

Study of the self-activity of a $\text{LaBr}_3\text{:Ce}$ scintillation detector

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10/10/2014

Abstract

In this study the properties of a Lanthanum Bromide $\text{LaBr}_3\text{:Ce}$ scintillator were investigated, with a particular attention for the study of the internal radiocativity of this crystal. Using coincidence measurements and fine spectral analysis of the crystal with an HpGe detector we were able to get a full reconstruction of the radiocative isotopes contained in the crystal. The difference of reconstruction of an α γ and e^- by the $\text{LaBr}_3\text{:Ce}$ were also discussed. Finally this study tries to highlight some of the major advantages and inconvenients of LaBr_3 used as a particle detector.

1 Introduction

$\text{LaBr}_3\text{:Ce}$ scintillation detectors currently present an interesting set of characteristics for nuclear physics and γ -spectroscopy in general. Their time resolution is excellent [1], making them a suitable candidate for triggering purposes and for neutron- γ discrimination by time of flight. Moreover, the high density of the crystal lattice and the high Z of lanthanum ensure both a small Compton cross section at low energies and a good stopping power for very energetic γ -rays. Since $\text{LaBr}_3\text{:Ce}$ detectors are also relatively stable in efficiency over a broad range of energies, as shown in Table 1, they are good candidates for high-energy applications.

relative efficiency	1064 keV	1771 keV
hpGe	x1	y1
$\text{LaBr}_3\text{:Ce}$	x2	y2

Table 1: Comparison of the relative efficiencies of a germanium detector and a lanthanum(III) bromide scintillator. Results are obtained using a ^{207}Bi source and under the hypothesis that all the activity at 569 keV is seen by both detectors.

Finally, $\text{LaBr}_3\text{:Ce}$ detectors exhibit the best energy resolution among scintillators, with a theoretical value of 2,6% and operational values of $\sim 3\%$ at

662 keV [2][3]. For our device, a $6\times 6\text{ cm}^2$ crystal connected to a cylindrical photomultiplier tube of the same diameter, we measured an optimal resolution of 4,3% at this same energy. The discrepancy between these values is mainly due to the geometry of the scintillator-to-photomultiplier juncture. In fact, when a fraction of the effective area of the scintillator is lost the resolution increases proportionally. This equates to a $4/\pi$ factor in our configuration, which, when taken into account, brings the intrinsic value for the crystal's energy resolution down to $\sim 3,4\%$. However, that is probably still an overestimation since it neglects the contribution of the electronics to the final resolution.

The many qualities of these scintillation detectors make of paramount importance a precise knowledge of their self-activity, especially if one wishes to investigate phenomena that occur at very low rates. This internal activity is the consequence of the presence in the crystal of ^{138}La and ^{227}Ac , respectively a rare isotope and a chemical homologue of ^{140}La . Fig. 1 summarizes all the different contributions to the self-activity.

2 Experimental Setup

Two main approaches were taken in order to investigate the internal activity. The first one simply consisted in shielding the $\text{LaBr}_3\text{:Ce}$ scintillator using lead layers and in using it to register every single event. The resulting signal was then amplified and fed directly to the acquisition unit.

This method allows for a complete reconstruction of every contribution to the self-activity but doesn't produce a satisfactory signal over background ratio, especially at low energies. For this reason, a threshold at $\sim 150\text{ keV}$ is used with this configuration. In addition, it is very difficult with this setup to isolate modes that overlap in energy or to study the ^{138}La β^- electron. Lastly, cutting at $\sim 3\text{ MeV}$ is found to be reasonable because of the quenching effects for α particles, which are due to their high ionization power.

The internal activity was also measured in coincidence with a high purity germanium detector. The setup for this acquisition mode is shown in Fig. 2.

