

Characterization of damage in in-situ radiated plastic scintillators at the Tile calorimeter of the ATLAS

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Abstract. Ukrainian Polystyrene-based plastic scintillator (UPS923A) samples manufactured by the Institute of Scintillating materials in Ukraine were investigated using Raman scattering techniques. Three irradiated samples of the same type (UPS923A) from the Minimum Bias Trigger scintillator (MBTS) taken from three different positions: Top (T1), Bottom 1 (B1) and Bottom 2 (B2) in the ATLAS detector were investigated. And compared to an un-irradiated sample (D1) of the same type and a 40 MegaGy UPS923A irradiated sample. The aim of this investigative project was to understand how the molecular structures of plastic scintillators are damaged due to high energy collisions at LHC using Raman scattering techniques. It was also to observe if there are any variations in the molecular damage of the plastic at different positions in the MBTS. It was found that the Raman spectra of the irradiated samples at three different positions in MBTS are similar in shape and have similar peaks, thus the extent of the molecular damage at this positions is not easily distinguishable between the samples. It was also observed that the intensities of the Raman spectra peaks of irradiated samples are smaller in magnitude than the intensities of the peaks in the un-irradiated sample, thus bond breaking occurred during radiation interactions to decrease the amount of specific species in the molecular structure of the plastic. The 40 MegaGy irradiated sample Raman spectrum shows extensive molecular damage. Using Raman scattering analysis, it was observed that the benzene rings in UPS923A molecular structure was damaged due to radiation.

1. Introduction

The Tile calorimeter of the ATLAS (A Toroidal LHC Apparatus) experiment at CERN, in Geneva uses plastic scintillators as one of its detection systems to detect high energy proton-to-proton collisions happening inside the Large Hadron Collider (LHC). The ATLAS experiment is also used to detect high energy particles such as the Higgs bosons and thus these experiments will help in the understanding of how these particles behave and to determine which role they have played in the formation of the universe. In July 2012 the ATLAS team announced their discovery of these particles.

The ATLAS detector has few different detector systems, some of them are: Minimum Bias Trigger Scintillators, Zero-Degree Calorimeter, Luminosity Cherenkov Integrating detector and the ALFA Roman pots. It thus uses two minimum bias trigger scintillators (MBTS). These MBTS detectors are installed in a forward calorimeter cryostats located approximately 3.6 m away from the collision point [1].

The MBTS detectors are designed in such a way that they contain 16 alternating 2cm polystyrene scintillators separated by metal plates each and connected to a nominal center consisting of two rings (inner and outer) [1].

It is very important to understand how MBTS detectors are damaged by radiation as this would affect the data collected. Therefore studies have been conducted in this subject by ATLAS teams in different countries around the world. New plastic scintillators have been proposed as a replacement of the old one since the ATLAS detector at LHC is undergoing upgrades. As a result a more radiation resistant plastic scintillator has to be chosen as a replacement to improve the quality of the collected data [1].

Polystyrene Based Plastic Scintillators (UPS923A) was manufactured by the Institute of Scintillating Materials in Ukraine. These plastic scintillators have a high radiation hardness compared to PVT (Polyvinyltholuene). And also they do not degrade naturally. They are made of polystyrene which contains 2% PTP (1, 4-diphenylbenzene) and 0.03% POPOP (1, 4-di-(5-phenyl-2-oxazolyl) benzene) [2].

This study was conducted using three irradiated UPS923A samples from the MBTS detector found on the Tile calorimeter and a 40 MegaGy irradiated UPS923A sample. These samples were irradiated in situ. These samples are then compared to an un-irradiated UPS923A sample. This study uses Raman scattering as a tool to understand how the molecular structure of the plastic scintillator have been destroyed. The three irradiated samples were taken from the top and bottom positions in the MBTS detector. This study will help in identifying any differences between the samples in terms of radiation damage in the molecular level of the plastic. Thus this study will help in the ATLAS upgrades as it outlines how UPS923A scintillator becomes damaged due to radiation at different levels in the MBTS detector. This investigation is more concern about the molecular damage of the plastic. Therefore it will help in determining how strong UPS923A scintillator is.

2. Experimental procedure

Raman spectroscopy is one of the light scattering methods used to investigate the molecular structures of materials without disturbing the material's molecular packaging [3].

