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Radiation Hardness Study of Optical Fibers

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Abstract

Gurzhiev A.N. et al. Radiation hardness study of optical fibers: IHEP Preprint 95-121. – Protvino, 1995. – p. 8, figs. 7, tables 1, refs.: 9.

The paper reports the results of our investigation of radiation resistances for some types of quartz and plastic fibers. Qiartz fibers with high concentration of OH radicals in their cores showed a radiation resistance of about 6 Mrad/m in UV region (λ=337 nm). Quartz fibers partially recover their optical characteristics at room temperature and have entirely recovered after 1 h heating at 300-400°C. Fragile plastic fibers showed up to 300 times lower level of radiation resistance against normal ones.

Аннотация

Гуржиев А.Н. и др. Исследование радиационной стойкости волоконных световодов: Препринт ИФВЭ 95-121. – Протвино, 1995. – 8 с., 7 рис., 1 табл., библиогр.: 9.

В работе представлены результаты исследования радиационных характеристик некоторых типов световодных кварцевых и пластмассовых волокон. Кварцевые волокна с высоким содержанием радикалов OH в керне показали радиационную стойкость 6 Мрад/м в ультрафиолетовом диапазоне длин волн (λ=337 нм). Кварцевые световодные волокна частично восстанавливают свои оптические характеристики при комнатной температуре и полностью восстанавливались при нагревании в течение 1 ч при 300-400°C. Хрупкие пластмассовые световодные волокна показали до 300 раз меньшую радиационную стойкость, чем нормальные.

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Hadron calorimeters are widely used for secondary particles energy measurements with modern experimental setups. As a rule they consist of heavy absorbers such as iron, lead or copper interleaved with scintillation plates forming a tower structure [1]. Such hadron calorimeter is supposed to be used in the CMS experimental setup [2]. Scintillation light flashes from plates are reemitted by wavelength shifting (WLS) fibers and then transmitted to receivers through clear plastic fibers. However, characteristics of optical elements can vary due to aging or radiation damage. Recently it has been proposed to use ultraviolet light pulses of a nitrogen laser (λ_{em}=337 nm) for the time stability testing of optical elements as well as the hadron calorimeter calibration as a whole. Signals from the nitrogen laser were supposed to feed in the calorimeter scintillation plates via radiation resistant quartz fibers.

The radiation resistance requirements for the calorimeter optical elements depend on the region of pseudorapidity. The hadron calorimeter [2] will cover the region of pseudorapidity of $1.6 < \eta < 3.0$. It is anticipated that at $\eta \leq 2.5$ the maximum dose will be about 0.8 Mrad at the integral luminosity of 10^{42} s^{-1} [2]. However for $2.6 < \eta < 3.0$ radiation doses up to 3-4 Mrad/yr are expected. Some optical elements may have a relatively low level of the radiation resistance due to their prolonged sizes [3] or mechanical loads they undergo. It is evident that the least radiation resistant optical elements in the construction will determine the radiation resistance of the whole calorimeter.

Since the quartz fibers are proposed to be used in the control-measuring system, some requirements for the stability of their optical characteristics should be more stringent then for other optical elements. So the decrease of transparency for quartz fibers should be less than 10% after 10 Mrad irradiation. This 10% level of losses will be used in all our estimations of other fibers radiation resistance. The radiation properties study of optical fibers was undertaken in order to reveal their possible application in the CMS hadron calorimeter [2].

1. Measurements technique

The optical fibers were irradiated in a flux of γ-quanta from radioactive sources ^{137}Cs at room temperature air. The dose rate was about 6 rad/s (190 Mrad/yr) which was about

50 times higher than the expected maximum dose rate for the CMS hadron calorimeter. Therefore, the recovery processes should be taken into account when estimating the optical fibers radiation resistance. Fibers of 1-2.5 m long were curved in circles of 9 cm in diameter and then γ-irradiated.

