Radiation Hardness Tests of CsI(Tl) Crystals for the GLAST Electromagnetic Calorimeter

S. Bergenius,[1] S. Carius,[2] P. Carlson,[1] J.E. Grove,[3] G. Johansson,[2] W. Klamra,[1]
L. Nilsson[2] and M. Pearce[1]
(1) Dept. of Physics, The Royal Institute of Technology, Stockholm, Sweden
(2) Department of Technology, Kalmar University, Kalmar, Sweden
(3) Naval Research Laboratory, Washington DC, USA

Abstract

The electromagnetic calorimeter of the Gamma ray Large Area Space Telescope (GLAST) consists of 16 towers of CsI(Tl) crystals. Each tower contains 8 layers of crystals (each 326.0×26.7×19.9 mm^3) arranged in a hodoscopic fashion. The crystals are read out at both ends with PIN photodiodes. Crystals produced by Amcrys-H (Ukraine) are used. As a part of the quality control procedure during crystal production, samples from the uncut boules are systematically irradiated with gamma rays from a ^{60}Co source. Studies have also been carried out to verify the correspondence between the post-irradiation properties of the boule samples and the full size crystals which are subsequently cut from the boule. The full size crystals have also been irradiated with a 180 MeV proton beam and the radiation induced attenuation measured.

1. Introduction

The Gamma ray Large Area Space Telescope (GLAST) [3] will detect gamma rays in space over the energy range 10 keV - 300 GeV. Launch is scheduled for 2006, and the design lifetime is 5 years. The GLAST electromagnetic calorimeter [2] consists of 16 towers of CsI(Tl) crystals and each tower contains 8 layers of crystal logs arranged in a hodoscopic fashion. In total there are about 1600 crystals, each measuring 326.0×26.7×19.9 mm^3. The flight crystals are read out with PIN diodes at each end. The radiation hardness of the CsI crystals is important to ensure optimum performance throughout the duration of the experiment. The long, narrow shape of the crystals is not an optimal shape for minimizing the effects of radiation damage, since one prominent effect is increased attenuation of the scintillation light.

The crystals are grown by Amcrys-H in Ukraine, and between 25 and 50 full sized crystals are cut from one boule (fig. 1). From each boule, two samples (each 25.0 mm in diameter and 25.0 mm in height) are cut from the top and the bottom respectively. The concentration of thallium (and possibly other traces)

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Fig. 1. *Left:* A CsI boule being cut. *Right:* A full-size crystal (top) and a boule sample.

generally varies from top to bottom and so some variation in radiation damage can be expected. A high thallium concentration reduces the radiation tolerance [1]. The bottom samples are irradiated with gamma rays to check the radiation hardness of the boule.

Two radiation tests have been performed, one with ^{60}Co gamma rays with an average energy ∼1 MeV, and one with 180 MeV protons from a cyclotron. One aim of the first test was to check for a correspondence between the irradiation properties of the full-size crystal and the boule sample.

2. Radiation Hardness Tests

The boule samples are read out at one end with a PIN photodiode. The boule samples are accepted if they exhibit less than 50% degradation in light output after 100 Gy of ^{60}Co gamma rays. The light output is characterised using a ^{22}Na source.

A first test of the gamma radiation hardness of a full-size CsI(Tl) crystal was performed. The ^{60}Co radiation facility at the Karolinska Institutet in Stockholm, Sweden was used, delivering a dose rate of 20 Gy/h in the crystal. Crystal performance was monitored using the 0.846 MeV line from a ^{56}Co source. The crystal was read out at each end by PM tubes via a 2 mm air gap. Before irradiation a reference measurement was made. The light output from both ends was measured with the ^{56}Co source placed at different positions along the crystal. Irradiation was done in steps giving accumulated doses of 20, 50, 150, and 180 Gy. To ensure uniform irradiation, the crystal was rotated 90° after each irradiation step. Exposure to high fluxes of radiation can induce long-lived light emission in the crystal, so called "afterglow". Thus, the crystal was left to cool down after each irradiation period.

