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LISE++ development: Application to projectile fission at relativistic energies

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Abstract. A new model of fast analytical calculation of fission fragment transmissions through a fragment separator has been developed in the framework of the code LISE++. In the development of this new reaction mechanism in the LISE++ framework it is possible to distinguish the following principal directions: kinematics of reaction products, production cross-section of fragments, spectrometer tuning to the fragment of interest to produce maximal rate (or purification).

PACS. 25.70.De Coulomb excitation – 25.85.-w Fission reactions – 07.05.Tp Computer modeling and simulation – 29.30.-h Spectrometers and spectroscopic techniques

1 Introduction

The program LISE++ [1,2] calculates the transmission and yields of fragments produced and collected in a fragment separator at medium- and high-energy facilities (fragment- and recoil-separators with electrostatic and/or magnetic selections). The projectile fragmentation and fusion-evaporation [3], assumed in this program for the production reaction mechanisms, allows one to simulate experiments at beam energies above the Coulomb barrier. The LISE++ code operates under the MS Windows environment and provides a highly user-friendly interface. It can be freely downloaded from the following internet addresses: `www.nscl.msu.edu/lise` or `http://dnr080.jinr.ru/lise`.

Further development of the program is directed towards high energies, and involves other types of reactions. High-energy secondary-beam facilities such as GSI, RIA, and RIBF provide the technical equipment for a new kind of fission experiments. The advantage of inverse kinematics for the electromagnetic excitation mechanism and for the detection of the short-lived fission fragments has been demonstrated in several experiments with relativistic ^{238}U primary projectiles at GSI [4]. Therefore a new model of fast analytical calculation of fission fragment transmission through a fragment separator, a fast algorithm for calculating fission fragment production cross-sections have been developed in the framework of the code LISE++.

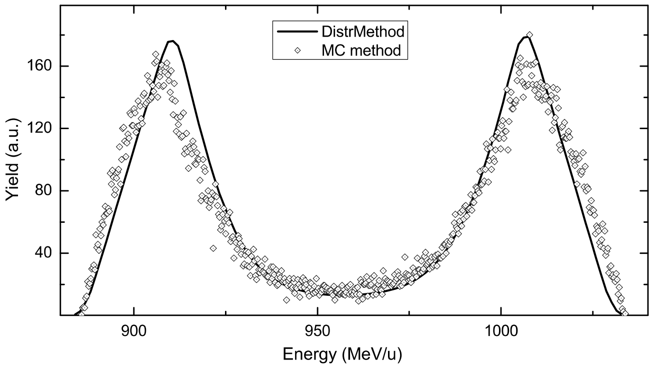

Fig. 1. Calculated energy distributions of ^{128}Te in the fission of ^{238}U(1 GeV/u) on a lead target (1 mm). Angular acceptances: $H = \pm 12$ and $V = \pm 15$ mrad, beam angular emittances: $H = \pm 3$ and $V = \pm 3$ mrad. Calculated transmissions by DistrMethod and MCmethod are equal to 32.6% and 33.9%, respectively.

2 Fission fragment kinematics at intermediate and high energies

The kinematics of the fission process is characterized by the fact that the velocity vectors of the fission residues populate a narrow shell of a sphere in the frame of the fissioning nucleus. The radius of this sphere is defined by the Coulomb repulsion between both fission fragments. In the case of reactions induced by relativistic heavy ions, the transformation into the laboratory frame leads to an ellipsoidal distribution which will characterize the angular distribution of fission residues [5]. Only forward and

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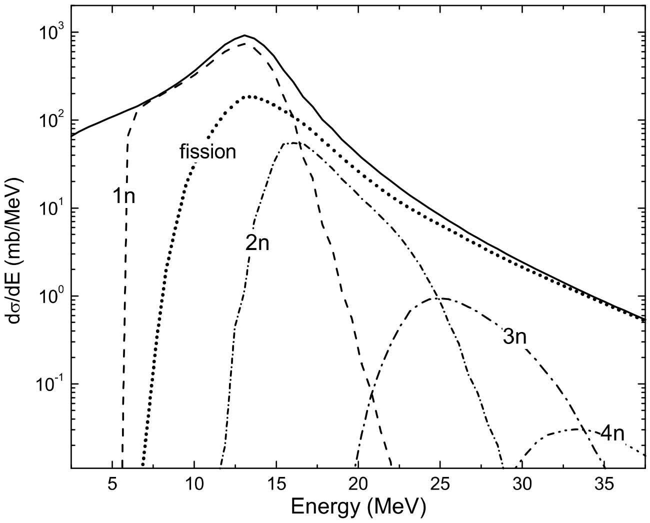

