Nuclear Instruments and Methods in Physics Research A325 (1993) 446–450
North-Holland

NUCLEAR
INSTRUMENTS
& METHODS
IN PHYSICS
RESEARCH
Section A

On-line monitoring of radiation damage in optical fibers

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Received 6 September 1992 and in revised form 22 September 1992

We report on the construction and the performance of a setup which is monitoring the transmission of optical materials during irradiation with a measurement precision of about 2%.

1. Introduction

Upgradings of existing particle colliders as well as the new generation of colliders are designed for the highest achievable luminosity. Examples are the TeVatron upgrade, or the next generation hadron colliders SSC and LHC [1].

Those luminosities are the cause for high levels of radiation in the experimental setup, especially in the region close to the particle beams. We attempted to contribute to the search for radiation hard materials by constructing a device which can measure the effects of radiation on materials during the irradiation process. The design of the device has as main goals:

- small systematic errors, also over a long period of time.
- capability to measure different parameters simultaneously, like for example the transmission of fibers at different wavelengths of light.
- modular construction allowing to extend the setup in such a way that a large number of different probes can be studied at the same time.

A device with those properties can provide detailed knowledge useful for the study and understanding of the fundamental processes defining radiation hardness. It can also be used to perform a systematic empirical search for the best available material.

For the measurements described in this article we equipped the setup with plastic lightguiding fibers and we measured their relative transmission for different wavelenghts. The setup could, without substantial modifications, also be used to measure transmission or light emission of any other kind of scintillator or lightguide.

A first engineering run with a simpler version of the setup was described in ref. [3].

2. Basic design

Light of a certain wavelenght is transmitted through an optical fiber to a photodiode. The photocurrent is amplified and monitored. The result of the measurement is the change in transmission with time.

There are also photodiodes viewing the light emitters directly, without any fibers in between. They are used to monitor changes in the output signal which are not due to a change in the transmission of the fiber. In that way one can correct for changes in either the electronics or in the light emission and the sensitivity of the photodiode. In addition electronic test pulses of constant amplitude into the entrance of an amplifier monitor changes of its amplification separately. The whole setup is controlled by an IBM personal computer via CAMAC. No part of the equipment needs to be touched during the measurement.

The light to be monitored can come either from LEDs of different colours or it can be provided by a normal lamp and a colour filter. The amplifiers can be either operating in dc or ac mode. Amplifiers which are sensitive to pulses are potentially more precise; they can operate even in the presence of day light for example. However, dc amplifiers are easier to build and cheaper.

We wanted to see which of the different input and readout techniques is most suitable, and so we equipped our device with both coloured LEDs and with a white

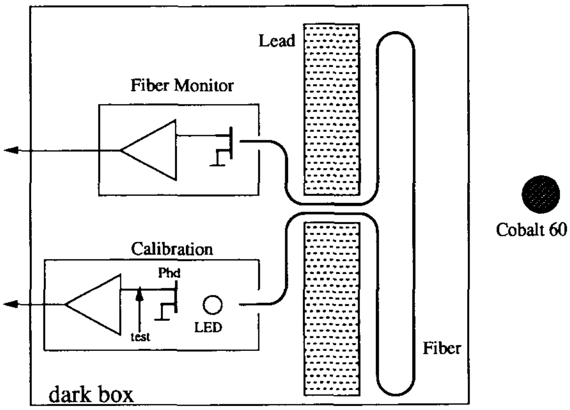

Fig. 1. Schematic view of the experimental setup.

lamp and a colour filter, and we used both ac and dc amplifiers, as described in more detail in the following.

3. Actual setup

The input light pulses were provided by red and green LEDs (maximum of transmission at 635 nm and 570 nm, respectively) and by a 4.5 V lamp. The input signals provided by the pulsed LEDs were read by photodiodes equipped with ac amplifiers. The LEDs were also directly viewed by a photodiode, without a fiber in between, such that changes in the light output of the LED could be observed as well. The continuous light from the lamp was read out by a photodiode with an amplifier working in dc mode. Also this lamp was monitored by a photodiode viewing it directly.

