Preliminary results on $^{238}\text{U}(n,f)$ prompt fission neutron energy spectra at 2, 5.2 and 15 MeV measured using a p-terphenyl scintillator

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CEA/DAM/DIF

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7 November 2013
• Emitted mostly in flight by accelerated fission fragments
• Important role in many applications ⇒ accuracy of nuclear criticality calculations
  • Conventional and advanced reactors
  • Non-proliferation applications
Prompt fission neutron energy spectra (PFNS)

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  - Conventional and advanced reactors
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- Theoretical description of prompt fission neutron energy spectra (PFNS) difficult
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- Theoretical description of prompt fission neutron energy spectra (PFNS) difficult
- Few experimental data
- Discrepancies between measured PFNS and evaluations

\[ P(E) \]

Energy [MeV]

\[ ^{238}\text{U}(n_{14.3\text{ MeV}},f) \]

![Graph](image)

ENDF/B−VII.1  
ENDF/B−VI  
JEFF−3.1.2  
JEFF−2.2  
Boikov et al., 1991  
Baryba et al., 1979

\[ ^{238}\text{U}(n_{14.3\text{ MeV}},f) \]

\[ P(E) \]

Energy [MeV]

\[ ^{238}\text{U}(n_{14.3\text{ MeV}},f) \]

- Baryba et al. EXFOR 40740 et Boikov et al. EXFOR 41110
• Important role in many applications ⇒ **accuracy of nuclear criticality calculations**
  - Conventional and advanced reactors
  - Non-proliferation applications

• Theoretical description of prompt fission neutron energy spectra (PFNS) difficult

• Few experimental data

• Discrepancies between measured PFNS and evaluations

• 2009 : International program aiming at improving the adequacy and the quality of PFNS launched by the IAEA

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1 Baryba et al. EXFOR 40740 et Boikov et al. EXFOR 41110
2 INDC(NDS)-0541
1. Experimental
   - Experimental technique
   - Experimental tools
     - Data acquisition system FASTER
     - Fission chamber
     - P-terphenyl neutron detector

2. Prompt fission neutron spectra measurements

3. Conclusion and outlook
1 Experimental
   Experimental technique
   Experimental tools
      Data acquisition system FASTER
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2 Prompt fission neutron spectra measurements

3 Conclusion and outlook
Measurement campaigns

- CEA - Bruyères-le-Châtel - France:
  - \(^{238}\)U(n,f) induced by 2 MeV neutrons
  - \(^{238}\)U(n,f) induced by 5.2 MeV neutrons
  - \(^{238}\)U(n,f) induced by 15 MeV neutrons

- JRC-IRMM - Geel - Belgique
  - \(^{235}\)U(n,f) et \(^{237}\)Np(n,f) induced by 500 keV neutrons
Time-Of-Flight technique (TOF)

\[ E_n = (\gamma - 1)m_n c^2 \]

\[ = \left( \frac{1}{\sqrt{1 - \frac{L^2}{TOF^2}} - 1} \right) m_n c^2 \]
- Digital acquisition system Fast Acquisition SysTem for nuclEar Research (FASTER) currently being developed at the LPC Caen

- Programmable logic devices $\rightarrow$ Real time treatment of signals (0 % dead time)

- Module close to the detectors $\rightarrow$ optimization of the ratio $\frac{\text{signal}}{\text{noise}}$
• Cylinder containing about 100 electrodes on which the actinides are deposited

• Ionization gas: P10 (10% methane and 90% argon)
• Organic crystal of doped p-terphenyl ($C_{18}H_{14}$) optically coupled to a photomultiplier

Crystal: $\varnothing 75 \times 50$ mm
P-terphenyl neutron detector: General points

- Organic crystal of doped p-terphenyl ($C_{18}H_{14}$) optically coupled to a photomultiplier

- Excellent n-$\gamma$ discriminations properties

- Good light output $\rightarrow$ detection in the low energy domain

![Graph showing neutron and gamma discrimination](image-url)
1. Intrinsic timing resolution → (479.4 ± 15.3) ps

