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Neutron Capture Cross Section of ^{239}Pu

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The Detector for Advanced Neutron Capture Experiments (DANCE) has been used to measure the ^{239}Pu(n,γ) cross section from 10 eV to the keV region. Three experimental run conditions were used to characterize the prompt fission γ-ray spectrum across the entire energy regime, measure the cross section in the resolved resonance region, and obtain necessary count rate well into the keV region. The preliminary cross sections are in good agreement with current evaluations from 10 eV to 80 keV.

I. INTRODUCTION

^{239}Pu(n,γ) is a reaction channel that competes strongly with ^{239}Pu(n,f), which makes accurate measurements of this process important for both nuclear energy and defense programs. The Advanced Reactor Concepts (ARC) program is considering new reactor designs which have faster neutron spectra than traditional light water reactors, requiring improved nuclear data in the keV region. The ^{239}Pu(n,γ) cross section above 2 keV has been identified as a particular need for the ARC program [1], and more generally the cross section from 10 keV to 500 keV is of interest [2].

Because fission competes strongly with capture, measurements on fissile isotopes which rely on γ-ray detection are presented with unique challenges in removing this source of contamination from the data. Some mechanism for characterizing the effects of fission on the data and removing it to obtain an accurate capture spectrum must be utilized.

Such a mechanism has been developed for DANCE [3], using the beams available from the Los Alamos Neutron Science Center (LANSCE). This method utilized a combination of three experimental run conditions and has been tested on the ^{235}U system [4]. The prompt fission γ-ray spectrum was characterized by an experiment using a thin (1 mg) ^{239}Pu target in conjunction with a fission tagging Parallel Plate Avalanche Counter (PPAC). Acceptable count rates at high incident neutron energies were obtained using a second experiment with a thick (50 mg) target, and a ^{208}Pb/Ni target was used to characterize scattered neutron background in the thick target data. The final capture cross section was measured as a ratio to the known fission cross section. Preliminary results will be outlined below.

II. EXPERIMENTAL SETUP

DANCE is placed at flight path 14 of the Manuel Lujan Jr. Neutron Scattering Center at LANSCE [5]. An 800 MeV proton beam with a 20 Hz repetition rate impinges on a pair of tungsten targets surrounded by a moderator to produce spallation neutrons, which travel through the moderator [6] and down a 20.2 m flight path to the target location with a flux of approximately $3 \cdot 10^5$ n/s/cm^2/decade.

DANCE is a 160 element BaF_2 calorimeter which subtends approximately 3.5π with a single γ-ray efficiency of 85% [7]. Three major targets were used for this experiment. The thin target consisted of 1 mg of ^{239}Pu electroplated onto both sides of a 3μm Ti backing. The sample was covered by a pair of 1.5 μm Al mylars for containment, and this assembly served as the cathode for a PPAC [8]. The PPAC was configured in an anode-cathode-anode arrangement with the anodes operated at 375 V and the cathode at ground. Outer windows for the PPAC were constructed of Kapton (25.4 μm thick) which completed the assembly. The PPAC was placed at the center of DANCE, and the active area was 7 mm in diameter. The active volume was filled with 4.5 Torr of isobutane gas with a flow rate of 4 cc/m.

The thick target consisted of a 50 mg, 1.2 cm diameter ^{239}Pu foil flashed with 0.005" of Ni on each side. The scattering target consisted of two 0.005" Ni foils with an irregular 0.7×1 cm 30 mg ^{208}Pb foil in between.

A brief summary of the data acquisition is provided below, with details provided elsewhere [9, 10]. Acqiris

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DC265 8-bit digitizers with 2 ns sampling intervals processed signals from both DANCE crystals and the PPAC. The data were taken in a combination of acquisition modes to optimize the coverage of incident neutron energies and count rates. For the thin target experiment, fast signals from the PPAC provided coincidence timing between fission fragments and DANCE.

III. ANALYSIS

This work reports on the current status of analysis for all run conditions. For both the thin and thick ^{239}Pu targets, the analysis proceeded in three basic modes - background subtraction, cross section calculation, and uncertainty estimation. This work will report on the first two steps as uncertainty estimation is extremely preliminary for both datasets.

A. Background Subtraction

Neutron induced fission and scattered neutrons both contribute to the background and must be characterized separately. An example subtraction is shown for the thin target data in Figure 1. The total energy spectrum is shown for incident neutron energies from 30 eV to 1 keV, and the black solid line defines data before any subtractions take place. PPAC coincidence data (grey dashed line) is used to characterize the fission contribution to the total γ-ray energy spectrum and subtracted, resulting in the dashed black line. A blank PPAC was used to characterize the scattered neutron background (grey dot-dashed line) and normalized to the fission subtracted data in the 7.3-9.2 MeV region (shaded) where capture on Barium in the DANCE crystals dominates. This line is subtracted to produce the final capture energy spectrum (grey solid line). The ^{239}Pu capture Q-value peak is then selected (vertical black lines) to produce a neutron capture yield $Y_{n,\gamma}$.

