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Technical notes

Temperature dependence of plastic scintillators

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ABSTRACT

Plastic scintillator detectors have been studied as dosimeters, since they provide a cost-effective alternative to conventional ionization chambers. Several articles have reported undesired response dependencies on beam energy and temperature, which provides the motivation to determine appropriate correction factors. In this work, we studied the light yield temperature dependency of four plastic scintillators, BCF-10, BCF-60, BC-404, RP-200A and two clear fibers, BCF-98 and SK-80. Measurements were made using a 50 kVp X-ray beam to produce the scintillation and/or radioluminescence signal. The 0 to 40 °C temperature range was scanned for each scintillator, and temperature coefficients were obtained.

1. Introduction

Plastic scintillator detectors (PSDs) have long been used as dosimeters [1] due to their good characteristics, such as water equivalence, dose-rate independence, spatial resolution, etc. For a time, it was accepted that their response to radiation was temperature independent [2]. In a paper published in 2009, Nowotny and Taubeck [3] presented evidence for temperature dependence of the response of some polystyrene based scintillators (namely for polystyrene scintillator with 1.5% CaWO4 added). Later, in 2013 two papers [4,5] presented measurements on the BCF-12 and BCF-60 (also polystyrene based) reporting non-vanishing temperature coefficients for both scintillators. The results for BCF-12 have been confirmed by Lee et al. in a work published in 2015 [6]. These works focused on the widely used BCF-12 and BCF-60 scintillators, as the information on other plastic scintillators is scarce. It is not yet well established if scintillators based on other materials (acrylic—PMMA, Polyvinyltoluene—PVT, etc.) exhibit the same temperature behavior. The temperature effect has been observed for scintillation light emission but could affect other types of emission like radioluminescence. In the present work four different scintillators and two different optical cables have been studied for their light yield temperature dependence.

2. Material and methods

2.1. Experimental setup

The PSDs understudy were exposed to a 50 kVp X-ray beam produced by a Philips Oralix dental X-ray tube, with 2 mm Al inherent filtration. An irradiation time of 3 s and approximate dose of 5 mGy was chosen for each exposure. A Farmer ionization chamber PTW 30013 [7] connected to a PTW UNIDOS® E electrometer [8] was used to monitor the X-ray beam stability. The chamber was placed between the tube exit and the PSD, approximately 30 cm from the tube (Fig. 1). The readings from the chamber were used to correct the signal obtained with the PSD. This procedure ensures that any variation in signal in the PSD is due to temperature changes and not to a variation of the beam flux.

A summary of the scintillator properties studied is given in Table 1. Two of the four scintillators were based on a polystyrene substrate; BCF-10 and BCF-60, whilst one was PVT based, BC-404 and the other is PMMA based, RP-200A. Scintillators were coupled to a 2.0 mm Super Eska™ SK-80 (Mitsubishi) PMMA optical cable [9] using optical grease (BC-630 Silicone Optical Grease, Saint-Gobain) [10].

The scintillator and optical cable were protected from daylight by a black polyester sleeve. A 3.2 mm in diameter heat-shrinkable type sleeve was used for the optical cables and scintillators, except for the BC-4004 scintillator where a slightly larger sleeve was used. The optical cable was read by an Hamamatsu R647P PMT [11]. The PMT was directly connected to a Standard Imaging MAX 4000 electrometer, integrating the current from the PMT.

Two optical cables were also studied. The BCF-98, polystyrene based clear fiber and the PMMA based SK-80 fiber, also used as an optical cable when coupled to a scintillator. For the used X-ray beam (50 kVp), the light produced in these optical cables is due to radioluminescence [12]. Some properties of the optical cables are presented in Table 2.

The cooling system was constituted by a 40 × 40 cm^2 Peltier cell. The cell was also used as heating element, when polarity was reversed.

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Table 1
Scintillator properties.

Scintillator	RP-200A	BC-404	BCF-10	BCF-60
Substrate material	PMMA	PVT	Polystyrene	Polystyrene
Manufacturer	Rexon	Saint-Gobain	Saint-Gobain	Saint-Gobain
Diameter (mm)	3	4	2	2
Length (mm)	10	13.6	20	20
Wavelength of max emission (nm)	415 (1)	408 (2)	432 (2)	530 (2)
Density (g/cm^3)	1.18 (1)	1.032	1.05	1.05

(1) Extracted from Rexon [13] datasheet, (2) Extracted from Saint-Gobain datasheet [14].

Table 2
Clear optical cable properties.

