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Production Cross-section and Reaction Yield of ^{82}Sr for $^{82}Sr/^{82}Rb$ Generator

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ABSTRACT

There are many radioisotopes used for diagnostic and therapeutic purposes in nuclear medicine. One of the radioisotopes used for diagnostic purposes is ^{82}Rb. It is used in positron emission tomography (PET) as to be positron emitter and commonly obtained from $^{82}Sr/^{82}Rb$ generator. In this study, we have investigated some possible production mechanisms of ^{82}Sr by regarding $^{82}Sr/^{82}Rb$ generator. $^{85,87}Rb(p,xn)^{82}Sr$ and $^{80,82,83,84,86}Kr(^{3}He,xn)^{82}Sr$ reaction channels have been investigated using the Constant Temparature Fermi Gas Model (CTFGM), Back Shifted Fermi Gas Model (BSFGM), and Generalised Superfluid Model (GSM) models within the framework of TALYS 1.9 nuclear reaction code. It has been seen that the production cross-sections, reaction yields and total activation values calculated up to 60 MeV beam energy value are in agreement with the available data in the literature.

Keywords: Production cross-section, Reaction yield, Strontium-82.

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Introduction

Today, radioisotopes are commonly used in the diagnosis and treatment of many diseases in nuclear medicine. While gamma or positron emitting radioisotopes are preferred for diagnostic use (^{99m}Tc, ^{18}F), beta emitter radioisotopes are preferred for therapeutic use (^{67}Cu, ^{188}Re, ^{90}Y, ^{131}I) [1]. Studies on these commonly used radioisotopes and potential radiosiotopes are still ongoing [2]. One of the commonly used radioisotopes in nuclear medicine is ^{82}Rb radioisotope, which is obtained from $^{82}Sr/^{82}Rb$ generator. ^{82}Sr has a half-life of approximately 25.55 days. It transforms into the short half-life (76.38 s) radioisotope ^{82}Rb by 100% EC [3] as shown in Figure 1. ^{82}Rb is used in Positron Emission Tomography (PET) applications in nuclear medicine. ^{82}Rb is obtained from the decay its parent, ^{82}Sr, which is commercially avaible as $^{82}Sr/^{82}Rb$ generator system [4]. Radionuclide generators are a convenient method for in situ radioisotope production and provide an alternative to cyclotrons for rapid and regular production of short half-life radionuclides for clinical use [5,6].

In the process from past to present, many studies have been carried out on the production of ^{82}Sr by different nuclear reaction channels. For example, one of the proton bombardment studies, such as the $^{85}Rb(p,4n)^{82}Sr$ reaction [7,8], has been done by Kastleiner et al. in 2001. In the experimental study using the stacked foil technique, the margin of error has been calculated as 13-26% and best reaction cross section value obtained has been determined as 195 mb at 45 MeV [9]. Another study has been conducted by Buthelezi et al. in 2006 [10] for the $^{nat}Rb(p,xn)^{82}Sr$ [10,11] reaction. In the experimental study, Rb target nuclei has been bombarded with proton and cross section measuruments has been taken in the energy range of 1-100 MeV and compared with the theoretical values obtained with the help of ALICE nuclear reaction program for the same reaction values. Maximum cross section value obtained has been determined as 148 mb at 67,37 MeV. In 2019, Zagryadskii et al., in their experimental study using a different reaction channel ($^{82,83,84}Kr(^{3}He,xn)^{82}Sr$), bombarded $^{82,83,84}Kr$ target with ^{3}He, and cross section measurements has been made in the energy range of 20-75 MeV. Determiden the best values obtained as 193, 173 and 110 mb at 33, 45 and 64 MeV, respectively [12]. Apart from these, many different studies are avaible in the literature for the production of ^{82}Sr radioisotope; $^{nat}Rb(d,xn)^{82}Sr$ [13], and $^{nat,80,82,83}Kr(\alpha,xn)^{82}Sr$ [14]. In this study, we have investigated some possible production mechanisms of ^{82}Sr by regarding $^{82}Sr/^{82}Rb$ generator. In this study, it is aimed to examine the nuclear reaction channels at low energy values and to provide preliminary data for the experimental studies to be made for the radioisotope production of the optimal values obtained. In this context, $^{85,87}Rb(p,xn)^{82}Sr$ and $^{80,82,83,84,86}Kr(^{3}He,xn)^{82}Sr$ reaction channels have been investigated using the Constant Temparature Fermi Gas Model (CTFGM), Back Shifted Fermi Gas Model (BSFGM), and Generalised Superfluid Model (GSM) models within the framework of TALYS nuclear reaction code. It has been discussed the production cross-section, reaction yields and total activation values calculated up to 60 MeV beam energy value are agreement with the available data in the literature.