A Raman microscope called Horiba Lab Ram manufactured by Horiba Scientific through Jobin Yyou technologies was used to get the data for Raman spectra of each sample. An Argon (green) laser with wavelength of 574nm was used to cause Raman-effect in all the samples except for the 40MegaGy sample. For this sample a 785 nm laser was used instead. A silicon sample was used as a reference to find the reference spectrum. The data collected from Horiba Lab Ram microscope was then used to plot the different Raman spectra for all the samples.

3. Raman spectra analysis for each sample

The Raman spectra for each sample were plotted in order to be able to observe the change in the molecular structure of each sample. This will help in the understanding of how UPS923A plastic scintillator responds to radiation. And also to investigate which bonds are broken during radiation and how these changes affect the scintillation mechanism of the plastic scintillator. Thus the Raman spectra for all the irradiated samples are compared to the un-irradiated sample Raman spectrum to investigate the changes that occurred. Also the peak intensities give a clue on how the plastic scintillator becomes damaged due to radiation.

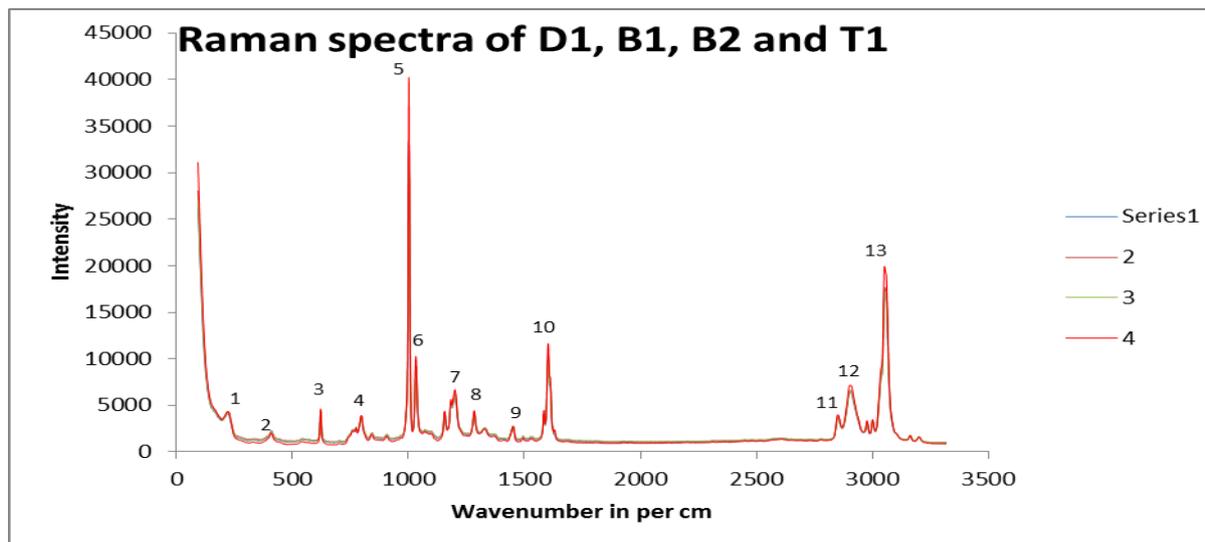


Figure 1. Raman spectra of all irradiated sample from the Tile calorimeter compared to an equivalent un-irradiated sample (see text).

Red represents D1 (un-irradiated sample), Brown represents B2 (2nd bottom irradiated sample), Green represents T1 (top irradiated sample) and Blue represent B1 (bottom irradiated sample). Figure 1 shows the Raman spectra of the irradiated samples and those spectra have numbered peaks intensities which are defined in Table 1.

Using Figure 1, it can be argued that the spectrum of each sample in the MBTS detector, at each position: 1st bottom (B1), 2nd bottom (B2) and top (T1) irradiated samples have similar Raman spectra shape as the Raman spectra of un-irradiated D1 sample. All these samples have 13 peaks in their Raman spectra. It is also noted that the peaks intensities for D1 un-irradiated sample Raman spectrum are larger than that of the irradiated samples, which suggest that some bonds in the plastic scintillator before irradiation were broken.

It can be noted that the molecular structure of irradiated samples and the un-irradiated sample compared is the same. Thus the peaks of D1, B1, B2 and T1 have the same wavenumber and therefore have the same functional group in each sample. But the intensities of the peaks for each irradiated samples are different from the intensities of the un-irradiated sample. Looking at Figure 3, it can be seen that peak 2 of D1 has smaller intensity compared to peak 2 of B1, B2 and T1, which suggest that the irradiated samples have more δ (CC) aliphatic chains compared to the un-irradiated sample.

