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A fission fragment detector for correlated fission output studies

S. Mosby [a,*], F. Tovesson [a], A. Couture [a], D.L. Duke [a,b], V. Kleinrath [a,c], R. Meharchand [a], K. Meierbachtol [a], J.M. O'Donnell [a], B. Perdue [a,1], D. Richman [a], D. Shields [a,b]

[a] Los Alamos National Laboratory, Los Alamos, NM 87545, USA
[b] Colorado School of Mines, Golden, CO 80401, USA
[c] Idaho State University, Pocatello, ID 83201, USA

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ABSTRACT

A digital data acquisition system has been combined with a double Frisch gridded ionization chamber for use at both moderated and unmoderated neutron sources at the Los Alamos Neutron Science (LANSCE) facility. The high efficiency of the instrument combined with intense LANSCE beams and new acquisition system permits fission output measurements across 11 orders of magnitude incident neutron energy. The acquisition and analysis system is presented along with the first in-beam performance tests of the setup.

1. Introduction

Nuclear fission is an important meeting point between the worlds of applied nuclear data and fundamental research. The energy release and emitted particles play an important role in the understanding and continued development of numerous practical applications, while many parameters and complicated interactions are challenging for both theoretical and experimental scientific efforts.

Past theoretical efforts in this area focused on predicting the average quantities for experimental observables, or only addressed fission induced by thermal neutrons [1–4]. In recent years, however, the need for improved predictive capability and advances in computing have lead to the development of more complete models [5–7]. These advanced models allow for more stringent experimental tests, including an increased emphasis on correlations between fission outputs and full spectral shapes instead of average quantities. Extending measurements to incident neutron energies well beyond thermal is also important for populating sufficient parameter space to stringently test these modern theoretical models.

Modern accelerator facilities such as the Los Alamos Neutron Science Center (LANSCE) [8] make the next generation of fission studies possible, primarily by providing significant improvements in neutron flux ranging from sub-thermal into the hundreds of MeV. The facilities at LANSCE are spallation neutron sources and therefore serve as white sources. This enables the measurement of relevant physics observables across the entire neutron energy spectrum simultaneously—a distinct advantage over mono-energetic sources for conducting multi-parameter phase space surveys. As a result, the development of an experimental program to address the needs of modern theory and applications is underway.

This work reports on the development of an acquisition and analysis framework which enables the use of an ionization chamber in conjunction with the neutron beams available at LANSCE to measure fission fragment properties. The framework is flexible so that additional γ-ray and/or neutron detectors could be added to explore correlations between different fission outputs while surviving the unique beam structure and associated constraints of the LANSCE facility. The hardware, acquisition system, and analysis software are described in detail, and the resulting performance is documented.

2. Hardware and beam lines

The ionization chamber is schematically shown in Fig. 1 and consisted of two gas volumes with two circular Frisch grids and anodes separated by a common cathode which also supported the sample. In this case, the sample consisted of 1045 μg of ^{235}U evaporated with a 2 cm diameter onto a 100 $\mu g/cm^2$ carbon film which was in turn secured to the cathode. Details of the chamber's design can be found in Ref. [9]. The grids were constructed of

* Corresponding author.
E-mail address: smosby@lanl.gov (S. Mosby).
[1] Present address: CCRi, 1422 Sachem Pl, Charlottesville, VA 22901, USA.

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0.05 mm radius (r) wires with a spacing (a) of 1 mm. The anode and cathode radii were 6 cm, while the inner radius of the grid was 4.5 cm. The distance from cathode to grid (D) was 3 cm, while the grid to anode distance (d) was 0.7 cm. The plates were assembled by stacking on Teflon rods inside an aluminum cylinder with radius of 9 cm and length of 13.5 cm. The active volume was filled with P10 gas pressurized to 95 kPa with a flow rate of < 0.1 l/min.

In order to cover the entire neutron energy range of interest, experiments were performed at two different experimental areas and utilized two different spallation neutron sources at LANSCE, with associated beam structure and constraints. Neutrons from sub-thermal to 500 keV were accessed at flight path 12 of the Manuel Lujan Jr. Neutron Scattering Center (Lujan Center) [8] which views a hydrogen moderator. A pulsed 800 MeV proton beam impinged upon a pair of tungsten targets [10] with a repetition rate of 20 Hz to produce spallation neutrons, which were subsequently reflected by the moderator system and travelled approximately 22 m to the experimental station. The cold neutron spectrum resulted in flight times that ranged from 2 μs to the entire 50 ms pulse spacing.

Neutrons from 200 keV to ≥ 100 MeV were accessed at the 90° flight path at the Weapons Neutron Research Facility (WNR) [8].

