Süleyman Demirel Üniversitesi Fen Edebiyat Fakültesi Fen Dergisi
Süleyman Demirel University Faculty of Arts and Sciences Journal of Science
2017, 12 (2): 12-18

Investigation of Excitation Functions of Copper Radioisotopes Used in Nuclear Medicine with TALYS Code

Hüseyin Ali YALIM[*1], Niyazi BALÇIN[2], İsmail Hakkı SARPÜN[1]

[1]*Afyon Kocatepe Üniversitesi, Fen Edebiyat Fakültesi, Fizik Bölümü, 03040, Afyonkarahisar, Türkiye*
[2]*Kocatepe Üniversitesi, Fen Bilimleri Enstitüsü, Fizik Bölümü, 03040, Afyonkarahisar, Türkiye*

**corresponding author e-mail: hayalim@aku.edu.tr*

(Received: 18.08.2017, Accepted: 25.10.2017)

Abstract: ^{60,61,62,64,67}Cu radioisotopes of copper are used for various applications in diagnostic or therapeutic nuclear medicine. These radioisotopes' wide range of half-lives enable designing and synthesizing of various radiopharmaceuticals. Because of availability and cost of production, the research efforts in copper radiopharmaceuticals are focused on the calculations of reaction cross sections showing the possibility of the productivity in this process. In this paper, excitation functions of copper radioisotopes have been investigated through the theoretical calculation of reaction cross sections by using TALYS nuclear reaction code in the incident particle energy up to 50 MeV.

***Key words**:* Copper radioisotopes, Excitation functions, Reaction cross sections, TALYS code.

Nükleer Tıpta Kullanılan Bakır Radyoizotoplarının Uyarma Fonksiyonlarının TALYS Kodu ile İncelenmesi

Özet: ^{60,61,62,64,67}Cu radyoizotopları, nükleer tıpta tanı veya terapi amaçlı olarak çeşitli uygulamalar için kullanılır. Bu radyoizotopların geniş yarı ömür spektrumu çeşitli radyofarmasötiklerin tasarımını ve sentezini sağlamaktadır. Kullanılabilirlik ve üretim maliyeti nedeniyle, bakır radyofarmasötiklerindeki araştırma çabaları, esas olarak, bu süreçte tasarlanan üretkenliğin olasılığını gösteren reaksiyon kesitlerinin hesaplanmasına odaklanmıştır. Bu çalışmada bakır radyoizotopların uyarma fonksiyonları, 50 MeV'e kadar parçacık gelme enerjisinde TALYS nükleer reaksiyon kodu kullanılarak reaksiyon tesir kesitlerinin teorik olarak hesaplanması ile araştırılmıştır.

***Anahtar kelimeler**:* Bakır radyoizotopları, Uyarma fonksiyonu, Reaksiyon tesir kesiti, TALYS kodu.

1. Introduction

Copper radioisotopes (^{60,61,62,64,67}Cu) are used for various biomedical applications in diagnostic or therapeutic nuclear medicine. These radioisotopes have a wide range of half-lives which enable designing and synthesizing of various radiopharmaceuticals. Because of varying range of half-lives and positron energies, a significant research effort has been conducted on the copper radionuclides [1]. Additionally, the convenient coordination chemistry of copper enables its reaction with a wide variety of well-designed macrocyclic chelators forming stable complexes attached to targeting molecules that may be linked to antibody fragments, proteins, peptides, and other biologically relevant small molecules [2].

The production of radioisotopes has a steadily increasing significance, and cyclotrons and reactors are constantly used for this improving issue [3,4]. For nuclear reactor production, the cross-section data are much valuable and can be adequately produced by nuclear model evaluations. Theoretical nuclear models are used to evaluate the reaction cross sections of nuclear reactions, if the experimental measurements are improbable to be produced due to the experimental difficulties [5-12].

In this paper, excitation functions of copper radioisotopes were investigated through the theoretical evaluation of cross sections by using TALYS nuclear reaction code in the incident particle energy up to 50 MeV.

