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Study of properties of the plastic scintillator EJ-260 under irradiation with 150 MeV protons and 1.2MeV gamma-rays

V. Dormenev¹, K.-T. Brinkmann¹, M. Korjik², and R. W. Novotny¹

¹Justus-Liebig-Universität Giessen, II. Physikalisches Institut, Heinrich-Buff-Ring 16
D 35392 Giessen, Germany

²Institute for Nuclear Problems, Bobruiskaya11, 220030, Minsk, Belarus

Email: v.dormenev@exp2.physik.uni-giessen.de

Abstract. One of the most critical aspects for the application of a scintillation material in high energy physics is the degradation of properties of the material in an environment of highly ionizing particles in particular due to hadrons. There are presently several detector concepts in consideration being based on organic scintillator material for fast timing of charged particles or sampling calorimeters. We have tested different samples of the organic plastic scintillator EJ-260 produced by the company Eljen Technology (Sweetwater, TX, USA). The ongoing activity has characterized the relevant parameters such as light output, kinetics and temperature dependence. The study has focused on the change of performance after irradiation with 150 MeV protons up to an integral fluence of $5 \cdot 10^{13}$ protons/cm² as well as with a strong ⁶⁰Co γ -source accumulating an integral dose of 100 Gy. The paper will report on the obtained results.

1. Introduction

Plastic scintillators play a significant role in the construction of large area detectors in high energy physics (HEP) experiments. Future concepts for detectors, particularly at collider facilities, will require a unique combination of the material features and affordable price. Crucially important will be a minimal level of radiation damage effects under the electromagnetic part of the ionizing radiation as well as due to high energy hadrons. It requires a tolerable deterioration of the optical transmittance, a moderate level of the damage of the scintillation mechanism itself and a minor contribution of the radio-luminescence due to radioactive nuclides which might be generated by nuclear reactions in the material of the detector itself.

A systematic study of the radiation hardness of inorganic optical and scintillation materials has been performed by us since several years [1-7]. We compared damage effects in a variety of inorganic scintillators after irradiation with γ -quanta of a ⁶⁰Co source, 150 MeV protons (KVI, Groningen, The Netherlands) and 24 GeV/c protons (PS, CERN, Switzerland). It resulted in a detailed understanding of the damaging processes in different inorganic samples, in particular in self-activated, Ce³⁺ doped and cross-luminescent crystalline materials.

2. The investigated samples

Here we report on first results of the study of commercially produced plastic scintillation material EJ-260 (ELJEN Technology, Sweetwater, USA). This plastic represents a bright, fast, green light emitting scintillator with properties similar to other products available on the market such as BC428 and NE103, respectively. The relevant parameters are given in table 1. Three different samples with a



thickness of 1.25 cm were investigated before and after irradiation with γ -quanta (^{60}Co source, $E_{\gamma} \approx 1.2$ MeV), 150 MeV protons, respectively.

Table 1. Some selected properties of the investigated scintillation material EJ-260 produced by ELJEN Technology, Sweetwater, USA.

Light Yield	Luminosity	Decay Time	Light attenuation	H/C ratio	Softening Point
%	nm	ns	cm		$^{\circ}\text{C}$
Antracene					
60	490	9.2	350	1/1.1	75

3. Experimental results

The samples were investigated with respect to their optical transmission and luminescence properties before and after irradiation. The initial light output was measured with a calibrated photomultiplier tube (Hamamatsu R2059-01) with bialkali photocathode using different integration gates. Figure 1 illustrates the obtained results.

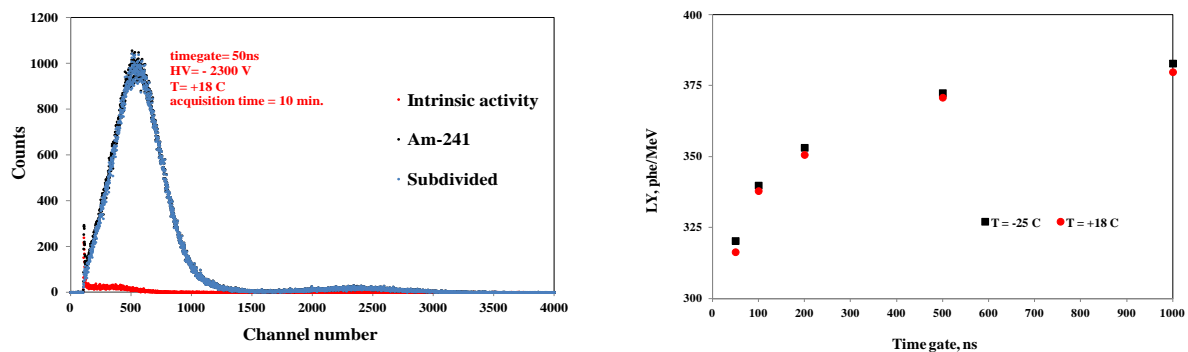


Figure 1. (left) Response to low energy γ -rays of a ^{241}Am source (59.5keV) including the contribution due to background. (right) Light output as a function of integration gate and temperature measured with a ^{241}Am γ -source. The used photomultiplier had a quantum efficiency of 18% at the relevant emission wavelength.

3.1. The radiation damage due to γ -rays

No damage of the material properties was observed after the irradiation with γ -quanta up to an absorbed dose of 100 Gy which is rather consistent with similar studies. The samples did not show any changes in the optical transmittance (see figure 2), scintillation kinetics or light output.

