Measurements of $^{233}$U($n,\gamma$) with DANCE

NCSP Technical Program Review

LANL ND3 (Unresolved and Fast Measurements of $^{233}$U ($n,\gamma$))

Esther Leal Cidoncha, Aaron Couture and Gencho Rusev

22-25 February 2021
Motivation

- Th-U alternative to U-Pu fuel cycle due to its reduced amount of transuranium elements.
- Experimental $^{233}$U(n,γ) cross section data in the literature are scarce and were measured decades ago.
- Previous 2008 measurement at LANL combining the “fowler” PPAC with DANCE.
- For $^{233}$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.

$^{233}$U(n,g) and $^{233}$U(n,f) cross sections from ENDF/B-VIII.
LANL 2008 experiment

- Previous 2008 measurement at LANL combining the “fowler” PPAC with DANCE.
  - Two $^{233}\text{U}$ samples placed back to back were electrodeposited in a thick backing.
  - Analysis method consisted in tagging the coincidence signals between DANCE and the PPAC as fission. Then a second coincidence method between the two PPAC anodes was used to identify the cases in with the two FF or just one FF are detected in the PPAC.
  - The PPAC efficiency was around 37%, lower than expected (80%). Hence the statistics in the keV region were inadequate to calculate the cross section up to 100 keV.
LANSCE facility

- Neutrons produced by proton spallation on a W target.
- Flight path 14 (20 m).
- White neutron spectrum (En=th-1 MeV).
DANCE and NEUANCE

DANCE (Detector for Advanced Neutron Capture Experiments)
- 4PiBaF$_2$ gamma-ray calorimeter composed by 160 crystals with an inner cavity of 17 cm [1].
- Used to measure neutron capture cross section data on small quantities of radioactive isotopes.
- We can measure En, Esum, Ecl, and Mcl, providing more information than with C6D6 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 [2].
- Possibility to use a thick target.
- 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.

The 30 mg of $^{233}\text{U}$ were supplied from Oak Ridge National Laboratory (ORNL).

Material composition:

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Atom (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{233}\text{U}$</td>
<td>99.9843</td>
</tr>
<tr>
<td>$^{234}\text{U}$</td>
<td>&lt;0.0002</td>
</tr>
<tr>
<td>$^{235}\text{U}$</td>
<td>0.0017</td>
</tr>
<tr>
<td>$^{236}\text{U}$</td>
<td>0.0004</td>
</tr>
<tr>
<td>$^{238}\text{U}$</td>
<td>0.0134</td>
</tr>
</tbody>
</table>

Two samples have been prepared by Evelyn M. Bond at LANL.
- 20 mg
- 10 mg
**233U experiment (nov.-dec. 2020)**

- **DANCE & NEUANCE:**
  - 10 days of data taking with the 20 mg $^{233}$U sample.
  - 1 day of data taking with the 10 mg $^{233}$U sample.
  - 2 days of radioactive gamma sources for calibration (before and after the $^{233}$U measurements).
  - Measurements with a $^{235}$U sample to cross-check the performance and the systematics.
  - Measurements with a $^{208}$Pb sample to set a trigger to select fission neutrons and reject scattered neutrons.

- **Neutron beam monitors:**
  - **Fission chamber:**
    - In parallel to measure $^{235}$U(n,f) reactions during the whole data taking to calculate the neutron flux.
  - **Si detectors:**
    - In parallel to measure $^6$Li(n,t) reactions to calculate the neutron flux.
DANCE calibrations

- Intrinsic radioactivity of BaF$_2$ used to calibrate the DANCE crystals.
- Using the Alpha-decay chain of the $^{226}$Ra present in the BaF$_2$.
  - $^{226}$Ra (4.8 MeV)
  - $^{222}$Rn (5.5 MeV)
  - $^{218}$Po (6.0 MeV)
  - $^{214}$Po (7.7 MeV)
NEUANCE calibrations

- Calibration using gamma sources:
  - $^{22}$Na (511 keV and 1274.537 keV).
  - $^{137}$Cs (661.657 keV).
  - $^{88}$Y (898.047 keV and 1836.090 keV).
Flux calculation

- Flux shape:
  - $^6\text{Li}(n,t)$ Standard
  - $^{235}\text{U}(n,f)$ Ref
  - $^{235}\text{U}(n,f)$ Standard

- Normalization:
  - To the $^{235}\text{U}(n,f)$ second Standard (7.8-11 eV).
PSD NEUANCE

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

- Clear discrimination between fission neutrons and gamma-rays.
$^{233}\text{U} (n,\gamma) \text{ DANCE spectrum}$

- Raw counts of the $^{233}\text{U}(n,\gamma)$ reaction measured with DANCE, before fission tagging.

**Resonance Region**

**keV Region**

Preliminary
Conclusions and next steps

- Previous measurement of the $^{233}\text{U}(n,\gamma)$ reaction measured in 2008 using DANCE combined with the “Fowler” PPAC at LANSCE: poor statistics in the keV region.
- New measurement at LANSCE combining DANCE and NEUANCE at the end of 2020.
- There was a delay on the $^{233}\text{U}$ target production due to COVID issues with transportation.
- The $^{233}\text{U}$ material was provided by Oak Ridge National Laboratory (December 2020).
- Two samples of 10 mg and 20 mg of $^{233}\text{U}$ have been prepared at LANL by Evelyn M. Bond (December 2020).
- The 20 mg sample has been measured during 10 days of data taking (December 2020).
- Data analysis in process (2021 - 2022).
- Continue data taking in 2021 to increase the statistics.
Acknowledgements

The $^{233}\text{U}$ was supplied by DOE/SC Isotope Program. Thanks to our collaborators John Ullmann (P-3), Catherine Fry (P-3) and Todd A. Bredeweg (C-NR), to Oak-Ridge National Laboratory for providing the $^{233}\text{U}$ material and to Evelyn M. Bond for preparing it.