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Survey of the properties of BGO crystals for the Extreme Forward Calorimeter at BELLE

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Abstract

We check the scintillation light yield of all BGO crystals used for the Extreme Forward Calorimeter at BELLE. The percentage spread of the distribution is only 6%. The nonuniformity of the light yields measured lengthwise for the forward EFC is close to 13% and is $\sim$ 0% for the backward EFC. The test crystals, two per ingot, from mass-production are subjected to the radiation hardness test. The results obtained at BINP and NTU are in good agreement. Some EFC crystals, selected randomly, show the light yields drop about 25-50% after receiving 1 Krad dose and remain stable afterwards. There is little sensitivity to the rate that the 1 Krad dose is received, since the recovery process is very slow, in the order of days to weeks.

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We check the scintillation light yield of all BGO crystals used for the Extreme Forward Calorimeter at BELLE. The percentage spread of the distribution is only 6%. The nonuniformity of the light yields measured lengthwise for the forward EFC is close to 13% and is $\sim 0\%$ for the backward EFC. The test crystals, two per ingot, from mass-production are subjected to the radiation hardness test. The results obtained at BINP and NTU are in good agreement. Some EFC crystals, selected randomly, show the light yields drop about 25-50% after receiving 1 Krad dose and remain stable afterwards. There is little sensitivity to the rate that the 1 Krad dose is received, since the recovery process is very slow, in the order of days to weeks.

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1 Introduction

The Extreme Forward Calorimeter (EFC) [1] has been installed in the BELLE detector [2] at the **KEK B**-factory. It can improve the coverage of small angles around the beam pipe and can be used as luminosity monitor or tagger for two-photon events. The electromagnetic shower medium chosen is Bismuth Germanate ($Bi_4Ge_3O_{12}$), commonly known as BGO. The scintillation light induced by the electromagnetic shower is collected by photodiodes and amplified by preamps. Due to its proximity to the accelerator beam pipe and the high luminosity of the **B**-factory, we chose radiation-hard BGO crystals [3] produced by the Institute of Inorganic Chemistry, Novosibirsk, Russia.

EFC consists of two parts, forward and backward, which surround the beam pipe and are mounted on the front surfaces of the cryostats of the final-focusing quadrupole magnets. Each part consists of 160 BGO crystals with 5 segments in θ and 32 segments in ϕ. The BGO crystals have trapezoidal shapes where individual crystals point to the interaction point. The dimension of each crystal is about 2 cm $\times$ 1.5 cm $\times$ 12 cm. The exact shape varies according to its θ position. We have total 10 different types of crystals, labeled as F1 to F5 and B1 to B5. F1 (B1) is the inner most segment and F5 (B5) is the outer most segment in the forward (backward) region. There are also 40 spare crystals, 4 crystals for each type.

After receiving crystals, many tests were performed to ensure the individual crystal quality. The most important ones are that of light output and radiation hardness.

2 Experimental Setup and Procedure

Figure 1 shows the schematic diagram of the setup to determine the light output of each crystal. A 90 μCurie radioactive source, ^{137}Cs, was used to determine the scintillation light yield of each crystal. A lead collimator focuses γ's within a cone which has 2 mm diameter at top, 8 mm diameter at bottom, and 35 mm in depth. A Photo-Multiplier Tube (PMT), Hamamatsu R329-05, 2-inch in diameter, was used for detecting the light. A reference crystal was in the cycle of testings in front of PMT to reduce the systematical errors from 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 system. The gate width was set to be 1 μsec for complete integration. Empty signal triggers were made with a pulser to accumulate pedestal events simultaneously.

The light collection is not uniform along the crystal direction because of the non-rectangular shape of the crystal. We took three measurements along the crystal direction, one in the middle and two points $\pm$4 cm from the middle. The light output, $\langle$A$\rangle$, is defined as the average of these three measurements. We also define the nonuniformity as $\frac{(A3-A1)}{\langle A \rangle}$.