Cable	SK-80	BCF-98
Substrate material	PMMA	Polystyrene
Manufacturer	Mitsubishi	Saint-Gobain
Diameter (mm)	2	2
Irradiated length (mm)	40	40
Density (g/cm^3)	1.19	1.05

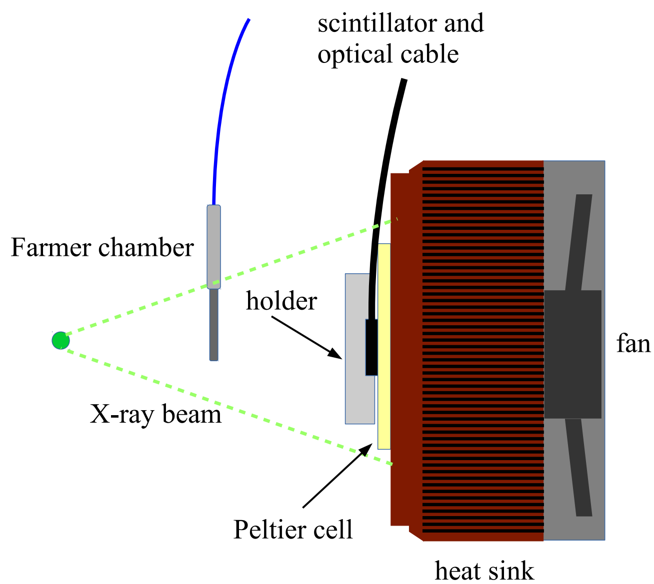

Fig. 1. Drawing of the irradiation setup (not to scale).

Current was provided by a Tenman 72-10480 digital-control DC power supply capable of delivering up to 3 A.

2.2. Temperature measurement

The temperature was measured with a K-type thermocouple sensor connected to a Benning MM 7-1 multimeter, which has a measurement resolution of 0.1 °C and an accuracy of ± 2 °C [15]. The sensor was placed inside a black polyester sleeve, the same used to cover the scintillator and the optical cable. In this way, the sensor is subjected to the same thermal conditions as the scintillator. The sensor and scintillator were held in place, side by side, over the Peltier cell by a PMMA holder.

2.3. Temperature dependence

Ideally, the response from the dosimeter should be constant for a sufficiently wide range of temperatures. In order to correct the dosimeter readings, it is critical to study the scintillator's temperature dependence. In this study, we adopted a linear model [5] for the scintillator response over a limited range

$$S = S_0 \left(1 + \alpha \left(T - T_0\right)\right) \quad (1)$$

where S is the scintillator response at temperature T, S_0 is the response at some reference temperature T_0 and α the temperature coefficient.

3. Results and discussion

The normalized response S/S_0 for the scintillators is presented in Fig. 2. As shown, the response variation with temperature is not linear and Eq. (1) can only be applied in a limited range. The reference temperature T_0 was chosen to be the nearest available value to 20 °C. A linear fit is performed using data in the range 10 to 30 °C to obtain the temperature coefficient. The same procedure was applied to the data obtained with the optical cables (Fig. 3). The obtained temperature coefficients are presented in Table 3.

Except for BC-404, all the other scintillators present a clear temperature dependence within the measured range. The measured temperature coefficient value for BCF-10 is similar to the BCF-12 scintillator ($\alpha = (-2.6 \pm 0.3) \times 10^{-3}$ °C^{-1}) [6] (also a blue-emitting scintillator [14]). On the other hand, the value obtained for the BCF-60 scintillator is less than 5×10^{-3} °C^{-1}, reported in earlier works [4,5], but still showing a significant decrease on light yield with temperature. The PMMA based RP-200A scintillator also presented a measurable temperature dependence. Only the BC-404 PVT-based scintillator showed a negligible temperature dependence within the entire measured range (nearly 50 °C).

The measurements with the optical cables showed that they both exhibited a temperature dependence, with the temperature coefficient for the BCF-98 fiber being twice that for the SK-80 cable. These results, in line with previous measurements by other authors [4–6], stress the need for more comprehensive studies on the subject in order to fully understand the underlying physical mechanisms of the light yield temperature dependence in plastic scintillators and plastic optical cables.

4. Conclusion

In this work temperature coefficients were measured for four scintillators and two optical cables. The obtained results are in line with previous studies for similar scintillators. The non-vanishing temperature coefficients confirm the small temperature dependence of the polystyrene and PMMA based scintillators. The effect is present in scintillators and optical cables. This is an indication the effect is already present at the substrate level. A smaller, nearly absent, temperature dependence was measured for the BC-404 PVT based scintillator. According to the manufacture datasheet [14] this is the expected behavior for the BC-4xx PVT based series in the −60 to 20 °C range. The present work extends that range up to 50 °C for the BC-404 scintillator. This scintillator has already been successfully used in PSDs prototypes tested in X-ray beam qualities used in tomosynthesis [16] and Cone Beam CT [17]. The temperature insensitivity of the BC-404 scintillator makes it a good candidate to be used in PSDs placed near the human body, where changes relative to room temperature can be expected.

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