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RADIATION HARDNESS OF NEW KURARAY DOUBLE CLADDED OPTICAL FIBERS

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1 Introduction

An Intermediate Fiber Tracker (IFT) is planned [1] as one of the CDF [2] Tracking upgrades to be installed for the Run II of the Tevatron.

The tracker is a set of cylindrical layers of scintillating fibers of 0.6 mm in diameter and $\sim 2m$ long starting from about 20 cm distance from the intersecting beams. Visible Light Photon Counters (VLPC) [3] are planned as photodetectors and the light will be transported to them by about 5 m long clear fibers light guides.

The base line luminosity for Run II is $2 \times 10^{32}\ cm^{-2}sec^{-1}$. At such a luminosity one may expect that IFT can get up to 60 krad/year dose for neutron fluency up to $2 \times 10^{11}\ n/cm^2$ for 1 year. These estimates are based on the results of simulation of CMS radiation conditions at LHC [4].

The expected light output for a minimum ionizing particle crossing at 90^0 the IFT is in the order of $8 - 10$ photoelectrons [3],[5]. However current tests are showing a somewhat lower yield. Current simulation results indicate that we can have as low as $\sim$6 p.e. without degrading appreciably the tracking efficiency. Within the current understanding this corresponds to about $20 - 30$ % less than the foreseen light output. A loss of light output below this level will start degrading the detector performance. For this reason it is very important to understand the radiation resistance of both the clear and scintillating fibers used.

In this work we present a new study of the degradation of clear polystyrene and scintillating fibers with a polystyrene core doped with 1% of p-terphenyl plus 1500 ppm of 3-hydroxyflavone (3HF). These fibers were irradiated by γ's and fast neutrons. All the studied fibers were of S-type (with S=70 particularly in our case), manufactured by KURARAY and had a double cladding.

The clear fibers had a 0.8 mm diameter and the scintillating 0.5 mm.

2 Fibers Radiation Hardness Investigation Methods

When irradiating plastic fibers by ionizing particles rather complicated processes take place inside the fibers with the structure changing and creating and accumulation of chemically active radicals. As a result both the fiber's transparency and the scintillating fiber light yield deteriorate.

The scheme of our experimental set up to study the fiber property changes due to radiation is shown in Fig. 1. The light pulses from Nitrogen laser were attenuated by the filters (F) and splitted (S) to 3 channels. The Nitrogen laser used had the following parameters:

irradiated light wave length	$\lambda = 337\ nm$
light pulse width	$\sim 10\ nsec$
light pulse repetition frequency	$\sim 10\ Hz$
intensity instability	$\pm 3\ \%$

The first channel was used for the investigation of fiber transmission in the green part of the spectrum, which is corresponding to the scintillating 3HF fiber light emission ($\lambda_{em} = 530nm$). For that in this first channel the re-radiator was put . To do this a thin polystyrene scintillator with 2% of p-terphenyl and 0.05% of R-26 (the derivative of theoxantene) was used with the light emission wave length ($\lambda_{em} = 530nm$). With the help of the optical connector the light was sent to the fiber being investigated. The intensity of the laser light pulse, after going through the fiber under test, is measured with a phototube PM1 (XP2020), whose signal is digitized with a ADC read out throught a PC. By measuring the light intensity before and after the fiber irradiation we determined the change of the relative light transmission.

The second channel was used for the study of the scintillating fibers only. In the fibers studied the scintillation was exited by laser UV-light at the fiber end and the light signal was measured before and after the irradiation.

The third channel was used to monitor the laser intensity with the PM2.

3 Results On Fiber Radiation tests

3.1 Irradiation by ^{137}Cs γ-source

The fiber samples have been irradiated with uniform γ-flux from ^{137}Cs-sources; the dose a rate was ~6 rad/sec (~190 Mrad/year). The irradiation was done at room temperature, in air.

Before the irradiation the fibers were rolled in 9 cm diameter coils to fit the limited volume of the irradiation chamber. As first we have shown that the process of rolling does not affect the radiation hardness change.

