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SINGLE TILE-FIBER UNIT OF SDC CALORIMETER

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ABSTRACT

The SDC collaboration for one of the SSC experiments has decided to use the tile-fiber system as the active medium of the calorimeter. Using commercially available scintillating plates and wave shifting fibers, the light output and radiation damage have been measured. The uniformity is within 5%, except near the edges for tiles of sizes 10 cm × 10 cm and 25 cm × 25 cm. The tested tile-fiber systems with radiation damage of up to 10 megarads retain their uniformity. The loss of light is about 15% for one megarad. Most scintillators and fibers are similar to each other, with variation in radiation damage of 10% to 20%. Light output increases approximately linearly with the diameter of the fiber. Radiation damage is less for tiles with multiple fibers.

KEYWORDS

Scintillator, Wavelength Shifting Fiber (WLS), Calorimeter

INTRODUCTION

The tile fiber system was chosen for the SDC calorimeter for the central calorimeter and the end caps. At Florida State University we initially concentrated on the light output and radiation hardness of individual components and have measured and irradiated over 100 different types of scintillators and fibers (Bertoldi et al., 1992). A variety of groove patterns were machined in tiles. Figure 1 shows the "sigma" system chosen for the active medium, where only one fiber comes out of each tile. This reduces the cost of assembly but with some reduction of light output and somewhat more susceptible to radiation damage. For the calorimeter central barrel the choice is a blue scintillating tile with a green wave length shifting (WLS) fiber. Radiation damage to the active medium occurs in all of the components. In the tile, the damage to the polymer reduces the emission of short wavelength UV light, and also reduces the attenuation length. The primary fluor that converts the short wavelength UV to long UV and the secondary fluor that converts the long wavelength UV to blue light also show radiation damage. For the WLS fiber, the polymer in the fiber core gets damaged thereby reducing the attenuation length. Similar results have also been reported by others (Fazeli et al., 1992; Barbaro et al., 1991). The aim of this research effort is to choose the best polymers and fluors that reduce the radiation damage without compromising light output.

LIGHT OUTPUT MEASUREMENT AND IRRADIATION

The light output was measured by bi-alkali 12 stage photomultiplier (PM) tubes. The bi-alkali PM tube used was the Hamamatsu R329, although other PM tubes with more green sensitivity

were also tried. The blue light emitting scintillating plates were excited by X-rays, producing light similar to that produced by charged particles. Individual fibers were excited by either X-rays or blue scintillator light. The X-rays were produced by a commercial X-ray tube [1] with a maximum accelerating potential of 30,000 volts and a maximum current of 0.2 mamp into the cupper target. The blue light source was produced by exciting a small "L" shaped scintillator with long wavelength UV light (360 nm) and focused with a lens on the fiber. No UV light reached the fiber. All these measurements were performed in a 2 meter long, lead lined, light tight box where the excitation source was moved horizontally by a 1.5 meter long threaded rod controlled by a PC. The output of the PM tube was read by an ADC card connected to the same PC. The sample could be moved vertically by an external hand crank. Absolute calibration of light yield is desired. Figure 2 shows our measuring system where two vertical scintillating fibers were used for calibration. For the measurements we insisted that the output of the calibration scintillators be the same within two percent.

