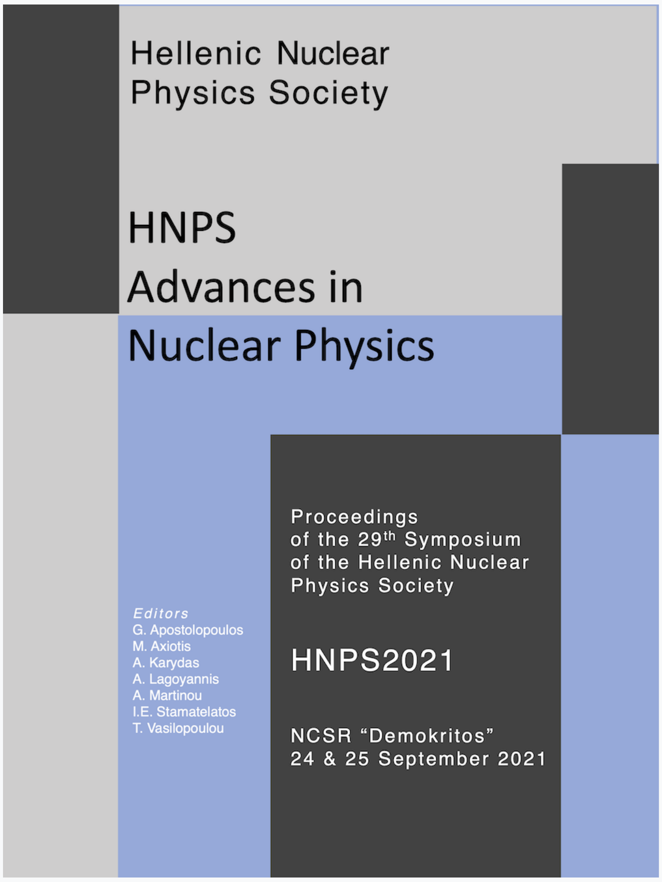
HNPS Advances in Nuclear Physics

Vol 28 (2021)

HNPS2021



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doi: 10.12681/hnps.3713

To cite this article:

Patas, S. (2022). Activation Cross Section Measurement of the (n,2n) Reaction on 203Tl. *HNPS Advances in Nuclear Physics*, *28*, 242–246. https://doi.org/10.12681/hnps.3713 doi: 10.12681/hnps.3713

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

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Abstract The aim of the present work was to study the cross-section of the (n,2n) reaction on ^{203}Tl, by irradiating a natural TlCl pellet target with monoenergetic neutron beam at 18.9 MeV. The cross section of the ^{203}Tl(n,2n)^{202}Tl reaction, was measured implementing the activation method, with respect to the ^{197}Au(n,2n)^{196}Au and ^{27}Al(n,α)^{24}Na reference reactions. The monoenergetic neutron beam was produced in the 5.5 MV Tandem accelerator of NCSR Demokritos, using the ^{3}H(d,n)^{4}He reaction. After the irradiation, the induced activity of the samples was measured with a HPGe detector, which was properly shielded with lead blocks to reduce the contribution of natural radioactivity. Monte Carlo simulations implementing the MCNP code have been performed to take into account the gamma-ray self-absorption results as well as the estimation of the neutron flux through the reference foils. Finally, a comparison of theoretical calculations with the code EMPIRE and experimental data was carried out, with the aim of finding a suitable model for the description of the reaction cross section under study.

Keywords neutron activation analysis, cross section measurements, Monte Carlo simulations, Empire code theoretical calculations

INTRODUCTION

Studies of neutron-induced reactions are of considerable significance, both for their importance to basic research in Nuclear Physics and Astrophysics [1-3] as well as for practical applications in nuclear technology, medicine and industry. Thallium is widely used in pharmaceuticals, electronics, fiber optics, infrared detectors and nuclear medicine. However, little information is available in literature for neutron induced reactions on Tl isotopes, with many discrepancies among the existing experimental data, especially in the energy region above ~14 MeV, as shown in Fig. 1.

