Study of linearity and internal background for $LaBr_3$(Ce) gamma-ray scintillation detector

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Abstract

Cerium-doped lanthanum bromide, $LaBr_3$(Ce), crystal is the latest among the scintillation counters and shows same attracting properties for γ spectroscopy that makes it a suitable solution for security, medical, geophysics and high energy physics applications. $LaBr_3$(Ce) exhibits a proportional light yield response to γ-ray energy. Very good linearity was seen up to 2 MeV. $LaBr_3$(Ce) has also relatively high intrinsic radiation background due to naturally occurring ^{138}La and ^{227}Ac radioisotopes. A good use of $LaBr_3$(Ce) needs an accurate determination of the self activity, particularly when low background is required or when events are collected at very low trigger rates. The impact of internal background on energy resolution and linearity is discussed.

Keywords: scintillation counters, inorganic scintillators, $LaBr_3$(Ce), γ-ray spectroscopy
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1. Introduction

Most of the modern γ-spectroscopy measurements require higher technological performances hence a new generation of scintillator detectors has been developed. Cerium-doped lanthanum bromide scintillator, $LaBr_3$(Ce), is very attracting for its high brightness (>65000 photons/MeV) that results in a very good energy resolution (<3% FWHM at ^{137}Cs). Its high density (5.1 gr/cm^3) and fast decay time (16 ns) allows a timing comparable to BaF_2. The general properties of $LaBr_3$(Ce) are described in Ref.s [1-3]. At the beginning of its commercialization $LaBr_3$(Ce) crystals have only been available in small size mainly due to the crystal anisotropic characteristics. In fact, $LaBr_3$(Ce) shows strong anisotropy in thermal expansion, heat transfer and mechanical strength hence its larger ingots are likely to cracking during the cool down process after the growth. But larger crystals are necessary in order to reach a good efficiency and to stop all the energy delivered in γ-ray interactions. In the last few years, cylindrical counters 3” x 3” of $LaBr_3$ enriched at 5% with Ce have been made available by Saint Gobian Crystals firm. Large crystal growing technology must show that the very good performances achieved in smaller crystals (typically 1” x 1”) have not been spoiled due to material non-uniformity [4] or optical self-absorption of the emitted scintillation light. The purpose of this work is to present the results of energy resolution, internal background and energy linearity for 3” x 3” $LaBr_3$(Ce) crystal.

2. Experimental

The investigated $LaBr_3$(Ce) detector is a 3” x 3” crystal wrapped with Teflon foil as reflector and sealed in a aluminium can. The crystal was coupled to a photomultiplier tube (PMT) Hamamatsu R1306, as suggested by Ref. [4]. The working voltage has to be kept rather low because of the extremely high photon yield in the fast emission time that produces a very high instantaneous current which can take to saturation of either the PMT and/or its following analog electronic chain. For this reason a voltage divider scheme, modified according to Ref. [5], was used. The PMT signal was picked off at the sixth dynode with an extra capacitance added to the fifth dynode. With the modified voltage divider the current is taken before reaching its maximum gain. Operational voltage is ranging from 680 to 770 V. The PMT dynode signals were fed into a fast preamplifier and then to a spectroscopy amplifier CAEN N568B set in bipolar mode with a shaping time of 0.5 μs. Data were collected in list mode using a VME data acquisition system including CAEN ADC V879. In Fig. 1 it is shown the FWHM energy resolution vs γ-ray energy from various sources (^{152}Eu, ^{137}Cs, ^{60}Co, ^{22}Na). All the sources were collimated by 10 mm thick lead where a hole of 2 mm diameter was drilled. The source was positioned 5 cm from the center of the front surface of the $LaBr_3$(Ce) cylinder. The data are fitted by the curve: FWHM(%)=$\frac{a}{\sqrt{E_\gamma(keV)}}$ + b, with a and b free parameters. From Fig. 1, it is evident the good agreement achieved with the expected behavior; the values of the best fit parameters a and b are 98.524 keV$^{1/2}$ and -0.599, respectively. The reduced χ^2 was found equal to 1.04. In applications where low background is required and/or when events are collected at extremely low trigger rates, an accurate determination of self-activity is necessary. The internal activity of $LaBr_3$(Ce) crystal (studied in Ref.s [4,6]) is mainly due to the presence of the unstable isotope ^{138}La. Natural lanthanum contains 0.09% ^{138}La, which half life is equal to 1.05×10^{11} years that corresponds to an activity of around 1.5 Bq/cm^3 in $LaBr_3$. ^{138}La decays into ^{138}Ba by electron capture with a branching ratio of 66.4% and to ^{138}Ce by β^--emission in the other 33.6%. The first decay branch emits a 1436 keV gamma line in coincidence with a 32 keV Ba X-ray.

