Understanding the collective enhancement in the nuclear level density

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It is now a very well known fact that the density of nuclear states increases rapidly with excitation energy and soon becomes very large. Along with the intrinsic excitations, the nucleus also displays collective vibration and rotational motion. These collective excitations have a significant effect on nuclear level density (NLD), in particular, for deformed nuclei and their contribution is defined as the collective enhancement in the NLD. Therefore, the total level density is expressed as $\rho(E^*,J) = \rho_{int}(E^*,J) * K_{coll}$, where $\rho_{int}(E^*,J)$ is the intrinsic single particle level density [1] and K_{coll} is the collective enhancement factor [2]. Although the NLD is indispensable in the study of nuclear decay, the collective enhancement in the NLD is still not well-understood due to the lack of experimental data. The magnitude and exact form of K_{coll} still remains an open question. In order to address this issue, series of experiments have been carried out at VECC using the alpha beams from the K-130 Cyclotron and employing the indigenously developed LAMBDA spectrometer [3,4], multiplicity filter [5] and liquid scintillator based neutron detectors [6].

The first signature of collectivity was observed for several deformed nuclei (^{169}Tm, ^{173}Lu, ^{185}Re) from the neutron evaporation spectra studies [7,8] at VECC. A sharp change in the inverse level density parameter was observed for all the three deformed nuclei in the excitation energy interval of 14-21 MeV, but only a weak effect was observed for the near spherical ^{201}Tl [7,8]. These experiments suggested the fadeout of the collective enhancement in the excitation range 14-21 MeV. The sharp change in the inverse level density parameter observed for ^{173}Lu and ^{185}Re are shown in Fig 1 while small or no change in observed for near spherical nucleus. These interesting results motivated us to look for a clear enhancement in particle spectra and giant dipole resonance (GDR) γ-decay spectra by populating the compound nuclei in the expected excitation energy range.

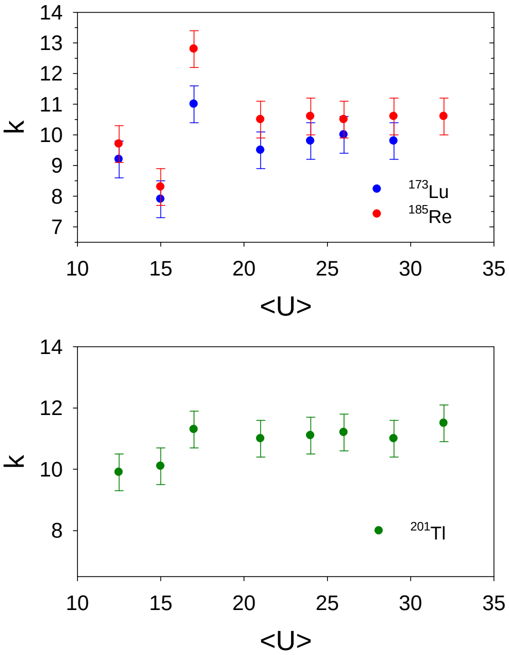

Fig. 1. The inverse level density parameter as a function of excitation energy for deformed nuclei (upper panel) and near spherical (lower panel).

The GDR is the collective mode of excitation of the nucleus and provides direct information about nuclear deformation [9]. Moreover, the GDR parameter do not change from the ground state value at moderate temperature (T ~ 1 MeV) [10]. Thus, it provides an excellent probe to see the enhancement in the NLD as well as to measure the deformation simultaneously. Consequently, to get the direct evidence of enhancement, the neutrons and the high energy GDR γ-rays were measured from ^{169}Tm at 26 MeV excitation energy.

It was intriguing to find a large yield simultaneously in the neutron energy spectrum and the GDR γ-ray spectrum, for the first time, in the deformed nuclei [11]. The neutron and the high energy γ-ray spectra, each measured at two different angles, are shown in Fig 2 (a) and (c).

The simultaneous enhancement in both neutron and GDR decay is the direct evidence of the enhancement independent of any model. It was also interesting to note that all decay channels where the enhancement was observed explored the same excitation energy region in the daughter nuclei. The experimental results showed that the relative enhancement factor is of the order of 10 and the fadeout occurs at ~14 MeV excitation energy, much before the commonly accepted transition from deformed to spherical shape.

In order to address this issue, the nuclear shape transition as a function of T was also studied in ^{169}Tm using GDR as a probe [12]. It was observed that the shape fluctuations about the equilibrium shape are quite large at T~1.2 MeV (shown in Fig 3). These fluctuations convolute the static ground state deformation which could lead to the loss of collectivity much before the shape transition from deformed to spherical.

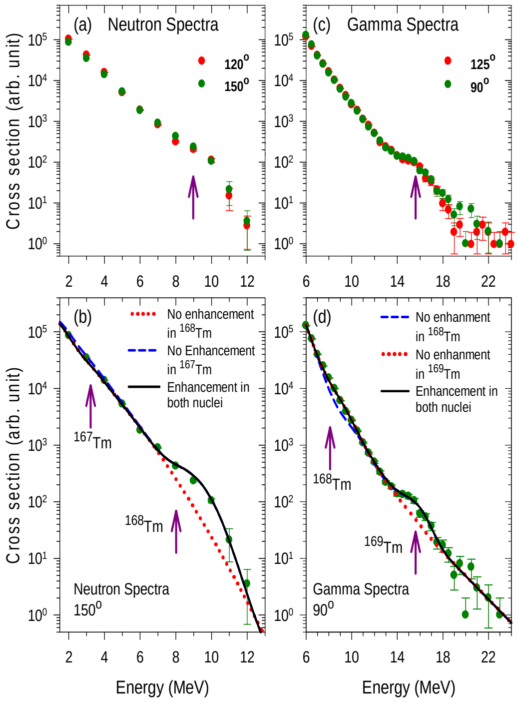

Fig. 2. The neutron (a) and the high energy γ-ray spectra (c) measured at two angles are compared with each other. (b) and (d) The neutron and γ-spectra compared with respective CASCADE calculation. The enhancement in the spectra and the contribution from different nuclei are shown with arrows.

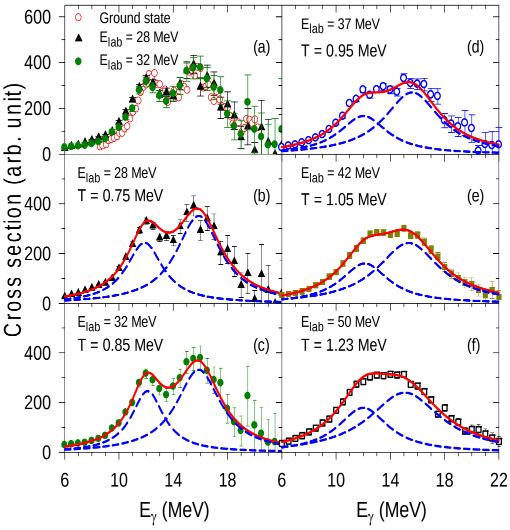

Fig. 3. The linearized GDR strength functions at different beam energies for the reaction ^{4}He + ^{165}Ho. The data at 28 and 32 MeV are compared with the available ground state photoabsorption cross section. The solid lines are the best-fit two component Lorentzian used in the CASCADE calculation. The individual components due to prolate shape are also shown with dashed lines.

These interesting results as well as the results of our recent experiments where an enhancement in the proton channel is also observed for deformed nuclei will be presented during the conference.

References

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