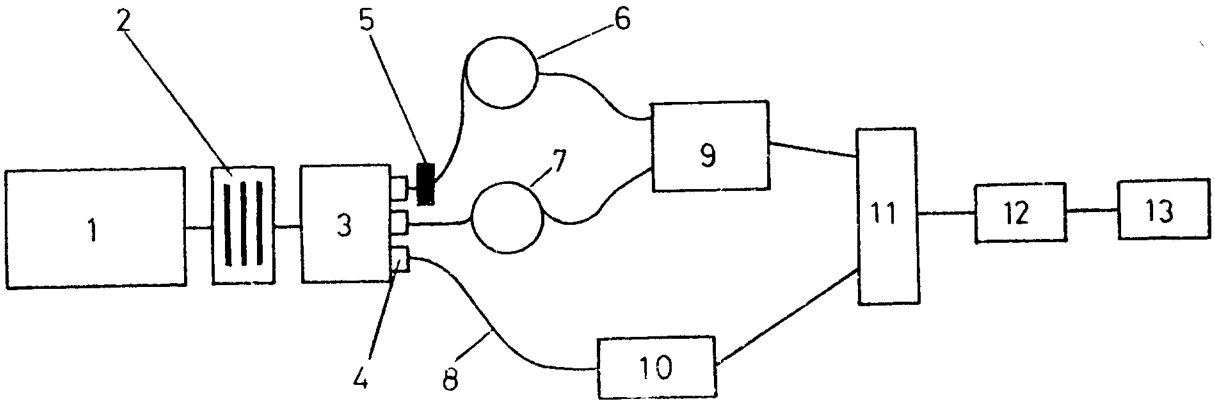

Fig. 1. Experimental layout: 1 – nitrogen laser LGI-21, 2 – neutral filter, 3 – divider, 4 – optical connector, 5 – scintillator, 6,7 – tested optical fibers, 8 – quartz fiber, 9 – PM UVP-56, 10 – PM FEU-84-3 (for calibration), 11 – ADC, 12 – data acquisition system, 13 – personal computer.

Fig.1 shows the measurement scheme. The light pulses from the nitrogen laser LGI-21 (1) (the pulse duration ~10 ns, frequency ~10 Hz and intensity ~ 10^{15} photons/s) were attenuated by 3100 times with neutral filter (2) and split into 3 optical channels with divider (3). The first channel was used for the laser calibration because the instability of the laser light pulses was ±3%. The second channel was used to measure transmission properties of optical fibers in the UV wavelength region. The light that passed through the tested fibers from the third or second channel was detected with a photomultiplier (PM) UVP-56 (9). The third channel was used to measure transmission properties of optical fibers in the green wavelength region. For that purpose a thin (0.5 mm) scintillator (5) reemitting light in the green wavelength region (λ_{em}=530 nm) was placed in the third channel before the tested fibers. The signals from each of PMs were fed in an ADC and then in our data acquisition system (12). The information was read out with a PC. The laser synchroimpulses formed 90 ns gate pulses which were used to trigger the ADC. The electromagnetic background from the working laser during the amplitude measurements was $\leq$ 2%. The light output from the tested fibers was estimated before the irradiation I_o as well as just after the irradiation I and in the process of recovery.

2. Results

The radiation resistance of quartz fibers in the visible wavelength region (400-600 nm) for the calorimetry application has been recently studied in [4,5]. It was shown that the radiation resistance for the best quartz fibers reached ~1 Grad in the visible region [4] and much lower levels in the UV-region [5]. For the calorimeter calibration, quartz fibers with high radiation resistance, namely, in the UV region (for the wavelength of 337 nm) are needed. Some characteristics of the tested quartz fibers manufactured at the Institute of General Physics are presented in Table 1.

Table 1. Some characteristics of quartz fibers

№	Type of fibers	Core ∅, μm; type	Clad., μm; type	Cover, μm; type	Conc. of OH, ppm	Figures notations
1	quartz-pol.	300; KU-1	40; SIEL*	50; P-610	1200	x-Q-PB
2	quartz-pol.	300; KU-1	50; SIEL	50; P-610	1000	□-Q-PW
3	quar.-quar.	400; KU-1	50; $SiO_2 + F$**	50; Allum.	3	•-Q-Q
4	quartz-pol.	200; KU-1	100; SIEL	- -	-	Δ-QP-200
5	quar.-quar.	400; KU-1	50; $SiO_2 + F$	50; Allum.	1200	+-Q-QAl
6	quartz-pol.	50, KU-9	25; SIEL	- -	1200	o-Q-P,KU9
7	quartz-pol.	125; KU-33	50; SIEL	50; P-610	1000	∇-Q-PR
8***	quartz-pol.	300; KU-1	40; SIEL	50; P-610	1200	x-Q-PB,a

*SIEL - silica-organic polymer with the refraction index n=1.42.

