$^{233}\text{U}(n,\gamma)$ measurements at LANSCE

ND2022

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Motivation

- Th-U alternative to U-Pu fuel cycle due to its reduced amount of transuranium elements.
- $^{232}\text{Th}$ is more abundant in nature than uranium.
- In the Th fuel cycle the $^{232}\text{Th}$ transmutes into the fissile isotope $^{233}\text{U}$.

$$n + ^{232}_{90}\text{Th} \rightarrow ^{233}_{90}\text{Th} \rightarrow ^{233}_{91}\text{Pa} \rightarrow ^{233}_{92}\text{U}$$

- $^{233}\text{U}(n,\text{f})$ produces a large rate of emitted neutrons, enough to maintain the chain reaction.
- For this reason, the Th fuel cycle may be the basis of thermal breeder reactors, being also suitable to use in fast reactors.
- Chemical advantages from thorium vs uranium: higher melting point and thermal conductivity.

Illustration of the thorium fuel cycle.
Motivation

- Experimental $^{233}\text{U}(n,\gamma)$ cross section data in the literature are scarce and were measured decades ago.
- New report [1] suggests that a simultaneous measurement with capture would be useful.
- For $^{233}\text{U}$ fission is around one order of magnitude more likely than capture.
  - Good discrimination between gammas coming from capture and fission is required.
  - New measurement proposed at LANL combining NEUANCE and DANCE.

![Graph showing $^{233}\text{U}(n,\gamma)$ and $^{233}\text{U}(n,f)$ cross sections from ENDF/B-VIII.]

LANSCE facility

- Neutrons produced by proton spallation on a W target.
- FP 14 = 20 m.
Time-of-flight measurements

Neutron Energy:

\[ E_n = m_n c^2 \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} - 1 \]

with:

\[ v = \frac{L}{T} \]

Flux\(_n\) = \(3 \times 10^5\) n/s/cm\(^2\)/dec
Detectors

**DANCE (Detector for Advanced Neutron Capture Experiments)**

- $4\pi\text{BaF}_2 \gamma$-ray calorimeter composed by 160 crystals with an inner cavity of 17 cm radius [2].
- Used to measure neutron capture cross section data on small quantities of radioactive isotopes.
- We use clusters that are a group of neighbor crystals.
- We can measure $E_n$, $E_{\text{sum}}$, $E_{\text{cl}}$, and $M_{\text{cl}}$, providing more information than with C6D6 detectors.

Detectors

**NEUANCE (NEUtron detector array at dANCE)**

- Neutron detector array that consists in 21 stilbene crystals arranged in a cylindrical geometry around the beam pipe [3].
- NEUANCE detects neutrons with energies above 200 keV (fission neutrons have these energies), therefore **low energy scattered neutrons** that are below this threshold are discriminated.
- Used to detect neutrons coming from fission and determine by coincidence with DANCE, the gammas coming from fission.
- Those events are suppressed with a fission tag, and then the fission gamma shape is characterized with fission events to subtract the remaining fission background.
- Possibility to use a thick target.
- NEUANCE can also detect gammas.

PSD NEUANCE

- Neutrons & gammas separation using the plot (long-short)/long vs long.

- Clear discrimination between fission neutrons and $\gamma$-rays.
Fission tagging process

- Search for coincidences between the two detectors.
- The DANCE gammas in coincidence with the NEUANCE neutrons are tagged as fission gammas.
- The purpose of tagging is to define the shape of the fission $\gamma$-ray spectrum that can be subtracted from the untagged spectrum.

![Normalization window](image)

No fission events
Background studies

- The background varies with the neutron energy, therefore it is subtracted per En bin.

Mcl=(4,6)

Q value peak = 6.845 MeV
Capture to fission ratio

En = (0.3, 3000) eV

Normalization to the evaluation by eye for comparison

Preliminary Experimental Evaluation

1000b/d
Capture to fission ratio

$E_n = (3, 300) \text{ keV}$

Experimental

125b/d

Ratio

Preliminary

Los Alamos National Laboratory
Scientific opportunities with DANCE

- Gamma decay photon strength studies [3].
- R-Matrix analysis of RRR to obtain the Resonance Parameters.
  - Statistical studies to calculate the level density, level spacing, …
- R-Matrix analysis for spin determination by measuring the multiplicities of gamma-ray cascades following neutron capture [4].
- New spallation target would improve the resolution, increase the neutron flux, and open a broader type of measurements.
- Measurements for NNSA applications, nuclear astrophysics, …

Conclusions and next steps

- New measurement at LANSCE combining DANCE and NEUANCE at the end of 2020 and 2021.
- The $^{233}$U material was provided by Oak Ridge National Laboratory (December 2020).
- Two samples of 10 mg and 20 mg of $^{233}$U have been prepared at LANL by Evelyn M. Bond (December 2020).
- The experiment was performed in December 2020 and June/July 2021.
- Data analysis ongoing.
- We are looking forward to deliver the capture/fission ratio from (1-300) keV by the end of the FY2022.
Acknowledgements

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Thanks to our collaborators John Ullmann (P-3), Cathleen Fry (P-3) and Todd A. Bredeweg (C-NR) and Evelyn M. Bond.
233U targets

- The 30 mg of 233U were supplied from Oak Ridge National Laboratory (ORNL).
- Material composition:

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Atom (%)</th>
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<tbody>
<tr>
<td>233U</td>
<td>99.9843</td>
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<tr>
<td>234U</td>
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<td>0.0004</td>
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<tr>
<td>238U</td>
<td>0.0134</td>
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</tbody>
</table>

- Two samples have been prepared by Evelyn M. Bond at LANL.
  - 20 mg
  - 10 mg