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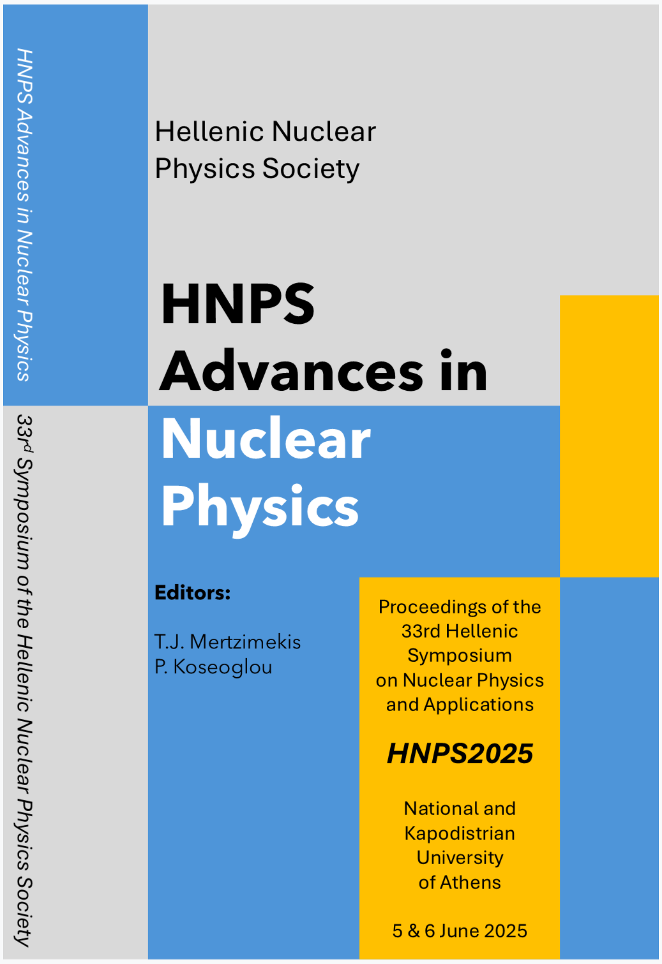

Neutron Activation Cross Section Measurement of the (n,2n) Reaction on ^{203}Tl at 14.6 MeV

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ARTICLE

Neutron Activation Cross Section Measurement of the (n,2n) Reaction on ^{203}Tl at 14.6 MeV

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Abstract
In the present work an experimental measurement of the ^{203}Tl(n,2n)^{202}Tl reaction cross section is presented, at the incident energy $E_{n,lab}$ = 14.6 MeV, using the activation technique, relative to the reference reaction ^{27}Al(n,a)^{24}Na. The experiment took place at the 5.5MV TANDEM Van de Graaff accelerator of N.C.S.R. "Demokritos", and the neutron beam was produced via the ^{3}H(d,n)^{4}He reaction. The foils were irradiated under an 80° angle. A BF_3 detector was utilized to monitor the neutron flux during the irradiation. The irradiated foils were placed in front of HPGe detectors to measure the induced activity by gamma-ray spectroscopy. The neutron fluence was simulated using the MCNP software.

Keywords: neutron activation; cross section measurement; thallium

1. Introduction

Thallium has many applications of immense significance, particularly in nuclear medicine [1], pharmaceuticals, infrared detectors, fiber optics and electronics. Hence, investigating neutron-induced nuclear reactions on thallium is an undertaking of great importance, as it can provide vital information on the field of nuclear physics and applications. However, there is little data available in literature regarding neutron-induced reactions on both stable isotopes of thallium [2, 3]. Additionally, there are many inconsistencies amongst the existing experimental data, particularly in the 11 to 15 MeV energy range, as shown in Fig. 1. Natural thallium consists of two stable isotopes: ^{203}Tl, (abundance of 29.515%), and ^{205}Tl (abundance of 70.485%) [4]. As the measurement was performed at the incident neutron energy of 14.6 MeV, only the ^{203}Tl(n,2n)^{202}Tl reaction channel was both open and measurable with the activation technique. ^{202}Tl decays via the electron capture (EC) process to ^{202}Hg, with a half-life of 12.47 d, while ^{202}Hg de-excites by emitting a gamma ray with 439.5 keV energy and an intensity of 91.5%.