The radiation hardness of five scintillating fiber samples 1 m long was studied. The measurements of scintillating light yield excited by UV-laser light was done before (I_0) and immediately after (I) the fiber was irradiated. The results obtained are shown on Fig. 2. The dependence obtained can be caused by a decrease of scintillating efficiency and also by the worsening of the fiber transmission. In order to separate the contributions of these two processes we studied the transmission of fibers before and after the irradiation. To do that the fiber was illuminated on its end by the green light with the wave length corresponding to 3HF scintillator light emission ($\lambda_{em} = 530nm$).

In Fig. 3 we present the green light relative transmission (I/I_0) and also the relative light yield of fiber excited by UV-light, — both as a function of the dose absorbed.

It follows from Fig. 3 that these two behaviors are practically identical. Therefore , we conclude that the γ-irradiation decreases the fibers transmittence, but not the fiber scintillating efficiency.

The studies described here show a level of radiation hardness lower than previously published data on 3HF fiber radiation properties [6],[7].

The investigation of clear fiber transmission changes as a function of the γ dose was made for 4 different samples 2.5 m long each. The samples were illuminated by green light ($\lambda_{em} = 530nm$) and the light signal values were measured at the fiber's output before (I_0) and after (I) the irradiation.

In Fig. 4 we present the fiber relative light transmission (I/I_0) as a function of the dose absorbed. Some rise in the light yield (I/I_0)out of the clear fiber for the absorbed dose is, probably, connected to some small improvement of cladding-to-core adhesion as a result of the radiative annealing.

Fig. 4 also shows that one of the samples had demonstrated some improvement of the light transmission by the fiber after ~25 krad dose. Such an improvement of green wavelength shifting plastic fibers transmittence was first described in Ref. [8]. One hypothesis is that this phenomenon is caused by accumulation of the free radicals up to a high concentration when their recombination is going intensively.

The results obtained show the significant worsening of the clear fiber transmission even for a small radiation dose. It is important to note that the radiation hardness found by some other groups for Kuraray clear fibers was an order of magnitude higher [9].

3.2 Irradiation by Fast Neutrons

Fast neutron irradiation of fibers was done on JINR pulsed reactor, at room temperature, in air.

An average neutron flux with an energy $E_n = 0.4 \div 12$ MeV was $6.7 \times 10^9\ n/cm^2sec$. The tests were done on three fiber groups; each of them was irradiated up to a fixed neutron fluency. These fiber groups consisted of two scintillator fibers 1 m long each end two clear fibers 2.5 m long. The three groups were exposed to the following neutron fluencies: $3.2 \times 10^{12}\ n/cm^2$; $2.5 \times 10^{13}\ n/cm^2$; $7.1 \times 10^{13}\ n/cm^2$ with typical error of ± 10%.

In Fig. 5 we show the I/I_0-ratio (measured by the above described methods) for scintillating and for clear fibers in function of neutron fluency. Due to reactor operation our measurements have been done on four days after actually irradiation of the samples.

In first approximation we observe a similar deterioration of fibers both if γ irradiated or n irradiated as can be seen by comparing Fig. 2, Fig. 4 and Fig. 5.

3.3 Fibers properties recovering

As one knows, after the irradiation the light yield of scintillators (in air) is recovering constantly. This is connected mainly to the radicals concentration decreasing when they interact with oxygen. The degree of recovery is essentially determined by the absorbed dose value and by chemical composition of the scintillator.

We have investigated the recovering ability of four samples of the scintillating (l=1 m) and of four samples of clear (l=2.5 m) fibers irradiated by γ dose up to 0.5 Mrad from ^{137}Cs-source.

In Fig. 6 we present the relative light signal (I/I_0) dependence as function of recovery time. It can be seen from the figure, the scintillating fibers recovered their light yield in four days by factor 2, but the clear fibers demonstrate practically full absence of their transmittence recovery.

In Ref. [7] it was observed that double cladding clear fibers as well as scintillating ones recover their properties after the irradiation. Significant to note that the recovery process is rather fast and takes about one day.

In our case the slow recovery observed is probably caused by the high degree of crystallinity of the fiber polymer material which makes oxygen diffusion from the air more difficult.

4 Conclusions

Optical fibers degradation study after irradiation by γ and fast neutrons shows a level of radiation hardness, lower than what is expected from results of previous studies.

The worsening of scintillating fibers due to irradiation is possibly connected to the use of the new technology of the manufacturing of fibers with double cladding.