2. Material and Methods

TALYS simulation program is a Unix-based computer program used to predict the possibility of a nuclear scattering reaction [13]. It is a nuclear code program that allows researchers to simulate long-running or difficult nuclear reactions scientifically.

In this paper, the reaction cross sections of some nickel isotopes target induced with either proton or deuterium have calculated in the incident energy range of 0-50 MeV by TALYS 1.6 code to investigate excitation functions of copper radioisotopes.

On the other hand, for comparison between the experimental and the calculated data, the relevant experimental values were taken from the EXFOR nuclear reaction library [14].

3. Results

The nuclear reaction cross sections, which can support the production of ^{60}Cu, ^{61}Cu, ^{62}Cu, ^{64}Cu and ^{67}Cu radioisotopes used for various applications in diagnostic or therapeutic nuclear medicine, were calculated for the incident particle energy up to 50 MeV by TALYS 1.6 nuclear reaction code and compared with the experimental values available in the EXFOR nuclear data library [14]. The results are presented in Figs.1-8.

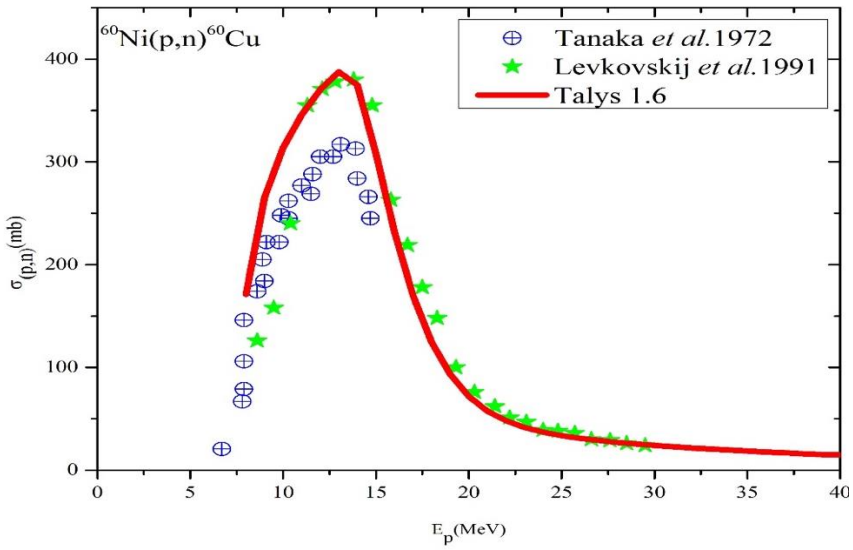

Figure 1. The excitation function of ^{60}Cu from proton induced reaction of ^{60}Ni.

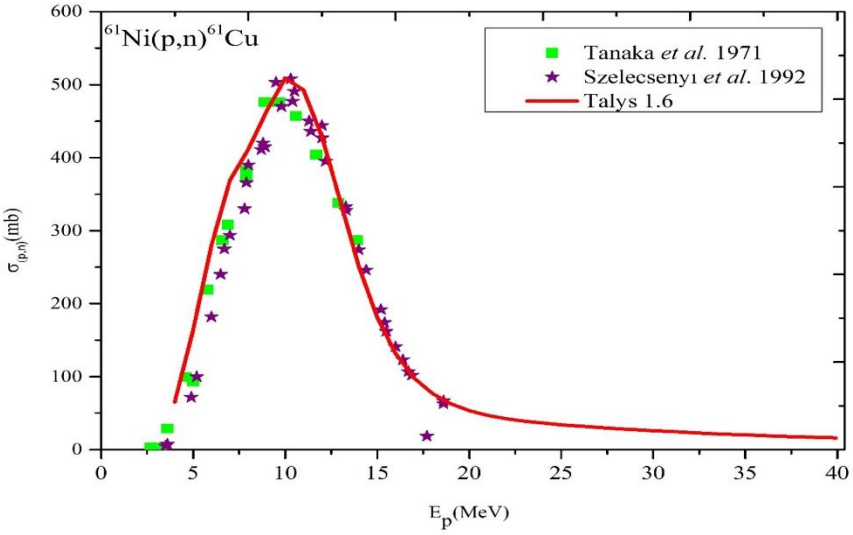

Figure 2. The excitation function of ^{61}Cu from proton induced reaction of ^{61}Ni.