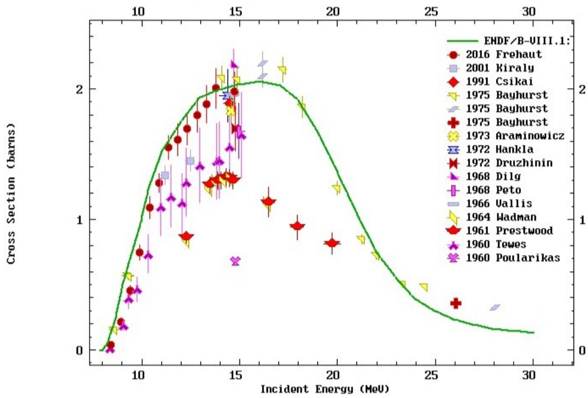

Figure 1. Existing experimental data for the ^{203}Tl(n,2n)^{202}Tl reaction, alongside the evaluation library ENDF/B-VIII.1.

2. Experimental Procedure

The experiment took place at the 5.5 MV TANDEM Van de Graaff accelerator at the neutron facility of N.C.S.R. "Demokritos" [5]. The neutrons were produced via the ^{3}H(d,n)^{4}He reaction, which can deliver quasi-monoenergetic neutron beams in the energy range of 16 to 20 MeV. However, in order to reach energies lower than 16 MeV (in our case 14.6 MeV), one should ideally use a different reaction. Since the other available reactions for neutron production at the N.C.S.R. "Demokritos" do not cover the range 11.5-16 MeV, that solution was unfeasible. Therefore, a different approach was required. The abovementioned energy range for the ^{3}H(d,n)^{4}He reaction refers to the energy of neutrons produced under a 0° angle in relation to the direction with which the deuteron beam hit the tritiated titanium target. At a different angle, due to the kinematics of the reaction, the energy decreases. A clear example of this is illustrated in Fig. 2, for five separate neutron energies relative to the angle under which the sample is placed. Additionally, the cross section of the reaction (and therefore the fluence) decreases at angles $\theta > 0^\circ$ in accordance with a factor analogous to the Legendre polynomials $P_l(\cos\theta)$. Hence, to obtain lower neutron energies, the samples were placed at 0° and 80° angles with regards to the beam, and 7 cm away from the Ti-T target. It also follows that the neutron fluence under that angle is lower by approximately 8 times compared to the neutron beam delivered in a straight line. This set-up was successfully used for the first time at N.C.S.R. "Demokritos" and is adequate for cross section measurements at neutron energies below 16 MeV, provided that the cross section of the reaction is high enough to get reasonable statistics as the neutron fluence is low.

The thallium chloride (TlCl) pellet used for the experiment weighed approximately 1 g and had a diameter of almost 13 mm. It was placed between two aluminum foils, which were utilized to determine the neutron fluence via the reference reaction ^{27}Al(n,α)^{24}Na. The fluctuations of the neutron beam were recorded using an uncalibrated BF_3 detector, located about 3 m away from the tritiated titanium target, and were accounted for in the data analysis stage. The irradiation lasted a little over 4 h, and once it was concluded, the samples were promptly placed in front of two HPGe detectors with a relative efficiency of 80%. The absolute efficiency of those detectors was obtained with a calibrated point source of ^{152}Eu, which was placed at the same distance as the activated samples. Utilizing Monte Carlo simulations (MCNP5 [6]), the yield of the gamma-ray transitions originating in the decay of the product nuclei was corrected for the self-absorption in the irradiated sample along with the efficiency corrections due to the different geometry of the samples compared to the point source.

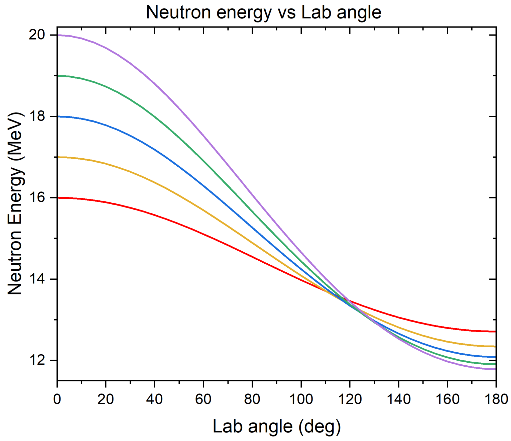

Figure 2. Presentation of the dependence of neutron energy on the angle under which the sample is placed in the laboratory.

