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NEUTRON EMISSION FROM ^{101}Rh PRODUCED VIA ^{12}C+^{89}Y REACTION AT 49.5 MeV* **

M. Popkiewicz, S. Osuch, Z. Szefliński, A. Sztampke, Z. Wilhelmi, M. Wolińska and R. Zagańczyk

The Institute of Experimental Physics, Warsaw University
Hoża 69, 00-681 Warsaw, Poland

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The neutron detecor **MONA** (**MO**dular **N**eutron **A**rray) was used to measure neutron spectra originated in the ^{12}C+^{89}Y system. The neutron spectra were measured at six selected angles by TOF method at average laboratory energy of 49.5 MeV. The temperature of the source was determined through off-line analysis and was found to be 1.62 MeV. The level density parameter a, was determined within the framework of a Fermi-gas model, to be equal to $a = A/9.4$.

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1. Introduction

Since the middle of 80's the evidence of the so called entrance channel effect has been reported. Observed neutron multiplicity in asymmetric channel was in a good agreement with statistical model, whereas the neutron emission observed in symmetric channel was strongly suppressed both in comparison to the asymmetric channel and theory [1]. This puzzle is not yet definitely solved, however there are some indications, based on the measurement of charged particles spectra, that in the symmetric collision the formation time is 2–4 times longer than the calculated evaporative lifetime of the composite system [2]. Therefore, the emission of precompound particle evaporated during the formation time should be considered. The emission of the energetic precompound neutron would decrease the available excitation energy and consequently, the number of emitted particles. It

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should be possible to extract this group of neutrons, as they should be both highly energetic and anisotropic in the center-off-mass frame. Observation of such precompound neutrons is the purpose of our future experiments. The present work is the first step in the entrance-channel mass asymmetry dependence studies of the compound nucleus formation time in heavy ion reactions. The aim of our study of the neutron emission induced in the ^{12}C+^{89}Y reaction was to check our ability to measure precisely the energy spectra of nuclei created with use of the Warsaw Cyclotron.

2. Method

The experiment was carried out using ^{12}C beam at average laboratory energy of 49.5 MeV. Thick self supporting target foil of 5 mg/cm^2 was prepared by rolling. The target made of natural yttrium (^{89}Y is isotopically pure to 100 %) was placed in the target chamber onto tantallum backing, which acts as a catcher foil. The beam intensity was monitored by integration of the beam current. The neutron spectra were measured at six selected angles using multidetector system MONA (MOdular Neutron Array) which was designed for studies of heavy ion induced neutron emission at intermediate energies [3]. The liquid scintillators of cylindrical shape with diameters of 4" and thicknesses of 1" were placed at distances from the target of 50–70 cm.

Due to the beam structure of the Warsaw Cyclotron which cannot provide us with fast narrow start signal we have developed the TOF method of measurement of neutron energy, using the γ registration as a reference signal. The application of γ-ray reference signal affects the time spectrum of registred neutrons due to delayed γ's. Some changes in the spectrum are also caused by the finite time resolution of the system as well as the long time of flight of neutrons through the detector.

These contributions mentioned above can be taken into account in order to form the response function of our detector which is defined as the registered time spectrum of monochromatic neutron beam. The set of subsequent response functions for different energies forms response matrix of the detector. The primary neutron spectrum represented by the vector P_j is then folded as described by matrix equation

$$M_k = \sum_j \mathcal{R}_{kj} P_j \,, \tag{1}$$

where M_k is the vector representing the measured time spectrum and $\mathcal{R}_{kj}$ are the elements of the response matrix. In order to obtain the primary spectrum one should solve the equation (1) by multipliplication of the folded (measured) spectrum by inverse matrix $\mathcal{R}^{-1}$. However we used the iterative

method of solvig the matrix equation (1) to find the primary neutron spectrum. The neutron spectra have been corrected for the efficiency response of the neutron detector. The efficiency of our neutron detectors is a slowly varying function of energy which was obtained by a Monte Carlo simulation [4]. Additionally the ^{252}Cf source was used to measure the efficiency of the spectrometer as the ^{252}Cf source serves as standard for neutron measurements of known energy distribution. The unfolded spectrum have been transformed into the center-off-mass frame. Resulting energy spectrum denoted by open squares is shown in the Fig. 1. For comparison, the spectrum not corrected for the response function is also shown (open circles) in the figure.

