Gamma-ray and Neutron Multiplicities in Low-Energy Fission of Heavy and Superheavy Compound Systems

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Evaporation residue (EVR) formation in heavy ion fusion reactions may be viewed as a two-step process. First, an excited compound nuclei (CN) is formed in which all degrees of freedom (N/Z, energy, angular momentum, mass) are completely equilibrated. Second, its de-excitation after x neutrons and charged particles are evaporated. In other words, we are dealing with two probabilities: formation and survival. According to modern ideas, the formation probability strongly depends on the entrance channel properties such as projectile-target mass-asymmetry, target/projectile deformations, initial angular momenta, etc. The survival probability is a function of excitation energy, particle separation energies (depending on nucleonic composition of CN), and certainly individual properties of EVRs (fission barriers).

It is obvious that the lower the CN excitation energy, the higher the survival probability. Cold fusion reactions [1] with doubly magic ^{208}Pb target, or the neighboring ^{209}Bi isotope, due to the Q-value of the reaction, will lead to formation of systems with minimal possible excitation energy in the interval of E_x = 10-30 MeV. Cold fusion might be the ideal tool for synthesis of heavy and super-heavy nuclei, if it were not for the strong limitation in CN formation due to a drastic drop of formation probability for symmetric target-projectile combinations. In low-energy fusion-fission reactions this limitation manifests itself as a practically complete disappearance of symmetric fission fragments, and is attributed to the restriction of the equilibrium of the mass-asymmetry degree of freedom, leading to so-called quasi-fission.

In measurements of fission fragment angular distributions [2], in systematics of the dispersions of the fission fragment mass-energy distributions [3], and the pre- and the post-fission neutron multiplicities, [4] there are clear indications that quasi-fission is taking place. Despite a large number of experiments, unfortunately, there are no direct ways to separate products of complete fusion-fission and quasi-fission reactions and, most importantly, to obtain quantitative information. Simultaneous measurements of pre- and post-fission neutron and gamma-ray multiplicities in coincidence with the fission fragments could be extremely useful for accurate separation products of complete fusion-fission and quasi-fission reactions and a better understanding of the mechanism of compound nucleus formation.

Experiments have been performed at the K-500 Cyclotron at the Texas A&M University

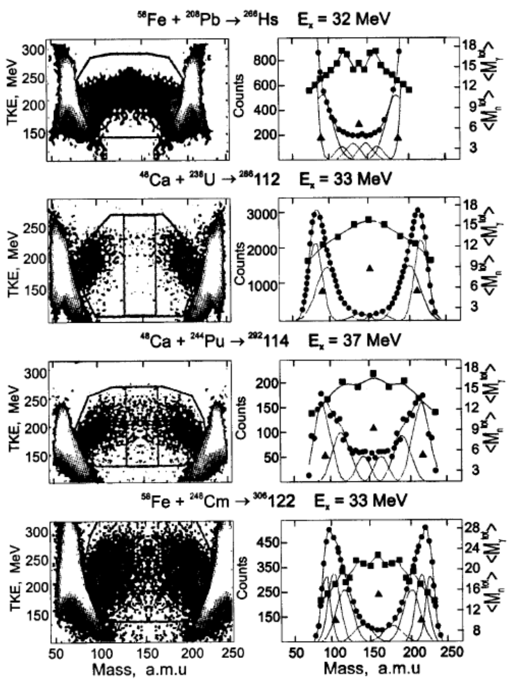

Figure 1.

Cyclotron Institute and the U-400 accelerator at the Flerov Laboratory of Nuclear Reactions, Dubna, Russia. Time-of-flight spectrometers, DEMAS-III, CORSET, and an array of 6 NaI gamma-ray detectors were used for registration of fission fragments and γ-rays. Compound systems of ^{224}Th, ^{266}Hs, ^{286}112, and ^{306}122 were formed in Ca and Fe induced reactions. Neutron multiplicities were measured with DEMON multidetector array [5].

On figure 1, two-dimensional TKE vs. mass distributions (left panel), γ-ray and neutron multiplicities as a function of fragment mass (right panel) are shown. The main difference in the presented TKE vs. mass distributions is a practically complete disappearance of symmetric fission fragments for systems with larger Z. Average total g-ray multiplicities as a function of fission fragment mass has a well-defined minimum for symmetric fission of ^{266}Hs. For the heaviest systems, there are two minimums in the range of mass numbers 86 and 134. This may be associated with the influence of closed shell near Z=50, 80, and A=134. Similar behavior in γ-ray multiplicities were observed earlier for low-energy fission of light Th isotopes [6].

In Figs. 2a and 2b, the mean of total γ-ray and neutron multiplicities as a function of compound nuclei excitation energy and atomic number are shown. For events after complete fusion-fission, γ-ray multiplicities exhibit strong growth with the excitation energies, when for the quasi-fission events this number stays practically unchanged. Similar tendencies may be observed for neutron multiplicities as a function of Z of fissioning nuclei.

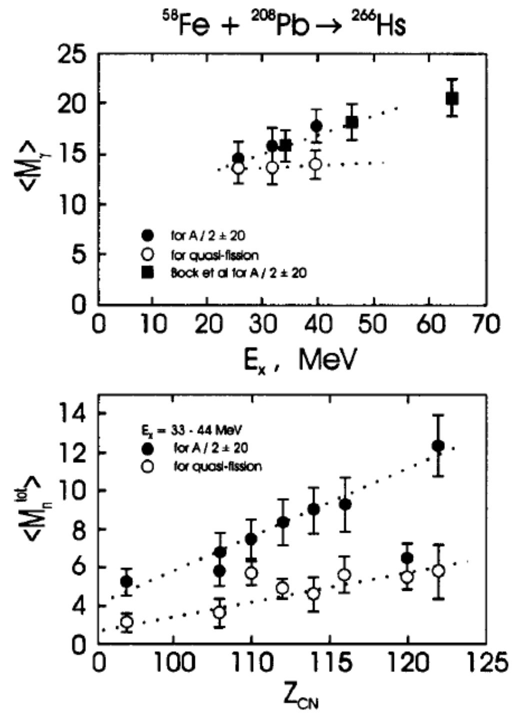

Figure 2.

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