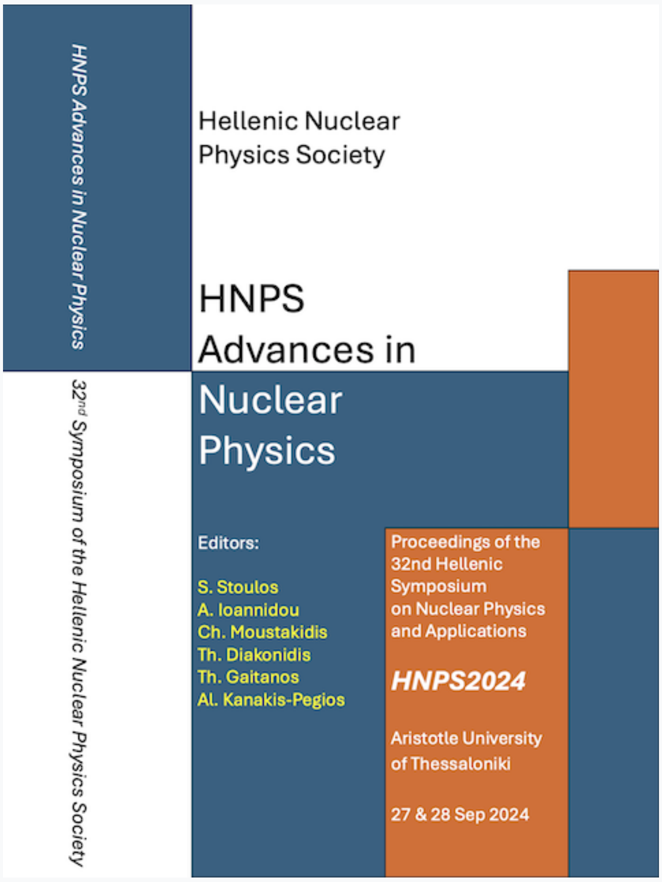
HNPS Advances in Nuclear Physics

Vol 31 (2025)

HNPS2024



First results from cross-section measurements of α-capture reactions on 93Nb and 96Mo relevant to nuclear astrophysics

Maria Peoviti, Michail Axiotis, Varvara Foteinou, Nikolaos Patronis, Fotios Maragkos, Sotirios Harissopulos, Paraskevi Dimitriou

doi: [10.12681/hnpsanp.8153](https://doi.org/10.12681/hnpsanp.8153)

First results from cross-section measurements of α-capture reactions on ^{93}Nb and ^{96}Mo relevant to nuclear astrophysics

M. Peoviti[1,2,*], M. Axiotis[1], V. Foteinou[2], N. Patronis[2], F. Maragkos[3,4], S. Harissopulos[1], P. Dimitriou[5]

[1] *Institute of Nuclear and Particle Physics, NCSR "Demokritos", 15310 Aghia Paraskevi, Greece*
[2] *Department of Physics, University of Ioannina, 45110 Ioannina, Greece*
[3] *Central Unit for Ion Beams and Radionuclides, Ruhr-University Bochum, 44801 Bochum, Germany*
[4] *Department of Physics, National Technical University of Athens, Zografou Campus, 15780 Athens, Greece*
[5] *Nuclear Data Section, International Atomic Energy Agency, 1400 Vienna, Austria*

Abstract The present work reports on preliminary cross-section results of the ^{93}Nb(α,γ)^{97}Tc and ^{96}Mo(α,γ)^{100}Ru reactions at energies between 6 and 7 MeV, a range relevant to p-process nucleosynthesis. The measurements were conducted at the RUBION Dynamitron Tandem Laboratory of the Ruhr-University Bochum, Germany, using the 4π γ-summing method, utilizing the high efficiency of a 12”×12” NaI(Tl) scintillator.

