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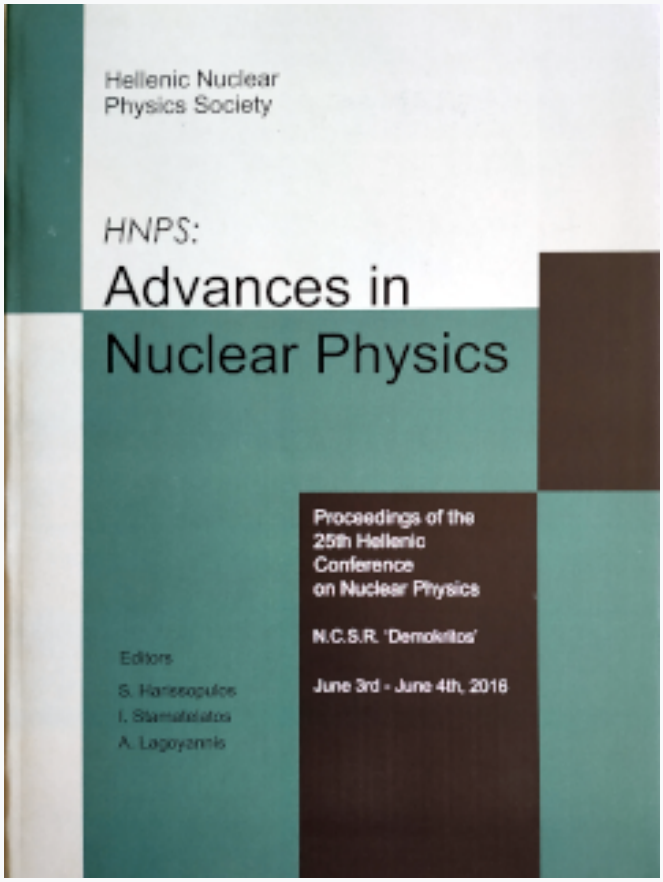

Study of the 193Ir(n,2n)192Ir Reaction Cross Section

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Study of the ^{193}Ir(n,2n)^{192}Ir Reaction Cross Section

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Abstract The ^{193}Ir(n,2n)^{192}Ir reaction cross section was measured relative to the ^{27}Al(n,a)^{24}Na and ^{197}Au(n,2n)^{196}Au reactions by means of the activation technique at two neutron beam energies: 10.0 and 10.5 MeV. The neutron beam was produced via the ^{2}H(d,n)^{3}He reaction. The deuteron beam was provided by the 5.5 MV Tandem Van de Graaff accelerator of the N.C.S.R. "Demokritos". After the irradiations the induced activity of the samples was measured through a 56% relative efficiency HPGe detector. The total reaction cross section for the population of the ground state (4^{+}) and the first isomeric state (1^{-}) was determined. The adopted method for the correction concerning the population of the product nucleus ^{192}Ir through the ^{191}Ir(n,γ)^{192}Ir reaction is also presented.

Keywords Nuclear Reactions, (n,2n) reaction cross section, neutron activation, Iridium

INTRODUCTION

Investigation of neutron threshold reactions is of considerable interest for testing and improving nuclear models. Refined experimental data for (n,2n) reactions combined with the corresponding theoretical calculations utilize the optimization of the parameterization of nuclear models towards to a deeper understanding of the reaction dynamics. In this way the nuclear processes that take place during the formation and the de-excitation of the compound nucleus can be studied in detail.

Concerning the ^{193}Ir(n,2n)^{192}Ir reaction cross section, in the energy region from the reaction threshold up to 14 MeV neutron beam energy the available experimental information is limited. Up to now the ^{193}Ir(n,2n)^{192}Ir reaction cross section has been measured only at two near threshold energies from Bayhurst et al. [1]. As can be seen in Fig. 1 where all the available experimental information is presented, in the energy region between 9.5 Mev and 14 MeV there are no data. Accordingly, within the present work the experimental study of the ^{193}Ir(n,2n)^{192}Ir reaction at two neutron beam energies: 10.0 MeV and 10.5 MeV was taken over. In the next sections the experimental details are presented along with the adopted data analysis techniques and preliminary results.

