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EUROPEAN NUCLEAR SCIENCE AND APPLICATION RESEARCH 2

GRANT AGREEMENT NUMBER: 654002

D 9.3 - **SCINTILLATOR RESPONSE TO GAMMA AND PARTICLE RADIATION.**

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References and applicable documents

[1] H. Murakami et al., IEEE Transactions on Nuclear Science Vol 39 (1992) 0018-9499

[2] M. Bendel et al., European Physics Journal A49 (2013) 69, R3B collaboration, CALIFA Endcap TDR http://www.fair-center.eu/forusers/experiments/nustar/documents/technical-design-reports/nustar-tdr-overview.html

List of acronyms and abbreviations

CsI(Tl)	A transparent scintillator material, economical, doped with Tl with emission at 550 nm which is better suited for LAPD and SiPM
APD	Avalanche Photo Diode
LAAPD	Large Area Avalanche Photo Diode
GAGG	Novel scintillator material, non hygroscopic, robust, emission at 550 nm. Well suited to be coupled to LAAPD. Good energy resolution

Executive Summary

In this JRA, we exploit novel scintillator materials and explore new techniques and concepts such as phoswich detectors and segmented or hybrid scintillators. We focus on developing the capability to simultaneously detect high-energy gamma rays, neutrons and charged particles.

This deliverable is related to Task 2 **Phoswich detectors**. The work presented has mainly been performed by the participating group of USC with some inputs from the rest of the collaboration.

As was discussed in the project application a large number of new promising scintillator materials are becoming commercially available. These new materials have to be characterized with gamma rays, charged particles and neutrons, in large volume and, as most of them are highly hygroscopic, they need to be encapsulated. The features of these new materials make it difficult to produce working detectors out of them.

In this first delivery, several new crystal-materials have been obtained commercially, and prototypes have been constructed in order to be able to test the material as possible detectors for nuclear science.

Introduction

Phoswich detectors are where two different scintillators are optically coupled. Typically, the scintillators are chosen so that the light output of the two materials has very different timing properties so that the energy deposited in the two parts of the phoswich can be extracted. Phoswich solutions are attractive for discriminating high-energy charged particles and gamma rays. They can also be a good solution for making economic use of novel scintillators to make detectors which have high energy resolution for low-energy gamma rays and high efficiency at the expense of resolution for high-energy gamma rays.

In this first report, a study of the gamma and particle response of Phoswich detectors based on non-hygroscopic scintillator crystals has been performed.

Goal: The determination of the gamma and particle response of Phoswich detectors based on non-hygroscopic scintillator crystals.

Scope: The construction of experimental setups dedicated to the study of nuclear reactions induced by radioactive beams at relativistic energies has boosted the development of new generation calorimeters dedicated to the simultaneous detection of gamma rays and energetic light charged particles. In the particular case of the charged particle detection, these detectors may have a very large dynamic range (from keV to hundreds of MeV). The use of the called scintillator Phoswich technique, based on the combined used of two scintillation detectors with different decay times, and each one recording the energy lost by the radiation in the medium is an elegant solution to overcome this challenging requirement. The choice of the materials that will form these Phoswich units is far from trivial and many parameters such as emission light, yield of photons, robustness, transparency and decay time, determine the performances of this kind of devices. This document addresses the first steps towards the use of Phoswich detector based on GAGG (a novel scintillation material) and the well known CsI(Tl).

Material: We have purchased a set of CsI(Tl) and GAGG:Ce detectors with the following geometries (1x1x1 cm^3 and 1x1x5 cm^3) (see figure 1). All crystals are wrapped with 3M Vikuiti™ and readout with LAAPD (Hamamatsu S8664-1010) that matches perfectly with the peak emission of both scintillators and optimises the response of these detectors in terms of intrinsic energy resolution. Main properties of CsI(Tl) and GAGG are summarised in table 1.

