Measurement of $^{235}\text{U}(n,f)$ cross section between 10 and 30 keV

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Motivations and physical interest

- Discrepancies (~8%) in the n_TOF neutron flux measure between detectors using fission and the ones using $^6$Li(n,t) and $^{10}$B(n,α)

- Discrepancies in the $^{235}$U(n,γ) measure at DANCE ($^{235}$U(n,f) used as reference)

- Increase the standard $^{235}$U(n,f) accuracy and extend its range (at present at thermal and between 150 keV and 200 MeV)

- Collect data for fission reactors of new generation
Neutron standards

Standard reaction used as reference

Measured reaction $X+n \rightarrow$ products

Neutron beam

Target

Detector

Main used standards:

$^{10}\text{B}(n,\alpha)^7\text{Li}$

$^{197}\text{Au}(n,\gamma)$

$^{6}\text{Li}(n,t)^4\text{He}$

EuNPC 2018
September 2018 - Bologna
The new measurement

A new measurement of the $^{235}\text{U}(n,f)$ cross section has been made during the autumn 2016 using a custom experimental apparatus.

- The standards $^6\text{Li}(n,t)$ and $^{10}\text{B}(n,\alpha)$ are used as references
- The measurement has been performed at the n_TOF facility
- Silicon detectors are used to measure the emitted products
- Silicons are placed in beam in order to maximize the geometrical efficiency, measuring products emitted forward and backward
**n_TOF facility**

- Neutrons produced through a spallation process
- Extremely high instantaneous flux
- High neutron energy resolution
- Wide neutron energy range (from thermal to GeV)

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**EuTNP 2018**
September 2018 - Bologna

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**Measuring Neutrons produced through a spallation process**

**Extremely high instantaneous flux**

**High neutron energy resolution**

**Wide neutron energy range** (from thermal to GeV)
Setup

- Stack of 6 silicon detectors 5x5 cm² single pad 200 μm in beam

<table>
<thead>
<tr>
<th>Target</th>
<th>Thickness (μm)</th>
<th>Al backing (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^6$LiF</td>
<td>1.9</td>
<td>50</td>
</tr>
<tr>
<td>$^{10}$B$_4$C</td>
<td>0.08</td>
<td>18</td>
</tr>
<tr>
<td>$^{235}$U</td>
<td>0.15</td>
<td>250</td>
</tr>
</tbody>
</table>
Events selection – $^6\text{Li}(n,t)^4\text{He}$

Reaction products are selected using the signal amplitude.

The threshold depends on the neutron energy.
Events selection – $^{10}\text{B}(n,\alpha)^{7}\text{Li}$

$^{7}\text{Li}$

Exp. threshold

$\alpha$

$\sim$6% of lithium produced is in the ground state with more kinetic energy available for the $\alpha$.
Events selection – $^{235}\text{U}(n,f)$
Count rate

Count rate for different reactions:
- $^6$Li(n,t)
- $^{10}$B(n,α)
- $^{235}$U(n,f)

Good ratio
Signal / Background
Detectors stability

No systematic deviation has been observed

$^{235}\text{U}(n,f)$
Data analysis

\[
\sigma_{\text{fission}} = \frac{C_{\text{fission}} \cdot fAbs_{\text{fission}} \cdot \varepsilon_{\text{std}}}{C_{\text{std}} \cdot fAbs_{\text{std}}} \cdot N \cdot \sigma_{\text{std}}
\]

- \( C_{\text{fission}} \) and \( C_{\text{std}} \): measured count rates after background subtraction.
- \( fAbs \): coefficients representing the correction due to the absorption in dead layers, estimated with MC simulation.
- \( \varepsilon_{\text{std}} \): efficiency of the detector measuring the standard reference, estimated with MC simulation.
- \( N \): normalization coefficient, includes all the terms not depending on neutron energy (between 7.8 and 11 eV).
- \( \sigma_{\text{std}} \): standard cross section used as reference.
The neutron fraction hitting each target has been evaluated using Monte Carlo simulations, taking in account all the dead layers.
Efficiency – MC

The combination of detection and geometrical efficiency has been calculated using MC for the reactions $^6$Li$(n,t)$ and $^{10}$B$(n,\alpha)$ from thermal to 160 keV. In this phase detectors has been calibrated and the experimental errors has been introduced.
Ratio forward / backward

$235U(n,f)$
Ratio $^{6}\text{Li}(n,t) / ^{10}\text{B}(n,\alpha)$
Cross section – $^{235}$U(n,f)

Combined data of $^6$Li(n,t) and $^{10}$B(n,α) used as reference.

![Graph showing cross section data comparison between n_TOF and ENDF/B-VIII](image)

-5% deviation indicated in the graph.
Deviation from ENDF

Differences between our data and ENDF in units of sigma (statistical only).
Conclusions

- An accurate measurement of the $^{235}$U(n,f) cross section has been performed at n_TOF using $^6$Li(n,t) and $^{10}$B(n,α) as reference.

- Preliminary data confirm an overestimation (around 5%) of the $^{235}$U(n,f) in ENDF between 10 and 30 keV.

- New good quality data has been collected in the keV region, that will help to refine the evaluation of the structures of the uranium fission cross section.
Thank you
The sensitivity to the experimental cut has been evaluated with small variation of the threshold.
Experimental cuts systematic

This source of systematic uncertainty has been proved to be negligible.
Efficiency systematic

The dependence of the efficiency by the geometrical setup has been evaluated with small changes in the simulations:

1) Moving the beam center on the XY plane

2) Reducing the distance between target and detector
Standard cross sections

![Graph showing cross sections as a function of neutron energy (eV)].

- **B10**
- **Li6**
- **U235**