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Measurement of Light Yield, Timing and Radiation Damage and Recovery of Common Plastic Scintillators

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Abstract. PEN and PET (polyethylene naphthalate and teraphthalate) are common plastics used for drink bottles and plastic food containers. They are also good scintillators. Their ubiquity has made them of interest for high energy physics applications, as generally plastic scintillators can be very expensive. However, detailed studies on the performance of the scintillators has not yet been performed.

At various tests, we measured the light yield and timing properties of PEN and PET with Fermilab and CERN test beams. We also irradiated several samples to varying gamma doses and investigated their recovery mechanisms. Here we report on the measurements performed over the past few years in order to characterize the scintillation properties of PEN and PET and discuss possible future implementations.

1. Introduction

Future and upgrade collider experiments impose unprecedented radiation conditions on the active media of their detector components such as scintillator tiles and wavelength shifting fibers. In order to address this demand, which is likely to gain further interest in the near future, we have developed radiation-hard scintillator materials and wavelength shifting fibers.

In terms of intrinsically radiation-hard scintillators, we have investigated thin plates of PEN (Polyethylene Naphthalate) and PET (Polyethylene Terephthalate). These materials have found previous implementations in beamline instrumentation. We studied the light yield and timing properties and the radiation damage and recovery properties of PEN and PET.

We developed a new scintillator material with Peroxide- cured polysiloxane bases doped with the primary fluors pTP, pQP, or PPO (2.5-Diphenyloxazole) and/or the secondary fluors 3-HF or bis-MSB. We investigated the radiation damage and recovery properties of this newly developed scintillator and it response to Minimum Ionizing Particles (MIPs) [1, 2]. With improved production process and equipment, the performance of the newly developed scintillators was validated.

Here we report on the various measurements performed in the past few years and discuss possible future implementations.

2. Timing, Light Yield, Radiation Damage and Recovery of PEN and PET

PEN and PET are bright and inexpensive intrinsically radiation-hard plastic scintillators [3]. The light yield of PEN was measured as 10,500 photons/MeV making an intrinsic blue scintillation with an emission spectrum peak of 425 nm [4]. PET has an emission spectrum that peaks at 385 nm [5].

Figure 1 shows the timing properties of PEN (top) and PET (bottom) as measured in the laboratory with 337 nm pulsed Nitrogen laser. Time constants of 27.12 ns and 6.88 ns are measured for PEN and PET respectively. The scintillation time constants were also measured with 120 GeV protons of the Fermilab Test Beam Facility (FTBF) [6] in order to eliminate the intrinsic timing effect of the laser and time constants of 34.91 0.08 ns and 6.78 0.07 ns were measured for PEN and PET respectively [7]. It should also be noted that PET has two time constants (fast and slow) whereas the response of PEN can be described only by a fast component which is much larger compared to the fast component of PET.

Figure 2 shows the response of various scintillator tiles to 150 GeV muons of the CERN SPS test beam [8]. Of particular interest are the PEN and PET tiles for which the responses are 30 fC/MIP for PEN and 20 fC/MIP for PET. The light yields obtained are 1.1 photoelectrons/MIP for PEN with 57% efficiency to detect MIPs; and 0.86 photoelectrons/MIP for PET with 57% efficiency to detect MIPs. These results are shown in Figure 3 top and bottom for PEN and PET respectively.

We tested samples of PEN and PET using laser stimulated emission on separate tiles exposed to 1 Mrad and 10 Mrad gamma rays with a 137Cs source. PEN exposed to 1.4 Mrad and 14 Mrad emit 71.4% and 46.7% of the light of an undamaged tile, respectively, and maximally recover to 85.9% and 79.5% after 5 and 9 days, respectively. PET exposed to 1.4 Mrad and 14 Mrad emit 35.0% and 12.2% light, respectively, and maximally recover to 93.5% and 80.0% after 22 and 60 days, respectively. Figure 4 shows the percent damage after irradiation for PEN (top) and PET (bottom) samples that were irradiated to 1.4 MRad (left) and 14 MRad (right) over the course of approximately two months. The trends were fit to the sum of an exponential and a constant.

