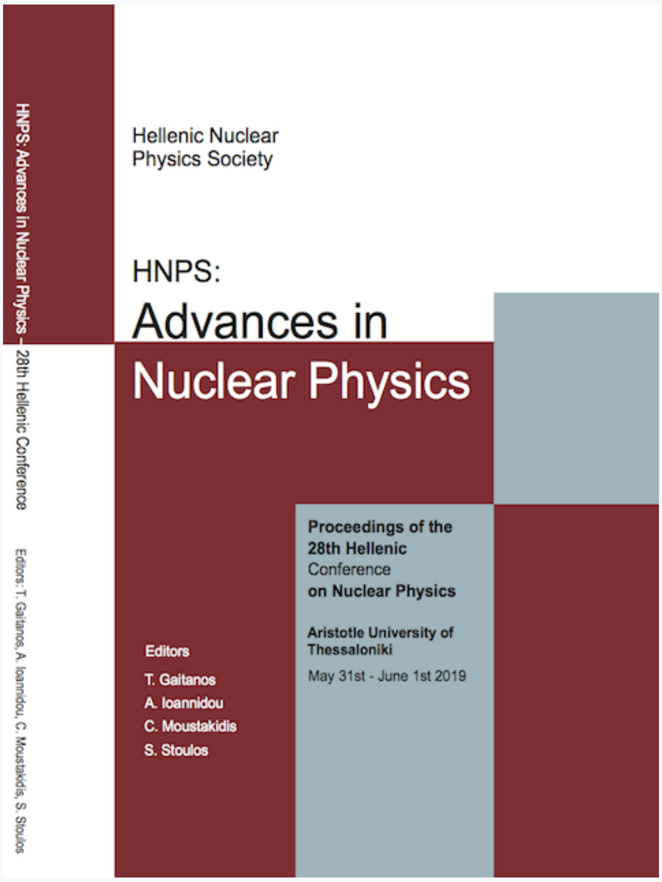
HNPS Advances in Nuclear Physics

Vol 27 (2019)

HNPS2019



Production Cross–Section Calculations of 62Cu via Charged Particles Induced Reactions

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doi: 10.12681/hnps.2476

Production Cross–Section Calculations of ^{62}Cu via Charged Particles Induced Reactions

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Abstract *The utilization of radioisotopes has been increasing proportionally with the scientific and industrial developments. Among many known and used examples of them, ^{62}Cu has a wide usage due to its suitability for many specific requirements such as in medical applications. By considering the importance of radioisotopes and especially ^{62}Cu, in this study, the theoretical calculations of cross–section values for ^{62}Cu via ^{59}Co(α,n)^{62}Cu, ^{61}Ni(d,n)^{62}Cu, ^{62}Ni(d,2n)^{62}Cu and ^{62}Ni(p,n)^{62}Cu reactions were carried out by employing three phenomenological level density models via TALYS 1.9 code. Obtained results were compared with the available experimental data from Experimental Nuclear Reaction Data (EXFOR) Library by graphically and mathematically.*

Keywords *copper, production, TALYS, level density*

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INTRODUCTION

Scientific and technical developments contribute to the improvements in many fields that affect the human life and daily routine either directly or indirectly. The applications in various fields such as medical studies, have been improved thanks to the developments in scientific and technical studies. With all the knowledge obtained from the past and ongoing studies in supporting fields, medical and clinical investigations are now more advanced and specialized to cure various diseases. In many modern medical application and device, nuclear physics related products are utilizing where radioisotopes could be pointed on top of the list. There exists many radioisotopes which were developed for different applications such as diagnostic and treatmen yet they could be connected with a common point, nuclear physics studies, which effect their development process directly. Among the known and employed radioisotopes, one noticeable could be given as ^{62}Cu, which is a very well known and widely employed β^+ emitter with a half-life value of 9.67 minutes. ^{62}Cu generally used as a tracer in conjunction with ^{64}Cu and uses cerebral and myocardial blood flow for in-vivo applications. As a short-lived isotope among all clinically appropriate copper isotopes, ^{62}Cu is also employed in positron emission tomography (PET) studies. In addition, it has been proposed for the labelling of PTSM (pyruvaldehydebis) to undertake myocardial and brain blood flow studies [1, 2]. By considering the importance of this radioisotope, many studies were done to provide as much as detailed information about it [3-7].

