Performances of a 1”x1” Cs_2LiYCl_6 scintillator detector

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***Abstract*—In this work we have measured the performances of a 1”x1” sample of a CLYC scintillator (Cs_2LiYCl_6) with 95% enrichment of ^{6}Li produced by RMD. Different PMT models, with borosilicate glass window or quartz window have been used. The Pulse line-shape and Pulse shape discrimination for different type of incident radiation (gamma-rays and thermal neutrons) have been investigated. The response to thermal neutrons has been measured using an AmBe source and a digital oscilloscope. A measurement of the internal radiation and the energy resolution for different gamma rays have been additionally performed.**

***Index Terms*—Cs_2LiYCl_6, elpasolites, neutron detectors, gamma-ray detectors, radiation detectors, scintillators, pulse shape discrimination.**

I. Introduction

In the last years several new scintillator materials have been discovered. A class of scintillators, the elpasolite, discovered approximately 10 years ago, present excellent performances in term of gamma and neutron detection efficiency [1], [2], [3], [4], [5]. The CLYC (Cs_2LiYCl_6) belongs to the elpasolite crystal family, as well as CLLB ($Cs_2LiLaBr_6$:Ce) and CLLC ($Cs_2LiLaCl_6$) crystals. In particular the light yield of CLYC is around 20000 photon/MeV. In general, it exhibits excellent proportionality, which may lead to a good energy resolution. CLYC crystals incorporate Li ions and therefore can also be exploited for thermal neutron detection. This is due to interaction of thermal neutrons with ^{6}Li that produces alpha and triton particles. These heavy charged particles generate a single full energy peak with energy between 2.9 and 3.5 MeVee (electron equivalent). The light yield per single thermal neutron is around 70,000 photons. The wavelength of the scintillation emission light of CLYC is related on the nature of the incident radiation. For gamma/x-ray the main emission is due to Ce^{3+}/STE and it is located between 350 to 450 nm. The secondary emission, Core-to-Valence Luminescence or CVL, is located between 250 and 350 nm and it can only be excited by gamma-rays or electrons only. CVL is characterized by 1 ns decay time and it is absorbed by Ce^{3+} ions in larger crystals. For the neutron excitation, instead, the scintillation pulse do not include either the CVL or prompt Ce^{3+} component. Thanks to this properties, a pulse shape discrimination between gamma-ray and thermal neutron can be achieved with CLYC scintillators.

In this work, we discuss the properties of the introduced CLYC crystal concerning the pulse shape discrimination, the internal radiation and the energy resolution.

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PMTs	Material Window	Rise Time [ns]
R2059	Quartz	1.3
R6231-100mod	Quartz	8.5
H6533	Borosilicate	0.7
R6233	Borosilicate	9.5

TABLE I
HAMAMATSU PMTS PROPERTIES [8].

II. Measurements

A. Pulse Shape Discrimination

The measurements of the CLYC properties have been performed in the gamma spectroscopy laboratory of the University of Milano. We have used a cylindrical CLYC sample of 1”x1” with 95% of ^{6}Li produced by RMD [6]. The measurements have been performed coupling the crystal with several HAMAMATSU PMTs, [9], characterized by different entrance windows and different time response, see Tab. I.

The possibility to use Pulse Shape Discrimination (PSD) for the identification of the incident radiation is one of the most interesting features of CLYC. Namely PSD permits, in fact, to distinguish gamma-rays and thermal neutrons because of the differences in the scintillation decay response (CVL and Ce^{3+}) of this crystal to the different type of radiation. Indeed, the gamma trace contains the CVL component (decay time 1 ns) together with a slowly decaying component of scintillation light channelled through the Ce^{3+} ions. The neutron trace, instead, is characterized by a much slower decay time constants.

The pulse signals of CLYC were digitalized using a digital oscilloscope (Wave Runner HR66Zi) with 600 MHz bandwidth, 2 GHz sampling frequency. A ^{137}Cs and AmBe sources were used. Pulse signals measured with CLYC coupled to PMT-R6231-100mod are show in Fig. 1. As can be seen the gamma-ray trace has a faster rise time (13 ns) compared to the neutron trace (41 ns). Similar behaviours, weighted by the PMT time response, have been observed also in the other PMTs [9].

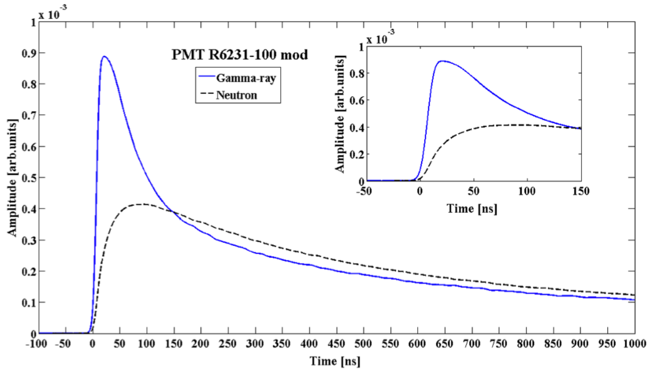

Fig. 1. Pulse signals for gamma-ray (blue solid line) and neutron (black dashed line) measured with CLYC detector coupled to PMT-R6231-100mod. A ^{137}Cs source was used for gamma-ray pulses while an AmBe source for thermal neutron.

