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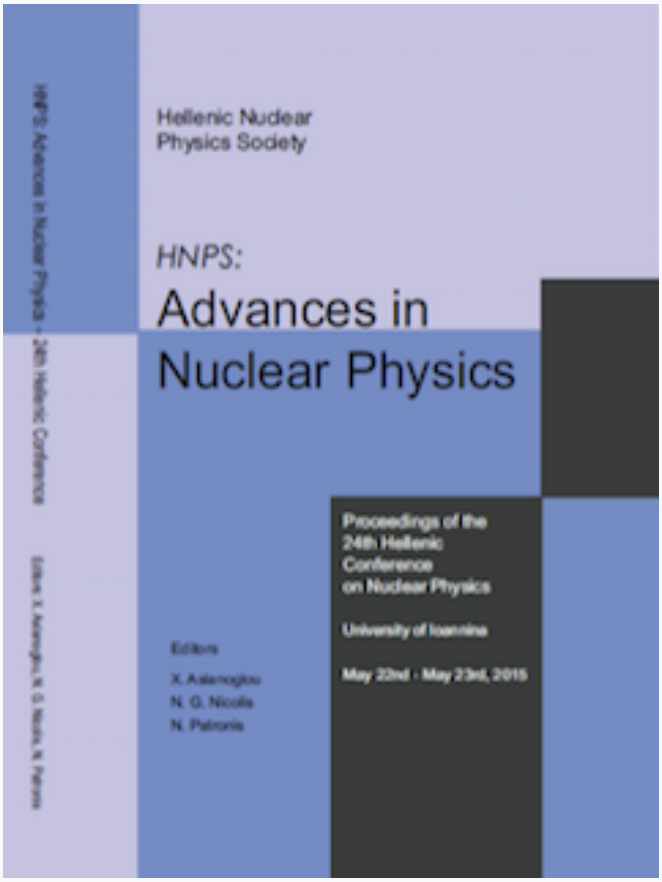

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Neutron Beam Characterization at the Athens Tandem Accelerator NCSR "Demokritos"

R. Vlastou[1], D. Sigalas[1], A. Kalamara[1], M. Kokkoris[1], M. Anastasiou[1], M.Diakaki[2], M. Axiotis[3], A.Lagoyannis[3]

[1]*Department of Physics, National Technical University of Athens, 15780 Athens, Greece.*
[2]*CEA/ Sarlay-DSM, Gif-Sur-Yvette, France.*
[3] *Institute of Nuclear Physics, NCSR "Demokritos", 15310 Aghia Paraskevi, Greece.*

Abstract A new Ti-tritiated target of 373 GBq activity has been installed at the 5.5MV tandem T11/25 Accelerator of NCSR "Demokritos", to produce neutrons in the energy range ~15-21 MeV by means of the $^{3}H(d,n)^{4}He$ reaction. The flux variation of the neutron beam is monitored with a BF_3 detector, while the absolute flux is obtained with respect to reference reactions, such as the $^{27}Al(n,a)$ reference reaction. In absence of time-of-flight capabilities, the energy spectrum of the neutron beam has been investigated by means of Monte Carlo simulations as well as by the Multiple Foil Activation Analysis technique, using reactions with different energy thresholds. The experimental results have been compared with the simulated ones in order to validate the simulations

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INTRODUCTION

Studies of neutron induced reactions are of considerable significance not only for their importance to fundamental research in Nuclear Physics and Astrophysics, but also for practical applications in nuclear technology, dosimetry, medicine and industry. All these tasks require improved nuclear data and accurate cross sections for neutron induced reactions at specific energies. However, neutron sources produced in the laboratory by accelerators in most cases are not purely monoenergetic. Apart from the primary-energy neutrons, low energy neutrons are present in almost all cases, due to neutron production and scattering near the source as well as to scattering effects in the experimental area. It is thus of importance that the performance of the neutron source is well understood and that the experimental conditions are well characterized [1,2].
In view of the above mentioned remarks and in absence of time-of-flight capabilities, the high energy neutron facility at the 5.5MV tandem T11/25 Accelerator of NCSR "Demokritos", has been characterized by means of the NeuSDesc and MCNP5 MonteCarlo simulations along with the multiple foil activation technique at various neutron energies.

