Performance of scintillator tiles with different doping concentrations after irradiation

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Abstract

The performance of plastic scintillator degrades when exposed to radiation. The reduction in light output may be ameliorated by using scintillator with higher dopant concentrations and with light output at longer wavelengths. We present results on the degradation of light output of scintillator tiles with embedded wavelength shifting fibers when irradiated by a ^{60}Co source for a variety of concentrations of the primary and secondary dopant, doses, and dose rates. Tiles made from a blue scintillator with blue-to-green wavelength shifting fiber and for green scintillator with green-to-orange wavelength shifting fiber are presented.

Keywords: organic scintillator, radiation hardness, calorimetry

1. Introduction

Sampling calorimeters using plastic scintillator tiles with wavelength-shifting (WLS) fibers as the active element have been part of hadron collider experiments since the mid 1990's, when the CDF plug calorimeter was constructed [1]. Both the CMS Barrel [2] and Endcap [3] calorimeters use a similar design. Prolonged exposure of plastic scintillator to ionizing radiation, however, can result in damage: light self-absorption (yellowing) increases and the transfer efficiency of the

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initial excitation of the polymer to the dopants combined with the probability of radiative decays for the dopants ("initial light output") can lessen. During the running of the LHC from its commissioning in 2009 through 2012, the CMS detector was exposed to an integrated luminosity of 25 fb^{-1}. Parts of the CMS endcap calorimeter are estimated to have received doses of 0.1 to 0.2 Mrad [4]. Studies of the radiation hardness of scintillator tiles prior to installation in the detector, using an electron linac and ^{60}Co sources, indicated an exponential reduction in light output with accumulated dose, with a exponential constant of around 7 Mrad [5, 6]. However, although the dose received by the CMS tiles was small compared to this number, significant light loss was observed [7].

The effect of radiation on plastic scintillator is known to depend both on dose and dose rate [8, 9, 10, 11, 12, 13, 14]. The increased self-absorption immediately after exposure is larger at high dose rate. However, after exposure, interactions with oxygen that diffuses into the plastic decreases the initial damage, and the "permanent" damage after a recovery time (typically a month) is usually independent of dose rate [8]. While the permanent damage to the light self absorption may be independent of dose rate, some studies indicate that the permanent damage to the initial light output depends on dose rate [15] and that increasing the dopant concentration can help alleviate this [16, 8]. The dose rates insitu at hadron collider experiments being much lower than those used for reactor and linac tests may be part of the explanation for the higher-than-expected damage to the CMS tiles.

In addition, many studies have shown that induced self-absorption is stronger at shorter wavelengths and thus scintillators that produce green light should be more radiation resistant than the more common blue scintillators [17, 8, 14]. Dose rate effects may therefore be smaller for such scintillators as well.

In this paper, we present measurements of the ratio of the light output before and after irradiation for tiles based on two different types of plastic scintillator manufactured by Eljen Technology, EJ-200 (a blue scintillator, similar to BC-408 from Bicron corporation) and EJ-260 (a green scintillator, similar to BC-428), before and after irradiation by a ^{60}Co source for doses of 50, 30, 10, 4, and 2

Mrad at various dose rates and for different concentrations of the primary and secondary dopant.

2. Tile design

We tested two different tile designs. Both used scintillator with dimensions of 10 cm x 10 cm x 4 mm. A blue-to-green multi-clad WLS fiber from Kuraray (Y-11) with a diameter of 1mm was used for with the EJ-200. A green-to-orange multi-clad WLS fiber from Kuraray Corporation (S-type O-2) with a dye concentration of 100 ppm and a diameter of 1 mm was used with the EJ-260. Aluminum was sputtered onto one end of the fiber to increase the light output. A square "σ"-shaped groove similar to that used for the CMS tiles [2] was machined into the plastic, and the fiber was inserted into the groove. The tiles were wrapped with a tyvek covering, held together with tape.

3. Results

The tiles were irradiated at the University of Maryland ^{60}Co source. The dose was measured using I don't know. The light output was measured using cosmic rays. Scintillator-based counters above and below the tile were used for triggering. No attempt was made to select minimum ionizing (mip) muons. The muons were thus of low energy and produce more light than mips.

For the EJ-200 tile, the light output was measured using a Hamamatsu R7600U-200-M4 photomultiplier tube. As photomultiplier tubes have lower sensitivity for orange light, a sipmm of some sort was used for the EJ-260 tiles. The fiber was connected to the photodetector using optical glue. Data was collected with a Tektronix MSO 5204 oscilloscope interfaced with Labview.

Figure 1 shows the light output for the EJ-260 tile before irradiation. Due to the excellent resolution of the sipmm, clear peaks corresponding to different numbers of photoelectrons are seen. The average number of photoelectrons is xxx.

Figure 1: Light output for the EJ-260 tile before irradiation. The peaks correspond to integer numbers of observed photoelectrons.

Table 1 shows the ratio of the average light output for the EJ-200 tiles to that before irradiation. Figure 2 shows the ratio of the average light output for the EJ-200 tiles to that before irradiation as a function of dose rate for several total doses.

Table 2 shows the ratio of the average light output for the EJ-260 tiles to that before irradiation. Figure 3 shows the ratio of the average light output for the EJ-260 tiles to that before irradiation as a function of dose rate for several total doses.

