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Comparison of digital and analogue data acquisition systems for nuclear spectroscopy

A. Al-Adili [a,b], F.-J. Hambsch [a,*], S. Oberstedt [a], S. Pomp [b], Sh. Zeynalov [c]

[a] EC-JRC, Institute for Reference Materials and Measurements, B-2440 Geel, Belgium
[b] Division of Applied Nuclear Physics, Uppsala University, 751 20 Uppsala, Sweden
[c] JINR-Joint Institute for Nuclear Research, Dubna 141980, Russia

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ABSTRACT

In the present investigation the performance of digital data acquisition (DA) and analogue data acquisition (AA) systems are compared in neutron-induced fission experiments. The DA results are practically identical to the AA results in terms of angular-, energy- and mass-resolution, and both compare very well with literature data. However, major advantages were found with the digital techniques. DA allows for a very efficient α-particle pile-up correction. This is important when considering the accurate measurement of fission-fragment characteristics of highly α-active actinide isotopes relevant for the safe operation of Generation IV reactors and the successful reduction of long-lived radioactive nuclear waste. In case of a strong α-emitter, when applying the α-particle pile-up correction, the peak-to-valley ratio of the energy distribution was significantly improved. In addition, DA offers a very flexible expanded off-line analysis and reduces the number of electronic modules drastically, leading to an increased stability against electronic drifts when long measurement times are required.

1. Introduction

Data acquisition systems for nuclear spectroscopy have observed important developments in recent years. The transition from conventional analogue electronic modules to modern digital systems made it possible to enhance the detection efficiency and analysis performance [1]. In digital systems the detector signals are digitized directly after the pre-amplifier allowing for sequential digital signal processing (DSP) transformations such as shaping, filtering and pile-up correction during off-line analysis. Optimizing the settings for best signal treatment can be done off-line in the analysis of the fully digitized signal. In the present study digital data acquisition (DA) and analogue data acquisition (AA) are compared, particularly, in the field of fission-fragment spectroscopy. A dedicated experiment on neutron-induced fission of ^{234}U and ^{235}U was performed with DA and AA systems set up in parallel, in order to compare the two techniques, investigate possible advantages of the digital system and to verify consistency of the results.

2. Experimental tools

The measurements have been performed at the Van de Graaff accelerator of the Institute for Reference Materials and Measurements (IRMM) in Geel, Belgium. Protons from the 7 MV accelerator were used for neutron production via the reactions ^{7}Li(p,n) and T(p,n). The neutrons induce fission in ^{234}U (92 μgU/cm^2) and ^{235}U (45 μgU/cm^2) samples which are prepared by vacuum evaporation on gold-coated polyimide foils. The fission fragment (FF) detection was carried out by means of a Twin Frisch-Grid Ionization Chamber (TFGIC) with a common cathode (Fig. 1) [2]. As detection gas P-10 (90% Ar+10% CH_4) was used with a constant pressure of 1.05 bar and a flow of 0.1 l/min. The energies and emission angles of both FF are measured simultaneously. Mass distributions and total kinetic energies (TKE) are calculated using the conservation of energy and momentum. The absolute energy calibration is performed using neutron-induced fission at thermal energy, ^{235}U(n$_{th}$,f), as a reference, with TKE $= (170.5 \pm 0.5)$ MeV and heavy fragment mean mass $\langle A_H \rangle = 139.6$ [3]. During the experiments a precision pulse-generator was used to monitor pulse-height drifts due to changes in the electronic circuits.

2.1. Signal generation

In the ideal case of a Frisch-grid ionization chamber the collected charge on the anode, Q_A, is the sum of all ion pairs, n_0,

* Corresponding author.
E-mail address: Franz-Josef.HAMBSCH@ec.europa.eu (F.-J. Hambsch).

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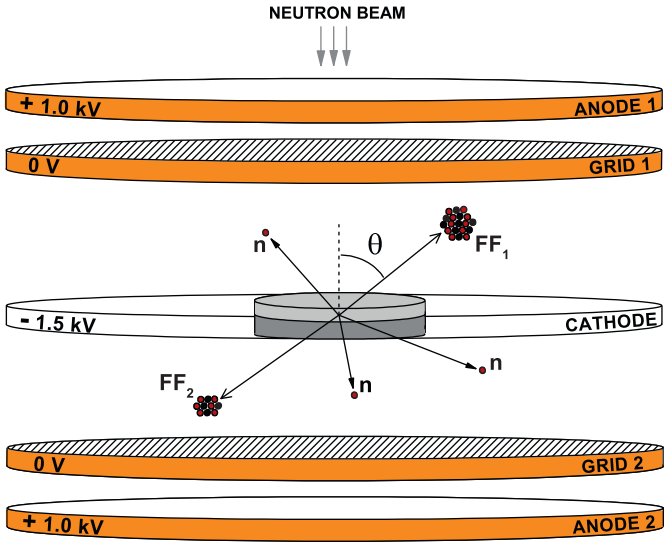

Fig. 1. Schematic drawing of the Twin Frisch-Grid Ionization Chamber (TFGIC) with two anodes, two grids and one common cathode.

