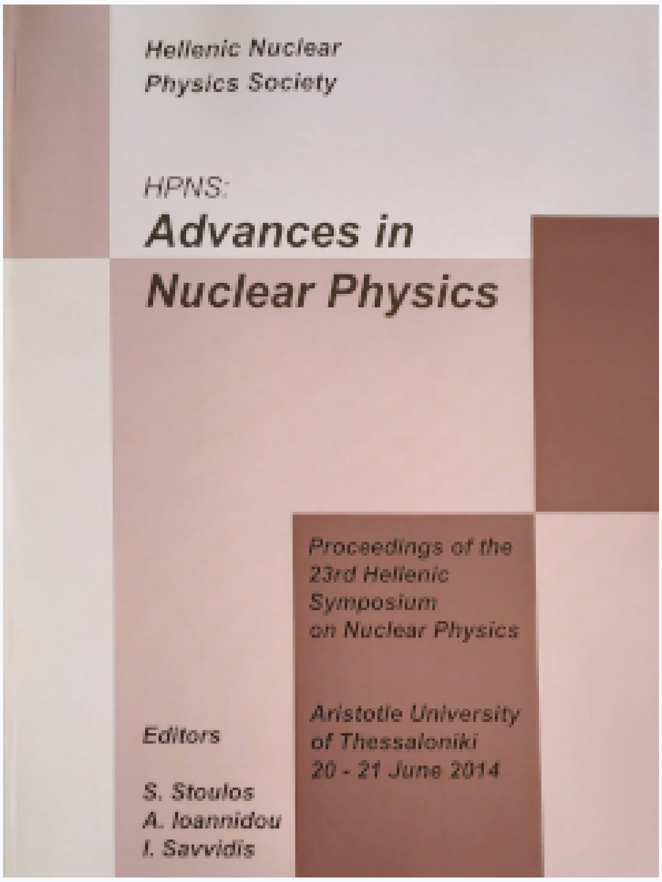
HNPS Advances in Nuclear Physics

Vol 22 (2014)

HNPS2014



Activation cross section for the (n,2n) reaction on 197Au

A. Kalamara, M. Serris, M. Anastasiou, M. Diakaki, M. Kokkoris, N. Patronis, V. Paneta, M. Axiotis, A. Lagoyannis, R. Vlastou

doi: [10.12681/hnps.1930](https://doi.org/10.12681/hnps.1930)

Activation cross section for the (n,2n) reaction on ^{197}Au

A. Kalamara[1], M.Serris[4], M.Anastasiou[1], M. Diakaki[1], M. Kokkoris[1], N.Patronis[3],V.Paneta[1,2], M.Axiotis[2], A. Lagoyannis[2] and R. Vlastou[1]

[1]*Department of Physics, National Technical University of Athens, 15780 Athens, Greece.*
[2] *Institute of Nuclear Physics, NCSR "Demokritos", 15310 Aghia Paraskevi, Greece.*
[3] *Department of Physics, University of Ioannina, 45110 Ioannina, Greece.*
[4] *Hellenic Army Academy, 16673 Vari, Athens, Greece.*

Abstract

The cross section of the reaction channels ^{197}Au(n,2n)^{196}Au^{g+m1} and ^{197}Au(n,2n)^{196}Au^{m2} has been experimentally determined at 15.3 MeV, relative to the ^{27}Al(n,α)^{24}Na reference reaction, using the activation technique. The irradiation was carried out at the 5 MV tandem T11/25 Accelerator Laboratory of NCSR "Demokritos" with monoenergetic neutron beam provided by means of the ^{3}H(d,n)^{4}He reaction, using a new Ti-tritiated target of 373 GBq activity. The induced γ- ray activity was measured with a high resolution HPGe detector.

1. Introduction

Accurate neutron-induced reaction cross sections are of considerable importance for fundamental research in Nuclear Physics and Astrophysics as well as for practical applications in nuclear technology, medicine and industry [1,2]. Although a lot of cross section data have been measured in the energy region up to 14 MeV, in order to validate different model calculations and investigate reaction mechanisms, data are needed at higher energies, above 15 MeV, where the pre-equilibrium emission (PE) becomes important and more reaction channels are open. In particular, ^{196}Au produced via the (n,2n) reaction on ^{197}Au, presents an interesting isomeric pair: ground and isomeric states with spin values of 2^- and 12^-, respectively [3,4]. The presence of these, high- spin, isomeric states in the residual nucleus provide a sensitive test for testing nuclear model parameters and due to the fact that the existing data in literature for the second isomeric state are limited, further measurements on ^{197}Au are needed.

