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Production Cross-Section Calculations of Medical ^{177}Lu Using Neutron and Proton Induced Reactions

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Abstract. In this study, we aimed to investigate the alternative ways to produce ^{177}Lu, an isotope which has a growing rate of usage in radionuclide therapy applications. For this purpose; we analyzed the ^{176}Lu (n,γ)^{177}Lu, ^{176}Yb (n,γ)^{177}Yb$\xrightarrow{\beta^-}$^{177}Lu, ^{181}Ta (n,n+α)$^{177\text{-}M}$Lu, ^{nat}W(p,x)^{177}Lu reactions with the TALYS 1.6 and EMPIRE 3.2 theoretical nuclear reaction codes. Obtained results with the TALYS 1.6 and EMPIRE 3.2 codes are also compared with the experimental data exists in the literature for each reaction.

Keywords: ^{177}Lu, Cross–Section, TALYS 1.6, EMPIRE 3.2.

Nötron ve Proton Girişli Reaksiyonlar Kullanarak Tıbbi ^{177}Lu Üretim Tesir Kesiti Hesaplamaları

Özet. Bu çalışmada, radyonüklit terapi uygulamalarında giderek artan bir kullanım oranına sahip olan ^{177}Lu izotopu için alternatif üretim yollarının araştırılması amaçlanmıştır. Bu amaçla; ^{176}Lu(n,γ)^{177}Lu, ^{176}Yb(n,γ)^{177}Yb$\xrightarrow{\beta^-}$^{177}Lu, ^{181}Ta(n,n+α)$^{177\text{-}M}$Lu, ^{nat}W(p,x)^{177}Lu reaksiyonları TALYS 1.6 ve EMPIRE 3.2 teorik nükleer reaksiyon kodları kullanılarak analiz edilmiştir. Ayrıca, TALYS 1.6 ve EMPIRE 3.2 kodları ile elde edilen bulgular her bir reaksiyon için literatürde mevcut deneysel veriler ile karşılaştırılmıştır.

Anahtar Kelimeler: ^{177}Lu, Tesir Kesiti, TALYS 1.6, EMPIRE 3.2.

1. INTRODUCTION

Scientists have developed different methods of cancer therapy to treat different types of cancers such as chemotherapy, radiation therapy, immunotherapy, hyperthermia and photodynamic therapy etc. The most known type of cancer therapy is radiation therapy in where radioisotopes used [1]. In last years, ^{177}Lu peptide compound using in radionuclide therapy applications are increasing because of the obtained successful clinical results in treatment of stomach, intestine, pancreas and breathing system cancers [2]. The most common way to produce ^{177}Lu radionuclide isotope is either by directly ^{176}Lu(n,γ)^{177}Lu reaction or by beta emitting of ^{177}Yb after ^{176}Yb (n,γ)^{177}Yb reaction [3]. Besides of these routes of producing ^{177}Lu, there may be different types of reactions for obtaining ^{177}Lu.

The probability of a reaction's occurrence is known as "reaction cross–section" [4]. The investigation of the reaction cross–section is always an important point on the scientific research. The knowledge of reaction cross–section provides us the help of avoiding from unexpected nuclear reactions and also the contribution to the material development and evaluating radionuclides [4]. Even with the help of advanced science and developed facilities, there may exist lack of data and information on the reaction

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cross–section due to the experimental difficulties such as time, cost and etc. or some other specific reasons. These type of obstacles are bringing the theoretical calculations forefront with their ease of applicability and many time proved reliability [4].

In this study, we aim to investigate the alternative ways to produce ^{177}Lu. For this purpose; we analyzed ^{176}Lu(n,γ)^{177}Lu, ^{176}Yb (n,γ)^{177}Yb$\xrightarrow{\beta^-}$^{177}Lu, ^{181}Ta(n,n+α)$^{177\text{-}M}$Lu, ^{nat}W(p,x)^{177}Lu reactions with the TALYS 1.6 [5] and EMPIRE 3.2 [6] theoretical nuclear reaction codes. Obtained results with the TALYS and EMPIRE codes are also analyzed with the experimental data exists in the EXFOR [7] for each reaction.

