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Görüntüleme İzleyici Olarak Kullanılan Zirkonyum İzotoplarının (n,p) ve (γ, p) Reaksiyon Tesir Kesitlerinin İncelenmesi

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Özet

Nükleer görüntüleme ajanlarını kullanarak tanı geliştirme çalışmalarının ilerlemesinde kullanılan radyoizotopların özelliği görüntü kalitesinde etkin bir rol oynamaktadır. Çalışmamızda ampirik ve yarı ampirik tesir kesiti formülleri kullanılarak gama ve nötron ile etkileşime giren, görüntüleme izleyicileri olarak kullanılan Zirkonyum izotopları için (n, p) ve (γ, p) reaksiyon tesir kesiti hesaplamaları gerçekleştirilmiştir. Ayrıca, TALYS 1.6 kodu ile (n, p) ve (γ, p) reaksiyon tesir kesitleri hesaplanmıştır. Hesaplama sonuçları deneysel EXFOR verileri ile karşılaştırılmış ve uyumlu oldukları görülmüştür.

Anahtar kelimeler: **z**irkonyum, **t**esir kesiti, **r**adyoizleyiciler, **E**XFOR

Investigation of (n,p) and (γ,p) Reaction Cross-Sections of Zr Isotopes Used as Imaging Tracers

Abstract

The feature of the radioisotopes used in the progress of diagnostic development studies using nuclear imaging agents plays an effective role in image quality. In our study, reaction cross section calculation of (n,p) and (γ, p) were done for zirconium isotopes used as imaging tracers that interact with gamma and neutron by using empirical and semi empirical cross section formulae. Some cross section formulae were used in the calculations for zirconium isotopes that interact with gamma and neutron. Also, TALYS 1.6

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code used for (n, p) and (γ, p) reaction cross section calculations. Calculation results were compared with experimental EXFOR data and they were found to be compatible.

Keywords: zirconium, **c**ross section, **r**adiotracers, **E**XFOR

1. Introduction

Radiotracers, which are used to as a monitor in biological and chemical processes, are widely used in many fields from medicine to industry. In radiology, radioactive isotopes are sent to the body to monitor the formation of biological formations as part of diagnostic x-ray examinations. The radiotracers can be also used to investigate the mechanism of a chemical reaction and to monitor radioactive degradation. Also, radioisotopes can be existing in the structure of radiopharmasotics. These radiopharmasotics are used to obtain images of the body by Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT) [1].

Chromatographic separation and quantification of individual metabolites are advantages of radiolabeled drugs. These are mostly used in body metabolic absorption and distribution or metabolism regulation and breakthrough studies. After many radio viewer agents used in this field, it was seen that the zirconium atom could also be used for this purpose [2].

The zirconium in group 4B in the periodic table has proton number of 40 and an atomic weight of 91,224. It melts at 1855 degrees and boils at 4409 degrees. Due to the being a greyish-white and ductile metal, it is extremely resistant to heat and corrosion. It shows superconducting properties at low temperatures. For this reason, zirconium-niobium alloys are used in magnet making. Zirconium is not reactive at normal temperatures; becomes reactive at high temperatures. It is oxidized in air and liquid and gains resistance to corrosion [3, 4].

^{89}Zr can be produced on a cyclotron [5, 6]. Its half-life $t_{1/2}$: 78.4 h, β+ formation 22.8%, $\beta+_{max}$ Energy =901 keV, electron capture 77%, Eγ energy= 909 keV. ^{89}Zr is widely used in immuno-PET imaging. It can easily mark antibodies due to the appropriate half-time and positron generation capability. As the radionuclide decays, it is released from a positron atomic nucleus. These positrons, which will cause an event called anhilation at 511 keV after short distance and disappear when they encounter electrons. It is possible to these randomly moving gamma rays to escape from the organism so that they can be detected by the PET scanner to form an image [5, 6].

