Nuclear Instruments and Methods in Physics Research A242 (1985) 89–94
North-Holland, Amsterdam

RADIATION DAMAGE OF CsI(Tl) CRYSTALS IN A LONG TERM EXPOSURE AT PETRA

Susanne SCHLÖGL, Hartwig SPITZER and Kay WITTENBURG

II. Institut für Experimentalphysik, Universität Hamburg, 2000 Hamburg 50, FRG

Received 18 March 1985 and in revised form 22 July 1985

We have tested the radiation resistance of two 10 cm long CsI(Tl) crystals in the radiation environment of the PETRA e^+e^- storage ring. The crystals were exposed for 38 d to an average dose of 50 and 20 rad, respectively. The exposure leads to a continuous decrease of pulse height with a final reduction of $13 \pm 1\%$ (crystal 1 with photodiode readout at 50 rad) and $19.5 \pm 2\%$ (crystal 2 with photomultiplier readout at 20 rad). Most of the damage occurred in the first days of exposure. After the end of the exposure we observed a partial recovery of a few percent.

1. Introduction

Recently CsI(Tl) has been proposed as a scintillator material for high resolution electromagnetic calorimeters [1–6]. As an example the CLEO upgrade project foresees the use of CsI at the CESR e^+e^- storage ring [5]. In many respects CsI is equivalent or superior to BGO. In particular the high light yield with an emission maximum at 550 nm matches well with silicon photodiode readout. One of the properties which might limit the use of CsI at storage rings is its sensitivity to background radiation. Typical radiation levels to be expected are 30–100 rad/month at a radial distance of 25 cm from the interaction point of the DORIS ring.

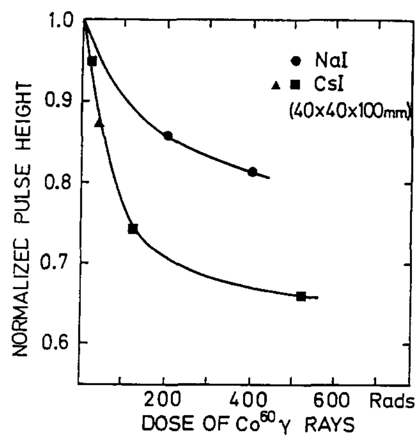

Fig. 1. Pulse height reductions in NaI and CsI crystals from exposures to γ rays between 20 and 520 rad. The data points indicated by full circles and squares are from ref. [7] using a ^{60}Co source, the triangle is from ref. [8] using a ^{137}Cs source.

Previous work on the radiation resistance of long CsI crystals concentrated on short term exposures to the radiation of ^{60}Co and ^{137}Cs sources [7, 8].

The studies revealed the following picture:

1. From exposures of up to 100 rad the pulse height of CsI decreases substantially (up to 25%).

2. At low doses the initial damage grows linearly with dose, whereas at higher doses (above 100 rad) saturation effects occur. Fig. 1 illustrates the results.

3. The radiation damage does not recover spontaneously, however it can be cured by heat treatment [4].

The previous measurements were performed using photomultipliers, which had maximum quantum efficiency below 500 nm. From experience with BGO and scintillator we would expect, that the radiation damage is less severe at wavelengths above 500 nm where silicon photodiodes have a good quantum efficiency. Both, the damage recorded with photodiode readout and the cumulative effect of small daily doses over an extended period of time, have not yet been reported. We have therefore tested the radiation susceptibility of CsI crystals ($1.5 \times 1.5 \times 10$ cm^3) using photomultiplier and photodiode readout. The crystals were exposed under realistic conditions in a partially shielded position on the beampipe of PETRA for 38 d.

2. Experimental procedure

In the following we first describe the setup for pulse height measurements and subsequently the irradiation procedure. The setup is similar to the one described in ref. [8]. The properties of the two crystals are listed in table 1.

Table 1
Properties of test crystals

Crystal [a]	Size (mm^3)	Delivery date	Cs resolution $\Delta E/E$ [b] (%)	Uniformity [c] (%)
1	15×15×100	Oct. 83	7±0.5	5.5
2	15×15×100	Oct. 83	10±0.5	8

[a] The crystals were made by BDH, Poole, Dorset, England BH 12 4NN.
[b] Head on energy resolution of ^{137}Cs γ rays (E_γ = 662 keV) measured with a photomultiplier Hamamatsu R268. ΔE is full width at half maximum.
[c] Uniformity of pulse height (ph) given by $(max_{ph} - min_{ph})/max_{ph}$ measured over 8 cm of the crystal length.