3. Development of New Scintillators

As a novel approach to develop radiation-hard scintillators, we doped peroxide-cured polysiloxane bases with pTp, pQp, PPO and/or the secondary fluors 3-HF or bis-MSB. The polysiloxane scintillator base and the other chemicals were purchased from Gelest, Inc. Following the first phase of the production, the custom control circuits were upgraded and the oven was modified. As a result, the production process was highly optimized and tiles of various sizes could be produced (3 cm 3 cm, 10 cm 10 cm and the so-called finger tiles of size 2 cm 10 cm). The tiles can also be machined and polished with no mechanical issues. In order to prepare the samples for testing, we opened grooves for the WLS fibers and made dimples to directly couple the Silicon Photomultipliers (SiPMs). The scintillators are usually referred as Scitillator-X.

Two 3 cm 3 cm tiles (one of which was polished) with SiPMs directly coupled to the dimples were tested with 150 GeV muon beam to measure the response of the tiles to MIPs. The SiPMs were downstream and the tiles were centered with respect to the beam. The lateral size of the beam was much larger than the size of the SiPM, and the muons passing through the tile and 1 mm away from the SiPM location were selected using wire chamber profiles. Figure 5 shows the charge spectra of the polished (top) and unpolished (bottom) scintillator in response to traversing MIPs. The distribution is fit to Gaussian + Landau. The mean for the Gaussian and the most probable value for the Landau functions are constrained to be identical, denoted

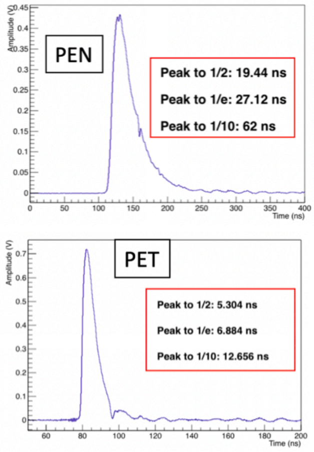

Figure 1. The timing properties of PEN and PET measured in the laboratory.

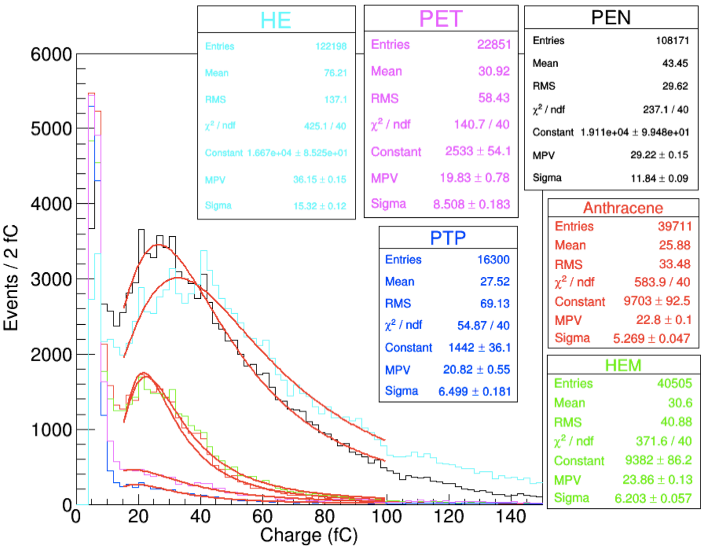

Figure 2. Response of various scintillator tiles to 150 GeV muons.

