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The influence of neutron radiation damage on the optical properties of plastic scintillator UPS 923A

Skhathisomusa Mthembu^{*a*,1}, Yuri Davydov^{*b*,2}, Vladimir Baranov^{*b*,3}, Bruce Mellado Garcia^{*a*,4}, Joyful Mdhluli^{*a*,5}, Elias Sideras-Haddad,^{*a*,6}

^a School of Physics, University of the Witwatersrand, Johannesburg, Wits 2050, South Africa. ^b Joint Institute for Nuclear Research, Dubna, Russia, 141980.

E-mail: ¹skhathisomusa.mthembu@cern.ch, ²davydov@jinr.ru, ³vladimir.baranov@cern.ch, ⁴bruce.mellado.garcia@cern.ch, ⁵joyemmie@gmail.com, ⁶elias.sideras-haddah@wits.ac.za

Abstract. Plastic scintillators are vital in the reconstruction of hadronic particle energy and tracks resulting from the collision of high energy particles in the Large Hadron Collider (LHC) at CERN. These plastic scintillators are exposed to harsh radiation environments and are susceptible to radiation damage. The effects of radiation damage on the transmittance, luminescence and light yield of Ukraine polystyrene-based scintillator UPS 923A were studied. Samples were irradiated with fast neutrons, of varying energies and fluences, using the IBR-2 reactor FLNP (Frank Laboratory for Nuclear Problems) at the Joint Institute for Nuclear Research. Results show a small change in the transmittance of the higher energy visible spectrum, and a noticeable change in the light yield of the samples as a result of the damage. There is no change observed on the luminescence as a result of radiation damage at studied fluences. The doses and fluences of the neutrons shall be increased and changes in optical properties as a result of the radiation shall be further studied.

1. Introduction

The very nature of detection depends on the mechanisms governing the interactions between incident radiation and the detector material. Scintillators are materials that exhibit luminescence under the presence of ionising radiation. As a result of this luminescence, radiation measurements could be performed, historically, by observing the brightness and intensity of the flashes produced by the radiation incident on the scintillator [1]. There are two common types of scintillators, namely organic and inorganic, with primary differences being structural and from their interactions with ionising radiation. Inorganic scintillators are crystals made from oxides such as bismuth germanate (BGO), or alkali halides such as sodium iodide (NaI) and cesium iodine (CsI). Organic scintillators, or plastic scintillators, as elaborated on in this paper, are of particular interest because of their use in high energy physics for the indirect measurement of the momentum and charge of particles incident on and traversing through them. The plastic scintillator UPS 923A is investigated, because of it's use in the CDF detector at the Fermilab Tevatron [2]. It consists of a polystyrene base/bulk material doped with 2%p-terphenyl (PTP) as the primary fluor and 5-phenyl-2-[4-(5-phenyl-1.3- oxazol-2-yl)phenyl]-1.3oxazole (POPOP) as a secondary fluor that acts as a wavelength shifter for the sensitivity of the photomultiplier tubes (PMTs) collecting the scintillation light [3]. Large scintillator and

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Figure 1: Schematic diagram of IBR-2 reactor at JINR for neutron irradiation of the samples (a) and a schematic of the irradiation facility (b): 1 is the metallic container to hold the samples; 2 the transport beam; 3 are samples for irradiation; 4 is the first biological shield; 5 the second biological shield; 6 is the massive part of irradiation facility; 7 the water moderator; A is the active zone of the IBR-2 reactor; x the distance of moderator surface to the samples, 8 is shutter of biological shield; 9 the emergency stops; 10 is a seen mechanical stop, 11 the rail way. All hatched elements on the figure are parts of the biological shield off the irradiation.

other electronic arrangements [4] relay these measurements' information to complex detection systems for the reconstruction of these particles' trajectories, momenta, and other parametric information of interest, as done by the Tile Calorimeter(TileCal) of ATLAS (A Toroidal LHC Apparatus) at CERN (Geneva, Switzerland) [5].

The optical properties of interest are the transmittance, luminescence and light yield of the scintillators. The transmission study observes how much light, and at what wavelengths, is absorbed as a result of radiation dosage, the luminescence looks at how the scintillating ability (or flourescence) of the material is affected by the varying radiation fluences at varying wavelengths, and the light yield is a more involved study of how the flourescence of a sample is affected by radiation damage under ionising radiation from a specific source [6].

2. Method Overview

The optical properties of Ukraine polystyrene-based plastic scintillator (UPS 923A) were tested by irradiating three of four identical samples of dimensions $20\text{mm} \cdot 20\text{mm} \cdot 6\text{mm}$ with fast neutrons of fluences $1.8 \cdot 10^{14}$, $1.7 \cdot 10^{13}$ and $3.8 \cdot 10^{12}$ neutrons /cm², and studying the change in transmittance, luminescence and light yield of the samples as a function of the radiation dose. The irradiation of samples was performed on channel no. 3 of the IBR-2 reactor at the JINR (Joint Institute for Nuclear Research), Dubna, Russia, as shown in Figure 1 [7]. Three of the four samples were placed at increasing distances from the neutron source, for irradiating at fluences stated above.