Keywords p-process, (α,γ) cross-section, 4π γ-summing method

INTRODUCTION

Elements heavier than iron are synthesized in various stellar environments primarily through the s-process and r-process. A third nucleosynthetic mechanism, the p-process, is responsible for producing a small group of proton-rich isotopes, known as p-nuclei. These isotopes originate from pre-existing neutron-rich "seed nuclei", which under extremely high-temperature conditions -ypically occurring during or just before a supernova explosion- undergo neutron, proton, or α-particle photodisintegration, often followed by $β^+$-decay. This chain of nuclear reactions leads to the formation of p-nuclei, making the p-process a key contributor to our understanding of the chemical element production in our solar system.

Despite its significance, astrophysical p-process models struggle to accurately reproduce the observed abundances of p-nuclei in our solar system. These discrepancies may arise not only from inaccuracies in the models themselves, but also from insufficient experimental data of the nuclear reaction cross-sections involved in p-process nucleosynthesis. Abundance calculations rely on an extensive reaction network consisting of over 20000 nuclear reactions and nearly 2000 stable and unstable isotopes, with mass numbers between 70 and 190. Given the impracticality of directly measuring all relevant cross-sections -particularly for isotopes far from the valley of stability- predictions based on the Hauser-Feshbach (HF) theory are widely used. However, theoretical uncertainties in HF calculations stem from uncertainties in the nuclear parameters used. To improve predictive accuracy, these nuclear parameters must be tested at energies relevant to the p-process, which for (α,γ) reactions range from 6 to 12MeV, with the aim of refining HF parameterization and reducing uncertainties in abundance predictions [1].

The present work reports preliminary results of the cross-section measurement of the ^{93}Nb(α,γ)^{97}Tc and ^{96}Mo(α,γ)^{100}Ru reactions, at beam energies within the respective Gamow window. For both reactions, the Gamow window was determined to range from approximately 4.5 to 10.3 MeV in the laboratory frame.

* Corresponding author: marpeoviti@gmail.com

EXPERIMENTAL DETAILS

The experiments were conducted at the RUBION Dynamitron Tandem Laboratory (DTL) of Ruhr University Bochum, Germany [2], using the 4π γ-summing technique. Measurements were performed with a 12”×12” NaI(Tl) scintillator with almost 4π solid angle coverage for photons emitted at its center (Fig. 1). The sample-holder system was positioned at the detector’s center through the 35-mm hole along its axis.

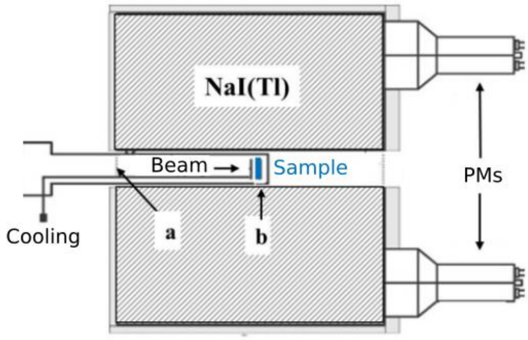


Figure 1. *Schematic representation of the experimental setup in DTL.*

The samples used for the experiments were a 69 μg/cm² ^{93}Nb film evaporated onto a Ta backing and a 750 μg/cm² self-supported ^{96}Mo foil (Fig. 2).