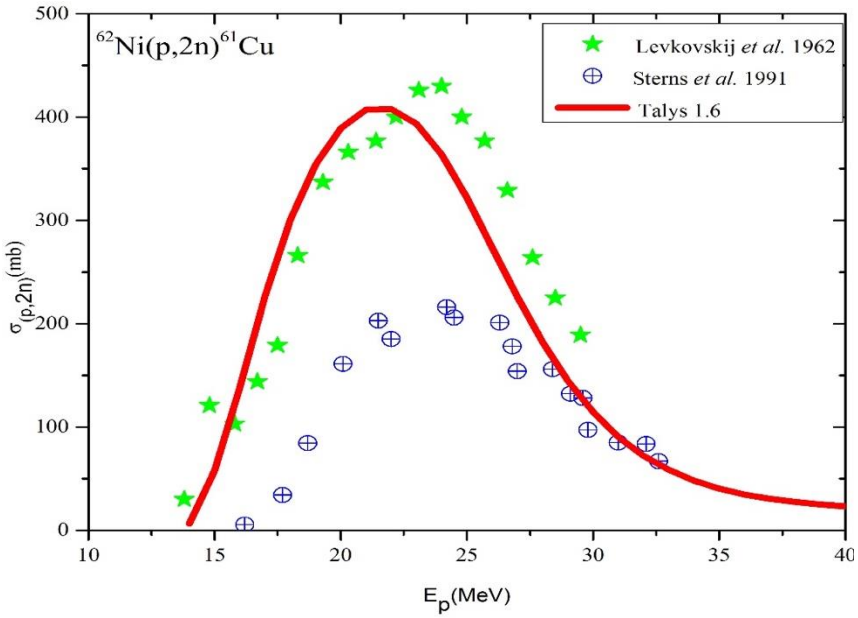

Figure 3. The excitation function of ^{61}Cu from proton induced reaction of ^{62}Ni.

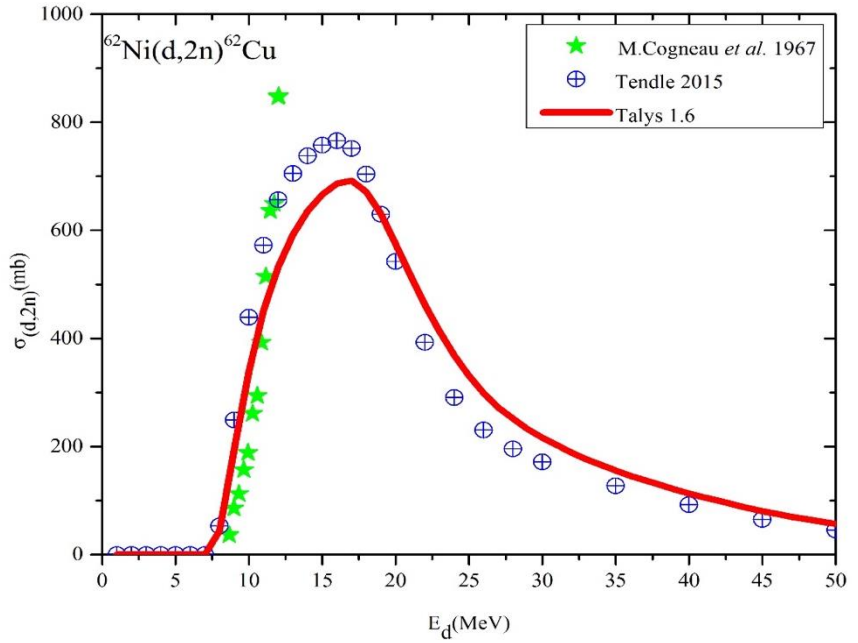

Figure 4. The excitation function of ^{62}Cu from deuterium induced reaction of ^{62}Ni.