Looking at peak 5, it can be seen that the intensity of this peak in D1 is very high compared to intensities of the same peak in the irradiated samples. These suggest that there is a depletion of ν (CC) aromatic ring chains after irradiation, thus bonds were broken in the benzene ring. But when B1, B2 and T1 are compared to each other, it is noted that radiation damage is not constant in MBTS detector since their peak intensities are not equal (see Figure 3).

Using Figure 2, it can be noted that the Raman spectrum of UPS923A 40 MegaGy sample is different from the other Raman spectra of the samples from MBTS detector. Again using Figure 2, it can be seen that all the peaks in the Raman spectra ranges from 700-900 cm^{-1} . This region corresponds to the ν (CC) alicyclic, aliphatic chains vibrations region when using Horiba Raman band analysis (refer to [4] and Table 1) for comparison. This suggests that the benzene ring was completely destroyed, thus that the material was extensively damaged by radiation. This also tells us that as the radiation dose is increased, radiation damage increases, thus more bonds are destroyed in the molecular structure of the plastic scintillator.

Table 1. Peak analysis using Horiba Raman Analysis Table [5] for all samples.

Assigned Peak number:	Functional group/vibration	Region In per cm	Peak Wavenumber in per cm	Raman
1,2,6,7,8	δ (CC) aliphatic chains	250-400	221.334	strong
3,4	ν (CC) alicyclic, aliphatic chains vibrations	600-1300	621.92	medium
5	ν (CC) aromatic ring chain vibrations	1000	1003.73	Strong/medium
9	δ (CH ₂) δ (CH ₃) asym	1400-1470	1449.52	medium
10	ν (C=C)	1500-1900	1603.65	strong
11,12	ν (C-H)	2800-3000	2851.61	strong
13	ν (=C-H))	3000-3100	3053,72	strong

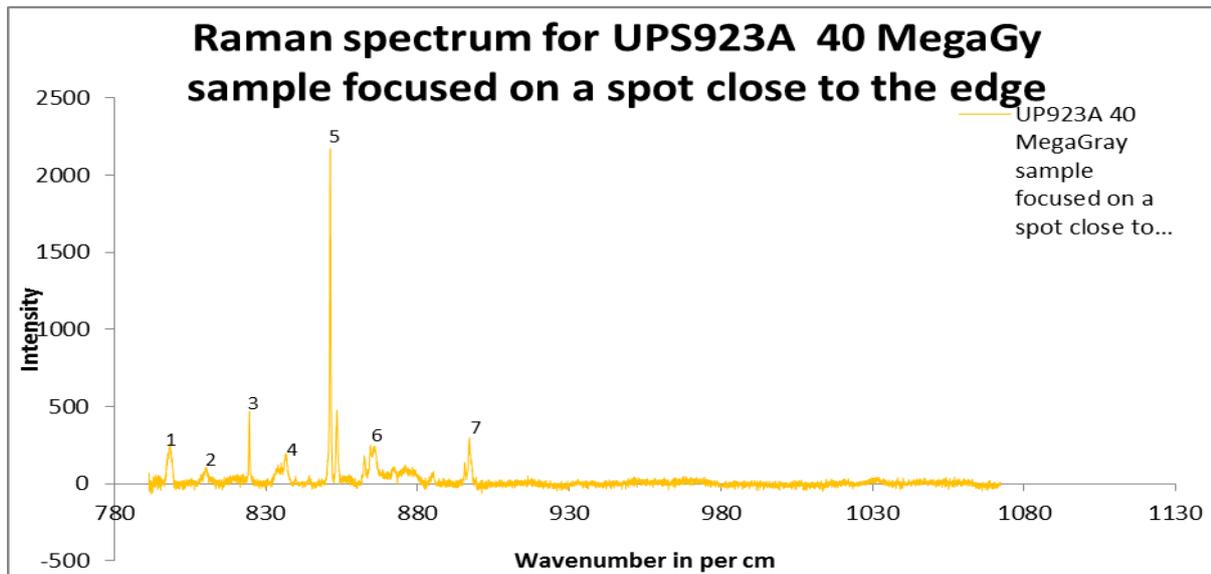


Figure 2. Raman spectrum for UPS923A 40 MegaGy sample.