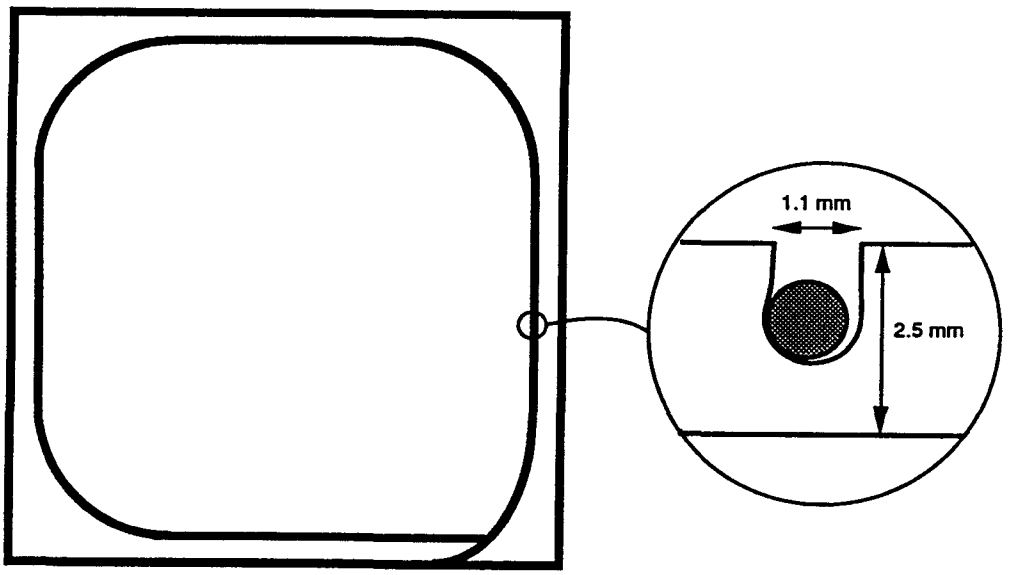

Fig. 1. The "sigma" shape tile-fiber system

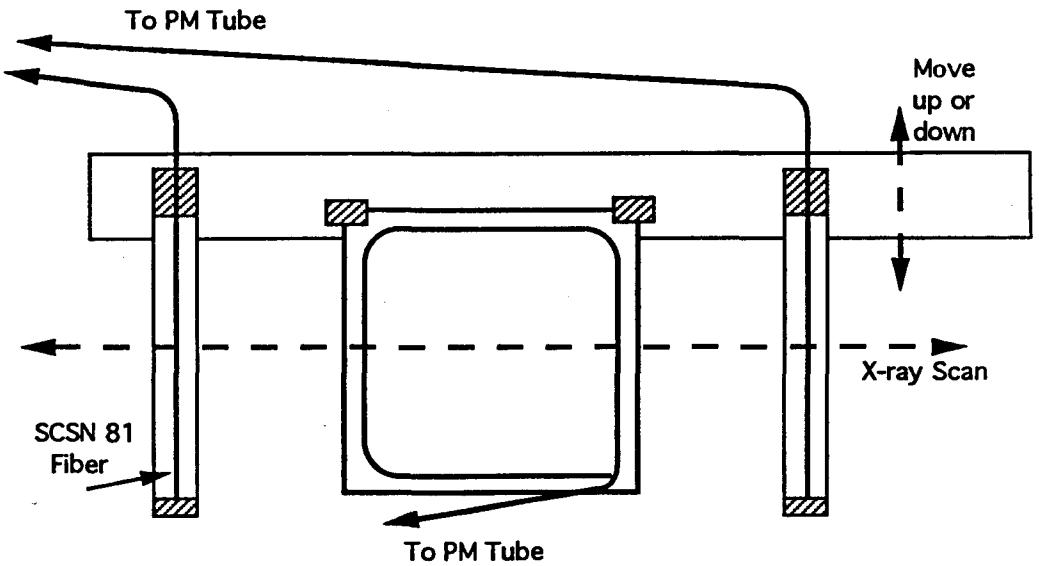

Fig. 2. Light output measuring system

[1] The X-ray system was obtained from X-Tech Co., 275 Technology Circle, Scotts Valley, CA 95066.

The irradiation was accomplished by a 3 MeV electron accelerator, with beam diameter of about 2 cm which can be swept horizontally at 200 Hz over a 25 cm range. The electron beam current can be varied from a few nanoamps to one miliamp. Normally the beam is swept horizontally, while the sample is moved vertically by a 60 cm diameter wheel. So long as the samples are less than 1 g/cm^2 thick, the electrons will pass through and still be relativistic. The electron current was monitored by a Faraday cup. The exact dose of radiation was measured by 50 micron thick radiachromic film [2]. The spectral response of the film was measured by a Milton Roy 1201 spectrophotometer. The radiation dose was computed with an error of $\pm 7\%$. The rate of the irradiation is usually about 1 Mrad every 15 minutes. Earlier tests have shown that reducing this dose rate by a factor of 20 does not change the damage. Since the electron accelerator is near our measuring laboratory, we can measure samples as early as half an hour after exposure. Typically all the 2.5 mm thick tile scintillators and all the fibers had recovered substantially within a week.