2. CALCULATION METHODS

In this study, with the help of two theoretical calculation codes named as TALYS 1.6 and EMPIRE 3.2, we aimed to investigate the different production ways of medical isotope ^{177}Lu. TALYS 1.6 and EMPIRE 3.2 are two most used and reliable codes among the others which scientists have developed to compute reaction cross–section, spectrum of out-going particles and dose calculations including many theoretical nuclear models. Two versions of the exciton model, which are Two Component Exciton (TCE) [8] model in TALYS 1.6 and Exciton [9] model in EMPIRE 3.2 computer code, have been used for the reaction cross–section computations of ^{177}Lu isotope in this study.

3. RESULTS and DISCUSSION

For ^{177}Lu radionuclide, which has a growing usage rate in medical field, cross–section calculations have been performed for possible production routes. To be able to discuss the production route differences from the others exist in the literature, ^{176}Lu(n,γ)^{177}Lu, ^{176}Yb(n,γ)^{177}Yb$\xrightarrow{\beta^-}$^{177}Lu, ^{181}Ta(n,n+α)$^{177\text{-}M}$Lu, ^{nat}W(p,x)^{177}Lu reactions have been simulated with TALYS 1.6 and EMPIRE 3.2 computer codes. Obtained results have been compared with the experimental data in Figs. 1-4.

Beside the default model calculations, performed with TCE and Exciton models exist in the TALYS 1.6 and EMPIRE 3.2 respectively, Modified Two Component Exciton and Modified Exciton models, which have been recently developed and still in development process, were also employed in calculations.

The comparison of calculated cross–sections of ^{176}Lu(n,γ)^{177}Lu reaction with the experimental values has been given in Fig. 1. All model calculations are in good harmony with the experimental values in the all possible incident particle energy range. Among the modified models, Modified TCE model results are in good agreement more than Modified Exciton model results.

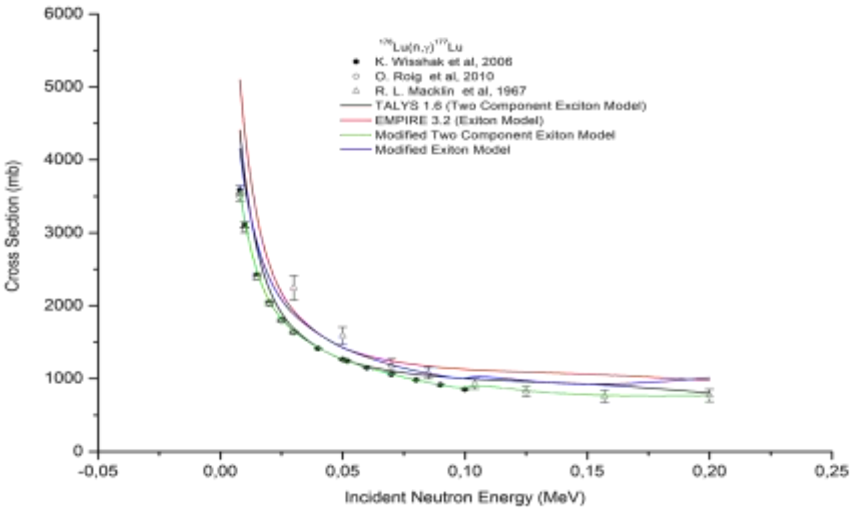

Figure 1. The ^{176}Lu (n,γ)^{177}Lu reaction computation with EXFOR experimental data.

The calculated production cross–sections of ^{177}Lu via ^{176}Yb (n,γ)^{177}Yb$\xrightarrow{\beta^-}$^{177}Lu reaction have been compared with the experimental measurements in Fig. 2. All model results display similar structure with the experimental data along the incident neutron energy. Modified TCE model has more agreement with the experimental values yet Modified Exciton model results are also in good agreement with the experimental values within the error bars.