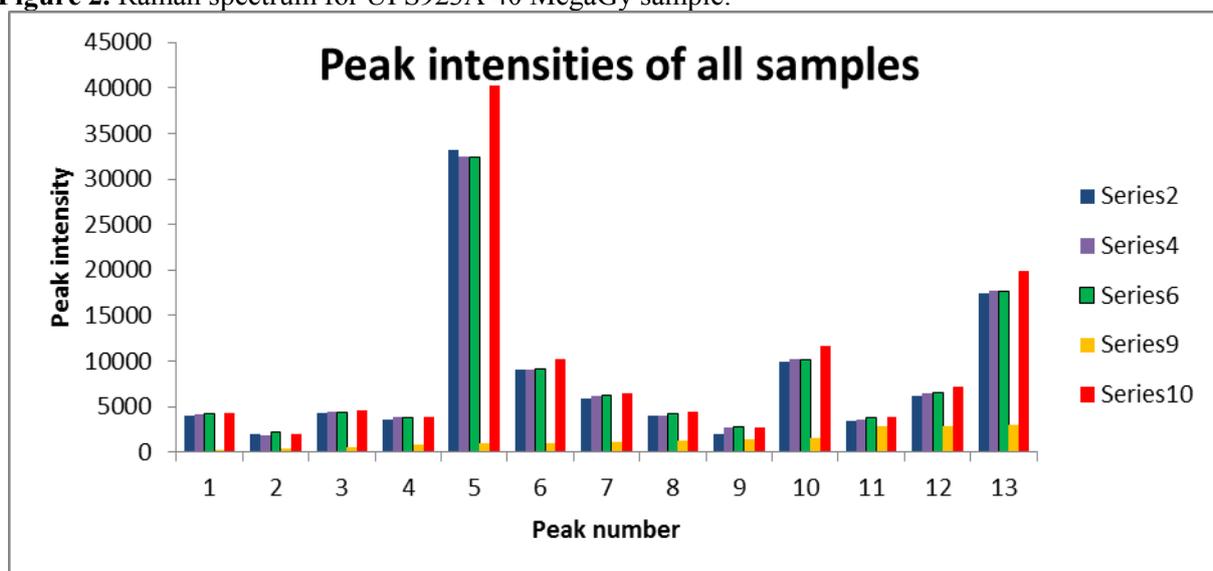


Figure 3. Compared peak intensities of all samples (see text).

Red represent D1 (un-irradiated sample), Blue represent B1 (1st bottom irradiated sample), Purple represent T1 (top irradiated sample) and Orange represent 40 MegaGy irradiated sample.

It can be noted that the peaks intensities of B1, B2 and T1 are not the same, which suggest that radiation damage in the MBTS detector is not constant; it depends on where the plastic scintillator is located. According to Figure 3, the bottom sample (B1 and B2) was damaged more than the top (T1) sample plastic scintillator from MBTS detector. It can be noted that the peak intensities for peak 1,2,3,4,6,7,8,9,10,11,12,13 of B1 are smaller than those of T1 and B2. These suggest that the radiation damage in B1 is greater than the radiation damage of the same type of plastic scintillator at position B2 in MBTS detector.

4. Summary

Radiation damage in the MBTS detector is not constant; it depends on the position of the plastic scintillator relative to action or collision point. This can be supported by the differences observed for the peaks intensities of B1, B2 and T1. Therefore, it has been observed that B1 (bottom irradiated sample) becomes damaged more than the other plastic scintillator samples taken from the top position. This suggests that radiation damage to plastic scintillators depends on the amount of radiation exposure, that is, the higher the radiation exposure the more the plastic scintillator becomes damaged.

By comparing the 40 MegaGy sample with the other samples from MBTS detector, it can be observed that radiation damage destroys the molecular structure of plastic scintillators and the extent of the damage depends on the amount of radiation concern. It is also observed that the benzene ring in plastic scintillator's molecular structures is one of the highly destroyed functional groups and this observation is consistent with theoretical literature. This can be supported by the high difference between the peak intensities of peak 5 for each sample from MBTS detector compared to an un-irradiated equivalent sample D1. This suggests that these samples molecular structures are destroyed due to radiation damage. For the 40 MegaGy irradiated sample, the benzene ring is entirely destroyed due to radiation.

UPS923A plastic scintillator is relatively stronger as it can be seen in the results, that the benzene rings are not completely destroyed. This means that the plastic scintillator can still undergo scintillation process. But this will depend on the amount of radiation exposed.

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