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A SYSTEMATIC STUDY OF RADIATION DAMAGE TO LARGE CRYSTALS OF CSI(TL) IN THE BABAR DETECTOR

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(For the BaBar EMC Group)

We study the impact of radiation damage on large CsI(Tl) crystals in the BABAR electromagnetic calorimeter. Average radiation exposure of up to 400 Rad to date, originating primarily from beam backgrounds, has been measured by RadFETs located at the front face of crystals.

1. Introduction

The BABAR Electromagnetic Calorimeter[1](EMC) consists of 6580 CsI(Tl) crystals ranging between 16 and 17.5 radiation lengths. CsI(Tl) was chosen for its good mechanical properties, high light output, convenient emission wavelength for use with Si-photodiodes and reasonable signal response time. The crystals were produced[2] from a melt of CsI salt doped with 0.1% thalium using either Kyropoulos (Kharkov, Crismatec, Hilger) or Bridgman (Shanghai, Beijing) growth techniques. As sensitivity to radiation damage is generally found to be smaller for higher purity crystal, the quality of the salt and the recycled material was strictly controlled. In order to decrease the contributions to systematic errors on energy resolution it is important to understand the effect of radiation on CsI(Tl) crystals.

2. Sources of Radiation Damage

Radiation damage in the BABAR EMC is believed[3] to be almost entirely caused by 'non–physics' events, or so called 'beam backgrounds' in the EMC. There are two distinct types of this background in the BABAR experiment: single beam background and colliding beam background. The single beam background is mainly caused by fixed dipole magnets which are situated near the interaction point. They tend to sweep off-energy primary beam particles into machine elements near the detector, resulting in a low-energy shower ($<$

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10 MeV[1]) which enters the EMC. For colliding beams, there is also a major contribution of photons from small-angle radiative Bhabhas in which an e$^{\pm}$ strikes a machine element. In both cases the occupancy increases significantly at smaller polar angles (in the endcap and backward barrel), while single beam backgrounds also peak in the horizontal plane.

3. Dose Monitoring

3.1. *RadFET Monitoring*

The dose received by the front of the EMC is measured by 116 RadFETs[4] placed in front of the barrel and endcap crystals. RadFETs are real-time integrating dosimeters based on solid-state MOS technology. The dose increases approximately linearly with the integrated luminosity. The dose map obtained by the RadFETs reproduces the beam background angular distribution. The highest dose accumulated to date, 700 Rad, is observed in the innermost ring of the endcap (EC) while both backward (BB) and forward (FB) barrels have similar doses of about 250 Rad (Figure 1a) on average.

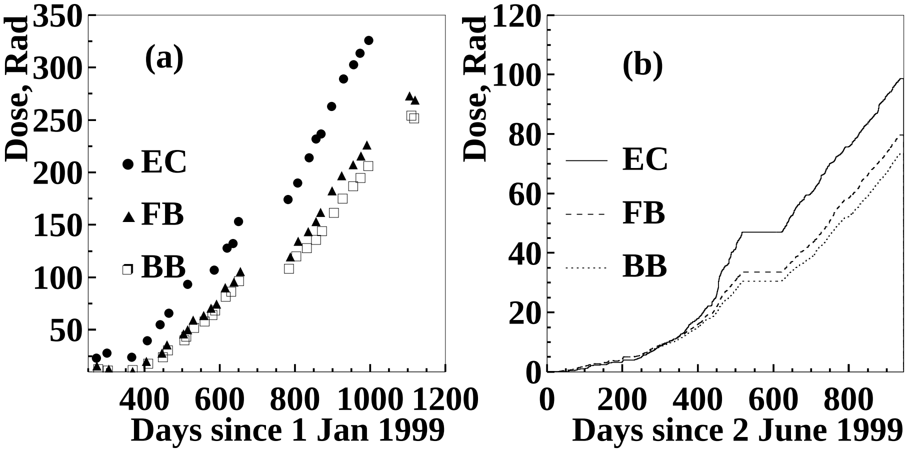

Figure 1. Average dose in the EMC measured by (a) the RadFETs, (b) the leakage currents.

3.2. *Leakage Currents*

An alternative way to calculate the dose accumulated by the crystals is using the leakage currents[5]. The dose then is proportional to the integral of beamcorrelated photodiode current (I):

$$Dose = \frac{E_{crystal}}{M_{crystal}} = \int \frac{I_{beams\,on} - I_{beams\,off}}{M_{crystal} \cdot C} dt, \qquad (1)$$

where $M_{crystal}$ is the mass of crystals in the section of the detector and C is the light output of 3900 photoelectrons/MeV obtained using the EMC readout (a light output of 7300 photoelectons/MeV was measured using a preamplifier with 2 μs shaping time). There are 10 independent bias voltage supplies for the EMC (four in the BB, four in the FB and two in the EC). Using the formula above, one can obtain the average dose in each sector. The RadFETs measure the dose seen at the front face of the crystal. The leakage currents average the above dose over the whole crystal volume. They give similar results within a scaling factor of approximately 3 (Figure 1b), which corresponds to the fraction of the crystal volume exposed to the radiation since the electro-magnetic showers deposit energy preferentially towards the front of the crystals.

