

# EXPERIMENTAL INVESTIGATION OF THE $^{94}\text{Zr}(p,\gamma)$ REACTION WITH IMPORTANCE FOR UNDERSTANDING THE ASTROPHYSICAL $p$ -PROCESS MECHANISM

**I.S. Timchenko<sup>1,2</sup>, A. Herzán<sup>1</sup>, M. Sedlák<sup>1</sup>, V. Matoušek<sup>1</sup>, M. Balogh<sup>1</sup>, O.S. Deiev<sup>2</sup>,  
C. Fransen<sup>3</sup>, T. Grečňárová<sup>1</sup>, P. Noga<sup>4</sup>, P. Reiter<sup>3</sup>, A. Repko<sup>1</sup>, M. Šolcova<sup>1</sup>,  
D. Váňa<sup>4</sup>, M. Venhart<sup>1</sup>, S. Vielhauer<sup>1</sup>**

<sup>1</sup> Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia

<sup>2</sup> NSC Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine

<sup>3</sup> Institute for Nuclear Physics, University of Cologne, Germany

<sup>4</sup> Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Advanced Technologies Research Institute, Trnava, Slovakia

The synthesis of elements heavier than iron occurs primarily through the  $(n,\gamma)$  reactions [1]. However, processes of the “rapid” ( $r$ -) and “slow” ( $s$ -) radiative neutron capture cannot produce 35 proton-rich stable nuclei known as the  $p$ -nuclei. The production of these chemical elements is referred to in astrophysics as the  $p$ -process [2]. The description of the  $p$ -process mechanism is crucial for explaining the discrepancy between observed and calculated abundances of chemical elements. A particularly large discrepancy is observed in the region of the light  $p$ -nuclei, such as  $^{92,94}\text{Mo}$  and  $^{96,98}\text{Ru}$ . To explain these differences or eliminate them, it is crucial to consider all possible channels of accumulation and decay of nuclei located in the vicinity of the  $p$ -nuclei.

The observed lack of experimental data in the vicinity of the  $p$ -nuclei complicates calculations of the abundance of chemical elements. Such calculations require reliable data on the cross sections and reaction rates for approximately 20,000 reactions involving 2000 stable and radioactive isotopes. Furthermore, high-quality experimental data are necessary to test various Hauser-Feshbach statistical model codes, such as NON-SMOKER and TALYS.

Proton-induced reactions on the stable Zr (90, 91, 92, and 96) isotopes are poorly studied. It is worth noting that the  $^{94}\text{Zr}(p,\gamma)^{95}\text{Nb}$  reaction has not yet been studied [3].

A series of measurements aimed at an experimental study of proton-induced reactions on stable  $^{94}\text{Zr}$  has been initiated, with the proton beam energies ranging from 1.5 to 6.1 MeV. For this purpose, thin self-supported targets with isotopically enriched material  $^{94}\text{Zr}$  (96%+), and accelerated protons delivered by the 6MV Tandem accelerator [4] at the Slovak University of Technology are used (see Fig. 1). The measurements are performed using the activation method and offline  $\gamma$ -ray spectroscopy.

The system for measuring the induced activity of irradiated  $^{94}\text{Zr}$  targets consists of three coaxial HPGe detectors and one BEGe detector, all cooled to liquid nitrogen temperature. The detectors are positioned in a close geometry for maximum detection efficiency.

The  $^{95}\text{Nb}$  nuclei are produced via the  $^{94}\text{Zr}(p,\gamma)$  reaction, in both the ground and metastable states. The  $^{95\text{m}}\text{Nb}$  metastable state with a half-life  $T_{1/2}$  of 86.6 h decays to the unstable  $^{95\text{g}}\text{Nb}$  ground state via internal transition with a branching ratio  $p$  of 94.4%. The unstable ground state  $^{95\text{g}}\text{Nb}$  with a half-life  $T_{1/2}$  of 34.975 days decays to excited levels of the  $^{95}\text{Mo}$  nucleus via the  $\beta^-$  decay. In our study of the  $^{94}\text{Zr}(p,\gamma)^{95\text{m,g}}\text{Nb}$  reaction, we measured the



Fig. 1. The 6.0 MV coaxial High-Current Tandatron™ Cockroft-Walton type accelerator at the Advanced Technologies Research Institute (ATRI) of the Faculty of Material Science and Technology of the Slovak University of Technology in Trnava, Slovakia.

