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Study of scintillation in natural and synthetic quartz and methacrylate

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ABSTRACT

Samples from different materials typically used as optical windows or light guides in scintillation detectors were studied in a very low background environment, at the Canfranc Underground Laboratory, searching for scintillation. A positive result can be confirmed for natural quartz: two distinct scintillation components have been identified, not being excited by an external gamma source. Although similar effect has not been observed neither for synthetic quartz nor for methacrylate, a fast light emission excited by intense gamma flux is evidenced for all the samples in our measurements. These results could affect the use of these materials in low energy applications of scintillation detectors requiring low radioactive background conditions, as they entail a source of background.

1. Introduction

Scintillation detectors are used, among many other applications, in rare event searches as the study of the neutrinoless double beta decay [1] or the direct detection of hypothetical dark matter particles pervading our galactic halo [2]. Improving the background levels and energy thresholds of scintillation detectors is still a challenging issue. Photomultiplier Tubes (PMTs) were typically a strong background source, however, ultra-low background models are becoming state of the art, and then, other contributions to the background become more relevant [3,4]. In the case of inorganic scintillators, being NaI (Tl) one with the most outstanding performance, PMTs are typically coupled to the scintillator crystal through light guides or optical windows made of different materials, whose design is based on geometry or background considerations. In the development of prototypes for the ANAIS (Annual modulation with NaI Scintillators) experiment [5] operating in the Canfranc Underground Laboratory (LSC, Laboratorio Subterráneo de Canfranc, Spain) and using NaI (Tl) crystals as target material, understanding of the different background contributions has been a major issue: residual radioactive backgrounds have been studied in [6], a very slow scintillation time constant in NaI (Tl) able to trigger the experiment and then, contribute to the background, was identified recently [7], and the results of the scintillation study of different materials considered to be used as optical windows and light guides are presented in this letter. This study was motivated by the identification, in previous ANAIS prototype tests using natural quartz optical windows, of a population of events, which contributed to the background at very low energy, and whose pulses showed an abnormal temporal behavior, since their decay was faster than expected for NaI (Tl) scintillation events. This letter describes a specific mounting and the set of measurements carried out in order to confirm and characterize a possible scintillation in natural quartz, and to test, under similar conditions, other suitable materials for the same purpose, namely synthetic quartz and methacrylate, to be sure that a similar effect is not present and they could be used in dark matter experiments. This study is not directly related with the dark matter search goal of ANAIS experiment, in whose context natural quartz was directly discarded as optical window because of the high radioactive content of the material. However, scintillation in natural quartz had not been previously related with fast populations of events in NaI (Tl) detectors, and in our opinion, this issue deserved more understanding.

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Events produced by a weak scintillation in the materials searched for would appear entangled with dark events from PMTs, being difficult to discriminate. This PMT noise is mainly due to thermoionic electron emission, but other contributions can be present due, for instance, to the emission of Cherenkov light (generated by radioactive contamination in the PMT, in their neighborhood or, even, by the interaction of cosmic rays) and ions in residual gas inside the PMT [8]. Operating two PMTs in coincidence is a common and effective practice in experiments demanding a low energy threshold in order to diminish the contribution from the thermoionic effect. However, Cherenkov light emission can produce coincident events, although they are expected to be quite asymmetric. Residual gas ions typically produce afterpulses, not relevant for coincidence measurements. The residual noise when operating PMTs in coincidence, as it is done in this work, attributed to accidental coincidences from dark events and to the generation of light in one PMT being detected by the other, had been studied in [9].

Quartz is not considered as a scintillating material in the literature [10,11]; a weak scintillation was reported under irradiation with α particles [10,12], although it was not characterized. However, quartz is largely used for dosimetry and dating thanks to thermal and optically stimulated luminescence, since it can emit when heated or illuminated an amount of light proportional to the radiation dose accumulated in time [13]. Imperfections (impurities or defects) in crystalline materials (as quartz) disturb the periodicity of the crystalline electric field, generating dips in the electric potential where free electrons may be trapped (the so-called electron traps). Ionizing radiation is able to excite electrons into the conduction band, that eventually could fall in such traps. Hence, the amount of electrons trapped is proportional to the radiation dose received. In the case of materials used for dosimetry or dating, when the irradiated material is heated or exposed to strong light, trapped electrons can absorb enough energy to return into the conduction band and then, recombine with holes in the valence band emitting part of the energy in the form of luminescence. In the case of quartz, used for optical dating, green or blue light is used to free the trapped electrons and luminescence in the ultraviolet is produced and read out. Then, scintillation in the ultraviolet range is expected from quartz also directly following energy deposition from ionizing radiation, in a time scale dependent on the lifetime of the radiative decaying states participating in the scintillation mechanism and with, probably, very low intensity. Characterization and understanding of such a scintillation was the main goal of this work.