**SiO_2+F is fluorated SiO_2.

***This sample was taken from another bundle.

Figs. 2-3 show some results of quartz fibers radiation properties measurements. As is clear from Figs. 2-3 their radiation resistance varies by more than three orders of magnitude, i.e. has the minimum level of the radiation resistance of about a few krad/m for fibers with low concentration of OH radicals (3-4 ppm) in their cores and reaches the maximum value of about 6 Mrad/m for fibers with high concentration of OH (1000-1200 ppm).

As has been shown in [5] quartz fibers do not practically recover their optical characteristics after the end of γ-irradiation. In contrast to that our measurements have shown that the quartz fibers recover the optical properties. The recovery properties of some quartz fibers of high radiation resistance (samples 5 and 6 in Table 1) after 37 Mrad and 35 Mrad irradiation respectively, are shown in Fig. 4. A significant improvement of the fibers transparency is observed in the first minutes just after the end of γ-irradiation. As is clear from Fig. 4 quartz fibers need about 2-3 days to complete all recovery processes. The levels of fibers transparency recovery are different. The presented results (Fig. 4) show that a quartz fiber of high radiation resistance (sample 5 in Table 1) quickly recovers its transparency to a level of I/I_o=0.50. The illumination of the quartz fiber with the laser light pulses 150 μJ/pulse during 2 hours improves its transparency to a level of I/I_o=0.55. The fiber has fully recovered its transparency to a level of $I/I_o \simeq 1.0$ after 1 hour heating [6] at 300-400°C.

We also measured the radiation resistance of CLEAR-PSM Kuraray plastic fibers 0.82 mm in diameter in the UV region because it is possible to use them for the laser light feeding to scintillators. Their initial light attenuation was about 4 Db/m. According to our estimation their radiation resistance in the UV region is 0.035 krad. Some measurement results are given in Fig. 5.

