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# Performance Assessment of a New Digital Readout Electronics for Nuclear Waste Drum Characterization by Photofission

Aly Elayeb, Adrien Sari, Iaroslav Meleshenkovskii, Roberto De Stefano, Alexandre Dabat-Blondeau, Yoann Moline

**Abstract**—Characterization of nuclear waste is a critical issue for the global nuclear industry. The importance of such activities is reflected in the EURATOM Horizon 2020 MICADO project aiming at designing mobile and stationary platforms for in-situ characterization of nuclear waste packages by photofission, i.e., fission induced by high-energy photons. Such applications require a corresponding electronics capable of handling specific measurement protocols compatible with various detection systems. However, electronics adapted to the measurement of delayed neutrons from photofission did not encounter significant technological advances since the 1970's. In this paper, we assess the performances of a new digital readout electronics developed recently in our laboratory for the detection of delayed neutrons from photofission using  $^3\text{He}$  proportional counters. Such measurements are applied to the characterization of nuclear waste mock-up drums. First, we describe the new digital readout electronics and compare it to the traditional 7820-7821 modules manufactured by *Canberra*. Second, we carry out measurements at the SAPHIR platform of CEA Paris-Saclay, France, operating at 9 MeV a Linatron M9 electron accelerator, manufactured by *Varex Imaging*. Validation measurements are conducted on bare samples of uranium or plutonium and the latter placed inside a 220-liter concrete-lined nuclear waste drum. Third, we highlight the advantages and performance enhancements achieved thanks to this new digital readout electronics. Further, this electronic system will allow the investigation of new photofission measurement methodologies such as simultaneous delayed neutron and high-energy delayed gamma counting with a single device in order to push back the current limits encountered in the field of the characterization of radioactive waste packages.

**Index Terms**—Radioactive waste drum characterization, active photon interrogation, photofission, delayed neutrons,  $^3\text{He}$  proportional counters, digital readout electronics.

## I. INTRODUCTION

MICADO which stands for “Measurement and Instrumentation for Cleaning And Decommissioning Operations” is a EURATOM - Horizon 2020 European project of Research and Innovation Program aiming at proposing a cost-effective solution for non-destructive characterization of nuclear waste [1]. Photofission is one of the techniques used for

such characterization. In this technique, high-energy photons generated by the *Bremsstrahlung* phenomenon in the conversion target of a LINear ACcelerator (LINAC) irradiates an area of interest of the drum. Then, between each pulse delivered by the LINAC,  $^3\text{He}$  detectors enable to count delayed neutrons from photofission reactions on uranium or plutonium isotopes in what is called interpulse counting mode. Additional measurements after the end of the irradiation, called post-irradiation measurements, can also be carried out on delayed neutrons and gammas to provide additional signal.

Traditional readout electronics used for neutron counting in photofission such as the 7820-7821 modules manufactured by *Canberra* present several limitations. They necessitate workarounds, using for example a MultiChannel Analyzer (MCA) in conjunction with software meant for spectrometry measurements such as the G2K suite leading to many drawbacks for photofission measurements. In this paper, we assess the performance of a new digital readout electronics, recently developed by CEA List and applied for the first time to photofission applications. First, we present the characteristics of this readout electronics and compare them to traditional 7820-7821 modules. Secondly, we introduce the experimental setup at the SAPHIR platform of CEA Paris-Saclay for active measurements with a Linatron M9 LINAC from *Varex Imaging*. Results for both bare samples and samples inside a concrete-lined waste drum are shown. Finally we discuss the key advantages of the digital readout electronics over the traditional electronic modules.

## II. CHARACTERISTICS OF THE DIGITAL READOUT ELECTRONICS AND COMPARISON WITH THE 7820-7821 CANBERRA MODULES

The developed readout electronics shown in Fig. 1 is a transportable four channel-multipurpose and integrated data acquisition system for neutron and gamma measurements. The System on Chip (SoC) integrates an FPGA and a Dual-core ARM Cortex-A9. It is based on fully configurable and reproducible Digital Pulse Processing (DPP) tiles associated to each channel and a fully streamed data-flow based on a DDR3-Direct Memory Acces (DMA) architecture [2]. Each channel is

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equipped with a 250 MHz 14 bit ADC and a current-to-voltage preamplifier with a bandwidth of 35 MHz and a dynamic range output of a few hundred mV. In comparison, the 7820 ADS module is a single channel NIM module that needs to be connected to a 7821 high-voltage NIM module and a spectrum analyzer for pulse processing. The bandwidth is around 20 MHz and the dynamic range output is 0 – 4 V.