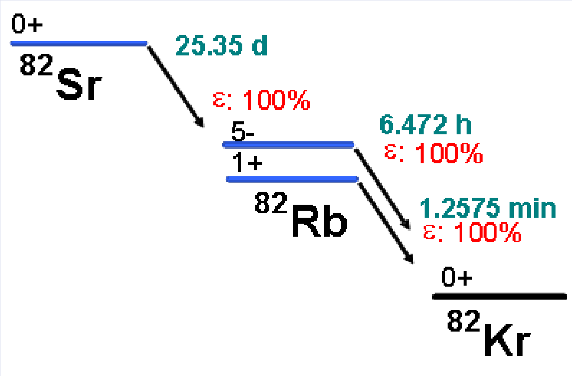

Figure 1. ^{82}Sr decay scheme.

Calculations

In this study, we have investigated some possible production mechanisms of ^{82}Sr by regarding ^{82}Sr/^{82}Rb generator using the TALYS nuclear reaction code. ^{85,87}Rb(p,xn)^{82}Sr and ^{80,82,83,84,86}Kr(^{3}He,xn)^{82}Sr reaction channels have been investigated using the Constant Temparature Fermi Gas Model (CTFGM), Back Shifted Fermi Gas Model (BSFGM), and Generalised Superfluid Model (GSM) models of Level Density Model up to 60 MeV energy value within the framework of TALYS nuclear reaction code. TALYS is a simulation program used for the analysis of nuclear reaction experiments and obtaining nuclear data. This program provides information about the interaction between particles and nuclei such as protons, neutrons and ^{3}He at energies in the energy range of 1 keV-200 MeV, helping to provide an optimization between experimental and theoretical data [15].

TALYS nuclear reaction code includes several nuclear reaction models that allow for a better understanding of nuclear reactions, which allows for a better evaluation of nuclear reactions. For example, Fermi Gas Model (FGM) is one of the best known level density models. Since it is based on the assumption that the single particle states that make up the excited energy levels of the nucleus ara equally spaced, it is a successful model at low energy levels but fails at high energy levels. In the CTFGM, the excitation energy was examined in two ways. In the low energy region (from 0 MeV up to matching energy E_M), the law of Constant Temperature was applied and in thehigh energy region, Fermi Gas law was applied. The constant temperature part of the total level density model is given in the equation below. The nuclear temperature T and E_0 are parameters that serve to adjust the formula to the experimental discrete levels [16].

$$\rho_T^{tot} = \frac{dN(E_x)}{dE_x} = \frac{1}{T}\exp\left(\frac{E_x - E_0}{T}\right)$$

BSFGM has been developed to alllow the coupling energy to be considered as a modifiable parameter at low energies. The expression for the total BFM level density is given by the following expression [17].

$$\rho_{BFM}^{tot}(E_x) = \left[\frac{1}{\rho_F^{tot}(E_x)} + \frac{1}{\rho_{0(t)}}\right]^{-1}$$

In addition, GSM is a model used to characterize phase transitions from superfluid behavior in the low energy region to the high energy region. The expression for the total GSM level density is given by the following expression [18].

$$\rho_{GSM}^{tot}(\mathrm{Ex}) = \frac{1}{\sqrt{2\pi}\sigma}\frac{\sqrt{\pi}}{12}\frac{\exp[2\sqrt{\sigma U}]}{a^{1/4}U^{1/4}}$$

Results and Discussion

In this study, we have calculated the production cross sections, reaction yields and total activation values up to 60 MeV beam energy value for ^{85,87}Rb(p,xn)^{82}Sr and ^{80,82,83,84,86}Kr(^{3}He,xn)^{82}Sr reaction channels via TALYS 1.9 code. The obtained production cross-section calculations are shown in Figures 2-7.