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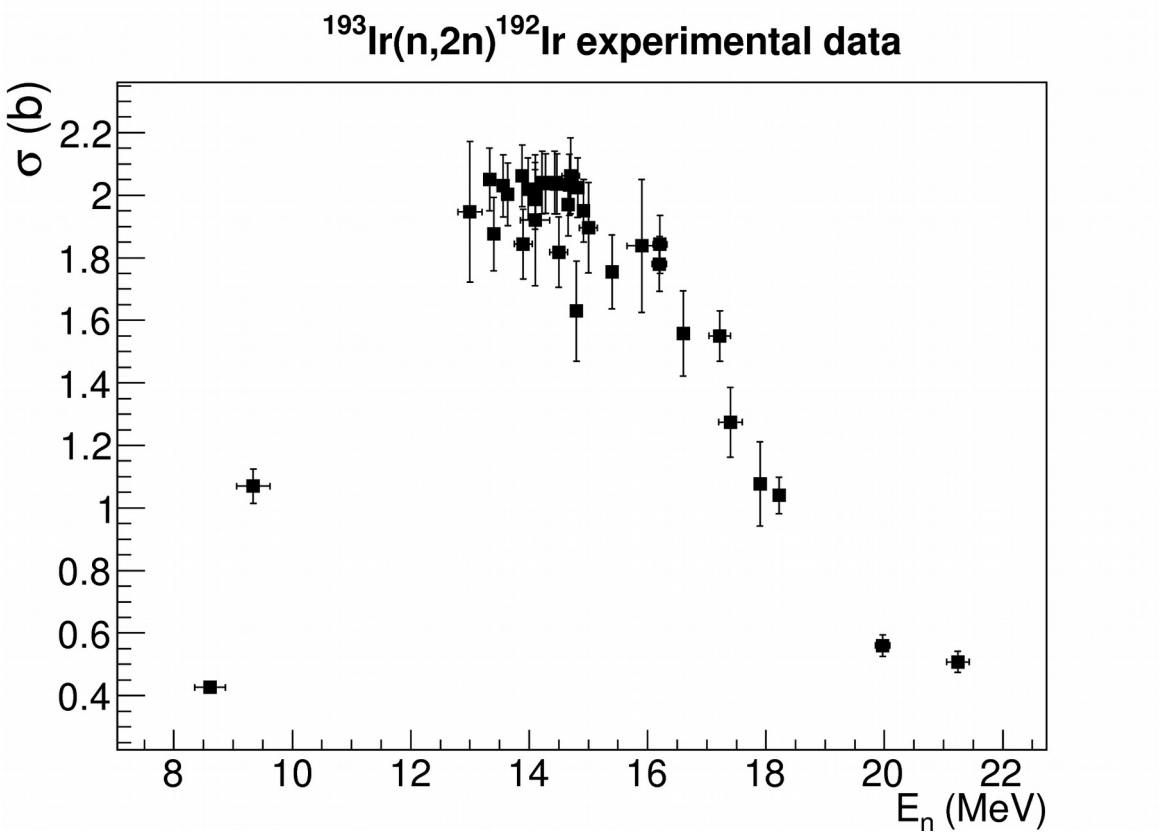

Fig. 1. Available experimental cross section data for the ^{193}Ir(n,2n)^{192}Ir reaction according to the EXFOR data base [2].

EXPERIMENTAL DETAILS

The ^{193}Ir(n,2n)^{192}Ir reaction cross section has been measured at energies 10.0 MeV and 10.5 MeV, by means of the activation technique. The irradiations were carried out at the 5.5 MV Tandem Van de Graaff accelerator of NCSR "Demokritos".

The neutron beam was produced via the ^{2}H(d, n) ^{3}He reaction, i.e. by bombarding the D_2 gas target with deuteron beam currents, typically kept between 2-6 μA. A 5 μm molybdenum foil served as the entrance window and a Pt foil as the beam stop of the gas cell. During the irradiations the gas target was cooled through a cold air jet, in order to minimize the effect of heating in the deuterium gas pressure, which was continuously controlled through a micrometric valve. Using this setup, a flux of the order of $\sim 4 \times 10^{6}$ n/(cm^2 ·s) was achieved. Two natural high purity iridium foils (37.3% 191 Ir and 62.7% 193 Ir) having a diameter of 13 mm, were used for the irradiations. Each 0.5 mm thick sample was placed between identically shaped 0.5 mm thick Al foils. This sample setup was sandwiched once more, between two gold foils, 0.25 mm in thickness and of equal diameter. The neutron flux was deduced from the Al foils using the ^{27}Al(n, α)^{24}Na reaction as reference [3]. The activity of the Au foils, however, was used for the determination of the effect of parasitic neutrons to the cross section measurement. The ^{197}Au(n,2n)^{196}Au reaction was also used as reference [3] for

the neutron flux estimation. Fully consistent results with respect the neutron beam intensity were obtained from both monitor reactions. The activation of Au foils utilized the determination of the thermal and epithermal component of the neutron field. This is an important parameter for the interpretation of the data given that the product nucleus (^{192}Ir) can be also populated from the ^{191}Ir(n,γ)^{192}Ir reaction (see next section).