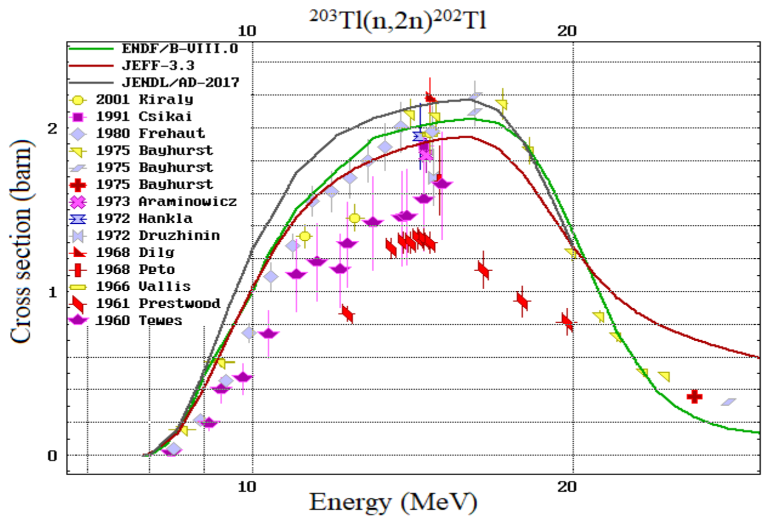

Figure 1: *Existing experimental data of* ^{203}*Tl(n.2n)*^{202}*Tl reaction [4,5].*

Of the two isotopes contained in natural thallium (^{205}Tl and ^{203}Tl with 70.47% and 29.53% abundances, respectively), only the ^{203}Tl can be studied using the neutron activation technique. The possible exit channels for 18.9 MeV neutrons impinging on ^{203}Tl, are presented in Fig. 2 and it is seen that only the ^{203}Tl(n,2n)^{202}Tl reaction will be investigated, since the produced nucleus ^{202}Tl de-excites via the 439.5 keV γ-ray with intensity Iγ = 91% and half-life of 12.31 days.

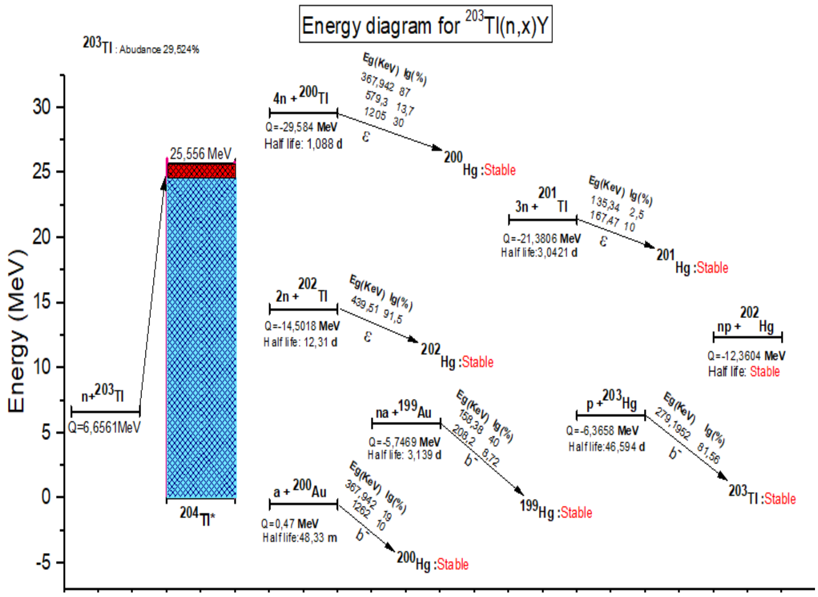

Figure 2: *Energy diagram for the ^{203}Tl(n,x)Y reaction.*

EXPERIMENTAL DETAILS

The experiments were carried out at the 5.5 MV Tandem accelerator of N.C.S.R. "Demokritos". The neutron beam, at 18.9 MeV, was produced via the ^{3}H(d,n)^{4}He reaction.

The Tl target was a natural TlCl pellet of ~1 g mass and 13 mm diameter, while the refrence targets were high purity Al and Au foils of the same diameter. The target and reference foil assembly was placed at approximately 1.5 cm from the tritium target, thus limiting the angular acceptance to ±23.5°, where the produced neutrons are practically isotropic and monoenergetic. The fluctuation of the neutron beam flux was monitored with a BF_3 detector located at 3m from the neutron source. The irradiation lasted for about 28 hours.

The irradiated samples were placed in front of a HPGe detector (of 80% relative efficiency), at 10 cm distance, thus eliminating the summing effect. For the reduction of the natural background radioactivity, the detector was properly shielded with lead blocks. The measurement completed after approximately 1 week The experimentally derived spectrum of the irradiated pellet is shown in Fig. 3.

