

Performance of Undoped BGO Crystals under Extremely High Dose Conditions

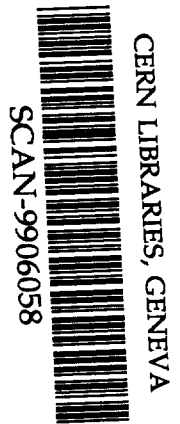
K.C. Peng^a M.Z. Wang^{a,*} C.H. Wang^b, K. Ueno^a, H.C. Huang^a,
Y.H. Chang^c, F.I. Chou^d, W.S. Hou^a, Y.Y. Wei^d

^a*National Taiwan University, Taipei, Taiwan*

^b*National Lien Ho College of Tech. and Commerce, Miao Li, Taiwan*

^c*National Central University, Chung Li, Taiwan*

^d*NSTDC of National Tsing Hua University, Hsin-Chu, Taiwan*



Abstract

We checked the performance of undoped BGO crystals under extremely high dose conditions (dosage up to 88 Mrad). The light outputs of the crystals drop by $\sim 30\%$ after receiving 10 Mrad of γ ray dose but remain stable throughout the rest of the test. The self-recovery behavior of BGO under 20 Mrad has also been studied. The reduced variation in light output from pre-radiated BGOs, together with a fixed recovery limit, indicate that a pre-radiation process may be helpful to stabilize the BGO performance in a low dose environment.

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*Internet address: mwang@phys.ntu.edu.tw

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1 Introduction

Following the material study of [1], we impose higher dose on undoped Bismuth Germanate ($\text{Bi}_4\text{Ge}_3\text{O}_{12}$) crystals, which has been known as BGO and extensively used for electromagnetic calorimetry in high energy physics experiments [2]. The advantages of BGO are its excellent e/γ energy resolution ($0.3 - 1\%/\sqrt{E(\text{GeV})}$), high density, short radiation length, large refractive index, suitable scintillating properties (fast decay time of ~ 300 ns and peak scintillation at ~ 450 nm) and non-hygroscopic nature. Our group is constructing such a calorimeter to improve coverage of small angles around the beam pipe of the BELLE detector at KEK B-factory. Due to the proximity of such calorimeters to the electron/positron beam pipes and the interaction point, radiation level is rather high for intense flux of synchrotron radiation, beam-beam interactions, and beam-gas background events. Therefore, it is necessary for us to study the radiation hardness and recovery mechanism of BGO crystals.

2 Experimental Setup

The schematic diagram of the setup in the irradiation facility of National Tsing Hua University, Taiwan, is shown in Fig. 1. The radioactive source is ^{60}Co with cylindrical shape and with radioactivity of ~ 1000 Curie. The diameter of the ^{60}Co cast is 3 cm, and the holder diameter is 6 cm.

Immediately after each irradiation, the samples were taken out from the irradiation cell to a near-by experimental booth. The trapezoid BGOs have been separated into two sets: LBGO (longitudinally irradiated) and TBGO (transversely irradiated). We define the equivalent dose as the amount of dose that would have been absorbed by water if placed at the position of the front surface of the sample. The average dose absorbed by the TBGO is about the same as the equivalent dose, where the average dose absorbed by the LBGO is about 40% of the equivalent dose^[1].

Total of 10 pieces of undoped trapezoid BGO crystals with approximate size of $12 \times 2 \times 1$ cm³, produced at the Institute of Inorganic Chemistry, Novosibirsk, Russia, were used in this irradiation test. Two out of ten BGOs were used as reference crystals. The rest were separated into two sets: 4 BGOs (2 LBGOs and 2 TBGOs) were used for high dose study and the other 4 TBGOs were later monitored for their self-recovery.

We measured the light output of all BGOs with 90 μCurie radioactive source ^{137}Cs . A lead collimator focuses γ 's within 2 mm hole and 15 mm depth onto BGOs. A Photo-Multiplier Tube (PMT), Hamamatsu R329-05, 2-inch in diameter, was used for reading out the light output from test samples. A reference crystal (labeled as BGO_r) was in the cycle of testings in front of PMT to simultaneously cancel out any variation due to the

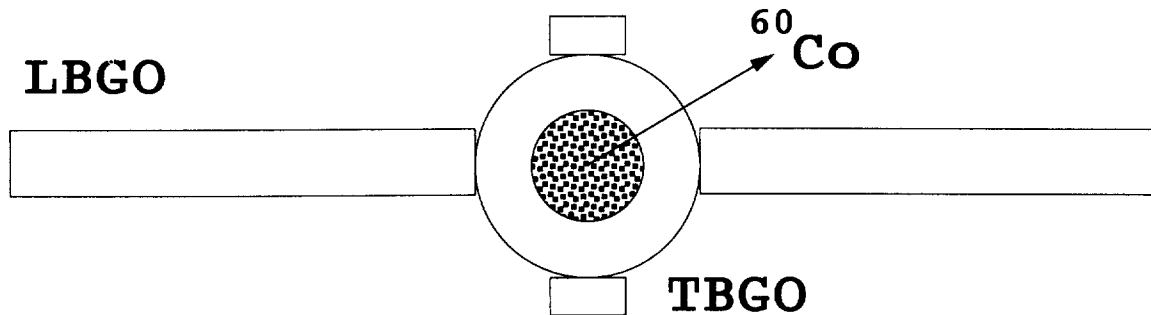


Figure 1: Top view of experimental setup in radiation source room. BGOs were 3 cm away from the center of ~ 1000 Curie ^{60}Co .

changes in the environment.