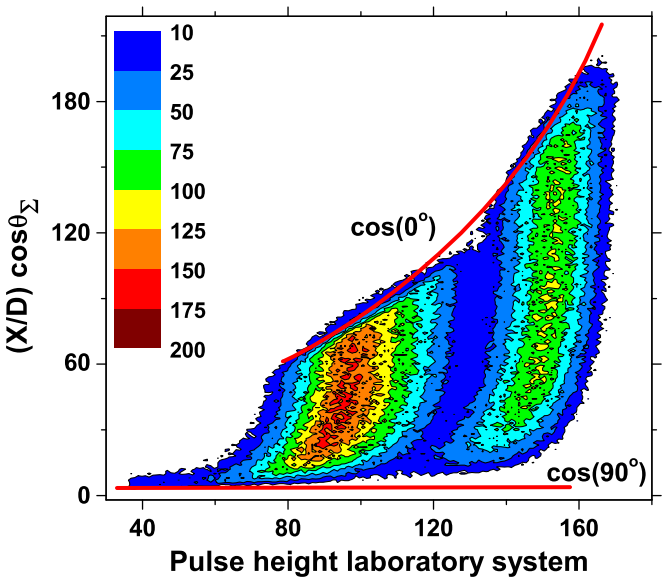

Fig. 2. Two-dimensional distribution of $\overline{X}/D\theta_{\Sigma}$ versus pulse height.

created by the ionization process according to

$$Q_A = -n_0 e. \tag{1}$$

By insertion of a grid, shielding the anode from the cathode-grid region, the charge induced on the anode plates is proportional to the FF energy independently of the emission angle. However, the grid shielding is not perfect and the signals have to be corrected for this so-called grid inefficiency [2,4]. The grid-inefficiency factor for the TFGIC was $\sigma = 0.03$ as calculated from Ref. [4, Eq. (14)]. The signal induced on the grid, corrected for grid inefficiency, contains the information on the emission angle:

$$Q_G = n_0 e \frac{\overline{X}}{D} \cos\theta_{\Sigma} \tag{2}$$

where $\overline{X}/D$ is the centre-of-gravity of the electron-cloud distribution divided by the cathode-grid distance D. Typical signal shapes for anode, grid and cathode are shown in Ref. [2, Fig. 2]. To deduce the emission angle two possibilities exist, the summing and drift-time methods. In the following, we discuss both methods and compare them both for the digital and analogue case.

2.1.1. Summing method

The grid signal is bipolar. It has a negative contribution from electrons drifting in the cathode-grid region and a positive one from electrons in the anode-grid region. To avoid the bipolarity a summation of the grid and anode signals is performed leading to a unipolar sum signal:

$$Q_{\Sigma} = -n_0 e \left(1 - \frac{\overline{X}}{D} \cos\theta_{\Sigma}\right) \tag{3}$$

from which the cosine of the FF emission angle θ_{Σ} may be extracted. The FF angle as determined from the summing method is given by

$$\frac{\overline{X}}{D} \cos\theta_{\Sigma} = \frac{P_A - P_{\Sigma}}{P_A} \tag{4}$$

where P_A is the anode pulse height created from Q_A and P_{Σ} is the summing pulse height from Q_{Σ}. The value of $\overline{X}/D$ depends mainly on the FF energy and is determined as the length of the distribution between cos(0°) and cos(90°) as shown in Fig. 2. A linear fit is applied to the data at cos(90°) and a parabola is fitted for cos(0°) at the half maximum of the distribution.

2.1.2. The drift-time method

In the drift-time method the emission angle θ_T is derived from the time the electrons are drifting in the chamber until they pass the Frisch-grid [5]. The electrons are assumed to have a constant drift velocity v. The drift time T is given by the difference of D and the projection of the FF range R on the beam axis $R\cos\theta_T$:

$$T = \frac{D - R\cos\theta_T}{v}. \tag{5}$$

Electrons created from fission events with large angles will have large drift-times, whereas electrons created in beam-axis direction will reach the grid faster and, hence, have a short drift-time. Several possibilities exist to deduce the drift-time T. For instance, measuring the time-difference between the anode's centre-of-gravity and the trigger position of the cathode. Other possibilities are to use constant fraction discrimination (CFD) or leading-edge (LE) techniques on the anodes. Once the drift-time T is determined one can obtain $\cos\theta_T$ according to

$$\cos\theta_T = \frac{T_{90^\circ} - T}{T_{90^\circ} - T_{0^\circ}} \tag{6}$$

where T_{0° is determined with a parabola fit and T_{90° with a linear or a hyperbolic fit of the edges of the two dimensional drift-time versus pulse-height distribution (see Fig. 5b). The investigation of the drift-time method was done both in AA and DA. In the analogue case, LE principle was used as stop triggering for the anode pulse. The LE level was adjusted slightly above the noise level. An amplitude walk was observed and corrected for in the AA case [5]. In the DA case the angle could be extracted according to all above mentioned possibilities (see Section 3.3).

3. Data acquisition and analysis

Five signals (two anodes, two grids and one cathode signal) were extracted from the ionization chamber and fed into charge-sensitive preamplifiers. The signals are treated independently in both acquisition systems. For the analogue case, the electronics needed are presented in Fig. 3 for one chamber side. The anode signals are fed into spectroscopic amplifiers with a shaping time τ of 2 μs, leading to a semi-Gaussian pulse-shape [6]. After the signal processing six ADC signals are stored, two pulse heights,