Abstract

The analysis technique applied to the data and the reaction cross section $^{234}\text{U}(n,f)$ from the FIC (Fission Ionization Chamber) detector at the n_TOF facility is presented here. A comparison of the measured neutron induced fission cross section of $^{234}\text{U}$ nucleus is given with the available data from the bibliography. The measurements took place at the installation of CERN in Geneva. The detector was placed in front of the neutron beam for the determination of the neutron induced fission cross section of various isotopes of the Th cycle. For the data acquisition, several flash Analog to Digital Converter (fADC) channels were used. This facilitated the detailed off-line analysis of data since all information was stored in the computer. The automation of the process was required because of the high amount of stored data.

The data analysis aimed at the discrimination of fission events. For this end we had to deal with three main issues: i) The subtraction of the background, ii) the fitting of the pulses and iii) the automation of the process.

1 Introduction

The neutron induced cross section data are needed for fundamental physics research (studies in the nuclear structure), as well as for nuclear applications (energy production through the Accelerator Driven System (ADS) [1] and nuclear waste transmutation [2]). The study of $^{234}\text{U}$ nucleus has a special
interest, since it presents the so called “Th anomaly”, first observed already since 1962 [5]. Also the operation of an ADS requires good knowledge of the $^{234}U$ neutron induced fission cross section (n,F) and the evaluated nuclear data from the databases present inconsistencies [3], since the experimental data used were produced decades ago, when high proton beam intensities were not available.

The n_TOF experiment [3] provides an exceptional facility for neutron induced cross section measurements with the neutron time of flight technique. The high proton beam intensity of CERN combined with the massive Pb spallation target, produces a high neutron flux in a wide energy range and makes possible the use of a long flight path (∼200 m) for the energy determination with high resolution. In the next sections we are going to describe the experimental facility and the data analysis.

2 Experimental Set-up

The neutron beam is generated by spallation. The high intensity ($7 \times 10^{12}$ protons per bunch) and high energetic (20 GeV) proton beam, provided by the PS accelerator at CERN impinges a massive lead block (80 × 80 × 60cm$^3$). Several elastic and inelastic reactions induced by the protons generate an intense neutron beam in a wide energy range. The neutrons produced are going through a thin water layer which is used for cooling the Pb target and moderation. They are transported through a ∼ 185 m vacuum tube, which is not collinear but at 10 degrees angle for minimizing the in-beam background, and entering the detector body, as can be seen at figure 1. Also a magnet was installed along the flight path for deflecting the charged particles.
Table 1
Targets used for $^{234}$U(n,f) measurement with the FIC detector.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>mass (g)</th>
<th>Uncertainty (%)</th>
<th>Diameter (cm)</th>
<th>Flight path length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{235}$U</td>
<td>4.0</td>
<td>20</td>
<td>2.6</td>
<td>185.666</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>10.0</td>
<td>10</td>
<td>2.6</td>
<td>185.671</td>
</tr>
<tr>
<td>$^{234}$U $^a$</td>
<td>5.46</td>
<td>5</td>
<td>2.6</td>
<td>185.706</td>
</tr>
<tr>
<td>$^{234}$U $^b$</td>
<td>5.17</td>
<td>5</td>
<td>2.6</td>
<td>185.716</td>
</tr>
<tr>
<td>$^{234}$U $^c$</td>
<td>5.17</td>
<td>5</td>
<td>2.6</td>
<td>185.726</td>
</tr>
<tr>
<td>$^{234}$U $^d$</td>
<td>5.46</td>
<td>5</td>
<td>2.6</td>
<td>185.736</td>
</tr>
<tr>
<td>$^{234}$U $^e$</td>
<td>5.28</td>
<td>5</td>
<td>2.6</td>
<td>185.746</td>
</tr>
<tr>
<td>$^{234}$U $^f$</td>
<td>5.40</td>
<td>5</td>
<td>2.6</td>
<td>185.756</td>
</tr>
<tr>
<td>$^{234}$U $^g$</td>
<td>5.41</td>
<td>5</td>
<td>2.6</td>
<td>185.766</td>
</tr>
<tr>
<td>”Dummy”</td>
<td>0</td>
<td>0</td>
<td>2.6</td>
<td>185.696</td>
</tr>
</tbody>
</table>

The $^{234}$U fission cross section was measured with a Fission Ionization Chamber (FIC) and a Parallel Plate Avalanche Chamber (PPAC) simultaneously. For this work the FIC detector was used. An “artistic” representation of the detector can be seen at figure 2. The neutrons, after flying 185.656 m (from the end of the Pb target to the first target inside the detector), as shown at 1, are entering the detector body. The FIC detector consists of an aluminum vessel, filled 90% Ar + 10% CF$_4$ at 720 mbar. Inside were placed circular electrodes with 12 cm diameter and 15 µm thickness, at 600 Volts and up to 20 circular targets perpendicular to the neutron beam with 10 mm distance. The targets were supported on Al backing (thickness 100 µm). The neutron entrance window was made of of Kapton (thickness 125 µm). The complete list of the targets used for the determination of $^{234}$U(n,f) cross section, is presented at Table 1. For $^{234}$U were used more than one target in order to have more mass to interact with the neutron beam, without having a thick target.