The crystals had all sides polished. They were wrapped in white reflective foil (aluminized Mylar sprayed with TiO_2 paint). Crystal 1 was glued with optical glue to a Hamamatsu S1790 silicon photodiode, which had a sensitive area of 1 cm^2. Using this diode the crystal gave a light yield corresponding to 10400 photo-electrons/MeV calibrated with a ^{207}Bi source. Crystal 2 was glued to a Hamamatsu R268 photomultiplier which has a spectral response from 300 to 650 nm with a maximum at 420 nm. During handling the crystals were kept under red light. The photodiode on crystal 1 was read out via a charge sensitive preamplifier (Canberra 2003BT), a shaping amplifier and a multichannel analyzer. The readout of the photomultiplier on crystal 2 was the same as in ref. [8]. The drift of the multiplier and the readout electronics was monitored by a LED which was glued to the photocathode window.

The irradiation was performed by mounting the crystals in partially shielded location on the PETRA beampipe next to the CELLO detector. Fig. 2 shows a side view of the detector layout. Two boxes containing the crystals were put on the beampipe about 60 cm away from the mini β-quadrupole (1). The average radial distance of the crystals from the beam was 15–25 cm. The beampipe was wrapped between points (n) and (o) by 4 mm of lead. Further radiation protection was provided by an iron wall (f), a lead brick wall (k) (total thickness 5 cm) and a lead glass shower counter (h). Three beam halo absorbers were placed in the beampipe at positions (n), (o) and (p). The boxes themselves were covered by a 1 mm layer of lead.

The scintillation light yield of crystal 1 was measured by positioning an uncollimated 3.6 μCi ^{207}Bi γ source mounted 2 cm away from the narrow end face. We chose the ^{207}Bi source for its relatively high γ energy (1060 keV) for monitoring under unfavourable noise and background conditions. Since no additional ^{207}Bi source was available, crystal 2 was monitored by a 10 μCi ^{137}Cs γ source mounted 3 cm away from the narrow end face. The choice of two different sources

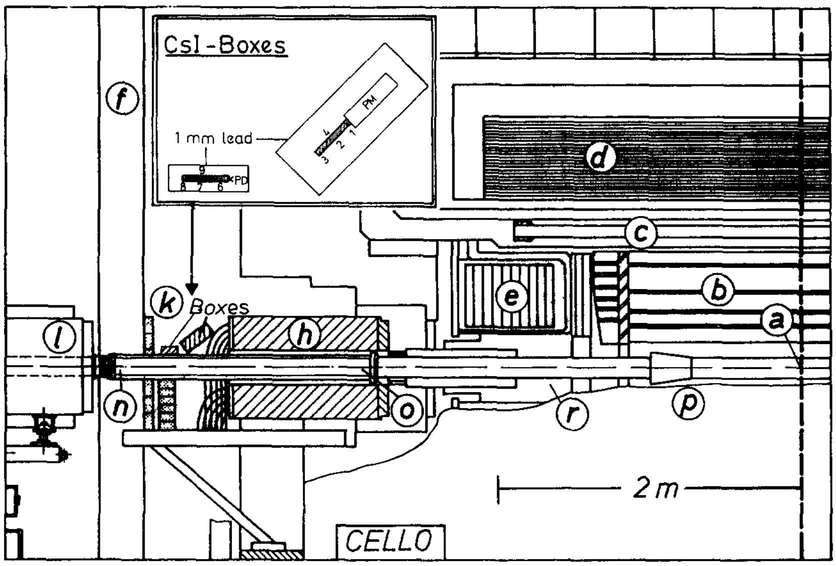

Fig. 2. Side view of the environment of the CELLO detector, where two CsI crystals were exposed to background radiation. The components relevant to the test are (a) interaction point, (c) solenoidal magnet coil, (e) endcap liquid argon counter, (f) massive iron shielding wall, (h) lead glass shower counter (17 radiation lengths), (k) lead wall of total thickness 5 cm surrounding the vacuum pipe, (l) mini-β-quadrupole, (n), (o), (p) positions of beam halo absorbers. Details of the boxes containing the crystals are shown in the insert. The numbers indicate the positions of the TLDs.

