

 GLAST LAT TECHNICAL NOTE	Document # LAT-TD-01213-01	Date 10 Jan 2003
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	Subsystem/Office Calorimeter Subsystem	
Document Title First Radiation Hardness Tests of CsI(Tl) Crystals from Amcryst H		

1. Introduction

The GLAST electromagnetic calorimeter will contain about 1500 CsI(Tl) crystals with the shape of 33 cm long logs having a cross section of $2.7 \times 2.0 \text{ cm}^2$. These crystals are purchased from Amcryst H in Ukraine. Between 25 and 50 crystals can be cut from one boule. According to the contract GLAST will test samples from each boule before it is cut into crystal logs. The boule samples are used to test the radiation hardness of the crystal material.

Before and after Summer 2002 boule samples were obtained from 4 different boules, viz. 32k4, 33k4, 34k4 and 40k4. Two pairs of sample crystals were obtained from boules 33k4 and 40k4, and a single sample crystal from each of the boules 32k4 and 34k4. All sample crystals have the shape of a cylinder being 25 mm in diameter and 25 mm long. A first set of 4 sample crystals, one from each boule, have been tested by using a ^{60}Co source at the Nuclear Chemistry Department of the Royal Institute of Technology in Stockholm. We here report on the results of these tests.

2. Test Procedure

The boule sample crystal to be tested was equipped with a PIN diode. The light yield was measured by using a $2 \mu\text{Ci } ^{22}\text{Na}$ source. Data was collected during 500 seconds. Fig. 1 shows a typical spectrum. As a measure of the light output from the crystal we used the mean of a gaussian fitted to the 511 keV annihilation peak. The crystal, with its diode mounted, was after the initial light yield measurement disconnected from the electronics setup and placed inside the intense ^{60}Co source (fig. 2).

The accumulated radiation dose was increased

in steps as listed in table 1. Before the irradiation of a crystal started, a reference spectrum was taken with the ^{22}Na source. After an irradiation period and when removed from the ^{60}Co irradiation chamber, the crystal was left to “cool down” for one hour. The crystal was subsequently connected to the data taking system again and exposed to the ^{22}Na source. The light yield was measured as prior to irradiation. All 6 sample crystals were subject to this test procedure.

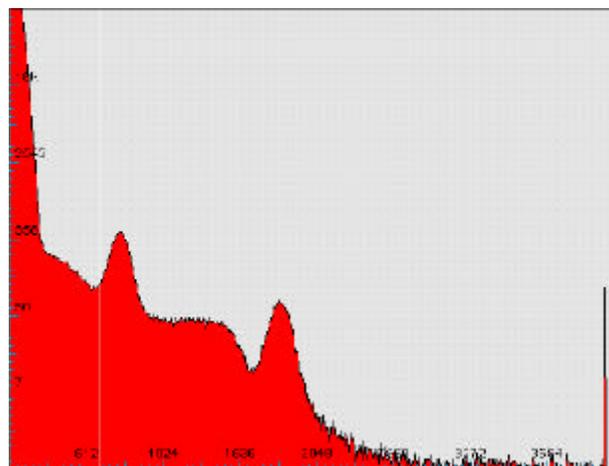


Fig.1: A typical pulse-height spectrum from ^{22}Na .

The effect of after-glow was monitored during the two first crystal tests (samples from boules 32k4 and 34k4). A pulse-height histogram was collected with the ^{22}Na source every 20 minutes. The robustness of the electrical setup was also checked. No variation in signal size could be observed. Temperature was also monitored.

Table 1: Listed are the accumulated doses in krad for the four irradiated crystals. The irradiation was carried out in steps. After each step crystal performance was monitored.

crystal	step 1	step 2	step 3	step 4	step 5	step 6	step 7
32k4	0.1	0.3	0.7	1.0	2.2		
34k4	0.2	0.5	1.1	2.2	3.6	5.4	7.2
33k4	0.2	0.6	1.3	2.5	4.2	6.3	8.4
40k4	0.2	0.6	1.3	2.6	4.3	6.5	8.6



Fig.2

3. Equipment

The equipment used for the test consists of several parts. We describe the test device being the boule sample crystal fitted with a PIN diode, the light yield measurement setup, and the intense ^{60}Co source.