The observed integrated dose induces damage to the crystals, which may be exhibited in two ways: a drop in the total light output and a change in the uniformity of the light output along the length of the crystal. We measure the change in the total light output using the standard BABAR calibration procedures[6]: radioactive source (6.13 MeV photons) and Bhabha events ($3 - 8.75$ GeV electrons).

4. Light Yield (LY) Monitoring

4.1. *Source Measurements*

We use 6.13 MeV photons from neutron–activated Fluorinert[7] circulating through a system of thin tubes in front of all crystals. These measurements are taken every 2 weeks and reach a precision of 0.33% for single crystals.

The dependence of the LY drop (averaged over EC, BB and FB) on the dose is presented in Figure 2a. The value of the degradation is currently 9% in the EC, 6% in the FB and 3% in the BB. The LY decreases as a function of dose as expected, but the drop in LY differs for FB and BB, although they received similar doses as measured by the RadFETs.

To address this effect the LY change was studied separately for each crystal vendor (Figure 3). Among crystals from the same vendor the values of the light yield degradation in the FB and the BB are similar. We are currently investigating the different rates of change of the LY in the barrel and the endcap. This may be explained by a significant portion of the EC crystals being irradiated both from the sides and from the front face, whereas the majority of the barrel crystals are irradiated from the front face only.

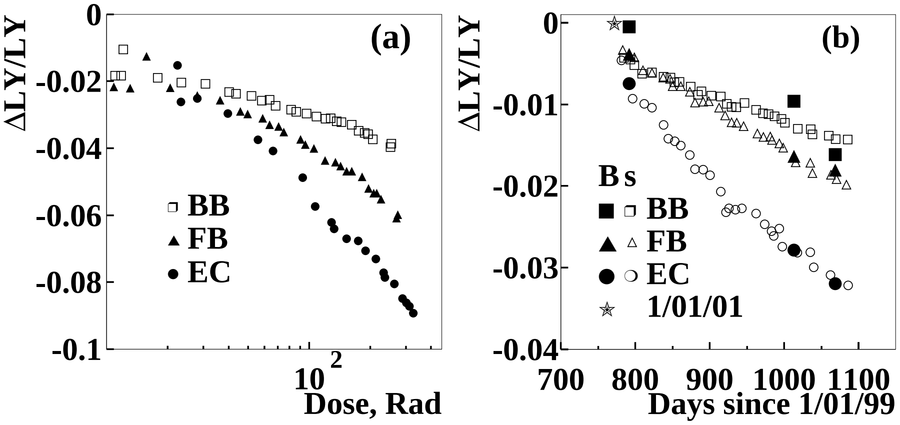

Figure 2. Average change in the light yield in the EMC measured with (a) source (August 1999–December 2001), (b) source(s) and Bhabhas(B) (January–December 2001).

4.2. *Bhabha Measurements*

Bhabha events allow the calibration of the calorimeter at high energies. In a 12-hour run at a luminosity of $3\times10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ we reach a precision of 0.35% per crystal. For the source measurements nearly all of the energy is deposited in the front part of the crystal whereas in Bhabha events a large fraction of the electro-magnetic shower is contained in the back part of the crystal which consequently has less radiation damage. Currently we do not see any difference between the Bhabha and the source LY change measurements (Figure 2b), thus there is as yet no evidence of non-uniformity. Our previous studies have shown that it might become an issue around 1 kRad[4]. To maintain a reasonable energy resolution the non-uniformity contribution to σ_E/E must be less than 0.5%.

5. Crystal Scanner Experiment

To study the light output uniformity behavior under irradiation we[a] have built an apparatus which allows *in situ* exposure and measurement of the longitudinal changes in the LY of large CsI(Tl) crystals. This experiment will help us to develop a correction function to be used in Monte Carlo simulation of detector performance which incorporates the effect of the radiation damage of the crystals.

