Probing Pre-equilibrium Neutron Emission in heavy ion reactions at large projectile energies

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Introduction

The neutron yield from thick target heavy ion interaction is of considerable interest in the fields of neutron dosimetry, shielding design of accelerators, medical applications and nuclear reactor. Though neutron emission from proton and alpha induced reactions are generally well explored [1][2], data are scarce for production of neutrons by heavy ion reactions. The state-of-the-art modern carbon ion therapy uses high energy ^{12}C beam for medical therapy and the design and operation of such accelerator facility require accurate knowledge on neutron shielding due to background neutrons produced by beam hitting on surfaces. The present work is proposed to study measurement of yield and angular distribution of neutrons from thick target of ^{56}Fe bombarded by ^{12}C. The chosen reaction is important as Fe is a prominent material in building heavy ion accelerator components. The new data are useful to the application of accelerator shielding design. In this study, the neutron energy spectra of reaction ^{12}C + ^{56}Fe is studied at projectile energy 10 MeV/A or above. The energy range is well-suited for studying Pre-equilibrium(PEQ) emission, where the dominance of reactions is expected. As there is no availability of experimental data for the above mention reaction, we would like to study pre-equillibrium contribution in nearby system ^{27}Al at energy 115MeV due to the availablity of experimental data by V.Suman et.al[3] for different angles 0^0,30^0,60^0, 90^0 and 120^0 is taken to compare with the code EMPIRE 3.2 and PACE 4, this work is suitable for understanding angular distribution of neutron emitted from a thick target bombarded by carbon projectile

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Methodology

There are several nuclear reaction model codes available to simulate compound nucleus reaction and decay process. The main reaction processes involved are direct (DIR), pre-equilibrium (PEQ) and compound nuclear processes. Direct reactions are modelled through coupled channel calculations, PEQ reactions are calculated based on two widely used models, exciton model and hybrid model. Compound nuclear reactions are calculated using Hauser-Feshbach theory. Some of the codes appropriate for estimation of neutron yield we use PACE 4 and EMPIRE 3.2. Among this the PACE do not have the PEQ model included. Code EMPIRE has provisions to invoke hybrid, exciton or other models such as multi-step direct(MSD) and multi-step Compound(MSC) models.

Angular distributions of neutron yield are calculated for ^{12}C on ^{27}Al target at energy 115MeV. Table. I shows the angular distribution of the emission neutrons at thick target neutron yield.

TABLE I: Angular distribution of neutron yields from 115 MeV ^{12}C on thick Al target

Angle(Degree)	EXP	EMPIRE 3.2	PACE 4
0	$5.1\text{x}10^{-4}$	$1.17\text{x}10^{-4}$	$0.0370\text{x}10^{-4}$
30	$1.98\text{x}10^{-4}$	$0.901\text{x}10^{-4}$	$0.027\text{x}10^{-4}$
60	$0.885\text{x}10^{-4}$	$0.707\text{x}10^{-4}$	$0.0176\text{x}10^{-4}$
90	$0.608\text{x}10^{-4}$	$0.65\text{x}10^{-4}$	$0.0108\text{x}10^{-4}$
120	$0.344\text{x}10^{-4}$	$0.478\text{x}10^{-4}$	$0.0073\text{x}10^{-4}$

Result and discussion

Fig. 1 shows trends of emission neutron angular distributions for 115 MeV projectile energy.

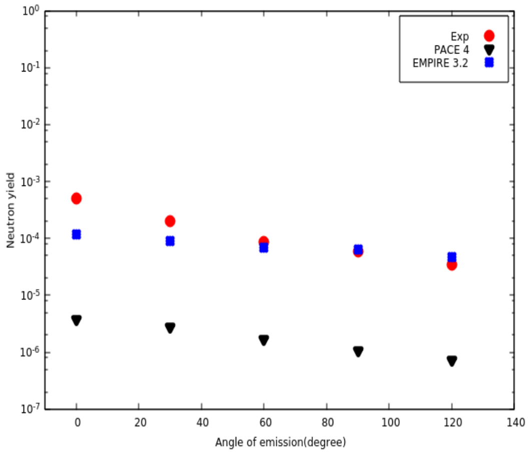

FIG. 1: The energy integrated angular distribution of the neutron yield obtained from 115 MeV ^{12}C projectiles incident on a thick Al target.

In this case, the EMPIRE 3.2 estimates a closer agreement with experimental data. The PACE 4 estimates are found to be still large underestimated with respect to the experimental data. The EMPIRE results are almost in agreement with the experimental value. For the 0^0 angle, the neutron yields were found to be 5 times higher than the corresponding EMPIRE calculation and almost same at backward angles above 60^0. At the projectile energy used in this work, It is expecting a contribution of PEQ in the total neutron yield and could be the reason for the lower values obtained by the PACE 4 code. Thus it is concluded that at high beam energies significant amount of high energy neutrons are produced this neutrons in turn induces secondary reactions with core and structural materials. Such neutrons may be produced in near system Fe also. It has been observed that the PEQ parameters of the code EMPIRE 3.2 satisfactorily reproduces the above result, using the same optimized parameters of above systems the angular distribution of ^{56}Fe when bombarded by ^{12}C is calculated, which is shown in Fig. 2. It is expecting that the calculated data will be verifed with the proposed experiment at NAND array, IUAC.

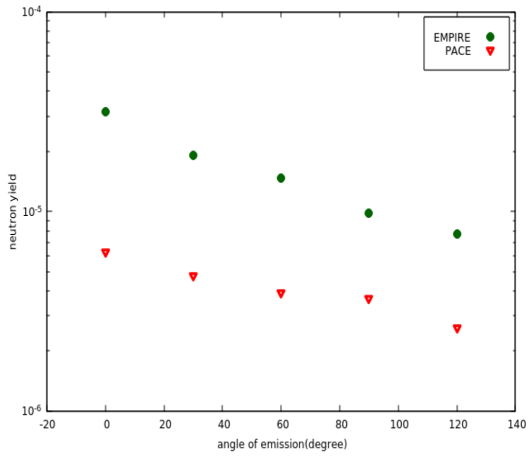

FIG. 2: The energy integrated angular distribution of the neutron yield obtained from 125 MeV ^{12}C projectiles incident on a thick Fe target.

Acknowledgments

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