The observed nonuniformity from prototype samples is around 40% where the surfaces of sample crystals are all polished. Note the crystals were wrapped with 100 μm thick Teflon and 25 μm thick aluminum tape. We also observe that B types have higher nonuniformity than F types. Since the nonuniformity deteriorates the energy resolution, it was decided that the biggest surface of the B type crystals were left unpolished. The unpolished surface of the F types is chosen to be the second biggest one. The light loss due to the unpolished surface is about 20%.

To test the radiation hardness of BGO crystals, we use the same setup as above. Two test crystals with rectangular shape, 1 cm $\times$ 1 cm $\times$ 10 cm, were produced from every ingot during mass-production. One of the test crystal is kept in Russia and was tested by the Budker Institute of Nuclear Physics (BINP), Russia. The other was shipped to National Taiwan University (NTU), Taiwan. We checked the test crystal performance before and after irradiation with 10 Mrad dose [4]. We also randomly selected some actual crystals (B type only) to check their recovery behavior after receiving small amount of dose (in Krad range). This is to mimic the real BELLE running environment. The irradiation facility is located at National Tsing Hua University (NTHU), Taiwan. The radioactive sources are ^{60}Co's with cylindrical shape and with radioactivity of $\sim$ 30000 and 1000 Curie.

For the 10 Mrad test, the performance of the test crystals from different ingots were checked at NTU. The transit time is about 1.5 hours between NTHU and NTU. For the low dose test, the setup is moved to NTHU. Immediately after each irradiation, the samples were taken out from the irradiation cell to a near-by experimental booth. 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.

3 Results

The measured relative light output and nonuniformity for B and F types are shown in Fig. 2. The distribution of relative light output is nicely shaped with spread at only 6%. The nonuniformity of B type is centered at $\sim$0. It is clear that the light collected at $A3$ position is still bigger than that at $A1$ for F type crystals. The nonuniformity is around 13% for F types. If we break down further into 10 different types, shown in Fig. 3, there is some interesting pattern in the nonuniformity plot. This indicates that further improvement can be made with a finer treatment for different types.

Results from BINP and NTU for determining the radiation hardness of the test crystals are shown in Fig. 4. They agree with each other very well. The light yields seem to drop more for these test crystals from mass-production compared to previous sample crystals which were produced in small quantity and tested by us before [5][6]. We also put two B type crystals under 10 Mrad irradiation. Their light outputs dropped by 50%.

The results for the low dose test to mimic the BELLE running environment are shown in Fig. 5. Note two of them have already been preradiated with 10 Mrad dose. They recovered very slowly after days to a bit higher value (from 50% to 60%). It is clear that all crystals from the same ingot reach a somewhat stable state after receiving 1 Krad dose. The drop is close to 50% which is about the same value obtained in 10 Mrad test.

We randomly selected more actual crystals from different ingots to study the dose rate issue. These crystals were separated into groups to obtain 1 Krad dose. The exposure time is between one hour and twenty hours. The results are summarized in the following table.

Time of measurements	Dose rates									
	1.0 Krad/h×1 h			0.2 Krad/h×5 h		0.125 Krad/h×8 h		0.05 Krad/h×20 h		
	B1.05	B1.07	B1.08	B1.09	B1.10	B1.11	B1.12	B2.05	B2.07	B2.08
Just after irradiation	0.60	0.59	0.62	0.62	0.69	0.68	0.74	0.48	0.52	0.52
5 days	0.56	0.56	0.58	0.69	0.67	0.67	0.75	0.53	0.56	0.53
13 days	0.52	0.55	0.57	0.64	0.63	0.62	0.70	0.68	0.77	0.74
14 days	0.57	0.60	0.62	0.70	0.68	0.69	0.76	0.63	0.72	0.68

Table 1: Monitoring the light output of BGO crystals after accumulating 1 Krad dose at different rates.

The light yields seem to drop significantly just after accumulating 1 Krad dose in all cases. The drop is between 25% and 50% depending on different ingots. It is clear that the recovery is not fast. This feature is also different from the crystals produced in small quantity [6][7] which show fast recovery between 1 hour to 10 hour after receiving Mrad dose. We think that, owing to this, the dose rate will not make much difference for BELLE operation conditions and most of the crystals will reach stable state after receiving 1 Krad dose or around Krad scale.