The thick target experiment did not have an explicit fission tag, so the fission background had to be estimated by a process showed qualitatively in Figure 2. The multiplicity in DANCE is plotted against total γ-ray energy for all data (panel a) and PPAC coincidence data for the thin sample (panel b). Fission exhibits a characteristic surface running along the diagonal, while capture only contributes to the low multiplicity ($M^{cl} < 6$) events. Therefore the fission surface was characterized by the PPAC coincidence data, and the surface was normalized to the thick target data in the boxed region where fission dominates so the subtraction could be performed. The subsequent scattered neutron background was then characterized by the Pb/Ni target data and subtracted using the process described in the preceding paragraph.

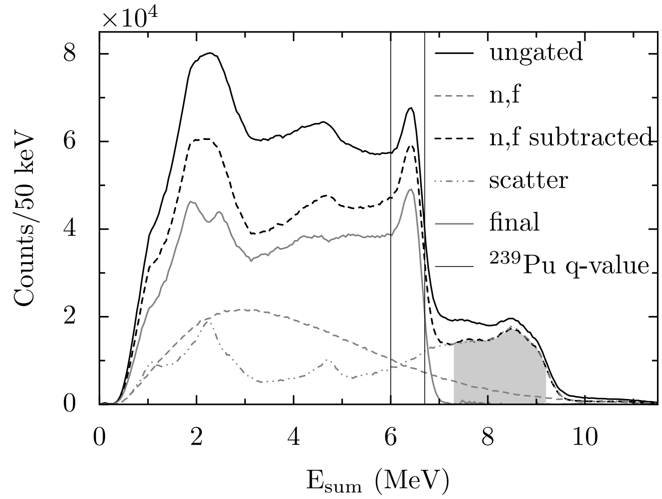

FIG. 1. Total γ-ray energy spectrum demonstrating the background subtraction process (see text).

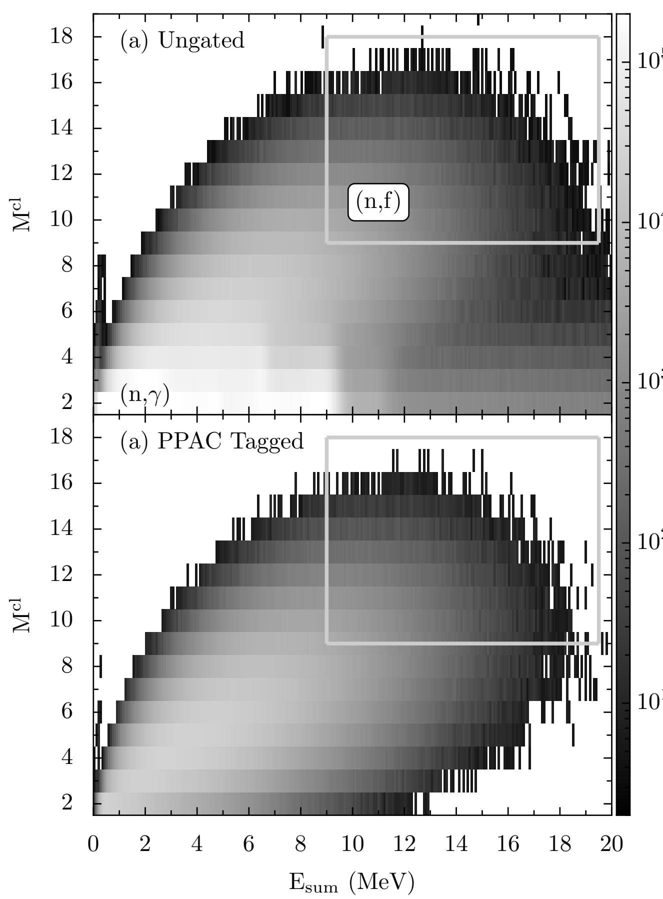

FIG. 2. M^{cl} vs. E_{sum} for ungated (a) and PPAC coincidence (b). The box defined a region where only fission contributes to the spectrum, and is used to normalize the fission surface in the thick target data.

