

242Pu absolute neutron-capture cross section measurement


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Abstract. The absolute neutron-capture cross section of 242Pu was measured at the Los Alamos Neutron Science Center using the Detector for Advanced Neutron-Capture Experiments array along with a compact parallel-plate avalanche counter for fission-fragment detection. During target fabrication, a small amount of 239Pu was added to the active target so that the absolute scale of the 242Pu(n,γ) cross section could be set according to the known 239Pu(n,f) resonance at Eγ,n,R = 7.83 eV. The relative scale of the 242Pu(n,γ) cross section covers four orders of magnitude for incident neutron energies from thermal to ≈ 40 keV. The cross section reported in ENDF/B-VII.1 for the 242Pu(n,γ) Eγ,n,R = 2.68 eV resonance was found to be 2.4% lower than the new absolute 242Pu(n,γ) cross section.

1. Introduction

The 242Pu(n,γ) reaction is important because precision (n,f), (n,γ), and (n,2n) cross sections are key input to network calculations of the radioactive diagnostic chain. These calculations are a priority for the United States Department of Energy’s Stockpile Stewardship program and related initiatives. New reactor concepts rely on network calculations like the Pu-Am diagnostic chain and catalyzed interest in improved cross section measurements for neutron-induced reactions on actinides [1,2]. In a reactor, plutonium-containing nuclear fuel undergoes reactions that produce long-lived 242Pu (t1/2 = 3.8 × 108 years). Improved cross sections for neutron capture by 242Pu may impact calculations relevant to the development of next-generation reactors [2].

Prior to this study, little experimental data were published on the 242Pu(n,γ) reaction. References [3–10] report cross sections for thermal neutron capture, and Ref. [11] provides cross sections at incident neutron energies Eγ ≈ 6–90 keV. Meanwhile, the 242Pu(n,f) cross section has been well-studied [12–26], and reported cross sections span an incident neutron energy range from ≈ 102 – 108 eV. In this work, a new (n,γ) measurement [27] was performed at the Los Alamos Neutron Science Center (LANSCE) using the Detector for Advanced Neutron-Capture Experiments (DANCE) array [28] in combination with a parallel-plate avalanche counter (PPAC) [29]. The measured absolute neutron-capture cross sections cover an incident neutron energy range from thermal to ≈ 40 keV. This is the first direct measurement of the 242Pu(n,γ) cross section between Eγ ≈ 0.025 – 6000 eV. The (n,γ) cross sections reported in the evaluation ENDF/B-VII.1 [30] were derived indirectly from total cross section measurements in combination with (n,γ) cross section models and the available (n,γ) data. Details of the experiment, the analysis, and results are described in the sections below.

2. Experiment

The measurement of the 242Pu(n,γ) cross section, as a function of incident neutron energy (Eγ), was carried out at the LANSCE Lujan Center [31] using the DANCE array. DANCE is located at a flight path 21.23 m away from the neutron source. Neutrons are produced by bombarding a tungsten target with 800-MeV protons at a repetition rate of 20 Hz, and they are slowed by a water moderator [32]. The incident neutron energy, ranging from thermal to several hundred keV, is determined from the time-of-flight difference between the beam pulse and event detection. This experiment was performed over a period of 17 days with a 242Pu target installed within a PPAC. An additional seven days of beam were collected on a blank target in a duplicate PPAC assembly and represent the background data in the inclusive mode.

A double-sided, electroplated target composed of 0.642 mg of 99.93% enriched 242Pu with an active area ≈ 7.6 mm in diameter, was fabricated at Lawrence Livermore National Laboratory (LLNL) with the electroplating cell described in Ref. [33]. With an atomic ratio of 5.0%, 239Pu was added to the target to set the absolute scale of the 242Pu neutron-capture cross section with the well-known 239Pu(n,f) cross section. The uncertainty of this atomic ratio was measured to be better than 1% using the mass spectrometer at LLNL.

3. Analysis

Detector efficiencies for the DANCE array (εDANCE) and the avalanche counter (εPPAC) were key quantities necessary to extract the measured neutron-capture cross sections. Gates

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applied to the event-by-event-built summed γ-ray energy (E_{sum}) versus cluster multiplicity (M_{cl}) spectrum allowed signal-to-noise optimization, and these filters enabled a precision determination of the cross section as a function of incident neutron energy [34].

The E_{sum} efficiency was calculated from the ratio between the 3.5−4.5 MeV area and total area in the γ-ray spectrum associated with the E_{n,R} = 2.68 eV resonance. The same procedure was performed for the less intense 242Pu(n,γ) resonance at E_{n,R} = 67.6 eV [30]. The weighted mean of these efficiencies was 39.58(5)%.

Deterioration of the data quality for E_{n} > 1 keV was evident when this procedure was applied at higher neutron energies.

The cluster multiplicity efficiency was calculated from the ratio between the area of M_{cl} = 0−9. The 242Pu(n,γ) resonance at E_{n,R} = 67.6 eV was also studied in this manner. The weighted mean of the M_{cl} efficiencies for these two resonances was determined to be 59.6(4)%. As a result, the DANCE array efficiency, the product of the M_{cl} and E_{sum} efficiencies, was \epsilon_{DANCE} = 23.6(1)\%.

The absolute scale of the 242Pu(n,γ) cross section was set according to the cross section \sigma(n,γ) of 242Pu is the absolute 242Pu(n,γ) resonance at E_{n,R} > 1 keV where the data are systematically lower than the evaluated data, and at E_{n} = 2.68 eV resonance. The 242Pu(n,γ) cross section was already \approx 6\% lower than the average reported by Ref. [11] is within 2\sigma of the new data.

In addition to the measured cross section, the 242Pu(n,γ) resonance energies, γ widths (Γ_{γ}), and neutron widths (Γ_{f}) for 38 resonances with energies between 2.66 and 495 eV were extracted to the first order using the R-matrix code SAMMY [36]; the fission widths, Γ_{f}, were set to values quoted in ENDF/B-VII.1 [30]. The average Γ_{γ} for resonance energies within the range 2.66−495 eV was 23.0 meV and 1.7% higher than the average reported in ENDF/B-VII.1 [30]. These widths may help improve model calculations of neutron-capture cross sections at higher incident neutron energies beyond the scope of the current work.

This measurement was performed under the auspices of the US Department of Energy by Lawrence Livermore National Security, LLC under contract DE-AC52-07NA27344 and by Los Alamos National Security, LLC under contract DE-AC52-06NA25396. Additional funding was provided by the U.S. DOE/NNSS Office of Defense Nuclear Nonproliferation Research and Development.
The isotopes used in the measurement were obtained from Oak Ridge National Laboratory.

References