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Characterization of the Radiation-Induced Damage in a PEN (Polyethylene Naphthalate) Scintillation Detector †

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Abstract: The radiation hardness of a Polyethylene naphthalate (PEN) thin film scintillator has been characterized in terms of the light yield loss after irradiation with 11 MeV protons and 1 MeV electrons. The light yield distributions induced by excitation with radioactive sources have been measured on samples irradiated with different doses and the induced light loss has been computed. Results showed the good radiation hardness behaviors of PEN scintillators, with a light yield loss of ~15% at 10 Mrad and ~35% at the maximum delivered dose of 80 Mrad.

Keywords: plastic scintillators; Polyethylene Naphthalate; materials radiation damage

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1. Introduction

Scintillators are transparent materials that emit light upon excitation by energetic charged particles. They are employed in several applications in order to detect energetic particles and measure their properties [1]. Recent works proved the possibility of using common low-cost plastic polymers like Polyethylene Naphthalate (PEN) as a scintillator for radiation sensing applications. PEN offers excellent scintillation properties like high density (1.33 g/cm^3), a peak emission wavelength at ~425 nm and a light yield of roughly 10^4 photons/MeV [2–4].

Because of these good properties and of its ease of manufacture and low cost, PEN has drawn the attention of the scientific community. Its field of employment ranges from dosimetry purposes in irradiation facilities or nuclear medicine [5] to particles energy measurement in High Energy Physics (HEP) colliders and underground experiments [6,7]. However, many of these applications require the instrumentation to operate in very high radiation environments and have pushed the problem of the detector's radiation hardness to the high priority level [8]. Several works already probed good characteristics of PEN irradiated up to 20 Mrad [9–11].

In this work, we investigate the radiation hardness of a PEN thin-film scintillator. Several samples have been irradiated in air with a 11 MeV proton beam and with a 1 MeV electron beam at the maximum doses of 15 Mrad and 80 Mrad, respectively. The radiation-induced damage has been measured in terms of light-yield loss as a function of the dose. This investigation revealed good radiation hardness behaviors of the PEN, with a light yield loss of ~15% at 10 Mrad and ~35% at the maximum delivered dose of 80 Mrad.

The results described in this work enrich the literature on radiation hardness studies on plastic scintillators, providing useful studies for the introduction of PEN scintillators in nuclear, space and HEP applications.

2. Materials and Methods

Several tiles of 30 × 40 mm² were obtained from a Teonex® PEN film of 100 µm thickness, as shown for an example in Figure 1.

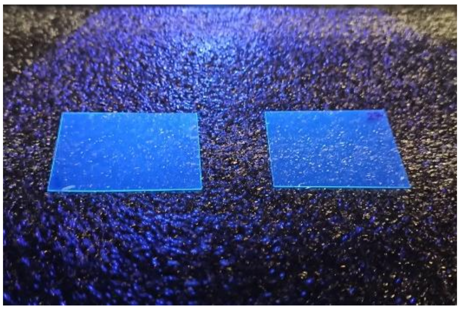

Figure 1. Two 30 × 40 mm² tiles of a PEN thin film scintillator illuminated with UV light.

Samples have been irradiated in air in a controlled room temperature with two particle species (protons and electrons) at several doses. The proton irradiation has been performed at the Tandem accelerator of the INFN Laboratori Nazionali del Sud. The actual energy of the beam on the sample surface was 11 MeV, and the maximum achieved dose was 15 Mrad. The irradiation with 1 MeV electrons has been performed at ILU-6 accelerator at the Centre for Radiation Research and Technology of Institute of Nuclear Chemistry and Technology (INCT) in Warsaw (Poland). In this case, given the high particle flux available, doses up to 80 Mrad have been achieved.

The radiation-induced damage has been measured in terms of the scintillator light-yield loss. The PEN scintillator light yield has been characterized upon excitation with radioisotope sources by coupling the samples to a Hamamatsu R5900 Photo-Multiplier Tube (PMT) with a square and flat light input surface. A schematic representation of the experimental setup is reported in Figure 2

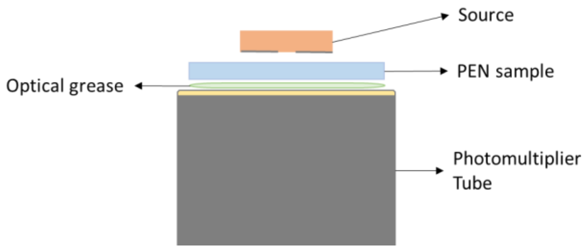

Figure 2. Schematic representation of the experimental setup for the PEN thin film scintillators light yield measurement.