B. Cross Section Calculation

The capture cross section was measured as a ratio to fission. Both run conditions observed simultaneous fission and capture yields, so the cross section could be expressed as:

$$\sigma_{n\gamma} \;=\; A_{n\gamma}\sigma_{nf}\frac{Y_{n,\gamma}}{Y_{n,f}} \tag{1}$$

where $\sigma_{n\gamma}$ is the capture cross section, $A_{n\gamma}$ is a scaling factor relating the capture to fission yield ratio to a cross section ratio, σ_{nf} is the ENDF fission cross section, and $Y_{n,f}$ is the fission yield determined by PPAC coincidences. $A_{n\gamma}$ was calculated using the integral cross section for capture and fission from 35 - 100 eV, expressed as:

$$A_{n\gamma} = \frac{I_{nf}}{I_{n\gamma}}\frac{Y_{n,f}}{Y_{n,\gamma}} \tag{2}$$

I_{nf} and I_{γ} are the ENDF integral cross sections from 35 - 100 eV, while Y_{nf} and $Y_{n\gamma}$ are associated integral yields from the data for fission and capture respectively. This method eliminates uncertainties in the neutron flux, detector efficiency, and sample size / illumination which traditionally are quite significant.

IV. RESULTS AND DISCUSSION

The preliminary cross sections from both datasets are shown in Figure 3 compared to ENDF. The thin target data extend from 10 eV to 10 keV, and are in good agreement with the evaluation below 500 eV. Above that energy there is some discrepancy which is under investigation. The thick target cross section is extremely preliminary and results from online analysis. It currently covers the energy range of 37 eV to 80 keV and is in fairly good agreement with ENDF across the entire energy range. Data exist for energies as low as 10 eV with this sample and will be merged into the cross section calculation, while extending the measurement to higher incident neutron energies will require detailed analysis of background. This work is ongoing.

V. SUMMARY

The ^{239}Pu(n,γ) cross section has been measured across the incident neutron energy range of 10 eV to 80 keV by a ratio to fission technique. A thin ^{239}Pu target was used in conjunction with a PPAC to characterize the prompt fission γ-ray spectrum and measure the capture cross section at lower energies. The measured γ-ray spectrum was used to subtract fission background from data taken with a thick 50 mg sample. The thick target was used to obtain the necessary capture count rate at high neutron energies, and online analysis of the data appear promising. Further analysis of backgrounds in that dataset may extend the cross section measurement above 100 keV.

VI. ACKNOWLEDGMENTS

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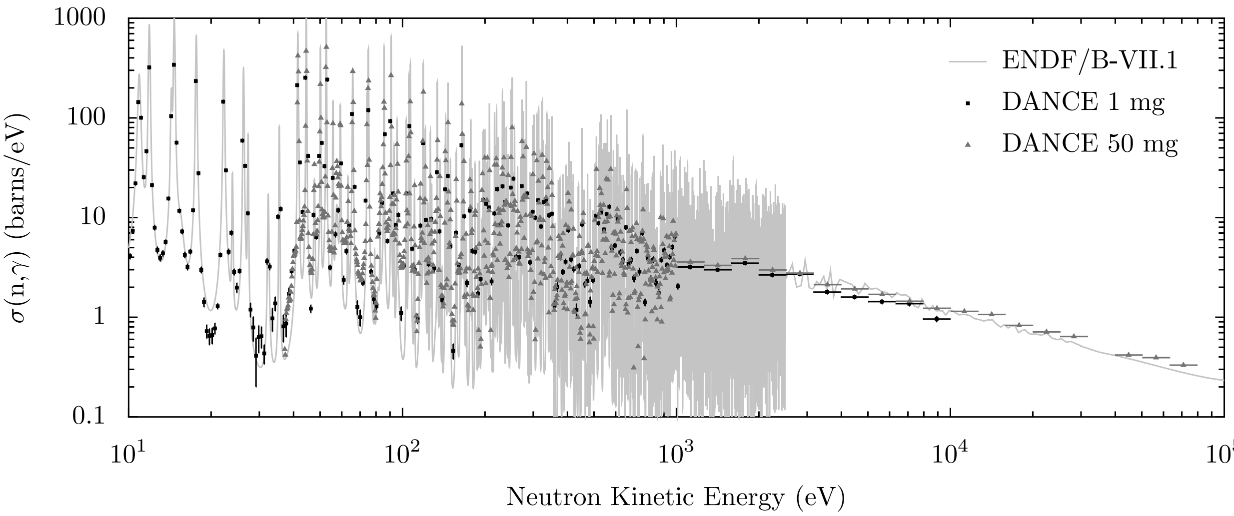

FIG. 3. DANCE ^{239}Pu(n,γ) cross section compared to ENDF.