2. Deposited energy in the scintillator resolution

3. Neutron response using a $^{252}$Cf scintillating active target
   a. Light output function
   b. Neutron detection efficiency
• Time-of-flight measurement using an active scintillating target\(^3\) of \(^{252}\text{Cf}(\text{sf})\) above a pit

\[ L = 0.915 \text{ m} \]

\[ L = 0.979 \text{ m} \]

\(^3\text{G. Belier et al., NIMA 664 (2012)}\)
- Time-of-flight measurement using an active scintillating target\(^3\) of \(^{252}\text{Cf}\)(sf) above a pit
- Projection of the total charge for several energy bins

\[ E_{\text{ee}} \text{ [MeV]} \]

\[ E_{\text{n}} = 2.00 \pm 0.10 \text{ MeV} \]

\[^3\text{G. Belier et al., NIMA 664 (2012)}\]
- Monte Carlo simulation code for the neutron response of liquid scintillators
- Input parameters: detector geometry, detector composition and light output curve

![Graph showing neutron response for different energies](image)

- Counts vs. \( E_{ee} \) [MeV]

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4 (PTB, Germany). ISSN 0572-7170
Neutron detection efficiency

\[ \varepsilon(E) = \frac{\text{detected neutrons}}{\text{neutrons emitted in fission}} = \frac{\Omega}{4\pi} \times \varepsilon_{\text{intrinsic}}(E) \]

- Experimental energy spectrum compared to Mannhart evaluation\(^5\)

\(^5\)Standard recommended by the IAEA
Neutron detection efficiency

$\varepsilon_{\text{intrinsic}}$ vs $E_n$ [MeV] for $500$ keV neutrons. The graph shows data for BC501A and P-terphenyl detectors.

7/11/2013 A. Sardet
1 Experimental

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Fission cross-section of $^{238}$U

$^{238}$U(n,f)

Fission cross-section [b]

Energy [MeV]

EXFOR
Performed measurements

ENDF/B-VII
Experimental setup for $^{238}\text{U}$ at 5.2 MeV

- Fission chamber ($^{238}\text{U}$)
- Shadow bar (iron + CH2 + lead)
- Shielding cone (Lead and paraffin)
- P-terphenyl

$d(2\text{MeV}) + D \rightarrow n(5.2\text{MeV}) + ^{3}\text{He}$

Van de Graaff

Target(TiD)
Experimental setup for $^{238}$U at 5.2 MeV
Example of a TOF spectrum for $^{238}\text{U}(n,f)$ at 5.2 MeV

- **TOF [ns]**
  - 0 50 100 150 200 250 300

- **Energy [MeV]**
  - 0 0.5 1 2 5

- **Counts**
  - 0 50 100 150 200 250 300

- **Prompt $\gamma$ peak**
- **Neutrons**
- **Flat background noise**

- **Remaining $\gamma$-peak**: 5.9 %
PFNS for $^{238}\text{U}(n,f)$ at 2 MeV

Fit by a Maxwellian between 0.8 and 5.5 MeV

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<th>T (MeV)</th>
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<tbody>
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<td>This work</td>
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<td>Baba et al.</td>
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PFNS for $^{238}$U(n,f) at 5.2 MeV

- Fit by a Maxwellian between 0.7 and 5.5 MeV

$^{238}$U(n$_{5.2\text{MeV}}$,f)

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<td>Trufanov et al.</td>
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PFNS for $^{238}\text{U}(n,f)$ at 15 MeV

- Fit by a Maxwellian between 0.9 and 5.5 MeV

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<td>This work</td>
<td>$1.15 \pm 0.07$</td>
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<tr>
<td>Baryba et al.</td>
<td>$1.23 \pm 0.04$</td>
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Outline

1. Experimental
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Conclusion and outlook

• Conclusion
  • P-terphenyl characterized
  • Preliminary results for $^{238}\text{U}$ at 2, 5.2 and 15 MeV

• Outlook
  • Simulations to study the distortion of the spectrum caused by shielding and the environment (MCNP)
  • Analysis of the measurements on $^{235}\text{U}$ and $^{237}\text{Np}$ at 500 keV
  • Comparison to models and evaluations
  • Other measurements at other energies and on other actinides