Clear fibers radiation hardness can be improved by the addition of antiradiate dopants if the transmission worsening was caused by radiation damage of the fiber material and not by surface damages appearing on the cladding boundaries.

To conclude we note that the fiber's radiation hardness depends on many factors: quality of material, chemical composition, production technology etc. Therefore any, even quite small changes in production technology or in chemical composition may change strongly the radiation hardness and consequently need require a radiation test.

We also note that, at least for the scintillating fibers, a significant recovery rate was observed, so the comparison with other results may depend on the time of the measurement relative to the irradiation. No such effect was observed for clear fibers.

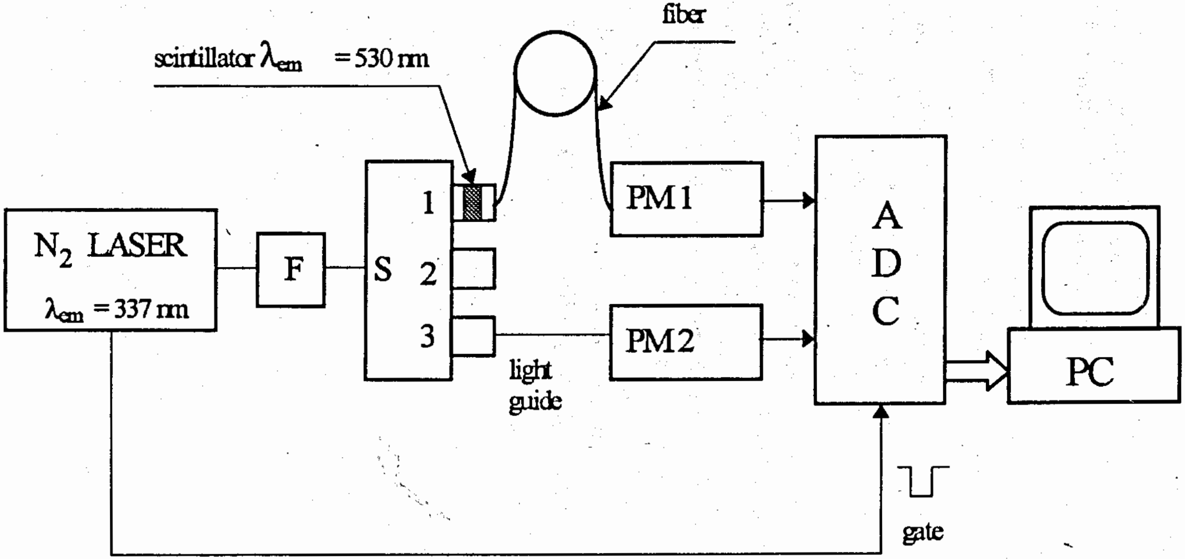

Fig. 1. Experimental set up for measurement of optical fibers properties.

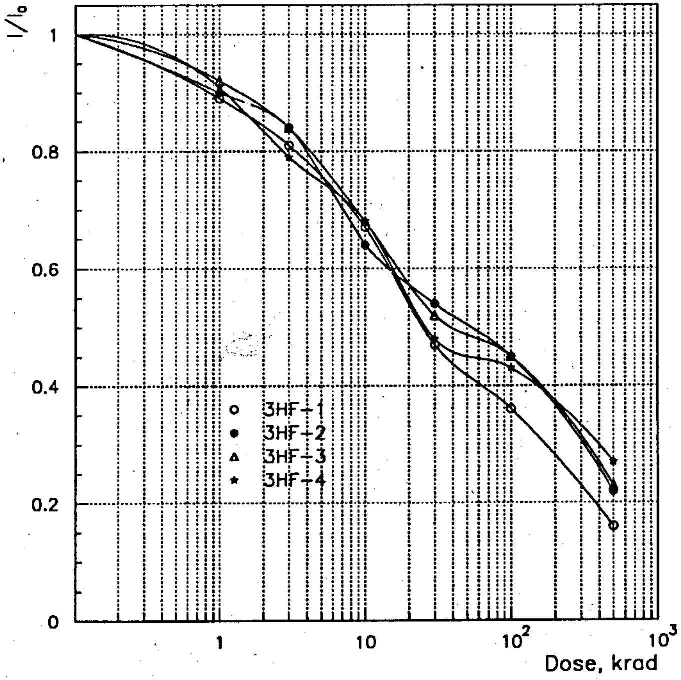

Fig. 2. Relative light yield I/I_0 for scintillating fibers as a function of the dose absorbed for four samples.