Zirconium is quite resistant to organic and inorganic acids, salt solutions and strong alkalis due to its corrosion resistance. Due to its corrosion resistance, it extends the service life in the areas it is used and thus increases the maintenance cost and productivity. Due to its resistance to brittleness and cracking, it can also be used in the construction industry to help reduce costs. For example, they are preferred in nuclear power plant construction because of these features. Since zirconium fuel rods will work efficiently for many years, it will minimize factors such as equipment failure and construction cost [2].

Ceramics containing zirconium compounds are useful in bio ceramic applications because of their inert behavior and hardness in chemical reactions. Therefore, it can be used in implants produced for hip and knee joints of ceramics containing zirconia. Also, these ceramics can be used in the production of implant teeth [2].

In the scope of this study, (n,p) [7,8] and (γ, p) [9] cross-sections were calculated for zirconium isotopes used as imaging tracers. Some cross-section formulas [7, 14-16] in the literature were used in the calculations for zirconium isotopes that interact with gamma and neutron. Also, TALYS 1.6 code used for (n,p) and (γ, p) reaction cross section calculations[10, 11]. After the calculation, obtained results were checked against each other and available EXFOR data [12].

2. Material and Method

Cross Section Calculations

The cross-section refers to the reduction in the particle or beam of the target during the reaction or, in other words, the likelihood of the reaction to occur [13]. The concept of cross-section is very important in terms of estimation and functionality of nuclear reaction models in nuclear reaction experiments that cannot be performed experimentally. Many formulas are available to calculate the theoretical cross-section. These empirical and semi-empirical cross-section formulae have different parameters in the literature. Levkovskii (1964) [14], Tel et al. (2003, 2008, 2018) [7-9], Kumabe and Fukuda (1987) [15], Konno et al. (1993) [16] (n,p) cross section systematics are given in table 1.The systematic of (γ, p) proposed by Tel et al are given in Table 2.

Table 1 The systematics of (n,p) cross-section formulae around 14-15 MeV incident energy region

Author	Mass region	Formula, $\sigma(n, p)$ (mb)
Levkovskii [14]	40≤A≤208	$= 45.2(A^{1/3}+1)^2 \exp\left[-33s\right]$
Tel et al. [7]	$17 \leq A \leq 239 \begin{cases} for\, even-Z, even-N \\ for\, even-Z, odd-N \\ for\, odd-Z, even-N \end{cases}$	$= 14.56(A^{1/3}+1)^2 \exp\left[-26.58s\right]$ $= 16.33(A^{1/3}+1)^2 \exp\left[-26.17s\right]$ $= 9.71(A^{1/3}+1)^2 \exp\left[-21.87s\right]$ $= 7.31(A^{1/3}+1)^2 \exp\left[-20.21s\right]$
Kumabe & Fukuda [15]	19≤A≤62 63≤A≤89 90≤A≤160	$= 21.84 \exp\left[-34s\right]$ $= 0.79A^2 \exp\left[-43.2s\right]$ $= 0.75A^2 \exp\left[-45.0s\right]$
Konno et al. [16]		$= 31.42(A^{1/3}+1)^2 \exp\left[-29.07s\right]$

Table 2. The (γ, p) reaction cross section formulae for 20±1 MeV [9].

Formula (mb)	Mass region	R^2
$\sigma(\gamma, p) = 5.40(A^{2/3}) \exp\left[-23.228s\right]$	$40 \leq A \leq 108$	0.666
$\sigma(\gamma, p) = 5.64(A^{2/3}) \exp\left[-27.326s\right]$	even-Z, even-N	0.752

Besides, nuclear reaction calculation and analysis operations in the energy range of 14-15 MeV were performed with TALYS 1.6 code [10]. It is possible to generate nuclear data for analysis and applications of basic microscopic experiments in TALYS software created for simulation of nuclear reactions [10].

3. Result and Discussion

In this study, for the reactions of $^{89}Zr(n, p)^{89}Y$, $^{90}Zr(n, p)^{90}Y$, $^{91}Zr(n, p)^{91}Y$, $^{92}Zr(n, p)^{92}Y$, $^{94}Zr(n,p)^{94}Y$ and $^{96}Zr(n, p)^{96}Y$ theoretical nuclear cross section calculations for 14-15 MeV neutron arrival energy were performed. Calculation results are shown in table 3.