The transmittance experiment was performed at the Joint Institute for Nuclear Research (JINR). Samples were placed in a SHIMADZU SolidSpec-2700DUV spectrophotometer[8]. Light from 300nm to 800nm, at 1nm intervals, was transmitted through each sample, and the relative intensity spectra of the transmitted light were observed for analysis.



Figure 2: Schematic diagram of the setup for the light yield experiment

The luminescence experiment was conducted at the University of the Wiwatersrand. A laser was shone onto the sample at the Raman Spectrometry Laboratry. A Lexel 95 SHG model argon ion laser that uses a frequency-doubling crystal to generate 244nm from the 488nm laser line was used for the luminescence studies. The incident UV laser beam was focused onto the sample using a Thorlabs 20x UVB objective. The beam was scanned over a square of size 20micron x 20micron to give some local averaging of the luminescence. The backscattered light was dispersed via a 150 lines/mm grating in a Horiba LabRAM spectrograph onto a liquid nitrogen cooled CCD for detection. The accumulation time was 1 second/spectrum and acquired via LabSpec v5 software. The relative intensity spectra of the luminescence were observed for analysis.

The light yield experiment was performed at the JINR. The experiment was set up as shown on Figure 2 $\,$

The sample was placed under a light-proof cap with a 137 Cs source in close proximity as a gamma source and a Hamamatsu R 2059 PMT for the detection of the sample's fluorescence. The signal from the PMT was relayed to a Keithley 6487 picoammeter and the ampere spectrum from the picoammeter was interpreted by computer software. The picoammeter relative intensity (at given currents) spectra were observed for analysis.

3. Analysis and preliminary results

Transmittance

In this study, the transmittance (%) is defined as the intensity of light collected after transmission through the sample divided by the intensity of the light at that wavelength without the sample (transmittance through air). Figure 3 shows the spectral intensities of transmitted light, at given wavelengths, for each sample. Transmission loss is observed at the low energy UV range of the spectrum, from 400nm to 550nm, for sample 1.

Luminescence

Luminescence, for this experiment, is defined as the intensity of light at a given wavelength arising from the excitement of the sample with a 244nm laser. In Figure 4, a translation increase on the intensity axis is observed for increasing radiation dose, with sample 1 of highest received



Figure 3: Transmitted intensity per wavelength plot for the four samples where reference is the unirradiated sample (or s0), s3 (sample 3) irradiated at $3.8 \cdot 10^{12}$ neutrons /cm², s2 (sample 2) at $1.7 \cdot 10^{13}$ neutrons /cm² and s1 (sample 1) at $1.8 \cdot 10^{14}$ neutrons /cm².

fluence having the largest intensity and the reference sample having the lowest intensity.



Figure 4: Luminescence per wavelength plot for the four samples where Reference is the unirradiated sample 0, Sample 3 irradiated at $3.8 \cdot 10^{12}$ neutrons /cm², Sample 2 at $1.7 \cdot 10^{13}$ neutrons /cm² and Sample 1 at $1.8 \cdot 10^{14}$ neutrons /cm².

Light Yield

The light yield is defined as the current intensity per unit time, observed for each sample. Where luminescence observes relative energy changes by wavelength, the light yield experiment does so by current output as recorded by the picoammeter and transferred to PC data acquisition software. The data from the experiment are saved as histograms of event numbers per current,

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Figure 5: Light yield per wavelength histograms for the four samples where Reference is the unirradiated sample (a), sample 3 irradiated at $3.8 \cdot 10^{12}$ neutrons /cm² (b), sample 2 at $1.7 \cdot 10^{13}$ neutrons /cm² (c) and sample 1 at $1.8 \cdot 10^{14}$ neutrons /cm² (d). The x-axes represent the current, and the y-axes represent the intensity.

and ROOT is used to fit a Gaussian distribution on the histograms to calculate the average current, standard deviation, etc. as shown in Figure 5. The current is correlated to the mean of the Gaussian, and the currents are compared for the different samples.

The mean currents from the different samples were normalised to the reference sample, and the results observed on Figure 6.

4. Summary

The optical properties of irradiated UPS 923A were studied as a function of irradiation damage. The study showed that, at the fluences achieved for the irradiation of the scintillator, a noticeable change in the transmittance is observed at fluences of order $1.8 \cdot 10^{14}$ neutrons /cm². The luminescence studies showed no observable radiation damage effects for the doses achieved, and

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Figure 6: The light yield against irradiation neutron fluence.

the translation of the intensities attributed to surface damages. For a more conclusive study on the effects of radiation damage, higher fluences should be reached. From the light yield studies, the mean current decreased with increasing radiation. Higher radiation fluences should be achieved to establish a direct functional correlation between dosage and radiation damage from neutron radiation. Increasing the dosage will also result in a wider study of radiation damage on the plastic's atomic composition, enriching our appreciation and understanding of plastic scintillators and detection as a whole.

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