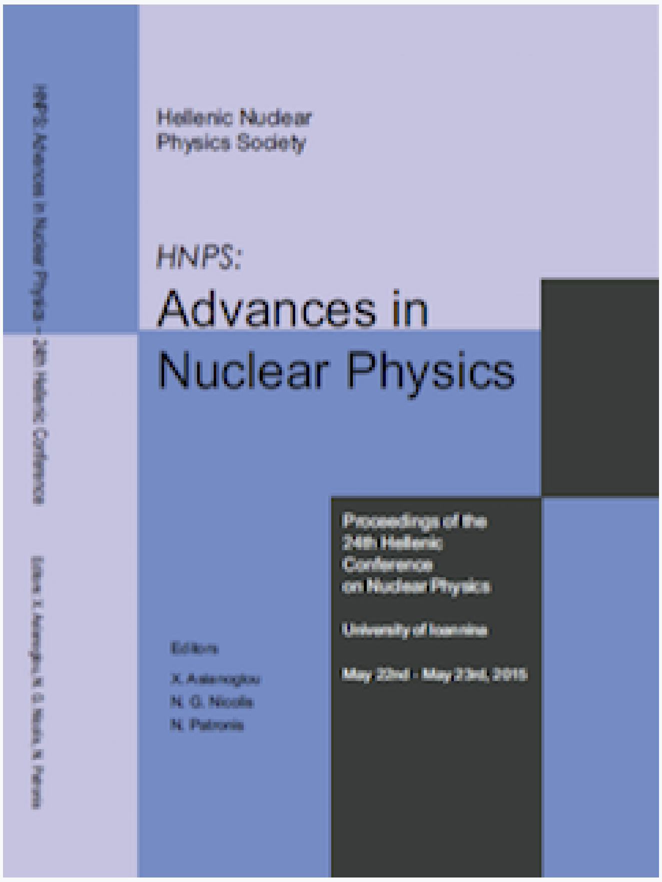
HNPS Advances in Nuclear Physics

Vol 23 (2015)

HNPS2015



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doi: 10.12681/hnps.1892

Computational study of the neutron flux produced by the $^{2}H(d,n)^{3}He$ reaction

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Abstract

Quasi-monoenergetic neutron beams, in the energy range of 4-10 MeV produced via the $^{2}H(d,n)^{3}He$ reaction, have been used for cross section measurements at the 5.5 MeV tandem T11/25 Accelerator Laboratory of NCSR "Demokritos". For accurate cross section measurements, it is important that the energy profile of the neutron beam and the experimental conditions are well characterized. Therefore, an investigation of the energy dependence of the neutron fluence, especially taking into account the deuteron break up phenomenon, has been carried out in the present work, using the recently developed analytical and Monte-Carlo simulation code NeusDesc. Fission experimental data from ^{238}U ultra-thin targets, were used to validate the simulated results. The fission fragments of the $^{238}U(n,f)$ reaction have been detected via MicroMegas detectors and using the well known cross section of the ^{238}U isotope, the neutron flux has been deduced. The simulated reaction rates were in good aggrement with the experiment ones, thus confirming the validity of the simulations.

EXPERIMENTAL DETAILS

EXPERIMENTAL MEASUREMENTS

The first part of this work, was the experimental measurements for the NeusDesc code validation. The experimental set up for the neutron beam productionat the tandem Accelerator Laboratory of NCSR "Demokritos" is shown Fig. 1. Neutrons produced via the $^{2}H(d,n)^{3}He$ reaction, irradiated a series of Uranium targets (^{238}U, ^{236}U, ^{238}U, ^{235}U) and the fission fragments from the (n,f) reactions were detected with Micromegas detectors. The ^{2}H target was a 3.7cm long gas cell with deuterium gas at a pressure of ~1bar with a 5μm Mo entrance foil and an 1mm pt beam stop foil.

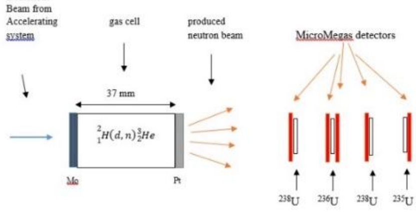

Figure 1: Experimental set-up

Apart from the main neutron beam parasitic neutrons were produced at lower energies, mainly arising from the deuteron break-up reaction $^{2}H(d,np)^{2}H$, but also from the $^{nat}Mo(d,n)$, $^{12}C(d,n)^{13}N$ and $^{16}O(d,n)^{17}F$ reactions.