WAVE SHIFTING FIBERS

The two types of WLS fibers that were tested have a polystyrene core doped with K27 fluor and acrylic cladding. We have tested 1.0 mm and 0.72 mm diameter BICRON fiber BCF91A [3] with three different K27 fluor concentrations. The other fiber we tested was KURARAY Y11 [4] which had a diameter of 0.8 mm. Figure 3 shows the light output of BICRON fibers excited by X-rays and blue light. The attenuation length of all the fibers, measured by a bi-alkali PM tube is about 2 meters. Each fiber was then irradiated to 2 Mrad except the first 20 cm (used for calibration) and a 10 cm portion in the middle (to determine damage to the fluors). The lower curve in each plot of figure 3 is the light output of the same fibers measured after a week of recovery. The standard concentration fiber had the least radiation damage as measured by the decrease in attenuation length. The radiation damage of the Y11 fiber (not shown) was identical to that of the standard concentration BCF91A fiber. There is a bump (where the fiber was shielded from damage) in the damaged fibers excited by X-ray but none in the damaged fibers as excited by the blue light. The higher the concentration of the K27 fluor, the smaller the bump. Also, the attenuation length of the damaged fiber is shorter for the higher K27 fluor concentration. A tentative conclusion is that blue light penetration in the fiber is very small while most of the X-rays penetrate the full width of the fiber.

The WLS fiber produces some direct scintillation, even though it should not contain any primary fluor. Figure 4 shows the X-ray excitation of two 1.0 mm diameter fibers. The BICRON BCF91A is WLS fiber while the KURARAY SCSF81 is a scintillating fiber. The WLS has only 22% of the light output of the scintillating fiber. Inside a tile-fiber system, the small amount of scintillation yield from the fiber compensates for the scintillator which was removed during grooving. The length of the fibers between excitation and PM tube was about 60 cm. Since all the tested fibers have an attenuation length of about 2 meters, the fiber length is not critical.

TILE FIBER SYSTEM

Figure 5 shows typical scans across the tile-fiber systems. The tiles shown here are the KURARAY SCSN81 and the BICRON BC499-27. The fiber was BICRON BCF91A. The groove has the "sigma" shape and the edges of the tiles were painted white with titanium dioxide. The end of the fiber inside the plate was mirrored by aluminum sputtering. The light output was uniform ($\pm 3\%$) over most of the area except near the edges. The peak and valley near the edges are due to the WLS fiber and the groove cut respectively. Even though the grooving removes a portion of the scintillator, this deficiency is somewhat compensated by the weak scintillation of WLS fiber. The light output of the BICRON tile-fiber system is 22% brighter than that of the KURARAY tile-fiber system.

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[2] The radiachromic film (FWT-60-00) is made by Far West Technology, Inc. 330-D South Kellogg, Goleta, CA 93117

