Recebido: Abril 1996
Received: April 1996

LIGHT ATTENUATION STUDIES IN THE PLASTIC SCINTILLATOR DETECTOR

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ABSTRACT

The light attenuation effects produced on the plastic made with polystyrene plus PPO scintillator and POPOP shifter were evaluated using an alpha-radioactive source. An alpha-radioactive source was applied onto the top face of different thickness cylinders (40 mm diameter) of the plastic scintillator coupled to the phototube, which generates a pulse height according to the transmission proprieties. The pulse height attenuation in function of the thickness (x) of the 16 plastic cylinders, ranging from 1mm to 164mm was determined. The experimental data showed can be fitted by a function of two exponential term of the form: Relative Pulse Height = $0.481e^{-0.02112x} + 0.519e^{-0.0016x}$

Key words: radiation detector; light attenuation; plastic scintillator

RESUMO

O efeito da atenuação luminosa produzida no plástico cintilador, confeccionado à base de poliestireno com cintilador PPO e conversor POPOP, foi estudado. Dezesseis fatias de detetores plásticos cintiladores (espessuras variando de 1 a 164mm e com 40mm de diâmetro) foram acoplados a uma fotomultiplicadora e a altura de pulso para cada fatia foi determinada utilizando-se uma fonte emissora alfa. A atenuação da altura de pulso em função da espessura (x) dos detetores plásticos foi determinada e os dados experimentais mostraram a concordância deste estudo à combinação de duas exponenciais: Altura de Pulso Relativa = $0,481e^{-0,02112x} + 0,519e^{-0,0016x}$

Descritores: detetor de radiação; atenuação luminosa e plástico cintilador.

INTRODUCTION

Light transmission is one of the most important parameters to project large organic scintillators. Two different attenuation processes may occur during the pathway of the light through the detector: a) the photon reabsorption process due to the optical transparency and b) optical and geometric effects related to reflection and refraction.

The optical transparency, "T_p", is given by the relationship:

$$T_p = e^{-\mu x} \quad (1)$$

where μ (mm^{-1}) is the attenuation coefficient that varies with the light wavelength and x is the path length. The output light efficiency in a scintillator detector is intrinsically correlated to the high optical transparency for its own fluorescence radiation [1,7,9].

Another factor which influenciates the disappearing of photons in the detector block is related to geometric and optical effects. In this scintillation process, the molecules emit photons isotropically and a fraction of them may escape from the detector [1]. Our plastic detectors have refraction index equal to 1.51 [4], hence, the critical angle for refraction is 41.5° related to the perpendicular to the plastic wall surface. Incident photons above 41.5° may be lost and attenuate the signal produced in the optical sensor [3,4]. This effect can be minimised mirroring the detector surface. Paints based on Titanium and Teflon® bands [5] are reliable reflectors.

The photophysics process of the scintillation in the plastic scintillator detector is shown in Figure 1. The incident radiation interact with the detector block with the emission of the photons which sensibilizes the photomultiplier.

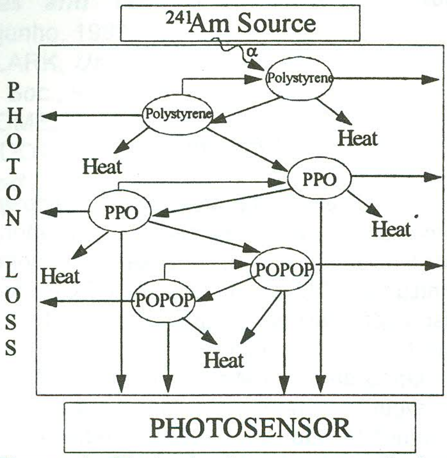

Figure 1: Photophysics process of plastic scintillator.

In most detectors there is some overlap of the absorption and emission spectra, resulting in the loss, by absorption, of the photons emitted in this region. The wavelength photons in this overlap region are extinguished in few millimeters of the pathway, since there occurs, within the desexcitation process of the molecules, some energy loss by heat dissipation [1,12]. Therefore, only those photons with wavelengths out of the overlap region are able to go through a larger pathway of the detector and reach the optical sensor, photomultiplier or photodiode [1,9].

Several practical methods for measuring the light attenuation in plastic scintillators have been published [6,8,9,12]. Nicoll and Ewer [12] recommend to use large detectors to define the absorption coefficient, because light attenuation in a large scintillator can not be deduced from the attenuation in a short (20 cm) scintillator, since the preferential absorption of the shorter wavelengths photons occurs in the first 20 cm of the scintillator.

