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Characterization of large 5x5 inch BGO detectors with light readout by means of R11833-100, 5 inch photomultiplier

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ABSTRACT

The performance of the large 5x5 inch BGO scintillators coupled to the R11833-100 PMT was investigated by gamma spectrometry in comparison with the well-known 5x5 inch BGO coupled to the R877 PMT. The tests included measurements of light output in terms of photoelectron number and energy resolution. Time resolution was also measured in coincidence experiments with 511 keV annihilation quanta from a 22Na gamma source.

1. INTRODUCTION

There are many types of scintillation detectors used in commercial applications, but NaI:Tl and BGO are still the most popular crystals in a wide variety of experimental setups and commercial devices. Although the BGO (bismuth germanate) scintillator was first obtained and studied by A. Durif in 1957, their advantages cannot be beaten also nowadays, especially when large volumes of inorganic crystals are needed. At present, the most common commercial configuration of the large 5x5 inch BGO detector, that can be purchased, is its combination with a 5 inch photomultiplier (PMT) from Hamamatsu R877 PMT.

The presented measurements were carried out as part of the project Retrofitting Equipment for Efficient Use of Variable Feedstock in Metal Making Processes (REVaMP) [4], which is financed under the Horizon 2020 program. One of the project's goals is to create a prototype of a scanning device for elemental analysis of steel scrap, being a raw material for the production of various types of steel. Within the Project, in the steel use case, the system incorporating the Neutron Activation Analysis (NAA) will be developed to analyze the material directly on a truck (Truck Sensor, TRS). The TRS demonstrator will be based on a DT neutron generator with an associated particle feature.

The large NaI:Tl and BGO detectors are intended to detect gamma radiation induced in scrap samples due to interaction with neutrons. Application of the associated particle detector on the neutron generator should significantly lower the background recorded in these detectors. In order to utilize this feature, the signals in NaI:Tl and BGO must be started by the alpha detector and recorded in a time frame related to 14MeV neutrons time of flight to a given volume inside the sample.

Therefore, not only parameters such as the energy resolution are important, but also the time resolution. In order to verify the energy resolution and the time resolution of the TRS detectors, the photomultiplier Hamamatsu R11833-100 with high quantum efficiency and Super BiAlkali (SBA) photocathode was proposed as an upgrade of the standard R877 PMT.

In order to verify the possible improvement, the 5x5inch BGO detector will be tested in two variants: standard - with R877 PMT and upgraded - with R11833-100 PMT.

The aim of the study is to answer the question if the use of such large BGO scintillator with a better photomultiplier can improve the collected spectra compared to the same detector coupled to standardly used PMTs and whether this improvement is worth the price differences.

Fig. 1. Detectors used in the experiment, from the left: 5x5inch BGO coupled to the R11833-100 and 5x5inch BGO coupled to the R877.

2. EXPERIMENTAL DETAILS AND RESULTS

A Number of photoelectrons and energy resolution

The number of photoelectrons was estimated using the Bertolaccini, et al. method.

Table I:
Comparison of the Number of Photoelectrons and Energy Resolution for Selected Gamma Lines Obtained for the Tested Detectors.

Detector		Phe number	Energy resolution (%)				
Scintillator	Photodetector	(phe/MeV)	511keV	662 keV	1274 keV	4.4 MeV	6.1 MeV
BGO 5x5inch	R 11833-100	1200±100	11.2±0.3	9.9±0.3	7.0±0.2	5.6±0.2	4.2±0.1
	R 877	1050±100	12.6±0.4	11.1±0.3	7.9±0.2	5.8±0.2	4.3±0.1