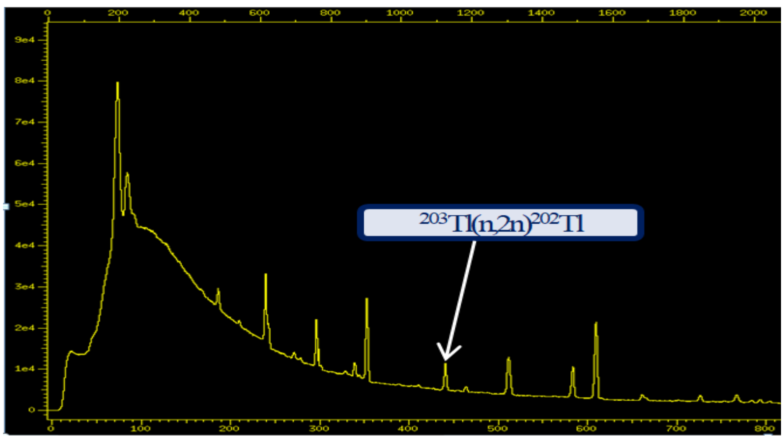

Figure 3: Energy spectrum of the irradiated Tl pellet measured by a HPGe detector with 80% relative efficiency

DATA ANALYSIS AND RESULTS

The cross section of the ^{203}Tl(n,2n)^{202}Tl reaction, was measured implementing the activation method, with respect to the ^{197}Au(n,2n)^{196}Au and ^{27}Al(n,α)^{24}Na reference reactions. The neutron flux

Φ calculated from the experimental data had a satisfactory agreement with the MCNP5 [6] Monte Carlo simulations for the neutron flux, with a 0.1% deviation among them, as shown in Fig. 4.

For the calculation of the cross section **σ**, as described in [7], the formula below has been used:

$$\boldsymbol{\sigma} = \frac{N_P}{N_\tau}\frac{1}{\Phi} \quad ,$$

N_τ : the number of target nuclei irradiated.

N_p : the number of nuclei produced by the irradiation, calculated by the formula :

$$N_p = \frac{\text{Counts}}{\varepsilon \cdot F \cdot I_\gamma \cdot D \cdot f_c}$$

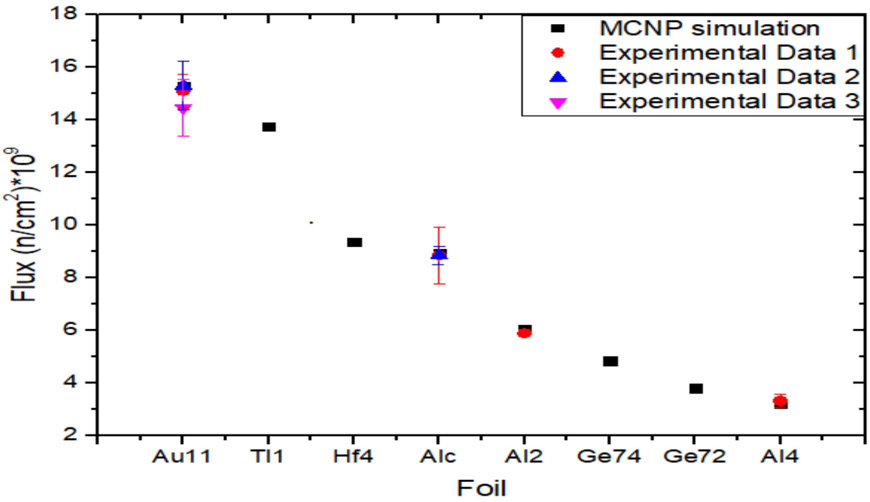

Figure 4. *Comparison of neutron fluxes (MCNP code – Experimental Data) [6]*

Counts : the number of the integrated peak counts.

ε : the absolute efficiency of the HPGe (80%) detector for the energy 439.5 keV.

F : corrective factor for the extended geometry of the measurement and self-absorption on target materials.

I_γ : intensity of the γ – ray peak of interest (439.5 keV).

D : corrective factor through which the de-excitation of the produced ^{202}Tl nuclei is taken into account, from the end of the irradiation, until the end of the activity measurement.

f_c : a correction factor that calculates the balance between production and de-excitation of nuclei during the irradiation.

The calculation of the cross section **σ**, from this experiment, for the the **^{203}Tl(n,2n) ^{202}Tl** reaction, as shown in Fig. 5, resulted in:

σ = 1.40 ± 0.06 barn.

THEORETICAL CALCULATIONS

In pursuit of finding a suitable optical model for the description of the reaction cross section under study, theoretical calculations, with the code EMPIRE [8,9] based on the Hauser-Feshbach theory [10], in comparison with the experimental data was carried out.