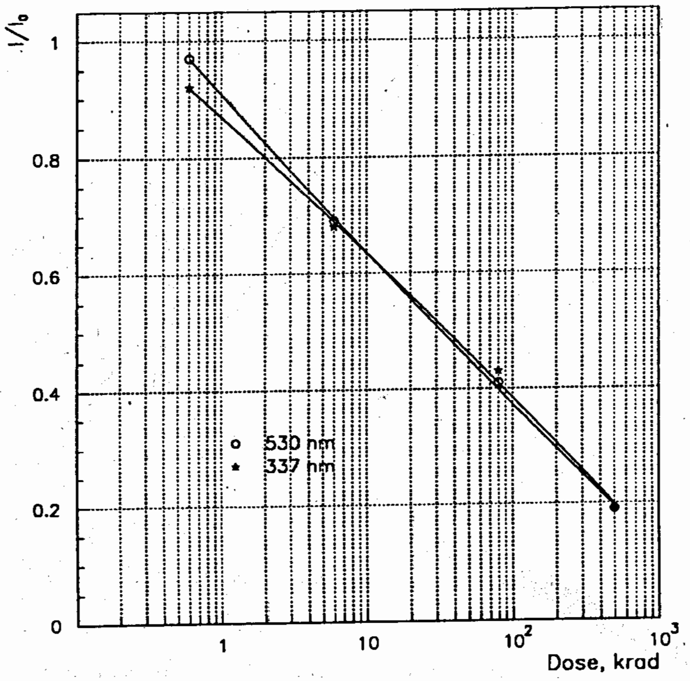

Fig. 3. The green light relative transmission and scintillating fibers relative light yield, – both as a function of the dose absorbed.

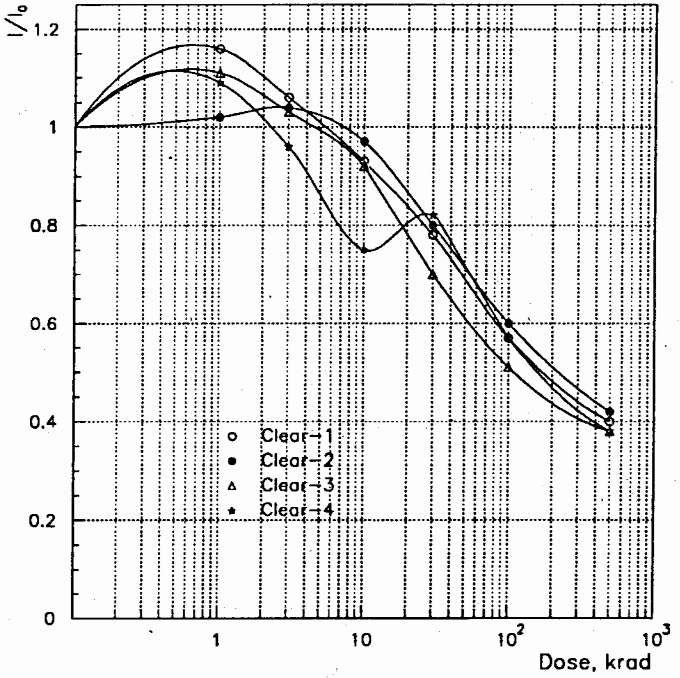

Fig. 4. Clear fibers light transmission as a function of the dose absorbed for four samples.

