cases, to extract the strength of nuclear viscosity. The estimates given by different authors predict a quite wide range of dissipation strengths and different dependencies on temperature and deformation (see reviews [15–17] and references therein). However, this kind of approach is founded on the reliability of the SM to reproduce the observables in the evaporation residue (ER) channel, and this has not yet been fully explored.

The lack of experimental constraints to the SM appears to be, in several cases, one of the sources of controversial results. Indeed, the limits of this model have been evidenced by considering a large set of observables [18,19]. Dynamical models based on a stochastic approach combined with an evaporative model, for light particles and gamma quanta, seem to be a more suitable tool for the description of the collective evolution of excited nuclei [20,21]. Although much work has been devoted to fission dynamics, there are still many open questions: the time-scale, the strength and nature of dissipation, the dependence on the temperature and shape of the fissioning system.

The dynamics of the fission process is expected to affect the evaporation residue channel because of the fission hindrance due to nuclear viscosity. For this reason, the study of the evaporation residues channel can play a very important role. Systems of intermediate fissility constitute a suitable environment for measuring potentially informative observables related to the ER channel, being characterized by higher probability for charged particle emissions and integral ER cross section comparable with the fission one. In order to address fission dynamics such advantages were largely exploited by using as probes the light particles [22] and, only recently, by using the fission-fragment charge distribution [23]. However in order to fruitfully benchmark the existing models, the experimental uncertainties have to be minimized. Thereby larger angular coverage apparatuses are an essential add-on to step forward.

Here we report on the analysis of the evaporation and fission decays of ^{132}Ce compound nuclei at $E_x = 122$ MeV, produced by the 200 MeV ^{32}S + ^{100}Mo reaction. For this system, ER and fusion-fission (FF) angular distributions and cross sections, light charged particle (LCP) multiplicities and spectra as well as ER-LCP angular correlations were measured in several experiments [18,24]. The measured quantities were compared with the SM calculations, carried out by changing many physical ingredients of the model, and with calculations of a Dynamical Model (DM) based on the 3-D Langevin equations. We found that the ER observables, especially