REQUEST FOR ACTION (RFA) RESPONSE

GLAST LAT Project
Calorimeter Peer Review   17 – 18 March 2003

Action Item:	CAL – 020
Presentation Section:	Detector Elements
Submitted by:	Rafe Schindler

Request: Radiation testing - To what extent is radiation damage reproducible? Are the results just fluctuations due to experimental procedures? Tables had no error bars.

Reason / Comment: Verify test results are true representations of capability vs test procedure variance.

Response: 8 May 2003, Staffan Carius, Sara Bergenius

The measurements for the irradiation of the 326 mm CsI log are shown in Figure 1. The light yield was measured prior to the test and after 2 kR, 5 kR, 15 kR, and 18 kR total dose. For each measurement, the crystal was removed from the beam and allowed to rest in the Crystal Optical Test Station, which was inspired by the BaBar test stations. The crystal is viewed at both ends by a Hamamatsu R669 PMT, and a collimated ^{56}Co source is positioned in the center of the crystal. A spectrum is accumulated for 5 minutes. The

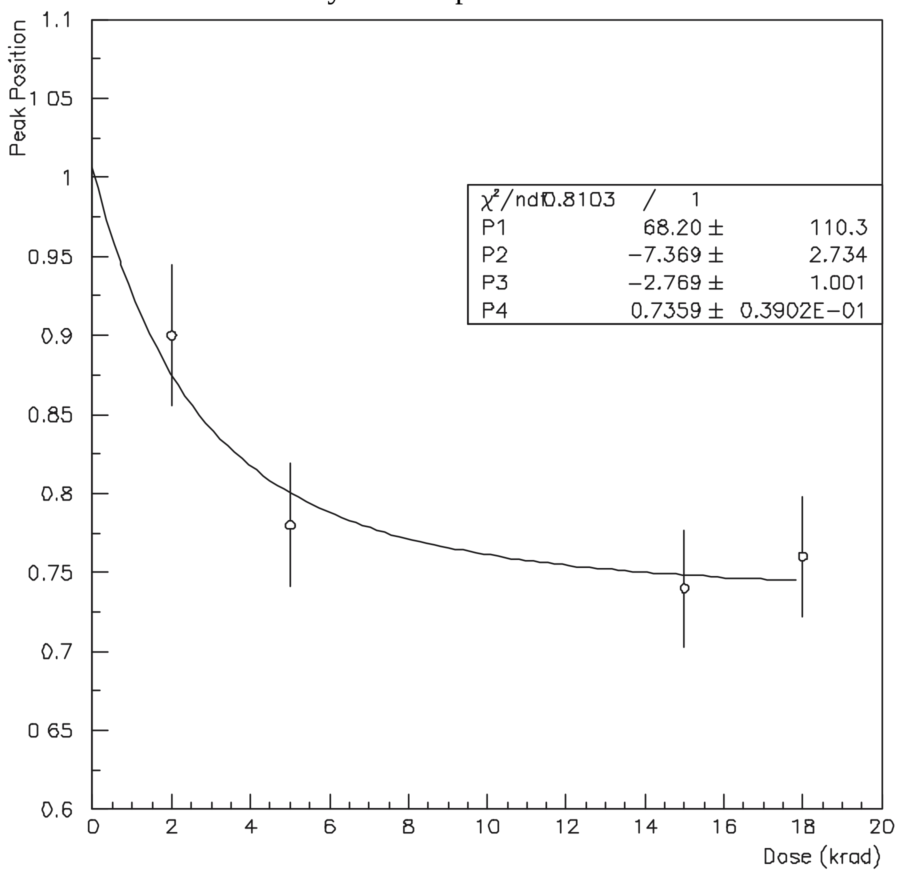

Figure 1. Measured data with fitted light yield curve.

846 keV line and nearby continuum are modeled by the sum of a gaussian, and exponential, and a constant.

Error Analysis

The analysis of data is done with PAW [1]. Peak fitting uses the MINUIT package. The function used to fit the peak region of the histogram is a sum of a gaussian, an exponential and a constant:

$$f(x) = \frac{A}{\sqrt{2\pi\sigma^2}} e^{-(x-x_0)^2/2\sigma^2} + Be^{-\alpha x} + C$$

where A, B, C, x_0, σ, and α are the fit parameters. Of relevance for the test is the fitted value x_0 of the gaussian mean, which is taken as a measure of the peak position and the light output from the CsI crystal. The rms uncertainty Δx_0 is delivered from the fitting program and used for further error analysis.

The light output L from the crystal depends on the deposited energy E, the longitudinal distance from the PM to the deposited energy, and the efficiency e in the light coupling between crystal and PM. In addition, it will depend on the radiation dose. The longitudinal position of the ^{22}Na source used as a standard candle is accurately reproducible, not to cause any significant variation in light output. Thus, we can write

$$L = eyE$$

where y expresses the signal degradation due to radiation damage. It is the precision in determining y that is the focus of this error analysis. We have seen that the efficiency in the light coupling is reproduced within 4% when removing the crystal and putting it back in the test bench again, i.e. $\Delta e/e = \pm 2\%$.