3. MCNP Simulations

In neutron-induced reactions an accurate simulation of neutron fluence is vital, as the neutrons are chargeless particles which cannot be easily measured directly. Hence, the experimental neutron fluence (which is calculated with respect to the reference reaction (27]Al(n,α)^{24}Na) is used in conjunction with Monte Carlo simulations to determine with a high degree of precision the number of neutrons passing through and potentially interacting with the TlCl pellet during the irradiation. In our case, those simulations were carried out utilizing the MCNP5 code. The geometry of the experiment was reproduced in the simulation as shown in Fig. 3. The simulated neutron source was created utilizing NeuSDesc [7]. The mean neutron beam energy and its associated uncertainty were estimated from the extracted neutron spectrum using Monte Carlo simulations performed with the MCNP code.

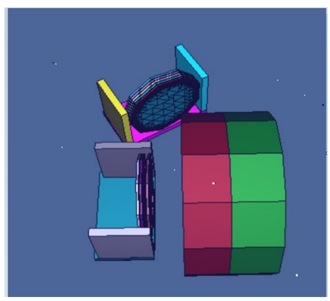

Figure 3. Representation of the objects included in the MCNP5 simulation; the tritiated titanium target, alongside the assortment of foils used in the experiment.

4. Data Analysis and Results

The experimental cross section of the ^{203}Tl(n,2n)^{202}Tl reaction was determined with respect to the ^{27}Al(n,α)^{24}Na reaction. The cross section of the reference reaction was obtained from the evaluation library IRDFF-II. The number of target nuclei was calculated based on the mass of each foil. For the TlCl pellet, the mass of the cellulose was subtracted in order to calculate the mass of the relevant thallium isotope. The correction factor accounting for the neutron beam fluctuations included a correction for the decay of the product nuclei during the irradiation. In addition, a different correction factor was used to describe the decay of the radioactive nuclei for the time elapsing after the conclusion of the irradiation and before the activated sample was placed in front of the HPGe detector for the acquisition of the gamma ray spectrum.

The preliminary cross section value at 14.6 MeV is shown as a red circle in Fig. 4, in comparison with the evaluated library ENDF/B-VIII.1, as well as the most recent data (after 1970) available in EXFOR. It can be observed that the current estimation is in good agreement with the rest of the data around this energy, with the sole exception of Druzhinin et al. (1972) [8]. It is especially encouraging that the most recent data set, produced by Frehaut (1980) [9] and subsequently corrected by Granien (2016) [10], is in good agreement with our estimates. Additionally, the ENDF/B-VIII.1 library is consistent with our estimation.

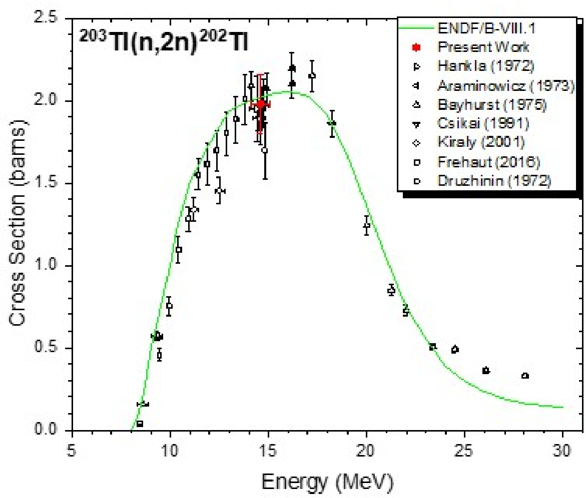

Figure 4. The preliminary experimental cross section of the (n,2n) reaction on ^{203}Tl at 14.6 MeV is presented in red, while the ENDF/B-VIII.1 library is represented by a green line. The most recent experimental data (from 1970 and onwards), are displayed in black and white symbols.

5. Summary

The measurement of the cross section of the reaction ^{203}Tl(n,2n)^{202}Tl relative to the ^{27}Al(n,α)^{24}Na reaction was obtained at the incident neutron energy of 14.6 MeV, at the neutron facility of the 5.5 MV TANDEM Van de Graaff Accelerator at N.C.S.R. "Demokritos". The irradiation lasted circa 4 hours, and once it concluded, the activated samples were placed in front of two HPGe detectors. An extensive Monte Carlo simulation was utilized in order to accurately determine the neutron fluence on the TlCl pellet. The experimental cross section calculated is consistent with both the past estimates of other researchers, and the most recent evaluated library.

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