Comparison of neutron yield at 100 MeV/A ^{12}C on a thick C target: A Pre-equilibrium approach

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Introduction

Particle emission from a hot nuclear system in the intermediate energy ranges of few tens to few hundreds of MeV/A is very important in the field of nuclear and particle physics. There are many experimental affirmations in the aforementioned energy range confirming enhanced particle yields at intermediate energies due to the presence of pre-equilibrium (PEQ) emissions along with particle evaporation [1]. The prediction of yield distributions of emitted particle becomes more challenging in thick target systems due to continuous degradation of projectile energy within the target medium. In the present work, an effort has been made to reproduce the experimentally measured neutron yield [2] from the bombardment of 100 MeV/A ^{12}C beam on a thick natural C target (98.93% ^{12}C and 1.07% ^{13}C) by reaction model calculation. The calculations use a combination PEQ emissions from an in-house developed PEQ code for heavy ion interactions (HION) [3,4] and evaporation contributions from the projection angular momentum coupled evaporation (PACE4) code [5]. In the present form of HION, emission probabilities are estimated with nucleon-nucleon (N-N) collision rates calculated from spatial nucleon density distributions. A combination of single and multiple PEQ emission is considered. Spatial nucleon density distribution in composite system was estimated using semiphenomenological approach [6].

Method of calculation

In the present work the thick target evaporation yield is calculated using PACE4 code with A/8 level density parameter and the thick target yield is estimated using the method discussed in Nandy *et al.* [3]. PEQ emission probabilities are calculated using HION code [3,4] with modified collision rate calculation based on spatial nucleon distribution and multiple PEQ emission [7]. In multiple pre-equilibrium (MPEQ) formalism we have considered two different modes of multi-particle emissions, viz. simultaneous and sequential MPEQ. The simultaneous one refers to multiple neutrons emissions from a single exciton hierarchy whereas sequential MPEQ with neutrons emitted from residual system generated upon one neutron emission.

Results and discussion

The comparison between the experimental neutron yields [2] from (^{12}C+C) composite system and corresponding evaporation estimate is presented in Fig. 1.

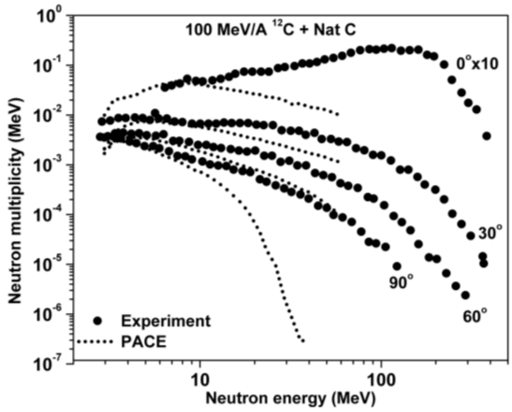

Fig.1 Experimental neutron yield vs. evaporation estimates for ^{12}C beam on a thick C target.

Evaporation is calculated using Hauser-Feshbach formalism. Neutron yield from C target is calculated considering the projectile beam to have continuously degrading energy within the target medium. For simplification, thick target is assumed to be a series of multiple thin slices, in each of which the projectile looses a specified energy ΔE. The net neutron distribution at different angles is estimated as a sum of the emissions from all these projectile energies. Figure 1 clearly indicates that at large angles, the evaporation somewhat reproduces the trend of experimental yield but completely fails to predict at forward angle. At 0° evaporation underestimates experimental yield largely at neutron energies > 20 MeV. This in a way supports the presence of a PEQ contribution. The PEQ contribution is calculated using HION code considering both single and multiple particle emissions. Density dependent N-N collision rates and corresponding emission probabilities from composite system are used. Nucleon density distribution of composite system is estimated using the semi-phenomenological approach. It shows near consistent central nucleon density for neutrons ~0.089 fm^{-3} and protons ~0.086 fm^{-3}.

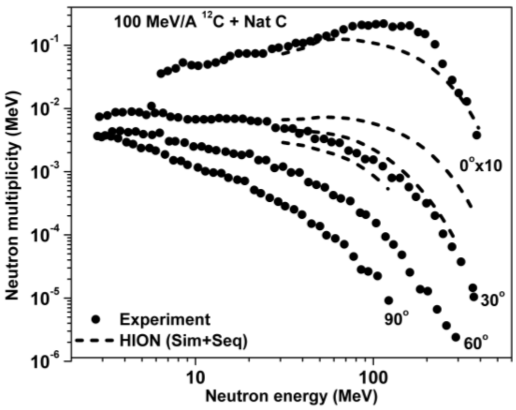

Fig. 2 Experimental yield vs. PEQ from HION (simultaneous + sequential) estimate for ^{12}C beam on a thick C target.

Neutron yield obtained using the single and simultaneous multiple PEQ probabilities for $^{12}C+^{nat}C$ system at 100 MeV/A is compared with the experimental data in Fig. 2. The PEQ contributions are presented as dashed line for all emission angles. In the forward direction the PEQ formalism reproduces the neutron yields up to 70 MeV emission energies. Beyond this energy experimentally obtained yields are found to be higher than the estimated PEQ yields and may be attributed to the direct processes at these energies. At all other angles the PEQ yields are found to be higher than the experimental results. At higher emission energies, evaporation does not reproduce the yield. Moreover, PEQ contribution progressively decreases at higher emission angles. As the slope of PEQ contribution is fairly reproduced by the calculations, PEQ yields are normalized to the experimental data at 100 MeV for 30°, 60° and 90°. These are presented in Fig. 3. The figure shows a good match at all angles indicating that HION can reproduce the yield pattern at all angles. The overprediction of PEQ contribution in HION needs to be investigated further.

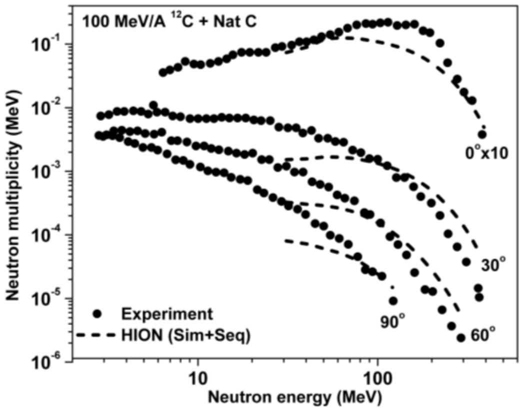

Fig. 3 Experimental yield vs. PEQ from HION (Simultaneous + Sequential) normalized at 100 MeV for 30°,60° and 90°.

Conclusion

In this work, neutron yield from bombardment of ^{12}C beam on a thick C target has been theoretically estimated and compared with the experimental data [2] at beam energy of 100 MeV/A. The observation showed that considering a single and multiple PEQ formalism using HION code, the neutron yields could be reproduced till 70 MeV neutrons at 0°, whereas contribution of PEQ component reduced at higher emission angles. A further investigation involving direct reaction formalisms to account for underestimation at 0° and emission probability based on event by event scattering interactions for backward angles is necessary.

References

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