The samples have been optically coupled to the PMT by means of a thin layer of optical grease. The radioactive source was positioned on the other face of the scintillator on top of a thin collimator. Two sources have been used: a ^{241}Am, which decays mainly via alpha-decay with the main emission of a 5.486 MeV alpha particle, and a ^{137}Cs source, which decay via beta-decay by emitting electrons with a maximum energy of 0.51 MeV.

The output signal from the PMT has been sent to an amplifier whose output is read and acquired with a spectroscopy Multichannel Analyzers (MCA) interfaced with a PC.

3. Results

Prior to the irradiation campaign, all samples have been characterized in terms of light yield showing a good consistency with each other.

Fluctuations stay within 2–3%, mainly due to a non-perfect reproducibility of the optical coupling with the PMT.

After the irradiation, samples were kept in a dark environment with a controlled temperature of 25 °C for 60 days prior to characterizing them. According to [9], PEN scintillators show a partial damage recovery mechanism reaching a plateau with a characteristic time of about ten days. Figure 3 shows, as an example, the light yield spectra measured on proton irradiated samples with the Cs and Am sources. As the intent of this paper is to study the relative degradation induced by radiation, an absolute multichannel analyzer calibration was not performed. The effect of irradiation is clearly observable as a reduction of the pulse height, here measured in terms of *channels* of the MCA.

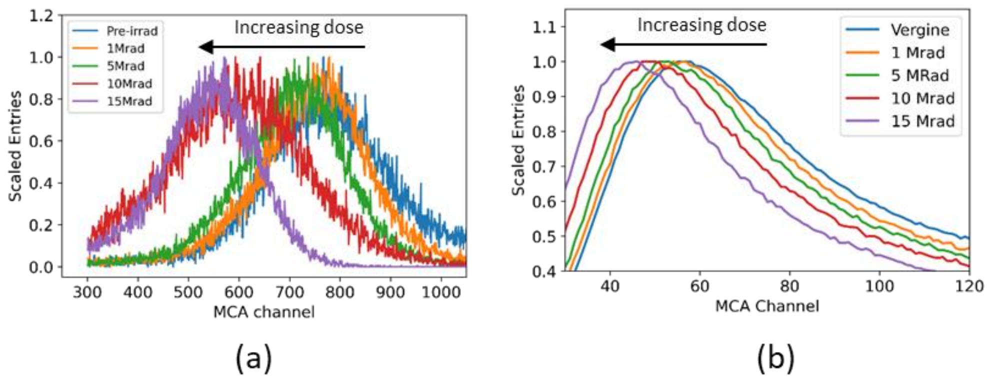

Figure 3. Light yield spectra of proton irradiated thin film PEN scintillators excited by (**a**) alpha particles from a ^{241}Am source and (**b**) electrons from a ^{137}Cs source.

The percent light loss after irradiation has been then computed as a function of the delivered dose. Similar trends have been observed in measurements with Am and Cs. In Figure 4, we report the percent light yield loss measured with the Cs source in samples irradiated with protons and electrons.

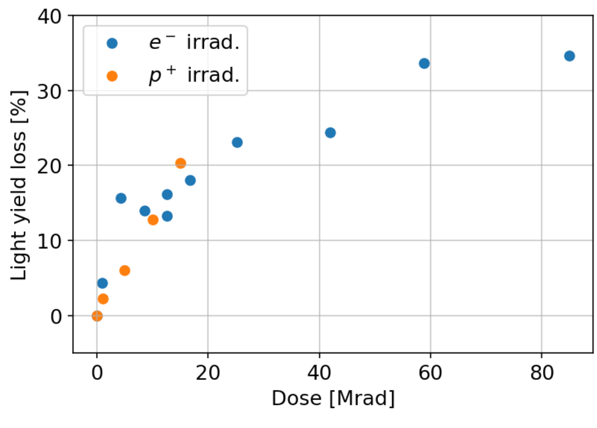

Figure 4. Percent light yield loss after electron and proton irradiations as a function of the delivered dose measured upon excitation with a ^{137}Cs source.

This investigation revealed a reduction of the light yield emission, with similar trends for both irradiation beams. A slowing down of the damage with increasing dose is clearly observable, suggesting that most of the chemical reactions that lead to the deterioration of performances occur early in the exposure.

4. Conclusions

Polyethylene Naphthalate (PEN) thin film scintillators have been characterized in terms of the light yield loss after irradiation with 11 MeV protons and 1 MeV electrons. A reduction of the light yield emission, with similar trends for both irradiation beams, has been observed.

This investigation revealed the good radiation hardness behaviors of PEN scintillators. A light yield loss of ~15% at 10 Mrad and ~35% at the maximum delivered dose of 80 Mrad was observed.

Institutional Review Board Statement:

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Data Availability Statement:

Conflicts of Interest: The authors declare no conflict of interest.

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