In order to correct for all parasitic neutrons originating from (d,n) reactions on various low-Z materials along the beam line, collimators, deuteron gas-cell and surrounding materials, gas-in and gas-out measurements were performed using the set-up shown in Fig.1. The contribution of the parasitic neutron has been deduced by subtraction the charged normalized spectra of the fission fragments from the gas-in and gas-out irradiations.

The calculation of the experimental neutron flux (F) is explained by the following relation: $F\left(\frac{n}{cm^2 \cdot s}\right) = \frac{N_{ff}}{\sigma_{\left(^{238}U(n,f)\right)} \cdot N_t \cdot eff}$, where the N_{ff} is the pure fission fragments per second, the σ is the well known cross section of the $^{238}U(n,f)$ reaction according to the neutron energy range, the N_t is the number of target atoms calculated from the target mass and the eff (efficiency) is the number of fission fragments born and came out from the target.

NEUSDESC SIMULATIONS

The neutron flux in the energy range from 4-10 MeV, was simulated with the NeusDesc code and compared to the experimental results using the $^{238}U(n,f)$ reaction with very well known cross section, in order to validate the code. The neutron mean beam flux simulations are based on relativistic kinematics from Refs. [1],[2], while the deuteron breakup model uses non-relativistic kinematics [3]. The energy loss of the incident ions is calculated by dividing the target in 100 slices and calculating the stopping power, energy and angular straggling in every slice using the SRIM-2008 [4] code. The neutron yield calculated from: $Y=\Sigma\sigma_{d\text{-}d} * I * N_t$, where the I quantity is the rate of the deuteron beam and calculated from the current that is given as an input to the code, the N_t is the number of deuterium target persons calculated from the van der Waals equation of state using the length of the cell is given as an input to the code and the $\sigma_{d\text{-}d}$ is the cross section of the $^{2}H(d,n)$ reaction according to the deuteron energy beam. Finally, the simulated neutron flux is calculate at the required distance (d) by the formula: $F = \frac{Y}{d^2} \left(\frac{neutrons}{cm^2 \cdot s}\right)$. An example of neutron flux at a high level deuteron beam energy is shown in Fig. 2.

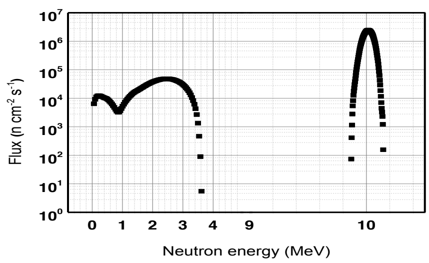

Figure 2: Neutron Flux from En=7150 Mev with the break up phenomenon.

RESULTS AND DISCUSION

A comparison between the neutron flux via simulation and experiment has been performed in low energies, where the deuteron break up phenomenon in neutron induced reactions does not exist, in order to determine the exact geometry and the description of the problem involved in the code. In this way, the reliability of the code for low energy neutrons before the appearance of the break up phenomenon has been ensured, in order to advance the study at higher neutron energies where the break up phenomenon is important. In order to eliminate any systematic error during the experiment, the comparison was made with the neutron flux rates between the front target distance and the back target distance. In the high energy region, the simulated reaction rates for the neutron induced fission on ^{238}U, were in good agreement with the experiment ones, thus confirming the validity of the simulations. Thus, the NeuSDesc code has been tested and validated in the whole neutron range from 4 to 10 MeV.

CONCLUSION

The simulated reaction rates, in the energy range from 4-10 MeV, were in good agreement with the experimental ones, thus confirming the validity of the simulations. Thus the NeuSDesc code can be reliably used in simple experimental geometry conditions and for the deuteron break up calculation up to En=10 MeV. In additional, input card from the NeuSDesc code can be used in complex geometry conditions with MCNP simulations. The proportion of the neutrons from deuteron break up phenomenon, compared to the total neutron flux per deuteron beam energy, is shown in Figure 2.

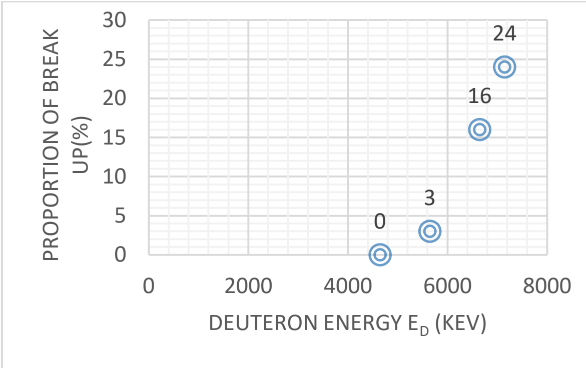

Figure 2: The proportion of the neutrons from deuteron break up phenomenon, compared to the total neutron flux.

It is observed that the deuteron break up phenomenon becomes important above En=6 MeV.

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