The proton irradiation test was conducted with a cyclotron at The Svedberg Laboratory (TSL) in Uppsala, Sweden. The cyclotron delivered a 180 MeV proton beam. The crystal was placed at 45° angle to the beam axis in order to obtain as uniform illumination as possible. It was rotated so that the protons had to penetrate the shortest distance, i.e. the 26.7 mm dimension of the crystal was put transverse to the beam direction. Between irradiation periods, the crystal was rotated 180° to obtain a more uniform energy deposition throughout the penetration depth. Protons deposited 41 MeV in the crystal with a variation of 18% between front and rear surface. The accumulated dose was given in steps of 20, 70 and 175 Gy. The degradation in light output from the crystal was measured with cosmic muons depositing 5.6 MeV/cm on average. A penetrating muon was identified by a telescope made from two plastic scintillators. The crystal was equipped with photodiodes at each end. The diodes were shielded by 10 cm of lead during proton irradiation. These covered a 2 cm wide area and were placed above and below the crystal at its middle. The setup had been calibrated by taking a muon spectrum before the crystal was exposed to any protons. The centroid of the fitted muon peak was taken as a measure of the light output from the crystal.

3. Results

Fig. 2 shows the result from the radiation hardness tests. Light pile-up due to afterglow complicated measurements. The decay time for the afterglow was measured after the last irradiation period, and the other measurements were corrected for this effect. After 6 h the afterglow gives 20-30% larger pulse at 0.846 MeV. After 16 h some afterglow was still present. After 70 h the asymptotic value had clearly been reached.

After 180 Gy, the light output from the long crystal had decreased by (24±4)%. Previous boule sample tests showed a decrease in light production of 19% after 86 Gy and 15% after 92 Gy, respectively, for two different sample crystals, one from the top of the boule, the other from the bottom (see fig. 2). This agrees well with the number (17±4)% found in the present test when the source was placed close to the PM. No significant difference could be seen between the left and right PM with the source at the same relative position.

The result of the proton radiation test is also shown in fig. 2. The noise from induced radioactivity had an upper end point around 8 MeV. Due to the short beam time available, only measurements after the final dose of 175 Gy are presented. The measurement of the light output was repeated several times after the final irradiation period and showed that the average light output had decreased with (21±7)% relative the original light output after 175 Gy of proton radiation.

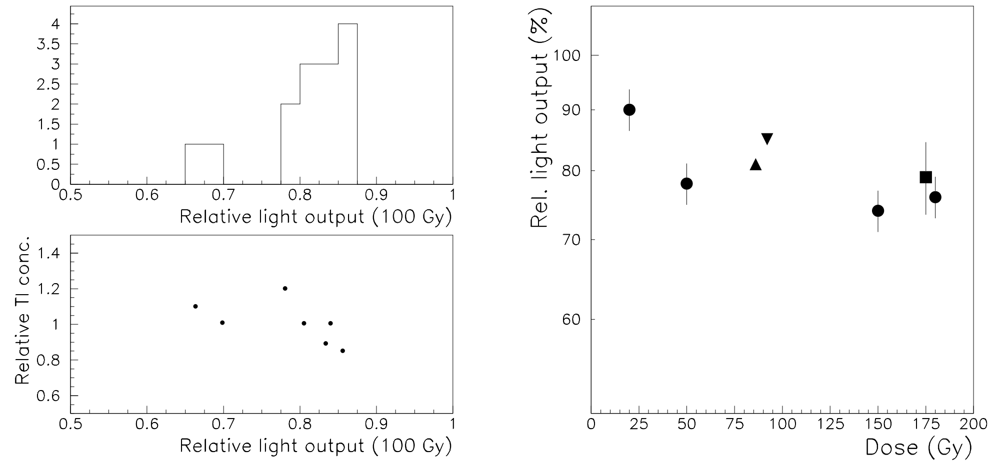

Fig. 2. *Upper left:* Relative light output from 14 boule samples after 100 Gy of gamma radiation. *Lower left:* Relative light output from a subset of 7 boule samples after 100 Gy of gamma radiation for different thallium concentrations. *Right:* Relative light output of gamma irradiated full-size crystal (circles), gamma irradiated boule samples (triangles) and a proton irradiated full-size crystal (square) versus accumulated dose.

4. Summary

The GLAST CsI(Tl) crystals show radiation damages of similar magnitude for equivalent ionising doses of ^{60}Co gamma rays and 180 MeV protons. We find that the average light output from a full-size (326.0 mm long) crystal decreases (24±4)% after 180 Gy of gamma radiation, and as seen with PM tubes. From the differences between the far and near end we also conclude that there are two components contributing to the radiation damage. When the source is placed far from the PM, and the light has to travel throughout the crystal, the decrease in light output is significantly larger than when the source is placed close to the PM. This effect was similar for left and right PMs. Thus, we conclude that both light production as well as light attenuation in the crystal material becomes worse after irradiation. After 175 Gy of 180 MeV protons, the average light output from a full-size crystal decreases by (21±7)%.

5. References

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