4. Conclusions

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Table 1: Ratio of average light output from tiles to that before irradiation for the tile using EJ-200 scintillator. For the concentrations of the dopants, NpMs refers to N times the default concentration of primary and M times the default concentration of the secondary dopant the commercial version of the product.

Dose	Dose rate	light output ratio for dopings			
(Mrad)	(Mrad/hr)	1p1s	0.5p1s	1.5p1s	2.0p1s
0	–	1.0	xx	xx	xx
2	0.1	xx	xx	xx	xx
2	0.3	xx	xx	xx	xx
2	1.0	xx	xx	xx	xx
4	0.1	xx	xx	xx	xx
4	0.3	xx	xx	xx	xx
4	1.0	xx	xx	xx	xx
10	0.3	xx	xx	xx	xx
10	1.0	xx	xx	xx	xx
30	1.0	xx	xx	xx	xx
50	1.0	xx	xx	xx	xx

irradiations. We would like to thank the University of Maryland FabLab, especially who helped, for help with fiber sputtering. This work was supported in part by U.S. Department of Energy Grant DESC0010072.

References

[1] S. Aota *et al.*, A scintillating tile/fiber system for the cdf plug upgrade em calorimeter, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 352 (3) (1995) 557 – 568. `doi:http://dx.doi.org/10.1016/0168-9002(95)90005-5`.

[2] S. Abdullin *et al.*, Design, performance, and calibration of cms hadron-barrel calorimeter wedges, The European Physical Journal C 55 (1) (2008) 159–171. `doi:10.1140/epjc/s10052-008-0573-y`.

Figure 2: Ratio average light output for the EJ-260 tiles to that before irradiation versus dose rate for several total doses.

[3] The CMS hadron calorimeter project: Technical Design Report, Technical Design Report CMS, CERN, Geneva, 1997.

[4] ECFA High Luminosity LHC Experiments Workshop: Physics and Technology Developments Summary submitted to ECFA. 96th Plenary ECFA meeting.
URL `https://cds.cern.ch/record/1983664`

[5] V. Hagopian, I. Daly, Radiation damage of fibers, AIP Conference Proceedings 450 (1) (1998) 53–61. `doi:http://dx.doi.org/10.1063/1.56958`.

[6] A. Byon-Wagner, Radiation hardness test programs for the {SDC} calorimeter, Radiation Physics and Chemistry 41 (12) (1993) 263 – 271. `doi:http://dx.doi.org/10.1016/0969-806X(93)90064-2`.

[7] J. F. Butler, D. U. C. B.-L. I. Contardo, M. M. Klute, J. U. o. M. Mans, L. I.-B. Silvestris, Technical Proposal for the Phase-II Upgrade

Table 2: Ratio of average light output from tiles to that before irradiation for the tile using EJ-260 scintillator. For the concentrations of the dopants, NpMs refers to N times the default concentration of primary and M times the default concentration of the secondary dopant the commercial version of the product.

Dose (Mrad)	Dose rate (Mrad/hr)	light output ratio for dopings						
		1p1s	2p1s	4p1s	1p2s	1p4s	2p2s	4p4s
0	–	1.0	xx	xx	xx	xx	xx	xx
2	0.1	xx	xx	xx	xx	xx	xx	xx
2	0.3	xx	xx	xx	xx	xx	xx	xx
2	1.0	xx	xx	xx	xx	xx	xx	xx
4	0.1	xx	xx	xx	xx	xx	xx	xx
4	0.3	xx	xx	xx	xx	xx	xx	xx
4	1.0	xx	xx	xx	xx	xx	xx	xx
10	0.3	xx	xx	xx	xx	xx	xx	xx
10	1.0	xx	xx	xx	xx	xx	xx	xx
30	1.0	xx	xx	xx	xx	xx	xx	xx
50	1.0	xx	xx	xx	xx	xx	xx	xx

of the CMS Detector, Tech. Rep. CERN-LHCC-2015-010. LHCC-P-008, CERN, Geneva, upgrade Project Leader Deputies: Lucia Silvestris (INFN-Bari), Jeremy Mans (University of Minnesota) Additional contacts: Lucia.Silvestris@cern.ch, Jeremy.Mans@cern.ch (Jun 2015).
URL `https://cds.cern.ch/record/2020886`

[8] 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`.

[9] 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`.

[10] K. Wick, D. Paul, P. Schrder, V. Stieber, B. Bicken, Recovery and dose rate dependence of radiation damage in scintillators, wavelength shifters

Figure 3: Ratio average light output for the EJ-260 tiles to that before irradiation versus dose rate for several total doses.

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.

[11] 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.

[12] 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.

[13] 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.

[14] 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

[15] 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.

[16] C. Zorn, S. Majewski, R. Wojcik, K. Johnson, Progress in the design of a radiation-hard plastic scintillator, Nuclear Science, IEEE Transactions on 38 (2) (1991) 194–199. doi:10.1109/23.289296.

[17] A. Bross, A. Pla-Dalmau, B. Baumbaugh, J. Godfrey, J. Jaques, J. Marchant, J. Piekarz, R. Ruchti, Development and characterization of new scintillation materials for fiber tracking and calorimetry, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 307 (1) (1991) 35 – 46. doi:http://dx.doi.org/10.1016/0168-9002(91)90128-D.