[3] BICRON Corporation, 12345 Kinsman Road, Newbury, OH 44065, USA

[4] KURARAY Corporation, Nakajo, Japan

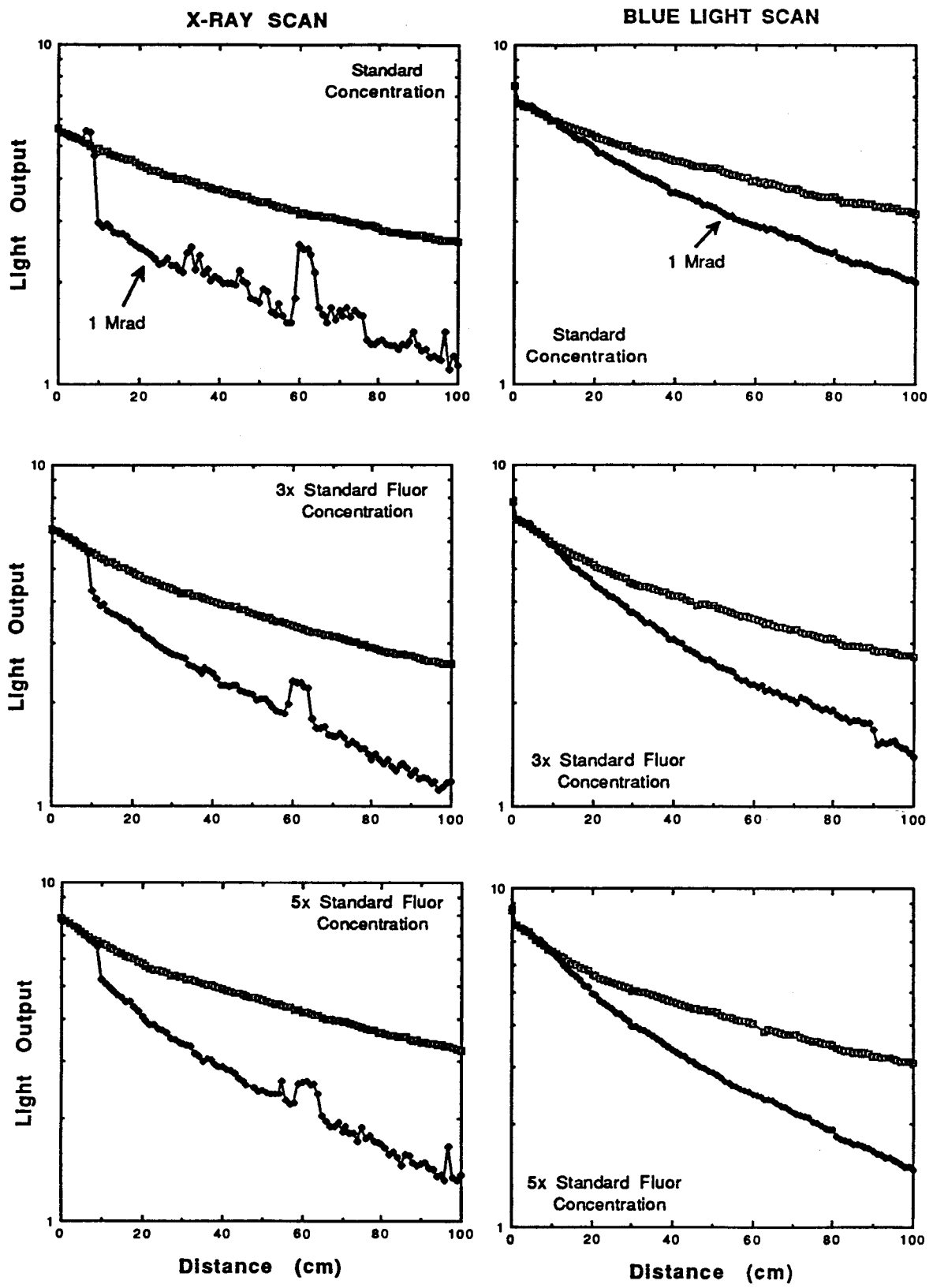


Fig. 3. Light output of BRICRON BCF91A wave shifting fibers, before irradiation and after recovery from 2 Mrad dose; excited by 30 KeV X-rays and blue light. Concentrations are those of K27 fluor.

The middle and lower curve of each figure are measurements after a 3 Mrad irradiation and about 10 days of recovery. The BICRON tile has more light output, but it has more radiation damage.

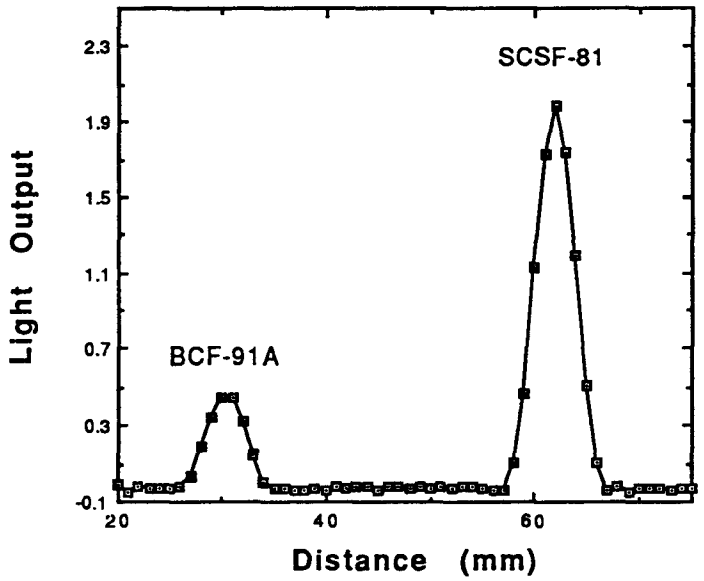


Fig. 4 Relative light intensity of BCF91A and SCSF81 fibers (1.0 mm) as measured by a bi-alkali PM tube