3.1 Test Device

Each sample crystal has one end surface highly polished. At this surface a Hamamatsu 3590-05 PIN-diode was attached, using a wax-like meltmount substance [1]. The meltmount had to be heated to 70°C to become enough viscous for application. It was left on the epoxy surface of the diode for about 2–3 minutes in the oven. By then it had spread over the entire surface and it could be pressed onto the crystal. The sample crystal with its PIN-diode was wrapped in white Tyvek and light tight black Tedlar.

3.2 Light Yield Measurement Setup

The ^{22}Na source used to measure the crystal light yield was collimated by using a 45 mm thick lead block with a 10 mm hole. The lead collimator was placed directly in front of the crystal, against the crystal surface being opposite the PIN-diode. A support structure was used to fix the crystal against the collimator. It was necessary to shield the preamplifier to reduce noise pickup from external fields. Thus, the ^{22}Na source, collimator, crystal and preamplifier were housed in a metal box (see fig. 3).

The signal from the PIN-diode was treated using a 5093 preamplifier from eV Products. The signal from the preamplifier was fed to a NIM linear amplifier Tennelec TC205A. Shaping time was set to $3\ \mu\text{s}$ and the gain factor to 500. The pulses from the NIM amplifier were analyzed with a multichannel analyzer Amptek MCA-8000 having 4096 channels. The spectrum was recorded with a laptop computer.



Fig.3: Details of the preamplifier assembly. Lead collimator and attached ^{22}Na source is also seen.

3.3 The ^{60}Co Source

The source contains a number of 203 mm long stainless steel pencils filled with ^{60}Co in the form of metallic cobalt. These are mounted in a cylindrical geometry measuring 209 mm between centers of opposing pencils. There are in total 48 slots that can be loaded with ^{60}Co pencils. Not all 48 were loaded at the time of these tests. A motor driven drawer consisting of a steel-encased lead cylinder enables the object to be irradiated to be lowered down in the center of the source. For these measurements the sample crystals were placed at the bottom of the cylinder, since the gamma flux is smallest at the bottom.

4. Calibration of Dose Rate

The dose rate of the source is calibrated by the Nuclear Chemistry Department once per year using a chemical method denoted Fricke dosimetry [2], which is based on oxidation of ferrous ions (Fe^{2+}) to ferric ions (Fe^{3+}) under the influence of ionizing radiation. The amount of Fe^{3+} formed through irradiation is determined by measuring the optical density at 304 nm, the wavelength of maximum absorption for ferric ions. This is done using a spectrophotometer. A non-irradiated sample is first analyzed and used as reference. The method gives an accuracy of about 9% fwhm mainly coming from determining the amount of Fricke solution.

We performed a calibration run using Fricke standard solution in a vessel having the same size and shape as the CsI sample crystals, i.e. a cylinder being 2.5 cm in diameter and 2.5 cm high. The absorption at 304 nm was measured directly after irradiation and compared to a non-irradiated sample of the same solution. This procedure was repeated a few times, viz. after the accumulated exposure time was 2.5, 5.0, 7.5 and 10 minutes. The difference in absorption between the irradiated and non-irradiated solutions was plotted versus accumulated time of exposure. The dose rate was calculated from the slope in the diagram using data from [2], which gave the result 8.0 ± 0.7 krad/h. The dose rate in CsI is however somewhat different.

^{60}Co gives two gamma energies (both in 100% of the decays), viz. 1.173 MeV and 1.333 MeV.

The gamma absorption coefficients (μ) for CsI(Tl) at these two gamma energies are 0.296 cm^{-1} and 0.277 cm^{-1} , respectively. For standard Fricke solution they are respectively 0.0669 cm^{-1} and 0.0626 cm^{-1} [3]. For a certain gamma trajectory penetrating a distance d of the material (CsI or Fricke solution) a fraction $1 - e^{-\mu d}$ will be absorbed in the material. For the largest possible penetration distance the ratios between the fractions for CsI and Fricke solutions are 3.08 and 3.14 for the two gamma energies respectively. For the smallest penetration distance both ratios approach 4.42.

