Radiation damage of scintillator rods with different concentrations of dopants and antioxidants

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Abstract

The performance of plastic scintillator degrades when exposed to radiation. In this paper, the reduction in light output is studied for scintillators with varying concentrations of the primary dopant, secondary dopant, and dissolved antioxidant as a function of dose rate. The scintillators used polystyrene or polyvinyltolune as the substrate, and produced blue or green light. some findings here

Keywords: organic scintillator, radiation hardness, calorimetry

1. Introduction

Plastic scintillator has long been an inexpensive way to detect charged particles produced in particle physics experiments. Plastic scintillators consist of a plastic substrate, often polystyrene (PS) or polyvynyltoluene (PVT), into which wavelength shifting primary and secondary fluors have been dissolved. When a charged particle traverses the scintillator, the molecules of the substrate are excited. This excitation can be transferred to the primary fluor radiatively in the deep UV at low concentrations or via the Förster mechanism [1] at concentrations above $\approx 1\%$ [2]. The primary fluor transfers the excitation radiatively to the secondary fluor. The visible light by de-excitation of the secondary flour must traverse the scintillator to reach a photodetector, and can be absorbed by "color centers" along its path.

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Prolonged exposure of plastic scintillator to ionizing radiation, however, can result in damage: light self-absorption by the color centers (yellowing) increases when the radicals created during irradiation re-terminate in ways that absorb visible light. The transfer efficiency of the initial excitation of the polymer to the dopants combined with the probability of radiative decays for the dopants ("initial light output") can lessen when bonds form that absorb in the ultraviolet.

The effect of radiation on plastic scintillator is known to depend both on dose and dose rate [3, 4, 5, 6, 7, 8, 9, 10, 11]. Two well-studied [12, 13, 14, 15, 16, 5, 17] sources of dose rate effects in plastics involve oxygen. The penetration depth of oxygen during irradiation depends on the dose rate. The rate of peroxide formation in the areas containing oxygen can as well [12]. At low enough dose rate, oxygen permeates the plastic and the radicals created during irradiation tend to quickly form peroxides that absorb in the ultraviolet [12], affecting the initial light output. The rate of peroxide formation may depend on the dose rate if the bond formed is bimolecular. At high enough dose rate, however, the penetration depth for oxygen may be thinner than the thickness of the plastic, and many short-lived "temporary" color centers can form in the oxygen-free regions. These color centers anneal after irradiation either by reforming bonds or by forming peroxides when oxygen re-permeates the plastic.

Because of this, dose rate effects might be ameliorated either by increasing the concentration of the dopant or by increasing the concentration of antioxidants, preventing the formation of peroxides.

In this paper, we present measurements of the light output of blue and green scintillator rods before and after irradiation for various concentrations of dopants and antioxidants, and as a function of the material used for the substrate. The damage is studied for for dose rates from xxx to xxx.

2. Sample and irradiation details

The rods were supplied by Eljen Corporation, and are similar to EJ-200, a blue scintillator, and EJ-260, a green one, using either polystyrene (PS) or polyvinyltoluene (PVT) as the substrate. They are rectangular, with dimensions of 1x1x5 cm^3, and the edges were diamond milled. The concentration of the primary dopant and the secondary dopant was 0.5, 1.0, and 2.0 times the nominal concentration. The amount of antioxidant was 0, 1, and 2 times the nominal concentration. Fig. **??** [left] shows a photograph of some of the rodes.

High dose rate irradiations (xxx–xxx krad/hr) were performed at the National Institute of Standards and Technology, Gaithersburg, MD, using their Colbalt-60 (Co-60) source. Intermediate dose rate irradiations (xxx–xxx krad/hr) were performed at Goddard Space Flight Center's Co-60 source. Very low dose rate were measured using the GIF++ facility[**?**] at CERN. The source is Cs-137? and the dose rate xxx krad/hr.

3. Measurement technique

The light output from the rods is measured before and after irradiation using an alpha source, as shown in Fig. 1 [right]. Before measurement, the rods were allowed to anneal at least 2 months, until all the temporary damage was gone. The rod is placed on a Hamamatsu RXXX PMT, and the source is placed on the rod. An alignment jig ensures reproducibility of the alignment of the three pieces. The measurements were made using a textronics scope XXXXX, with a charge integration window of xxμs. A typical output spectrum is shown in Fig. 1 [right]. The distribution is fit to a Gaussian near the peak, and its mean is used as a measure of the light yield. The uncertainty in the light output is taken as the variation in this mean for measurements taken at different times, and after removing and replacing the rod from the jig, and is $\pm 2\%$.

The amount of radiation damage is quantified using D defined in Equation 1.

$$\frac{L(d)}{L_0} = \exp -d/D \tag{1}$$

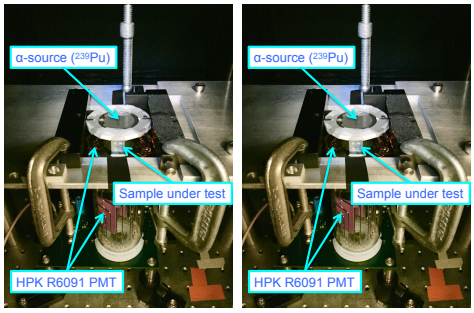

Figure 1: [left] photograph of some of the rods [right] Apparatus for measurements with alpha source.

where $L(d)$ is the light output after a dose d, L_0 is the initial light output, and D is the exponential dose constant from the fit.

4. Results

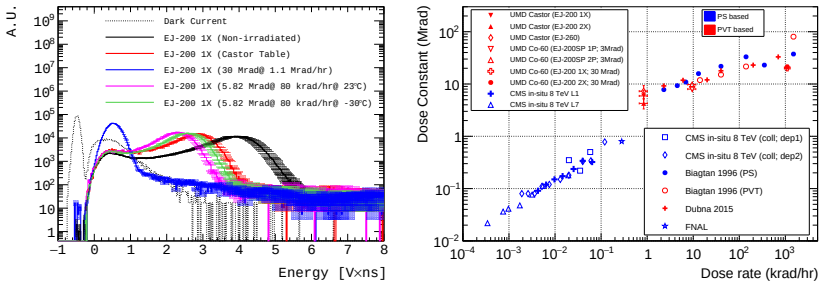

Figure 2: [left] A typical energy spectrum [right] resulting dose constants and comparison with the HE data. need version without HE data

5. Conclusions

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