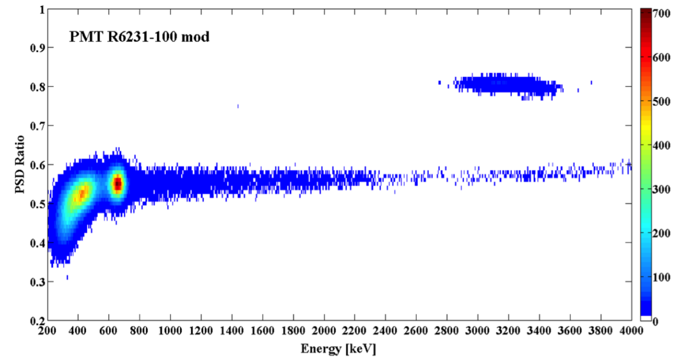

Fig. 2. PSD Ratio, Eq. 1, as a function of the incident radiation energy, measured with CLYC detector coupled to PMT-R6231-100mod. A FOM of 5 has been achieved. The ^{137}Cs full-energy peak events are visible at 662 keV while thermal neutron events are located at 3.2 MeV.

To evaluate the discrimination efficiency of this detector, the measured pulses have been integrated within two time window as done in [6]. The first window ($w1$) starts at the onset of the trace and has a 40 ns width. It measure the rise part of the signal and the CVL (if present or if transmitted). The second window ($w2$) integrate the signal between 120-280 ns. The ratio between these two integrals is different for gamma-ray or thermal neutron events and therefore provides the basis for pulse shape discrimination. In this work the PSD Ratio

$$PSDRatio = \frac{w2}{w1 + w2} \tag{1}$$

has been used in order to compare the results, see Fig. 2. A third window (width 5000 ns) has been defined to record the full integral and to evaluate the energy of the incoming radiation. A Figure-of-Merit (FOM) can, thus, be determined as

$$FOM = \frac{C_n - C_\gamma}{\Delta_n + \Delta_\gamma} \tag{2}$$

where C_n and $C\gamma$ are the centroids in the scatter plot for neutrons and gamma-rays. The parameters Δ_n and Δ_γ are the FWHMs for thermal neutrons and gamma-ray regions, respectively, as projected on the y-axis. As reported in ref [6] a value for FOM = 1.5 provides a rejection ratio better than 10^{-6} (in the case of ideal Gaussian shapes of the projected peaks).

The measured PSD scattered plots for PMT-R6231-100mod is shown in Fig. 2. A FOM of 5 has been achieved.
A similar behaviour was observed also for the other PMTs of Tab. I. We have verified that PSD can be performed efficiently with both quartz or borosilicate windows and with fast or slow PMTs [9]. The difference between the photomultiplier is the value of the FOM extracted. Using the method described above a FOM ranging from 2.5 to 5 has been extracted from data at room temperature.

B. Internal-natural Radiation

In order to discriminate between internal and natural radiation in the CLYC crystal, a measurement of the energy spectrum with and without Pb shielding have been performed.

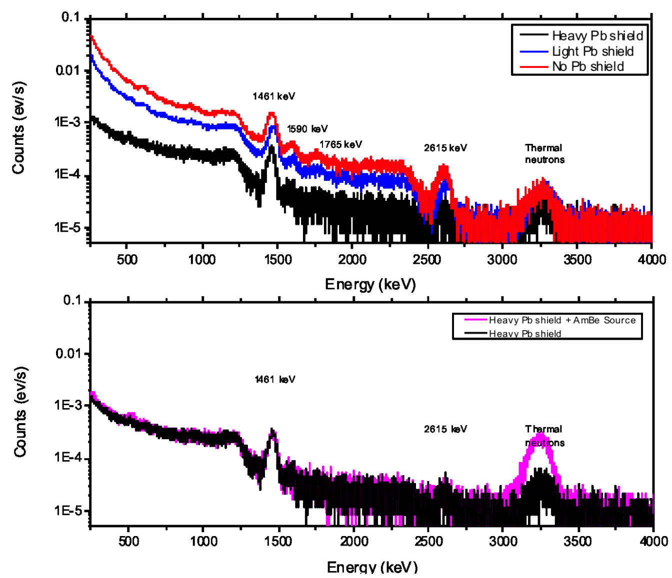

Fig. 3. Top panel: the natural-internal radiation measured with the CLYC detector. Three different kinds of Pb shield have been used. Bottom Panel: the measured natural-internal radiation measured with and without and AmBe source placed 1.5 m away from the detector. Spectra are normalized on the live time.