The targets that placed inside the detector are very thin, and the induced fission fragments (FF) are escaping the target. One FF will ionize the gas and the other will be adsorbed from the Al backing of the target. The charge produced from the ionization is collected at the electrodes, thus creating a pulse to the detector signal. The electrodes are connected with amplifiers and flash Analog to Digital Converters (fADC, CAEN V676), were the signal is converted from analog to digital, making possible the recording of the detector signal to the computer hard disk, allowing us it’s full reconstruction at later times (off line). A sample signal is presented at figure 3. At the upper corner the start of the detectors signal is magnified. The big pulse at the start of the signal is due to $\gamma$ rays produced by the spallation, the so called “gamma flash”, and is used for determining the neutrons creation time. For the precise flight
distance we have to account for the distance covered in the Pb target and the water layer. This is done with Monte Carlo simulations and the equivalent distance correction is a function of neutron energy \( \lambda(E) \) [4]). The neutron energy is calculated with the equation 1. With \( t_{ntof} \) we denote the neutron time of flight. \( t_{fission} \) and \( t_{flash} \) is the time fission and “gamma flash” is detected. \( d \) is the neutron flight distance which is the sum of the known length \( L \) from the Pb target to the detectors target and the correction \( \lambda(E) \).

\[
E = \frac{m_n}{\sqrt{1-\beta^2}}, \beta = \frac{d}{t_{ntof} \cdot c}, t_{ntof} = \frac{d}{c} + t_{fission} - t_{flash}, d = L + \lambda \quad (1)
\]

3 Data Analysis and Results

The counting of the fissions induced to each target is done by applying “pulse shape analysis” technique to the detectors signal. Before applying this technique it was necessary to correct the detectors signal due to the undershooting and the rippling of the baseline, because of electronic noise produced by the high intensity pulse of the “gamma flash”. To correct for these effects, the signals for each target were added and “average signals” were created. These “averages” were subtracted, after fitted with MINUIT [7] with a simple function (equation 2) and the resulting signal was processed. The “pulse shape analysis” technique tries to fit with the use of MINUIT in each local maxi-
mum of the detector signal the “pulse function” (equation 3). In case of success the value and the errors of the parameters are stored for further analysis.

\[
Y(t) = Y_0 + A \cdot Y_{average}(t) \tag{2}
\]

\[
Y(t) = Y_0 + A(1 - e^{-\frac{t-t_0}{\tau_1}})e^{-\frac{t-t_0}{\tau_2}} \tag{3}
\]

The amplitude distribution of the “dummy” (empty) target indicates the need for applying a lower limit to discriminate the fission events from background. The threshold was assigned to 400 in order to exclude more background events, including most of the fission events. In figure 4 we see the amplitude distribution of the “dummy” target as well as the $^{238}\text{U}$ target. After applying a threshold is necessary to correct the efficiency of the detector. This was done with the fitting of the phenomenological function (equation 4) to the amplitude distribution of each target. Three functions were fitted simultaneously $Y_1$, $Y_2$ and $Y_3$. $Y_1$ and their integral represent the number background events while $Y_2$ and $Y_3$ the number of fission events.

\[
Y(x) = Y_0 + \frac{A}{\sqrt{2\pi}wx} e^{\left(\frac{m-x}{\sigma}\right)^2} \tag{4}
\]

At figure 5 is presented the reaction rate, with and without applying threshold. The histograms have logarithmic scale with 500 bins per decade. From the reaction rate the $^{234}\text{U}(n,f)$ cross section is calculated with the equation 5, where X stands for the $^{234}\text{U}$ nucleus and R for the nucleus used as reference and can be $^{235}\text{U}$ (below 1 MeV) or $^{238}\text{U}$ (above 1 Mev) for which the (n,F) reaction cross section ($\sigma(E)$) is well known. With A and m we denote the
atomic number and the mass, with $\epsilon$ the efficiency correction applied and $N$ the normalization for the number of protons used in each target.

$$\sigma_X(E) = C \frac{S_X(E)}{S_R(E)} \sigma_R(E), C = \frac{A_X m_R \epsilon_X N_R}{A_R m_X \epsilon_R N_X}$$

The neutron induced fission cross section of $^{234}U$ nuclei is presented at figure 6, compared with other experimental and evaluated data.

References


Fig. 5. Reaction Rates with threshold applied (black line) and without (gray line)
Fig. 6. $^{234}U(n,F)$ cross section compared with experimental and evaluated data.