High-energy γ-ray spectra associated with selected evaporation residues in low-energy fusion reactions

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The spectra of high-energy γ rays in coincidence with evaporation residues ^{155,154}Er populated in the reaction of 241 MeV ^{64}Ni on ^{92}Zr have been compared with results from Monte Carlo statistical model calculations. The shape of the spectrum in coincidence with the ^{155}Er nuclei is reproduced only by simulations in which the spin distribution is extended towards very high spin values. [S0556-2813(97)06403-0]

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The giant dipole resonance (GDR) in highly excited compound nuclei is a topic of current interest in nuclear physics with heavy-ion beams [1]. High-energy γ-ray spectra, strongly affected by the GDR decay at energies $E_\gamma \geqslant 8$ MeV, have been extensively measured to study the shape of the nucleus as a function of excitation energy and angular momentum. Such measurements have also been recently proposed as an important probe of the reaction mechanisms [2].

The majority of the experimental data on the GDR strength function collected so far consists of γ-ray singles or γ-ray coincidences with evaporation residues or fission fragments as a whole. Only in a few cases have high-energy gamma-ray spectra been measured in a fully exclusive way, i.e., in coincidence with selected evaporation residues [3–5]. The latter data define the evaporative decay chain, implying severe constraints on the region of phase space involved in the decay and, as a result, allow one to perform very restrictive tests of the actual knowledge of the fusion-evaporation processes.

New possibilities have been opened in this field with the advent of the new generation of large γ-ray arrays. The gating on discrete, low-energy γ-ray transitions in high-resolution germanium detectors is an easy and convenient way to trigger on specific final evaporation residues. Additional selection of angular momentum regions or specific shapes in the nucleus are also possible with this technique. In this new generation of experiments, problems are both on the experimental and on the analysis sides. In fact, if the goal of collecting sufficient statistics of highly selective events is achieved, the question of the tools to interpret the data arises. Inclusive high-energy gamma-ray spectra have been analyzed so far by searching for the GDR parameters which minimize the χ square between the experimental line shape and that predicted by statistical model calculations. To this end a reduced version of the CASCADE program [6] has commonly been used. Analysis of the exclusive data requires Monte Carlo versions of the statistical model codes in which the filtering of the events can be possible to reproduce the experimental conditions. The Monte Carlo simulation of high-energy gamma-ray spectra is time consuming, because of the low probability of this emission. As a consequence, only in very few cases has this comparison been done until now.

We have recently measured high-energy gamma rays in coincidence with the GASP [7] spectrometer in the reaction ^{64}Ni+^{92}Zr at 241 MeV to study possible entrance channel effects in low energy fusion reaction [8]. High-energy γ rays in coincidence with the nuclei ^{155}Er ($1n$ evaporation) and ^{154}Er ($2n$ evaporation) were obtained. We have now compared those spectra with recent results from a Monte Carlo version of the statistical model code CASCADE [9], recently modified to include the gamma-ray decay. The results, useful in the understanding of the fusion reaction in nearly symmetric systems, are presented in this communication.

The experimental γ-ray spectra associated with the $1n$ and $2n$ evaporation channels in the reaction of ^{64}Ni + ^{92}Zr have been compared with this new Monte Carlo code simulations. As a first approximation we used standard statistical model parameters from our earlier work on the same reaction [10]. In particular, we set the limiting angular momentum at $J_{max}=46\ \hbar$ with a difuseness of $\Delta=4\hbar$. For the GDR parameters we employed strength $S=1$, energy $E=15$ MeV, and width $\Gamma=7$ MeV, which describe well the inclusive spectra [8].

The comparison between this simulation and the experimental spectra is shown in Fig. 1. It appears that the probability of emitting energetic gamma rays in the GDR region relatively to the statistical component is much larger in the calculated spectrum than in the measured one. This effect, which is already noticeable for the $2n$ decay (^{154}Er), becomes very large in the $1n$ case (^{155}Er). The large enhancement of the GDR component respect to the statistical tail shown in the calculation of Fig. 1 has been already experimentally evidenced in one case and was explained as a phase-space effect [3]. The enhancement sets in when the excitation energy available for the decay is such that a given xn decay chain is energetically possible only if the neutron emission is accompanied by an additional energetic gamma ray.

