# Measurement of $^{100}Mo(n,2n)^{99}Mo$ reaction cross-sections

Siddharth Parashari[1],* S. Mukherjee[1], H. Naik[2], S. V.
Suryanarayana[3], Rajnikant Makwana[1], Mayur Mehta[4],
Ratan Kumar[1], N. L. Singh[1], and SaiAkhil Ayyala[5]
[1]*Department of Physics, Faculty of Science,*
*The M. S. University of Baroda, Vadodara-390002, India*
[2]*Radiochemistry Division, Bhabha Atomic Research Centre, Mumbai-400085, INDIA*
[3]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai-400085, INDIA*
[4]*Institute for Plasma Research, Gandhinagar, Gujraat- 382428, India and*
[5]*G. B. Pant University of Agri. & Tech., Pantnagar, Uttarakhand-263145, India*

## Introduction

Molybdenum is an excellent structural metal at elevated temperatures. It has a wide potential for the use in reactor applications such as an accelerator-driven system (ADSs) or nuclear fusion device (ITER) [1]. The daughter nuclide of $^{99}Mo$ is $^{99m}Tc$, which is widely used in nuclear medicine for diagnostics because of its many advantages. It is also used in most of the diagnostic imaging like single photon emission computed tomography (SPECT) studies around the globe. The medical isotope $^{99m}Tc$ is directly produced from the $^{238}U(p,f)$ and $^{100}Mo(p,2n)$ reactions. The prodution from $^{238}U(p,f)$ is not sophisticated due to the cost, safety, licensing, radioactive waste production and the half-life of 6.01 h, is only permits to produce $^{99m}Tc$ from the $^{100}Mo(p,2n)$ reaction for its instant use. Therefore, as far as medical purposes are conerned, $^{99m}Tc$ can easily be produed directly using protn accelerator within small transit radius. From all aspets given above, measurement of production cross-sections for neutron energies upto 25 MeV is of prime interest. In the present work, we have measured the $^{100}Mo(n,2n)^{99}Mo$ reaction cross-section at average neutron energies of 17.12 MeV. The neutrons were produced using $^{7}Li(p,n)$ reaction. The present findings were also compared with previous data from EXFOR [2], ENDF-B/VIII.1 [3], JENDL-4.0 [4] and TALYS-1.8 [5].

## Experimental Methodology

The experiment was carried out at 14UD BARC-TIFR Pelletron facility, Mumbai, India, using the activation technique followed by off-line $\gamma$-ray spectroscopy. A known energies of proton beam from the Pelletron was bombarded on natural lithium (Li) target to generate the desired energy neutron beam from the $^{7}Li(p,n)$ reaction. Li was wrapped in tantalum (Ta) foils to from both sides. A thick Ta foil was used on the back of Li foil to stop the proton beam. Behind the Ta-Li-Ta stack, molybdenum (Mo) and indium (In) foils wrapped in aluminium were kept at suitable distance from Ta-Li-Ta stack. The whole arrangement was kept inside the 6 m irradiation port at pelletron. The irradiation was carried out for ≈5-7 hrs with 19 MeV proton beam to achieve sufficient activity. The irradiated samples of In and Mo were cooled for significant time to reduce the dose rate from the samples. Then the $\gamma$-ray counting of the samples were done by using pre-calibrated 80 $cm^3$ HPGe detector couple to a PC based 4096 channel analyzer. $^{152}Eu$ standard source was used for the energy and efficiency calibration. The resolution of the detector system during counting was 1.8 keV at 1408 KeV. The $^{115}In(n,n)^{115m}In$ reaction cross-sections were used as the neutron flux monitor.

## Data Analysis

Neutrons are generated by the $^{7}Li(p,n)$ reaction using the protons as the incident parti-

---

*Electronic address: `siddharthparashri5@gmail.com` cle on natural Li target wrapped with Ta foil. The production of ground state of $^7Be$ from the $^7Li(p,n)$ reaction has a threshold energy of 1.88 MeV. A variety of reactions takes place when the protons interact with the natural lithium target which results with a continuous neutron energy distribution. In the present work, the continuous neutron spectrum has been generated by using the neutron energy distribution given in refs. [6, 7]. These neutron distributions have a quasi-monoenergetic peak near $E_P$-1.88 MeV and a long tailing towards lower energies. This tail region consisting of lower neutron energies also contributes in the reaction cross-sections. Therefore, it is necessary to remove the contribution arising from the tail part of the neutron spectra. This correction can be done by considering spectral average cross-sections as given in refs [8]. Neutron flux was calculated using the spectra weighted average cross-section for the onitor reaction. Using this flux we have calculated the spectra weighted production cross-section for $^{99}Mo$ at average neutron energy of 17.12 MeV. Since, the neutron distribution generated using $^7Li(p,n)$ is not monoenergetic and hence have a tail part of all possible neutron energies, therefore, the tailing correction [8] has been done to remove the contribution coming from the low energy neutrons.

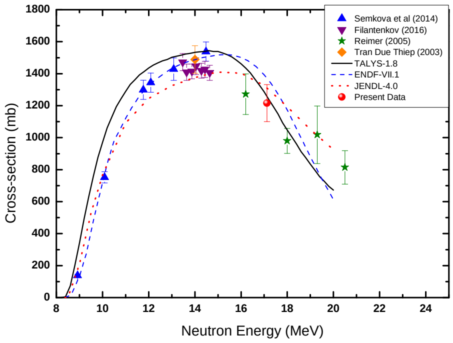

FIG. 1: Production cross-section for $^{99}Mo$ at 17.12 MeV neutron energy

## Results and Discussion

The measured reaction cross-section for $^{100}Mo(n,2n)^{99}Mo$ at average neutron energy of 17.12 Mev is found to be 1.216 ± 116 and is plotted in Fig. 1. The theoretical values from nuclear data libraries are also used to examine the trend of cross-section within the range of neutron energies of present work. It can easily be seen from the plot that the present is in good agreement with the theoretical data from TALYS [5] as well as with ENDF [3] and JENDL [4]. It can also be seen from the figure that there is a discrepancy in ENDF and JENDL values around 12-18 Mev. However, the theoretical values from TALYS are a bit higher around threshold. The prevoius data is also in good agreement with theoretical libraries except from Reimer (2005) which includes large uncertainties.

## Acknowledgments

One of the authors (SM) thanks the DAE-BRNS for the sanction of a major research project and for providing all the necessary funding and support. The authors are thankful to the staff of Pelletron facility TIFR, Mumbai for their excellent operation of accelerator and other supports during the experiment.

## References

[1] Reimer et al. Phys. Rev. C. **71**, 044617 (2005).
[2] EXFOR `https://www-nds.iaea.org/exfor/exfor.htm`.
[3] ENDF/B-VII.1 `http://www.nndc.bnl.gov/exfor/endf00.jsp`.
[4] K. Shibata et al.,Nucl. Sci. and Tech. **48**, 1 (2011).
[5] A. J. Koning et al., NRG-1755, ZG PETTEN, The Netherlands, (2015).
[6] C. H. Poppe et al. Phys.Rev. C 14, 438 (1976).
[7] S. G. Mashnik et al. Los Alamos National Laboratory, Los Alamos, NM 87545, USA (2008).
[8] H. Naik et al. Eur. Phys. J. A **47**, 51 (2011).