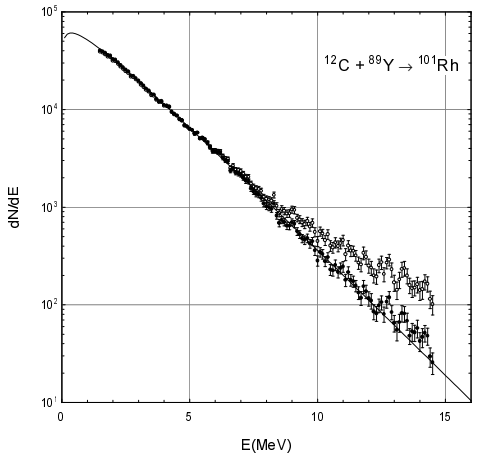

Fig. 1. Integral energy spectrum of neutrons in the center-of-mass reference system. The spectrum not corrected for the response function is denoted by open circles. The solid line represents the fitted curve.

3. Results

As the spectra comprise neutrons from all steps in the cascade and from all decay channels they present the sum of the spectra corresponding to different nuclear temperatures. It is obvious that the neutrons emitted early in the cascade, contribute more at higher neutron energies. It is customary to describe the energy spectra of neutrons emitted in a cascade process in terms of a Maxwellian distribution with the slope parameter corresponding to an effective temperature T_{eff}. The shape of the spectra have been fitted by the formula proposed by Le Couteur and Lang [5]

$$n(E)dE \sim E^{\lambda} \exp(-E/T_{\text{eff}})dE\,, \tag{2}$$

where $\lambda \simeq 0.4$ and $T_{\rm eff} \simeq T \cdot 11/12$. The density of levels in the daughter nucleus produced in the evaporation of a light particle plays an important part in the description of the energy spectra. Therefore, the level density parameter, a which appears in the Fermi gas level density formula can be derived from the shape of the neutron spectra. The effective temperature of the source was determined through off-line analysis of neutron spectra at six selected angles and was found to be $T_{\rm eff} = 1.62 \pm 0.05$ MeV. The excitation energy was derived from the the assumption of complete fusion reaction. Finally, the level density parameter a is deduced from the relation $E_{\rm eff} = aT_{\rm eff}^2$, where $E_{\rm eff}$ represents the effective thermal excitation energy in the daughter nucleus after the emission of a neutron. We take the average thermal excitation energy of the doughter as

$$E_{\rm eff} = E_x - E_{\rm rot} - S - 2T_{\rm eff}\,, \tag{3}$$

where E_x is the average excitation energy of the compound system, $E_{\rm rot}$ is the daughter rotational energy and S the particle separation energy. The rotational energy was calculated as $E_{\rm rot} = I(I+1)\hbar^2/(2J_{\rm rig})$. Here, $J_{\rm rig}$ is the rigid-body moment of inertia $J_{\rm rig} = 2mR^2/5$ with $R = r_0 A^{1/3}$ and I is the average spin. It should be emphasized that the hot nucleus may store excitation energy in other collective modes which are ignored in the equation (3). The level density was derived within the framework of a Fermi gas model. A level density parameter a, in ^{100}Rh at the average excitation energy $E_x = 42.5$ MeV, equal to $a = A/9.4$ was deduced. The parameter a can be compared with the empirically determined parameters a taken from the compilation of Dilg *et al.* [6] where an analytic formula $a = A/9$ approximating the mass dependence was applied.

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