4 Conclusion

We checked the scintillation light output of all BGO crystals used for EFC at BELLE. The percentage spread of the distribution is only 6%. The nonuniformity of the forward EFC is close to 13% and is $\sim$ 0% for the backward EFC. This indicates that perhaps we should have left the biggest surface unpolished for F type crystals also.

The test crystals, two per ingot, were tested for their radiation hardness at BINP and NTU separately. The results agree well. However, these crystals from mass-production are somewhat less radiation-hard than the crystals produced in small quantity. There is no fast recovery for both the test crystals and some randomly selected actual crystals. This feature is also different from the crystals produced in small quantity.

The radiation hardness study of these randomly selected EFC crystals shows that light yield drops about 25-50% after receiving 1 Krad dose and remain stable afterwards. The rate to receive 1 Krad dose does not make much difference since the recovery is slow, in the order of days or weeks.

Acknowledgements

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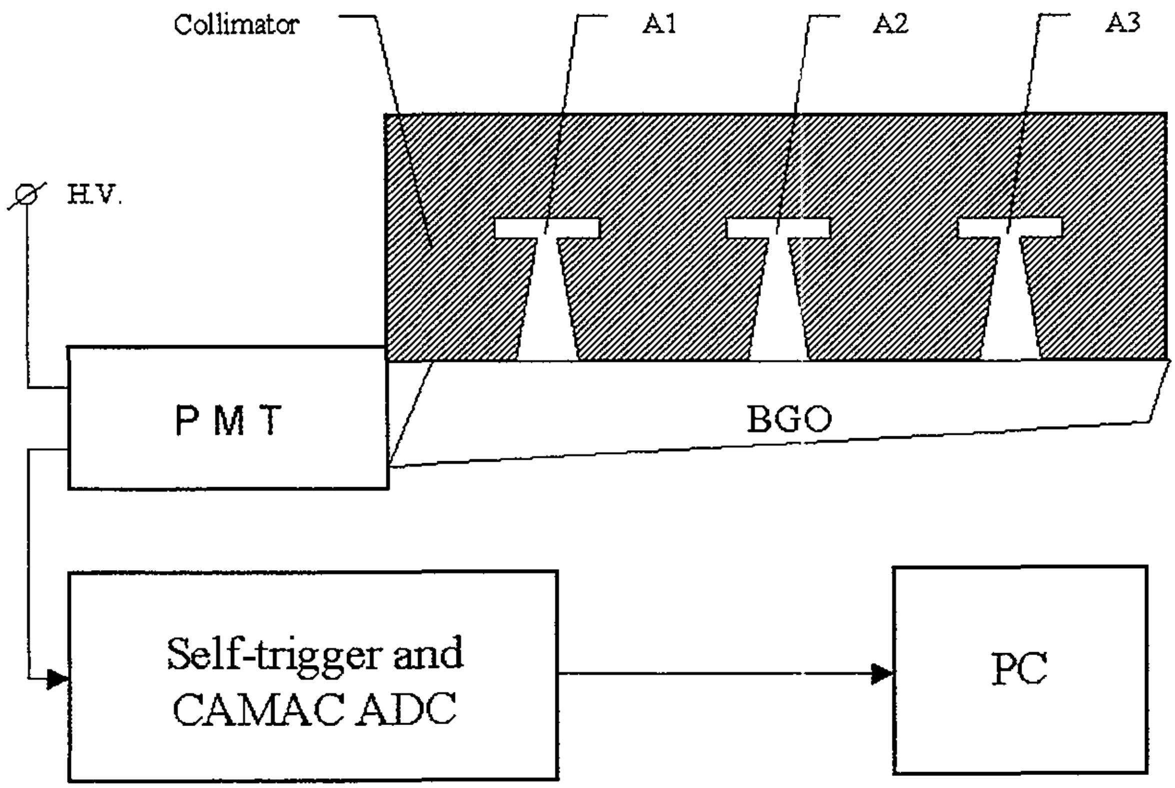

Figure 1: Schematic Diagram for the measurements of BGO light output. The light collection for the case where radioactive source is situated at A3, is the biggest and is the smallest for source at A1.