Fig. 1 shows a schematic drawing of the device. The light sources as well as the photodiodes and the amplifiers are behind a lead shielding consisting of up to 10 cm of lead bricks. The fibers are traversing the lead shielding and are exposed to the radiation over a length of about 1 m.

4. Radiation levels

We used a ^{60}Co source of the FRAE-CNR Institute at the Laboratory of Legnaro (INFN). It has an activity of 5400 Ci. The cobalt is inside a lead container and can be brought out of it by remote control. The absorbed radiation was measured using radiochromic films and alanine dosimeters behind the lead shielding. The radiation absorbed by the fibers in front of the shielding was calculated based on the distance between fiber and source.

Behind the lead wall, where the LEDs, the lamp, the photodiodes and amplifiers were installed, the exposure to radiation was between 40 and 80 krad, measured at six different places. The part of the fibers which was exposed to the source accumulated 1.8 Mrad.

The photodiodes also act as nuclear counters, since photons from the cobalt source get absorbed and cause a current. In the photodiodes which were equipped with dc amplifiers this effect was observed indeed. The effect can be used to monitor the radiation as well, something which we did not attempt however.

5. Measurement procedure

The exposure to the source was done in two steps. For the first 16.1 h of irradiation the distance between the fiber and the source was 43 cm. Then we decreased the distance to 26 cm in order to increase the intensity of the radiation. After another 22.5 h, at t = 39 h, we had the source switched off for 48 min, switched on for 16 min and then had it off for the rest of the experiment. This short reactivation of the source was performed for various checks and for some precision measurement on a very short time scale (discussed in fig. 5). After the source was switched off the fibers were observed for an additional 28.1 h in order to study recovery effects.

During the first period of 16.1 h the radiation absorbed by each fiber was 380 krad, and in the subsequent 22.5 h 1.4 Mrad; a total of 1.8 Mrad. The exposure of the fibers was not uniform over their length; from geometry we estimate a nonuniformity of about 25%.

6. Calibration

As mentioned in section 3, the LEDs where monitored by a photodiode directly, without fiber in between. In that way we could measure changes in the LED–photodiode–amplifier system. Indeed, the output signal from that amplifier was not found to be constant over time. There were three components in its response.

1) We observed a periodic fluctuation with a period of 24 h, the minimum occurring in the early morning. The amplitude of that fluctuation was 4%. We interpret it as a possible temperature sensitivity.

2) The signal was decreasing by 2% over the observation time. That might be due to radiation damages in either the LED or the photodiode surface or in the electronics of the amplifier.

3) Comparing the different 24 h periods we find a nonperiodic fluctuation of about 1%. We attribute it to an instability within the amplifier.

We correct the response of the amplifiers which monitored the various fibers for that periodic fluctua-

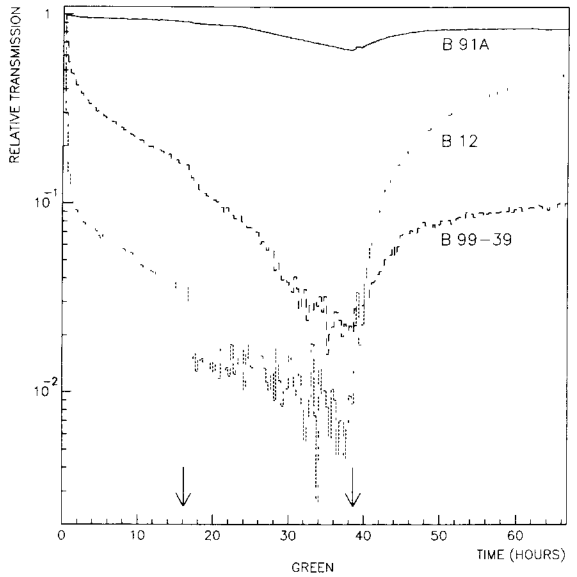

Fig. 2. Change in transmission for green light. The arrows indicate the time when the intensity of the source was increased at 16.1 h and when the source was switched off at 39 h