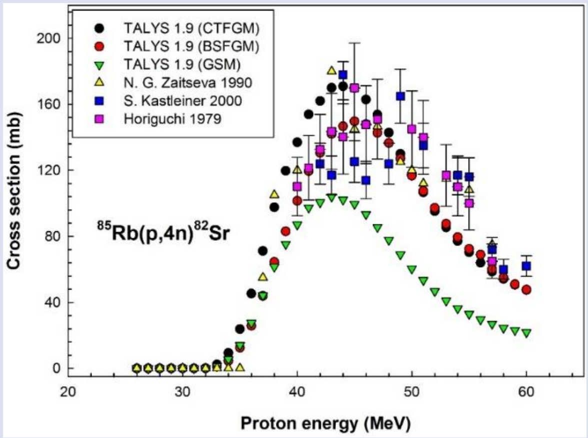

Figure 2. Cross-section for the ^{85}Rb(p,4n)^{82}Sr nuclear reaction.

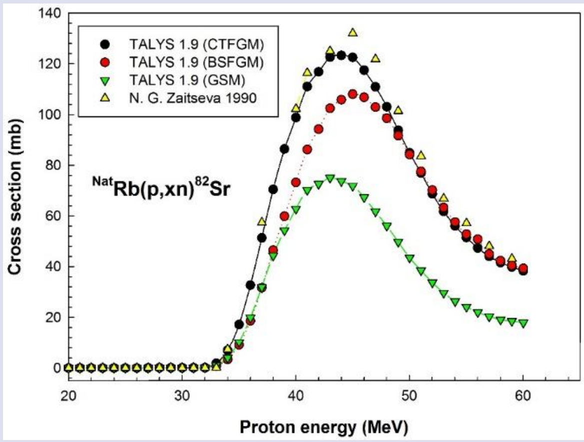

Figure 3. Cross-section for the ^{Nat}Rb(p,xn)^{82}Sr nuclear reaction.

In Figures 2 and 3, comparisons of $^{85}Rb(p,4n)^{82}Sr$ and $^{Nat}Rb(p,xn)^{82}Sr$ reactions cross section calculations with avaible data in the literature has been given in Ref. [9,19,20]. As seen in Figure 2 and 3, the calculated cross-section values up to energy values of approximately 32 MeV with the considered three TALYS models are around zero. Considering both reactions, the results of GSM model are not so compatible with the experimental data. GSM model gives low cross-section values. The other two models were generally found to be more compatible with the available data, especially in the high energy region. The best level density model for ^{82}Sr production by both reaction channels has been determined as CTFGM. According to the best model, maximum cross-section for $^{85}Rb(p,4n)^{82}Sr$ and $^{Nat}Rb(p,xn)^{82}Sr$ has been calculated as 170.982 mb at 44 MeV and 123 mb at 42 MeV, respectively. Considering the margins of error of the studies in the literature used in the comparison (margins of error are approximately 10-20%), it seens that the values obtained are acceptable.

In Figures 4-7, the production cross-section of $^{82,83,84,Nat}Kr(^3He,xn)^{82}Sr$ reactions are presented. As can be seen in figure 4, significant peak values in the energy range of 18-30 MeV were obtained for the $^{82}Kr(^3He,3n)^{82}Sr$ reaction channel and they were seen that CTFGM was the model that best fitted the available data. Maximum cross-section value for this reaction channel has been calculated as 202.393 mb at 22 MeV. Figure 5 and 6 show the cross-section values for the $^{83,84}Kr(^3He,xn)^{82}Sr$ reaction channels. As can be seen, the data in the low energy region were not obtained, the cross-section values showed a significant peak in the range of 40-60 MeV and the BSFGM model is the most compatible model with the available experimental data. In addition they were observed that the maximum cross-section value for these reaction channels were obtained from CTFGM, that GSM was not compatible with the available data and low cross-section values were obtained. Maximum cross-section value for this reaction channel has been calculated as 22.637 mb and 17.019 mb at 44 MeV and 58 MeV, respectively. The figure 7 was indicated the BSFGM for $^{Nat}Kr(^3He,xn)^{82}Sr$ reaction channel more consistant with the available data although the best cross-section values are obtained from CTFGM that indicated. The obtained data has been compared with the accessible data in the literature, and it was seen that the results are found acceptable when the margins of error in the studies has been taken into account (margins of error are approximately 13-26%) [12,13].

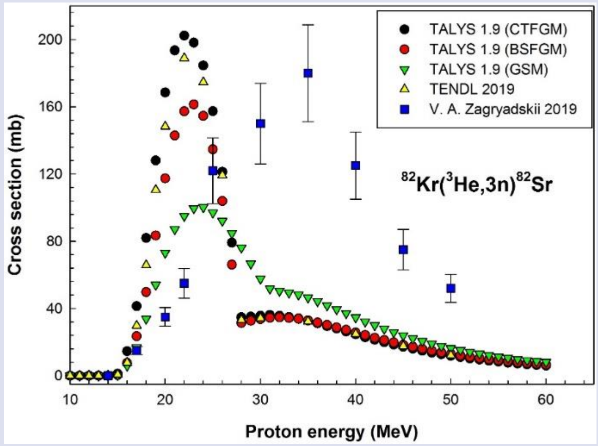

Figure 4. Cross-section for the $^{82}Kr(^3He,3n)^{82}Sr$ nuclear reaction.