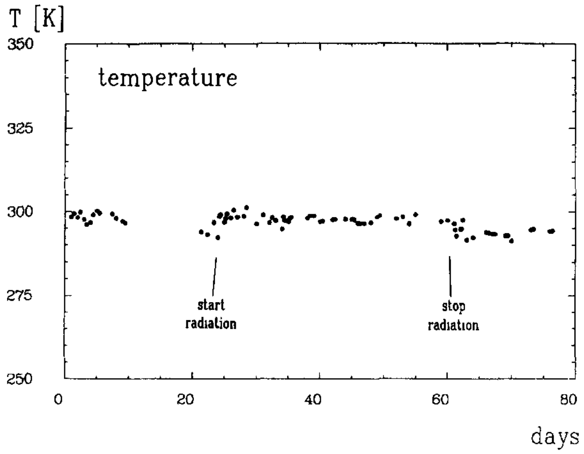

Fig. 3. Temperature history of the crystals before, during and after the exposure.

does not affect the measurement of pulse hight losses within the anticipated accuracy.

The crystal temperature was measured by a temperature sensor mounted near each crystal. Fig. 3 shows the temperature variation during the measuring period. The results given below have been corrected assuming a temperature coefficient of −0.3%/K for CsI [9] and of −0.6%/K for the LEDs.

3. Radiation dose and results

The crystals were exposed for a total of 38 d. The radiation dose was measured by thermoluminescent dosimeters (TLD) mounted on the side of the crystal facing the beam and on the opposite side as indicated in the insert of fig. 2. The measured integrated doses are shown in table 2.

We observe large dose variations of 26–84 rad for crystal 1 and 15–27 rad for crystal 2. The accuracy of each dose measurement was determined to be 10% by placing several TLDs at one particular location. We attribute the large variations to inhomogeneities in the radiation field resulting from nonuniform distribution of material around the beampipe. Because of space limitations and the variations of the radiation field it was not possible to subject the two crystals to equal doses.

Although we did not measure the day to day dose variations, we expect that the total dose was not received in one or two big accidents but rather in a more continuous way.

PETRA had typically six successful fillings per day and an average of 12 h of continuous beam per day. The beam energies were between 22.1 and 23.3 GeV.

In order to illustrate the energy range of the radiation hitting the crystal we show in figs. 4(a)–4(c) three energy spectra measured (a) in a period with no beam, (b) during injection ($E_{beam} = 6.9$ GeV) and (c) during a typical luminosity run ($E_{beam} = 21.1$ GeV). From fig. 4 we observe the following:

1. With beams off the pulse height spectrum of crystal 1 has three peaks resulting from noise (pedestal) and the 570 and 1060 keV lines of the ^{207}Bi source.
2. During injection this structure is still seen superimposed upon a low energy background from the storage ring.
3. During a luminosity run the background is the dominant signal, peaking at 250 keV and obscuring the source peaks.

The corresponding spectra from crystal 2 (fig. 5) show the following pattern:

1. During injection (fig. 5(a)) two peaks show up. One is from 662 keV photons of the cesium source. The leftmost peak is the 30 keV K_α line of barium atoms in the cesium source which are excited by synchrotron radiation. Although this peak is prominent, 30 keV photons are absorbed in the first few mm of the crystal and will contribute little to the overall radiation damage. The continuum between both peaks is a superposition of inherent machine background radiation and backscattered photons from the cesium source.
2. During a luminosity run (figs. 5(b), 5(c)) the machine background peaking at 250 keV is the dominating pattern.

Figs. 6(a) and 6(b) show the pulse height history of crystal 1 as monitored by the 570 and 1060 keV lines of the ^{207}Bi source in periods between fillings (no beam). The pulse height is normalized to the average value before the exposure. We observe an abrupt decrease in the first ten days of the exposure which then becomes more gradual. After 38 d the pulse height dropped to $88 \pm 1\%$ and $86 \pm 1\%$ of its initial value for the two lines.