In addition to all these studies, it is very important to carry out the production cross-section studies in order to obtain efficient and successful results in the production of the desired radioisotope. With this motivation, in this study, the cross-section calculations for the production of ^{62}Cu radioisotope via ^{59}Co(α,n)^{62}Cu, ^{61}Ni(d,n)^{62}Cu, ^{62}Ni(d,2n)^{62}Cu and ^{62}Ni(p,n)^{62}Cu reactions were done by using one of the most used and employed computation code which is TALYS [8]. The version of the code is selected as the lastest distribution, 1.9 and the effects of level density models available in the code have been investigated by employing three phenomenological level density models for each selected reaction route. Obtained outcomes for each route were compared graphically for an eyeball estimation. Also, a relative variance analysis have been done for more accurate comparisons by using the available experimental data from Experimental Nuclear Reaction Data (EXFOR) Library [9].

THEORETICAL CALCULATIONS

In the case of experimental disabilities or other concerns such as time and financial competencies, theoretical calculations and computations came forward since they provide a good foresight to the researchers. For such cases in nuclear physics studies, scientists developed various theoretical nuclear reaction models in where numerous parameters were included. Some of those parameters are independent from apart yet some affect one other. One important value about a nuclear reaction is known as the cross-section, which basically defines the probability of the interaction between an incident particle and target. Since this data provides useful information about a nuclear reaction process, it is important to be able to have it either experiemental studies or computations. By considering this, various calculation tools were developed where the improvements in the computer sciences have been used jointly. Among many of the exist and used calculation tools, one of the most preferred and employed one is used in this study, which is TALYS. It is possible to perform many calculations for various situation via TALYS where numerous theoretical models are also available. This study was carried out by considering both the importance of ^{62}Cu radioisotope, especially due to its possible applications in medical studies, and also the level density models, an important model that needed to be investigated detailly.

Nuclear level density could be explained as the excited levels around an excitation energy and it is one of the most interesting parameter to investigate. The fundamental level density model is known as The Fermi Gas Model (FGM) [10] and all other phenomenological models have been derived from it. Beside the phenomenological models, there exist some microscopic level density models too yet in this study only three phenomenological models were investigated. The FGM assumes that the nucleons hold the lowest excitation states. That assumption makes the model successful but only for lower energies. The failure of FGM at higher energies was resolved by dividing the energy region into two parts as low and high where the new approach has been named as Constant Temperature Fermi Gas Model (CTFGM). In the range from 0 MeV to matching, constant temperature law applied while above the matching energy FGM. In CTFGM, constant temperature law applied in the range from 0 MeV to matching while FGM is applied above the matching energy [11]. Although CTFGM could produce successful results, due to the difficulties in exact identifying the matching energies it could produce inconsistent results in higher energies. Due to this situation, it is aimed to adjust the energy levels by defining a shift parameter and thus Back Shifted Fermi Gas Model (BSFGM) was developed [12]. The last utilized level density model within this study is the Generalised Superfluid Model (GSM) which was characterized by a phase transition to the high energy region defined by the Fermi Gas Model from the low-energy superfluid behaviour that superconductivity correlations according to the Bardeen Cooper-Schrieffer theory [13].

In the comparisons of obtained calculation results with the available experimental data to identify the most consisten model, a relative variance analysis method was employed which is given in Equation 1

$$D = \frac{1}{N}\sum_{i=1}^{N}\left|\sigma_i^{theo} - \sigma_i^{exp}\right|/\sigma_i^{exp} \qquad (1)$$

where the result D tends to be zero for more consistency between the theoretical calculations and experimental data, which are represented with σ_i^{theo} and σ_i^{exp}, respectively for N numbered data.

