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Calculations of Yield Cross-Sections of ^{51}Cr, ^{99}Mo and ^{133}Xe Radioisotopes via Neutron Induced Reactions

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Abstract: Usage of medical radioisotopes for diagnostic purposes is increasing day by day. Because of this reason, many attempts are performed for finding more efficient way for production of medical radioisotopes. One of the projectiles used for production of medical radioisotopes is neutron. In the present paper we have investigated neutron induced yield cross-sections of ^{51}Cr, ^{99}Mo and ^{133}Xe radioisotopes which are commonly used in nuclear medicine as a generator for diagnostic purposes by using TALYS nuclear reaction code. For this purpose, the neutron energies for maximum yield cross-sections of ^{51}Cr, ^{99}Mo and ^{133}Xe radioisotopes have been calculated and compared with the available data.

1. Introduction

Nuclear medicine deals with diagnosis and treatment of various issues on human body by using radioisotopes. In the case of diagnosis, various radioisotopes are used by regarding effectiveness of them. This covers reliable emitted gamma-rays which give possibility of taking high quality images and not giving more radiation dose to patients. For this reason, low-energy gamma-rays and radioisotopes with short half-life are favorable for diagnostic nuclear medicine [1, 2]. However, radioisotopes with short half-life cannot be so useful if the radioisotopes production center is far away from nuclear medicine laboratory. Because of this reason, some radioisotopes are used as generator product. ^{51}Cr, ^{99}Mo and ^{133}Xe generators are some of the examples [1]. One of the mostly used radioisotopes in nuclear medicine applications is ^{99m}Tc which is the product of ^{99}Mo. It decays into ^{99m}Tc with 65.976 h half-life via beta decay [3]. Thus ^{99}Mo provides ^{99m}Tc source to nuclear medicine laboratory as to be generator for one or two weeks. The radioisotopes ^{51}Cr, ^{99}Mo and ^{133}Xe are used as sources for nuclear medicine applications. ^{51}Cr is used for labeling red blood cells and spleen scanning; ^{99}Mo is the source of ^{99m}Tc, the most commonly used radionuclide in nuclear medicine; and ^{133}Xe is used for lung ventilation studies. These medical radioisotopes can be produced via neutron induced nuclear reactions [1].

In the present study, the cross-sections for the yields of ^{51}Cr, ^{99}Mo and ^{133}Xe by neutron induced nuclear reactions have been calculated. The yield ratios of these nuclei as a function of incident neutron energy have been carried out by using TALYS nuclear reaction code. The results also have been compared with the available data.

2. Calculations

In the present study, neutron induced nuclear reactions considered as follows:

$$ {}^{50}_{24}\mathrm{Cr} + {}^{1}_{0}\mathrm{n} \rightarrow [{}^{51}_{24}\mathrm{Cr}] \rightarrow {}^{51}_{24}\mathrm{Cr} + \gamma \quad (1)$$

$$ {}^{98}_{42}\mathrm{Mo} + {}^{1}_{0}\mathrm{n} \rightarrow [{}^{99}_{42}\mathrm{Mo}] \rightarrow {}^{99}_{42}\mathrm{Mo} + \gamma \quad (2)$$

$$ {}^{132}_{54}\mathrm{Xe} + {}^{1}_{0}\mathrm{n} \rightarrow [{}^{133}_{54}\mathrm{Xe}] \rightarrow {}^{133}_{54}\mathrm{Xe} + \gamma \quad (3)$$

The cross-sections of the considered neutron induced reactions have been calculated by using TALYS 1.95 nuclear reaction code [4]. It is an open source software package for the simulation of nuclear reactions. It can simulate nuclear reactions where incident particles are neutrons, photons, protons, deuterons, tritons, ^{3}He and alpha-particles, in the 1 keV-200 MeV energy range and target nuclides of mass 12 and heavier. For this, it is implemented a suite of nuclear reaction. TALYS is a software for the simulation of nuclear reactions, which includes many state-of-the-art nuclear models to cover all main reaction mechanisms encountered in light particle-

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induced nuclear reactions. TALYS provides a complete description of all reaction channels and observables and in particular takes into account all types of direct, pre-equilibrium, and compound mechanisms to estimate the total reaction probability as well as the competition between the various open channels.

3. Results and Discussion

The calculated cross-sections of $^{50}Cr(n,\gamma)^{51}Cr$ reaction are shown in Figure 1 together with the available experimental data taken from Refs. [5-12]. As it can be seen in Figure 1, the cross section of $^{50}Cr(n,g)^{51}Cr$ reaction is decreasing by increasing of incident neutron energy. This is well known fact that neutrons with lower energy interact with nuclei for much more time with respect to neutrons with high energy. This makes the cross-sections bigger for lower neutron energy. In Figure 1, the general tendency of data points calculated with TALYS is similar to those of experimental data. However, two and three order of difference between calculated results and the experimental data are seen.