Thus, the purpose of this work was the experimental determination of the cross section of the reaction channels ^{197}Au(n,2n)^{196}Au^{g+m1} and ^{197}Au(n,2n)^{196}Au^{m2} at incident neutron energy 15.3 MeV. These measurements are complementary to previous ones at 17.1 MeV from our group [5]. The cross section for the population of the second isomeric state (12^-) of ^{196}Au and the sum of the ground (2^-) and the first isomeric state (5^+) cross sections were independently determined. The neutron beam has been produced at the 5.5MV tandem T11/25 Accelerator of NCSR "Demokritos" via the ^{3}H(d,n)^{4}He reaction, implementing a new Ti-tritiated target of 373 GBq activity. Moreover, the neutron beam energy has been studied by means of Monte Carlo simulation codes [6,7] and the neutron flux has been determined via the ^{27}Al(n,α)^{24}Na reference reaction.

2. The Experimental Procedure

The measurement was carried out at the 5.5MV tandem T11/25 Accelerator of NCSR "Demokritos". Quasi-monoenergetic neutron beam was produced via the ^{3}H(d,n)^{4}He reaction, implementing a new Ti-tritiated target of 373 GBq activity, which consists of 2.1 mg/cm^2 Ti-T layer on a 1mm thick Cu backing for good heat conduction. The ~1.5 μA deuteron beam enters through two 5 μm 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 ~10^6 n/s·cm^2. The study of neutron energy spectra generated by deuterons on the Ti-T target was carried out using the code NeuSDesc, developed at IRMM by Birgerssone and Lovestam [7]. The results for the neutron flux at a distance of 18 mm from the Ti-T target are shown in Fig.1, compared to the MCNP5 [6] simulation results for the neutron flux at the same distance. Thus, the mean neutron beam energy was estimated to be 15.3 ± 0.5 MeV.

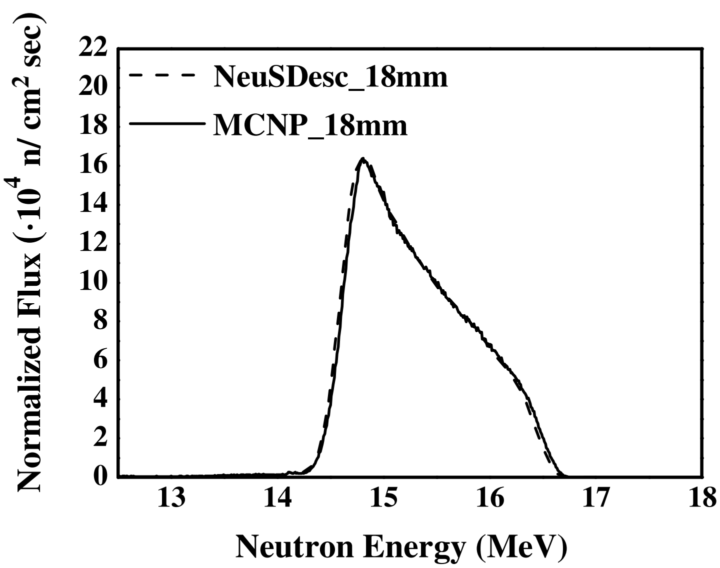


Fig. 1. Neutron flux calculated with NeuSDesc and MCNP codes at 18 mm distance from the Ti-T target.

The absolute flux of the beam was obtained with respect to the ^{27}Al(n,α)^{24}Na reference reaction and was found to be ~3.6x10^6 n/sec·cm^2. The variation of the neutron beam was monitored by a BF3 detector placed at a distance of 3 m from the neutron source. Data from the BF3 counter were stored at regular time intervals (200 s) by means of a multichannel scaler, and were used to correct for the decay of the product nuclei during irradiation and to account for fluctuations in the beam flux in the subsequent off-line analysis.

High purity Au and Al reference foils were placed at a distance of 1.8 cm from the neutron beam production and were irradiated for ~26 h. The induced activity of product radionuclides from the irradiated foils was measured with two HPGe detectors of 100% relative efficiency, properly shielded with lead blocks to reduce the contribution of the natural radioactivity. Gamma-ray spectra were taken at a distance of approximately 10 cm from the detectors and their efficiencies were determined via a calibrated ^{152}Eu source. Moreover, corrections for self absorption 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.

