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Construction and implementation of a TDCR system at ENEA

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HIGHLIGHTS

- Electronics component and optical chamber of new ENEA-INMRI home-made TDCR detector.
- CAEN Desktop Digitizer DT5720 and Control Software DPP-CI with the new TDCR device.
- Test of the TDCR off-line analysis data by customized CAEN and ENEA-INMRI software.
- Birks constants, *kB*, effects on ^{3}H activity measurements with the new TDCR device.
- Birks constants, *kB*, effects on ^{63}Ni activity measurements with the new TDCR device.

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ABSTRACT

A new 4π (LS) TDCR system was built at ENEA-INMRI. Three photomultiplier tubes, arranged in a planar 120° geometry around a spherical optical chamber, were directly linked to a CAEN Desktop Digitizer DT5720. This module, based on the Field Programmable Gate Array (FPGA) technology for real time Digital Pulse Processing (DPP), allowed to replace all the classical TDCR electronics by only one device. The activity of ^{3}H and ^{63}Ni standard sources were successfully measured by the new detector.

1. Introduction

A new TDCR detector, hereinafter called the ‘new ENEA counter’, was built at ENEA-INMRI in the framework of the EMRP[1] ENG08 Metrofission project. High performance Hamamatsu photomultipliers (PMTs) were selected in order to have good detection efficiency and to distinguish the single electron peak (Cassette and Bouchard, 2003; Qin et al., 2008). The new ENEA counter was equipped with the CAEN Desktop Digitizer DT5720, hereinafter called the ‘digitizer’, for Digital Pulse Processing (DPP) that can totally replace the classical acquisition electronics set-up most often used for TDCR detectors (Cassette and Vatin, 1992). The PMTs are directly linked to the digitizer without any preamplifier module. Thanks to the new front-end electronics based on the DPP technology implemented on the FPGA device the timing and charge information of each signal can be recorded in real time and saved in list mode in a file. This information is analyzed off-line in order to perform the computation of the events in triple coincidences (T) and the events in logical sum of double coincidences (D) as usually obtained in a classical mode by using the MAC3 device (Bouchard, 2000a, 2000b). Details of the new ENEA counter and the progress made in the TDCR technique by using the new front-end electronics DPP-FPGA based are presented. A particular attention was dedicated to the measurements of low-energy beta emitters, such as ^{3}H and ^{63}Ni. The good agreement between the results obtained by the new TDCR detector and by other liquid scintillation (LS) systems available at the Radioactivity Primary Standards Laboratory of the ENEA-INMRI, as the Hidex 300 SL metrological version and the Packard TriCarb 3100TR (Capogni et al., 2013), was obtained. Satisfactory results underline the improvement achieved by the ENEA-INMRI in the field of the activity measurements of pure beta radionuclides and opens new interesting perspective in this field in Italy.

2. The experimental set-up

A schematic diagram of the experimental set-up of the new ENEA counter is shown in Fig. 1.

It consists of three photomultipliers (PMTs) arranged around a spherical optical chamber in a planar 120° geometry. A voltage of approximately 2500 V is applied to the PMTs by a CAEN High Voltage power supply. The output signals of the PMTs are directly linked to the digitizer without any preamplifier. All classical electronics acquisition chain based on traditional Linear Amplifier,

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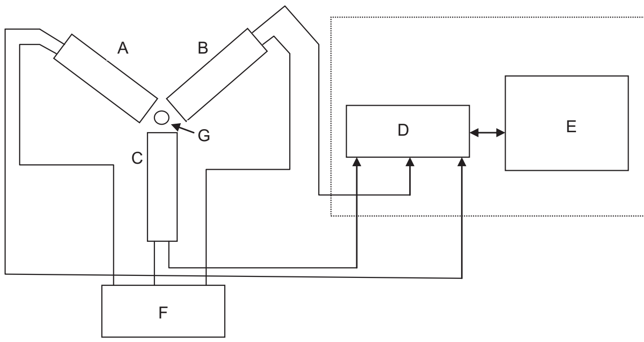

Fig. 1. Schematic diagram of the ENEA-INMRI fixed TDCR experimental set-up: PMTs Hamamatsu Mod. H1949-51((A), (B), (C)); CAEN Digitizer DT5720 (D); PC Software Code (E); HV Power Supply CAEN N1470 (F); vial (G).