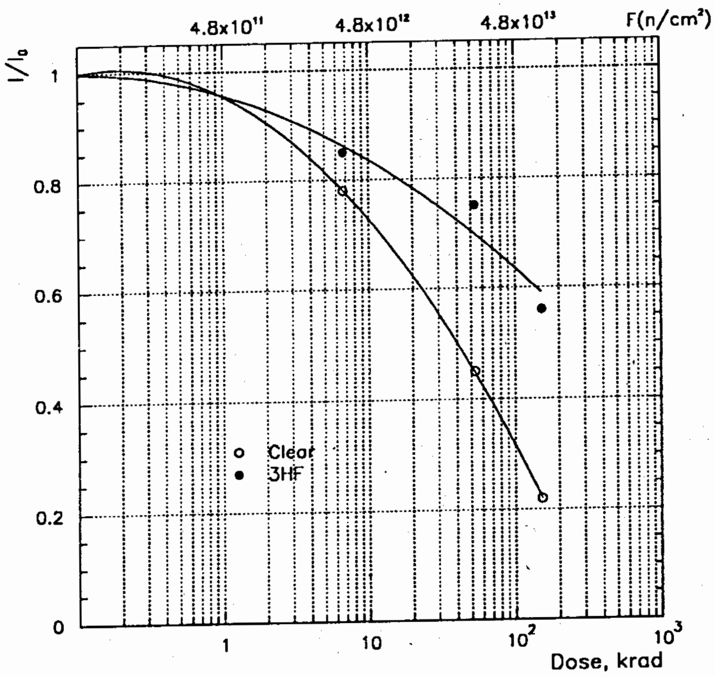

Fig. 5. Relative light yield for scintillating fibers and relative light transmission clear fibers – both as a function of neutron fluency (top scale) and dose absorbed (bottom scale).

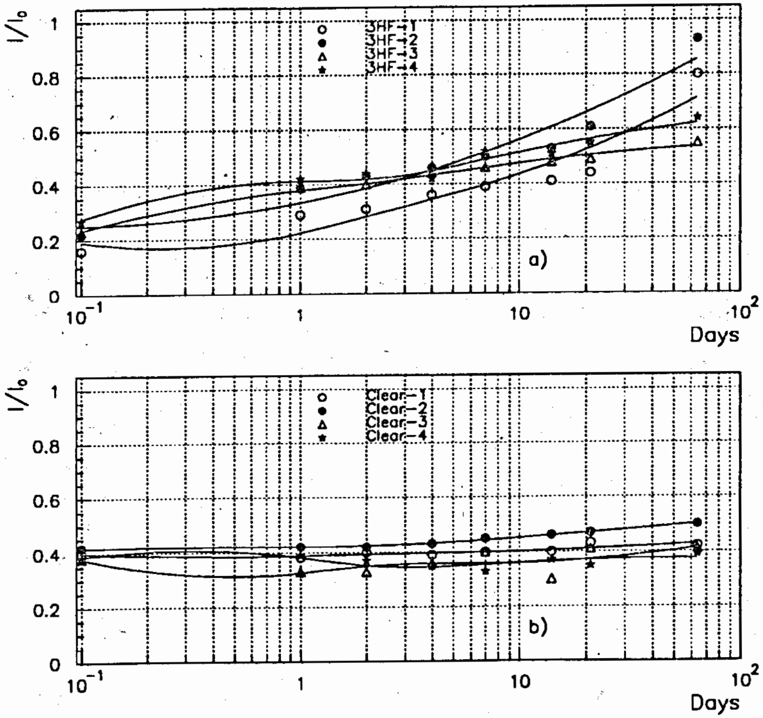

Fig. 6. The recovery of scintilloting fibers light yield (a) and of clear fibers transmission (b).

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Бедески Ф. и др. E13-96-248
Радиационная стойкость новых оптических волокон
с двойной оболочкой фирмы Курарай

Исследована радиационная стойкость новых сцинтилляционных и прозрачных волокон, облученных потоком γ-квантов ^{137}Cs и быстрыми нейтронами импульсного реактора. Все исследуемые волокна были *S*-типа (с $S = 70$) с двойной оболочкой. Изучение деградации оптических волокон после облучения показало, что уровень их радиационной стойкости ниже, чем ожидалось из результатов предыдущих исследований.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1996

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Radiation Hardness of New Kuraray Double Cladded Optical Fibers

The radiation hardness of the new plastic scintillating and clear fibers irradiated by ^{137}Cs γ-flux and by pulsed reactor fast neutrons were investigated. All the studied fibers were of *S*-type (with $S = 70$) and had a double cladding. Optical fibers degradation study after irradiation shows that the level of radiation hardness lower that what is expected from results of previous studies.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1996