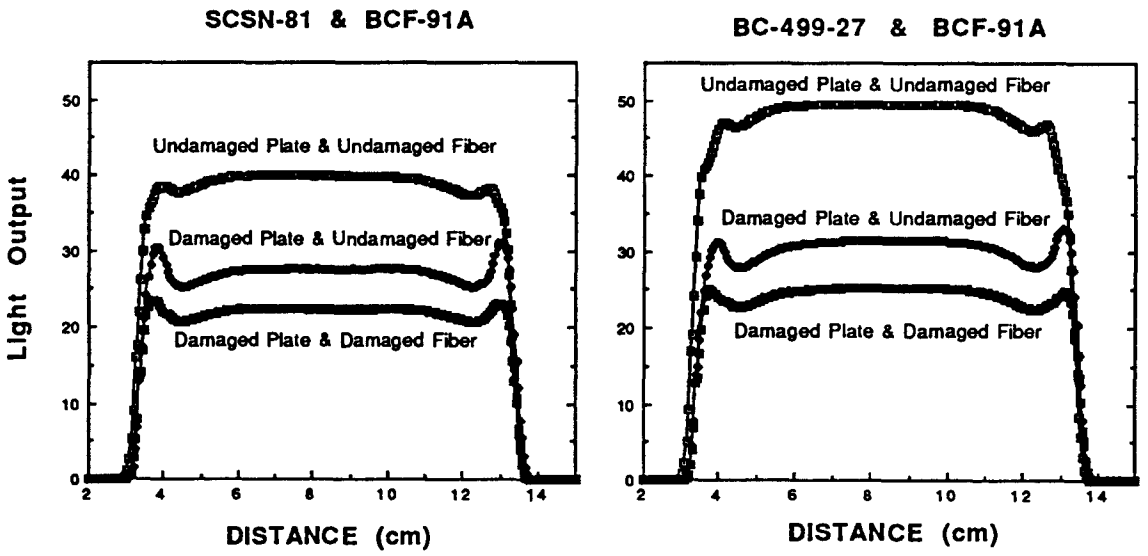
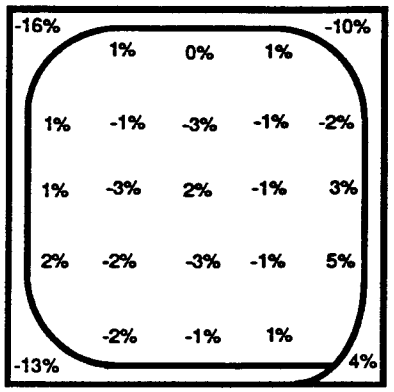


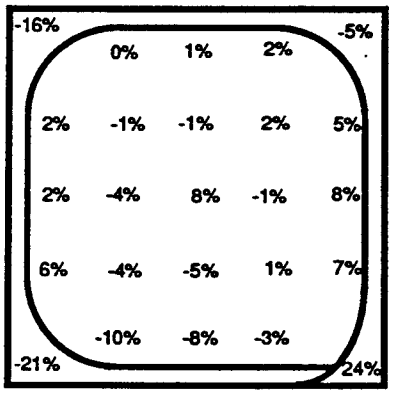
Fig. 5. Scan across 10 cm x 10 cm tile-fiber systems. Excitation is by X-rays. The damage curves were after 3 Mrad irradiation and 10 day recovery.

X-ray excitation of scintillators is not necessarily identical to charged particle excitation. A scan across the surface of the tile was performed using a Ruthenium source. Figure 6 shows the percent deviation from the average across the tile-fiber system. The average value was computed from the measured points inside the fiber outline. A scan across a 25 cm x 25 cm tile-fiber system yielded similar results. It is clear that in the vast portion of the area, the light is fairly uniform, but on the WLS fiber and the portion of the scintillator between the fiber and the edge, the light output variation is unacceptable. Correcting this nonuniformity might be accomplished by changing the reflectivity of the paint at the edges of the tile. One way to minimize the non-uniformity at the edges is to cut the groove as close to the edges as possible.



	Between fiber and edge	On fiber
Bottom	-10%	-7%
Left	-20%	1%
Top	-16%	1%
Right	-5%	5%

Fig. 6. Light output uniformity across Tile-fiber system. Each number is the percent deviation from the area average.



	Between fiber and edge	On fiber
Bottom	-30%	-14%
Left	-9%	13%
Top	-3%	13%
Right	19%	18%

Fig. 7. Light output uniformity across Tile-fiber system after an irradiation of 2 Mrad and recovery. Each number is the percent deviation from the area average.