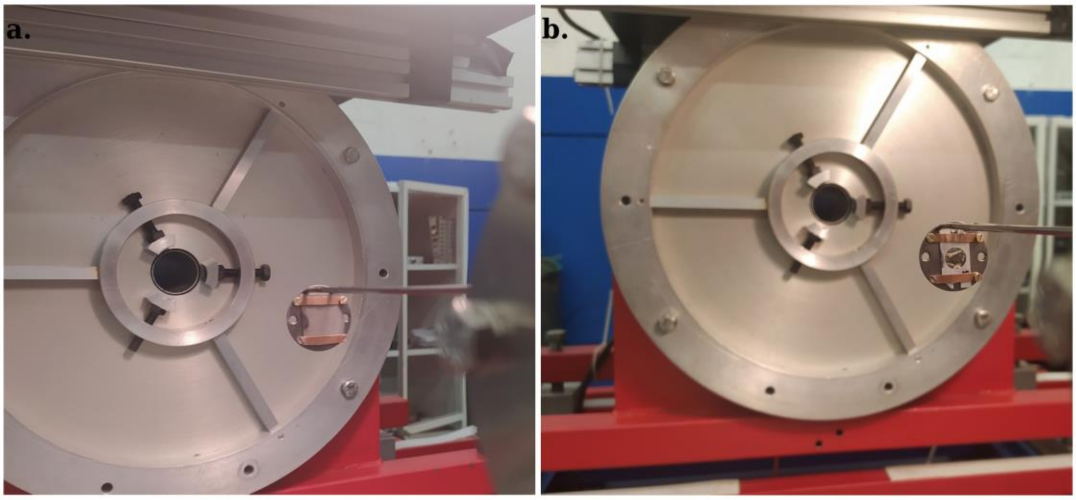


Figure 2. *Photographs of the experimental samples: (a) ^{93}Nb and (b) ^{96}Mo.*

DATA ANALYSIS

Figure 3 presents two typical spectra for the reactions under study at beam energy equal to 7.0 MeV. In both cases, the investigated photopeak, denoted as γ_Σ, appears at an energy equal to the reaction Q-value plus the beam energy in the center-of-mass frame. As shown in both spectra, γ_Σ is challenging to analyze due to its very low cross-section at the specific energy region and the overlap of the sum-peak with strong background. Additionally, several other peaks are visible, originating from natural background radiation and beam interactions with carbon and aluminum present in the beamline.

In the case of ^{93}Nb, a second peak appears at an energy approximately 1 MeV higher than the sum-peak of the reaction under study. The origin of this peak is α-particle capture from ^{16}O, an element naturally present in the target. Niobium oxidizes rapidly at high temperatures, such as those encountered during the evaporation technique, which was used to construct the sample. Rutherford Backscattering Spectrometry (RBS) analysis confirmed the presence of oxygen in the target, with an approximate 50-50 ratio with niobium. Unfortunately, the oxygen-induced sum-peak remained consistently strong across all spectra, further complicating the analysis of the niobium sum-peak and, in some cases, completely obstructing it.