RESULTS AND DISCUSSION

In order to achieve the aim of the study; CTFGM, BSFGM and GSM were employed during the cross-section calculations of ^{62}Cu radioisotope production reactions which are $^{59}Co(\alpha,n)^{62}Cu$, $^{61}Ni(d,n)^{62}Cu$, $^{62}Ni(d,2n)^{62}Cu$ and $^{62}Ni(p,n)^{62}Cu$. Otained calculation results were graphicallay represented as Figs. 1-4 and the relative variance analysis results were given in Table 1.

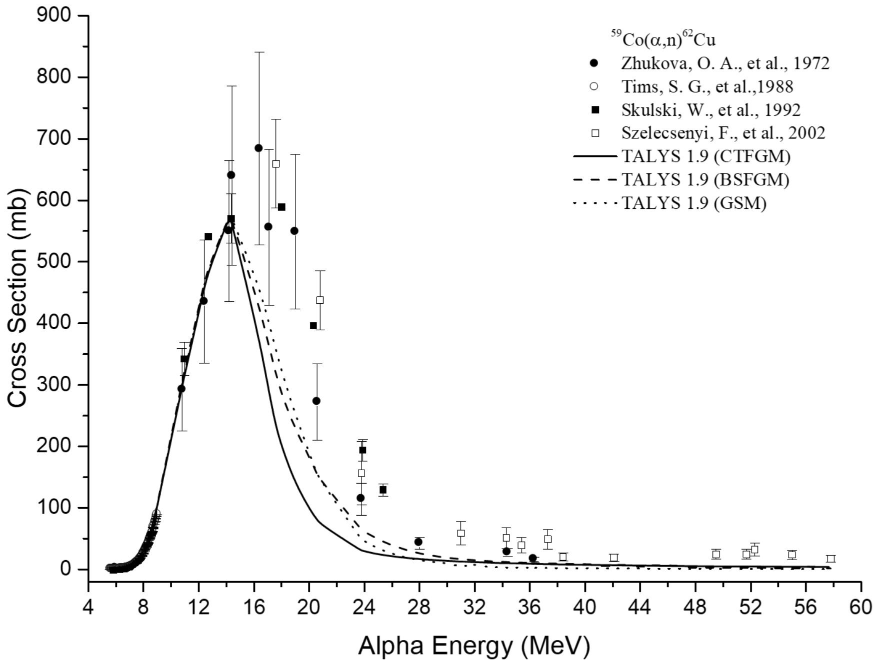

Figure 1. *$^{59}Co(\alpha,n)^{62}Cu$ reaction results*

As can be seen from Fig. 1, which represents the theoretical calculation results and experimental data [4, 14-16] for $^{59}Co(\alpha,n)^{62}Cu$ reaction, all employed models could managete to exhibit similar harmonies with the experimental data. The most incompatible results were generated by CTFGM while the most compatible model is BSFGM with a minor difference than GSM.

Comparisons of the results for $^{61}Ni(d,n)^{62}Cu$, $^{62}Ni(d,2n)^{62}Cu$ reaction with the experimental data of Cogneau et al., [17] were given as Figure 2 and 3. In $^{61}Ni(d,n)^{62}Cu$ reaction, it is seen that the theoretical calculation results show a similar distribution with a certain ratio below the experimental data, especially in the region after about 6 MeV incident particle energy. The most consistent model with the experimental data was obtained as BSFGM in the whole energy region. In $^{62}Ni(d,2n)^{62}Cu$ reaction, likewise to the $^{61}Ni(d,n)^{62}Cu$ reaction, the calculation results were obtained within a similarity with the experimental data. The increase in the cross-section data with the increase of incident particle energy could clearly seen from Fig. 3. Beside the similarities in the calculation results of BSFGM and GSM, the most consistent outcomes were generated from GSM which can be realized from the relative variance analysis results given in Table 1.