Much more agreement with the experimental data is obtained for $^{98}Mo(n,g)^{99}Mo$ reaction which is shown in Figure 2. At about 0.3 keV incident neutron energy, the kink is produced as in agreement with the experimental data even if the value of cross-section (87.8 barns) is quite bigger. The experimental data indicates that 0.3 keV and 0.01 keV neutron energy can be considered as to be the best incident neutron energy for obtaining of ^{99}Mo radioisotopes because these neutron energies give higher cross-sections for related nuclear reactions.

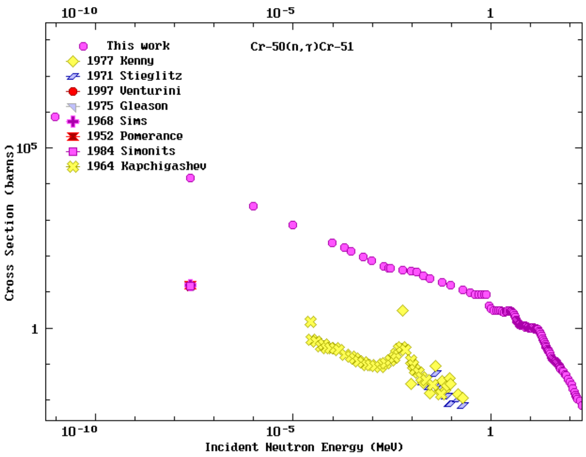

Figure 1. The calculated cross-sections of $^{50}Cr(n,g)^{51}Cr$ reaction as a function of incident neutron energy and the available experimental data [5-12].

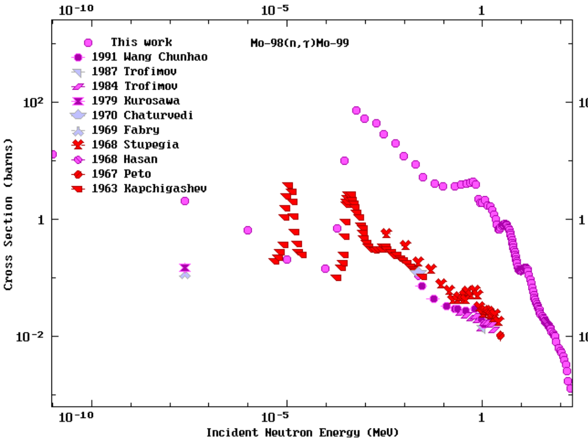

Figure 2. The calculated cross-sections of $^{98}Mo(n,g)^{99}Mo$ reaction as a function of incident neutron energy and the available experimental data [13-22].

We have also calculated the cross-sections of $^{132}Xe(n,g)^{133}Xe$ reaction which are shown in Figure 3. However, there is a limited number of experimental data for the related reaction. It should be noted that neutron with 1 keV energy give highest cross-section value which means that this neutron energy can be best candidate for producing of ^{133}Xe radioisotope effectively.

In the present study, yield cross-sections of ^{51}Cr, ^{99}Mo and ^{133}Xe radioisotopes via neutron induced reactions have been calculated. The neutron energy for obtaining maximum yield cross sections of ^{99}Mo and ^{133}Xe via neutron induced reactions has been determined as to be 1 keV.

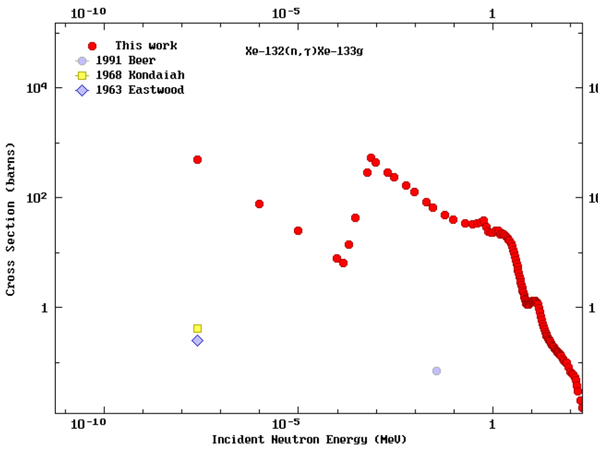

Figure 3. The calculated cross-sections of $^{132}Xe(n,g)^{133}Xe$ reaction as a function of incident neutron energy and the available experimental data [23-25].

4. Summary

In this work the production cross-sections of ^{51}Cr, ^{99}Mo and ^{133}Xe radioisotopes for neutron induced nuclear reactions have been carried out. For this purpose, TALYS nuclear reaction code has been used. The calculated results have been found to be one more order of experimental data. However, the general tendency of calculated cross-sections through the incident neutron energy is found to be close to the experimental ones.

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