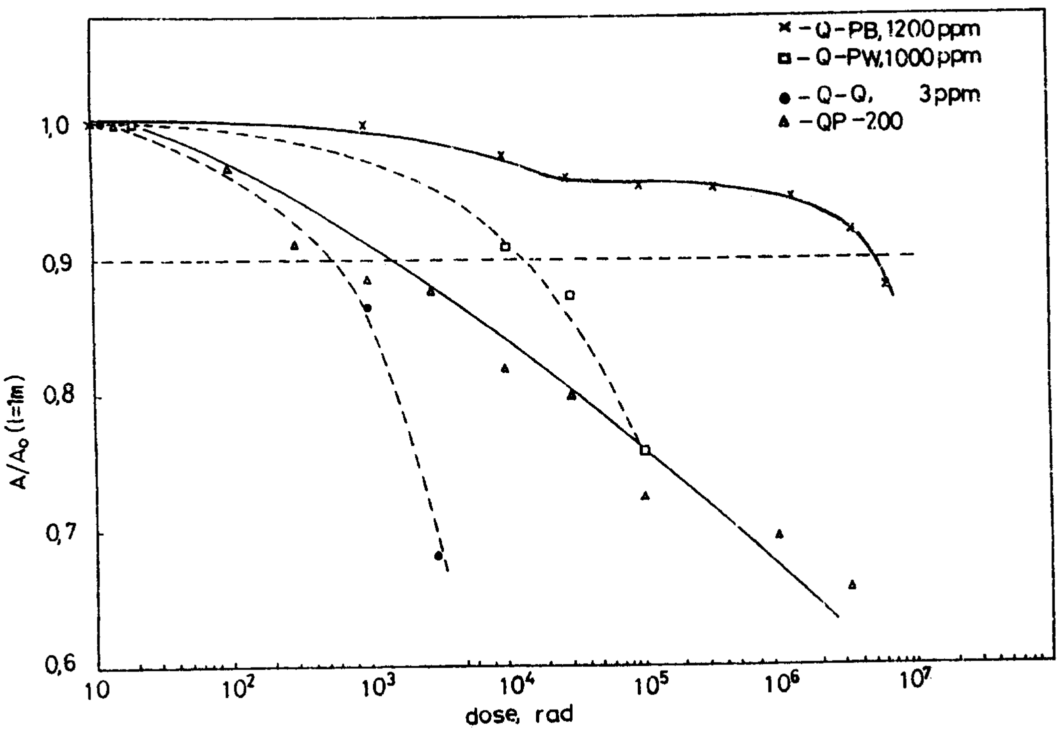

Fig. 2. Quartz fibers relative transmission I/I_o as functions of the dose.

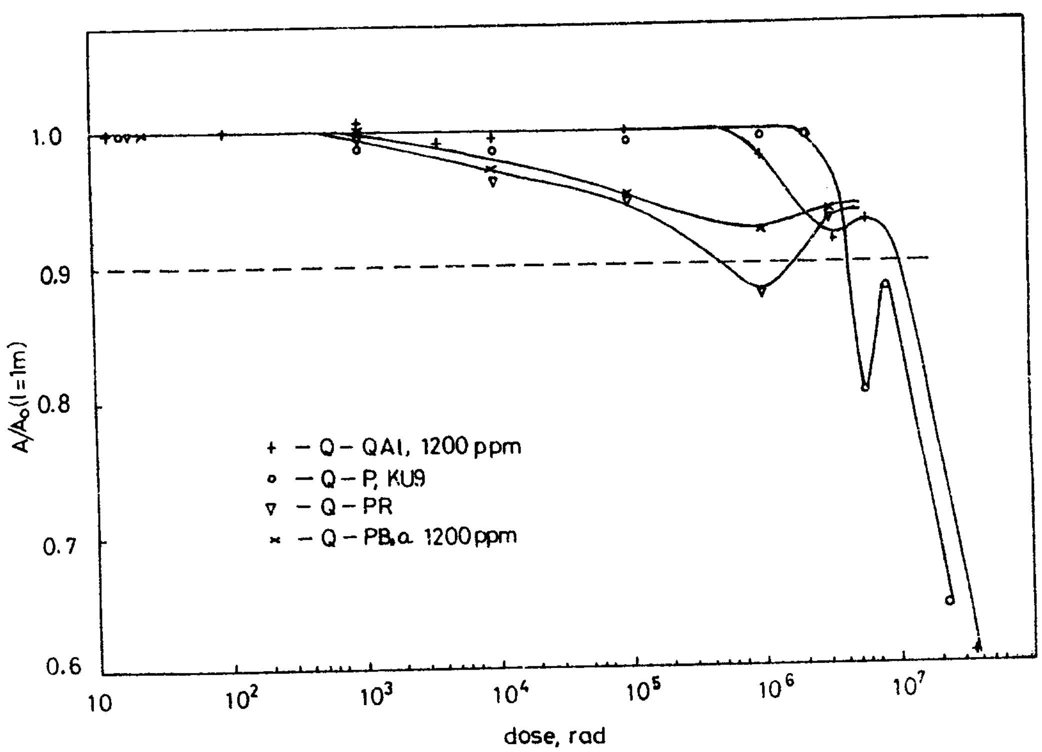

Fig. 3. Relative transmissions I/I_o for the most radiation resistant quartz fibers as functions of the dose.