The only way to improve the agreement between the simulated and measured γ-ray spectra is to change the initial CN spin distribution, by increasing the diffuseness Δ. In such a case the excitation energy available for the decay at the highest spins decreases and, as a result, the ratio of the high-energy γ rays to statistical γ rays also decreases in the $1n$ spectrum, mainly.

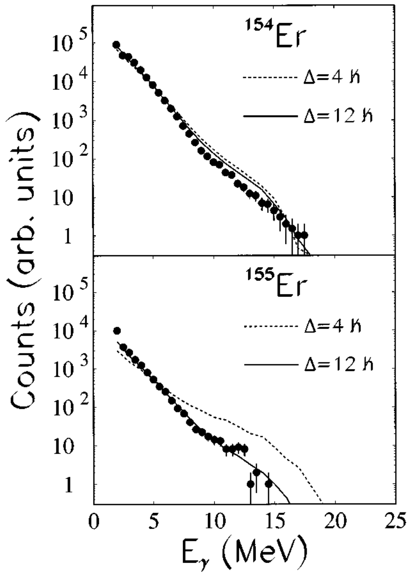

FIG. 1. High-energy γ-ray spectra in coincidence with transitions in the ^{155,154}Er compared with results from Monte Carlo statistical model calculations. For details see the text.

We found that simulations employing very large values of the diffuseness, as the case for $\Delta = 12\ \hbar$ reported in Fig. 1, produce spectra which fit the experimental data in a much better way.

The results reported in Fig. 1, although qualitative, suggest that, indeed, the CN spin distribution extends much beyond the maximun angular momentum predicted on the basis of simple geometrical models. One has to note that the importance of the increase of the spin distribution diffuseness in determining several observables in a near-barrier fusion reaction of nearly mass symmetric systems has been already evidenced in the past [11] and is discussed in the recent theoretical work of Winter [12].

This result is strongly supported by another observation which we made using the GASP data for the ^{64}Ni+^{92}Zr reaction. A superdeformed (SD) band was recently discovered in the nucleus ^{154}Er [13]. Despite the uncertainties in the spin assignment, this band is supposed to be populated above the angular momentum $J \sim 46\hbar$. We have searched for this band in a γ-γ matrix in which the condition to have a fold $k \geqslant 10$ was imposed. In spite of the target thickness, which was not properly suited for this application, we found evidence that the SD band is strongly populated in the ^{64}Ni+^{92}Zr reaction, as shown in Fig. 2. This demonstrates that the $2n$ channel extends in a sizable way at angular momenta larger that the value $J = 46\hbar$ considered previously as the limiting angular momentum for the fusion-evaporation reaction.

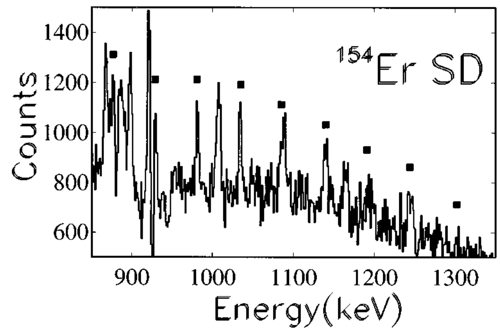

FIG. 2. The superdeformed band in ^{154}Er observed in the present experiment. The spectrum has been obtained by double gating on all combinations of clean in-band transitions [13] with conditions on the inner ball fold $k > 10$. Transitions belonging to the SD band are marked by heavy squares.

In summary, we have performed Monte Carlo simulations of the high-energy γ-ray spectra associated with specific evaporation residues from the reaction ^{64}Ni+^{92}Zr. The comparison with the experimental data for the $1n$ and $2n$ evaporation channels shows sizable discrepancies when using standard calculation parameters. It seems that the only way to remove this disagreement is to extend the CN spin distribution towards much higher angular momenta.

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