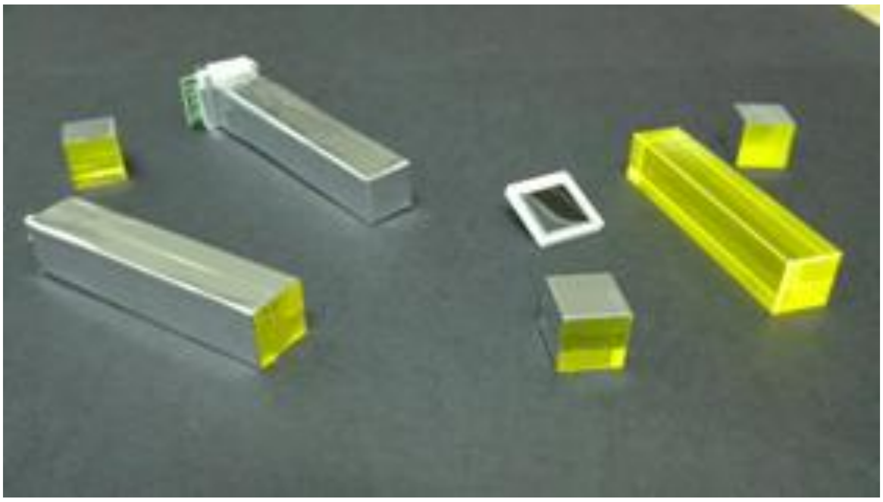

Figure 1: Different samples of GAGG that will be used for this study

Table 1: Summary of the basic properties of the scintillator materials used

	GAGG	CsI(Tl)
Density (g/cm3)	6.63	5.57
Peak emission (nm)	520	550
Decay time (ns)	87 (90%)	700
	255 (10%)	3000
Hygroscopic	no	Slightly
Photon Yield (kPhoton/MeV)	57	54

There are several hints that point to the combination of these two materials to be successful: both have rather similar densities and photon emission yield, the scintillation light emitted matches nicely, making very effective the readout with a unique photo-sensor. On the other hand both materials are rather robust and non- or slightly- hygroscopic, facilitating the construction of calorimeters with high granularity (minimization of the dead volume).

First Results:

We have evaluated the response of these materials in terms of energy resolution using in all cases Hamamatsu LAAPD S8664-1010. Table 2 shows the very good energy resolution obtained for crystals of 1 cm^3, obtained thanks to the excellent matching of these inorganic materials and the LAAPD selected. The data have been obtained using an Amptek MCA-8000A multichannel analyzer, a Mesytec MPRB-16 temperature regulated preamplifier, and an amplifier Mesytec MSCF -32.

Table 2: Summary of the ΔE/E recorded for a ^{137}Cs and ^{60}Co source

	ΔE/E @662 KeV	ΔE/E @1332 KeV
GAGG	4.62 %	2.18 %
CsI(Tl)	5.31 %	3.22 %

The next tests summarise the first steps to use these materials in Phoswich configuration. As depicted in figure 2 both crsytals are connected with optic grease (BC630) and wrapped with 3M Vikuiti™. In this case, the dimensions of the scintillators are: GAGG 1x1x1 cm^3 + CsI(Tl) 1x1x1 cm^3 (left) and GAGG 1x1x3 cm^3 + CsI(Tl) 1x1x1 cm^3 (right). In both cases CsI(Tl) are coupled to S8644-1010 using optical cement Scionix RTV861.

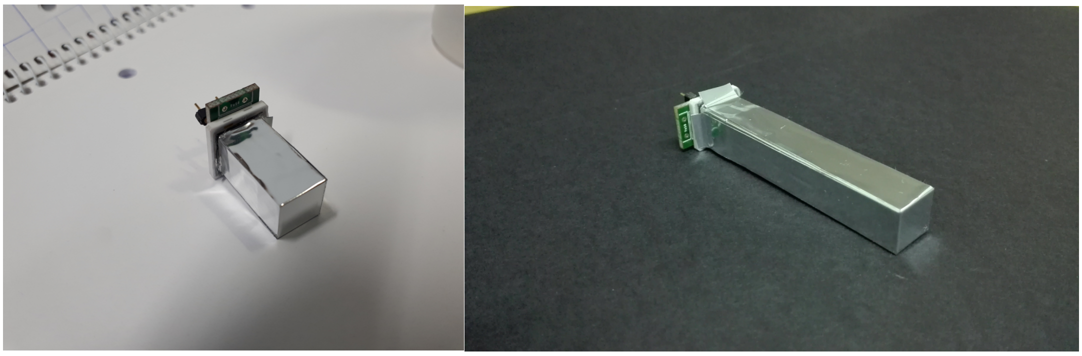

Figure 2: Left: Phoswich unit formed by GAGG 1x1x1 cm^3 + CsI(Tl) 1x1x1 cm^3. Right: Phoswich unit formed by GAGG 1x1x3 cm^3 + CsI(Tl) 1x1x1 cm^3

The idea is to evaluate the shape discrimination ability of this detector that combines an inorganic scintillator with fast decay time (GAGG) with another one with slow decay time.

We used a ^{137}Cs radioactive source to irradiate frontally the detector. In a first step individual detectors CsI(Tl) 1x1x1 cm^3 and GAGG 1x1x1 cm^3 were used. The corresponding signals were amplified (Mesytec MPRB-16) and recorded in an oscilloscope (Tektronix TDS 2022) and are depicted in figure 3 left and right respectively.