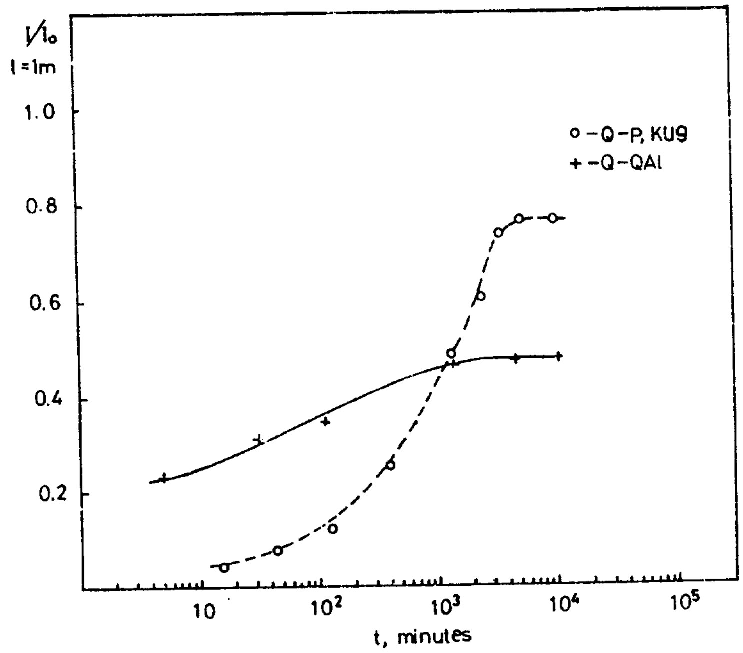

Fig. 4. Some quartz fibers relative transmissions I/I_o as functions of recovery at room temperature: + – quartz-quartz fiber Q-QAl after 37 Mrad irradiation; o – quartz-polymer fiber (Q-P,KU9); o – quartz-polymer fiber (QP-200) after 37 Mrad irradiation. Their characteristics are presented in Table 1.

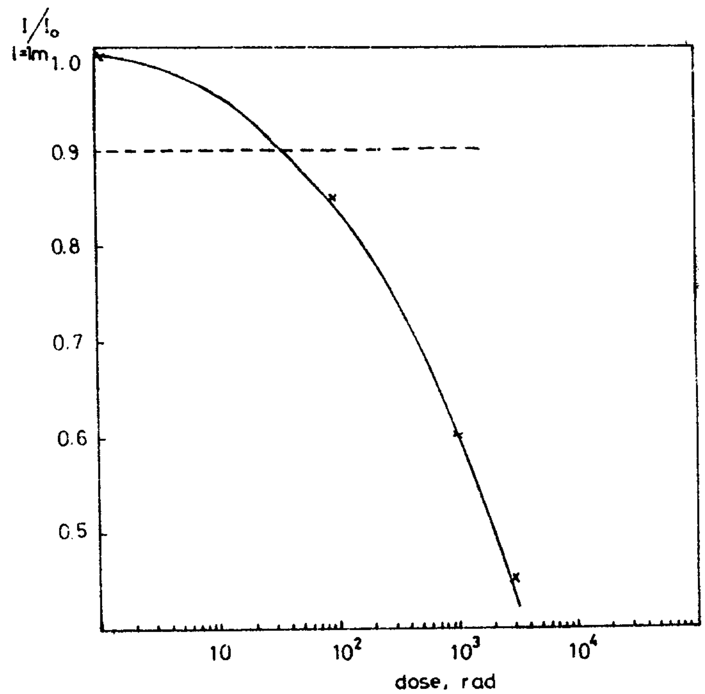

Fig. 5. Clear PSM plastic fiber relative transmission I/I_o at the wavelength of 337 nm as a function of the dose.

We defined the radiation resistance of Clear-PSM and Y-11 WLS Kuraray fibers in the green wavelength region. They may be used in a prototype of the CMS hadron calorimeter. Fig. 6 shows some results of the radiation resistance measurements for four (TK1-TK4). Clear PSM fibers taken from the same bundle. The maximum level of the radiation resistance for the plastic fibers is about 160 krad/m. Thus their levels of radiation resistance differ up to 300 times. Probable reasons for these deviations are the following: mechanical damage of plastic fibers, flaking of their claddings, appearance of microcracks in fiber cores under irradiation, etc. The lowest level of the radiation resistance (about 0.5 krad) has been shown by fragile fibers.