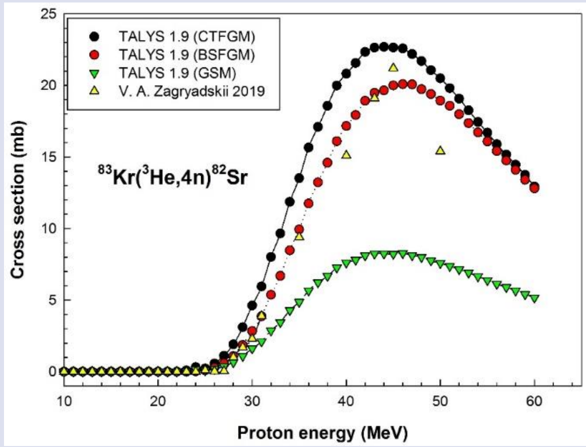

Figure 5. Cross-section for the $^{83}Kr(^3He,4n)^{82}Sr$ nuclear reaction.

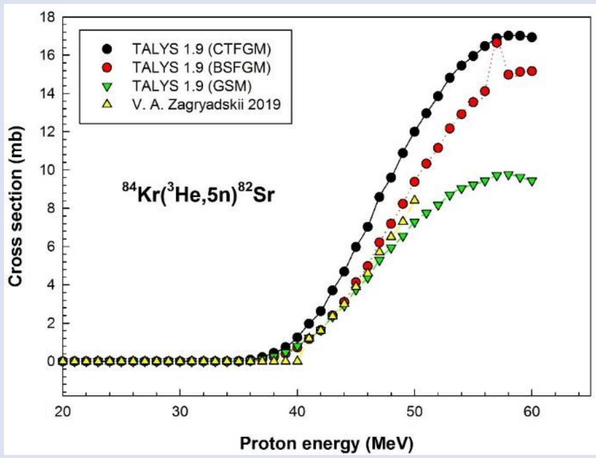

Figure 6. Cross-section for the $^{84}Kr(^3He,5n)^{82}Sr$ nuclear reaction.

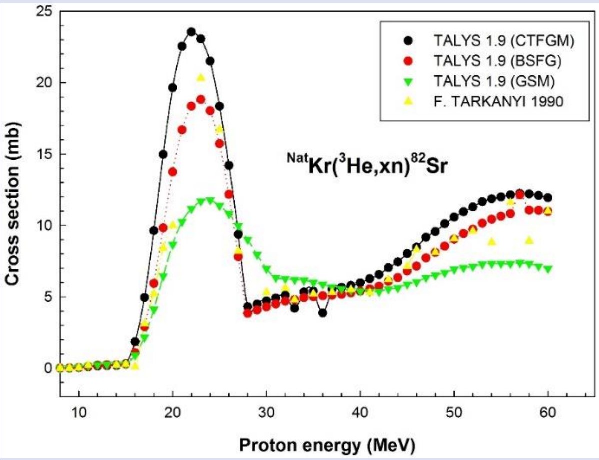

Figure 7. Cross-section for the $^{Nat}Kr(p,xn)^{82}Sr$ nuclear reaction.

Another important part of radioisotope production is reaction yield. Reaction yield allows us to obtain information about the different possible radioisotope production values of nuclear reactions. In this study, we have calculated reaction yield of $^{80,82}Kr(^{3}He,xn)^{82}Sr$ reactions for 5 mA. As can be clearly seen in Figure 8, $^{80,82}Kr(^{3}He,xn)^{82}Sr$ reaction yields are 0.01248 and 0.2160 GBq/mAh, respectively.

In addition, total activation values has been calculated as seen in Figures 9 and 10. Maximum total activaties values for $^{80}Kr(^{3}He,n)^{82}Sr$ and $^{82}Kr(^{3}He,3n)^{82}Sr$ reactions are 1.4782 and 25.5668 GBq, respectively. As seen in Figures 9 and 10, total activities are constant up to after cutting of the irradiation.

