Prediction of the IMF yields in spallation reactions by the statistical evaporation-fission model in ABRABLA

M. V. Ricciardi, A. Kelić, K.-H. Schmidt, GSI, Darmstadt, Germany

In the last decade, a European collaboration has successfully carried out a dedicated experimental program at the FRS at GSI, aimed to have comprehensive experimental information of the proton-induced spallation reactions. Results from the experiments on several systems (Au+ ^{1}H, Pb + ^{1,2}H, U + ^{2}H, Fe + ^{1}H, Xe + ^{1,2}H) in the energy range 0.3-1.5 GeV per nucleon were already published or are still being analyzed. Parallel to the experimental work, extensive effort has been put on the development of a simulation code, ABRABLA, capable to reproduce the experimental data. Here we report on the recent results achieved by including the emission of intermediate-mass fragments (IMF) in the evaporation-fission model.

The ABRABLA code is a statistical two-stage Monte-Carlo code that simulates both the nucleus-nucleus and the nucleon-nucleus collisions at relativistic energies assuming that the reaction can be divided in two stages. The first stage is an interaction stage, where the target nucleus loses part of its nucleons and is left in an excited state. This stage is followed by a deexcitation cascade (called "ablation", and the corresponding code "ABLA") where evaporation and fission are in competition. According to the statistical model, the probability for the evaporation of a certain particle is essentially given by the ratio of the available phase space in the daughter and in the mother nucleus. In the description of fission, the ABLA code explicitly treats the relaxation process in deformation space. The resulting time-dependent fission width is calculated using an analytical approximation to the solution of the Fokker-Planck equation. In this sense, ABLA is a dynamical code. The calculation of the fission yields is done on the basis of a semi-empirical model as described in ref. [1]. Specifically, for a given excitation energy the yield of a certain fission fragment is determined by the statistical weight of the transition states above the potential barrier, i.e. at the saddle point. This weight is in turn correlated to the density of nuclear levels. The potential energy at the saddle point depends on mass-asymmetric deformations, which lead to the formation of two fragments of different sizes. In the fission model of ABLA, the barrier as a function of mass asymmetry is defined by three components. The first is the symmetric component defined by the liquid-drop potential by means of a parabolic function with a curvature obtained from experimental data. This parabola is modulated by two neutron shells, represented by Gaussian functions. Shells are supposed to wash out with excitation energy. The heights and the widths of the Gaussians representing the shell effects and additional fluctuations in mass asymmetry acquired from saddle to scission are derived from experimental data. The above representation of the barrier as a function of mass asymmetry is valid only for the main fission region (from $Z\approx20$ to $Z\approx65$), while for very asymmetric mass splits the potential energy is expected to inverse the slope and start to decrease, as discussed in Ref. [2]. This behavior is reflected in the charge and mass distribution of the final products, as can be clearly seen in Fig. 1, where the nuclide production cross sections in ^{238}U+^{1}H at 1 GeV per nucleon are presented. The data were taken in the above-quoted experimental campaign (see Ref. [3]). As pointed out by Moretto [4], evaporation and fission should be treated as two manifestations of the same kind of binary decay with a continuous transition from one to the other. Technically, an extremely asymmetric binary split into two compact nuclei corresponds to an evaporation of a light nucleus from a heavy compound nucleus. Up to now the evaporation part of ABLA considered only the emission of light particles, specifically: neutrons, protons, tritons, deuterons, ^{3}He and alphas. In the code, we extended the evaporation to intermediate-mass fragments (IMF), i.e. to the emission of light nuclei with $Z>2$. The statistical weight for the emission of these fragments is calculated on the basis of the detailed-balance principle. The decay width as a function of the excitation energy depends on the inverse cross section on the level densities of the two daughter nuclei and on the level density of the mother nucleus above the ground state. The result of the code is in good agreement with the data, as can be seen in Fig. 1, which shows the charge distribution, and the mean value (<N>/Z) and width (FWHM) of the isotopic distributions along the entire production range.

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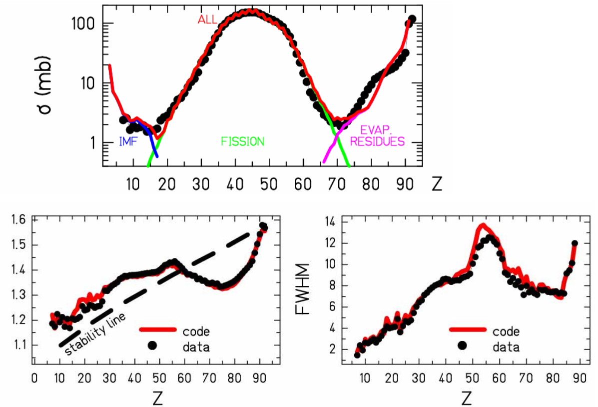

Figure 1: Cross sections for the nuclei produced in ^{238}U (1 *A* GeV) + p. The experimental data (full dots) [3] are compared with the results of ABRABLA (solid lines).

References

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