Levkovskii, Kumabe& Fukuda, Konno et al. and Tel et al. formulas have been yielded approximate results according to the calculations made using cross section formulas of reaction $^{89}Zr(n, p)^{89}Y$. The EXFOR data for this reaction could not be found. However, the calculation using TALYS 1.6 code has slightly higher results than others. $^{90}Zr(n, p)^{90}Y$ reaction calculations are compatible with each other's for all cross section formulae. Also, the experimental result that is taken from EXFOR is similar with theoretical calculations except TALYS 1.6 calculation. TALYS calculation is higher than other results. Similar to these results, $^{91}Zr(n, p)^{91}Y$, $^{92}Zr(n, p)^{92}Y$, $^{94}Zr(n,p)^{94}Y$ and $^{96}Zr(n, p)^{96}Y$ reactions calculations are compatible with each other as in previous results. The experimental results obtained from the literature are consistent with the calculations and the TALYS 1.6 code calculations are slightly higher than these results.

Author	$^{89}_{40}Zr$	$^{90}_{40}Zr$	$^{91}_{40}Zr$	$^{92}_{40}Zr$	$^{94}_{40}Zr$	$^{96}_{40}Zr$
Levkovskii[14]	47.97	34.71	25.30	18.56	10.2	5.74
Kumabe& Fukuda [15]	62.74	40.93	26.96	17.92	8.13	3.82
Konno et al.[16]	49.62	37.34	28.28	21.55	12.73	7.69
Tel et al.[7]	31.76	26.78	20.86	16.35	10.19	6.48
Exp. data [12]	-	34±4 [20]	19.5±1.5[17]	22.9±2.5[18]	9±0.8 [17]	13±4 [19]
TALYS 1.6 [10]	632.4	849.8	381.5	287.9	251.9	264

For $^{89}Zr(\gamma, p)^{89}Y$ and $^{90}Zr(\gamma, p)^{90}Y$ cross section calculations in the range of 20±1 MeV gamma arrival energy were performed. Calculation results are shown in table 4. In the literature, for the (γ, p) cross-sections reaction, Tel et al. formula is available and the calculations made with this formula are compatible with theoretical and experimental results for $^{90}Zr(\gamma, p)^{90}Y$. However, experimental data are not available in the literature for $^{89}Zr(\gamma, p)^{89}Y$.

Table 4. The calculation of (γ, p) cross-sections (mb) values at 20±1 MeV

Author	$^{89}_{40}Zr$	$^{90}_{50}Zr$
Tel et al.[9]	11.8	6.93
Exp. data: EXFOR [1,2]	-	33±7 [10]

4. Conclusion

The use of metallic radiotracers in technologies such as SPECT, PET and CARPT are increasing day by day all over the world. Zirconium and isotopes of these radiotracers are one of the usable ones. For imaging purposes, immune PET is preferred instead of immune SPECT due to higher resolution, sensitivity and more accurate image quantization. 89Zr is an ideal radionuclide for immuno PET. It converts to 89my via positron emission and electron capture, during which it converts to stable 89y with γ-beam emission (909 keV). Also, its use in PET imaging has increased significantly over the past decade, as it emits positron to 89Zr and has a Half-Life of 78.2 hours.

According to the theoretical (n, p) reaction calculations obtained in Table 3, the values obtained as a result of the calculations made with all cross-sectional formulas are compatible with each other and experimental data. However, the calculations made with TALYS 1.6 code give slightly higher values for the zirconium isotopes than the cross-sectional values calculated from the formulas.

In Table 4, (γ, p) reactions are calculated with the Tel formula in the literature and it is seen that the experimental calculation is compatible with the theoretical calculation for ^{90}Zr. These calculations provide preliminary information for experiments that lack experimental data and are difficult to perform.

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