The degradation in light output from the CsI crystal due to radiation damage is monitored by plotting the signal size S, as obtained from a specific amount of energy E deposited in the CsI material, versus the accumulated dose D of gamma radiation given to the crystal. The signal size S depend on the radiation damage y according to:

$$S(D) = cgL + p = cgeE \cdot y(D) + p$$

where c is the conversion constant of the ADC, g the amplifier gain, and p is the ADC pedestal value. Having a fixed signal source, changing the amplifier gain, and finally fitting a straight line to the graph determine the pedestal. This can be done accurately. We found –14 and 0 ADC channels, respectively, for the two PM channels. The variation in c and g are negligible. Taken together, we expect a systematic error of maximum 1 ADC channel due to pedestal and other minor sources.

The factor y due to radiation damage can now be written

$$y = \frac{L}{eE} = \frac{1}{eE}\frac{S-p}{cg}$$

where the major uncertainty comes from the statistical error $DS/S = Dx_0/x_0$ = ±5% when fitting S and the systematic error De in reproducing the light connection. Considering that p is small compared to S (<1.5%), we have (assuming normal and uncorrelated errors):

$$\left(\frac{?y}{y}\right)^2 = \left(\frac{?e}{e}\right)^2 + \left(\frac{?S}{S}\right)^2$$

However, in order to use y to estimate the expected signal size $S'(D')$ obtained for a known dose D' according to $S'(D')=yS_0'$, we also have to take into account the uncertainty DD in determining the dose D during the test measurement:

$$\left(\frac{?y}{y}\right)^2 = \left(\frac{?e}{e}\right)^2 + \left(\frac{?S}{S}\right)^2 + \left(\frac{dS}{dD}\right)^2\left(\frac{?D}{S}\right)^2$$

The total radiation dose given the whole CsI crystal is estimated from the tabulated dose rate values for water at r_0 = 80 cm distance from the ^{60}Co source. The tabulated dose rate value $\dot{D}_{\mathrm{H_2O}}$ for the time of the test is 3624±3 rad/h. This is the maximum dose at 5 mm depth obtained in water. The corresponding dose in CsI is 81% of this. Since the dose falls off exponentially with penetration depth, we have to average over the crystal width of 19.9 mm. Using an average attenuation coefficient for the two gamma energies of 0.2865 cm^{-1}, this gives a factor f_1=0.76. We also have to average over the length 333 mm of the crystal, because the radiation field intensity falls off towards the ends of the crystal due to decreasing solid angle and anisotropy of the source. This gives a factor f_2=0.97. Thus, taken together, we have

$$D = 0.81 f_1 f_2 \dot{D}_{\mathrm{H_2O}} \left(\frac{r_0}{r_1}\right)^2 \cdot t$$

where t is the time of exposure, and r_1 = 97 cm is the distance from the ^{60}Co source to the CsI crystal surface. This distance cannot be determined more accurate than ±2.5 mm (Dr). Assuming gaussian errors is a reasonably good approximation, we get the error DD according to:

$$\left(\frac{?D}{D}\right)^2 = \left(\frac{?\dot{D}_{\mathrm{H_2O}}}{\dot{D}_{\mathrm{H_2O}}}\right)^2 + 4\left(\frac{?r}{r_0}\right)^2 + 4\left(\frac{?r}{r_1}\right)^2$$

This gives a relative error DD/D = 8.1%. The error in t is negligible.

To determine the derivative dS/dD requires fitting an analytical function. The dependence of $S(D)/S_0$ can be reasonably well fitted by a power law:

$$\frac{S(D)}{S_0} = a\left(D + D_{\mathrm{o}}\right)^q + b$$

where a, D_o, q and b are fit parameters, D_o being an (unphysical) offset. The derivative

$$\frac{1}{S_0}\frac{dS}{dD} = aq(D + D_o)^{q-1} = -189(D + 7.37)^{-3.77} \ \text{krad}^{-1}$$

results in an overall relative error in y:

$$\left(\frac{?y}{y}\right)^2 = \left(\frac{?e}{e}\right)^2 + \left(\frac{?S}{S}\right)^2 + \left(aq(D+D_o)^{q-1}\right)^2\left(\frac{?D}{S/S_0}\right)^2 =$$

$$= \left(\frac{?e}{e}\right)^2 + \left(\frac{?S}{S}\right)^2 + \left(\frac{aq(D+D_o)^{q-1}}{a(D+D_o)^q + b}\right)^2 ?D^2 =$$

$$= (2\%)^2 + (5\%)^2 + \left(\frac{-189(D+7.37)^{-3.77} D}{-68(D+7.37)^{-2.77} + 0.73}\right)^2 (8.1\%)^2$$

The last term contributing the error from dose estimation is small and becomes negligible above 10 krad, where the curve flattens out. The asymptotic value then becomes

$$\frac{?y}{y} = \pm 5.4\%$$

The figure and table shows the fitted values $y=S(D)/S_0$ and errors.

Dose [krad]	Rel. signal size *y*
0	1,00±0,05
1	0,92±0,05
2	0,87±0,05
3	0,83±0,05
4	0,81±0,04
5	0,79±0,04
6	0,78±0,04
7	0,77±0,04
8	0,77±0,04
9	0,76±0,04
10	0,76±0,04
12	0,75±0,04
14	0,74±0,04
16	0,74±0,04
18	0,74±0,04
20	0,74±0,04