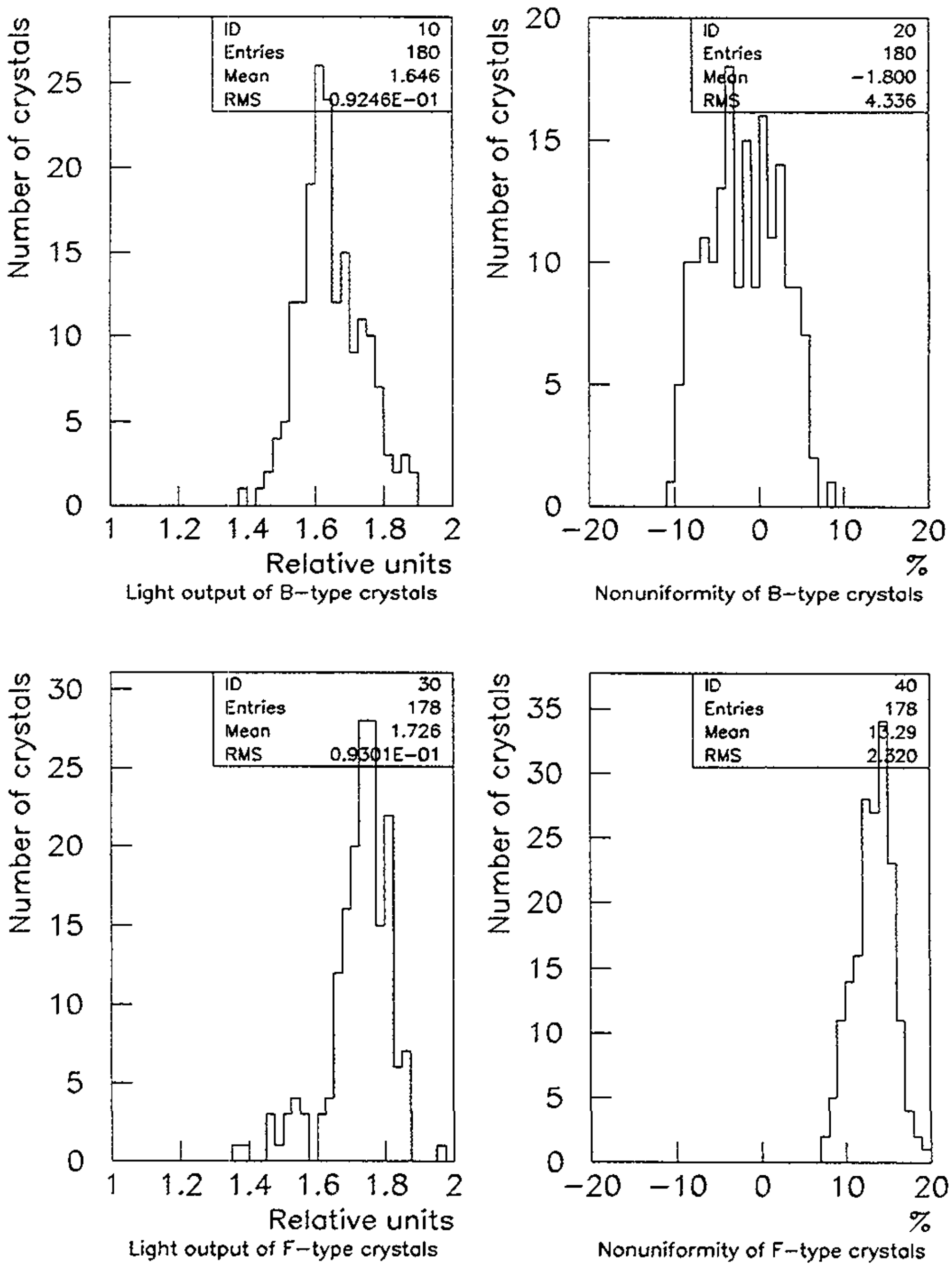

Figure 2: The light output and uniformity of the BGO crystals for B and F types. The percentage spread of the light output is only 6%. The uniformity of B type is better than that of F type.

