Towards the adoption of \(^{238}\text{U}\)(n,f) and \(^{237}\text{Np}\)(n,f) as primary standards for fast neutron energies

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Why do we need still to study $\sigma$?

1. Study of the fission process

2. Design of Gen-IV nuclear power plants
   - Neutron energy spectra from 0.5MeV to 20MeV
   - Highly enriched U to function
   - Improved target accuracy

Towards the adoption of $^{238}$U(n,f) and $^{237}$Np(n,f) as primary standards for fast $E_n$
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NPL Van de Graaff accelerator

Low-scatter area

scatter of neutrons of 100-200 keV lower energy than $E_n$

issue when using $^{235}\text{U}(n,f)$

Need of secondary standards with fission threshold

Towards the adoption of $^{238}\text{U}(n,f)$ and $^{237}\text{Np}(n,f)$ as primary standards for fast $E_n$
Fluence measurement

(1) Fluence measurement with a Long counter
(2) Fluence meas. with shadow cone + Long counter

Fluence per unit beam charged
Fluence measurement

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Experimental campaigns

Two campaigns under the CHANDA project: 2016 and 2017

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Experimental campaigns

Two campaigns under the CHANDA project: 2016 and 2017

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<thead>
<tr>
<th>Samples</th>
<th>$E_n$ (MeV)</th>
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<tr>
<td>$^{235}\text{U}/^{237}\text{Np}$</td>
<td>0.567, 1.2, 1.8, 2.0</td>
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<td>$^{235}\text{U}<em>{\text{new}}/^{235}\text{U}</em>{\text{old}}$</td>
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<tr>
<td>$^{242}\text{Pu}/^{235}\text{U}_{\text{new}}$</td>
<td>0.565, 0.9, 1.0, 1.1, 1.2, 1.8, 2.4</td>
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<td>$^{242}\text{Pu}/^{237}\text{Np}$</td>
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<th>Isotope</th>
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<td>$^{235}\text{U}_{\text{old}}$</td>
<td>555 (22)</td>
<td>99.83%</td>
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<tr>
<td>$^{235}\text{U}_{\text{new}}$</td>
<td>701 (4)</td>
<td>99.93%</td>
</tr>
<tr>
<td>$^{238}\text{U}$</td>
<td>681 (18)</td>
<td>&gt;99.99%</td>
</tr>
<tr>
<td>$^{237}\text{Np}$</td>
<td>489.5 (2.4)</td>
<td>&gt;99.99%</td>
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<td>$^{242}\text{Pu}$</td>
<td>671 (6)</td>
<td>99.97%</td>
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Towards the adoption of $^{238}\text{U}(n,f)$ and $^{237}\text{Np}(n,f)$ as primary standards for fast $E_n$...
Experimental campaigns

Two campaigns under the CHANDA project: 2016 and 2017

correlated results

Similarities:
• NPL facility (fluence determination technique)
• Some of the samples ($^{235}$U$_{old}$, $^{237}$Np)

Differences:
• More control on:
  • proton beam spot shape and size
  • neutron producing target – TFGIC distance
• new built TFGIC in 2017
• different DAQ boards
• *New* $^{235}$U sample in 2017

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1. Fission fragment characterization

2. Absolute fluence determination

- Flucal $\rightarrow$ fluence at the point of the samples from point source
- MCNP6 $\rightarrow$ correction for disk sample and disk neutron source
- MCNP6 $\rightarrow$ correction for target can scattering
- MCNP6 $\rightarrow$ correction for attenuation on the front face TFGIC
Data analysis

1. Fission fragment characterization

2. Absolute fluence determination

3. Neutron energy spectrum at the sample position

Main Bay geometry thanks to G. Taylor
Data analysis

1. Fission fragment characterization

2. Absolute fluence determination

3. Neutron energy spectrum at the sample position

Towards the adoption of $^{238}\text{U}(n,f)$ and $^{237}\text{Np}(n,f)$ as primary standards for fast $E_n$
Calculations (cross sections)

\[
\sigma(E_n) = \frac{C_{\text{corr}} \cdot k_{\text{FF,low}}}{\epsilon} \cdot \frac{A}{m \cdot N_A \Phi_n(E_n) \cdot k_{\text{PP-DD}} \cdot k_{\text{TS}} \cdot k_{\text{AttFC}}} \quad 1
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\]

Corrected counts below electronic threshold (2-5%)

+ Spontaneous fission ($^{242}\text{Pu}$ only)

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Reaction rate due to \(E'_n < E_n\) (4-10%)

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\[ \sigma(E_n) = \frac{C_{\text{corr}} \cdot k_{\text{FF,low}}}{\epsilon} \cdot \frac{A}{m \cdot N_A \Phi_n(E_n) \cdot k_{\text{PP-DD}} \cdot k_{\text{TS}} \cdot k_{\text{AttFC}}} \]