THE EXPERIMENTAL PROCEDURE

In the 5.5 MV tandem T11/25 Accelerator Laboratory of NCSR "Demokritos" a new neutron facility has been installed, producing beams at energies ~ 15-21 MeV by means of the $^{3}H(d,n)^{4}He$ reaction. The corresponding beam energies obtained from the accelerator, were 1.5-4.5 MeV deuterons. The new Ti-tritiated target of 373 GBq activity, consists of 2.1

mg/cm2 Ti-T layer on a 1mm thick Cu backing for good heat conduction. The flange with the tritium target assembly is air cooled during the deuteron irradiation.
For the investigation of the neutron beam flux, the multiple foil activation technique has been applied, which is widely used for the determination of the neutron flux density around the irradiated samples along with unfolding techniques [2-4]. As a trial case of the facility, the deuterons were accelerated to energy 2.0 MeV and passed though two 5μm Mo foils in order to degrade their energy to 0.8 MeV, where the cross section of the $^{3}H(d,n)^{4}He$ reaction is high enough to produce neutron beam at 15.3 MeV at a flux of the order of $\sim 10^{6}$ n/s·cm^2. Two collimators of 5 and 6 mm diameter were used and the beam current was measured both at the collimators and the target and was kept at ~ 1 μA. During the irradiations, the flux variation of the neutron beam is monitored by a BF3 detector placed at a distance of 3 m from the neutron production. The spectra of the BF3 monitor were stored at regular time intervals (~200sec) in a separate ADC during the irradiation process. The absolute flux of the beam was obtained with respect to the cross section of the $^{27}Al(n,\alpha)$ reference reaction, which is well determined in literature and was found to be $\sim 4x10^{6}$ n/sec·cm^2.
High purity foils of natural Au, Ti, Fe, Al, Nb, and Co were placed in close contact at a distance of 1.7cm from the neutron beam production, as shown in Fig. 1 and were irradiated for several hours. The induced activity of product radionuclides from the irradiated foils was measured with three HPGe detectors of 16%, 50% and 100% relative efficiency, properly shielded with lead blocks to reduce the contribution of the natural radioactivity. The neutron induced reactions on these foils have different threshold energies ranging from ~0 to ~9 MeV neutron energy as presented in Table 1. The table contains the information concerning the energy threshold E_{thr} of each reaction and the effective energy threshold E'_{thr} where the reaction cross section becomes high enough to yield measurable reaction rates, the half lives $T_{1/2}$ of the residual nuclei as well as the most prominent γ-rays Eγ resulting from their deexcitation and their intensity Iγ.

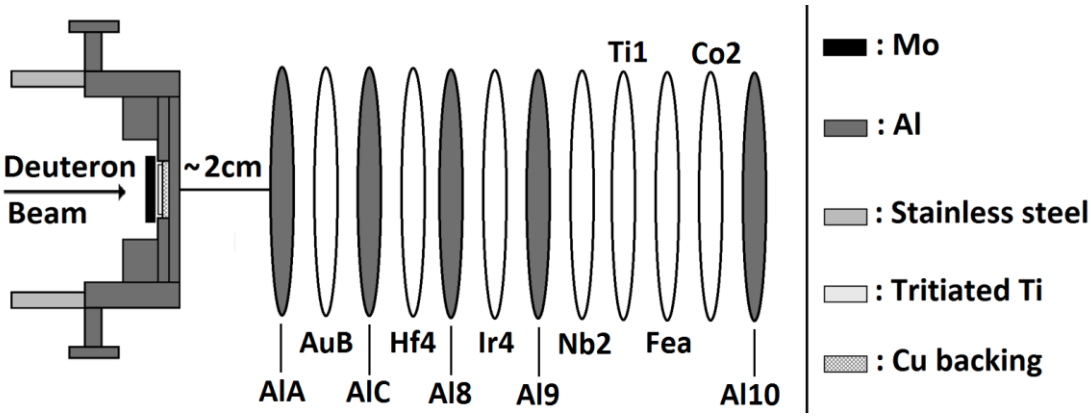

Fig. 1. Experimental set-up for neutron production and multiple-foil irradiation.