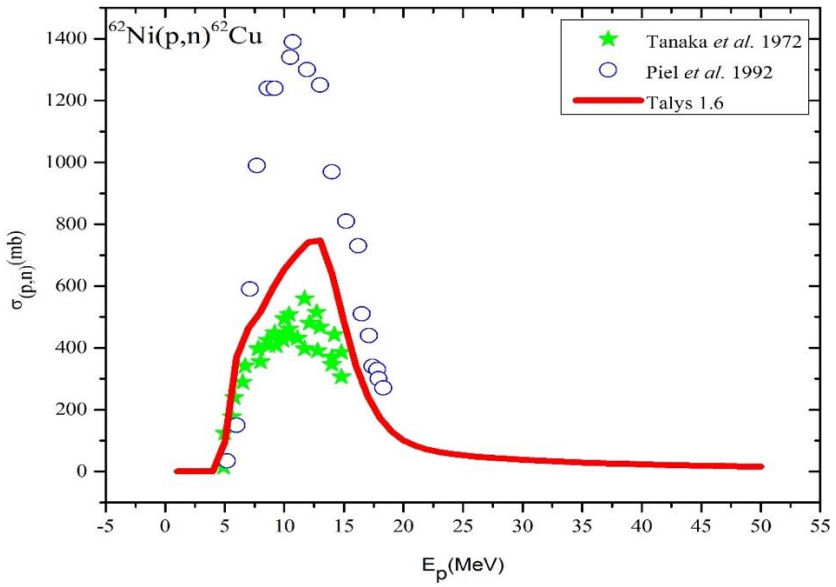

Figure 5. The excitation function of ^{62}Cu from proton induced reaction of ^{62}Ni.

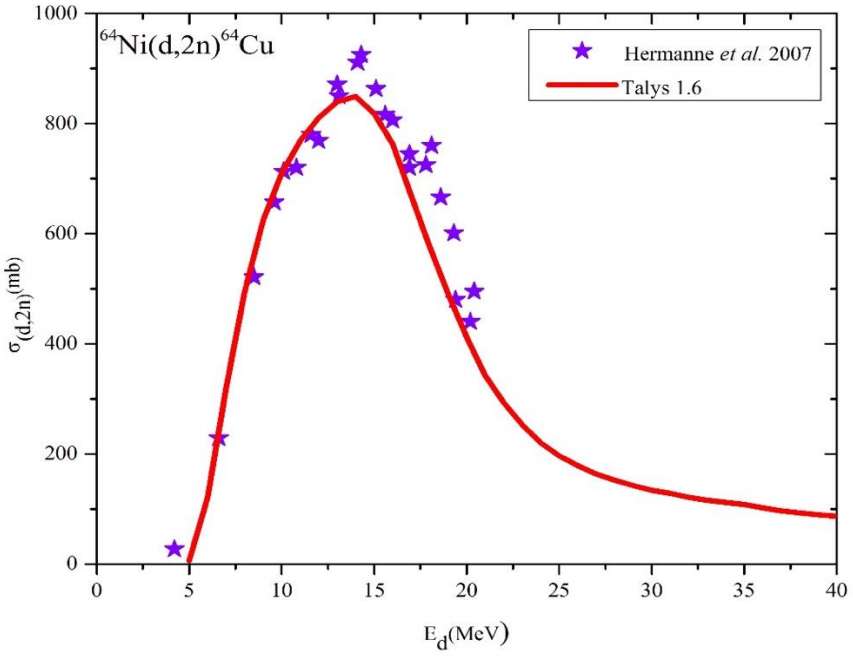

Figure 6. The excitation function of ^{64}Cu from deuterium induced reaction of ^{64}Ni.