The best agreement between theoretical calculations with the Empire code and experimental data was achieved with O. Bersillon 1975 [11] optical model with a specific set of parameters :

- **EMPIRE-specific level densities**, adjusted to RIPL-3 experimental observation data and to discrete levels, described according to the Enhanced Generalized Superfluid Model (EGSM) [12].
- **Enabled MSD**: This approach to statistical Multi-step Direct reactions is based on the Multi-step Direct theory of preequilibrium scattering to the continuum [13].
- **Enabled MSC**: Multi-step Compound processes follows the approach of the NVWY theory [14].
- **PCROSS 1.5**: The module PCROSS includes the pre-equillibrium mechanism as defined in the exciton model [15].
- **Disabled Direct input** [16].

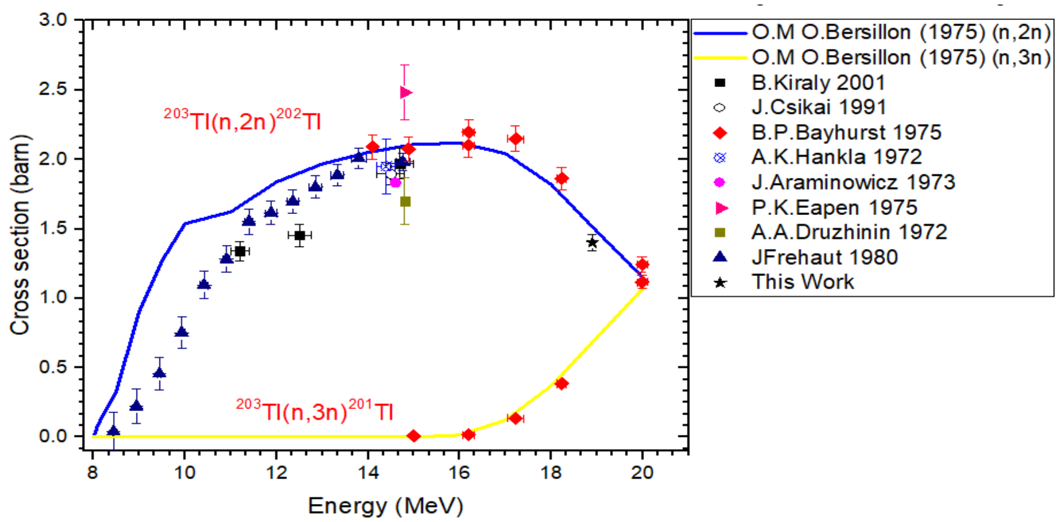

Figure 5: *The experimental point from the present work along with existing experimental data (since 1970) [5], and EMPIRE code theoretical calculation [8,9].*

The results of the calculations are shown in Fig. 5 for the ^{203}Tl(n,2n) (*blue line*) and ^{203}Ti(n,3n) (*yellow line*) as well as for the ^{205}Tl(n,2n) in Fig. 6. The agreement between the experimental data and the theoretical calculations is quite satisfactory. Further measurements are planned in the near future to cover the energy range up to 20 MeV.

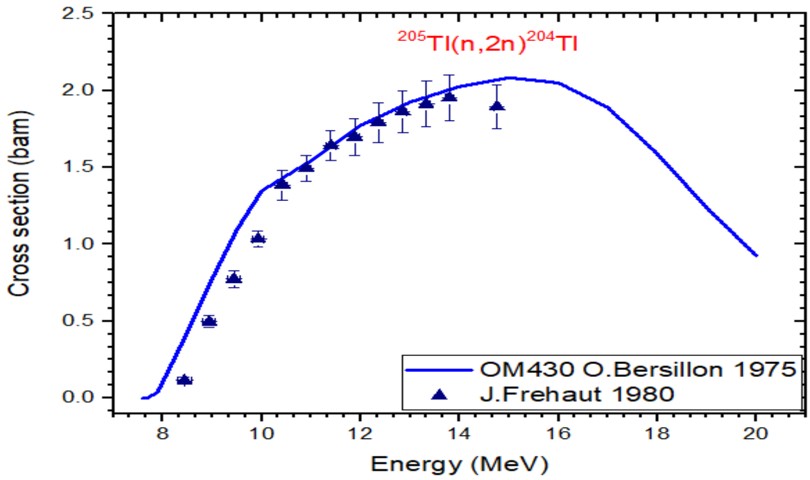

Figure 6: *Existing experimental data of J. Frehaut and EMPIRE code theoretical calculations [5,8,9]*

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