The radiation resistance of Y-11 WLS fibers was presented elsewhere [8]. When estimating those results [8] to the level of the radiation resistance accepted in this paper we draw a conclusion that their maximum radiation resistance was about 300 krad/m. Thus levels of their radiation resistance for this type of WLS fibers vary as well. Fig. 7 shows radiation properties of a Y-11 WLS fiber of about 24 krad/m. Note, that plastic fibers have recovered their optical characteristics negligibly (about 10-20%). Obviously, the presence of plastic fibers with much deteriorated levels of their radiation resistance in the CMS hadron calorimeter should be avoided.

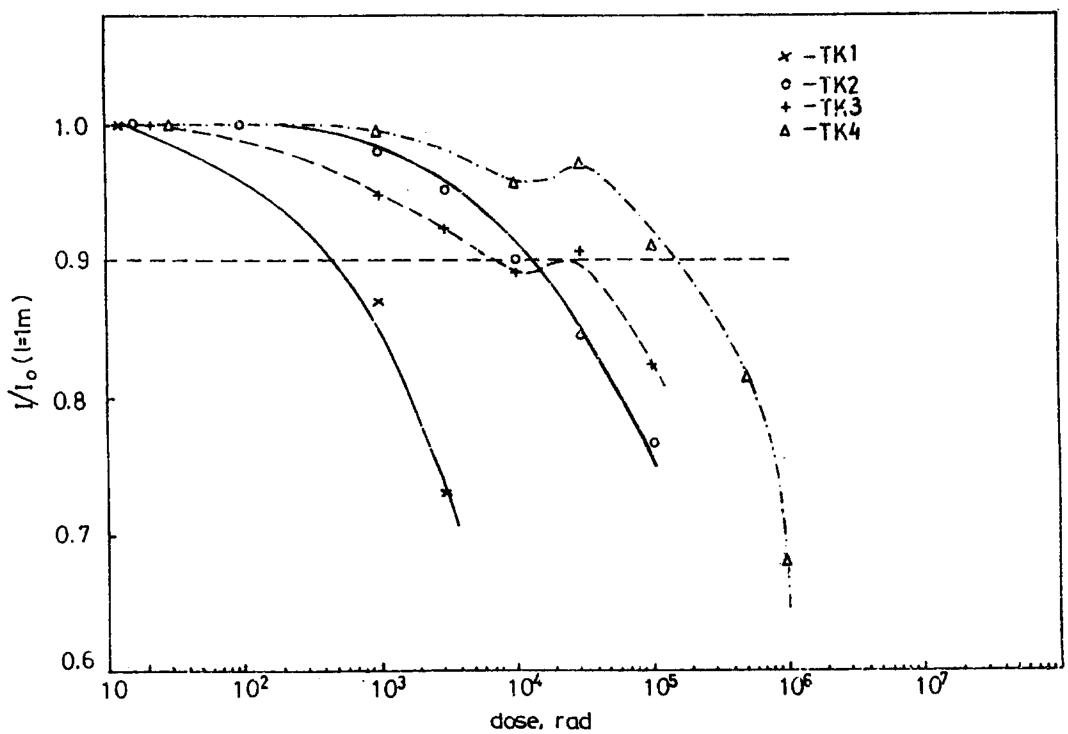

Fig. 6. Clear PSM plastic fibers relative transmissions I/I_o in the green wavelength region as functions of the dose.

