Radiation damage for 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 he edges were diamond milled. The amount of primary dopant and the amount of 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]. 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 amount of radiation damage is quantified using D defined in Equation 1.

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

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.

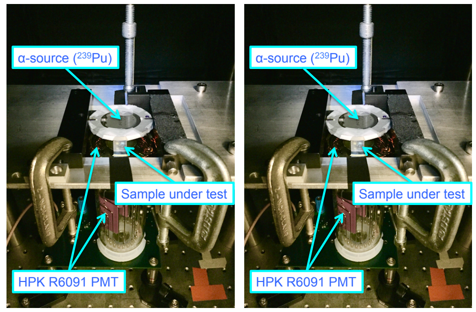

Figure 1: [left] photograph of some of the rods [right] Apparatus for measurements with alpha source.

4. Results

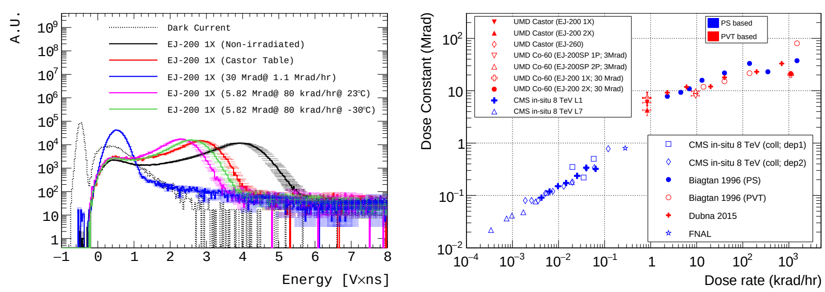

Figure 2: [left] A typical energy spectrum [right] resulting dose constants and comparison with the HE data. need version without HE data

5. Conclusions

6. Acknowledgments

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References

[1] T. Forster, Z. Naturforsch. a4 (1949) 321.

[2] J. Birks, The Theory and Practice of Scintillation Counting, International Series of Monographs on Electronics and Instrumentation, Volume 27, Pergamon Press, The Macmillan Company, New York, 1964. doi:https://doi.org/10.1016/C2013-0-01791-4.

[3] C. Zorn, Plastic and liquid organic scintillators, in: F. Sauli (Ed.), Instrumentation in High Energy Physics, 2nd Edition, World Scientific, 1993, Ch. 4, pp. 218–279. doi:10.1142/9789814360333_0004.

[4] U. Holm, K. Wick, Radiation stability of plastic scintillators and wavelength shifters, Nuclear Science, IEEE Transactions on 36 (1) (1989) 579–583. doi:10.1109/23.34504.

[5] K. Wick, D. Paul, P. Schrder, V. Stieber, B. Bicken, Recovery and dose rate dependence of radiation damage in scintillators, wavelength shifters and light guides, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 61 (4) (1991) 472 – 486. doi:http://dx.doi.org/10.1016/0168-583X(91)95325-8.

[6] B. Bicken, U. Holm, T. Marckmann, K. Wick, M. Rohde, Recovery and permanent radiation damage of plastic scintillators at different dose rates, Nuclear Science, IEEE Transactions on 38 (2) (1991) 188–193. doi:10.1109/23.289295.

[7] B. Bicken, A. Dannemann, U. Holm, T. Neumann, K. Wick, Influence of temperature treatment on radiation stability of plastic scintillator and wave-length shifter, Nuclear Science, IEEE Transactions on 39 (5) (1992) 1212–1216. doi:10.1109/23.173180.

[8] A. Bross, A. Pla-Dalmau, Radiation damage of plastic scintillators, Nuclear Science, IEEE Transactions on 39 (5) (1992) 1199–1204. doi:10.1109/23.173178.

[9] N. Giokaris, M. Contreras, A. Pla-Dalmau, J. Zimmerman, K. Johnson, Study of dose-rate effects on the radiation damage of polymer-based scsn23, scsn81, scsn81+y7, scsn81+y8 and 3hf scintillators, Radiation Physics and Chemistry 41 (12) (1993) 315 – 320. doi:http://dx.doi.org/10.1016/0969-806X(93)90069-7.
URL http://www.sciencedirect.com/science/article/pii/0969806X93900697

[10] K. Gillen, M. Celina, Predicting polymer degradation and mechanical property changes for combined radiation-thermal aging environments, RC&T 91 (2018) 27. doi:https://doi.org/10.5254/rct.18.81679.

[11] V. Khachatryan, et al., Dose rate effects in the radiation damage of the plastic scintillators of the cms hadron endcap calorimeter, JINST 11 (2016) T10004. doi:10.1088/1748-0221/11/10/T10004.
URL http://stacks.iop.org/1748-0221/11/i=10/a=T10004

[12] S. Shalaby, R. Clough, Radiation effects on polymers, Am. Chem. Soc. Symp. Ser. 475 (1991) 457.

[13] J. Bolland, Kinetic studies in the chemistry of rubber and related materials, J. L. Proc. R. Soc. A186 (1946) 218.

[14] Bolland, Kinetic studies in the chemistry of rubber and related materials. VII. –influence of chemical structure on the α-methylenic reactivity of olefins, Trans. Faraday Soc. 46 (1950) 358. doi:http://dx.doi.org/10.1039/TF9504600358.

[15] L. Bateman, Olefin oxidation, Q. Rev. Chem. Soc 8 (1954) 147.

[16] A. Cunlifee, Davis, Photo-oxidation of thick polymer samples - part II: the influence of oxygen diffusion on the natural and artificial weathering of polyolefins, Polym. Degrad. Stab. 4 (1982) 17. doi:https://doi.org/10.1016/0141-3910(82)90003-9.

[17] E. Biagtan, E. Goldberg, R. Stephens, E. Valeroso, J. Harmon, Gamma dose and dose rate effects on scintillator light output, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 108 (12) (1996) 125 – 128. doi:http://dx.doi.org/10.1016/0168-583X(95)00874-8.