The neutron flux was monitored by a BF_3 counter placed at 0° with respect to the neutron beam at a distance of 2 m from the deuteron gas target. The neutron yield, as measured by the BF_3 detector, was recorded at regular time intervals (40 s) by means of a multichannel scaler. This neutron flux history file was used in the analysis, for off-line correction of the fraction of ^{192}Ir nuclei, which had already decayed during activation. The sample sandwich was placed at 0° with respect to the neutron beam and at a distance of 7 cm from the center of the gas cell. At this distance, the angular acceptance of the samples setup was less than ±5.5°. During the irradiations, the gas cell was constantly operated at a pressure of 1100 mbar, in order to keep the uncertainty of the neutron beam energy distribution, as low as possible.

After the irradiations, the induced activity of the samples was measured with a HPGe detector (56% relative efficiency). The sample to detector distance was more than 10 cm so that any corrections for pile-up or coincidence-summing effects were negligibly small. The induced activity on the aluminum foils was determined afterwards using the same experimental setup. In less than one hour the activity of the aluminum foils could be determined with a statistical error better than2 % . The total cross section for the population of the the ground state (g – $T_{1/2}$=73.829 d), and the first isomeric state (m_1-$T_{1/2}$=1.45 min) was determined by recording the counting rate at 308.5 keV, 316.5 keV and 468.1 keV transitions of the daughter nucleus ^{192}Pt.

During the activity measurements the resulted decay spectra of ^{192}Ir were saved at regular time intervals. In this way the evolution of the photopeak net-area counts with respect the measuring time, could be compared to the theoretical curve for the expected half-life time. As can be seen in Fig. 2 the excellent agreement between the growth of the experimental net-area counts and the theoretical fitted curve for the expected half-life time, suggest that no contamination was present in the photopeak net-area. This procedure was followed for all the transitions. In Fig. 3 part of the recorded γ-ray spectrum is presented for the region around the stronger transitions.