Most studies of light attenuation were made using gamma-radiation. However, the gamma-radiation may introduce more complexity in this studies, mainly those interested in phenomena at short distance due to its high range, which originates several light centers generated at each interaction of gamma-radiation, with the detector in different positions. This dispersion of light center produces a degradation of the information related to the short distance phenomenon (fast coefficient μ_1). Then, using gamma-radiation only the long distance phenomenon (slow coefficient μ_2) can be determined.

In order to determine these two light attenuation coefficients in polystyrene plastic scintillator, the light absorption was evaluated using alpha-radiation from an ^{241}Am source. Since alpha-particle have short range, it can produce light photons isotropically in small areas of the top face. A fraction of these photons may reach the phototube generating a pulse height according to the transmission properties of the plastic matrix. So that, using alpha-radiation we expect to determine the two coefficients: a) the technical coefficient μ_2 (slow coefficient) and b) the optical absorption coefficient μ_1 (fast coefficient). In this way, the light absorption process can be explained with more details.

MATERIAL AND METHODS

In order to characterise the light absorption process in a plastic scintillator detector, the pulse height generated in the photomultiplier (RCA - model 6342A) was pre-amplified, amplified and applied to a multichannel ADCAM (ORTEC-model 918A). Same measurements were evaluated using an ^{241}Am source on the difference thickness of plastic detector ranging from 1mm to 163.8mm (16 detectors) with 40mm diameter. The detectors were obtained from a same block, that was made by polymerisation of styrene containing 0.5% of 2,5-Diphenyloxazole (PPO) and 0.05% of 1,4-Bis(5-phenyloxazol-2-yl)benzene (POPOP). Plastics cylinders were carefully polished and covered with a Teflon band, used as a reflector. Each detector was coupled to a photomultiplier using the same quantity (39.63 mg/cm^2) of Dow Corning silicon grease [3]. Background radiation measurements, were made with an ^{241}Am source, within 10 minute period at 23°C. All measurements were made with the same conditions and equipment and changing only the thickness of the plastic detectors.

The excitation and fluorescence spectra were determined using plastic detector of 2mm thickness x 6mm diameter and a fluorescence spectrophotometer, Perkin Elmer, model MPS-2A.

The light attenuation effect as a function of the detector thickness was studied taking the peak channel for each one of the 16 detectors (Figure 4). The height pulse of the peak channel was transformed in Volt (V) knowing that the 1024 channel corresponds to 10 Volts. The relative pulse height (RPH) versus the thickness data was fitted using the bi-exponential function as follow:

$$RPH = a_1 e^{-\mu_1 x} + a_2 e^{-\mu_2 x} \qquad (2)$$

where a_1, a_2, μ_1 and μ_2 are estimated parameters by non-linear least square method using the AnaComp computer code [10]. The μ_1 coefficient was considered as the signal attenuation component due to transparency effects in the detector by itself, while the μ_2 coefficient represents the signal attenuation due to the photons lost by reflection in the wall surface and others geometrical phenomena. The linear parameters, a_1 and a_2 were normalised ($a_1+a_2=1$) and considered as a fraction of the signal due to transparency failure and geometrical effects respectively. Figure 2 shows the analyses model and its data entry in the AnaComp computer code.

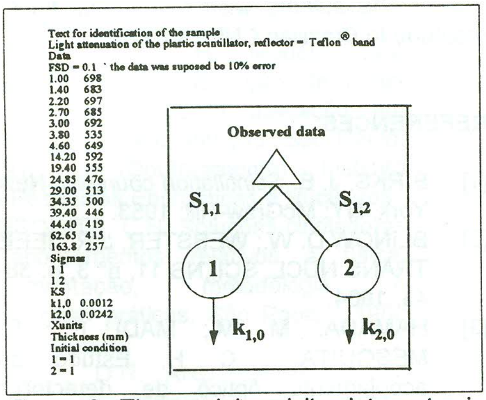

Figure 2: The model and its data entry in the ANACOMP in order to fit by non-linear least square method. In the model $\mu_1=k_{1,0}$, $\mu_2=k_{2,0}$, $a_1=s_{1,1}$ and $a_2=s_{1,2}$.

RESULTS AND CONCLUSIONS

The absorption and fluorescence spectra of the PPO and POPOP in the scintillator plastic detector is shown in Figure 3. There are overlap regions in the absorption and fluorescence spectra either PPO and POPOP. The overlap region for PPO is about 9% and for POPOP plus PPO 12% of the total fluorescence spectrum area for a 2mm thickness plastic scintillator. During polymerisation process an uncontrollable exothermic reaction occurs reaching temperature higher than 200°C, which could have damaged the scintillators. However, since the spectra profiles are in agreement with the literature data [3,11], there is an evidence that during the polymerisation procedures of the plastic scintillator, both PPO and POPOP were not damaged.