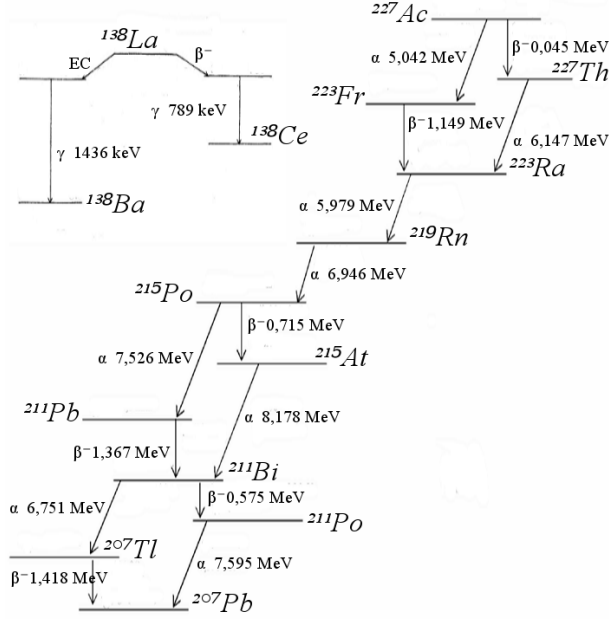


Figure 1: $\text{LaBr}_3\text{:Ce}$ internal activity [4]. Diagonal : decay chain of ^{227}Ac . Top-left corner : ^{138}La decay modes.

A fast amplification is performed on the signals of both detectors. These are then used to determine the occurrence of a coincidence, which serves as a triggering condition. Upon the fulfillment of said condition, decoupled signals from $\text{LaBr}_3\text{:Ce}$ and hpGe are registered by the acquisition card. In order to improve the performance, the delay between the two bare signals was measured with a time-to-amplitude converter and found to be of ~ 23 ns. Satisfactory results were obtained when applying gating of 25 ns to the fast $\text{LaBr}_3\text{:Ce}$ signal and of 20 ns to the hpGe one.

The signal to noise ratio is far greater in this configuration. Moreover, the ^{138}La β^- electron and several α decays from the ^{227}Ac chain are easily identifiable, which provides a good test for the hypothesis made for explaining the internal activity. The limit of this approach is of course the absence, in the resulting matrix, of all the contributions incapable of producing coincidences, for instance the α particles not associated with γ -emission. The joint use of informations from these two methods allows to reconstruct fully the self-activity spectrum.

3 Results

3.1 Coincidence Matrix Analysis

With the second setup proposed above, one can get access to the events detected in coincidence between the detectors. We then shall study each of this events to determine which are the main elements contributing

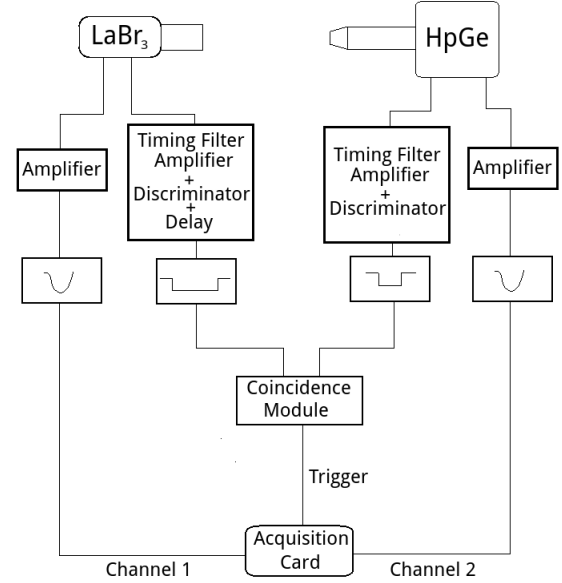


Figure 2: Schematics for the coincidence setup : an opportune electronic treatment and delaying are performed on the signals to produce a coincidence trigger which is then used by the acquisition card.

to the internal activity of the LaBr_3 .