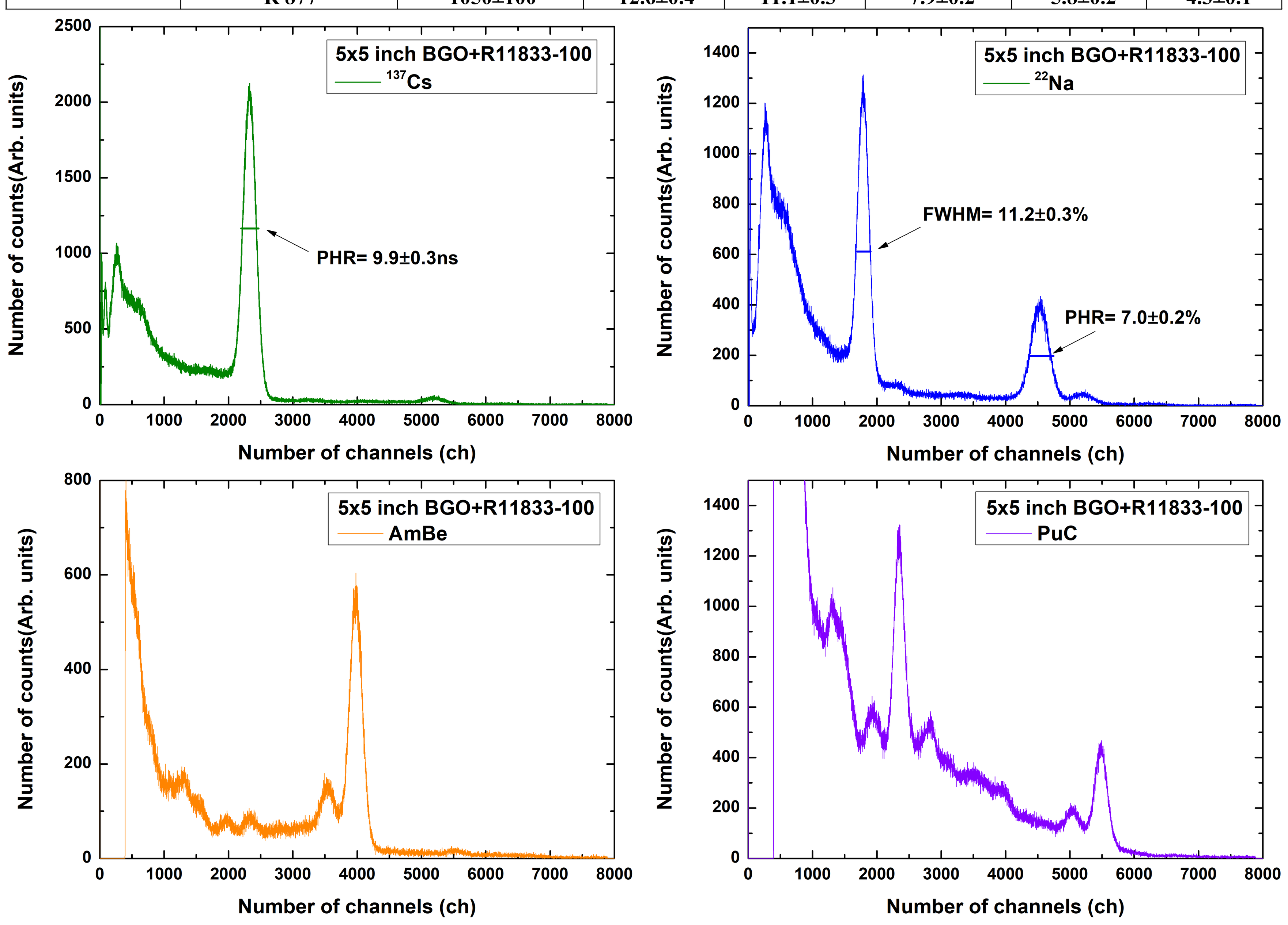


Fig. 1. The response of the BGO couple to the R11833-100PMT .

A. Light pulses from gamma-rays

TABLE II:
Table 1. Comparison of the rise time of both tested detectors.

