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PRELIMINARY RADIATION RESOURCE RESULTS ON SCINTILLATING FIBERS

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New results of measurements of a relative light output in typical polysterene scintillators and fibers at continuous (4 years) cyclic irradiations with γ rays are presented. The record time (10 hours) of spontaneous recovery of the samples, to which antioxidants and photostabilizers were added instead of antirads, is obtained. Extrapolation of these results to the area of «gigarad radiation levels» indicates the possibility of using cheap scintillating fibers in future «spaghetti» calorimeters instead of quartz fibers. In this case, the energy resolution of hadrons improves from $150\,\%\sqrt{E} \oplus 6\,\%$ to $54\,\%\sqrt{E} \oplus 1.5\,\%$.

The investigation has been performed at the Laboratory of High Energies, JINR.

Предварительные результаты радиационного ресурса сцинтилляционных фибр

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Представлены новые результаты измерения относительного световыхода обычных полистирольных сцинтилляторов и спектросмещающих волокон (фибр) при длительных (4 года) циклических облучениях гамма-квантами. Получено рекордное время спонтанного восстановления (10 часов) образцов, в которых впервые были введены антиоксиданты и фотостабилизирующие добавки вместо антирадов. Экстраполяция этих результатов в область «гигарадовых радиационных уровней» указывает на возможность замены кварцевых фибр на дешевые сцинтилляционные фибры в калориметрах типа «спагетти». При этом энергетическое разрешение калориметра по адронам изменяется со $150\,\%\sqrt{E} \oplus 6\,\%$ до $54\,\%\sqrt{E} \oplus 1,5\,\%$.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

SCINTILLATING FIBER PERFORMANCE

The fraction of energy deposited in the polymer and emitted as visible light, is approximately 3 %. This corresponds to an emission of 10 photons for each keV of deposited energy. A minimum ionizing particle deposits 1.7 MeV/cm in polystyrene, and so approximately 1700 photons are emitted for a 1 mm fiber. Using the above 3.8 % piping efficiency in each direction, we find that roughly 65 protons are piped in the fiber in each direction.

Attenuation effects in scintillating fiber are characterized by bulk absorption, Rayleigh scattering, and interface losses. The attenuation lengths have been measured to be as long as

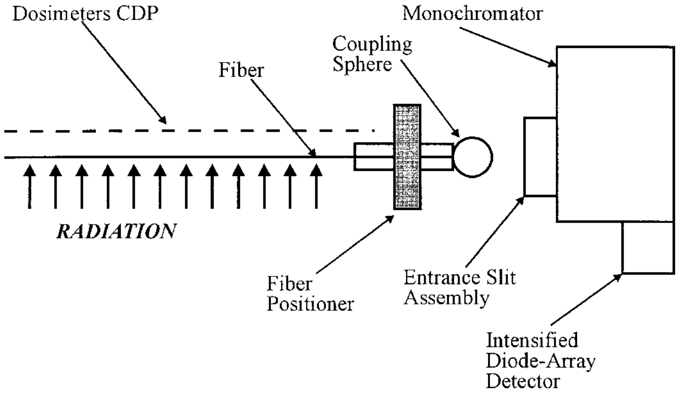

Fig. 1. Schematic view of monochromator system used for fiber attenuation studies

2 m in the spectral region around 425 nm. In order to optimize the waveguided properties of scintillating fiber, we must have precise technique to evaluate their performance. Attenuation studies are performed in order to measure attenuation as a function of wavelength where attenuation is described by:

$$\xi\left(\lambda, D\right) = \exp\left(-L\alpha\left(\lambda, D\right)\right)R\left(\lambda, D\right)^{\mathrm{tn}\theta\,(L/D)}$$

with: D — the dose irradiation; λ — wavelength; α — the absorption coefficient; R — the reflection coefficient; L — the distance in the fiber from the point of excitation to the detector end; θ — the reflection angle for a given photon; d — the fiber diameter.

The system we use for these measurements is shown in Fig. 1. It consists of a monochromator coupled to intensified diode array detector head, the microchannel plate intensifier having a S-20 photocathode. Using a 147 groove/mm grating, this system gave approximately a 0.5 nm resolution/diode. The measurements were performed by exciting the fiber with a UV source in source positions from 10 cm to 2 m from the fiber end. Light from the fiber was coupled to the entrance optics of the monochromator with a spherical lens. This arrangement matched the numerical aperture of the fiber to that of the monochromator more closely. The procedure for parametrizing the attenuation fiber performance consisted of the measurement of the fluorescence distribution as a function of distance from the excitation point to the fiber end, the wavelength bin distribution of the data, the representation of a wavelength binned signal as a function of distance. Figure 2 shows the resulting fit of the parameters $\alpha\left(\lambda, D\right)$ and $R\left(\lambda, D\right)$.