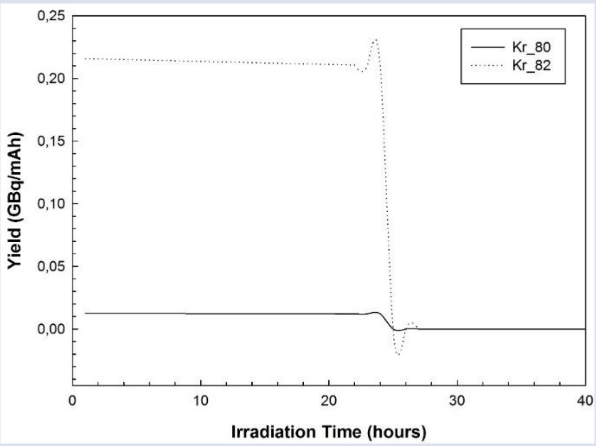

Figure 8. Reaction yields of $^{80,82}Kr(^{3}He,xn)^{82}Sr$ reactions.

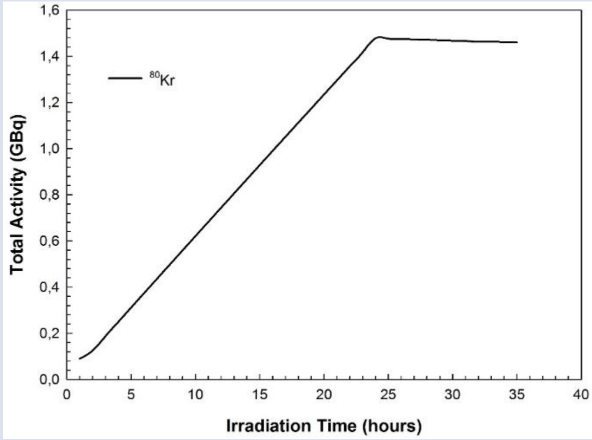

Figure 9. Total activity of $^{80}Kr(^{3}He,n)^{82}Sr$ nuclear reaction.

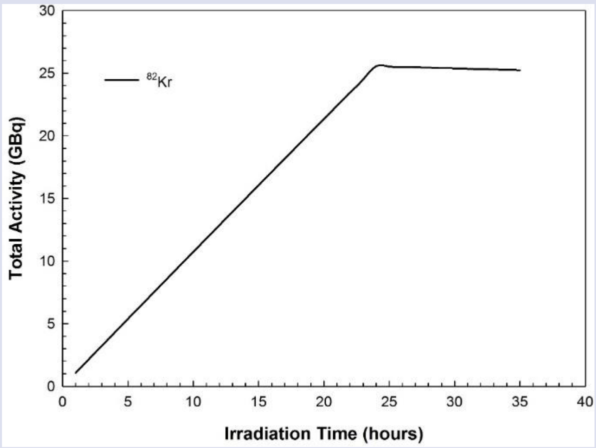

Figure 10. Total activity of $^{82}Kr(^{3}He,3n)^{82}Sr$ nuclear reaction.

Conclusion

The aim of this study was to examine the production cross sections of the 82Sr radioisotope used in nuclear medicine at low energy levels [0-60 MeV]. In this context, some possible production mechanisms of $^{85,87}Rb(p,xn)8^{2}Sr$ and $^{80,82,83,84,86}Kr(^{3}He,xn)^{82}Sr$ reaction channels have been investigated within the framework of TALYS nuclear reaction code. As a result of this study, it has been seen that the GSM calsulations were inconsistent with the existing data and low cross-section values were obtained. CTFGM and BSFGM calsulations generally yielded results consistent with the available data. But the maximum production cross-section values were obtained from CTFGM. Best production cross-section for $^{82}Sr/^{82}Rb$ generator were 170.982 mb for $^{85}Rb(p,4n)^{82}Sr$ reaction and 202.393 mb for $^{82}Kr(^{3}He,3n)^{82}Sr$ reaction at 44 MeV and 22 MeV, respectively. In addition, maximum reaction yield values for 5 mA current have been calculated as 0.01248 and 0.2160 GBq/mAh for $^{80}Kr(^{3}He,n)^{82}Sr$ reaction and $^{82}Kr(^{3}He,3n)^{82}Sr$ reaction, respectively.

The total activation values have been calculated as 1.4782 and 25.5668 GBq, respectively. Considering the margins of error in existing experimental studies and the inadequacy of specific experimental studies in this field, the comparison of the obtained results is open to discussion.

Conflicts of interest

There are no conflicts of interest in this work.

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