Radiation damage of scintillator rods with different concentrations of dopants

Geng-Yuan Jeng[a,*], A. Belloni[a], Shiyuan Duan[a], S. Eno[a], T. Edberg[a], C, Hinrich[a], C. Papageorgakis[a], Ruhi Perez[a], Cameron Sylber[a], Zishuo Yang[a], Yao Yao[a], Yingyue Zhu[a]

[a]*Dept. Physics, U. Maryland, College Park MD 30742 USA*

Abstract

The performance of plastic scintillator degrades when exposed to radiation. In this paper, the reduction in light output as a function of dose rate is studied for scintillators with varying concentrations of the primary dopant, secondary dopant

The scintillators used polystyrene or polyvinyltoluene 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. They consist of a plastic substrate, often polystyrene (PS) or polyvinyltoluene (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

*Corresponding author
Email address: Geng-Yuan.Jeng@cern.ch (Geng-Yuan Jeng)

scintillator to reach a photodetector, and can be absorbed by "color centers" along its path.

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 are unterminated or 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 or that decrease the relevent de-excitation mechanisms.

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. For PS, the penetration depth goes as [5**?**].

$$z_0^2 = 4$$

$\mathrm{mm}^2 krad/hr$ (1) There is an abrupt transition between areas with and without oxygen. The oxygen concentration in the oxidized regions is almost uniform [**?**]. For a tile with a thickness of 4, oxygen permeates the entire sample at a of 1krad/hr For s above this value, the damage to the scintillator will depend on the , as peroxides will form in the regions with oxygen, but will not in the regions without. 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 to shorten the path length for the ultraviolet light to the primary dopant.

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 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 PS or 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. Fig. **??** [left] shows a photograph of some of the rods.

High dose rate irradiations (xxx–xxx krad/hr) were performed at the National Institute of Standards and Technology, Gaithersburg, MD, using their Cobalt-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 ±2%.

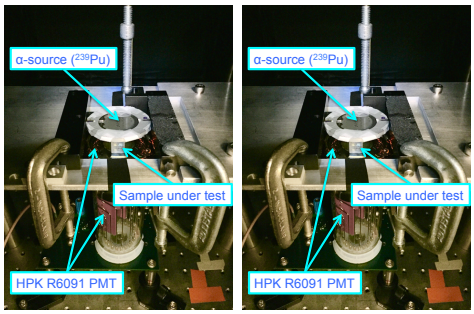

Figure 1: [left] photograph of some of the rods [right] Apparatus for measurements with alpha source.

The amount of radiation damage is quantified using D defined in Equation 2.

$$\frac{L(d)}{L_0} = \exp -d/D \tag{2}$$

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

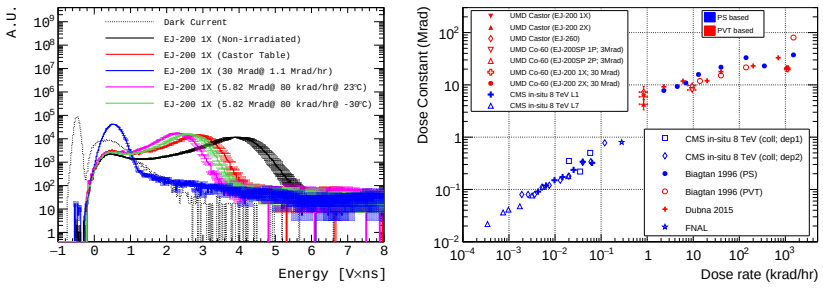

Figure 2: [left] A typical energy spectrum [right] resulting dose constants and comparison with the HE data. need version without HE data

5. Conclusions

6. Acknowledgments

The authors would like to thank Chuck Hurlbut of Eljen Corporation for supplying many of the rods. The authors would like to thank the staff Goddard Space Flight Center and at the National Institute of Standards and Technology irradiation Facilities group for assistance with the irradiations. This work was supported in part by U.S. Department of Energy Grant DESC0010072.

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.