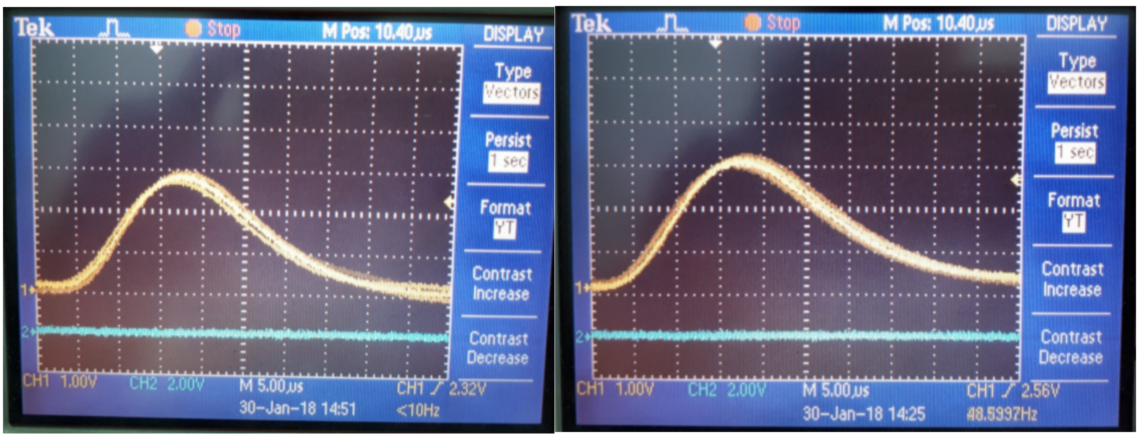

Figure 3: Screen shot of the signal recorded after irradiation with a ^{137}Cs radioactive source. Left: corresponds to a CsI(Tl) 1x1x1 cm^3. Right: case of GAGG 1x1x1 cm^3

Next picture (Figure 4) corresponds to the signal recorded by the phoswich device shown in figure 2 left, where contributions from each scintillator can be clearly disentangled. **The amplitude of the CsI(Tl) signals are slightly larger and exhibit longer raising times.** The next step in this work will be to record traces from these signals and study different algorithms to unambiguously identify between the components from each crystals. Among the many possibilities one can think on using very simple algorithms like the time interval between the first and second zero crossing of the signal that is connected with the decay time of the scintillation light [1] or the most attractive idea of exploiting pulse shape discrimination techniques such as the ¨moving window deconvolution¨ [2] used in the CALIFA calorimeter. The response of this device as a function of the crystal length (effect of scintillator transparency and light output non linearities) will be also addressed.

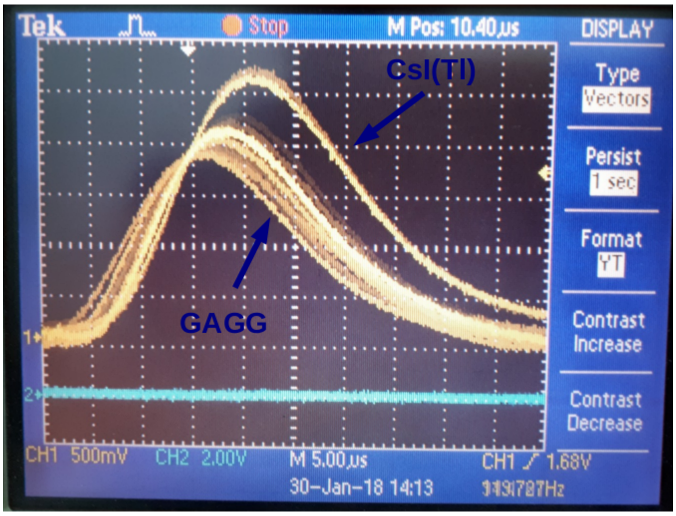

Figure 4: Screen shoot of the signal recorded by the GAGG 1x1x1 cm^3 + CsI(Tl) 1x1x1 cm^3 + S8664-1010

2 Publications and Outreach

2.1 Published papers:

2.2 Conference contributions and Outreach:

Conclusion

The study of new promising new Phoswich combinations has been initiated. These new Phoswich materials have so far been characterized with gamma rays. The features of the materials are being characterized especially for the the possibility to disentangle and separate the individual and combined response to impacting radiation. There are still several investigations and comparisons to be done before we can go from crystals to actual performing detectors, and especially to choose the best algorithm for the signal separation. Further, the response to charged particles are to be tested as well as the time response of the crystals.

The process of testing new materials is not straight forward especially one have here to take into consideration the mainly administrative difficulties in obtaining the crystals and the delay in delivery. Further, the access to beam time at different facilities where high energy gamma rays or particles can be obtained is an added headache.

The work is ongoing; we have a good starting point where now also the other Tasks can profit from our findings. The work will continue in the timescale new material are being delivered, an update of the report will be made along the time of the PASPAG project.