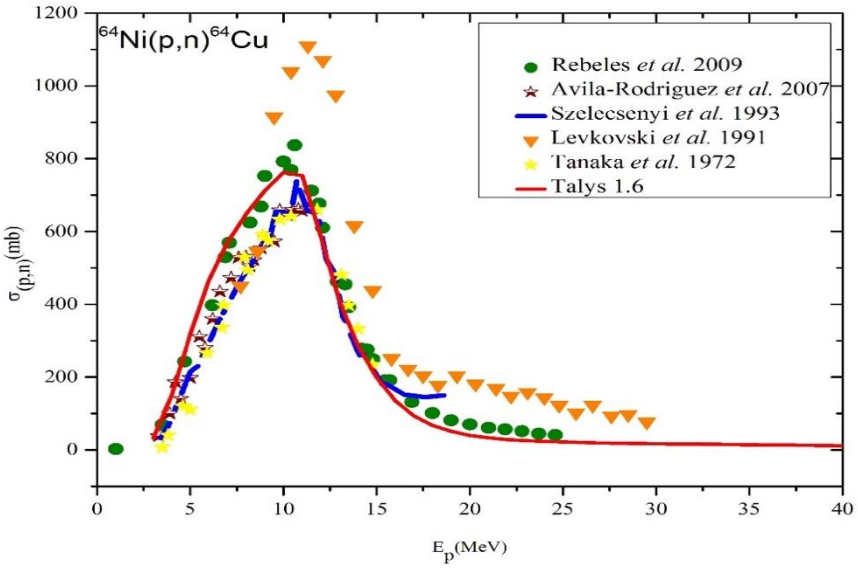

Figure 7. The excitation function of ^{64}Cu from proton induced reaction of ^{64}Ni.

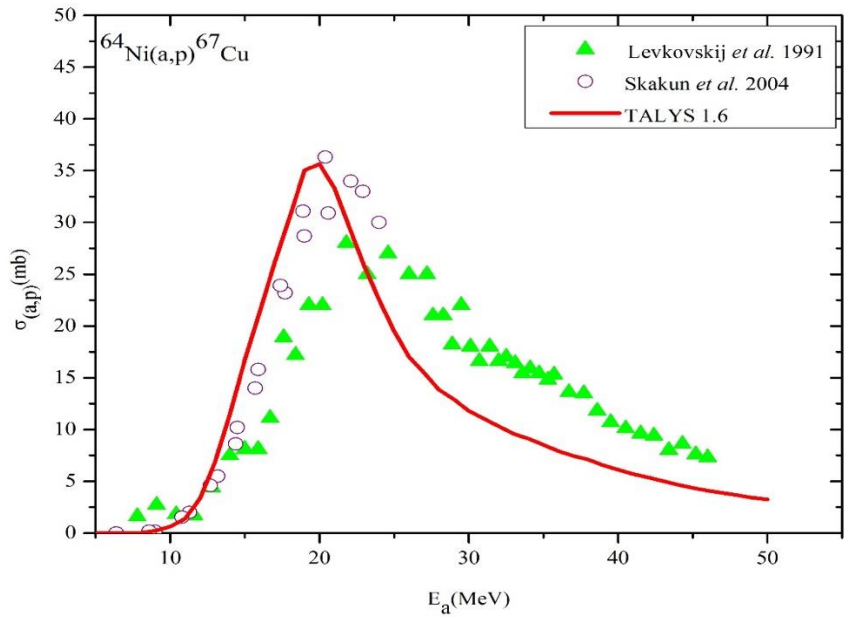

Figure 8. The excitation function of ^{67}Cu from alpha induced reaction of ^{64}Ni.

4. Discussions

The present study evaluates the excitation functions of copper radioisotopes by calculating the cross sections using TALYS nuclear reaction code in the incident particle energy up to 50 MeV. Although there are some discrepancies between the calculated and the experimental cross section values of the (p,n) and the (p,2n) reactions, the rest of the presented excitation function calculation results show a good agreement with the experimental data.

It is known that the compound nucleus model is quite successful for low incoming energies (10-20 MeV) in which the incoming particle is most likely to interact with the

nucleus. The energy range of incident particle for the production reactions of copper radioisotopes was obtained as 10-13 MeV for proton induced reactions and 15-18 MeV for deuterium-induced reactions, and these results were observed to be consistent with the compound nucleus model.