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Point-to-point to disk-to-disk correction (2-4%)

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Target can scatter correction (2-3%)

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Calculations (cross sections)

$$\sigma(E_n) = \frac{C_{\text{corr}} \cdot k_{\text{FF,low}}}{\epsilon} \cdot \frac{A}{m \cdot N_A \Phi_n(E_n)} \cdot \frac{1}{k_{\text{PP-DD}} \cdot k_{\text{TS}} \cdot k_{\text{AttFC}}}$$

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Attenuation of neutrons in the front face TFGIC (1.5-2%)

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\[ \sigma(E_n) = C_{\text{corr}} \cdot k_{\text{FF,low}} \cdot \frac{A}{\epsilon m \cdot N_A} \Phi_n(E_n) \cdot \frac{1}{k_{\text{PP-DD}}} \cdot \frac{1}{k_{\text{TS}}} \cdot \frac{1}{k_{\text{AttFC}}} \]

- Attenuation of neutrons in the front face TFGIC (1.5-2%)
- Corrected counts below electronic threshold (2-5%)
- Spontaneous fission ($^{242}$Pu only)
- Reaction rate due to $E_n < E_n$ (4-10%)
- Point-to-point to disk-to-disk correction (2-4%)
- Target can scatter correction (2-3%)

Towards the adoption of $^{238}$U(n,f) and $^{237}$Np(n,f) as primary standards for fast $E_n$
Calculations (spontaneous fission $^{242}$Pu)

$$T_{1/2, SF} = \frac{\%^{242}\text{Pu}}{A_{242}} \left( \frac{1}{C_{SF} t \ln 2 \cdot m_{242} \cdot N_A} - \sum_i^n \frac{\%^{i}\text{Pu}}{A_i \cdot T_{1/2, SF(i)}} \right)$$

<table>
<thead>
<tr>
<th>Source</th>
<th>Literature average</th>
<th>This experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holden (2000)</td>
<td>6.77 x $10^{10}$ (1.0%)</td>
<td>6.76 x $10^{10}$ (1.3%)</td>
</tr>
<tr>
<td>Chechev (2009)</td>
<td>6.79 x $10^{10}$ (1.4%)</td>
<td></td>
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<tr>
<td>Salvador-Castiñeira (2013)</td>
<td>6.74 x $10^{10}$ (1.3%)</td>
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Based on 5 measurements > 25000 events/each

Towards the adoption of $^{238}$U(n,f) and $^{237}$Np(n,f) as primary standards for fast $E_n$
## Uncertainty evaluation

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<tr>
<th>$E_n$ (MeV)</th>
<th>$u_{\text{total}}$ (%)</th>
<th>$u_m$ (%)</th>
<th>$u_C$ (%)</th>
<th>$u_{\varepsilon}$ (%)</th>
<th>$u_{c&lt;\text{thr}}$ (%)</th>
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<td>0.565</td>
<td>3.8-9.1</td>
<td>0.5-2</td>
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<td>1</td>
<td>20</td>
<td>1.3</td>
<td>3.2</td>
<td>&lt;1</td>
<td>3.2</td>
<td>27</td>
<td>1-1.4</td>
</tr>
<tr>
<td>0.9</td>
<td>4.0-9.4</td>
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* Data from 2017, similar values for 2016
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Preliminary $^{235}$U results

Towards the adoption of $^{238}$U(n,f) and $^{237}$Np(n,f) as primary standards for fast $E_n$

Correction factor from 2017 data using $^{235}$U$_{\text{new}}$ sample:

0.943
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Preliminary $^{237}\text{Np}$ results

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Preliminary $^{242}\text{Pu}$ results

Other mmts not yet in EXFOR:

- Tsinganis, nTOF, 2012
- Marini, CENBG + CEA, 2013
- Kögler, nELBE, 2014

Towards the adoption of $^{238}\text{U}(n,f)$ and $^{237}\text{Np}(n,f)$ as primary standards for fast $E_n$
Preliminary $^{242}$Pu results (threshold)

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Towards the adoption of $^{238}$U(n,f) and $^{237}$Np(n,f) as primary standards for fast $E_n$
Summary

- Cross sections key element on reactor design → improved accuracies

- VdG environments require new reference cross sections

- Two experiments performed for $^{235,238}\text{U}(n,f)$, $^{237}\text{Np}(n,f)$ and $^{242}\text{Pu}(n,f)$

- Uncertainties driven by counting statistics and distance between neutron producing target and detector

  Reaching uncertainties <5% requires new methodologies or increased accelerator output
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