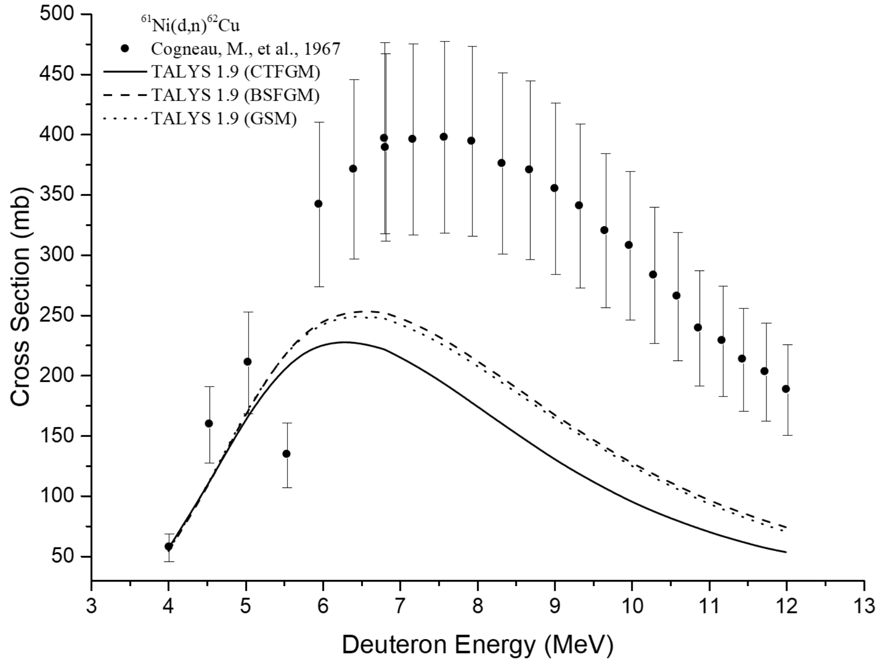

Figure 2. *^{61}Ni(d,n)^{62}Cu reaction results*

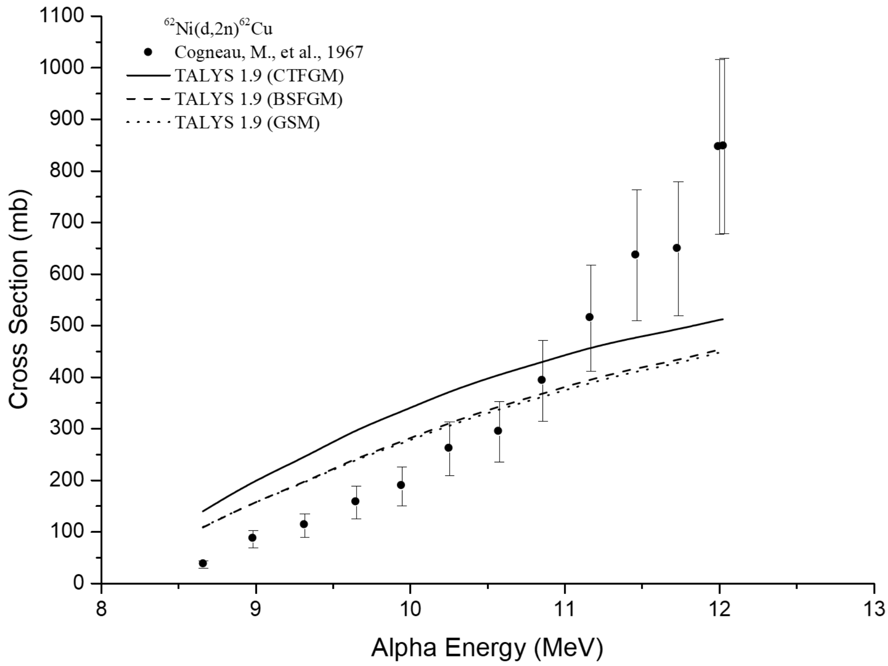

Figure 3. *^{62}Ni(d,2n)^{62}Cu reaction results*

Comparisons of the results for ^{61}Ni(d,n)^{62}Cu, ^{62}Ni(d,2n)^{62}Cu reaction with the experimental data of Cogneau et al., [17] were given as Figure 2 and 3. In ^{61}Ni(d,n)^{62}Cu reaction, it is seen that the theoretical calculation results show a similar distribution with a certain ratio below the experimental data, especially in the region after about 6 MeV incident particle energy. The most consistent model with the experimental data was obtained as BSFGM in the whole energy region. In ^{62}Ni(d,2n)^{62}Cu reaction, likewise to the ^{61}Ni(d,n)^{62}Cu reaction, the calculation results were obtained within a similarity with the experimental data. The increase in the cross-section data with the increase of incident particle energy could clearly seen from Fig. 3. Beside the similarities in the calculation results of BSFGM and GSM, the most consistent outcomes were generated from GSM which can be realized from the relative variance analysis results given in Table 1.

