Pre-equilibrium neutron emission in $^{19}F+^{89}Y$ reaction at 150 MeV

J. Acharya*, S. Mukherjee, N.L. Singh, A. Chatterjee
Department of Physics, M.S. University of Baroda, Vadodara - 390002, INDIA
K. Ramachandran, B.K. Nayak, P.C. Raut, Vishal Desai, E.T. Mirgule, S.V. Suryanarayana, K. Mahata, A. Saxena
Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA
G.F.Steyn
iThemba Labs, Sommerset West, South Africa
*. * email: jaiming89@gmail.com*

Introduction

The role of pre-equilibrium emission within the heavy-ion fusion process has not been fully characterized. The reaction mechanism for heavy ion interactions with medium and heavy targets gradually changes from fusion followed by statistical emission to pre-equilibrium emission [2] with increasing beam energy. It is expected that at around 6 MeV/nucleon, pre-equilibrium effects could begin to manifest and become significant after 7 MeV/nucleon. Several studies of particle emission at lower energies already exist and have established details of the statistical model compound decay. In contrast, pre-equilibrium emission studies are much less. The measured neutron cross-sections have been compared with theoretical predictions based on pure statistical model code PACE4 and Geometry Dependent Hybrid (GDH)-based code ALICE.

In this work we concentrate on the HMS Model and the ALICE 2014 code [2]. In fact this code has not yet been subject to stringent tests and this is one of the aims of the present work.

Neutron emission, light charged particle emission and excitation function are useful tools for such a study. In the experiment we measured both neutron and charged particle spectra for a range of targets, and for three ^{19}F beam energies. In this contribution we present the angle-dependent neutron spectra for ^{19}F + ^{89}Y at beam energy 150 MeV.

Experimental Details

The experiment was performed by using the TIFR-BARC Pelletron-LINAC facility in Mumbai. ^{19}F pulsed beam having two-bunch structure with a time of 107.3 ns between bunches have been used for the purpose. Beam currents of 1-3 pnA were used. The target was a self-supporting foil of spec-pure Y rolled to a thickness of 1.8 mg/cm^2. Targets were checked for impurities by X-ray fluorescence.

Fourteen NE213 neutron detectors were used to cover the angular range 25^o-143^o. The time of flight (TOF) distances were in the range of 65-82 cm. Background estimations were done using a blank target and shadow bar technique. The beam dump was well shielded as this is the main source of background neutrons. Attention was paid to the centering of the beam to reduce background from the target frame and collimators.

LAMPS-VME data acquisition system was used with an OR condition from the individual detectors qualified by beam RF signal. For each detector, TOF, pulse-shape (PSD) and anode signals were recorded. Master gate blocking and dead-time corrections were applied.

Detector efficiencies were obtained by making measurements with a ^{252}Cf source at the target position enclosed in a small 4π ionization chamber detecting fission fragments. In this case TOF was measured with respect to fission fragments. Comparison was made with the simulation code NEFF [3] and the detector thresholds in the code were adjusted to match the experimental results.

Neutron energy spectra were obtained by converting TOF to energy on an event by-event basis using the LAMPS program. Normalization was done in terms of target thickness (which was carefully measured), beam charge (from a calibrated current integrator) and detector efficiencies. TOF calibration was done by matching the distance between the 2 gamma peaks to the beam bunch separation (107.316 ns). Gates were applied in the two dimensional spectrum of TOF vs. PSD to discriminate neutrons from gamma rays. The spectra obtained at 4 of the angles are shown in Fig 1.

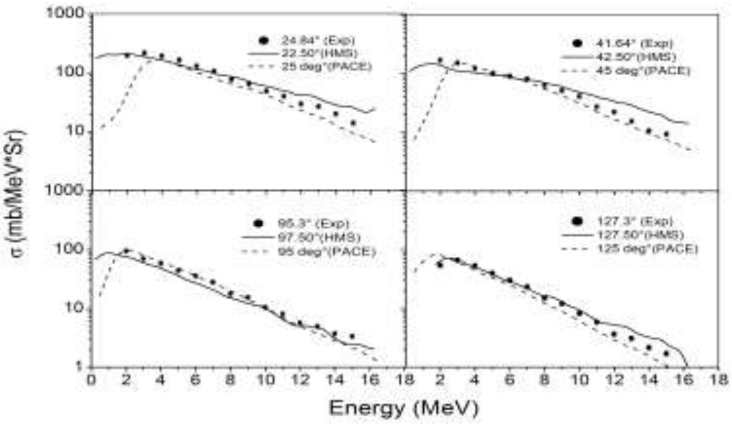

Fig. 1

Comparison with Calculations

In Fig 1, the data are compared with the code ALICE 2014 [2] which performs Hybrid Monte-Carlo Simulation calculations. The code was run without parameter adjustment, selecting the Obninsk level density [4]. There is a fair agreement with the data at all angles.

For the purpose of comparison we also made calculations using the statistical model code PACE4 [5], which does not include pre-equilibrium effects. The measured excitation functions are satisfactorily reproduced by the PACE4 calculations in the energy region ranging from peak to 8 MeV. However, at relatively higher energies, the enhancement of experimental cross sections in the tail portion of neutron spectra as compared to the theoretical predictions of code PACE4 has been observed. The observed deviation may be attributed to the pre-equilibrium emission of particles during the thermalization of the compound nucleus.The main deviation is seen in the high energy part of the spectrum, 8-16 MeV at the forward angle (24^{o}). At other angles, the calculations do not differ significantly.

The experimental spectrum at 24^{o} shows an increase at higher energies in comparison to PACE4. It may be observed that the effect of pre-equilibrium emission appears small at higher angles than at forward angles. This indicates that pre-equilibrium is forward peaking reaction mechanism.

References

[1] J. Acharya et al, Phys. Rev. C93, 024608, (2016) and references therein
[2] M. Blann and A.Y. Konobeev, RSICC Code Package PSR-550, https://rsicc.ornl.gov/;
[3] G. Dietze and H. Klein, NRESP4 and NEFF4, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany
[4] A.V.Ignatyuk et al., Phys. Rev. C 47, 1504 (1993).
[5] A.Gavron, Phys. Rev. C21**,** 230 (1980)
[6] M. Trabandt and W. Scobel, Phys. Rev. C39, 452 (1989)
[7] M. Blann and H. K. Vonach, Phys. Rev. C 28, 1475 (1983)