Collective enhancement in nuclear level density near 160 mass region

R. Shil[1], K. Banerjee[2,3], A. Chakraborty[1], J. Sadhukhan[2,3], P. Roy[2,3], R. Santra[2], A. S. Roy[3,4], Aniruddha Dey[1], S. Manna[2,3], A. Sen[2,3], D. Paul[2,3], T. K. Rana[2,3], P. Karmakar[2,3], R. Pandey[2], Samir Kundu[2,3], S. Mukhopadhyay[2,3], D. Pandit[2,3], D. Mondal[2,3], T. K. Ghosh[2,3], G. Mukherjee[2,3], Saumanti Sadhukhan[2,3], B. Mukherjee[1], and C. Bhattacharya[2*]

[1] *Department of Physics, Visva-Bharati, Santiniketan-731235, India*
[2] *Variable Energy Cyclotron Centre, 1/AF Bidhannagar, Kolkata-700064, India*
[3] *Homi Bhabha National Institute, Anushakti Nagar, Mumbai-400094, India and*
[4] *Bhabha Atomic Research Centre, Trombay, Mumbai-400085, India*

Nuclear level density (NLD) governs the statistical decay of an excited nucleus. It plays a crucial role in understanding the elemental synthesis in stars. NLD depends on various parameters of atomic nuclei like mass number (A), excitation energy(E^*), angular momentum(J), shell structure and isospin etc. Response of an excited nucleus is highly sensitive to the characteristics of NLD, depending on how these are populated either by single-particle or collective excitations. Both mechanisms may contribute simultaneously for a given nuclei [1]. Collective contribution $K_{coll}(E^*)$ can be counted on top of the single particle NLD $\rho_{int}(E^*)$ for obtaining the total NLD $\rho_{tot}(E^*)$ using the relation: $\rho_{tot}(E^*)$=$K_{coll}(E^*)\rho_{int}(E^*)$. Here, K_{coll}=$K_{rot}*K_{vib}$, where K_{rot} and K_{vib} are the rotational and vibrational enhancement factor, respectively. For highly deformed nuclei, several phenomenological and microscopic calculations estimated K_{rot} $\sim$100 and K_{vib} $\sim$ $2-10$ [1, 2]. This enhancement is however expected to fade-out beyond a critical excitation energy E^*_{cr}, which in turns reduces the NLD [2].

Several experimental attempts were made to determine K_{coll} and E^*_{cr}. High energy γ-ray measurement reported $E^*_{cr}\sim 8-10$ MeV and $K_{coll}\approx 10$ for $A\sim 170$ [3]. Recent measurement on transfer induced fusion reaction obtained the similar E^*_{cr} but K_{coll} value was found to be higher, which is 40 for ^{171}Yb [4]. These studies revealed that the experimental K_{coll} values are much lower compared to the theoretical predictions for 170 mass region [1, 2]. Therefore, further investigation in different mass region are required.

In the present work, we consider ^{162}Ho to study the NLD and its dependence on deformation. A reference nucleus ^{147}Gd in the nearby mass region is also considered to make a comparison. These nuclei can be produced in fusion-evaporation reaction using ^{4}He beam of energy $\sim$26 MeV. Experiment was performed in K130 Cyclotron using ^{4}He beam of energy in the range 26-42 MeV. A $^{144}Sm_2O_3$ target sandwiched between two Myler foils and a self supporting ^{159}Tb targets were used. Emitted neutrons were detected using eight liquid scintillator (BC501A) based neutron detectors placed in the range of 45^o-150^o and at a distance of 150 cm from the target center. The neutron energy spectra was measured using the time-of-flight (TOF) technique. Here, we report only the lowest energy data measured at backward angle (150^o). Backward angle data is chosen as it will least affected by the pre-equilibrium emission.