3.2 α decay chain

3.2.1 Identification

We are expecting the presence of Actinium impurity in the detector, indeed ^{138}La and ^{227}Ac are elements of the same column in the Mendeleev Classification as a consequence it is extremely difficult to separate this elements when synthesising a Lanthanum crystal. We will search for a signature of the decay chain 1 of Actinium, which are mainly composed of α decay. In fact we are looking for events involving an α particle produced in coincidence with a γ in the Lanthanum-Bromide Crystal, the α will be detected by the $\text{LaBr}_3\text{:Ce}$, when sometimes the associated γ will be for instance detected in the HpGe . This decay will be visible in a coincidence study and will allow the characterisation of the α emitters. We had to select the best candidates decays that may be observed in a coincidence experiment (data from [1]), for instance we are selecting the decays for the Actinium, which produce an α particle in coincidence with a γ with a branching ratio above 10 %. The α decay region is zoomed in on the insert on 5. With the full set of events we are able to identify each of the candidates proposed; With the simultaneous presence of this isotopes we can conclude that there is definitely a contamination of the crystal by ^{227}Ac . Moreover one must note that the calibration for α and γ particle is

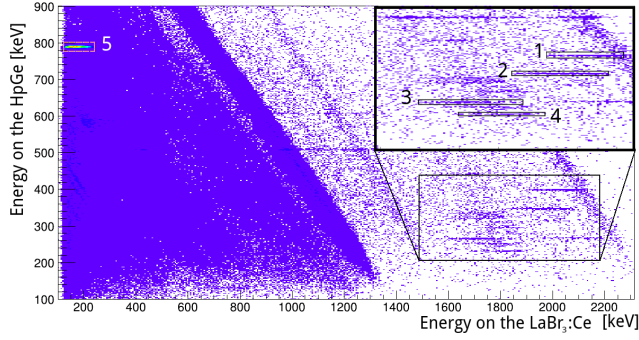


Figure 3: Representation of a coincidence matrix between HpGe and LaBr₃:Ce detectors. Events labeled 1-4 corresponds to α decays when 5 is a β decay

Isotope	E_α (keV)	E_γ (keV)	Branch	Id
²²⁷ Th	5755	256	12.3 %	4
²¹⁹ Rn	6553	272	10.8 %	1
²²³ Ra	5610	270	13.7 %	3
²¹¹ Bi	6278	350	13.1 %	2

Table 2: α - γ emitters in the Actinium decay chain where Id is the label of the isotope in 5

not the same, indeed instead of the E_α energy values expected in 2 we are measuring lower energy. This difference may be explained by a difference on the deposit mechanism for light or massless particles as the γ and heavy particle as the α . We are able to find the calibration for the α particle, with the measured energies $E_\alpha = 2.58 \cdot x + 1.31 (MeV)$ where x is the energy measured with the initial γ calibration. This simple results show that the light yield for an α particle is $\simeq 2.58$ lower than for a γ

3.2.2 Shape of the α deposits

Projecting the signal corresponding to an alpha decay give us some information on the energy deposit mechanism:

Despite the low statistic we are able to see an asymmetry of the peak, with the presence of a low energy tail. This could be explained by a recoil phenomenon in the crystal, when hit by an α

3.3 β^- decay

We are also expecting evidence for a β decay on the crystal that will simultaneously produce an electron in coincidence with a γ according to this mechanism:

$^{138}\text{La} \xrightarrow{\beta^-} ^{138}\text{Ce}^* + e^- + \bar{\nu}_e \rightarrow ^{138}\text{Ce} + e^- + \bar{\nu}_e + \gamma$ We are then expecting to detect in the LaBr₃ the electron and in coincidence the γ in the HpGe.