The signals from the PMT were gated by a self-trigger and digitized with a LeCroy CAMAC ADC 2249A. The CAMAC crate was controlled by a PC-based Data Acquisition (DAQ) system. The gate width was set to be 800 ns for complete integration. With a pulser, we made empty signal triggers and accumulated pedestal events simultaneously.

3 Results

We had two week-long experiments. In the first week, we concentrated on studying the performance under high dose irradiation. It was a continuous operation and the crystals were subjected to irradiation most of the time. The results are shown in Fig. 2. It is clear that all crystals show a stable performance after the first point. We observe no change up to 88 Mrad. However, the decrease in light output is quite dependent on the individual crystal. On average, the drop is about 30%. The performance characteristics are about the same for both LBGOs and TBGOs.

In the second week, we were allowed having access to a new facility with a 30 times stronger ^{60}Co source, but without our DAQ system nearby. We tested 5 new identical BGOs, with one as reference. Two of them were irradiated to 10 Mrad and two to 5 Mrad, all in 5 hours and all transversely. The light output decreased by $\sim 30\%$. We found a slow recovery after 3 days which recovered to $\sim 90\%$ of their original light output. Then, we sent these 3-day-recovered BGOs back for another round of irradiation with the same amount of dosage. Hourly measurements were performed immediately after the irradiation to monitor the BGO self-recovery. The results are shown in Fig. 3.

Unlike [4], we only assume one exponential time constant for this recovery, although there may be other time constants that form multiple exponentials to portray very fast

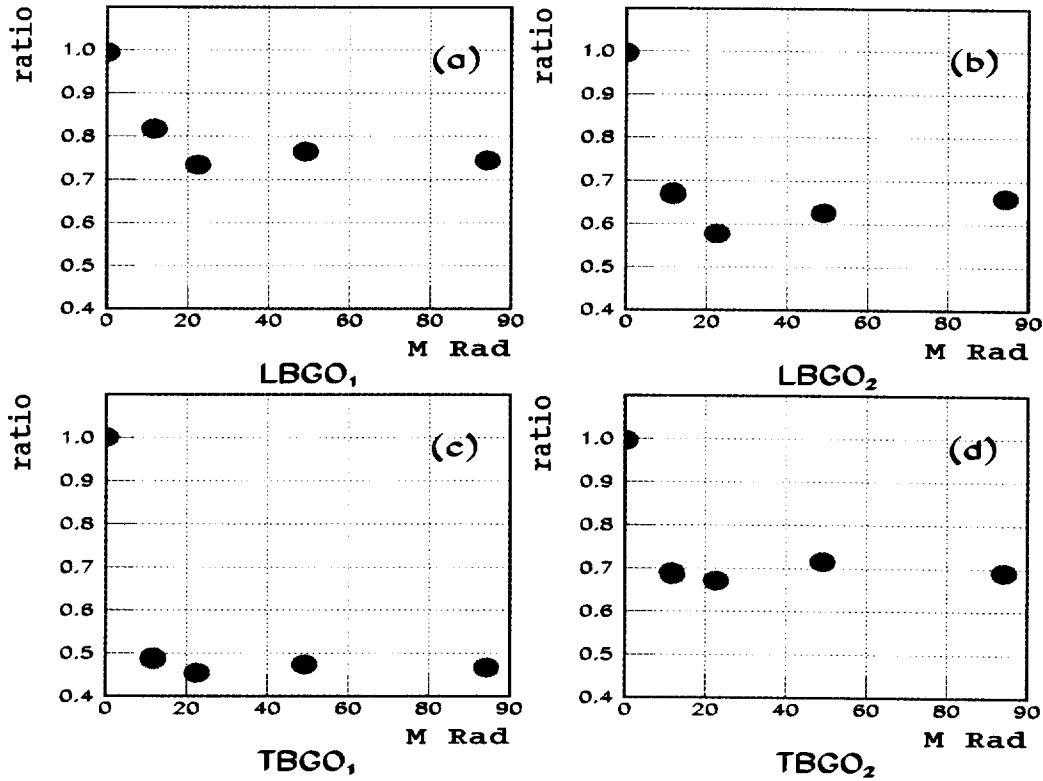


Figure 2: Results of the first week irradiation. The horizontal scale is in equivalent dose and the vertical scale is a ratio between BGO and BGO_r , with first point normalized to 1. (a) and (b) were irradiated longitudinally; (c) and (d) suffered more radiation damage for being irradiated transversely.

recovery (less than an hour), week-long self-recovery, etc. The fitting function is chosen to be

$$P_1 \times (1 - e^{-(t+P_3)/P_2}).$$

P_1 represents the dimensionless upper limit for self-recovery of a particular BGO in an unlimited time. P_3 is just a constant of shifting data points. Finally, P_2 is the self-recovery time constant.

