^{99}Mo production via ^{96}Zr(α,n) reaction: Cross section evaluation using EMPIRE-3.1 code

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Technitium-99m ($T_{1/2}$ ~ 6.01 h) is used for a wide variety of medical diagnotics tests, and it still continues to be one of the most important radionuclide that allowing around 30 million medical procedures world wide every year. This radionuclide is the deacy product of ^{99}Mo parent radionuclide($T_{1/2}$ ~ 65.94 h) , which currently produced in nuclear reactors via neutron induced fission reactions of highly enriched ^{235}U. This production route is facing political challenges that threaten availibility of ^{99}Mo in future and this prompted scientific community to investigate new production routes for these vital radionuclides and production using accelerators is recognized as one of the promising ones in short-term.

The reaction ^{96}Zr(α,n)^{99}Mo allows to separate high-specific-activity ^{99}Mo from the Zr target after irradiation. In order to use this reaction efficiently, enriched target of ^{96}Zr of suitable thickness and high current α-beam of appropriate energy are to be used. This method of production of ^{99}Mo has not been proven in trials yet. There are also uncertainities regarding nuclear data on this reaction. First measurement of ^{96}Zr(α,n)^{99}Mo excitation function was carried out by using the well known stacked foil activation technique at VECC, Kolkata, using 40 MeV α-beam and a natural Zr target[1]. Only the interaction of the α-beam with the ^{96}Zr contained in ^{nat}Zr (2.80% natural abundance) can lead to production of ^{99}Mo. Very recently a remeasurement of the same reaction has been performed at ARRONAX facility in France using 67 MeV α-beam[2]. A general good agreement in cross-section trend has been observed in both measurements, however the latter measurement showed a higher peak value and a shift of about 2 MeV towards larger energies. Theoretical estimation of the excitation function has been carried out in the former work using the programme ALICE and on the contrary the predicted cross section peak is shifted towards lower values by 2-3 MeV. The work in Ref. [2] did not provide a theoretical estimation for the excitation function. The available theoretical result [1] is thus lower by 4-5 MeV in peak position when compared with the recent experimental results[2]. We have carried out calculations using EMPIRE 3.1 code system for theoretical evaulations of the excitation funtions, motivated by the above anomalous situation for this important reaction.

The EMPIRE3.1 is equipped with a complex system of codes to describe all important reaction mechanisms[3]. The optical model and the direct reaction calculations are performed by the ECIS-03 code with discrete levels and deformation parametrs retrived from the RIPL-2 library. The direct channel calculations are performed by using coupled channels model or distorted-wave Born approximation method. As a significant part of the reaction cross sections from 10 to 200 MeV is formed by pre-equilibrium mechanisms, the code incorporates these aspects as well.

In the present study, pheonomenological level density models and optical model parameters were varied to obtain predicted cross sections for ^{96}Zr(α,n)^{99}Mo reaction. The experimental data from Ref.[1] and the Empire predicated cross sections using two set of parameters are shown in Figure 1. For a quick reference, the predicted cross sections using ALICE from[1] are also plotted in Fig.1. The optical model parameter set due to ‘Japan’(set1) provides the best agreement with the data in terms of the peak position and relative width of the peak. ALICE results[1] and the EMPIRE results with optical model parametrs due to Koenig(set2) are close to each other in terms of above parametrs but they are deviant from the experimental data.

The present results are calculated with equilibrium and preequilibrium reaction models. Reasons for the descrepancies in comparisons of code results with accurate experimental data are usually ascribed to different choices made in the calculations. In the model reaction cross sections and transmission coefficients are calculated using optical model parameters (OMP) and the phase space factor in residual nuclei are calculated using nuclear level density(NLD) prescriptions. The NLD options in EMPIRE 3.1 have been changed in calculations and they changed the magnitude of cross sections without affecting the peak positions whereas the OMP options shifted the peak positions as evidenced in Fig.1 plots.

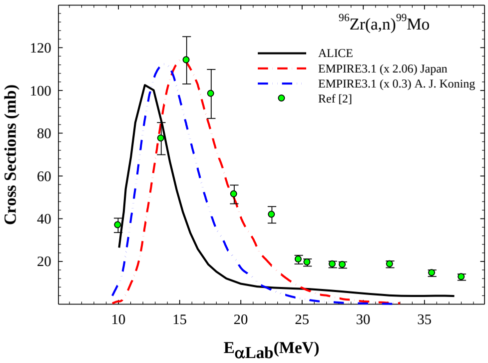

Fig.1: Experimental (from [1]) and calculated cross sections of ^{96}Zr(α, n)^{99}Mo. The EMPIRE results are multiplied by the factors shown in the legend, for display purpose. The ALICE result is from Ref.[1]

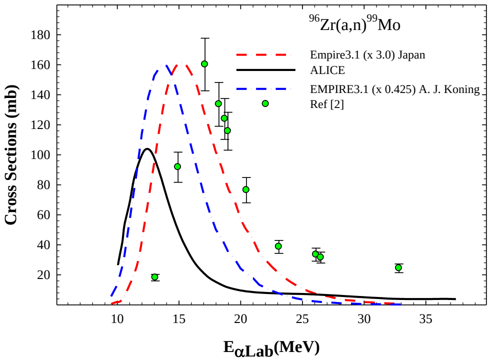

Fig.2: Same as Fig.1 except that the experimental data are from Ref.[2]

The experimental data from Ref.[2] is plotted in Figure 2 along with EMPIRE 3.1 and ALICE predictions with the multiplication factors as indicated. The deviations of the experimental data from the predications are visible. Experimental data from [2] show both a higher peak value and a shift of about 2 MeV towards higher energies when compared with the data from [1].

It is quite puzzling as what caused the discrepancy between the experimental data [1] and [2]. Further improved cross section measurements on the same reaction are therefore recommended. This is important to improve the accuracy of the nuclear data and to arrive at an ideal α particle energy range for the ^{99}Mo production. This is also important to nuclear model developments.

References

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