3. The interaction n+^{197}Au

The interaction n+^{197}Au is a compound nucleus reaction. When a neutron with energy 15.3 MeV impinge on a ^{197}Au nucleus, the compound nucleus ^{198}Au is produced in an excited state. The possible exit channels of the reaction are shown in Fig.2 and in the present work the ^{197}Au(n,2n)^{196}Au channel has been investigated, in which the residual nucleus is produced in an excited state.

The simplified decay scheme of the isomeric and ground states of the residual nucleus is presented in Fig.3. The population of the second isomeric state ($J^{\pi}=12^{-}$), which decays with a half-life of 9.7 h, has been measured through two γ-rays of 147.8 and 188.3 keV (Table 1). The measurements for the second isomeric state (m2) began ~1 h after the end of the irradiation and lasted up to 20 h (two half-lives).

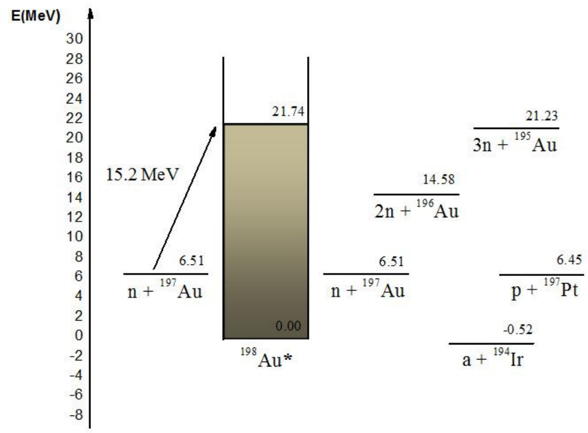


Fig. 2: Energy diagram for the $n+^{197}Au$ interaction.

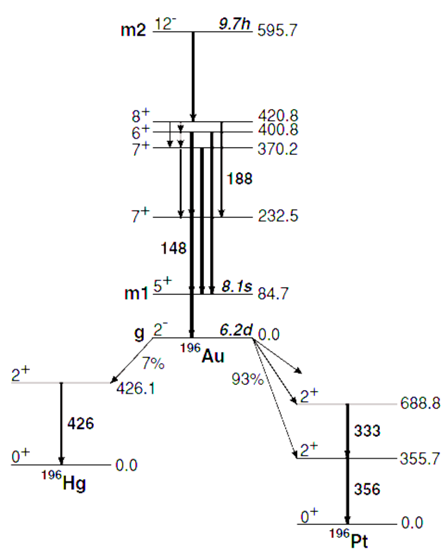


Fig. 3: Simplified decay scheme of the isomeric and ground states of the residual nucleus ^{196}Au. All energies are given in keV [3].

Due to the fact that the first isomeric state ($J^{\pi}=5^{-}$) decays with a half-life of 8.1s (relatively quickly), the measurements of the decay of the ground state ($J^{\pi}=2^{-}$) through the 355.7, 333.0, 426.0 keV γ-rays contains the population of both the ground (g) and the first isomeric state (m1). This measurement was carried out two days after the irradiation to ensure that the second isomeric state (m2) had fully decayed to the ground state (g). More details of the experimental technique are described in the work by Tsinganis et al. [3], presenting the measurements of the $^{197}Au(n,2n)^{196}Au$ reaction cross section carried out by our group at the T11/25 tandem Accelerator Laboratory of NCSR "Demokritos", in the energy range 9.0-10.5 MeV implementing the $^{2}H(d,n)$ reaction.

Table 1: Decay properties of the daughter nucleus.

Daughter nucleus	Half – life	γ- ray energy (keV)	Intensity per decay (%)
$^{196}Au^{g}$	6.18 d	355.7	87.0
		333.0	22.9
		426.0	7.0
$^{196}Au^{m2}$	9.6 h	147.8	43.5
		188.3	37.4

4. Results

The preliminary experimental results for the cross section of the ground and first isomeric state (g+m1) as well as the second isomeric state (m2) of the $^{197}Au(n,2n)^{196}Au$ reaction, are presented in Fig. 4 and Fig. 5, respectively, along with EXFOR data from literature.