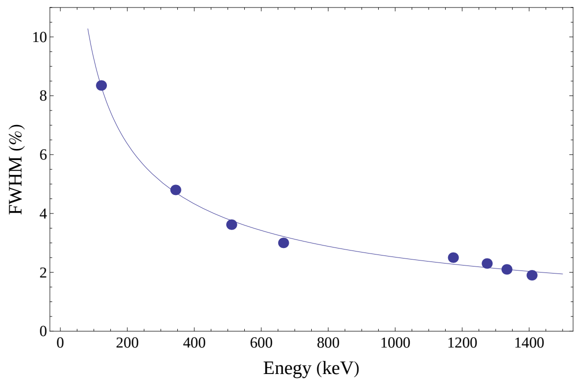

Figure 1: FWHM energy resolution (full circles) measured with the use of different collimated γ sources (^{152}Eu, ^{137}Cs, ^{60}Co, ^{22}Na) compared to the expected $E_\gamma^{-1/2}$ behavior (full line).

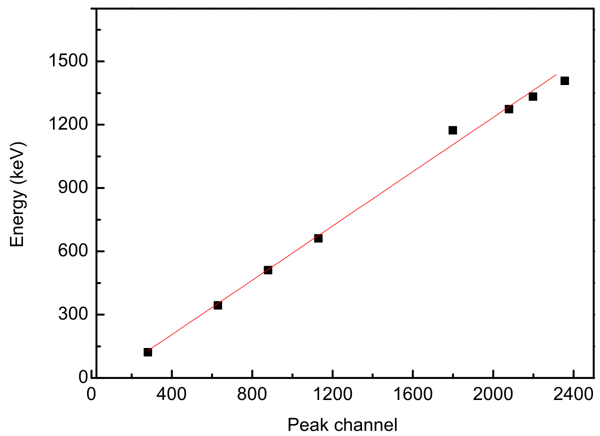

Figure 2: Linearity plot of the $LaBr_3$(Ce) 3" x 3" scintillator. The centroid channel of the peak is plot vs the photon energy.

The second branch releases 789 keV γ in coincidence with a β^- with an end-point energy of 255 keV. Being Ac the chemical homologue of La, it is also observed a contamination of ^{227}Ac isotope. ^{227}Ac produces together with the isotopes ^{221}Pb and ^{207}Ti of its decay chain a continuum spectrum up to around 1400 keV (1378 keV of end-point for ^{221}Pb and 1423 keV for ^{207}Ti). All this background is entirely below the energy of 1500 keV, but additional background is found in the energy region between 1500 and 2750 keV. The manufacturer attributes this radiation to particles emitted by five progenies of ^{227}Ac contaminant such as ^{227}Th, ^{223}Ra, ^{219}Rn, ^{215}Po and ^{211}Bi. The self activity in the $LaBr_3$(Ce) crystal was measured in singles modes with the scintillator surrounded with a lead castle shield of 30 cm thick. The rate of all the crystal self-activity was measured to be around 320 cts/s in the energy range from 50 keV up, corresponding to 0.92 cts/s/cm^3, slightly higher than the value measured in Ref. [6] with a crystal 1" x 1". The contribution due to the α-emitter progeny of ^{227}Ac, evaluated from the number of events at energy greater than 1500 keV up, is evaluated around 12% of the total internal background. It was noticed that the light yield produced inside the crystal along the α path is lower than the one associated to γ interactions. The dynamic range in which there is linearity between the signal amplitude and the energy of the incoming γ radiation varies as a function of the PMT applied voltage. The linearity is preserved up to 770 V, the first saturation effects appears at higher values and in the γ energy above 1500 keV. Fig. 2 shows the plot of E_γ vs the channel number for which the centroid of the peak corresponding to E_γ appears. The observed displacement of the 1408 keV point (the last one due to ^{22}Na source) can be explained with the proximity of 1436 keV γ line coming from direct ^{138}Ba decay and 1468 keV summing peak coming from 1436 plus the 32 keV X-ray. The displacement of the first line of ^{60}Co (1173 keV, the strongest displacement in Fig. 2) can be justified by the presence of the β^- continuum due to ^{227}Ac daughters. The β^- continuum counting is decreasing with the energy, then the effect is much lower in the second γ line of ^{60}Co (1332.5 keV), as it can be seen by Fig. 2. The reduced χ^2 of the linear fit was found less than or around to 1.1.

3. Conclusions

$LaBr_3$(Ce) is presently available in large ingots (>100 cm^3). The large crystals do not show any sensible degradation with respect to small ones (1"x 1") [4,6], keeping the same performances in energy resolution, linearity and internal activity. This study on $LaBr_3$(Ce) for investigating the possibility to use it as an alternative to HpGe detectors in underground nuclear astrophysics experiments at INFN Gran Sasso National Laboratories [7-9] when the γ spectra are not very complex. In this kind of measurements we deal with induced nuclear reactions at energy under the Coulomb barrier and events are collected at low trigger rates (few triggers per hour). An internal activity of 320 cts/s in all the detector, corresponding to 0.92 cts/s/cm^3, is worse than what we expect to find using HpGe covering the same solid angle (with a better resolution), but if the detector must surround the target as in the clover case [7] and/or if angular distributions are to be measured, the $LaBr_3$(Ce) offers an acceptable energy resolution with a strong convenience from the cost side. Another possible application for $LaBr_3$(Ce) is when a selective (anti)coincidence is required covering a (relatively) large solid angle near the target. In this case its excellent intrinsic energy resolution allows to set a much more precise and efficient energy windows (thresholds) than for instance NaI, with the additional option, if needed, of a much faster response.

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