Detector		Rise time
Scintillator	Photodetector	
BGO 5x5inch	R 11833-100	20 ±1ns
	R 877	56.6 ±1 ns

Both detectors were irradiated by a ^{137}Cs gamma source and an average anode signal of 10 000 acquisitions was recorded by a Tektronix Digital Oscilloscope type TDS5034B.

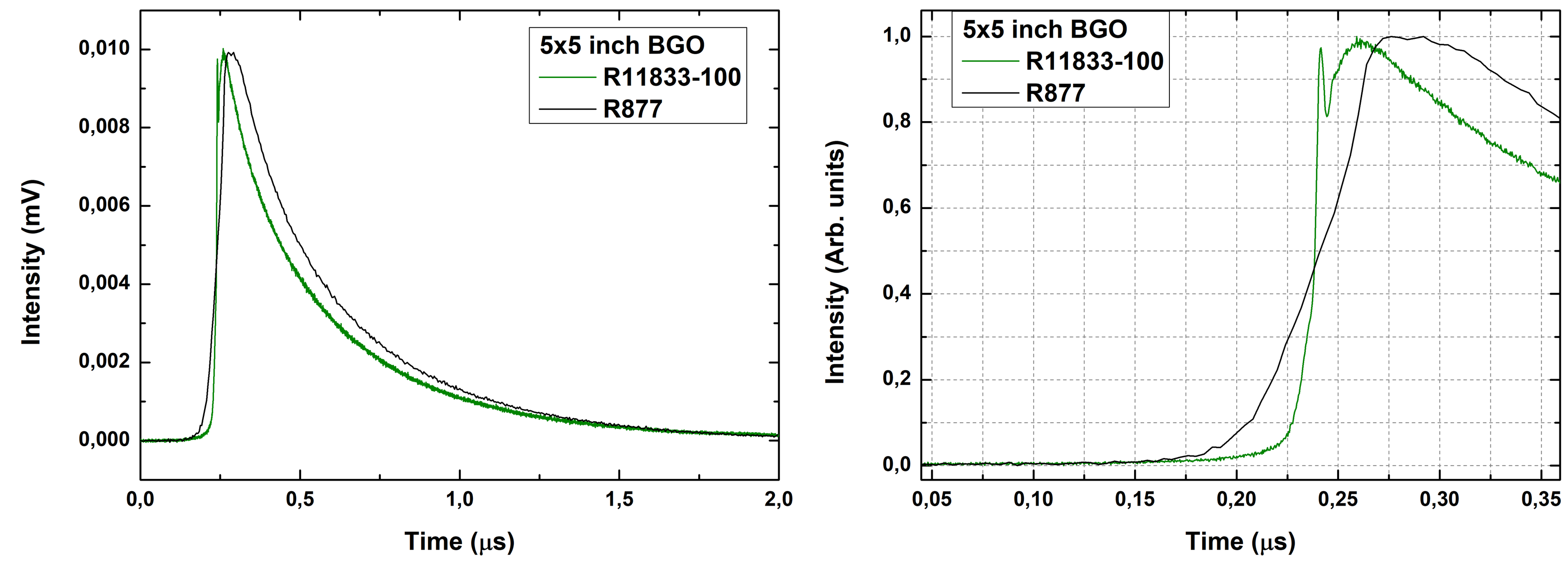
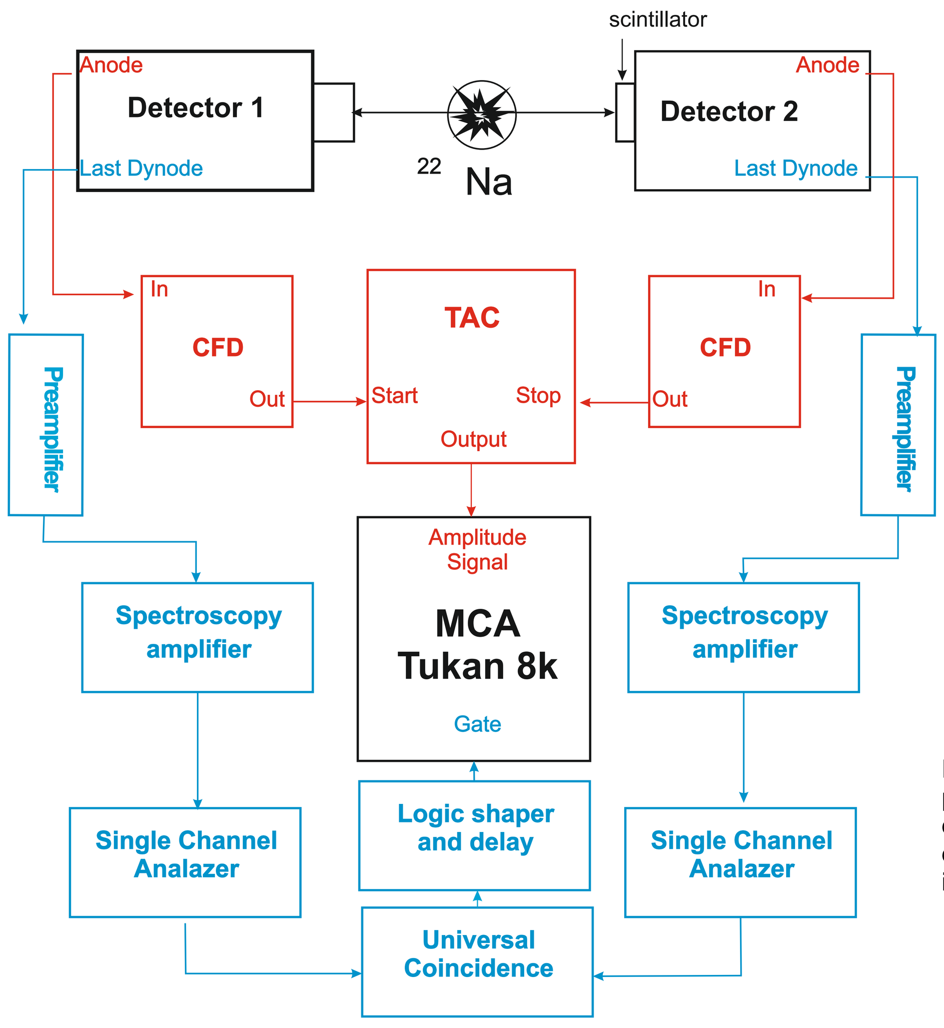