The sample of SCSF 81 (Kuraray, Japan) fiber 1 mm in diameter contains an antiradiation component: 4-phenyl-3HF in an amount of 1 %. Another PSM115 sample 1 mm in diameter, specially made by us, contains antioxidizing and photostabilizing components SSV [1]. The system of low activity γ-isotope sources and dosimeters (colour film) 75 microns thick was used for fiber irradiation as shown in Fig. 1. The dosimeters were calibrated on the α-, β- and γ-sources, and in a mixed field of radiation, as they were earlier tested in the WA-98 experiment (CERN) at 157.7 A GeV (Pb-Pb) [2]. In each exposure for $\sim$ 1030 hours, a dose of no more than $\sim$ 4 kGy for PSM115 and no more than $\sim$ 8 kGy for SCNF81 was accumulated to reduce the influence of irreversible effects in polysterene. The optical

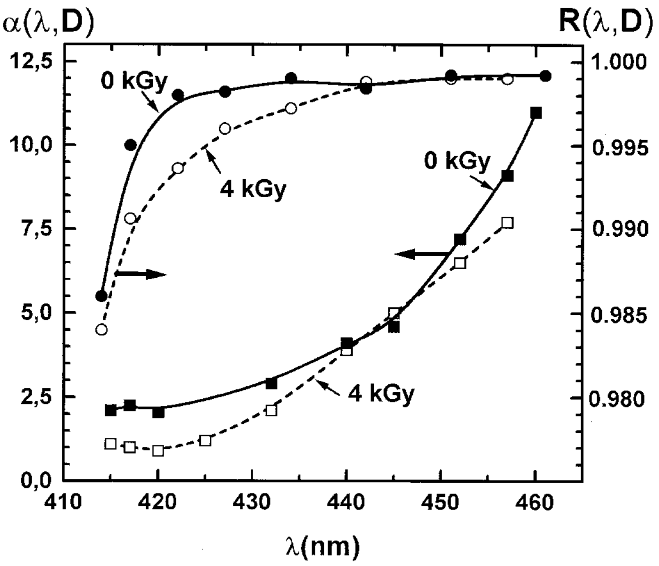

Fig. 2. Parameters $R(\lambda, D)$ and $\alpha(\lambda, D)$ measured in a fiber SCSF81 tupe sample

parameters were measured during recovery when the γ-sources were removed outside the shield. The dosimeters were also removed, and their optical density (appropriate to dose) was measured by a SF-26 spectrophotometer. The 19 cycles (exposure/recovery) for RSM115 and 10 cycles for SCSF81 in total are conducted; the time of recovery is respectively 10-20 hours and 400 hours. The preliminary results of a measurement of relative light output (conversion effectiveness) in continuous (1) and cyclic (2) exposures and the absorbed dose are presented on Fig. 3. The results of an exposure of the tile/fiber calorimeter modules (Ref. 3, Appendix A) and spaghetti calorimeter [4] are presented for comparison in the same figure.

DETECTOR APPLICATIONS

Calorimeters based on fiber optics wires are widely used in a number of experimental set-ups in the field of high energy physics. Since the photon yield is quite large in most experiments, conventional photomultiplier tubes (PMT) can be used as a readout device. All scintillator calorimeters use a lead or steel heavy absorber to stop incident particles. The scintillator can be installed in a number of ways, usually using one of three principal geometries. The first one employs scintillator layers and absorber plates. The light produced in the plate is read out by a wavelength shifting fiber. This fiber is doped with dye that absorbs the scintillation light in the plate and then emits fluorescence photons, the fraction of which is piped along the readout fiber to the photodetector.

Using the superposition method [1], we get the dependence of the limiting dose $D_{\text{lim}} = f\ (D_{\text{load}}, \xi)$, where ξ $\sim$(10-20 %) is the light loss after irradation. The coefficient K_3 is calculated for the resource formula $t_r = K_3\ (D_{\text{lim}} \setminus D_{\text{load}})$, if D_{lim} is determined from faster tests at $D_{\text{load}} \geq 10^2$ Gy/hour under irradiation with for the cyclic resource $t_R \gg t_r$.