The efficiency of the detectors at the position of the activity measurements (10cm) was determined via a calibrated ^{152}Eu source. Corrections for self-absorption of the sample, coincidence summing effects of cascading gamma rays and counting geometry were taken

into account along with the decay of product nuclides over the whole time range and the fluctuation of the neutron beam flux over the irradiation time.

Reaction	$T_{1/2}$	E_γ(keV)	I_γ	E_{thr}(MeV)	E'_{thr}(MeV)*
$^{197}Au(n,\gamma)^{198}Au$	2.69 d	411	98.6%		
$^{47}Ti(n,p)^{47}Sc$	3.34 d	159.4	68%	0	2.3
$^{46}Ti(n,p)^{46m+g}Sc$	83.83 d	889,3 1120.5	99.98% 99.99%	1.8	3.5
$^{56}Fe(n,p)^{56}Mn$	2.58 h	846.75	98.9%	2.97	6.0
$^{27}Al(n,\alpha)^{24}Na$	14.96 h	1369	100%	3.25	6.8
$^{48}Ti(n,p)^{48}Sc$	1.82 d	983.5	100%	3.2	7.0
$^{197}Au(n,2n)^{196}Au$	6.18 d	356	87%	8.11	8.2
$^{93}Nb(n,2n)^{92m}Nb$	10.1 d	934.44	99.07%	8.93	9
$^{59}Co(n,\alpha)^{56}Mn$	2.58 h	846.75	98.9%	0	9.1

Table 1. List of reactions used for the multiple foil activation analysis along with their energy threshold E_{thr}, effective energy threshold E'_{thr} , half lives $T_{1/2}$ of the residual nuclei, energyE_γ of the most prominent γ-rays and their intensity I_γ.

The reaction rate R_i was deduced from the analysis of the experimental spectra for each reaction i, according to the following expression:

$$R_i = \frac{\lambda_i \mathrm{N}_i(t_B)}{\mathrm{N}_{\pi i}[1-\exp(-\lambda_i t_B)]}$$

with $N_i(t_B)$ being the number of residual nuclei, with decay probability λ_i, produced during the neutron activation time t_B and N_{Ti} the number of target nuclei for each reaction i listed in Table 1. The results of the reaction rates are shown as squares in Fig. 2.