Note that the temperature was stable within 1°C

Table 2
Integrated dose measured by the TLDs shown in the insert of fig. 2

Crystal	Readout	Integrated dose	
		No. of TLD	Dose (rad)
1	photodiode S1790	6	26.3
		7	37.5
		8	84.4
		9	60.7
2	photomultiplier R268	1	15.4
		2	18.7
		3	27.6
		4	16.9

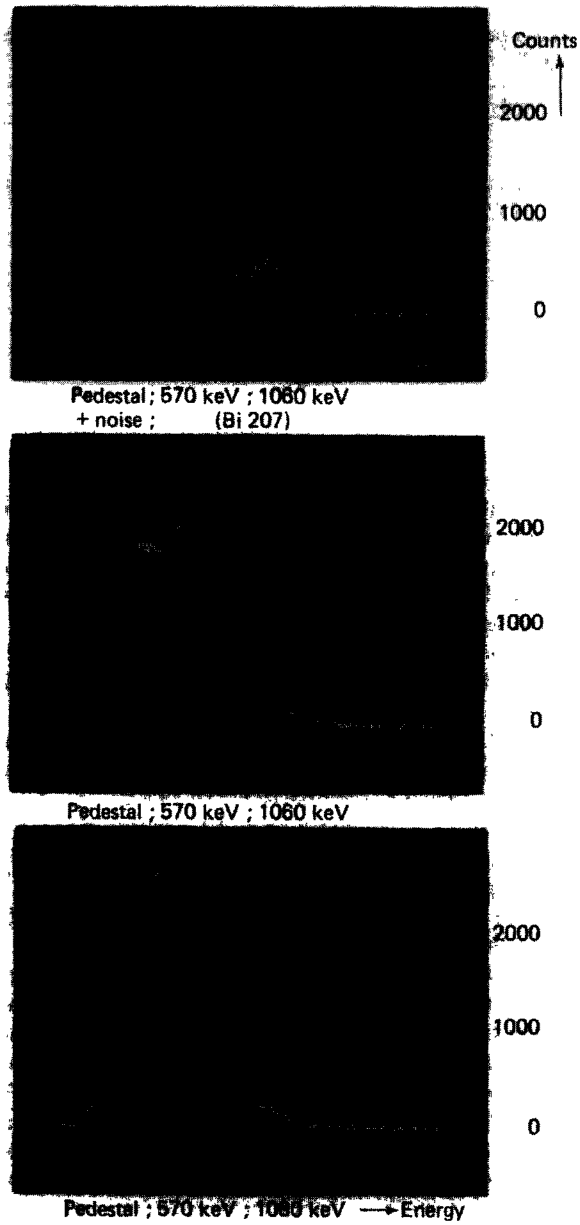

Fig. 4. Pulse height spectra measured by crystal 1 under three different beam conditions. (a) No beam, $E=0$ GeV, $I=0$ mA, accumulation time: 4.15 min; (b) injection, $E=6.9$ GeV, $I=1.0$ mA, accumulation time: 3.30 min; (c) luminosity run, $E=22.1$ GeV, $I \geq 3$ mA, accumulation time: 30 s. For details see the text.

