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Late gamma rays from neutron-induced fission and capture from ^{235}U

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Abstract. An experiment on ^{235}U was performed with a white-spectrum neutron beam at the Los Alamos Neutron Science Center. Gamma rays from the (n, γ) and (n, f) reactions were measured with the DANCE array. We present spectra of γ rays emitted shortly after any of the reactions occurs. A novel method for background estimation was applied. The spectrum of the late fission γ rays is compared with CGMF predictions.

Keywords: $^{235}\text{U}(n, \gamma)$ and $^{235}\text{U}(n, f)$ reactions, γ -ray spectra

1 $^{235}\text{U}+n$ experiment

The late emission γ rays from the $^{235}\text{U}(n, \gamma)$ and $^{235}\text{U}(n, f)$ reactions were studied in an experiment with a 26-mg/cm² thick target enriched to ^{235}U . The experiment was performed at flight path 14 of the Lujan Center using neutrons produced via spallation reaction of 800-MeV protons striking a tungsten target with a repetition rate of 20 Hz [1]. A 1-inch thick water moderator increases the neutron flux at low energies. The γ -rays were measured with the DANCE array, which consists of 160 BaF₂ detectors in a 4π configuration [2]. Pictures of DANCE are shown in Fig. 1. DANCE was equipped with the NEUANCE array [3] serving as a fission trigger by measuring the prompt fission neutrons. NEUANCE consists of 21 stilbene detectors in a cylindrical configuration located in the central cavity of DANCE (*cf.* Fig. 1). The signals from all DANCE and NEUANCE detectors were digitized by CAEN VX1730B cards (14-bit, 500 MHz). In offline analysis, coincidence events of detectors fired within 5 ns were built and ordered in time relative to the beginning of the neutron spill (T_0).

2 Preliminary results

The train of detector hits for a fission event starts with the detection of at least one neutron by NEUANCE. In the same 5-ns coincidence event, a few DANCE detectors register the prompt fission γ rays (PFG). This event is followed by a long sequence of events containing γ rays from de-excitation of isomeric states

Fig. 1. A photograph of DANCE (left). DANCE consists of 160 BaF₂ detectors in a 4π configuration. One of the DANCE hemispheres (right) with the beam line and NEUANCE installed in the central cavity.

in the fission fragments (late γ rays) as well as background events (beam related background, natural background, and cosmic rays). We applied a method, developed for similar experiments, to estimate the background [4]. The method requires three time spectra: PFG relative to T_0 , late γ rays relative to T_0 , and “late - prompt” events. See Appendix B in Ref. [4] for more details. A “late - prompt” spectrum with the estimated background is given in Fig. 2. Time 0 refers to the time of fission while the counts at later times correspond to the detected late γ rays. An energy spectrum of the late γ rays is produced by integrating the “late - prompt” spectrum from 50 ns to 2 μ s. The energy spectrum obtained is shown in Fig. 2 and compared with predictions [5] from the CGMF code [6]. Note, we estimate the background for each energy bin of the spectrum independently.

Fig. 2. A spectrum of “late - prompt” events (left) with background estimated using the method from Ref. [4]. Obtained spectrum of late γ rays from fission (right) compared with CGMF predictions from Ref. [5].

The product nucleus of the $^{235}\text{U}(n,\gamma)^{236}\text{U}$ reaction exhibits two low-lying isomeric states, one at 687.6 keV ($T_{1/2} = 3.78$ ns) and the other at 1052.4 keV ($T_{1/2} = 100$ ns). A partial level scheme of ^{236}U is shown in Fig. 3. We applied the same method for background estimation to obtain the energy spectrum of the late γ rays. The prompt γ rays, *i.e.* the γ rays feeding any of the isomers, are selected by the total γ -ray energy ($E_{\gamma}^{\text{total}}$) measured by DANCE: $E_{\gamma}^{\text{total}} = 6545.5 - 687.6$ keV or $6545.5 - 1052.5$ keV, where 6545.5 keV is the Q value of the $^{235}\text{U}(n,\gamma)$ reaction. The late γ rays are selected by the condition $E_{\gamma}^{\text{total}} = 687.6$ keV or 1052.5 keV, respectively. A sample γ -ray spectrum is given in Fig. 3.

Fig. 3. A partial level scheme of ^{236}U (left). A spectrum of late γ rays (right) de-exciting the isomeric state at 1052.5 keV at 50 ns since the $^{235}\text{U}(n,\gamma)$ reaction occurred.

In summary, we presented preliminary results for spectra of late γ rays from fission and neutron capture demonstrating the potential of DANCE to measure isomeric states with half lives from a few ns up to μs .

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