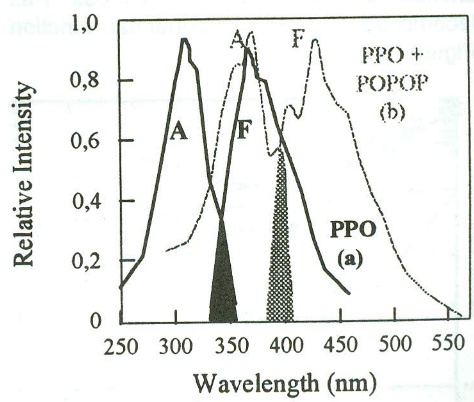

Figure 3: Absorption and fluorescence spectra of scintillator plastics containing: (a) PPO and (b) PPO plus POPOP, both measured with a 2mm thickness detector.

The light attenuation spectra shows a decrease in pulse height as a function of the detector thickness (Figure 4). The attenuation occurs due to the less photons quantity that reach the photomultiplier. Meanwhile, there is a positive correlation between the height peak and the detector thickness, however the resolution is better to the smaller thickness. The resolution of the system is defined as the full width at half maximum (FWHM) of the prompt coincidence peak. The resolution for 1 mm thickness is about 17%, while for 164 mm is about 21% (Figure 4). These data show that the increase of the detector thickness enlarges random phenomena, which degrades the signal formation.

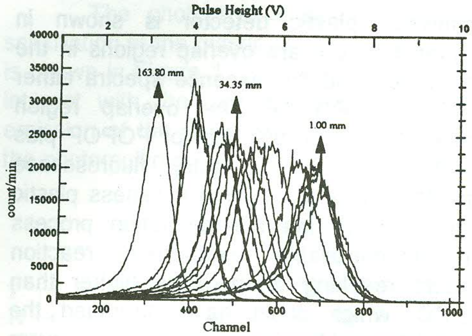

Figure 4: Attenuation effect spectra due to the plastic scintillator transparency phenomenon and the photons extinction by refraction phenomenon.

The light attenuation curve as a function of the detector thickness was decomposed in a bi-exponential function (Figure 5).

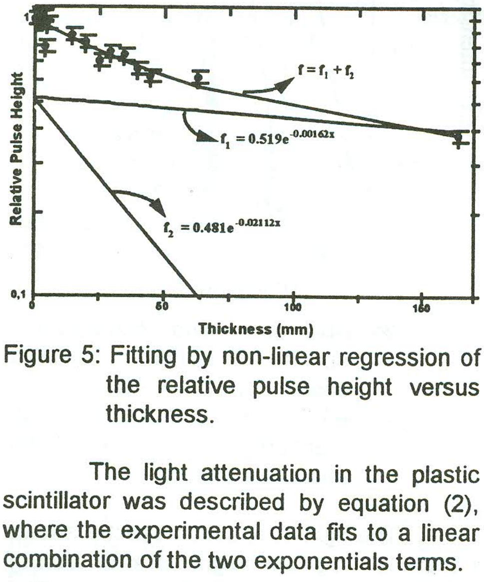

Figure 5: Fitting by non-linear regression of the relative pulse height versus thickness.

The light attenuation in the plastic scintillator was described by equation (2), where the experimental data fits to a linear combination of the two exponentials terms.

$$RPH = 0.481e^{-0.02112x} + 0.519e^{-0.0016x} \quad (3)$$

The first exponential of the equation (3) represents the light loss by the reabsorption process in the plastic scintillator due to the overlap region of the excitation and the fluorescence spectra. This phenomenon is characterised as a short distance phenomenon (fast coefficient). Photons reabsorbed are re-emitted and compete with other process, like heat. Consequently, these photons are extinguished and the electronic pulse generated will be proportionally decreased. The coefficient μ_1 (0.02112 mm^{-1}) results in a mean free path of 32.8mm, which means that a fraction a_1 = 0.481 or 48% of the light or the signal (Volts) is reduced by half after 32.8mm of the detector. The coefficient μ_2 (0.0016mm $^{-1}$) is identified as the technical coefficient. This value is in agreement with those described in the literature [2,6]. The signal attenuation due to the technical coefficient is very important for large detectors (such as those used as suppression-Compton). The phenomenon that acts in this process contributes with a fraction of a_2 = 0.519 or 52% of the original signal.

In global terms, the plastic scintillator using styrene as polymeric matrix and PPO and POPOP as scintillators has the signal attenuated by half in the first 95mm due to both coefficients and each subsequently 418mm is due only to the technical coefficient (Figure 5 and equation 3).

As expected, the use of alpha-radiation was able to determine not only the technical coefficient but also the optical absorption coefficient, which is due to the short distance phenomenon. The technical coefficient obtained was similar to the values found by other authors.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Brazilian CNPq support.

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