Statistical model (SM) analysis using TALYS-v1.96 was performed on these reaction. This requires NLD, which was estimated using the Back-shifted Fermi-gas (BSFG) model. Here, an isospin dependent prescription of NLD parameter was used [5]. Mea-

*Retired

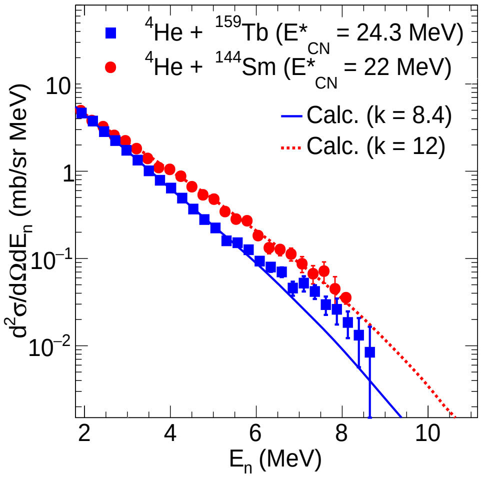

FIG. 1: Measured neutron energy spectra for ^{4}He + ^{159}Tb and ^{144}Sm are shown in symbols. Solid and dashed lines are the statistical model (SM) calculations.

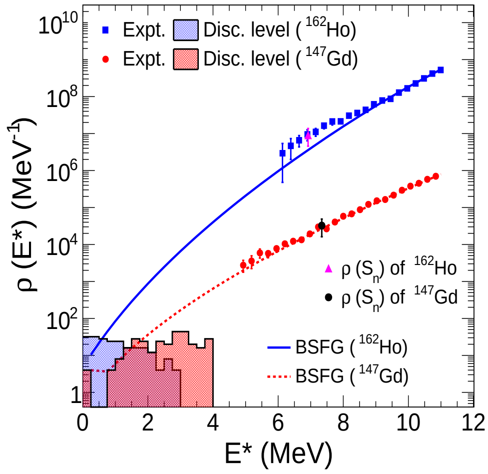

FIG. 2: Symbol represents the measured NLDs for ^{162}Ho and ^{147}Gd. Measured data are normalized at the neutron separation energy (S$_n$). Histograms are the NLDs obtained from known discrete energy levels. Lines are the estimated NLDs using BSFG model.

sured spectra were compared with the SM calculation by tuning the inverse NLD parameter k, which are shown in Fig. 1. Optimum value was chosen by plotting χ^2 as a function of k-value. For ^{4}He + ^{159}Tb, k-value is found to be 8.4±0.2 MeV, whereas for ^{4}He + ^{144}Sm, it is 12±0.4 MeV. This large change in the k-value for nuclei having similar excitation energy and mass may be due to the difference in deformations among the major residues produced.

To investigate further, NLDs were determined for the two major residues formed in these reaction *e.g.* ^{162}Ho and ^{147}Gd using the following relation [6],

$$\rho_{exp}(E^*) = \rho(E^*)_{BSFG} \frac{(d\sigma/dE_n)_{exp}}{(d\sigma/dE_n)_{BSFG}} \quad (1)$$

Extracted NLDs for ^{162}Ho and ^{147}Gd are shown in Fig. 2. NLDs were normalized at neutron separation energy S$_n$ and are compared with same obtained from known energy levels. A large change in NLD observed for the two nuclei in the similar excitation energy region. This large change in NLD values are indication of different excitation mechanism in two nuclei having different deformation.

The authors would like acknowledge the VECC Cyclotron operators for smooth running of the accelerator during the experiment. R. Shil and A. Chakraborty would like to thank UGC-DAE CSR, Kolkata for providing financial assistance through CRS project no. UGC-DAE-CSR-KC/CRS/19/NP10/0921/0963.

References

[1] A. Bohr, B.R. Mottelson, *Nuclear Structure*, vol. II, Benjamin, (1975).

[2] G. Hansen, A.S. Jensen, Nucl. Phys. A **406**, 236 (1983).

[3] D. Pandit *et al.*, Phys. Lett. B **816**, 136173 (2021).

[4] T. Santhosh *et al.*, Phys. Lett. B **841**, 137934 (2023).

[5] R. Shil and K. Banerjee *et al.*, Phys. Lett. B **831**, 137145 (2022).

[6] D.R. Chakrabarty *et al.*, Phys. Rev. C **51**, 2942 (1995).