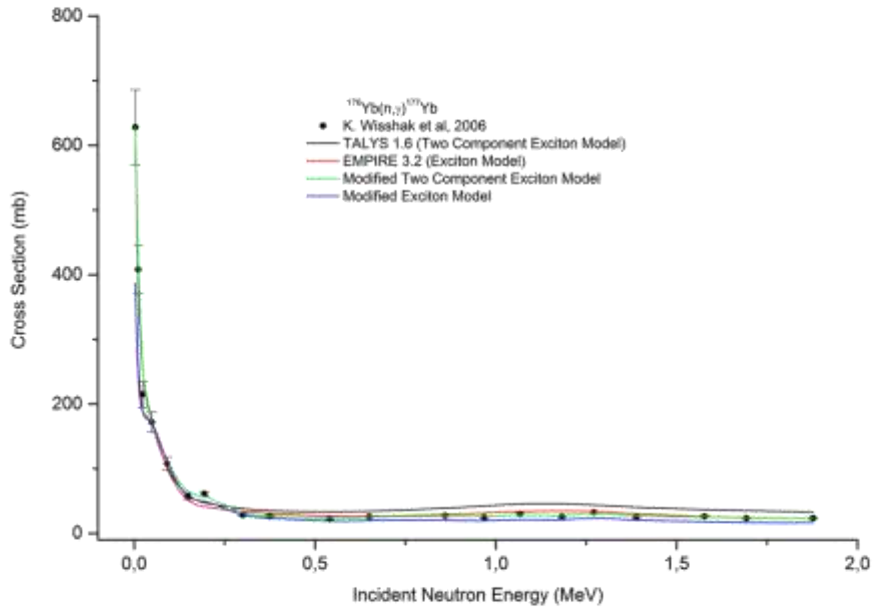

Figure 2. The ^{176}Yb (n,γ)^{177}Yb$\xrightarrow{\beta^-}$^{177}Lu reaction computation with EXFOR experimental data.

^{181}Ta (n,n+α)$^{177\text{-}M}$Lu reaction cross–section results have been given in Fig. 3. TALYS 1.6 and EMPIRE 3.2 calculations show an agreement between each other however they follow the experimental data from below. The Modified TCE Model shows almost perfect agreement with the experimental data and Modified Exciton model curve shows a similar harmony with the experimental data from below.

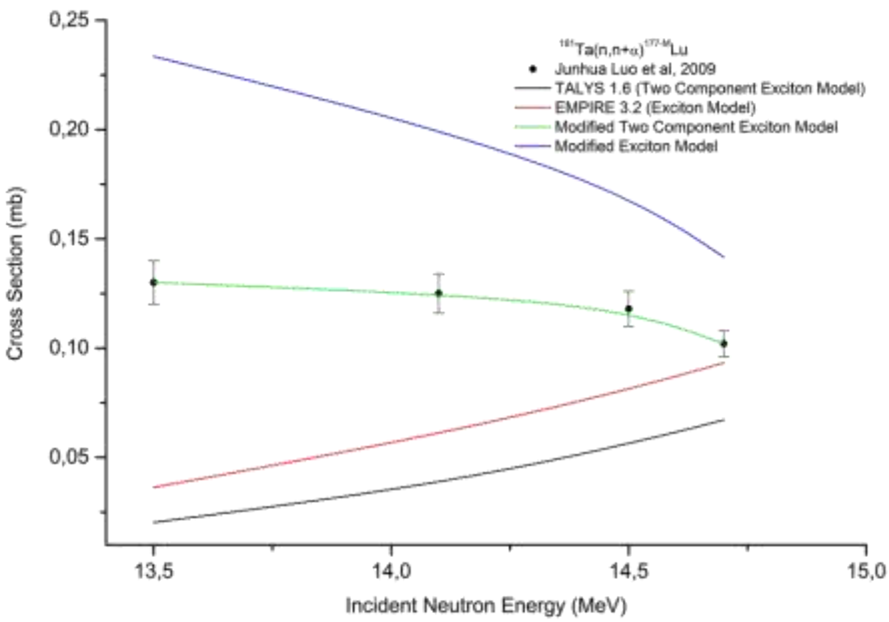

Figure 3. The ^{181}Ta (n,n+α)$^{177\text{-}M}$Lu reaction computation with EXFOR expaerimental data.