The top panel of Fig. 3 shows the natural-internal radiation measured with the CLYC detector with different kinds of Pb shield. The data are normalized to the live time and it is evident that (except for the thermal neutron peak) the intensity of the measured radiation decreases as the Pb shield increases. The neutron peak is located at 3.25 MeV and has the same intensity in all spectra as expected since neutrons are not seriously affected by the Pb shield. In order to highlight the neutron contribution, an AmBe thermalized neutron source was placed at approximately 1.5 m and the resulting spectrum is shown in the bottom panel of Fig. 3. It can be seen that the spectrum perfectly overlaps the one measured without the neutron source, except for the stronger neutron peak. The measurements show that the CLYC internal radiation is at least two order of magnitude smaller than that of an equivalent $LaBr_3$:Ce detector [7].

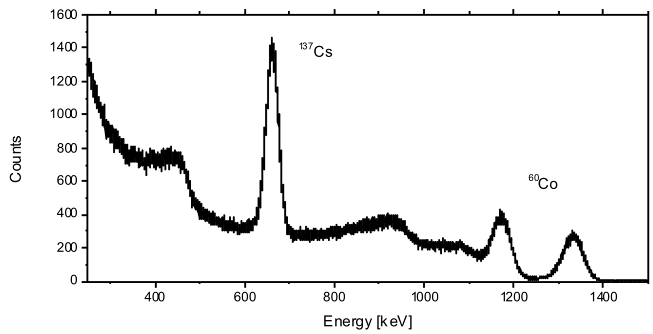

Fig. 4. Measured energy spectrum for 1"x 1" CLYC scintillators. A source of ^{137}Cs and ^{60}Co have been used. The measurement have been done using a spectroscopy amplifier mod. Tennelec Tc244 with a shaping time of 12 microseconds. A R10233-100SEL PMT at 700 V was used.

C. Energy Resolution

One of the characteristics of CLYC crystal is the good energy resolution thanks to the excellent linearity for low energy gamma-rays and to the light yield of the order of 20000 ph/MeV. The energy resolution of a 1"x 1" CLYC scintillators coupled to R10233-100SEL PMT fotomultiplier have been measured. A source of ^{137}Cs and ^{60}Co have been used. The measurement have been done using a spectroscopy amplifier mod. Tennelec Tc244 with a shaping time of 12 microseconds. Fig. 4 shows measured energy spectrum. The energy resolution achieved is 4.8% at 662 keV.

III. Conclusion

In these work we have presented results from the investigation of the performances of a 1"x1" sample of a CLYC scintillator (Cs_2LiYCl_6) with 95% of ^{6}Li crystal grown at RMD. Different PMT models, with borosilicate glass window or quartz window have been used. In particular we have measured the Pulse line-shape and the Pulse shape discrimination for different type of incident radiation, the response to thermal neutrons, the internal radiation and the energy resolution at 662 keV. Concerning the pulse line-shape, we observed that the trace generated by gamma-rays is completely different from the one of neutrons for all the PMTs used. We have verified that PSD can be performed efficiently with both quartz or borosilicate windows and with fast or slow PMTs coupled to CLYC detector. The difference is only in the value of the FOM extracted. A FOM ranging from 2.5 to 5 has been extracted from data at room temperature. We have also measured that that the CLYC internal radiation is approximately at least two order of magnitude smaller than that of an equivalent $LaBr_3$:Ce detector. Finally, the CLYC exhibit very good energy resolution under gamma-ray excitation. The best values we have measured is 4.8% at 662 keV.

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References

[1] C.M. Combe at al., *Journal of Luminescence*, vol. 82, 1999, pp. 299-350.
[2] J. Glodo at al., *IEEE Transactions on Nuclear Science*, vol. 55, June 2008, pp. 1206.
[3] W.H. Higgins at al., *Journal of Crystal Growth*, vol. 312, n. 8, April 2010, pp. 1216.
[4] J. Glodo at al., *IEEE Transactions on Nuclear Science*, vol. 58, February 2011, pp. 333.
[5] B. Smith at al., *IEEE Transactions on Nuclear Science*, vol. 60, April 2013, pp. 855.
[6] *http://rmdinc.com/about-us/dynasil-corporate-profile*
[7] A. Giaz at al., *Nuclear Instruments and Methods in physics research*, vol. A705, 2013, pp. 85.
[8] *http://www.hamamatsu.com/jp/en/3001.html*
[9] L. Pellegri at al., to be submitted to *Nuclear Instruments and Methods in physics research*.