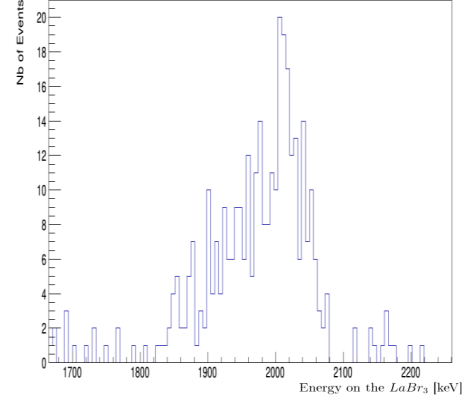


Figure 4: Distribution of the energy deposit of an α particle from ²¹¹Bi on the LaBr₃ at a real energy of $E_\alpha = 6278 \text{ keV}$

3.3.1 Identification and shape of the β^- decay

In the coincidence matrix 5 this decay was labeled 5, the associated γ match the expected energy of 789 keV. To be sure that it is indeed the correct β^- decay we may look at the kinetic distribution of energy of this decay.

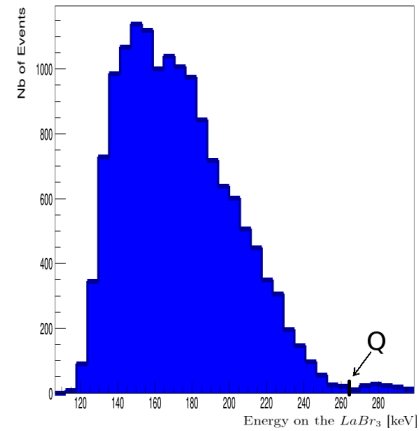


Figure 5: Distribution of the kinetic energy of a β^- decay in the LaBr₃

We identify the expected shape corresponding to the prediction for the Fermi theory for β decay. We also get the energy threshold of the reaction Q from this plot, with we evaluate $Q \simeq 262 \text{ keV}$ which again match exactly with the data from [3]. We can also note an important result, the calibration for the electron and a γ does not differ significantly, it is an important point that confirms our hypothesis on the difference between the kind of energetic deposit of heavy (α) and light massless particle (e^- and γ).

3.4 Relative activity of ^{138}La and ^{227}Ac

Another important parameter of this study will be the relative activity of the Lanthanum and the Actinium, such a study will give us information about the relative quantity of the isotopes in the crystal and by this way we shall get an access to the mass fraction of the polluting Actinium. To perform this analysis we did a long acquisition of the spectrum of the LaBr_3 with the HpGe : We can numerically compute the number of

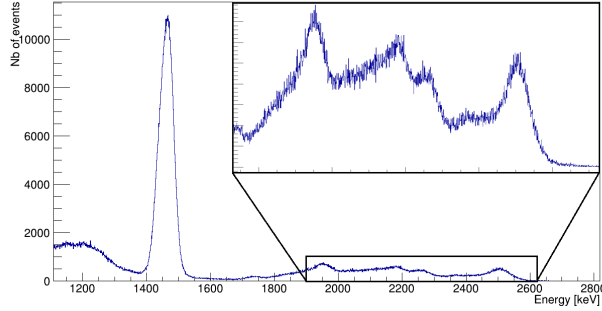


Figure 6: Full self activity spectrum of the LaBr_3 with the Actinium α decays contribution zoomed in and the peak of ^{138}La at $\simeq 1.46 \text{ MeV}$

events detected for both Lanthanum and Actinium, but we need to take into account the fact that only $\text{frac}23$ of the ^{138}La is detected (insert reason here) and we need also to weight the calculus with the efficiency of the LaBr_3 which is as shown below a function of the energy, then with η the efficiency

$$R = \frac{\frac{4}{3} \text{Activity of } ^{138}\text{La}}{\text{Activity of } ^{227}\text{Ac}} \frac{\eta(1460 \text{ keV})}{\eta(2.2 \text{ MeV})} = 4.02$$

Meaning that the activity of ^{138}La is in average 4 time higher than the activity of the Actinium.

4 Discussion

References

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