Fig. 2. Light pulse shape of the BGO scintillators coupled to the R877 and R11833-100 PMTs.

C. Time resolution



The comparative study of time resolution was conducted under identical experimental conditions. This involved using the same electronics and adjusting a similar pulse height of the anode signal for the tested photomultipliers to avoid secondary effects in the constant fraction discriminators. The measurements were performed using a 22Na gamma-source, with the energy window set at the 511 keV full energy peak.

Fig. 3. The slow-fast arrangement for timing measurements. In the fast part, related to the anode signal, the time spectrum of the response difference of the detectors is taken. In the slow part, formatted using dynode signals, the gate is generated, to choose the energy region of interest.

TABLE III:
Time Resolution Comparison for BGO Detectors with R877 and R11830-100 Photomultipliers

Gamma Source	Detector 1 (energy)	Detector 2 (energy)	Time resolution at FWHM, Δt (ps)		
			Measured	Corrected (detector 1)	Corrected (detector 2)
^{22}Na	BGO+R877 PMT	BaF_2	**8.19±0.25ns**	**8.19±0.25ns**	143±4ps
^{22}Na	BGO+R11830-100 PMT	BaF_2	**4.3±0.13ns**	**4.3±0.13ns**	143±4ps

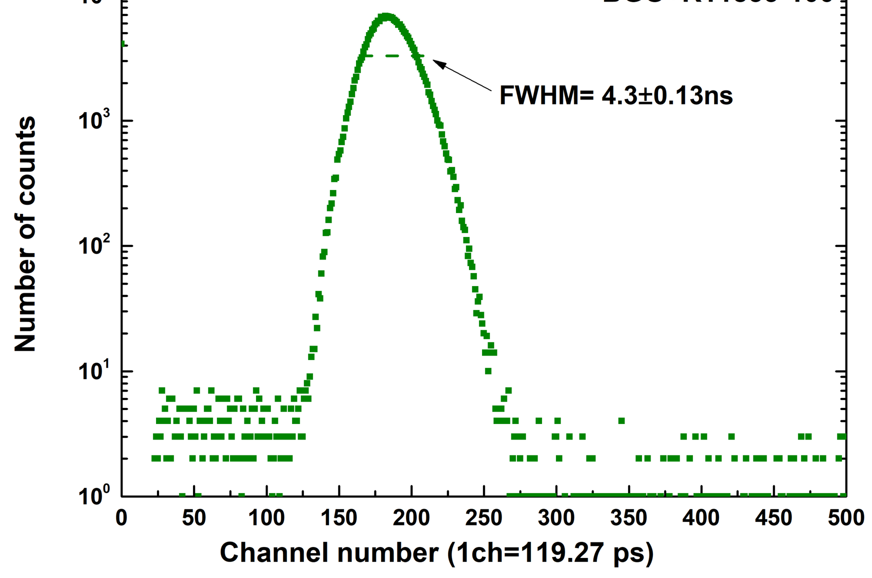


Fig. 4. The time response for 511keV from 22Na gamma source measured with BGO coupled to the R877 PMT and BaF2 detector.

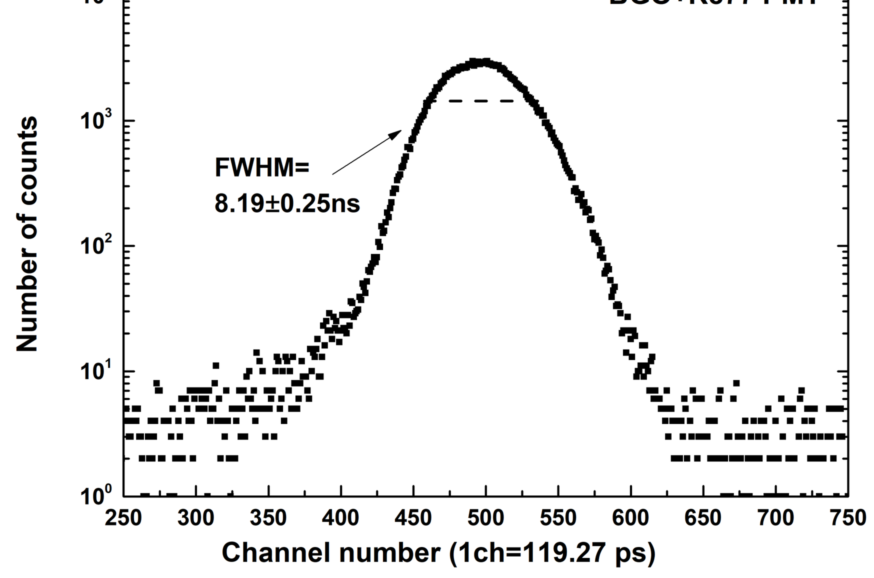


Fig. 5. The time response for 511keV from 22Na gamma source measured with BGO coupled to the R11833-100 PMT and BaF2 detector.

3. CONCLUSIONS

The number of photoelectrons is about 10% higher for BGO coupled to the R11833-100 PMT than when coupled to the R877 PMT, amounting to 1200 phe/MeV and 1050 phe/MeV, respectively. This results in a slightly better energy resolution obtained for BGO coupled to the R11833-100 over the entire tested energy range.

The time resolution obtained with BGO coupled to the R11833-100 PMT is almost twice as good as when BGO is coupled to the R877 PMT. This improvement is attributed to a much better pulse rise time, which is almost three times better for BGO coupled to the R11833-100 PMT.

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