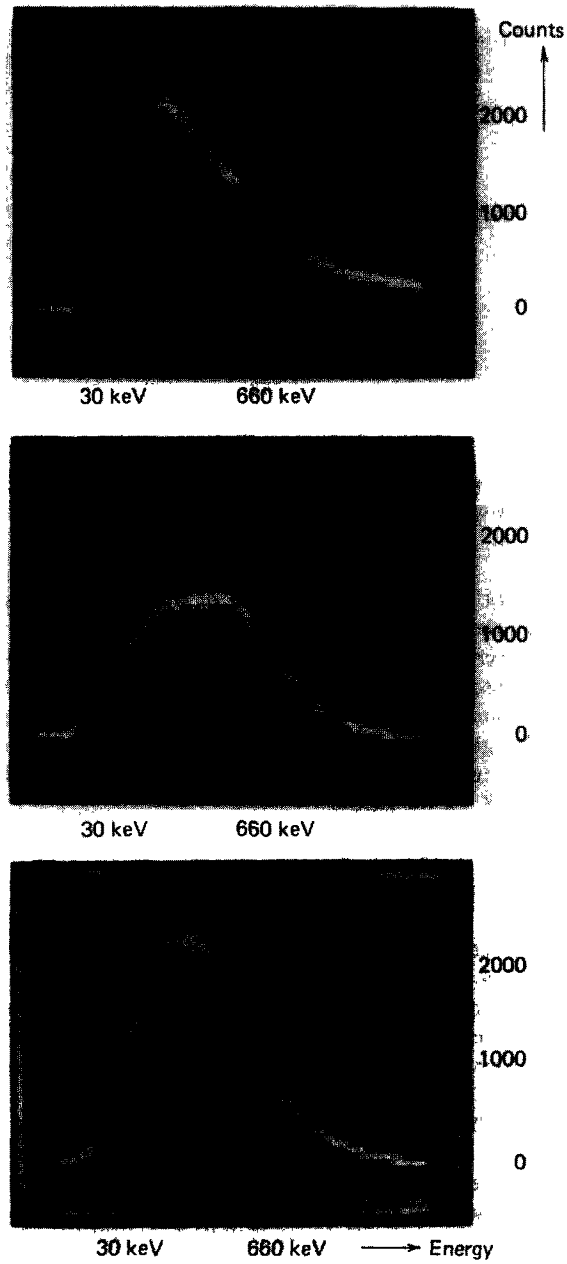

Fig. 5. Pulse height spectra measured by crystal 2 under three different beam conditions (a) Injection, $E=6.9$ GeV, $I=1.0$ mA, accumulation time: 1.00 min; (b) luminosity run, $E=22.1$ GeV, $I=4$ mA, accumulation time: 30 s; luminosity run, $E=22.1$ GeV, $I=6$ mA, accumulation time: 30 s.

until the end of the exposure, so that uncertainties in the correction for the temperature dependence are negligible. The estimated systematic uncertainty is 1%. After the end of the exposure the crystal was removed from the beam within one hour and monitored for another 15 d. We observe little change in the pulse height.

The data indicate a small continuous recovery by 2%. Assuming the temperature coefficient given in ref. [3] (+0.3%/degree at 20°C for photodiode readout) the recovery is 4.5%.

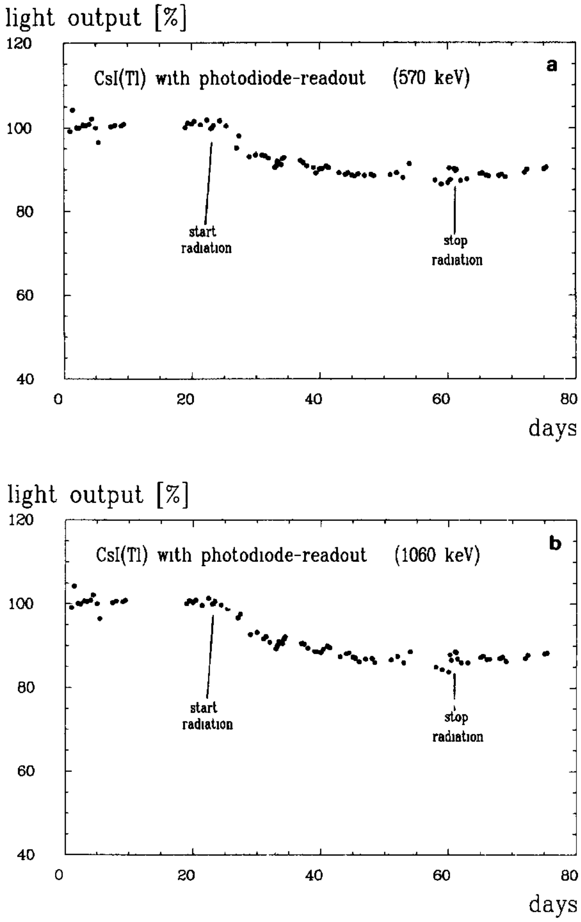

Fig. 6. Pulse height history of crystal 1 exposed to background radiation on the PETRA beampipe for 38 d. Shown in (a) and (b) is the light output of the 570 and 1060 keV γ lines of the ^{207}Bi source, respectively.