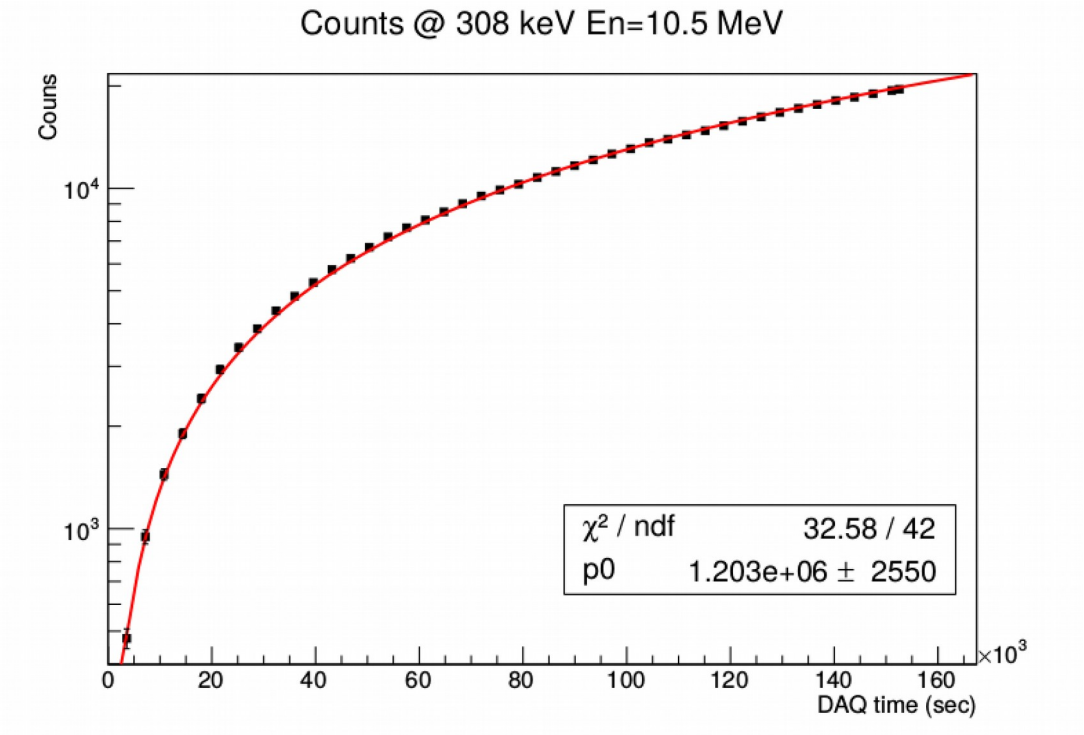

Fig. 2. Net-area counts at 308 keV line with respect the data-acquisition-time. The red line corresponds to the expected growth for the given half-life time of ^{192}Ir

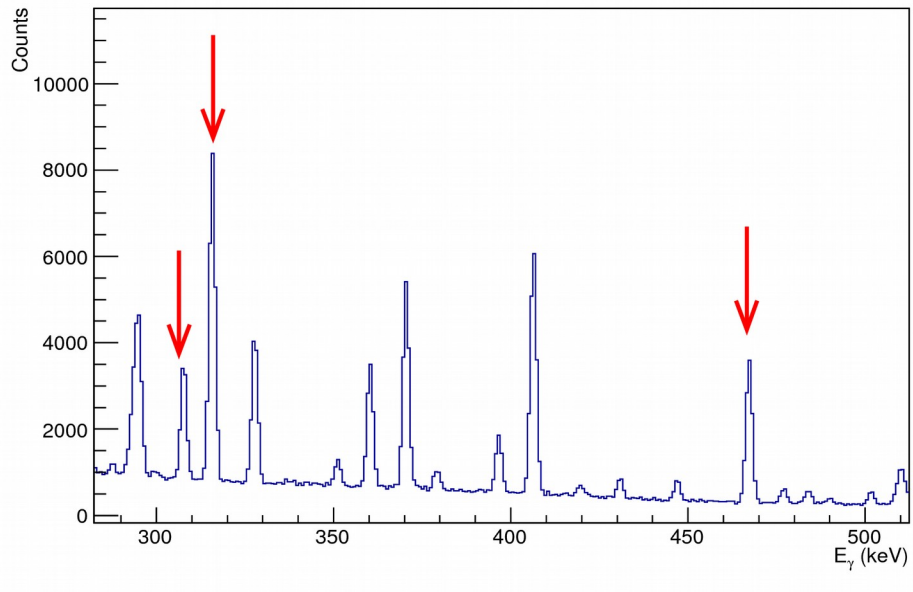

Fig. 3. Part of the γ-ray spectrum of the Iridium sample as resulted after the 10 MeV irradiation. The γ-ray lines (308 keV, 316 kev and 468 keV) that were used in the analysis are indicated with red arrows.

DATA ANALYSIS: CORRECTION FOR THE $^{191}Ir(n,\gamma)^{192}Ir$ REACTION RATE

The activation technique is an established method for the experimental study of nuclear reactions providing high accuracy and sensitivity. In those cases where the product nucleus of the reaction under study can be also populated through one or more competitive reactions, special care has to be taken in the data analysis and the physics interpretation of the experimental results. In particular, the contribution for each reaction-channel has to be accurately determined as to obtain the corrected reaction rate of the reaction of interest.