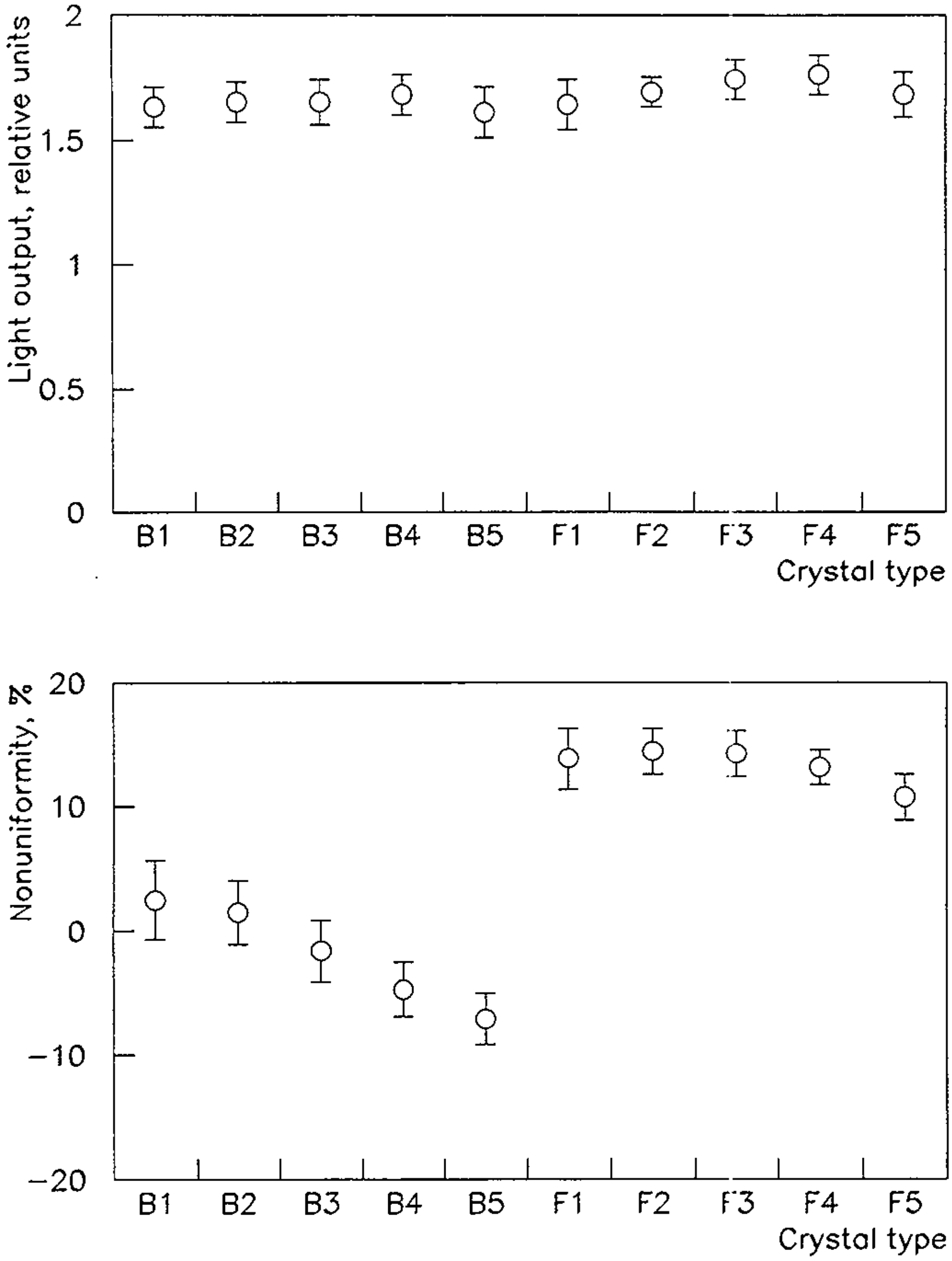

Figure 3: The light output and uniformity of the BGO crystals for 10 different types.