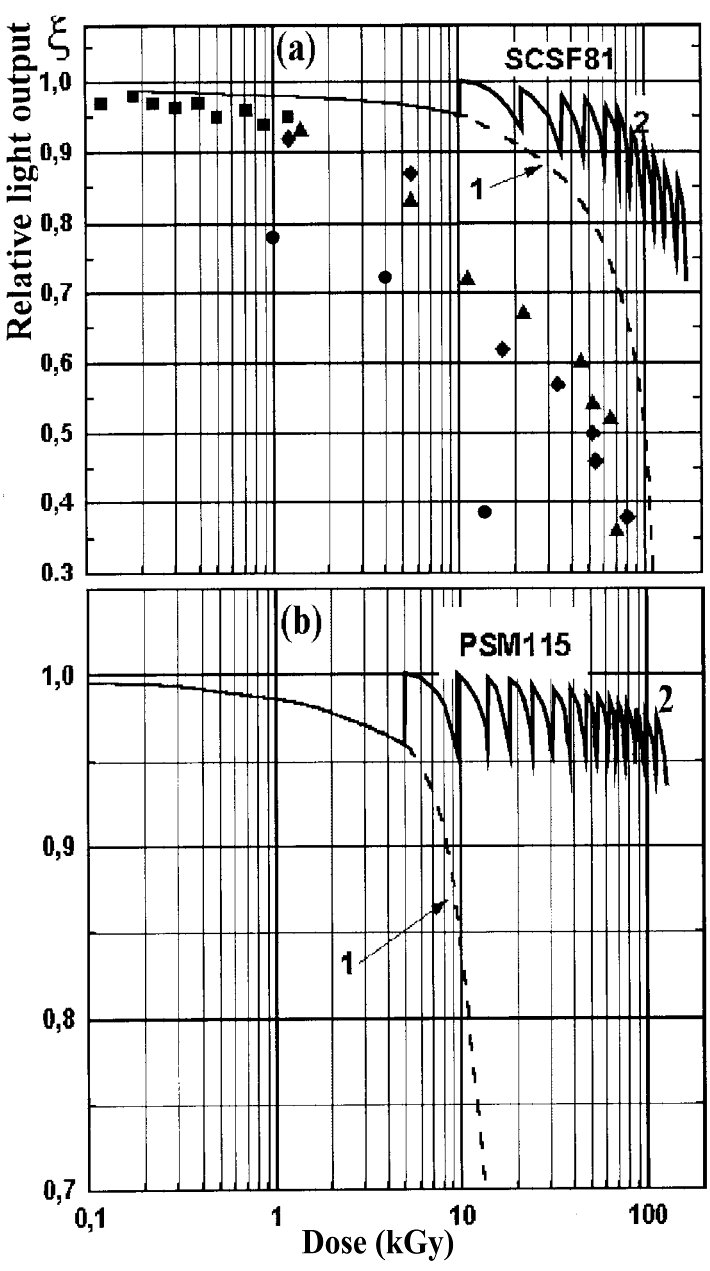

Fig. 3. The light output modification at $\lambda = 425$ nm for the samples of SCSF81 (a) and PSM115 (b) optical fiber types at continuous (1) and cyclical (2) exposure. Points of figure: for modules tile/fiber [3] — ■, ▲, ◆, — SCSF81/BCF91A (or Y7); for modules «spaghetti» — • — Y7 [4]

In the case of LHC radiation, the loads in the detectors are $10^{-1} \div 10^{-4}$ and the values of K_3 are within $2 \times 10^{-2} \div 7 \times 10^{-4}$. This is explained by photoradiation oxidizing [2,5].

Very forward calorimeters (VFC) in the LHC CMS detector must cover the range of radiation loads from 10^{-1} Gy/h ($\eta = 2,5$) to 40 Gy/h ($\eta = 5$). Operation at such a high rapidity requires the use of calorimetry techique that is radiation resistant (D_{lim} at least 10^7 Cy). This can be accomplished through a quartz fiber calorimeter. In this calorimeter, light is produced by shower particles through the Cherenkov effect generating a signal shorter than 10 ns in duration. The energy resolution is [6,7]:

$$\sigma/E \cong 150\,\%/\sqrt{E} \oplus 6\,\%\,.$$

Extrapolation of the low bound of curve 2 in Fig. 3*b* for PSM115 at $\xi = (10-20)\,\%$ «gigarad radiation level» gives $D_{\text{lim}} > 10^7$ Gy (Grad). This means that standard fibers can be used instead of quartz ones. However, it is necessary to use the new JINR Concept: rigid control of an irradiation dose and planning of breaks, when detectors recover their operating parameters [5]. In this work, the record time of recovery by 100 % for 10 hours is obtained at $D_{\text{lim}} = 4$ kGy, where antioxidants and photostabilizers were first used instead of «antirads».

The results [8] show that the energy resolution is comparable to standard value of the so-called spaghetti calorimeters (SCSF81/ Pb 1:3.17):

$$\sigma/E \cong 54\,\%/\sqrt{E} \oplus 1,5\,\%\,.$$

To confirm the results for VFC, it is necessary to conduct cyclic exposures of the calorimeter module (PSM115/ Pb) to γ-isotope sources and to verify the data of an accelerator beam.

CONCLUSIONS

In general, scintillating plastic optical fiber technology looks very promising for many detector applications in high energy physics. Some calorimeters have already been built.

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