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^{238}U(n, γ) reaction cross section measurement with C_6D_6 detectors at the n_TOF CERN facility.

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Abstract. The radiative capture cross section of ^{238}U is very important for the developing of new reactor technologies and the safety of existing ones. Here the preliminary results of the ^{238}U(n,γ) cross section measurement performed at n_TOF with C_6D_6 scintillation detectors are presented, paying particular attention to data reduction and background subtraction.

1 Introduction

The measurement of the ^{238}U radiative capture cross section is addressed within the NEA High Priority Request List [1] as one of the most relevant nuclear data requirement to be investigated in more detail. In fact, despite the large number of measurements present in literature, inconsistencies still affect the ^{238}U(n,γ) cross section both in its resolved resonance region up to 25 keV and in the unresolved one. This uncertainty influences the fast and the thermal reactor systems, and contributes to the uncertainty on Pu isotope density at the end of fuel cycles. Within this scenario, the Accurate Nuclear Data for nuclear Energy Sustainability (ANDES) project [2] of the European Commission 7^{th} Framework Programme supported a proposal of three measurements of this cross section in order to reach the accuracy of 2%. Among these measurements, two have been performed at the n_TOF CERN facility (Switzerland), and the other at the GELINA EC-JRC-IRMM facility in Belgium.

In this work the preliminary results of the measurement carried out at n_TOF with carbon fiber C_6D_6 detectors is presented, describing the characteristics of the experimental setup and paying great attention to data reduction and background subtraction in order to show how the aimed 2% accuracy in the cross section is achievable.

2 Experimental Setup

The measurement was performed at the n_TOF facility at CERN, a pulsed white neutron source which allows very accurate and precise measurements (more details can be found in Ref. [3]).

The γ−rays following the radiative neutron capture on ^{238}U were measured with a very low solid angle detection system in order to apply the total energy detection method, which requires a very low efficiency. Two deuterated benzene scintillators were used, placed head to head at 90° with respect to the beam, 9 mm away from the sample: one commercial BICRON and one custom made (FZK) [4].

Both the detectors and the geometry are optimized to have a very low sensitivity to $\gamma-$rays induced by scattered neutrons.

The sample measured is a highly enriched (99.99% of ^{238}U) uranium 53.80×30.02 mm rectangular plate, 0.235 mm thick with an areal density of $(9.595 \pm 0.04)\ 10^{-4}$ atoms/bars. It was wrapped in a 20 μm thick aluminum foil and a 25 μm thick kapton foil. In addition to the ^{238}U sample, gold, silver, graphite and lead samples with a similar geometry were analysed for normalization and background evaluation purposes.

3 Data reduction and background subtraction

The total energy technique requires the proportionality between the efficiency for detecting a capture cascade and the the total energy of the cascade following the neutron capture event. To achieve this proportionality, in addition to a low solid angle it is necessary to use the Pulse Height Weighting Technique (PHWT) [5].

To be as precise and accurate as possible, a careful study of the calibration between the *flash*-ADC channels and the deposited energy was done. Three different calibration sources were used, ^{137}Cs, ^{88}Y and Am-Be, with four different energies of $\gamma-$rays emitted. Moreover, a very accurate analysis of the stability of the two C_6D_6 detectors counts was performed, rejecting those runs which presented a too large deviation in terms of counts from the mean value [6].