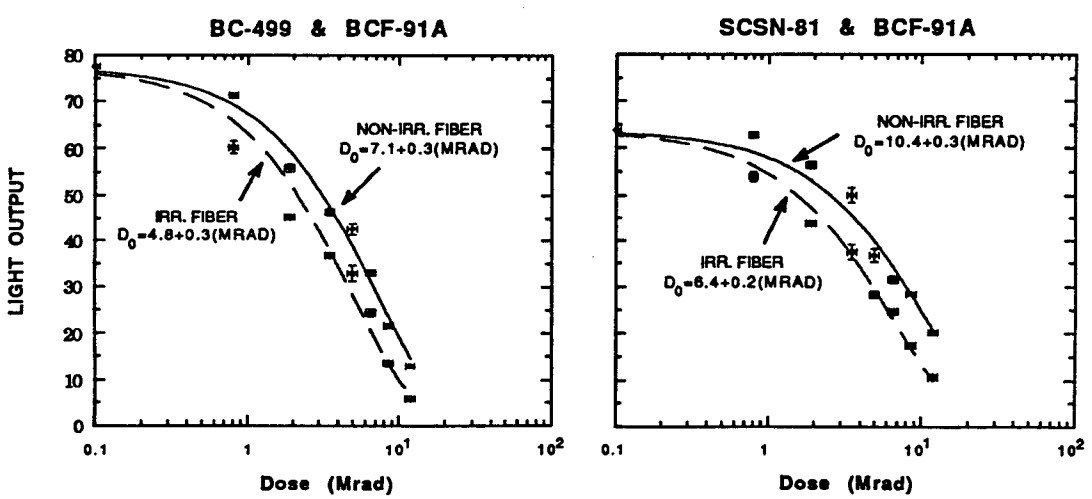


Fig. 8. Light output at the center of the tile-fiber system as a function of radiation. The upper curves are for undamaged fibers. Curves are fits to $I = I_o \exp(-D/D_o)$

The "sigma" tile-fiber system shown in figure 6 was irradiated by 3 MeV electrons to 2 Mrads. After 9 day recovery, the light output was measured. Figure 7 shows the area scan after radiation damage. The uniformity was essentially unchanged but the light output went down. Figure 8 shows the light output as a function of irradiation, up to 11 Mrad. Here the excitation was at the center of the tile. For this measurement, both BICRON BC499-27 and KURARAY SCSN81 tiles were used. The fiber used was BCF91A. In order to separate the fiber damage from the tile damage, light output was also measured with undamaged fibers. In general, about half the light reduction was due to the fiber and the other half due to the tile. The radiation damage of the BICRON tile was about 110% of the KURARAY tile. The curves were fitted to an exponential of the form light yield $I=I_0 \exp(-D/D_0)$ where D is the irradiation dose. D_0 is a measure of the radiation damage. For the SCSN81+BCF91A system $D_0 = 7\pm 1$ Mrad, and for the BC499-27 + BCF91A system $D_0 = 5 \pm 1$ Mrad. Note: the larger D_0, the more radiation hard is the tile-fiber system.

The light collection is a function of the diameter of the fiber, fluor concentration, etc. If the absorption of the blue light is a surface effect, then light output will be proportional to the diameter of the fiber. If the blue light absorption is a volume effect, then the light output will be proportional to the cross sectional area, or the square of the diameter. Under the assumption of identical fluor concentration, light output can be parameterized as a function of diameter to a power n, with n between 1 and 2. Figure 9A show scans across the tile-fiber with three different fibers, where two of the fibers were BICRON BCF91A of diameters 0.72 mm and 1.00 mm. The third fiber was KURARAY Y11 of diameter 0.80 mm. Using the data from the two BICRON fibers the value of of n was computed to be 1.2. The expected light output for a BICRON 0.80 mm diameter fiber was then computed. Comparing this value to the KURARAY Y11 fiber showed that the BICRON fiber produces 20% more light in the same tile.

Another measurement was performed by using 1.0 mm BICRON BCF91A fibers, with three concentrations of the K27 fluor. Figure 9B show X-ray scan across the same tile with the three fibers. The light output does not seem to depend on the K27 concentration. We attribute the small variation more to fiber production than to fluor concentration. As shown in figure 3, the lowest concentration showed the least radiation damage to attenuation length. There is a need to test fibers with even lower concentration.