In Section 2 the experimental setup and the plan of measurements carried out to study possible scintillation in different quartz and methacrylate samples, to be used as optical windows and/or light guides with NaI (Tl) crystals, are described. Analysis performed and results obtained are presented in Section 3, considering first the measurements made without sample and then those with the different samples. Section 4 gathers the conclusions.

2. Experimental set-up and summary of measurements

A test bench was conditioned at LSC to study scintillation from different samples. It consisted of two photomultipliers (Electron Tubes 9302B model, 3 in. diameter) faced at a fixed 10 cm distance between their respective photocathodes, in order to keep as much as possible the same geometry in the different measurements. The samples were placed centered in the inner space, between the PMTs (see Fig. 1), without using optical grease for the coupling to the PMTs to minimize the incorporation of unnecessary components that could affect the comparison between samples. Photomultipliers were operated at 1100 V. According to the 9302B series data sheet, the transit time is 40 ns and the single electron response (SER) rise time is 7.5 ns and 15 ns the corresponding FWHM. The nominal dark count rate at 20 °C is 500 s^{-1}. The spectral response curve ranges from 300 to 500 nm, having the maximum at 350–400 nm. Charge readout of the PMT is fast enough to keep the single electron time behavior. Samples and PMTs were housed in a 0.1-mm-thick μ-metal lining, covered by a plastic container made of PVC to avoid environmental light reaching the PMTs. Since the dark counting rate of PMTs can be affected by environmental gamma or cosmic ray fluxes, the set-up was operated in low background conditions: a 10-cm-thick lead shielding was used to reduce the contribution from environmental gamma radiation and all measurements were carried out at LSC, located in the Spanish Pyrenees, under a rock overburden of 2450 m.w.e. Underground operation at such a depth guarantees a significant cosmic ray suppression; the measured muon flux at LSC is of the order of 10^{-7} cm^{-2} s^{-1} [14,15], which means a reduction of about five orders of magnitude with respect to the flux above ground.

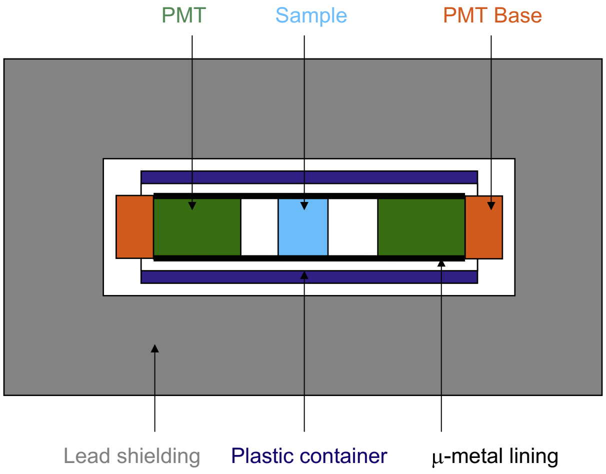

Fig. 1. Sketch of the scintillation test bench used for the measurements presented in this work: a plastic cylinder houses the scintillator sample and two PMTs lined in μ-metal, inside a lead shielding at the Canfranc Underground Laboratory.

Three different samples have been studied in this test bench: natural and synthetic quartz and methacrylate. Synthetic and natural quartz samples are from Suprasil and Homosil series from Heraeus, respectively. According to supplier specifications, for Homosil quartz only carefully selected crystal is used as raw material; it has no particulate structure and extremely favorable homogeneity properties. Suprasil 2 is a high purity synthetic fused silica material manufactured by flame hydrolysis of $SiCl_4$; the index homogeneity is controlled and specified in one direction. Other relevant information about the samples is given in Table 1; for quartz samples, two identical cylinders as those described in Table 1 were placed together in the bench. The samples were screened for radiopurity at the LSC using an ultra-low background HPGe detector in order to determine the corresponding activity of the ^{232}Th and ^{238}U natural chains and ^{40}K [6]. Results are shown in Table 1. For the natural quartz samples, data are compatible with equilibrium in both chains; for synthetic quartz and methacrylate, upper limits are given for ^{238}U, ^{226}Ra, and for the long-lived daughters of ^{232}Th.

Data acquisition directly ran at a Tektronix oscilloscope (Digital Phosphor Oscilloscope, TDS5034B) having 4 channels and a bandwidth of 350 MHz. Pulse shapes were digitized in a window of 2 μs taking 2500 samples. Trigger was done at photoelectron level in logical AND between the two PMT signals in order to reduce dark events. Time and the two digitized PMT pulses were recorded for each event; we will refer below to both digitized PMT signals as 0 and 1, respectively.