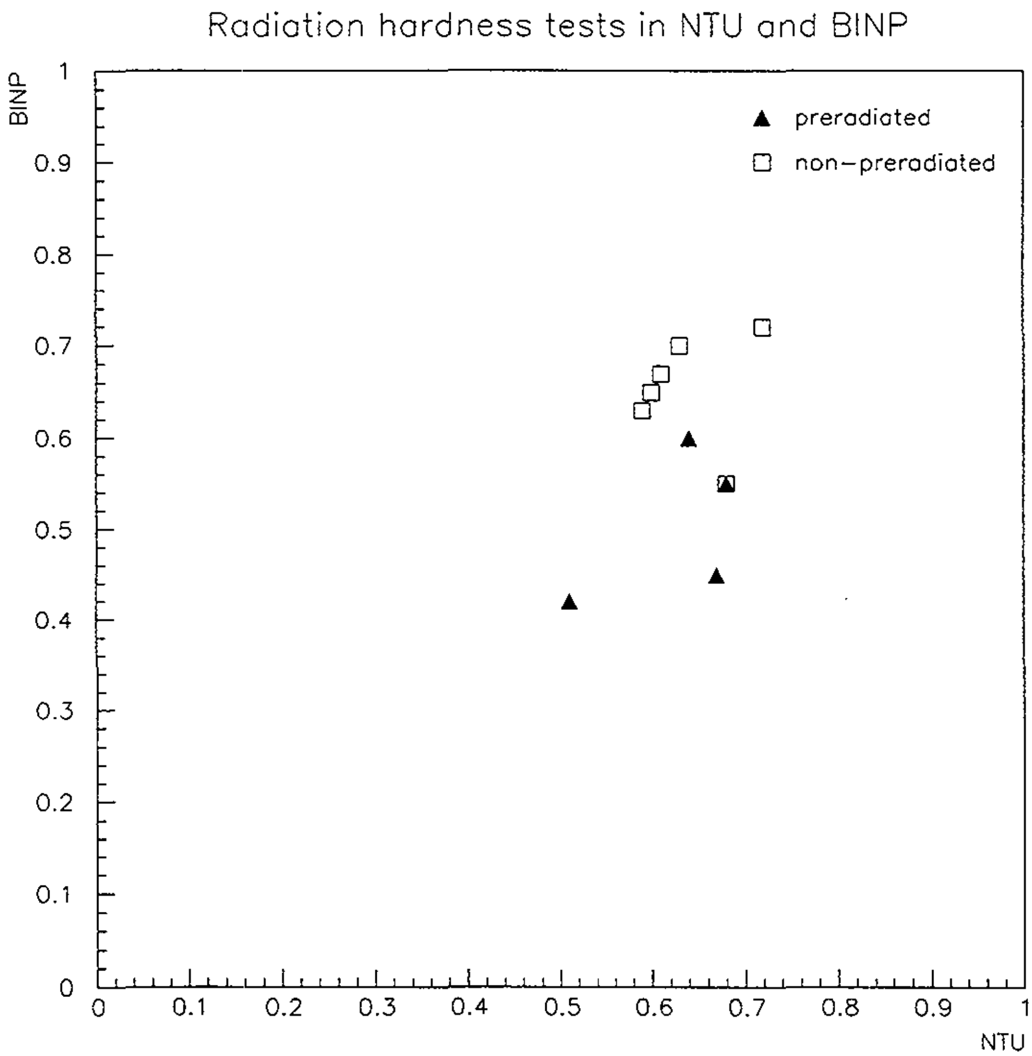

Figure 4: The relative light output of the test crystals after receiving 10 Mrad dose measured at BINP vs. results from the NTU test. There are two test crystals per ingot and therefore BINP and NTU keep one each. Note some crystals have been tested twice which were marked as preradiated.