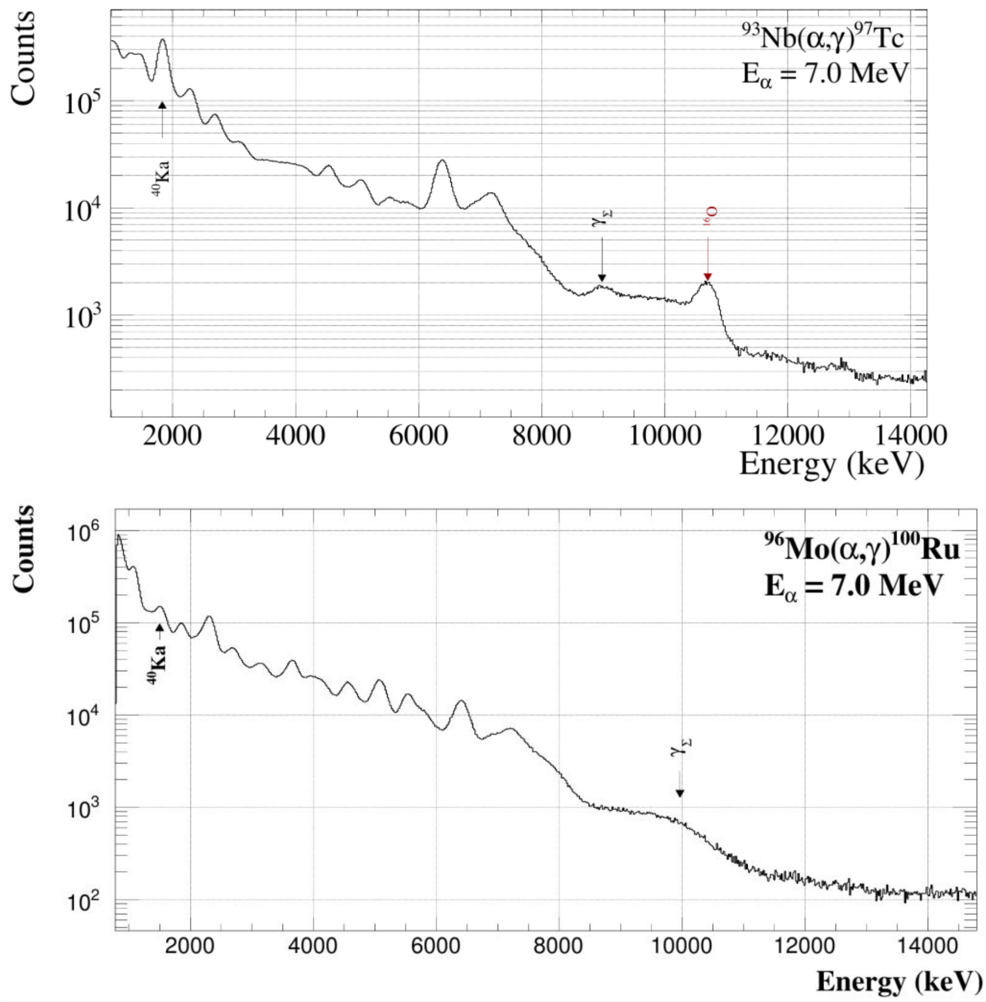


Figure 3. *Typical spectra of the two reactions under study.*

The cross-section is obtained using the formula:

$$\sigma = \frac{\mathrm{A} \cdot \Upsilon_{\Sigma}}{\mathrm{N_A} \cdot d \cdot \varepsilon_{\Sigma}} \quad (1)$$

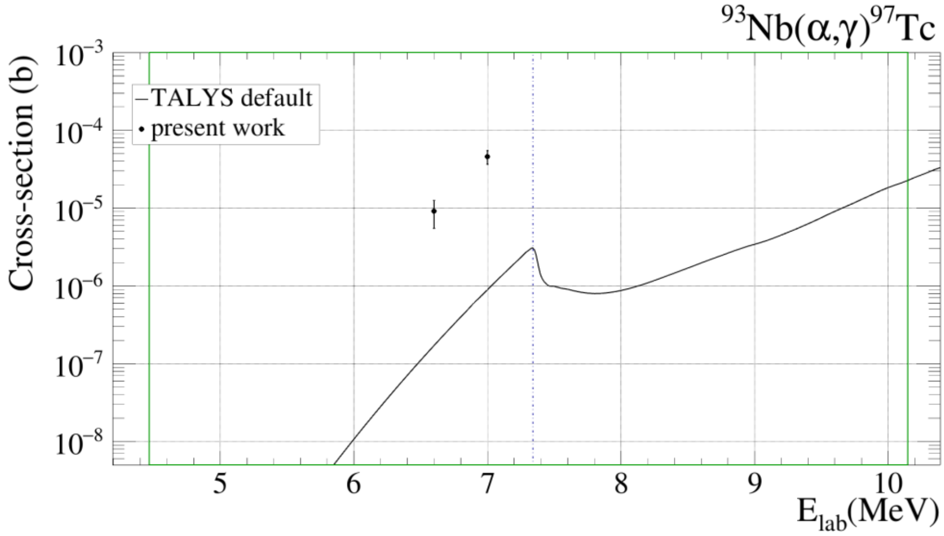
where A is the atomic number of the target-nucleus, Y_{Σ} is the number of counts in the photopeak normalized to the beam particles, N_A the Avogadro number, d the thickness of the foil and ε_{Σ} the efficiency of the detector.

For both samples, the nominal thickness value was used in the present results, with future measurements planned for validation.