We will study the spare full-size CsI(Tl) crystals from different vendors. The diagram of the apparatus is shown in Figure 4. An assembly consists of

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[a] T. Hryn'ova, P. Kim, M. Perl, K. Phillips, H. Rogers, R. Schindler, W. Wisniewski

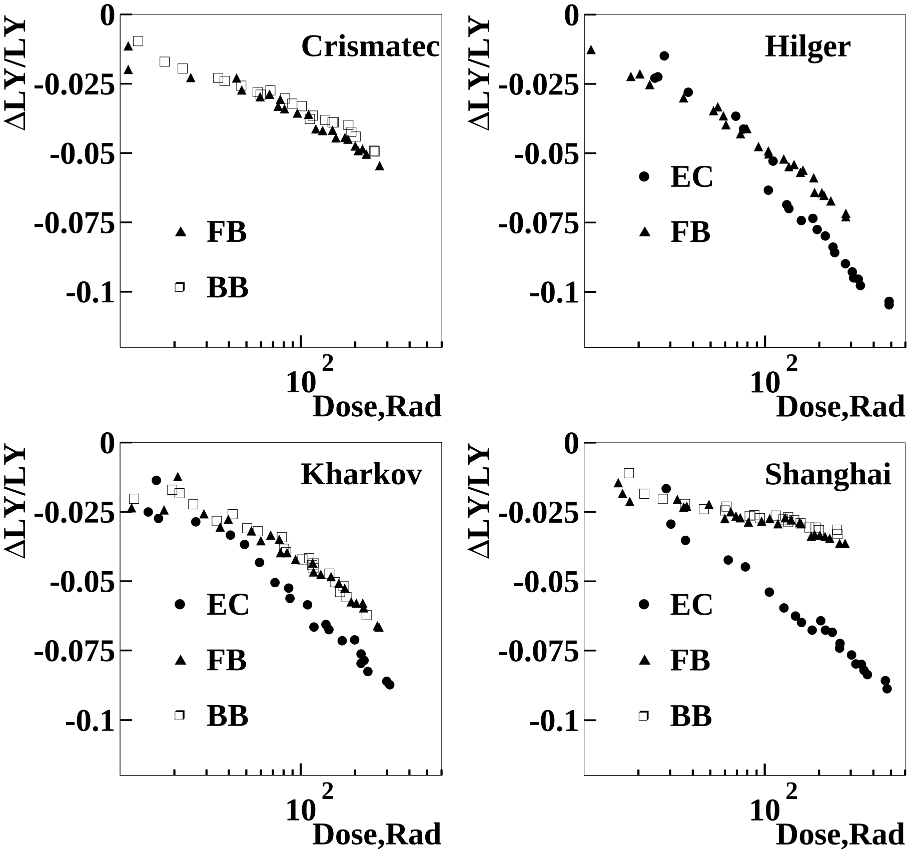

Figure 3. Average change in the LY in the EMC by vendor.

2×8 crystals each with Hamamatsu R2154-06 photomultiplier tubes (PMT) and 4 stepper motors moving two collimators with ^{88}Y sources in vertical and horizontal planes. The assembly is irradiated at a rate of 2 Rad/hour by photons from a ^{60}Co source which is located 1 m from the assembly. The front faces of all crystals are irradiated uniformly. A small CsI(Tl) crystal with PMT and ^{88}Y, ^{22}Na and ^{228}Th sources, located behind 10 cm of lead, is used as a standard reference to compensate for the drift of electronics. We use 10 AD592s[8] for the temperature monitoring. A light pulser system with light fibers connected to the face of each crystal is used to monitor the electronics. Radiation monitoring is done with 2 GM tubes with a computer readout for the current dose monitoring and 55 thermo-luminescent dosimeters for the total dose monitoring. Data is read out through the CAMAC crate/SCSI card[9] to

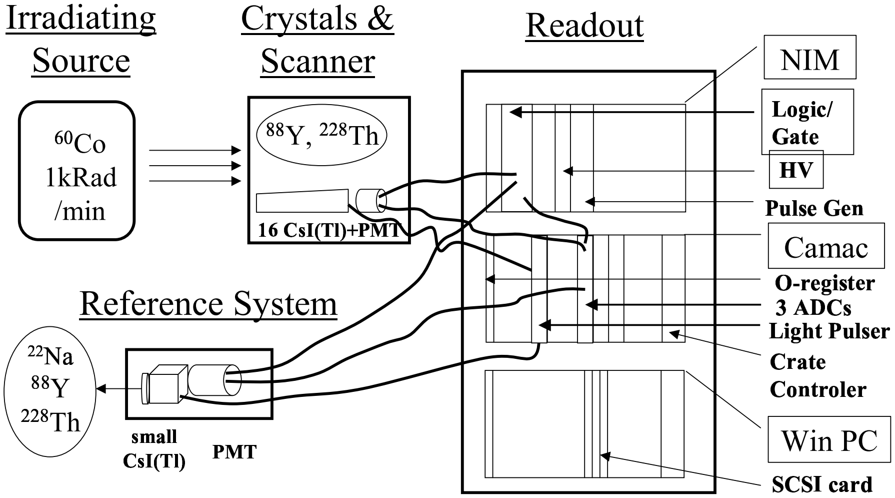

Figure 4. A diagram of Crystal Scanner Experiment.

a PC.