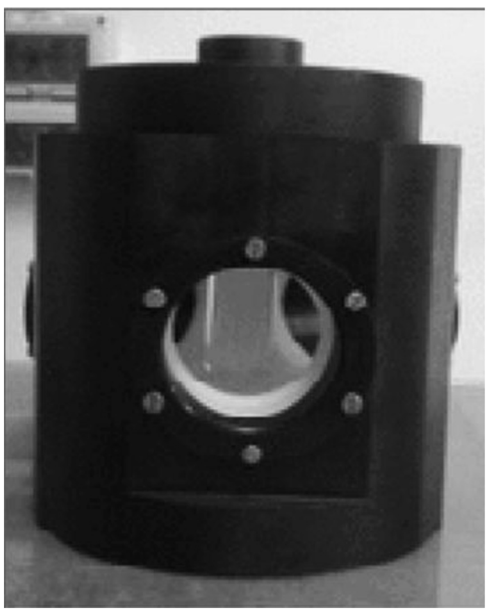

Fig. 2. The optical chamber of the new ENEA counter.

ADC, gate and delay generator modules are completely replaced by the digitizer, which is controlled by a computer by the CAEN Control Software (CS).

3. The TDCR detection system

In this section the main components of the new ENEA TDCR detection system (optical chamber and PMTs of the new ENEA counter, High Voltage power supply and digitizer) will be described.

3.1. The optical chamber

The optical chamber of the new ENEA counter has a spherical shape with inner radius of 40 mm; it is made of white PTFE (teflon) and it is surrounded by a black PTFE cylindrical box. This external box has a diameter of 150 mm and a height of 180 mm; it is provided with a lift and a shutter used to insert or remove the vials inside the optical chamber without turning off the PMTs. In Fig. 2 a picture of the optical chamber with the vial inserted is shown.

3.2. The PMTs

The photomultiplier tubes are 51-mm in diameter Hamamatsu Photonics type H1949-51, with 12 dynodes. They are arranged in a 120° planar geometry (Fig. 1). These devices are supported in the optical chamber by black caoutchouc O-rings that prevent stray light to enter. The PMTs selected have a good quantum efficiency (26%), short time of response, high gain, large photocathode area size (ϕ=46 mm), relative wide wavelength range (300–650 nm) and a wavelength peak (420 nm) sensitivity close to the blue light emission of the scintillator typically used in the LSC techniques. The main characteristics of the selected PMTs are described in (Hamamatsu PMT).

The PMTs were built with the cathode at ground potential and a high positive voltage applied to the anode, as specifically requested by ENEA-INMRI, for working in photon counting mode in order to satisfy the necessary photon sensitivity for the TDCR applications. The PMTs provide also a supplementary output from dynode 10 for spectroscopy applications.

3.3. The high voltage power supply

The CAEN HV Model N1470 power supply is a NIM module with 4 independent channels. It can provide a maximum voltage of 8.0 kV (I=3 mA) with the possibility to select a positive or negative polarity. It allows to monitor also the current (μA) of each PMT. The main characteristics of this device are given in (CAEN, 2014).

3.4. The digitizer

Coincidence measurements performed with LSC techniques require high performance technology to process the very fast light pulses (few nanoseconds) emitted by a liquid scintillator when a charged particle lose its energy in it. So the electronics used for the TDCR applications must be able to record very fast signals. New improvements in radionuclide metrology with FPGA-based nuclear instrumentation have been recently carried out in different National Metrology Institutes (NMIs) as described in (Bobin et al., 2012 and references therein). At ENEA-INMRI the digitizer was used for the first time for TDCR measurements. This device is a compact module characterized by 4 independent input channels, small size ($154 \times 50 \times 164$ mm^3), light weight (700 g) and operation capability without any crate. The board is provided with fast and precise ADCs (250 MegaSample/s, 12 bit), analog bandwidth of 125 MHz and 2 V peak-to-peak standard input dynamic range, making it suitable for the TDCR measurements. The device is directly coupled with the PMTs of the new ENEA counter. It is a waveform digitizer in which, as in a digital oscilloscope, when a trigger occurs, a certain number of samples defined by an acquisition window is saved in a memory buffer. The main feature of the digitizer is the firmware that performs Digital Pulse Processing (DPP) in order to record timing information and to evaluate the area of the input pulses (Charge Integration, CI mode). DPP algorithms are implemented on modern FPGA and can be reprogrammed at any time. For each trigger pulse a Trigger Time Tag (TTT), of 4 ns of resolution, and the total charge value of the gated signal are recorded in an ASCII or binary file, using only a few bytes of information (2 bytes for charge value and 4 bytes for TTT) per event. The charge sensitivity (40 fC) and the TTT resolution provided by the digitizer make this device specially skilled for TDCR applications in which a good identification of the single electron peak (SEP) and the precise knowledge of the time correlation between the events recorded in the three different channels are essential requirements.

4. Setting of the TDCR experimental parameters

The digitizer is remotely controlled by a computer via the CAEN Control Software DPP-CI running under Windows or Linux operating systems; this software gives the possibility to set all the