Inclusive thick target neutron yield measurements from 144 MeV ^{19}F+^{27}Al system

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Introduction

Neutron yield measurements from thick targets have been practiced by the accelerator radiation physics community as the data are the primary source for radiation shielding, induced activity, accidental exposure and skyshine calculations. In the absence of experimental data, nuclear reaction model codes and certain empirical expressions are also used to compute the source term. In addition to the double differential yield, the angular distribution of the neutrons emitted becomes an important parameter as the projectile energy increases and more of pre-equilibrium and direct reactions start to contribute resulting in the emission of higher energy neutrons. This will determine the anisotropy in dose equivalent in the forward and lateral directions. Nuclear reaction codes such as PACE [1] and EMPIRE [2] can be used in the energy domain where compound nucleus emission is predominant. The code HION [3] has pre-equilibrium model built in. We have earlier studied the energy-angle distribution of neutron yield from ^{19}F + Al reaction at 110 MeV energy [4]. In that study we found that the yield is better reproduced by EMPIRE while PACE reproduces the angular distribution better though both the codes use the Hauser-Feshbach treatment for the compound nucleus emissions. Here we compare double differential neutron yield obtained from the EMPIRE code with the experimental measurements for ^{19}F+Al reaction at 144 MeV.

Experiment

The neutron yield from 144 MeV ^{19}F projectiles incident on a thick Al target was measured. The experiments were carried out at the superconducting linac booster of the BARC-TIFR Pelletron-linac accelerator facility at TIFR. The Al target is thick enough to stop the projectiles completely and serves as the beam dump. But scattering of neutrons is negligible. This makes measurements in the extreme forward angles possible which allow a good test of the predictive capability of the model codes. Three EJ301 detectors (Scionix Holland make) were kept at a time at a distance of 1.5 mm from the target and the data obtained at 0°, 30°, 60° and 90° are reported here. Pulse shape discrimination was used to separate the neutrons from photons, while time of flight technique (TOF) was used to measure the neutron energy. For TOF, the detector event was used as the start signal while the buncher signal from the accelerator was used as the stop signal [5].

Results and Discussions

In figure 1, the experimental data are shown as closed circles, while the EMPIRE results are shown as solid lines. The super buncher of the linac gives a time spread of 0.8 ns FWHM which results in an energy uncertainty of less than 10% upto about 30 MeV. Neutron energy distribution is obtained from the EMPIRE code using the EMPIRE specific level density option which is recommended in the code as the best option for heavy ion induced reactions. From this energy spectrum angular distribution is calculated considering isotropic distribution in the CM (center of mass) frame and then converting it to the laboratory frame. The fusion cross section is calculated internally using the simplified coupled channel approach whose results are similar to the experimental data up to about 80 MeV above which this option over predicts the experimental as well as the Bass model predictions [6].

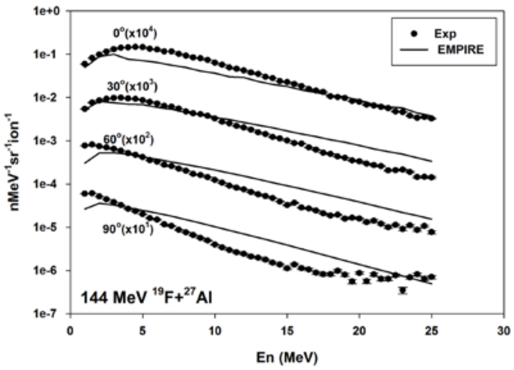

Fig. 1. The experimentally measured neutron spectra at different angles along with the calculated results using the EMPIRE code.

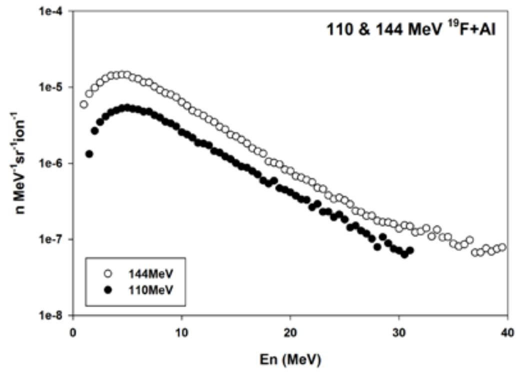

Fig 2. The experimentally observed neutron spectra at 0° from 110 &145 MeV $^{19}F+^{27}Al$.

Our comparison shows that the EMPIRE calculations do not predict the measured neutron energy distribution at different angles. In the forward direction, experimental data at low emission energies are underpredicted while the agreement is good at higher energies. With the increase in angle of emission, the calculations over predict the experimental data. This indicates that our assumption of isotropic emission in CM frame is not valid and a proper angular distribution function needs to be considered. Further, the slope of the experimental data and the calculated results do not show the same trend indicating a difference in temperature which also affects the average energy of emission.

In figure 2 experimentally obtained energy distributions of neutrons at 0° from 110 MeV and 144 MeV $^{19}F^{8+}$ projectile incident on thick Al taget are shown. It can be seen that the peak energy is more or less similar while the highest energy of emission is much larger in the case of 144 MeV as is expected. The slopes too appear to be similar. In both the cases, the EMPIRE results seem to predict the yield reasonably well, but since the slopes do not show any appreciable change at higher energies, the possibility of pre-equilibrium emission appears to be negligible at 144 MeV even though the energy is in the vicinity where such emissions have been reported.

Conclusions

The inclusive thick target neutron yield from 144 MeV ^{19}F projectiles bombarding a thick Al target has been studied using time of flight measurements at the superconducting linac at TIFR. The experimental data is compared with the results from the EMPIRE nuclear reaction model calculations. Assumption of an isotropic emission in the CM frame for the EMPIRE code with all other default parameters does not reproduce the experimental data.

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