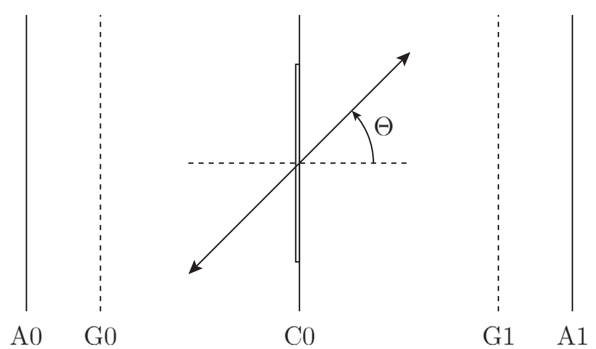

Fig. 1. Schematic of ionization chamber with signal notation.

This flight path directly viewed an unmoderated tungsten target which also utilized the 800 MeV proton beam to produce spallation neutrons. These neutrons travelled directly through a 10 m flight path to the experimental setup. The time structure of the proton beam differed significantly from the Lujan Center, however, and had a micro-pulse structure superimposed on a lower frequency macro-pulse. Macro-pulses arrive at 40 pulses per second sampled from the 60 Hz accelerator frequency and were 625 μs in length, and each macro-pulse contained approximately 340 micro-pulses separated by 1.8 μs.

3. Data acquisition system

The acquisition hardware consisted of a CAEN VX1720 VME based 12-bit waveform digitizer with a sample rate of 250 MS/s. This board was chosen for its combination of sample rate and number of bits. The proton beam pulse time reference (T0) signal had a rapid rise time which necessitated a minimum of 250 MS/s sample rate to achieve good timing resolution (see Fig. 2(d)). Even with the 250 MS/s sample rate, the T0 signal was slowed down using a Mini-Circuits BBLP-39 23 MHz flat time delay low pass filter in order to get several samples over its rising edge. Grid and anode signals were both processed by charge sensitive preamplifiers before digitization. As shown in Fig. 2(a) and (b), grid and anode signals had slow rise times but long exponential tails. Good pulse height resolution and dynamic range were achieved with the 12-bit digitizer. The fast cathode signal (Fig. 2(c)) was processed by a fast amplifier before digitization, and its leading edge was well matched to the sample spacing for this digitizer.

Table 1 shows the channel mapping for the VX1720 digitizer used. This digitizer was equipped with DPP-PSD firmware. While the PSD functionality was not used directly, the firmware-enabled controls such as an individual channel self trigger scheme were utilized for flexibility and zero suppression. These controls enabled the acquisition system to handle the two very different beam conditions mentioned in Section 2 without resulting in undesirable characteristics such as large dead-time or time range

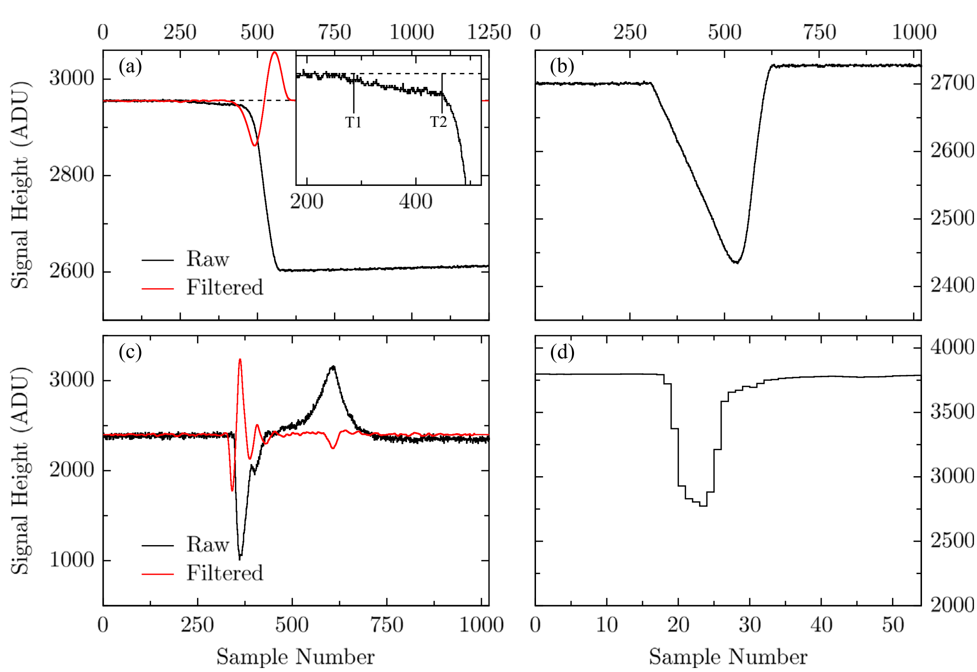

Fig. 2. Example waveforms traces. Panel (a) shows the anode signal (black) and its second derivative (red), and the inset shows the leading edge where the grid inefficiency can be measured (see text). Panel (b) shows the grid signal, while (c) contains the fast cathode (black) and its second derivative (red). Panel (d) shows the beam time reference signal. See text for details. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)