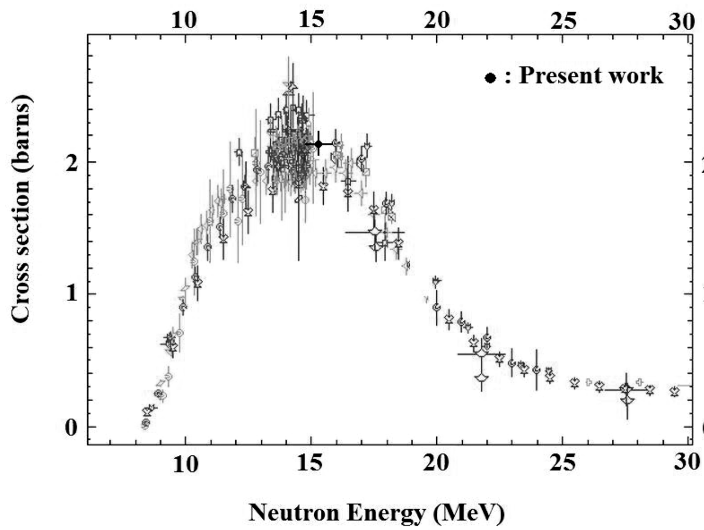


Fig. 4: Cross section data from the present work and EXFOR database of the $^{197}Au(n,2n)^{196}Au^{g+m1}$ reaction channel.

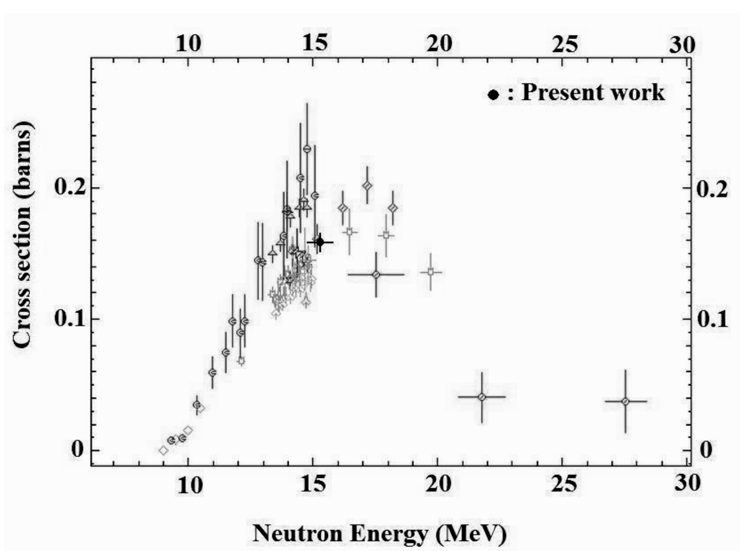


Fig. 5: Cross section from the present work and EXFOR database of the $^{197}Au(n,2n)^{196}Au^{m2}$ reaction channel.

5. Summary

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 ~ 15-20 MeV by using the $^{3}H(d,n)^{4}He$ reaction. The neutron beam energy has been studied by means of Monte Carlo simulation codes and the neutron flux has been determined via the $^{27}Al(n,a)$ reference reaction. The neutron beam at 15.3±0.5 MeV has been used for the cross section measurements of the (n,2n) reaction on ^{197}Au. The cross sections for the second isomeric state (σ_{m2}) and for the sum of the reaction cross section for the population of the ground and the first isomeric state (σ_{g+m1}) were measured independently. Furthermore, in order to study other possible exit channels of the interaction n+ ^{197}Au (i.e (n,p) channel, Fig.2) additional cross section measurements are planned at higher energies.

References

[1] P. Talou *et al.*, Nucl. Sci. Eng. **155** (2007) 84.
[2] A. Fessler *et al.*, Nucl. Sci. Eng. **134** (2000) 171.
[3] A. Tsinganis *et al*., Phys.Rev. **C83** (2010) 024609.
[4] M. Avrigeanou *et al*., Phys.Rev. **C85** (2012) 044618.
[5] R. Vlastou *et al*., Physics Procedia (2014), in press.
[6] J.F. Briesmeister, Ed., MCNP-A General Monte Carlo n-Particle Transport Code, version 4C, Report LA-13709, 2000.
[7] E. Birgerssone and G. Lovestam , JRC Scientific and Technical Reports (2007).