The present excitation function calculation results will provide a good reference for future experimental cross section investigations and nuclear model calculations.

References

[1] C.J. Anderson and R. Ferdani, "Copper-64 radiopharmaceuticals for PET imaging of cancer: advances in preclinical and clinical research," *Cancer Biotheraphy and Radiopharmaceuticals*, vol. 24 (4), pp. 379-392, 2009.

[2] A.R. Jalilian and J. Osso Jr., "The current status and future of theranostic Copper-64 radiopharmaceuticals," *Iran J Nucl Med*, vol. 25(1), pp. 1-10, 2017.

[3] S.M. Qaim, "Use of cyclotrons in medicine," *Radiation Physics and Chemistry*, vol. 71, pp. 917–926, 2004.

[4] B.L. Zhuikov, "Production of medical radionuclides in Russia: Status and future—a review," Applied Radiation and Isotopes, vol. 84, pp. 48–56, 2004.

[5] B. Demir, V. Çapalı, İ.H. Sarpün, and A. Kaplan, "Production Cross–Section Calculations of Medical ^{125}I Radionuclide Using α, d and γ Induced Reactions" *SDU Journal of Science (E-Journal)*, vol. 10 (2), pp. 116-121, 2015.

[6] B. Demir, A. Kaplan, V. Çapalı, İ. H. Sarpün, A. Aydın, and E. Tel, "Production cross–section calculations of medical ^{32}P, ^{117}Sn, ^{153}Sm and ^{186,188}Re radionuclides used in bone pain palliation treatment," *Kerntechnik*, vol. 80(1), pp. 58–65, 2015.

[7] R. Ünal, İ.H. Sarpün, and H.A. Yalım, "Comparison of level density models in (*γ, n*) reactions of some lanthanide nuclei," *Physics of Atomic Nuclei*, vol. 77 (3), pp. 310-315, 2014.

[8] H.A. Yalım, A. Aydin, İ.H. Sarpün, R. Ünal, B. Oruncak, A. Kaplan, and E. Tel, "Investigation of Nucleon Mean Free Path Dependence in Tritium Emission Spectra Produced by Proton Induced Reactions at 62 MeV," *Journal of Fusion Energy*, vol. 29 (1), pp. 55-61, 2010.

[9] İ.H. Sarpün, H.A. Yalım, R. Ünal, B. Oruncak, A. Aydın, A. Kaplan, and E. Tel, "Determination of (n, 2n) Reaction Cross Sections for Some Nuclei with Asymmetry Parameter," *Journal of Fusion Energy*, vol. 29 (4), pp. 387-394, 2010.

[10] A. Aydin, H.A. Yalim, E. Tel, B. Şarer, R. Ünal, İ.H. Sarpün, A. Kaplan, M. Dağ, "Level density parameter dependence of the fission cross sections of some subactinide nuclei induced by protons with the incident energy up to 250MeV," *Annals of Nuclear Energy*, 36 (9), pp. 1307-1312, 2009.

[11] A. Kaplan, "Investigation of Neutron-Production Cross Sections of the Structural Fusion Material ^{181}Ta for (α,xn) Reactions up to 150 MeV Energy," Journal of Fusion Energy, vol. 32 (3), pp. 382–388, 2013.

[12] U. Akçaalan, R. Ünal, İ.H. Sarpün, H.A. Yalim, and B. Oruncak, "Calculations of (γ, n) Reaction Cross Sections using Different Level Density Models for Some Lanthanide Nuclei," *Acta Physica Polonica A*, 128 (B-2), pp. 228-230, 2015.

[13] Koning A., Hilaire S., and Goriely S., "TALYS–1.6 A Nuclear Reaction Program, User Manual (NRG, The Netherlands)," *First Edition*, vol. 23, pp. 64–67, 2013.

[14] EXFOR/CSISRS, Brookhaven National Laboratory, National Nuclear Data Center, Database Version of April 2017.