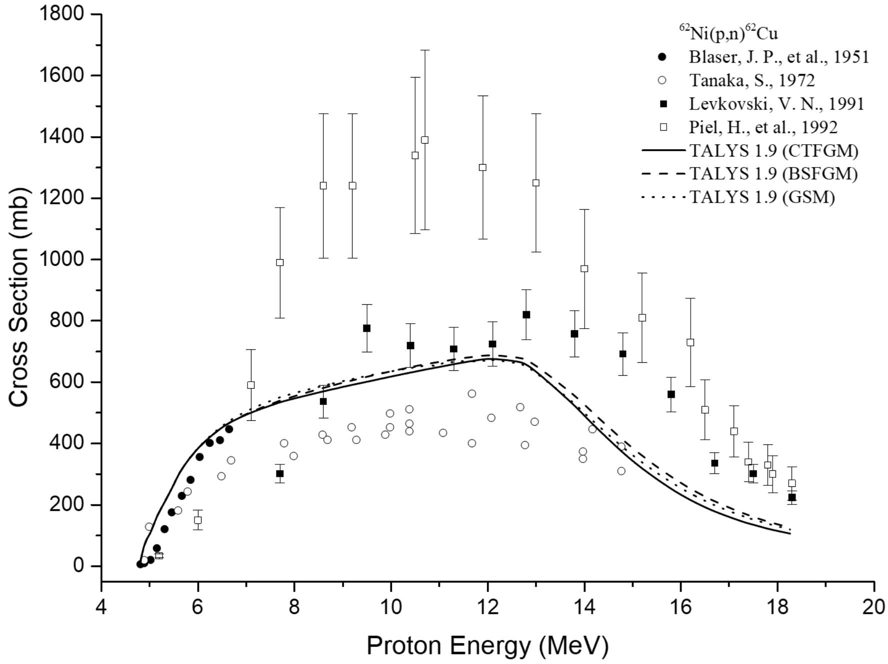

Figure 4. *^{62}Ni(p,n)^{62}Cu reaction results*

The last reaction involved into this study is ^{62}Ni(p,n)^{62}Cu. The comparisons of calculations and experimental data [18-21] for this reaction were given in Figure 4 where a coherence among the model results are clearly seen that becomes slightly less compatible with the increase of incident particle energy. Even all model calculations were obtained close to each other, the relative variance analysis results show that the most consistent model with the all experimental data within the whole energy region is BSFGM.

Table 1. *Relative variance analysis results*

Reaction	CTFGM	BSFGM	GSM
^{59}Co(α,n)^{62}Cu	0.269436283	0.244168096	0.289868291
^{61}Ni(d,n)^{62}Cu	0.543727327	0.467328635	0.4756399
^{62}Ni(d,2n)^{62}Cu	0.700607124	0.512103201	0.511834405
^{62}Ni(p,n)^{62}Cu	0.838637412	0.836829532	0.83879848

CONCLUSIONS

The obtained results were show that, the most consistent level density model and their compatibility rate could be differ for each reaction route where various parameters could affect the results. For this study, BSFGM model was succeed in three reactions which are ^{59}Co(α,n)^{62}Cu, ^{61}Ni(d,n)^{62}Cu and ^{62}Ni(p,n)^{62}Cu while GSM was the most compatible one for the ^{62}Ni(d,2n)^{62}Cu reaction. Beside the way that the level density models were employed within this study, more detailed studies on them like investigations on their parameters may be done to upgrade the models for the ability of obtaining more successful calculation results. Also, these kind of studies may provide positive impact to the theoretical model development studies which led the researchers to produce better estimations and foresights for any specific case, where there is no available experimental data or if the data is quite old as it in this study.

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