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Radiation Hardness of Lead Glasses TF1 and TF101

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Abstract

We have measured radiation hardness of two types of lead glasses, TF1 and TF101, for low energy γ -rays from ^{60}Co . TF101 containing cerium is a few tens times radiation harder than TF1 which contains no cerium. The radiation hardness, or the tolerable accumulated dose, of TF101 is 2×10^5 rad when the degradation of transmittance is required to be less than 1% for the unit radiation length $X_0 = 2.8$ cm. When the present result is compared with the work by Inyakin et al., the radiation hardness of TF101 glass should be similar both for γ -rays and for high energy hadrons.

Two types of lead glasses have been successfully used in the GAMS Cherenkov detectors [1], i.e. TF1 (SF2 class) and TF101 (radiation-hardened by adding 0.2% of cerium). Their radiation hardness has already been studied by Inyakin et al. [2] against 70 GeV protons and 30 GeV π^- mesons.

In the course of efforts to develop new dense and radiation-hard materials which could be used for grading up the GAMS detector as well as in the GLUON detector [3], we have measured the radiation hardness of the

lead glasses against low energy γ -rays. The result is presented below:

The lead glasses were casted at the Lytkarino factory, Moscow, and machined and polished at IHEP. Test samples with a size of $1 \times 1.2 \times 3.8 \text{ cm}^3$ were cut from spare modules for GAMS with a size of $3.8 \times 3.8 \times 45 \text{ cm}^3$. Optical transmission across 1 cm thickness was measured with a spectrophotometer (Hitachi 330) before and after irradiation.

Irradiation by ^{60}Co γ -rays was carried out at Japan Atomic Energy Research Institute (JAERI). Four cycles of irradiation followed by transmission measurement were carried out to cover the accumulated dose* from 10^3 to 10^6 rad by increasing the accumulated dose by a factor of 10 per cycle. Each cycle (irradiation, measurement and mailing of samples between KEK and JAERI) took about a week. Each irradiation period took 10 minutes, 1 hour, 3 hours and 1 hour for the accumulated dose of 10^3 , 10^4 , 10^5 and 10^6 rad, respectively, by mounting the samples at different distances from a calibrated ^{60}Co source. Since recovery of radiation damage upon exposure to UV light is known in many materials such as PbF_2 [4], CsI:Tl [5], BaF_2 [6] and GSO:Ce [7], we paid attention for safety lest a sample should be exposed to strong UV light, including sunshine, during any course of the irradiation-measurement cycle. All the samples were wrapped in aluminum foil except during a short period of transmission measurement which took about 10 to 15 minutes per measurement per sample.

*) We use an approximate conversion from 1 R (roentgen) of ^{60}Co γ -ray exposure to 0.88 rad ($\approx 0.0088 \text{ Gy}$) of the absorbed dose in lead glasses.

Figures 1 and 2 show the radiation damages of a standard TFI (TFI-00, 99.9% pure) sample and a highest purity one (TFI-000, 99.99% pure), respectively, caused by ^{60}Co γ -rays. No sizable difference is seen in the results between the above two samples, indicating that the observed radiation damage should not dominantly come from the impurity in the raw material. The radiation damage in TFI observed at 33 hours after irradiation by 10^3 rad is a little smaller than that observed by Yoshimura et al.[8] in an SF2 glass at 3 hours after irradiation by the same dose. From the present result, however, we cannot conclude whether the radiation damage itself should be smaller in TFI than in SF2, or the recovery in SF2 is not yet saturated at 3 hours after irradiation.

Figure 3 shows the radiation damages of a TFI01 sample. Although two TFI01 samples were irradiated, there was no sizable difference in the result between them. Comparing Fig. 3 with Fig. 2, we see that TFI01 is radiation harder about 20 times than TFI. After irradiation by 10^4 rad, the TFI01 glass turned visibly bright brownish with a tint of red.

Recovery in TFI01 (TFI) was studied after irradiation by 10^4 (10^3) rad. As seen in Fig. 3 (Fig. 2), the recovery is not complete even in 100 days, showing saturation in recovery. Annealing by UV exposure was also examined at 105 (113) days after irradiation by exposing the irradiated sample close to a UV fluorescent lamp (National GL-10, 10W). The exposure was stopped at one hour since the recovery was saturated after half an hour. Although the recovery due to UV exposure is significant, substantial damage still remains unrecovered (Figs. 2 and 3). The annealing effect of UV exposure is larger in cerium-containing glass (TFI01) than in ordinary one (TFI).

If we require the decrease of transmission to be less than 1% per unit radiation length $X_0 = 2.8$ cm in Cherenkov detectors read out by photomultipliers with abialkali or a multialkali photocathode, the tolerable accumulated dose in TFI01 should be about 2×10^3 rad from Fig. 3. If, instead, we require the decrease of transmission over the detector depth of 45 cm to be less than 1/e, the tolerable accumulated dose should be about 10^4 rad or a little higher.

Writing the transparency of 45 cm long module as $R = \exp[-(\text{Number of pions}/b)]$ for 30 GeV π^- injection, Inyakin et al. [2] obtained $b = (4 \pm 1) \times 10^{+2} \pi^-$ for TFI01 viewed by a photomultiplier (FEU-84) with a multialkali photocathode (S20). Taking into account the cross section of the test module ($3.8 \times 3.8 \text{ cm}^2$), the density of 3.8 g/cm^3 and the energy deposit of about 1.5 MeV/g/cm^2 for 30 GeV π^- , the above b corresponds to a tolerable accumulated dose of $(7 \pm 2) \times 10^3$ rad for the degradation of transmittance of 1% per X_0 .

Comparing the tolerable dose of TFI01 for high energy π^- with that for γ -rays, we find that both are of the same order of magnitude. This feature of TFI01, i.e. the radiation hardness of the same order of magnitude for both γ -rays and hadrons, is similar to CsI[9], but significantly different from GSO:Ce[7] and BGO[10], in which the radiation hardness is two orders of magnitude smaller for hadrons than for γ -rays.

Acknowledgements

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Figure captions

- Fig. 1 Transmission spectra of a TFI-00 lead glass across 1 cm thickness for different accumulated doses of ^{60}Co γ -rays. Numbers in parentheses give the time elapse after irradiation.
- Fig. 2 Transmission spectra of a TFI-000 lead glass across 1 cm thickness for different accumulated doses of ^{60}Co γ -rays. For the other items, see the caption of Fig. 1. UV means exposure to UV light for one hour (see the text).
- Fig. 3 Transmission spectra of a TFI01 lead glass across 1 cm thickness for different accumulated doses of ^{60}Co γ -rays. For the other items, see the captions of Figs. 1 and 2.

FIG. 1

FIG. 2

FIG. 3