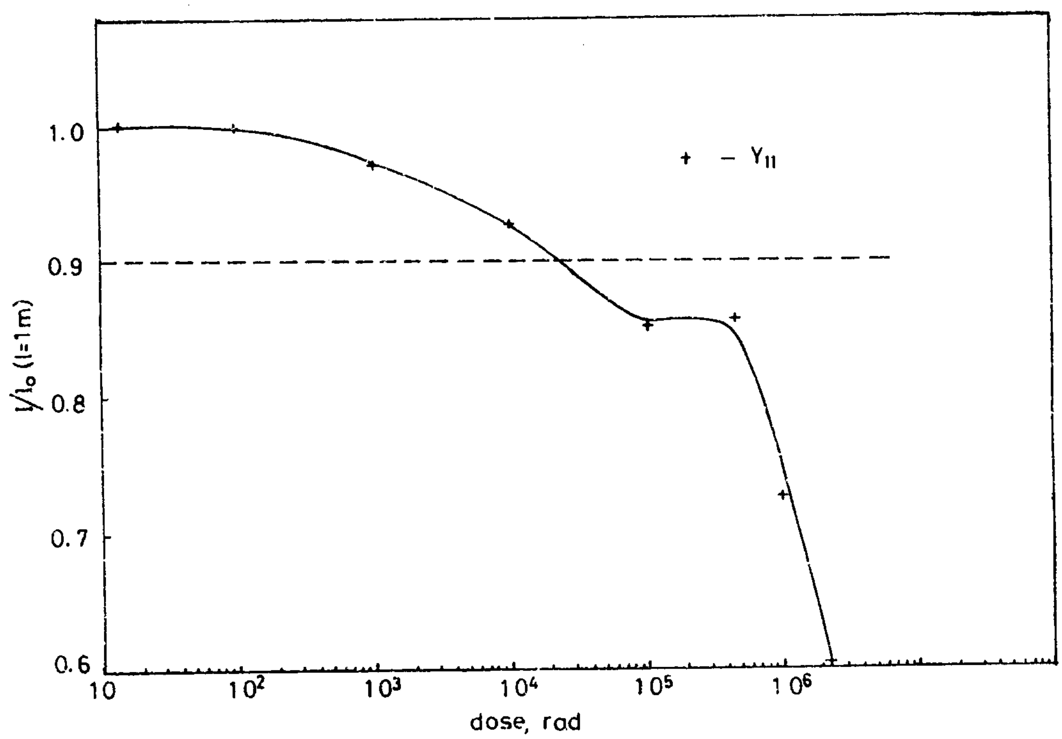

Fig. 7. Y-11 WLS plastic fiber relative transmission I/I_o as a function of the dose.

We tested the influence of plastic fibers curling in circles on their radiation resistance. So, plastic fiber samples were kept curled during 40 days before the irradiation. Measurements have shown that the radiation resistance of the curled fibers remained unaffected.

Here a common characteristic feature of behavior for different types of organic and inorganic fibers under the irradiation should be noticed. As is clear from Figs. 2-7, some I/I_o curves deter their falls at doses near the values of their radiation resistance. This means that there are processes improving fibers transmission properties under γ-irradiation. Note that fibers with low radiation resistance do not show such structure. There is evidently a general reason which is responsible for the appearance of a peculiarity which still needs explanation. Note that some plastic scintillators also showed the similar behavior [7,9].

3. Conclusion

1. The radiation resistance of quartz-quartz and quartz-polymer fibers in the UV-region (337 nm) has been studied. The radiation resistance of quartz fibers differs more than three orders of magnitude and strongly depends on the concentrations of OH radicals in their cores. Some types of quartz fibers have shown a radiation resistance of about 6 Mrad/m which is enough to use them in the CMS hadron calorimeter control system. The radiation resistant quartz-quartz fibers entirely recover their optical characteristics after being irradiated up to 1 Mrad and only partially – after doses over 3 Mrad. Quartz fiber heating at 300-400°C during 1 h improves their optical characteristics entirely.

2. The maximum value of the radiation resistance for plastic Clear-PSM fibers is about 160 krad/m. Among them there are fibers with up to 300 times lower levels of the radiation resistance. The maximum value of the radiation resistance for plastic Y-11 WLS fibers is about 300 krad/m. Among these WLS fibers there are samples with $\sim$10 times lower levels of their radiation resistance. The plastic fibers recover their optical characteristics weakly.

Note that all these measurements were performed under high dose rate irradiation. Obviously, such high dose rate measurements should be supplemented with results obtained at low dose rates irradiation like those which are expected in the different parts of the CMS hadron calorimeter.

3. The above cases of low levels of the radiation resistance for plastic fibers may be explained with the flaking of their claddings and the appearance of microcracks in the cores of fragile (or mechanically damaged) fibers under the irradiation.

4. The common characteristic feature of behavior for different types of organic and inorganic fibers is observed under the irradiation. At doses near the value of their radiation resistance fibers transmission properties deter their falls.

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