The frequency of various penetration distances was simulated and yielded the result shown in fig. 4. Combining this result with the ratio between numbers of absorbed gammas gives the result that the dose rate in a sample CsI(Tl) crystal is 81% of that in a sample of standard Fricke solution having the same size

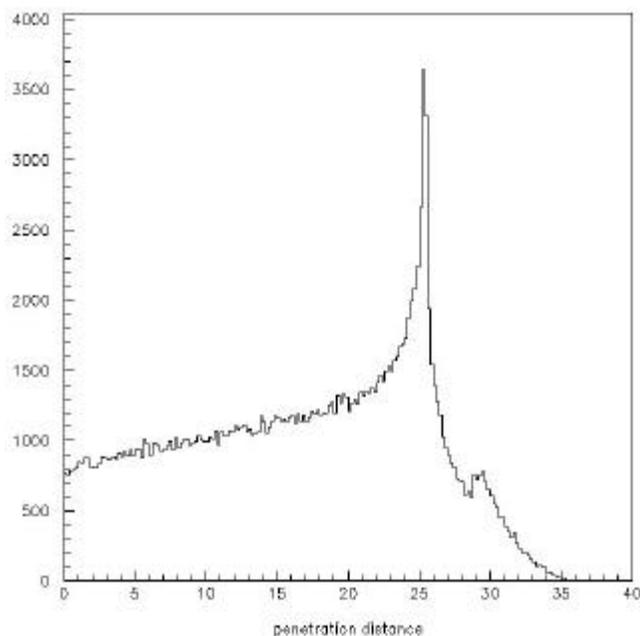


Fig. 4: Distribution of gamma penetration distances in mm from ^{60}Co in a sample crystal.

and shape. We conclude that the dose rate in a sample CsI(Tl) crystal was 6.5 ± 0.6 krad/h.

5. Results

Fig. 5 shows the relative position of the 511 keV peak as a function of the accumulated radiation dose for the 4 sample crystals. The error in peak position has a systematic component from limited reproducibility of connector resistances, estimated to 0.7%. Statistical uncertainty is less than 0.1%. The error in accumulated dose comes from limited accuracy in calibrating dose rate; see above.

The boule sample crystals are cut from the top or bottom of the boule. Because the concentration of thallium (and possibly other tracers) generally differ between top to bottom, we can expect some variation. A high thallium concentration reduces the radiation tolerance [4]. One pair sample crystals, from boule 40k4, was individually labeled by Amcrys H and could be identified with top and bottom of the boule. The other boule samples were not labeled upon delivery from the vendor and, hence, could not be identified with top and bottom of the boule. In the future all samples will be marked with “top” or “bottom”. According to Amcrys H the thallium concentration can be up to 25% larger at the bottom as compared to at the top of the boule.

None of the sample crystals shows a decreased light output after irradiation, which is less than 80% of the original light output. Some crystals received more than 8 krad. It can be clearly seen, however, that the crystal becomes more noisy after irradiation. The 511 keV peak after 4 krad and one hour after irradiation stopped is about 23% broader than before irradiation. The observed decrease in light performance is expected [4, 5] and is within the limits specified in the document “LAT Calorimeter CsI Crystal Performance Requirements” [6] and referred to in the purchase order.

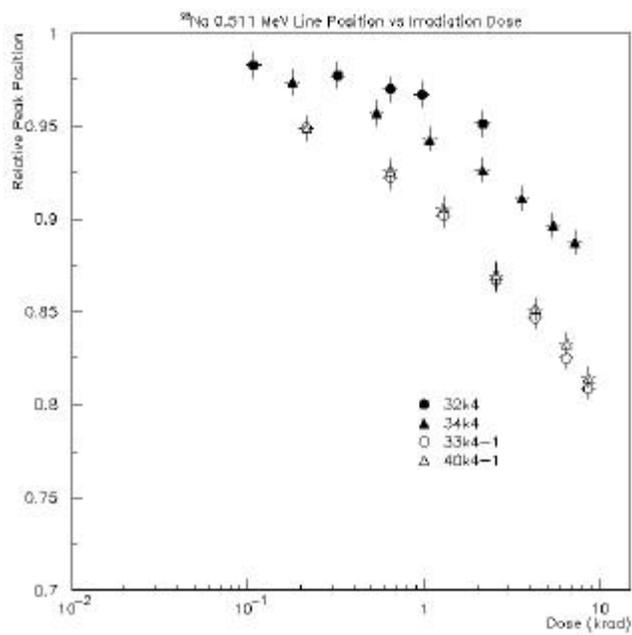


Fig. 5: Decrease in light output from a sample crystal vs. accumulated gamma dose.

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