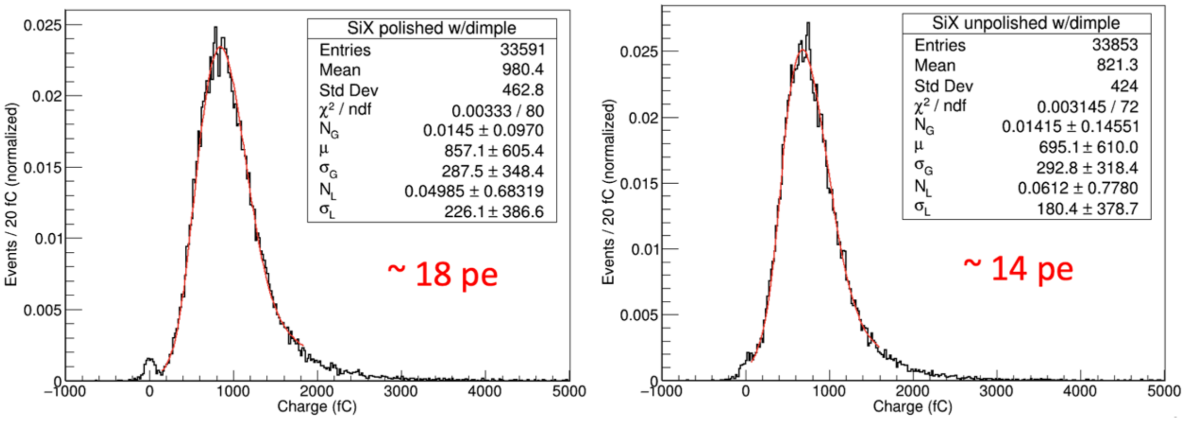

Figure 3. The light yield and detection efficiency of PEN (top) and PET (bottom) measured with 150 GeV muons.

as in Figure 2. The mean response of the polished (unpolished) tile to MIPs corresponds to approximately 18 (14) photoelectrons. With these results, the recent production process modifications are validated. The production procedure can be extended to various currently unprobed specifications.

4. Investigation of LED Stimulated Recovery from Radiation Damage

Scintillators have varying natural recovery properties from radiation damage. Various recovery conditions can be taken advantage of for prolonging the useful lifetime of active media. Intermittent maintenance shutdowns of collider experiments occur on the order of days, to years, which can provide sufficient time for the detector to cool off and its scintillator components to recover to some extent. It has further been shown that this natural recovery can be augmented

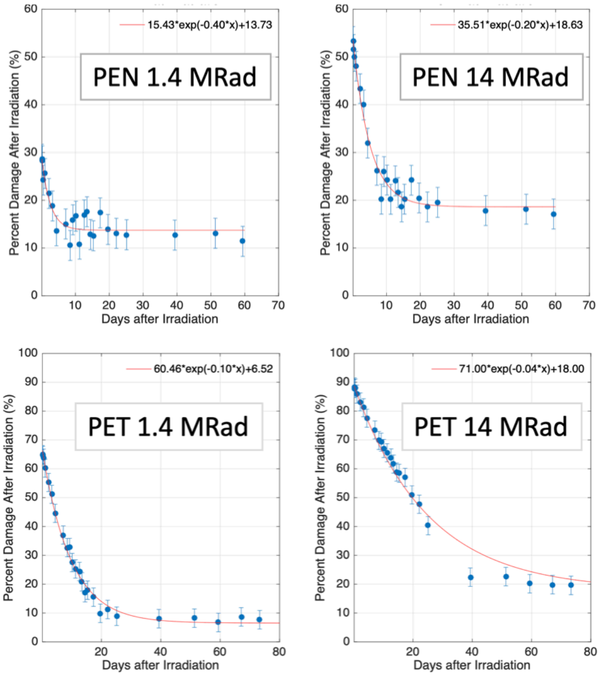

Figure 4. Percent damage after irradiation for PEN (top) and PET (bottom) samples that were irradiated to 1.4 MRad (left) and 14 MRad (right) for a duration of approximately two months.

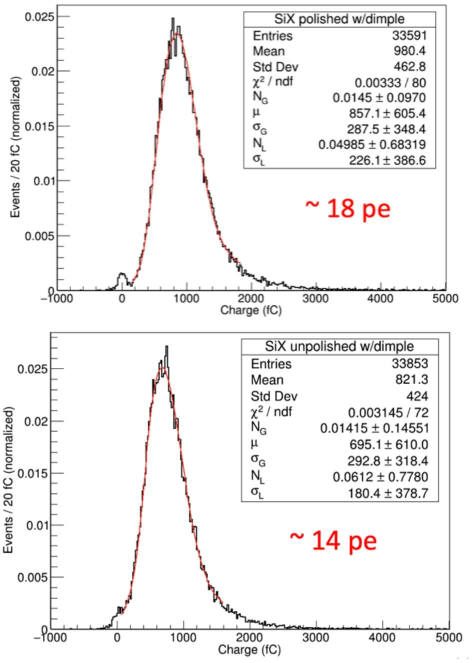

Figure 5. The charge spectra of the polished (top) and unpolished (bottom) scintillator in response to traversing MIPs.

by shining visible and infrared light to the damaged area, improving and extending the lifetime of this particular scintillator [9].

