PROCEEDINGS OF SCIENCE

Measurements of ^{90,91,92,93,94,96}Zr neutron capture cross sections at the n_TOF facility at CERN

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Neutron capture cross sections for zirconium isotopes have important implications in the field of nuclear astrophysics. In particular they play a key role in ascertaining the neutron density in the He burning zone of the Red Giant stars. Neutron capture cross sections of ^{90,91,92,93,94,96}Zr have been measured over the energy range from 1 eV to 1 MeV at the spallation neutron facility n_TOF at CERN. Based on these data, capture resonance strengths and Maxwellian-averaged cross sections were determined with much improved accuracy.

10th Symposium on Nuclei in the Cosmos
Mackinac Island, Michigan, USA
27 July – 1 August, 20008

1. Introduction

Neutron capture cross sections of ^{90,91,92,93,94,96}Zr are important in nuclear astrophysics because Zr belongs to the first *s*-process peak in the solar abundances distribution near neutron magic number N=50. Accurate *s*-process analyses have attracted great interest over the last decade thanks to progress in both astronomical observations and stellar models. Understanding of the *s*-process has advanced from a phenomenological description of the abundance distribution in the solar system towards a comprehensive picture, which includes the overall aspects of stellar and galactic evolution [1]. However, success of stellar *s*-process models could be achieved only after significant improvements in neutron capture cross section data, which reached uncertainties of only a few %. Despite these successes, cross sections for many nuclides still have not been measured with the required accuracy, particularly in the mass region A≤100 as well as for neutron magic nuclei, where cross sections are small and dominated by isolated resonances [2]. In particular, ^{90,91,92,93,94}Zr are characterized by low neutron capture cross sections and are predominately of *s*-process origin. In contrast, ^{96}Zr is considered to be an *r*-only isotope with a small *s*-process admixture [1].

2. Experimental apparatus

The neutron capture cross sections of ^{90,91,92,93,94,96}Zr were measured with high resolution at the n_TOF facility at CERN. A pair of C_6D_6 detectors was used to recorded prompt capture γ-rays from the sample at a source-to-sample distance of 185 m. The detectors, which are designed for minimized neutron sensitivity [3], were mounted perpendicular to the neutron beam at a distance of about 3 cm from the beam axis. The background due to in-beam γ-rays was reduced by placing the detectors 9 cm upstream of the sample position. The γ-response was calibrated by means of standard ^{137}Cs, ^{60}Co, and Pu/C sources. The data were acquired with fast flash ADC using the standard n_TOF data acquisition system [4]. The zirconium samples were prepared from oxide powder, pressed to pellets 22 mm in diameter, and encapsulated in thin walled aluminium cans. The relevant sample characteristics have been reported previously [5].

3. Analysis and results

Data analysis was based on accurate calibration of the C_6D_6 detectors. Ambient and sample related backgrounds were subtracted by means of spectra measured with an empty Al can and with a Pb sample. The absolute normalization of the capture yields was determined, to an accuracy of 3%, via the saturated resonance technique using a Au sample. The Pulse Height Weighting Technique (PHWT) [6] was applied to the C_6D_6 capture data to achieve a cascade detection efficiency independent of the particular de-excitation path. A resonance analysis of the experimental yield was performed with the *R*-matrix code SAMMY [7]. Due to the high energy resolution of the n_TOF facility, many new resonances were found. The resulting resonance capture yields (capture kernels) are, in general for all the Zr isotopes measured, 10-20% smaller than previously reported. These differences are most likely due to our use of a superior apparatus (reduced neutron sensitivity and better weighting functions) as well as an improved resonance analysis using a state-of-the-art *R*-matrix code [7].

For *s*-process studies, Maxwellian averaged cross sections (MACS) are required over a range of thermal energies. Because our capture kernels are generally lower than previously reported, MACS calculated from our data are, in general, lower than that listed in evaluated libraries. Results for ^{90}Zr are shown in Fig. 1, where our MACS are as much as 10% lower than previously reported.

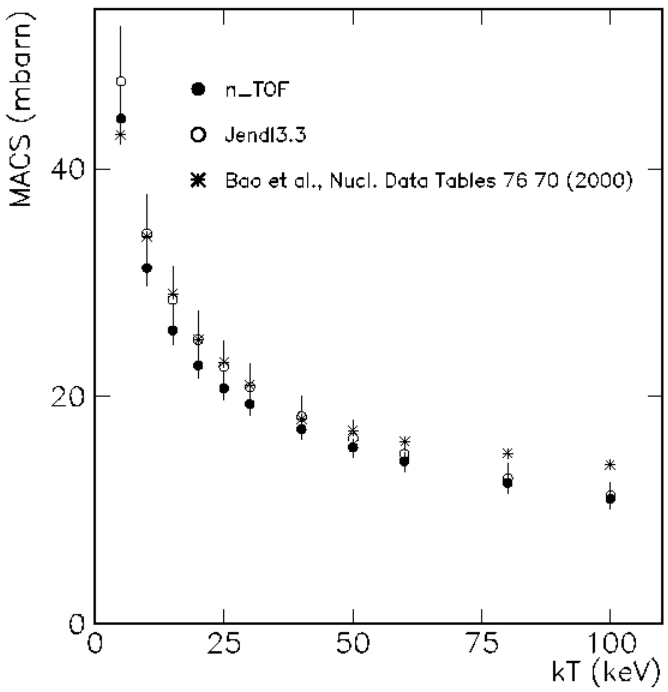

Figure 1: Comparison of MACS calculated from our ^{90}Zr data (full circles), with values obtained from JENDL3.3 (open circles) and the compilation of Ref.[2] (asterisks).

4. Conclusions

Neutron capture cross sections of ^{90,91,92,93,94,96}Zr have been measured at the CERN n_TOF facility. Improvements in the n_TOF apparatus compared to previous experiments resulted in significantly improved accuracy, which should be valuable for future studies of *s*-process nucleosynthesis in this mass region. Capture kernels obtained in this work are, in general, smaller than reported previously. Consequently our MACS are generally lower than those in evaluations and compilations. These changes are most likely due to the reduced neutron sensitivity of our apparatus, improved weighting functions used to calculate our cross sections, and the use of a state-of-the-art *R*-matrix code in our resonance analysis.

5. Acknowledgements

This Work was supported by European Community under contract FIKW-CT-2000-00107 and by the funding agencies of the participating institutes.

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