Fig. 7 shows the pulse height history of crystal 2 with photomultiplier readout. Here we observe a similar pattern. The pulse height drops rapidly in the first days of the exposure and then at a much slower rate. After 38 d it reaches $80.5 \pm 2\%$ of its initial value, a somewhat greater loss than for crystal 1, although the absorbed dose is smaller by a factor of 2.5. We conclude that the damage is more severe in the 370–470 nm wavelength range monitored by the photomultiplier with good efficiency than in the range above ~ 470 nm.

After removal of the crystal from the beam the corrected pulse height rises within hours by 3% to $83.5 \pm 2\%$. Assuming the temperature coefficient of ref. [3] (+0.6%/K for multiplier readout) the rise is 6.5%. The rise is somewhat larger than that observed in crystal 1 with photodiode readout indicating a slightly different recovery pattern at shorter wavelengths.

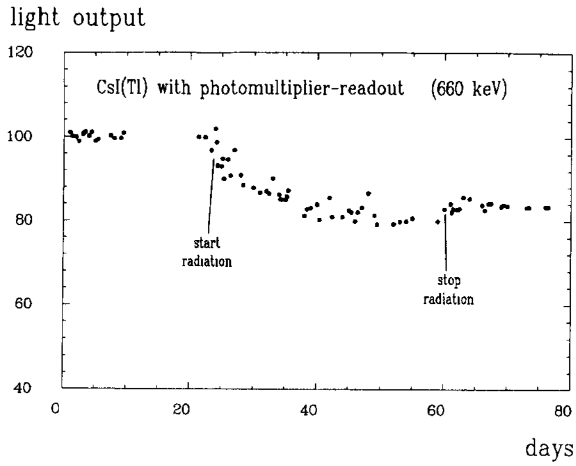

Fig. 7. Pulse height history of crystal 2.

4. Summary and discussion

From a 38 d exposure of two CsI(Tl) crystals in a partially shielded position on the PETRA ring we observed the following:

1. Irradiation of a 10 cm long crystal with silicon photodiode readout by 50 rad (with substantial dose variation along the crystal) led to a pulse height reduction of $13 \pm 1\%$. The pulse height recovered slightly after the end of the exposure by 2–4.5%.

2. Irradiation of a similar crystal with photomultiplier readout by 20 rad led to a pulse height reduction of $19.5 \pm 2\%$. The spontaneous recovery was of the order 3–6.5%.

3. Most of the pulse height reduction occurred in the first 10 d of the exposure.

In conclusion, the pulse height reduction seems to depend on the wavelength of the light. It is preferable to use photodiode readout, which samples larger wavelengths with a greater efficiency. We observe that the relative loss of pulse height per absorbed radiation dose is much smaller for crystals which have already been exposed for about 10 d to a few tens of rads than for virgin crystals. In calorimeter applications of CsI at e^+e^- storage rings it will be necessary to monitor the pulse height response regularly in order to cope with the radiation damage.

Acknowledgments

We thank Maren Riebesell for help with the test. The help of Mr. Ebeling with processing of the dosimeters is gratefully acknowledged. This work was supported by the Bundesministerium für Forschung und Technologie, Bonn.

References

[1] A. Minten, Proc. Workshop Experimentation at HERA, NIKEF, Amsterdam (1983) DESY HERA 83/20.
[2] E. Lorenz, IEEE Trans. Nucl. Sci. NS-31 (1) (1984).
[3] H. Grassmann, E. Lorenz and H.-G. Moser, Physikalisches Institut der Universität Erlangen-Nürnberg, Forschungsbericht No. 5 (1984).
[4] H. Grassmann, E. Lorenz, H.-G. Moser and H. Vogel, MPI für Physik München report MPI-PAE/Exp., Nucl. Instr. and Meth. A235 (1985) 319.
[5] CLEO upgrade proposal, Cornell University (USA) 1983.
[6] E. Lorenz, Study of a Detector for Ypsilon Physics at DORIS (Nov. 1984) unpublished.
[7] G.J. Bobbink, A. Engler and R.W. Kraemer, Carnegie Mellon University, Pittsburgh, USA, report CMU-HEP 83-13/Rev, submitted to Nucl. Instr. and Meth.
[8] Ch. Bieler et al., Nucl. Instr. and Meth. A234 (1985) 435.
[9] D. Williams, G.F. Snelling and J. Pickup, Nucl. Instr. and Meth. 39 (1966) 141.