We irradiated various scintillators to investigate their radiation damage and recovery characteristics. One particular sample of each kind was dedicated for LED stimulated recovery tests.

Four tiles of PEN were cut to 5 cm 5 cm 0.1 cm squares. Two tiles of an early version of the new elastomer scintillators composed of p-terphenyl mixed into epoxy, referred to as SiX for Scintillator-X, were prepared as 2.5 cm 4.5 cm 1 cm sizes [10]. Two tiles of Eljen brand [11] EJ-260 (EJN) were cut from a single tile to 2 cm 3 cm 1 cm sizes, and two tiles of over-doped Eljen brand EJ-260 (EJ2P) were cut from a single tile to 2 cm 3 cm 1 cm sizes.

Figure 6 shows the percent damage after irradiation for Scintillator-X (top), EJ-260 (middle) and EJ-260P (bottom) for 40 days following irradiation. SiX showed significant effect, the sample on RGB LED recovering 10% more and faster (4.5 vs 5.5 days).

Neither EJN nor EJ2P showed any significant effect from the LEDs, recovering approximately 24% and 27%, respectively, both for the RGB LED and dark box samples. The variation in permanent damage between the EJN RGB and EJN dark box tiles is primarily due to the systematic differences in the initial damage. The improvement of EJN recovery in the presence of LED stimulation is compatible with this difference. EJ2P does not exhibit any improvement in recovery when stimulated by RGB LEDs. The results indicate that blue scintillators respond to color spectrum but green scintillators are affected very little.

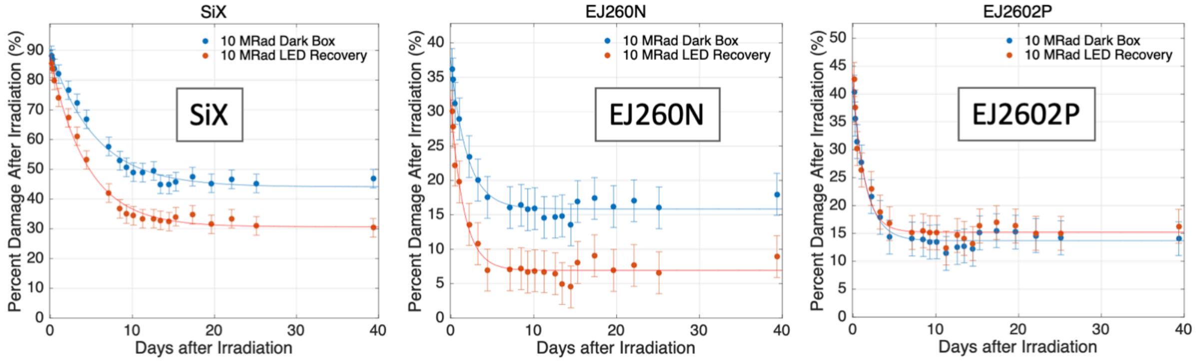

Figure 6. Percent damage after irradiation for Scintillator-X (top), EJ-260 (middle) and EJ-260P (bottom) for 40 days following irradiation.

5. Conclusions

The options of intrinsically radiation-hard scintillators are being expanded with the addition of Scintillator-X. Different variants of Scintillator-X should be probed. With the improved production techniques, various sizes and specifications are now possible.

Intrinsically radiation hard plastics PEN and PET remain to be feasible and cost-effective solutions. Further investigation of their properties, also their mixtures, are needed before implementation in large-scale experiments.

LED mediated recovery techniques are a possible solution to speed up radiation damage recovery. The techniques can now be implemented easily with on-detector electronics.

6. Acknowledgements

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