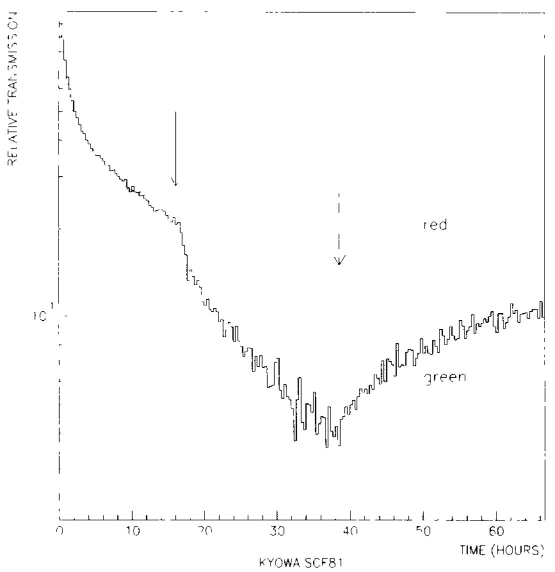

Fig. 3. Change in transmission for green and red light, Kyowa SCF81 fiber.

tion of 4% and for the 2% decrease. The correction is derived from the one amplifier viewing the photodiodes directly and it is applied to all the other amplifiers. The above mentioned nonperiodic fluctuation of 1% is such resulting in a systematic uncertainty of the corrected relative transmission of somewhat more than 1%. We will quote it as 2% in the following as a reasonably conservative number.

For the time being we consider this precision more than sufficient, but it could be increased by pulsing each of the amplifiers instead of one only.

7. Measurement and results

We had four different types of fibers installed. Bicron BCF-12 (scintillating fiber), Bicron BCF-91A (wavelength shifter), Bicron BCF-99-39 (wavelength shifter) and Kyowa SCF81 (scintillating).

We found that the light emitted by the two scintillating fibers was too weak to be detected by our apparatus. If the scintillation light would have been strong enough to be measurable, the monitoring of the transmission would still have been possible since we used pulsed light for those fibers.

Fig. 2 shows the change in time of the transmission of the three Bicron fibers for green light. The vertical axis of fig. 2 is the relative transmission, normalised to 1 in the first bin. It is pedestal subtracted and corrected for the instabilities in LED, photodiode and amplifier performance as discussed previously. The horizontal axis is the time in hours. Figs. 3 and 4 show the transmission of the fibers Kyowa SCF81 and Bicron BCF-99-39, corresponding to fig. 1. We see the decrease in transmission immediately after the source was switched on, and we see the change in Δtransmission/Δtime when the intensity of the radiation was increased at $t = 16.1$ h. All the fibers show some recovery as soon as the source is switched off.

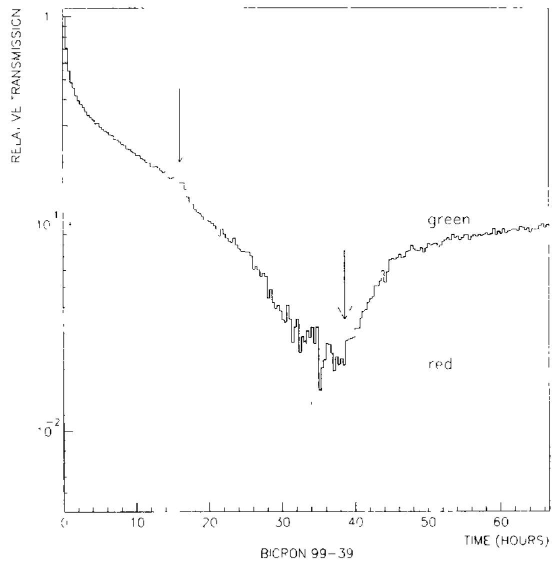

Fig. 4. Change in transmission for green and red light, Bicron 99-39 fiber.

