Fission dynamics in ^{132}Ce composite nuclei: study within a stochastic approach

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INTRODUCTION

It is well known that nuclear viscosity plays a fundamental role in the fission process [1-3]. Although much experimental and theoretical work has been devoted to this subject, many questions still remain open. They mainly refer to a precise determination of the fission time scale as well as to the nature of the dissipation. At issue is whether nuclear dissipation proceeds primarily by means of individual two-body collisions (two-body friction), as in the case of ordinary fluid, or by means of nucleons colliding with a moving potential wall (one-body friction).

The modified statistical model as well as dynamical models [4-8] based on the Lagrange, Fokker Planck and Langevin equations have been used in order to gain insight on these aspects of fission dynamics. The lack of constraints to the models appears to be, in several cases, the main source of controversies.

In this framework, we are carrying on a research program with 8πLP apparatus at LNL, aimed at studying the fission dynamics in systems of intermediate fissility. These systems, compared to the heavier ones, have larger prescission charged particle multiplicities as well as comparable fission and evaporation residue (ER) cross sections. Therefore, the measurements of the relevant quantities in both channels allow to put severe constraints on the models, providing more reliable estimates of fission delay and of viscosity parameter.

We report on the system ^{32}S + ^{100}Mo at E_{lab}=200 MeV which produces the composite system ^{132}Ce at E_x=122 MeV. The analysis of the pre-scission charged particles was already described in a previous report [9]. We have proceeded in the analysis of this system extracting the charged particle multiplicities in the ER channel as well as the ER and fission cross sections. The whole set of extracted quantities has been compared with the predictions of a dynamical model based on the Langevin equation.

The experiment was performed at the XTU Tandem-ALPI Superconducting LINAC accelerator complex of the Laboratori Nazionali di Legnaro. We used the BALL and the WALL section of the 8PLP apparatus to detect light charged particles. Fission fragments were detected in the telescopes of two rings of the BALL section. Evaporation residues have been detected by mean of four Parallel Plate Avalanche Counter modules (PPAC). Each one covers a forward angle of 2.5° and 7.5°. Evaporation residue and fission cross sections were measured by means of the electrostatic deflector of LNL coupled to the double-arm TOF spectrometer CORSET, as described in [10].

EVAPORATION RESIDUE CHANNEL

In figs. 1 and 2 we show, as solid points, the multiplicity angular distribution of protons and alpha particles, detected in coincidence with one of the PPAC versus the identification number of the BALL detectors.

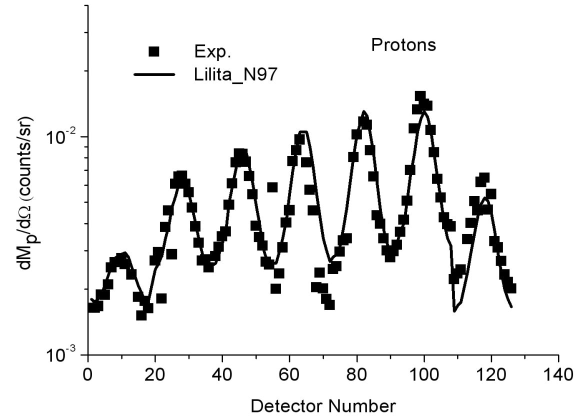

FIG. 1: comparison between experimental and theoretical angular multiplicity distributions for protons.

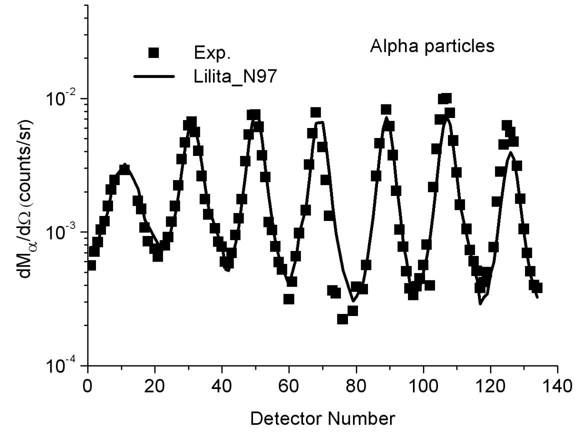

FIG. 2: comparison between experimental and theoretical angular multiplicity distributions for alpha particles.

The predictions of the statistical model, as implemented in the code Lilita_N97 [11] are also shown in the figure as solid lines; they have been normalized to the data. The same normalization factor allows to reproduce the observed behaviour resulting from the different correlation angles with respect to the trigger detector, for both protons and alpha particles. The integrated proton and alpha particle multiplicities have been obtained from the theoretical values, scaled by the normalization factor. These values are reported in Table 1 together with the fission and the ER cross-sections as well as with the pre-scission particle multiplicities.

	ER channel		Prescission channel			
	M_p	M_α	M_p	M_α	σ_{FF} (.mb)	σ_{ER} (mb)
Exp.	**0,91 ± 0.15**	**0,56 ± 0.09**	**0,055 ± 0,007**	**0,038 ± 0,005**	**70 ± 7**	**576 ± 50**
Theor.	**0.82**	**0.58**	**0.050**	**0.020**	**61**	**597**

TAB. 1*: Measured proton and alpha particles multiplicities in the ER and pre-scission channels and fission and ER cross sections, for 200 MeV $^{32}S + ^{100}Mo$ reaction. The predictions of a dynamical model [12] are also reported.*

DYNAMICAL MODEL CALCULATIONS

In this section we briefly describe the physics underlying the dynamical model [12] used in this study and the results obtained for our system. In a deterministic approach of fission, evolution of collective coordinates, describing the shapes of the nucleus towards fission, are governed by the conservative and frictional forces. The first ones are usually derived from macroscopic models. The second ones, which removes energy from the relative motion and transfer it to internal excitations; can be derived assuming one or two-body dissipation. As suggested by Kramer [13], collective variables fluctuates because of their coupling to the intrinsic degrees of freedom and can be considered as motion of Brownian particles that interact stochastically with a large number of internal degrees of freedom, constituting the surrounding heat bath. These fluctuations can be simulated, within a stochastic approach, using the Langevin equation, where a random force is added to the classical equation of motion. The strength of this force is related to the friction coefficient and the nuclear temperature.

In the dynamical model used in the present work, three geometrical shape parameters were chosen as collective coordinates [12]. The potential energy of the nucleus was calculated within the framework of a macroscopic model with finite range of the nuclear forces [14]. The inertia tensor is calculated by means of Werner-Wheeler approximation for incompressible irrotational flow [15]. A modified one-body mechanism of nuclear dissipation [16] has been used for determination of the dissipative part of the driving forces. In particular, friction tensor has been calculated on the basis of the wall-and-window dissipation formula, where the contribution from the wall formula has been modulated by the reduction coefficients k_s. In order to have a realistic treatment of particle evaporation in the ER and pre-scission channels, Lilita_N97 code has been linked to the dynamical model one.

Calculations have been carried out for different values of k_s; assuming different prescriptions of transmission coefficients and level densities for particle evaporation. The model is able to reproduce most of the measured quantities, assuming a reduction coefficient k_s=0.5. This value, which is consistent with the systematics, implies sizable transient times for fission, ranging from 15 to 20 x10^{-21} s at high angular momenta of the composite system, where fission is relevant.

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