The apparatus is specifically designed to measure sixteen crystals simultaneously and to minimize the systematic errors in these measurements by performing all the logitudinal scans completely *in situ*, interleaved with short ^{60}Co exposures. Data points are planned to be taken every $2-3\,$cm along the crystal length doubling the dose until it reaches 5 kRad. A typical spectrum is presented on Figure 5. This experiment had been assembled and is ready to begin collecting data.

6. Conclusion

The 6580 crystals in the BABAR EMC along with extensive dosimetry allow us to study the impact of radiation damage on CsI(Tl) crystals with high precision. Effects of radiation damage in the detector are visible but not yet problematic. Additional studies such as the Crystal Scanner test will help us to improve our understanding of the changes in the detector, decreasing systematic uncertainties in measurements which rely on the calorimeter.

Acknowledgments

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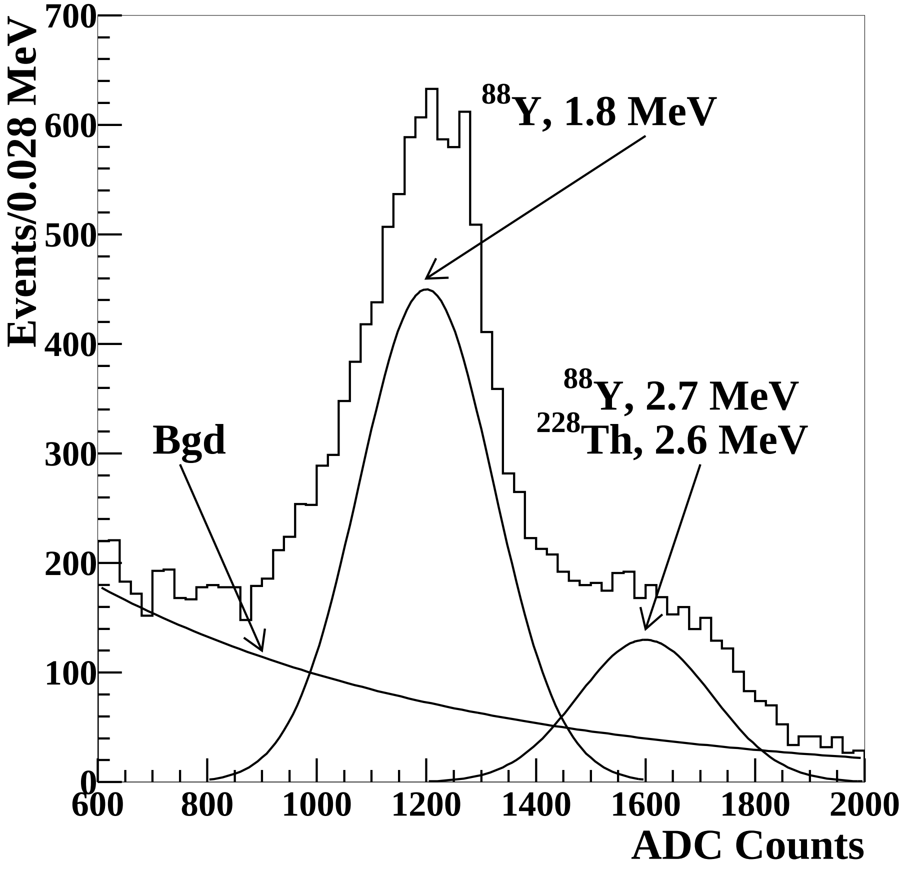

Figure 5. A typical spectra from the Crystal Scanner Experiment.

References

1. BABAR Collaboration, *Nucl.Inst.Meth.*, **A479**, 1 (2002).
2. Amcrys-H, Kharkov, Ukraine; Crismatec, Nemours, France; Hilger Analytical, Margate, Kent, UK; Shanghai Institute of Ceramics, Shanghai, P.R. China; Beijing Glass Research Institute, Beijing, P.R.China.
3. S. H. Robertson, private communications.
4. B. Camanzi *et.al.*, *Nucl.Instr.Meth.* **A457**, 476(2001).
5. I. Eschrich, these proceedings.
6. M. Kocian, these proceedings.
7. Fluorinet([C2F3CI]) is manufactured by 3M Corporation, St. Paul, MN, USA.
8. AD592 is a two terminal monolithic integrated circuit temperature transducer produced by Analog Devices, USA.
9. Jorway 73A CAMAC crate controller and CAMAC controller software (Fermitools).