Fig. 1. View of the 7820-7821 modules from Canberra (left) and the new digital readout electronics developed at CEA List (right).

### III. EXPERIMENTAL CAMPAIGN

#### A. Setup and Protocol

Active LINAC measurements are carried out with both readout electronics at the SAPHIR platform with a detection block made of five  $^3\text{He}$  150NH100 proportional counters in a polyethylene matrix and cadmium casing. The sample is positioned 1.5 m away from the LINAC target and placed inside a concrete-lined waste drum, as can be seen in Fig. 2. The LINAC is operated at 100 Hz and 9 MeV energy during 5 min-irradiations.

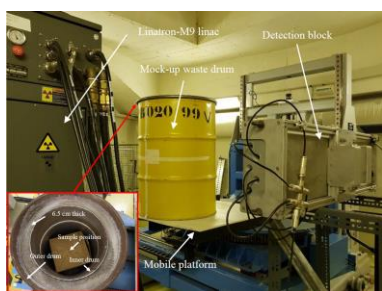


Fig. 2. View of the experimental setup at the SAPHIR platform including a 220-liter concrete-lined mock-up drum [3].

#### B. Results

Interpulse and post-irradiation results with both electronics are shown in Table I for  $^{238}\text{U}$ ,  $^{235}\text{U}$  and  $^{239}\text{Pu}$  bare samples. Post-irradiation total number of counts is significantly higher for the digital electronics.

TABLE I. DIGITAL READOUT ELECTRONICS RELATIVE DIFFERENCE TO 7820-7821 MODULE SIGNALS FOR INTERPULSE AND POST-IRRADIATION MODES

	Interpulse	Post-irradiation
$^{238}\text{U}$	0.37 %	269 %
<b>9.6 % enriched <math>^{235}\text{U}</math></b>	2.76 %	365 %
$^{239}\text{Pu}$	11.19 %	158 %

### IV. KEY ADVANTAGES OF THE NEW READOUT ELECTRONICS

Fig. 3 shows the sum of the detection block signals summed between each LINAC pulse (interpulse measurement). The 7820-7821 modules need a trigger signal from the LINAC that has oscillations and jittering that translates into artefacts at the

end of the signal. This requires truncating the region of interest at the end of the signal while the digital electronics recognizes the start of the pulse directly through threshold treatment without requiring an external trigger.

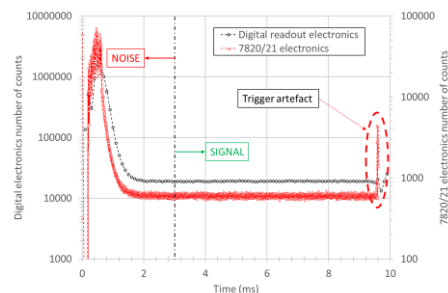


Fig. 3. Interpulse signal for both electronics with  $^{238}\text{U}$  bare sample.

Additionally, the bin parameters and acquisition method need to be changed manually by the user at the end of the irradiation to start the post-irradiation acquisition, as shown in Fig. 4. This leads to significant signal losses over this manipulation time of around 30 s compared to the digital electronics, which seamlessly carries the acquisition of the data. More data processing advantages such as time stamping features will be presented at the conference.

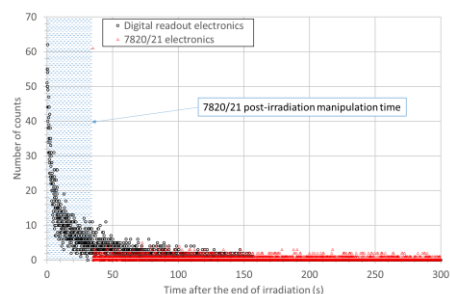


Fig. 4. Post-irradiation signals for both electronics with  $^{235}\text{U}$  bare sample.

### V. CONCLUSION

In this paper, we compare 7820-7821 modules traditionally used for photofission measurements with a homemade digital readout electronics developed by CEA List. The digital pulse processing features of the latter enable significant improvements in post-irradiation counting up to 350 % total counts increase without impeding interpulse measurements. Moreover, the multi-channel capabilities of the developed digital electronics open the compatibility possibilities with gamma-ray detectors for high-energy delayed gamma-ray spectrometry. Such an array of readout features enables coupling all photofission measurements with a single module, which no readout electronics currently does.

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