Emission of ^{5}He and Other Particle-Unstable Fragments From Hot Yb Compound Nuclei

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Standard statistical-model calculations have serious difficulties in predicting the shape of the kinetic-energy spectra for evaporated " particles measured in fusion reactions. The experimental spectra show enhancements at low kinetic energies compared to these predictions. Such effects have been observed for a large range of compound nuclei [1-7] and have been attributed to a lowering of the average Coulomb barrier for " emission due to a large compound nucleus deformation, surface diffuseness or expansion. An alternative explanation was prroposed in Ref. [7] attributing the effect to the sequential decay of particle-unstable clusters evaporated from the compound nucleus. For example, an " particle produced by the subsequent decay of the ^{5}He fragment retains, on average, only 80% of the ^{5}He kinetic energy. Therefore these " particles will, on average, have lower kinetic energies than the directly evaporated " particles. Statistical-model calculations including the evaporation of these fragments were found to account for a significant fraction, if not all, of the low-energy " particles needed to reproduce the "-particle energy spectra measured in Ni+Mo reactions.

In an experiment to investigate this possibility, evaporated light charged particles and neutrons were detected in coincidence with evaporation residues formed in the 11 MeV/A ^{60}Ni+^{100}Mo reaction. Charged particles were detected in four large-area position-sensitive Si E-)E telescopes, behind which were placed 16 neutron counters. A large variety of evaporated clusters Z<6, both stable and unstable, were found in coincidence with evaporation residues, but at low multiplicities.

Of the unstable clusters, ^{5}He and the first excited state of ^{8}Be (E^{*}=3 MeV) contributed most to the "-particle spectra at low energies. The lifetimes of these two clusters are extremely short, and they typically decay close to the compound nucleus, where its Coulomb field is still appreciable. This field modifies the final velocities of the decay fragments giving rise to a dependence of their relative energy on the orientation of their decay axis. For example, background-subtracted relative-energy spectra of *n*-" pairs from ^{5}He decay are shown in Figure 1 as the data points. The two distributions are gated on the emission angle of the " particle. Now the neutron is insensitive to the Coulomb field, while the " particle gets accelerated. Therefore, if the " particle is emitted backwards towards the compound nucleus, it then gets accelerated forward toward the neutron lowering their relative energy. On the other hand, if the " particle is emitted forward it is accelerated away from the neutron, lowering their relative energy. This effect is clearly evident in the data and the magnitude is consistent with the predictions of

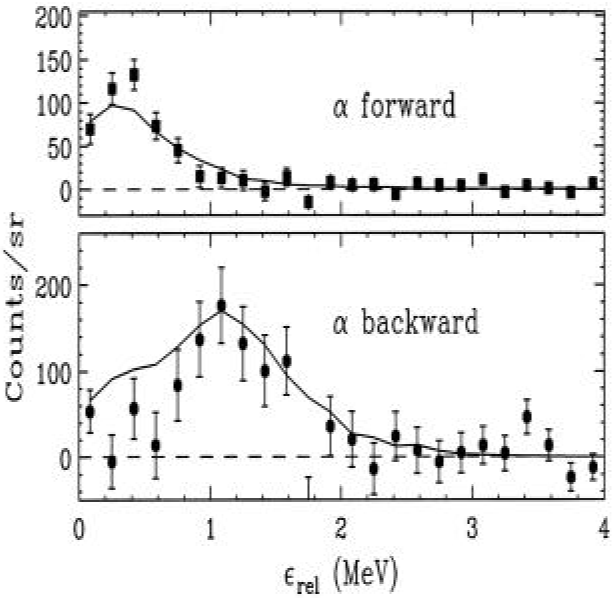

Figure 1. Background-subtracted relative-energy distributions for n-" pairs. Results are shown for ^{5}He decay where the " particle is emitter either forward or backward. The curves show predictions of Coulomb-trajectory simulations.

Coulomb-trajectory simulations indicated by the curves.

All together, " particles from the sequential decay of unstable clusters account for about 15% of all " particles in coincidence with residues. Figure 2 shows the experimental "-particle energy spectrum (data points) plotted together with the contributions from the sequential decay of the identified clusters. At this level, the important features of the "-particle energy spectrum like its peak energy and the slope at large energies are not greatly influenced by the contributions from sequential decay. However in the extreme “sub-barrier” region (12 MeV and less), the total contribution of " particles from sequential decay, indicated in the figure by the thick curve, accounts for most of the experimental yield. In conclusion, although the emission of unstable cluster does give rise to an enhancement of low-energy " particles, this enhancement is too small to explain the difference between the experimental energy spectrum and the predictions of standard statistical-model calculations. The cause of this discrepancy is presumably due to the Coulomb barriers used in these calculations.

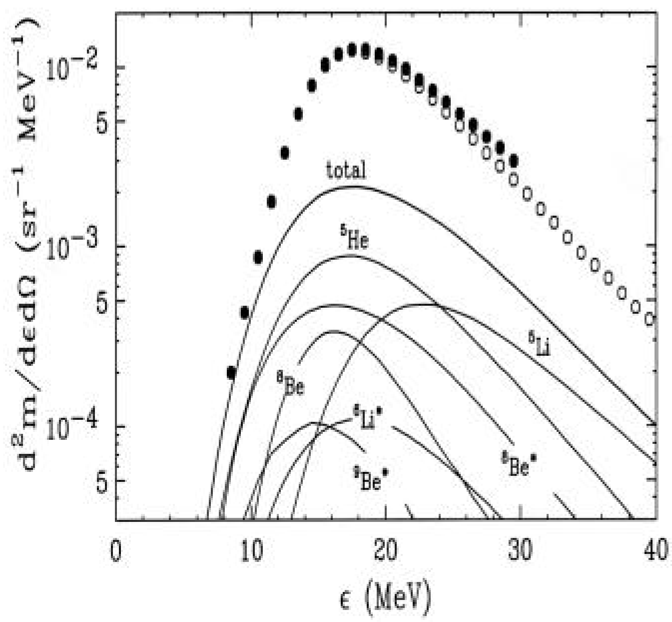

Figure 2. "-particle kinetic-energy spectra. Data points are the experimental results. Curves indicate the predicted contributions from each of the identified unstable fragments.

References

[1] G. La Rana *et al.*, Phys. Rev. C **35**, 373 (1987).

[2] R. Lacey *et al.*, Phys. Lett. **B191**, 253 (1987).

[3] M. Kildir *et al.*, Phys. Rev. C **46**, 2264 (1992).

[4] J. Boger *et al.*, Phys. Rev. C **49**, 1587 (1994).

[5] B.J. Fineman *et al.*, Phys. Rev. C **50**, 1991 (1994).

[6] M. Gonin *et al.*, Phys. Rev. C**42**, 2125 (1990).

[7] R.J. Charity *et al.*, Phys. Rev. C **56**, 873 (1997).