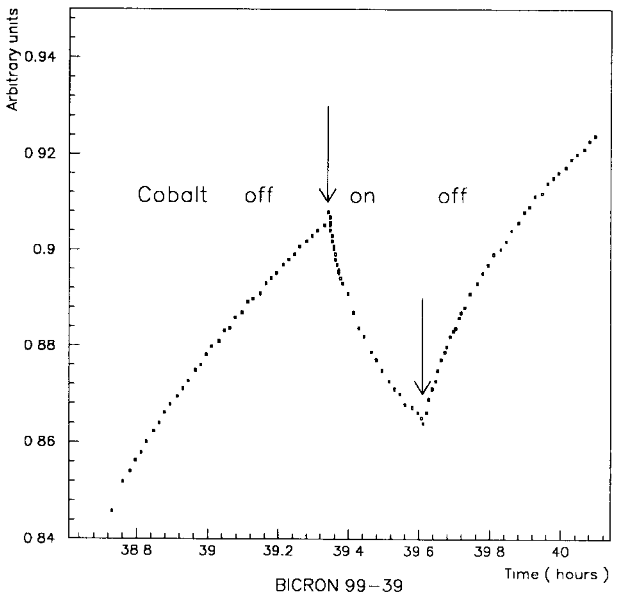

Fig. 5. Fiber response on expanded time scale, Bicron 99-39 fiber. The photodiode was read out by a dc amplifier.

The differences in radiation damage for different fibers are very large. We know [2] that all three Bicron fibers are made from the same basic material (polystyrene), only their dopants are different. From fig. 2 we can conclude that it is either the dopants or the interaction between the dopant and the polystyrene which contributes most to the radiation damage. Also the development of the radiation damage for green and red light is very much different for different fibers.

Another interesting effect is that Δtransmission/Δtime reaches a minimum for all the Bicron fibers at about $t = 25$ h. The radiation damage seems to progress increasingly slowly and then it accelerates again. The effect is not very strong, but significant. It confirms a similar observation which was made during the first engineering run described in ref. [3]. We cannot explain that strange kink in the transmission by technical problems in our measurement device; it must be a process in the fiber itself.

The plots show the performance of fibers over a long period of time and for a defined wavelength of light. To do a technical demonstration of the precision which can be obtained with our setup we show on a more expanded time scale the transmission of a fiber at times when the source was switched on and off. The fiber used is Bicron BCF-99-39. (The signal came from the 4.5 V lamp; for the limited purpose of this measurement we did not attempt to evaluate its continuous emission spectrum.) At about $t = 39$ h we had the source switched off and shortly afterwards reactivated for a short time, as described in section 5. We see the prompt response of the fiber to the radiation on that smaller time scale in fig. 5 with a precision of the order of a few tenths of a percent. Precisely at the times when the source was switched on or off there is a small but significant discontinuity. From a comparison with a photodiode which was not connected to any fiber we know that that discontinuity is due to the current produced by the photons of the cobalt source directly.

From fig. 5 we see that both the radiation damage and the recovery proceed very fast in the first minutes of irradiation or recovery.

8. Conclusion

We observed the transmission of different optical fibers over a time of 39 h, integrating 1.8 Mrad of radiation from a ^{60}Co source and another 28 h without radiation. The measurement precision was about 2%. We did the measurement for red and green light from LEDs and for light emitted by an ordinary 4.5 V lamp. The response to radiation was very different for different fibers, in some cases large recovery effects are observed on a time scale of several minutes only. The strange structure in Δtransmission/Δtime which we already described in ref. [3] is visible again. The setup is designed in a way which would allow its upgrading so that a large number of fibers could be measured simultaneously. The various components of the system are continuously calibrated and therefore one can potentially extend the measurement over a very long period of time without compromising the measurement precision.

Acknowledgement

We want to thank M. Atac (Fermilab) for many profitable discussions.

J. Ernwein (Saclay) provided us with dosimeters and much helpful advice. The support of V. Cavasinni (Univ. Pisa) and G. Bellettini (Univ. Pisa) was crucial for a speedy realisation of the experiment. Special thanks go to S. Lora (CNR Legnaro), who is responsible for the ^{60}Co source, for his friendly support. C. Hurlbut and F. Kniest from Bicron gave us some of their newly developed fibers.

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