In the present work the activity of the product nucleus ^{192}Ir was determined by recording the counting rate of the three more intense γ-ray lines (308 keV, 316 and 468 keV) coming from the de-excitation of the β-decay daughter nucleus (^{192}Pt). The same isotope (^{192}Ir) can also be populated from the $^{191}Ir(n,\gamma)^{192}Ir$ reaction. The (n,γ) reaction cross section at the neutron beam energies considered in the present work (10.0 MeV and 10.5 MeV) is very small -of the order of a few mb-. On the other hand, the neutron capture cross section becomes higher as lower the neutron energy is. For this reason the neutron flux of the parasitic neutrons had to be determined. Towards to an accurate characterization of the total neutron field, with emphasis to lower energies where the neutron capture cross section becomes important, the NeusDesk code [4] was used in combination with the MCNP Monte-Carlo simulation code [5]. The resulted neutron field was slightly adjusted as to reproduce the experimentally observed $^{197}Au(n,\gamma)^{198}Au$ reaction rate. Based on the neutron field that reproduces the observed reaction rates for $^{197}Au(n,2n)^{196}$ and $^{197}Au(n,\gamma)^{198}Au$ reactions, the contribution of the $^{191}Ir(n,\gamma)^{192}Ir$ reaction rate was determined according to the excitation function provided by ENDF/B-VII.1 data-base [6]. In this way, the counts attributed to the neutron capture reaction were subtracted from the observed photo-peak net-area counts as to deduce the correct $^{193}Ir(n,2n)^{192}Ir$ reaction rate.

RESULTS AND DISCUSSION

Within the present work the $^{193}Ir(n,2n)^{192}Ir^{g+m1}$ reaction cross section has been determined for the first time at two neutron beam energies : 10.0 MeV and 10.5 MeV. The results are presented in Fig. 4 along with previous measurements reported in the literature [2]. The present experimental work will be combined with extensive theoretical compound nucleus calculations towards to an accurate determination of the reaction excitation function. Through the comparison of the experimental results and the theoretical calculations valuable information can be deduced about the local parameterization of the compound nucleus models. The steps of the compound nucleus formation as well as the de-excitation mechanisms will be explored as to achieve a deeper understanding of the reaction dynamics in this mass-energy region.

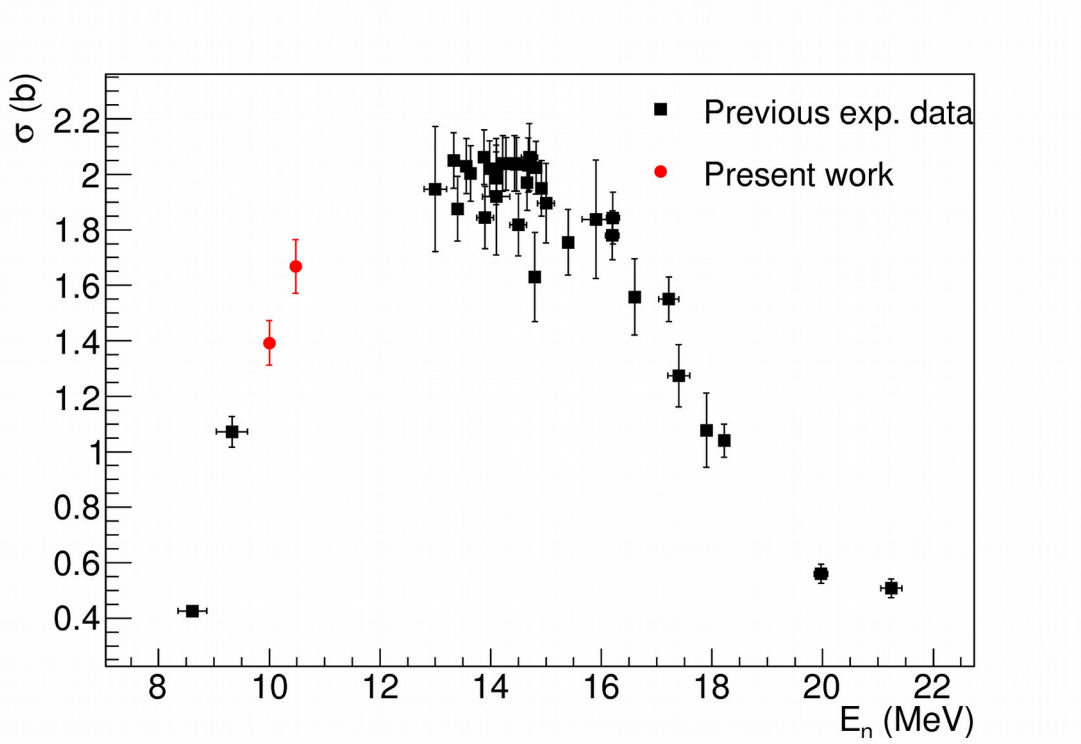

Fig. 4. Available experimental cross section data for the ^{193}Ir(n,2n)^{192}Ir reaction according to the EXFOR data base [2] along with the cross section data resulted from the present work (red bullets) .

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