Determining the efficiency for such measurements is challenging, as it depends not only on the energy of the sum peak (E_{Σ}) but also on the average multiplicity (i.e., the number of photons in a cascade). The RUBION detector setup has been fully characterized [3]. Two different efficiency determination methods are available: the “in/out” and the “global” method [3]. In this study, the "global" efficiency method was adopted, as the "in/out" method proved impractical due to the very low cross-section, which would require an excessively long measurement time for the "out" measurement.

RESULTS AND DISCUSSION

The preliminary results of this work are depicted in Fig. 4 together with default TALYS [4] calculations. Dead time corrections have not been applied to the results thus far. The errors that contribute to the results are the efficiency error (18%), the foil thickness error (10%) and the peak analysis error (greater than 20%).



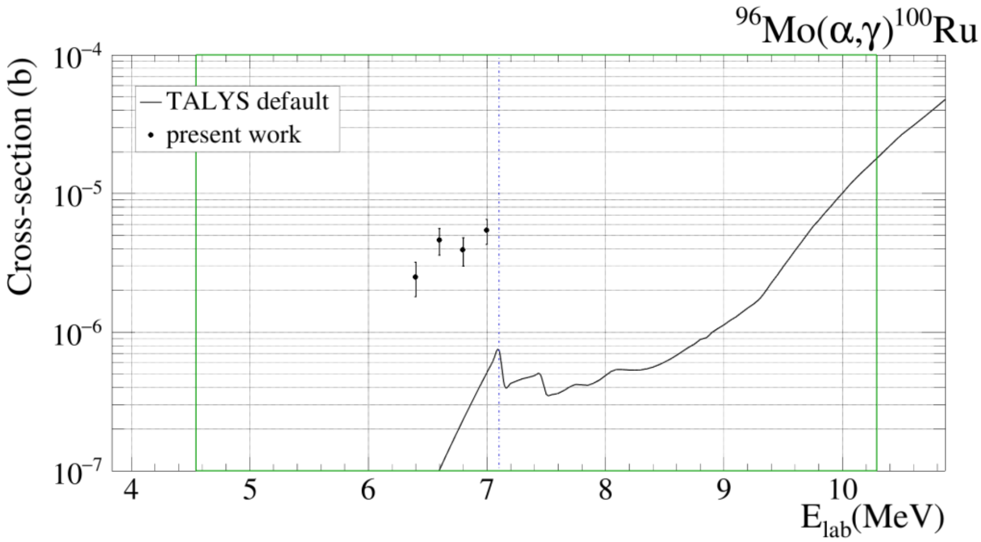


Figure 4. *The results from this work are depicted as black points* alongs*ide the black solid line representing the default calculation performed with TALYS [4]. The green rectangle corresponds to the Gamow window and the blue dotted line indicates the (a,n) channel threshold.*

CONCLUSIONS

The preliminary results from the cross-section measurements of the α-capture reaction on ^{93}Nb and ^{96}Mo are presented within this work. The measurements were performed via the 4π γ-summing method [3] at the RUBION Dynamitron Tandem Laboratory of the Ruhr-University Bochum, in Germany, for beam energies within the Gamow energy window of each reaction. Corrections in the cross section, as well as the beam energy, are yet to be applied in the results. Additionally, high accuracy target thickness/composition analysis and measurements are scheduled in the near future. Concerning the theoretical calculations, as can be seen in Fig. 4, there is significant room for improvement in the model parameterization. This aspect of the present work is currently in progress.

References

[1] S.V. Harissopulos, Eur. Phys. J. Plus 133, 332 (2018); doi: 10.1140/epjp/i2018-12185-8
[2] RUBION Webpage, https://www.rubion.rub.de/en/
[3] A. Spyrou, et al., Phys. Rev. C 76, 015802 (2007), doi: 10.1103/PhysRevC.76.015802
[4] A. Koning, et al., Eur. Phys. J. A 59, 131 (2023); doi: 10.1140/epja/s10050-023-01034-3