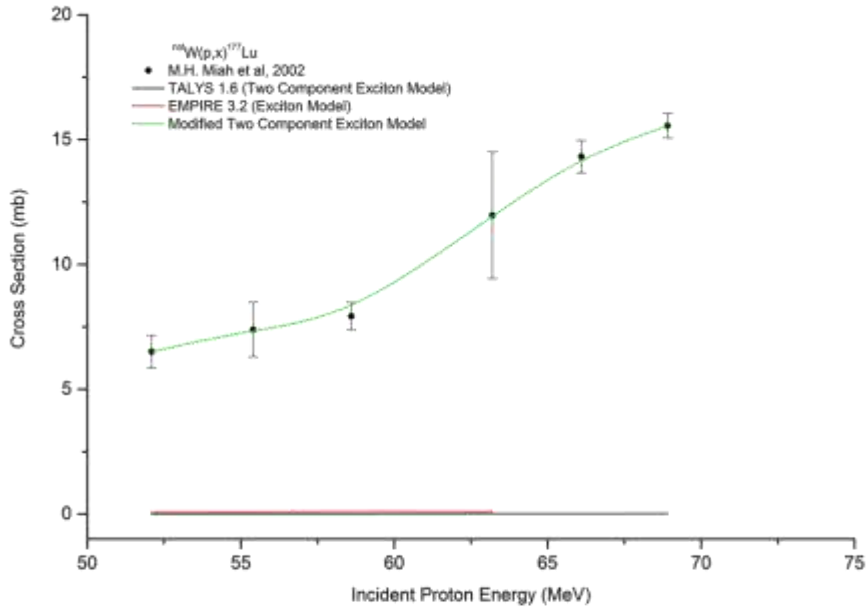

Figure 4. The $^{nat}W(p,x)^{177}Lu$ reaction computation with EXFOR experimental data.

In Fig. 4, the cross–section results of $^{nat}W(p,x)^{177}Lu$ have been given. Default TCE and Exciton model calculation results were obtained in a very narrow range in the cross–section axis and due to that the results seems almost straight lines below the experimental data. However, the Modified TCE model follows the experimental data almost perfectly.

4. SUMMARY AND CONCLUSIONS

For the investigation of the production routes of ^{177}Lu, $^{176}Lu\ (n,\gamma)^{177}Lu$, $^{176}Yb\ (n,\gamma)^{177}Yb \xrightarrow{\beta^-} {}^{177}Lu$, $^{181}Ta\ (n,n+\alpha)^{177\text{-}M}Lu$, $^{nat}W(p,x)^{177}Lu$ reactions have been investigated in this study. The obtained results have been compared with the exist experimental values in the literature. The summary and conclusion of the obtained results and discussion can be given as:

1- All the reaction model calculations, modified model calculations and experimental values give close results to each other for $^{176}Lu\ (n,\gamma)^{177}Lu$ and $^{176}Yb\ (n,\gamma)^{177}Yb \xrightarrow{\beta^-} {}^{177}Lu$ reactions in where the ^{177}Lu production has been performed with low energetic neutron induced particles.

2- For high energetic neutron induced reactions, given with $^{181}Ta\ (n,n+\alpha)^{177\text{-}M}Lu$ and $^{nat}W(p,x)^{177}Lu$ reactions, the exist reaction models in calculation codes gives far results from the experimental values. Due to that, the modification of the models is really needed to improve the estimation of cross–section calculations.

3- Modified Two Component Exciton model reaction calculation results give almost the same results with experimental values for all reactions.

4- In the cases of the lack of experimental values, inability to perform new reactions or failure of the exist theoretical nuclear reaction models, it is possible to use the modified nuclear reaction cross–section models.

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