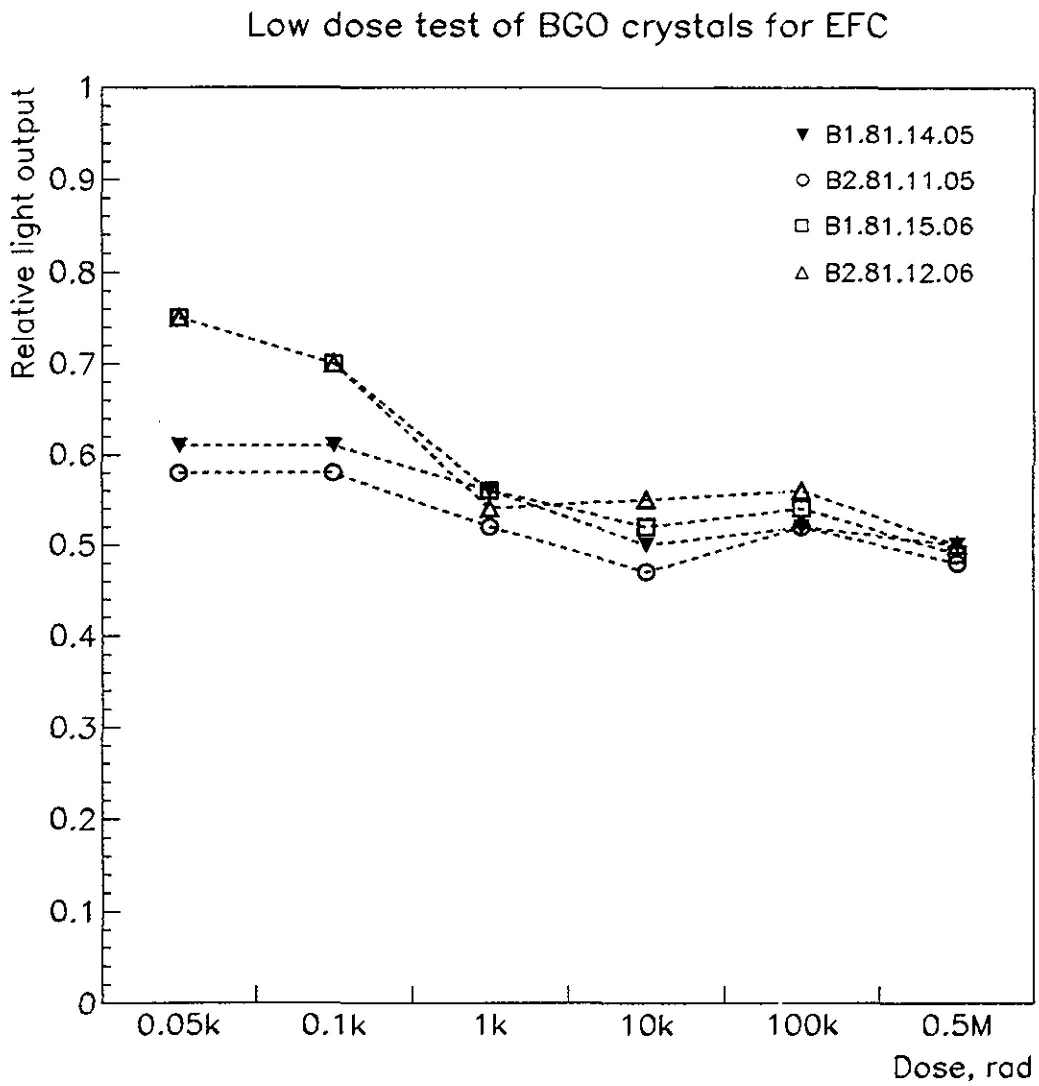

Figure 5: Light output vs. dosage. Crystals B1.81.14.05 and B2.81.11.05 have been preradiated with 10Mrad dose. The relative light output shown here are all normalized to the values before any radiation. Note these four crystals are from the same ingot with ingot number 81.