Fig. 2. The differential cross-section of electromagnetic excitation in ^{238}U on a lead target at 920 MeV/u (solid curve). De-excitation channels for excited ^{238}U nuclei as a function of excitation energy are denoted by letters in the figure.

backward cups of the sphere, defined by the angular acceptance of the fragment separator, are transmitted, and the longitudinal projections of their velocity distributions are shaping the two peaks (see fig. 1). Two different methods for fission fragment kinematics are available in LISE++:

- MCmethod (Monte Carlo) has been developed for a qualitative analysis of fission fragment kinematics and utilized in the Kinematics calculator.
- DistrMethod is the fast analytical method applied to calculate the fragment transmission through all optical blocks of the spectrometer.

In order to calculate the kinematics of the final fission fragment, the code looks for the most probable excited fragment for a given final fragment. For more detail information about LISE's fission fragment kinematics models use the LISE code sites. Calculated energy distributions for both models of ^{128}Te in the fission of ^{238}U(1 GeV/u) on a lead target are shown in fig. 1.

3 Coulomb fission fragment production cross-sections

Calculations of fission fragment cross-sections consist of three sequential steps. The average electromagnetic excitation and the total fission cross-section are calculated at the first stage. The electromagnetic excitation cross-section calculation (see fig. 2) is based on work of C.A. Bertulani [6] and the LisFus evaporation model [3] assuming that the reaction takes place in the middle of the target.

Statistical parameters (mean value $\langle E^* \rangle$, and area σ^f) of the de-excitation fission function $\mathrm{d}\sigma^f/\mathrm{d}(E^*)$ are used in the next stage to calculate an initial fission cross-section matrix of production cross-sections excited fragments using the semi-empirical model [7] based on a version of the abrasion-ablation model. This model describes the formation of excited prefragment due to the nuclear collisions and their consecutive decay. The model has some similarities with previously published approaches [8,9], but in contrast to those, Benlliure's model describes the fission properties of a large number of fissioning nuclei are a wide range of excitation energies. The macroscopic part of the potential energy at the fission barrier as a function of the mass-asymmetry degree of freedom has been taken from experiment [9]. Post-scission nucleon emission is the final stage. The code calculates five final cross-section matrices using the initial matrix. Use of the LisFus method [3] to define the number of post-scission nucleons is a big advantage of the LISE++ code which allows one to observe shell effects in the TKE distribution, and enables the user to estimate qualitatively the final fission fragment faster. All three stages together take no more than 5 seconds in the case of low-energy fission. The LISE calculation package of fission fragment cross-sections can be used for higher excitation energy. For example, calculated mean number of evaporated nucleons, as a function of the excited fission-fragment number of neutrons in the fission of the excited nucleus ^{238}U with excitation energy equal to 30 MeV, is shown in fig. 3.

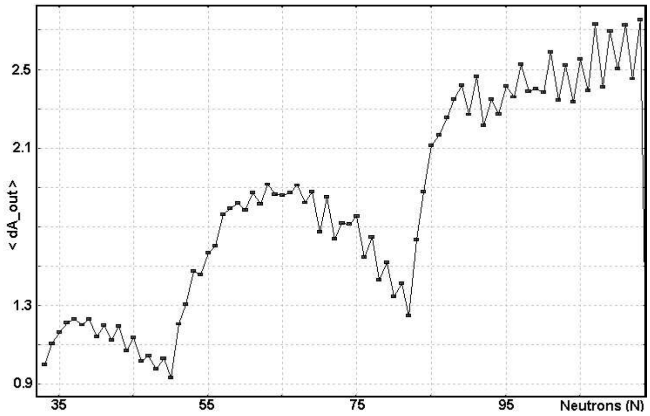

Fig. 3. Calculated mean number of evaporated nucleons as a function of the excited fission-fragment number of neutrons in the fission of the excited nucleus ^{238}U with excitation energy equal to 30 MeV.

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