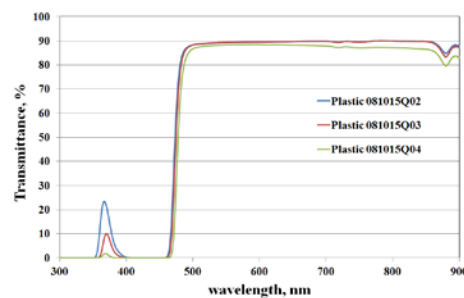


Figure 2. Optical transmission of the investigated samples before and after irradiation with γ -rays of an integral dose of 100 Gy.

3.2. The irradiation with 150 MeV protons

Figure 3(left) shows the results of the transmittance measurement of two samples obtained before and two months after the exposure to 150 MeV protons with a total fluence of $5 \cdot 10^{13} \text{p/cm}^2$. The samples had to be stored cooled due to a too high radioactivity. There is a significant reduction of the optical transmittance in the spectral range of the luminescence spectrum.

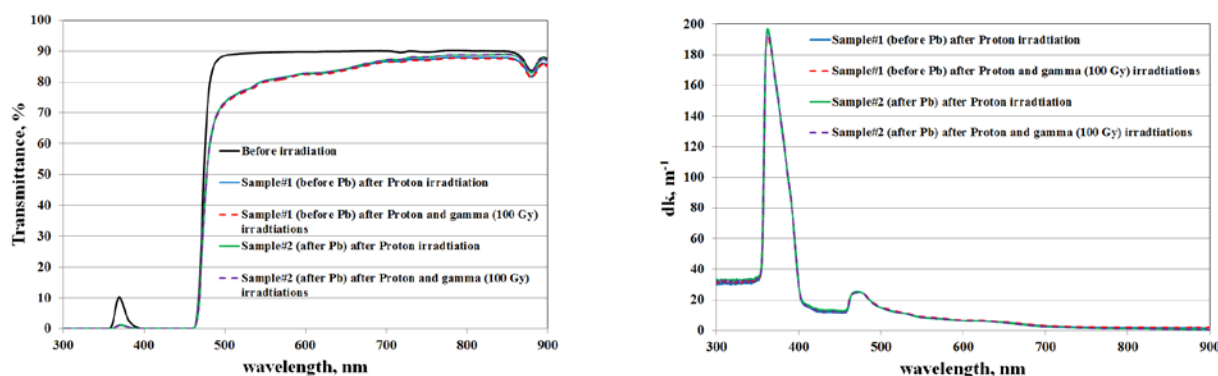


Figure 3. (left) Optical transmittance spectra of two pieces of the EJ260 plastic sample before and after irradiations with 150 MeV protons and low energy γ -rays. (right) Spectra of the radiation induced coefficient of the two pieces of the EJ-260 plastic sample after irradiations with 150 MeV protons and low energy γ -rays.

Figure 3(right) shows for a more quantitative picture the spectrum of the induced absorption coefficient. The spectral range of 380-480 nm is blocked for the observation due to the absorption band of the green emitting organic dye. However, a even larger induced absorption is observed in the gap between the absorption bands of the dyes (350-380 nm). It indicates that most of the color centers which are created in the plastic polymer matrix are created in the UV range. We assume that the damaging mechanisms of the matrix under high energy protons are similar to those we recognized in cases of inorganic materials [1-2, 4]. Even in a light matrix like a polymer high energy protons initiate a variety of nuclear reactions like $(p,^{12}\text{C})$ which lead to the production of light fragments: deuterium, tritium, ^3He and ^7Be . The presence of ^7Be radio-nuclides was confirmed by us in the proton-irradiated samples by characteristic γ -rays identified with a Ge-detector four months after the irradiation took place.

It is worth to note, that the recovery of the optical transmittance damage after the irradiation with protons is rather slow. The additional irradiation with γ -quanta of the proton irradiated samples did not show any additional damage (see Fig. 3). Most probably, similar to inorganic compounds, a creation of the clusters of the defects occurs in polymers as well. Contrary to color centers, which are usually based on a single defect, the color centers in clusters are recombining slowly [1, 2].

Figure 4 shows the dependence of the light yield of the sample irradiated by 150 MeV protons versus the gate width of the integration of the signal. Results were obtained at two temperatures of 18°C and -25°C , respectively.

We did not observe a significant difference in the scintillation kinetics measured at two temperatures. Moreover, we did not observe any slow components in the scintillation kinetics. The integrated light yield reaches a plateau after 500 ns. However, we observed a slowing down of the kinetics in the range below 500 ns. This could be caused by a damage of the organic dye and a change of the transfer efficiency from the UV to the green light emitting dye. Also a trapping of excitations created by additional colour centres cannot be excluded.

As a next step, a comparison of the damage effects between protons of 150 MeV and 24 GeV/c is already foreseen in collaboration with the group of E. Auffray et al. at CERN, Geneva.

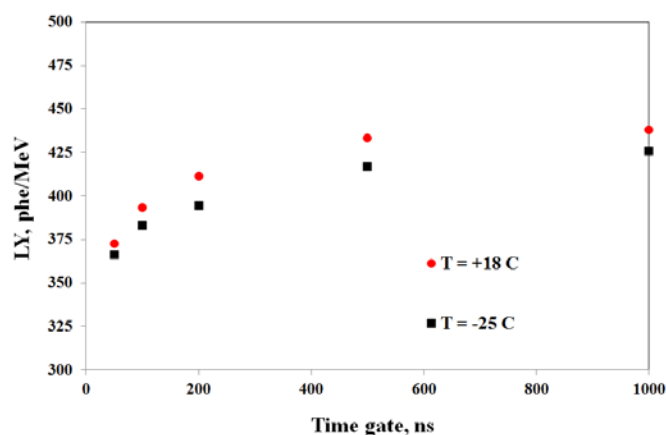


Figure 4. Dependence of the scintillation light yield on the integration gate of the PMT signal measured at two different temperatures for a sample after being irradiated with 150 MeV protons

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