Some caution must be taken for the interpretation of the first four data points since they are not scaled horizontally. The interval between point 1 and point 2 is about 8 hours including 5 hours of irradiation and 3 hours of returning to our Lab. The interval of point 2 – point 3 is a 72-hour self-recovery. The interval between point 3 and point 4 is 6 hours

with 5 hours of irradiation and 1 hour of transit. From point 4 on, the intervals are in units of hours and the fits are also shown. Due to self-recovery during transportation, the relative light output after irradiation should be smaller than the values shown in points 2 and 4. Note that the relative drop is considerably reduced for the second irradiation of the same amount of dose. Another report is now in preparation [5] for a better determination of the recovery time constant and a comparison with low dose data.

4 Conclusion

In this study, we observe a stable performance of undoped BGO crystals under very high dose conditions. However, the light output decrease by $\sim 30\%$ after receiving ~ 10 Mrad dose. The crystals may have suffered some permanent damage but can recover to 90% of their original light output in a period of a day. The reduced variation in light output and the same upper limit of recovery for pre-radiated samples, shown in Fig. 3, indicate that it is a good idea to pre-radiate all of the crystals before installing them into BELLE.

Acknowledgements

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Radiation & Self-Recovery Fit

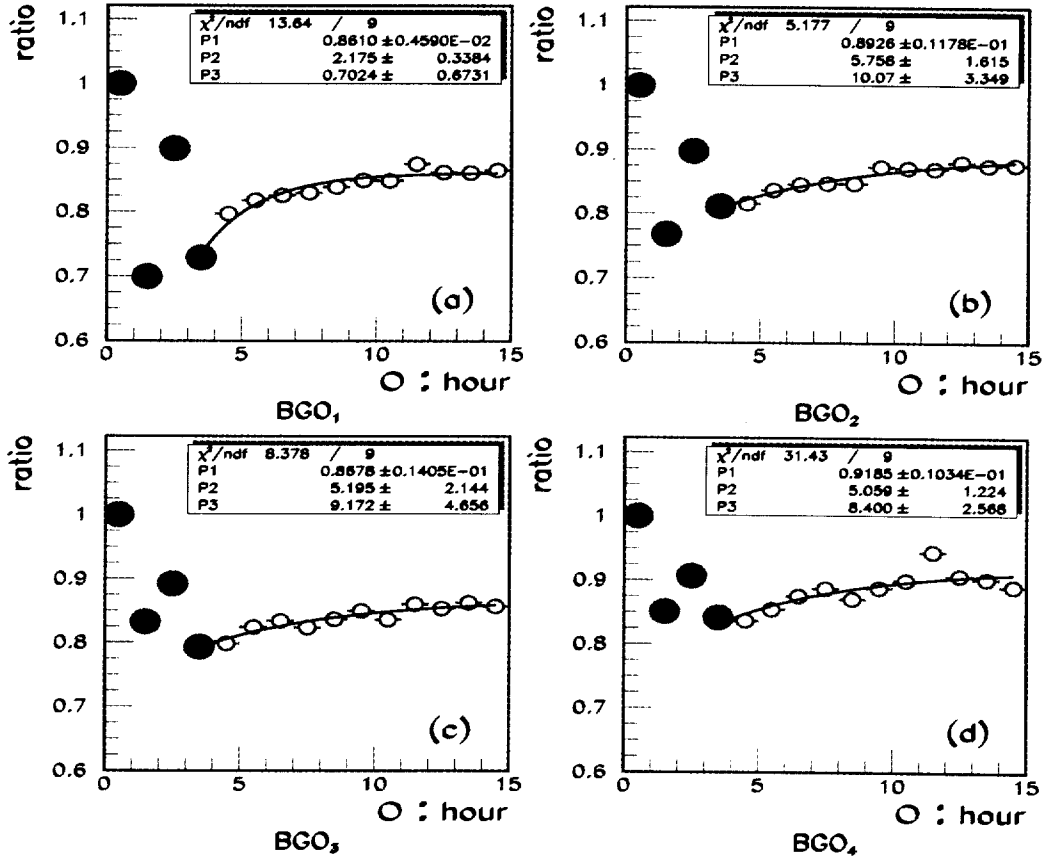


Figure 3: Results of the second week irradiation and self-recovery monitoring. The horizontal scale is in hour for open circle data points, and the vertical scale is a ratio of different samples to BGO_T , with first point normalized to 1. The dark points are not scaled horizontally. See text for more information. The fits through open circles show self-recovery time constants at room temperature after the second irradiation of 10 Mrad in (a)(b) and 5 Mrad in (c)(d). The statistical error on each data point is less than 1%.