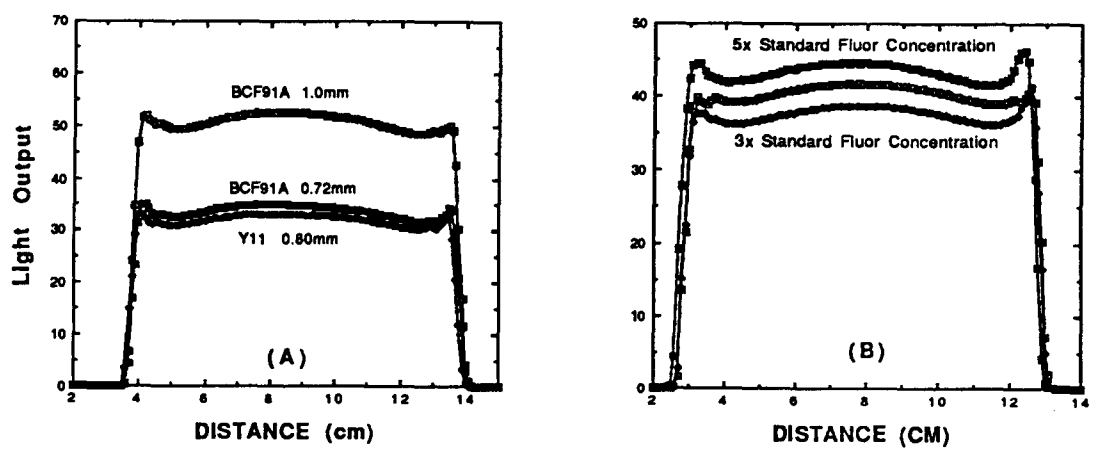


Fig. 9. X-ray scan across a sigma tile (BC 499-27)
A. With three different diameter fibers.
B. With three different K27 fluor concentrations.

SINGLE VERSUS FOUR GROOVES

Most of the blue light output reduction of an irradiated tile is due to radiation damage in the transmission of light in the polymer. For high radiation doses, an improvement can be accomplished by mutigrooving the tile, thereby reducing the blue light path length in the tile. Figure 10 shows

one such measurement where four (4) grooves were cut versus the single groove. The light loss due to irradiation in the four groove tile is approximately half that of the single groove tile.

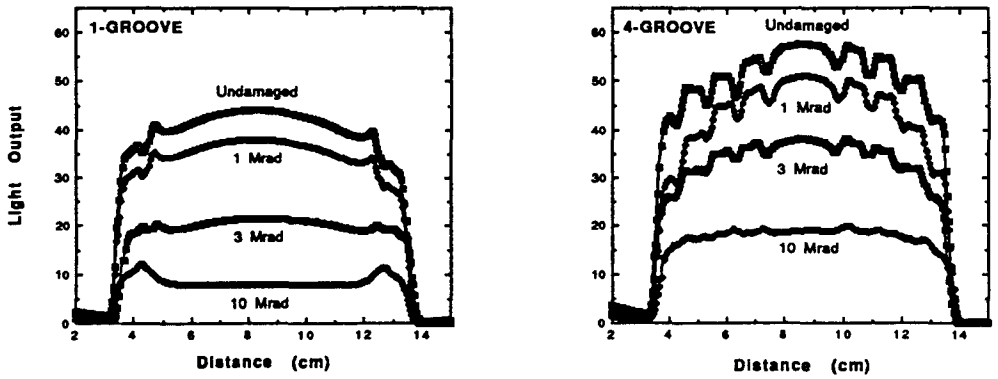


Fig. 10. Light output from X-ray scan of tile-fiber system.
Scintillator is SCSN81 and the fiber is BCF91.
A. Single groove.
B. 4-groove system.

CONCLUSION

With commercially available scintillating tiles and wave shifting fibers, calorimeter modules can be constructed where each tile fiber unit will have less than 2% light variation over most of the surface. Light loss due to radiation damage is 15% per Mrad up to several Mrad and can be corrected by calibration. Most scintillators have approximately the same amount of radiation damage, with the KURARAY SCSN81 about 10% better than the next best scintillator which is the BICRON BC499-27. The best wave shifting fiber, that was tested is the BICRON BCF91A with the standard concentration of K27 fluor. Light output is almost directly proportional to the fiber diameter and 1.0 mm fiber produces sufficient light for the active medium of a calorimeter. Finally, in high irradiation areas, multigrooving of the tile reduces the damage by reducing the path length the blue light has to travel in the damaged medium.

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