The evaluation and subtraction of all existing backgrounds represent a crucial step to succeed in reaching the required accuracy of 2% in the cross section. We identified and evaluated four different sources of backgrounds. First, a careful analysis of the natural radioactivity, the only time independent source of background, was performed through measurements without neutron beam. It was seen that the contribution of this background is dominant at low energies (below 1 eV) and it is sensitive to the position of ^{238}U sample. For these reasons we made one measurement for each of the five positions of the sample holder and we subtracted the proper contribution from the sample analyzed. Another main background, independent of the sample, is related to the interaction of the neutrons and photons in the beam with the vacuum windows. To evaluate this contribution runs are measured without any sample in beam. We checked also if the packaging of ^{238}U sample (i.e. aluminum and kapton foils) plays a role in the background, but it resulted negligible with respect to the experimental hall one. The background component due to scattered neutrons was evaluated through the analysis of two graphite samples, one 10 mm and the other 5 mm thick. For carbon, in fact, capture cross section is negligible with respect to elastic one, so all the counts seen by the detectors are caused by $\gamma-$rays emitted by scattered neutrons which are captured somewhere else and then emits $\gamma-$rays which are later detected. As a first step we compared the counts as function of time of flight for the two samples: the ratio was 2 which demonstrates that this background contribution scales only with the mass of the sample. Through the comparison between the measured yield and the elastic cross section of carbon we were able to determine the efficiency for the detection of scattered neutrons induced $\gamma-$rays. We applied this efficiency to the ^{238}U elastic cross section in order to find out the contribution to the total yield due to scattered neutrons, which is negligible. The last source of background identified is related to in beam $\gamma-$rays which Compton scatter on the sample and can be detected. To evaluate this contribution, sensitive to the charge number of the sample under study, we measured a ^{nat}Pb sample which has similar Z than uranium and a negligible capture cross section. In figure 1 the ^{238}U(n,γ) weighted counts as a function of incident neutron time of flight are shown before and after the subtraction of all the background contributions.

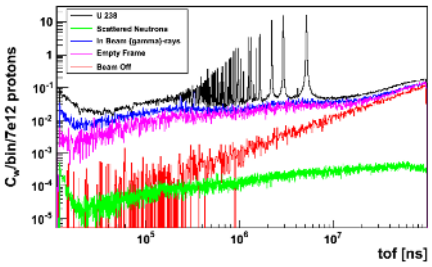

Figure 1. Weighted counts for the ^{238}U(n,γ) reaction (black) with all the main background components: natural radioactivity (red), sample independent (magenta), in-beam γ−rays (blue) and scattered neutrons (green).

4 Preliminary results and conclusions

The experimental capture yield was determined as the ratio between the weighted counts background subtracted and the neutron fluence at the sample position, all multiplied by a normalization factor which takes in account the fraction of the beam intercepted by the sample. The neutron fluence of the n_TOF facility has been accurately measured using five different detectors, in order to cover with the best precision obtainable all the energy range (more details can be found in Ref. [3, 7]). A careful determination of the normalization factor was carried out through the saturated resonance technique, using Au, Ag and ^{238}U samples. Some problems were encountered because of a difference between the values extracted with Au and Ag with respect with the ^{238}U one, difference which is under investigation [6]. Nevertheless, ^{238}U is self normalized, so we were able to extract a preliminary yield which is shown in figure 2.

Thanks to the well suited features of the n_TOF facility, the uncertainty due to counting statistics is for the unresolved resonance region of about 6%, while for the low energy region of about 3%, value which is expected to be lowered to a global uncertainty of 2% thanks to the combination with the other two measurements within the ANDES project.

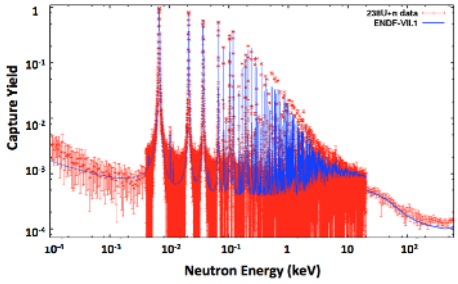

Figure 2. Preliminary experimental yield for ^{238}U(n,γ) reaction (red dots) compared with a calculation made using the resonance parameters present in the ENDF-VII.1 library (blue line).

References

[1] NEA, *Nucler Data High Priority Request List*, http://www.nea.fr/html/dbdata/hprl/ [Online]
[2] ANDES, Project FP7-249671 of the EURATOM FP7. http://www.andes-nd.eu/ [Online]
[3] C. Guerrero *et al.*, The European Physical Journal A **49**, 27 (2013)
[4] R. Plag *et al.*, Nucl. Inst. Meth. A **496**, 425 (2003)
[5] Abbondanno *et al.*, Nucl. Inst. Meth. A **521**, 454 (2004)
[6] F. Mingrone *et al.*, Nuclear Data Sheets (accepted for publication)
[7] M. Barbagallo *et al.*, submitted to The European Physical Journal A