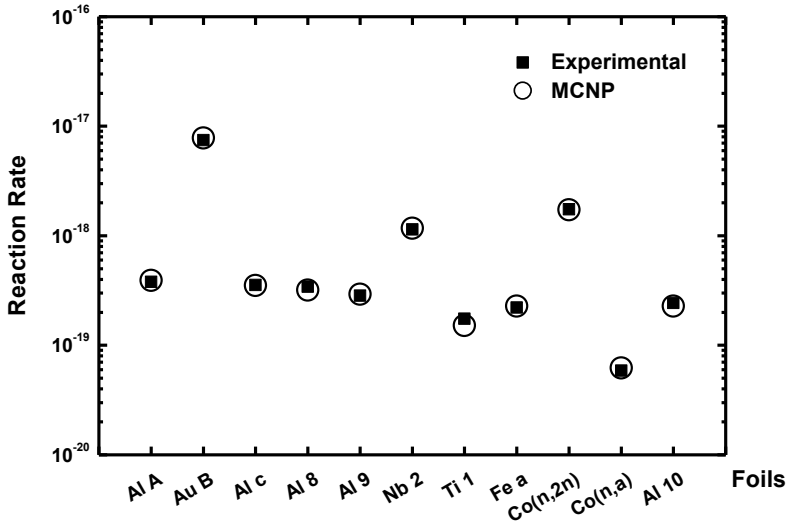

Fig. 2. The experimental and simulated Reaction Rate for the irradiated foils

MONTE CARLO SIMULATIONS

In absence of time-of-flight capabilities, the investigation of neutron fluence energy dependence has been carried out using the Monte Carlo simulation codes NeuSDesc [5] and MCNP [6]. The NeuSDesc software (developed at IRMM) estimates the neutron energy distribution at any distance, taking into account the details of the tritiated target. The output can then be used as input for MCNP simulations in order to include all the other details of the experimental setup (Al flange, Cu backing, target foils etc). The results of the MCNP simulations for the neutron fluence on three Al foils at the front, in the middle and at the end of the multiple foil stack (named Al A, Al 9 and Al 10), are shown in Fig.3. It can be seen that the peak neutron fluence on the last Al foil is reduced by 40% compared to that of the first Al foil due to the number of the in-between foils of Au, Hf, Ir, Nb, Ti, Fe and Co, while the contribution of the foils in the two peaks of the parasitic low energy neutrons varies from 33% around 1MeV and 10% around 12.5MeV. The main origin of these two parasitic neutron peaks arises from the Ti and Cu backing of the Tritium target along with the Al flange.

In order to test the reliability of the simulations, the neutron spectral distribution of Fig.3 has been used to calculate the reaction rates of the reations shown in Table 1 by using the expression :

$$R.R = \int_{Eth,i}^{\infty} \sigma_i(E) \cdot \Phi_i(E)\ dE$$

where $\sigma_i(E)$ are the excitation functions of the reactions taken from the ENDF-VII Library and $\Phi(E)$ the function of the neutron fluence normalized to the experimental fluence on each foil. In fact, the normalized neutron spectral distribution has been cut in energy slices ΔE starting from the threshold of each reaction up to the maximum neutron energy 15.3 MeV and the sum $R.R = \sum_{\Delta E} \sigma(E) \cdot \Phi(E)$ has been deduced. The results are shown as circles in Fig. 2 and are seen to agree well with the experimental values of the reaction rates, thus verifying the reliability of the simulations.

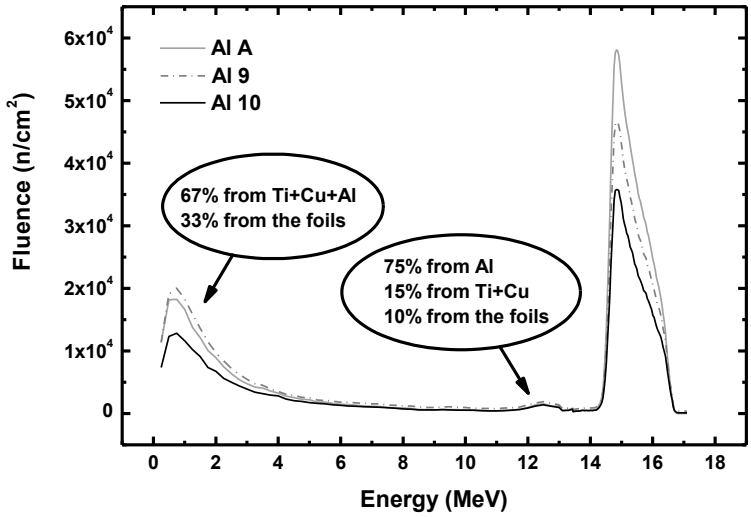

Fig. 3. The simulated neutron fluence at 15.3 MeV on the first (Al 9), middle (Al 9) and last (Al 10) Al foils

SUMMARY

A comprehensive understanding of the energy dependence of the neutron flux is of major importance for the reliability of neutron induced reaction cross section measurements. For the investigation of the quasi-monoenergetic neutron beams produced via the ^{3}H(d,n) reaction at the tandem Laboratory of NCSR "Demokritos", the multiple foil activation method has been applied along with Monte Carlo simulations implementing the NeuSDesc and MCNP codes. In addition, MCNP5 simulations indicated that the scattered neutrons from distant objects do not significantly influence the neutron flux close to the gas cell, where the actual cross section measurements take place and that only masses close to the target area would affect the beam.

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