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R & D RESULTS ON SCINTILLATING TILE/FIBER CALORIMETRY FOR THE CDF AND SDC DETECTORS

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Abstract

We present results from R&D on scintillating tile calorimeters with wavelength-shifter-doped optical fiber readout. Studies of absolute light yields and measurements of spatial uniformity of response of various tile/fiber assemblies are described. Preliminary results on radiation hardness of the scintillating tile/fiber components are also presented.

INTRODUCTION

In recent years a new technique for reading out the light from scintillator tiles in sampling calorimeters has been developed [1,2]. Traditionally, the light produced in the scintillator is collected by wavelength-shifting (WLS) plates connected to the edges of scintillator tiles. The WLS plates absorb light emerging from the scintillator and subsequently re-emit it at a longer wavelength. The re-emitted light is then transported to photomultipliers via normal light guides. In the new technique, the light is collected by WLS-doped optical fibers embedded directly in the scintillating tiles. Clear optical fibers, spliced to WLS fibers at the edges of the tiles, transport the light to phototubes outside of the calorimeter.

A program of R&D has been undertaken by our group, motivated both by a plan to upgrade the CDF plug- and forward-calorimeters with a new scintillator-based calorimeter [3] and by a proposal to develop a compensating scintillator plate calorimeter for the SDC detector [4]. During the 1990 Fermilab Fixed-Target Run, members from the CDF- and SDC-collaborations [5] built and tested small, prototype electromagnetic and hadronic tile/fiber calorimeters. Based on the results of these tests we have undertaken an intensive R&D program to identify and study the parameters that are crucial for the construction of a tile/fiber calorimeter; these include the tile light yield, tile-to-tile uniformity, positional response uniformity in a single tile, and the radiation hardness of the various components. The results of this R&D program are reported in this contribution.

EXPERIMENTAL SETUP

We use a cosmic ray telescope setup to measure absolute number of photoelectrons N_{pe} corresponding to the response of a tile to a minimum ionizing particle (m.i.p.). Light from a tile is read out by a photomultiplier connected to a charge integrating ADC. A coincidence of signals from four counters, located above and below the tile being measured, was used to trigger the ADC. More than 99.5% of triggers corresponded to a passage of a cosmic ray

muon through the telescope.

Figure 1 shows the ADC pulse height distribution for a 12 cm×12 cm×2.5 mm polystyrene (SCSN-81) tile with eight embedded green WLS fibers. The geometry of the tile is sketched in Fig. 2.

Assuming Poisson statistics, the ratio of the number of events with no measureable signal recorded in the ADC, N_0, to the total number of triggers N_{tot}, can be used to calculate the average number of photoelectrons for a m.i.p. at normal incidence, N_{pe}:

$$N_{pe} = -\ln \frac{N_0}{N_{tot}} \times f_{ang}, \tag{1}$$

where $f_{ang} = 0.87$, is a correction factor accounting for the average angle of incidence of cosmic ray muons. The absolute light yield per m.i.p. for this particular tile is equal to 3.3 ± 0.1 photoelectrons.

The spectrum in Fig. 1 was recorded using a Hamamatsu R329 phototube with standard bialkali photocathode material [6]. The photoelectron yield of a tile/fiber assembly can be enhanced by use of a phototube with a photocathode material whose quantum efficiency better matches the emission spectrum of the WLS fibers, which is shown in Fig. 3. Our recent measurements indicate that use of phototubes that employ "extended-green" photocathodes (for example Philips 2081B [7]) can increase number of photoelectrons per minimum ionizing particles by as much as a factor of two.

The second method of determining light yields of tile/fiber assemblies is based on a measurement of the DC current from a photomultiplier connected to the tile illuminated with collimated 1 mCu Cs^{137} γ source. This measurement allowed us to establish the light yield of a tile relative to a "standard" tile, i.e. one whose light yield has been determined using cosmic ray setup.

PRODUCTION OF TILES

A detailed description of production technique of tile/fiber assemblies can be found in Ref. [2]. We have used polystyrene SCSN-81 scintillator produced by Kuraray [8] and PVT scintillator BC-408 from Bicron [9]. Based on the results of the test-beam prototype studies [5], we decided to use 1 mm diameter, BCF-91 WLS fiber, produced by Bicron. The combination of BC-408 tile and BCF-91 fiber has a light yield that is about 1.6 times larger that of assemblies build with SCSN-81 tiles and BCF-91 fibers. Our studies indicate that tiles with polished edges have light yield equivalent to that of tiles with edges painted with white reflective paint, such as BC-620 from Bicron.

We have developed two alternative methods of embedding a WLS fiber in the scintillating tile. In the first method fiber is loaded into the tile and then glued into a 1 mm$\times$1 mm square groove [2]. In the second technique, a "ball-shaped" groove is cut into the scintillator tile and the fiber is loaded into the tile from its edge. A comparison of these two techniques is illustrated in Fig. 4. The advantage of the "square groove" method is that the glue provides good optical coupling between the scintillator and the fiber. Air coupling between scintillator and fibers reduces the tile light output to about 65% of that for the case of glued fibers. The advantage of the "ball-shaped" groove technique is that it avoids possibility of long term chemical damage to the fibers by the glue and, especially for the SSC applications, eliminates possible problems associated with radiation damage of the glue.

We use clear optical fibers, produced by Kuraray, with an attenuation length measured to be $\lambda_{att} \approx 7$ m to transport light from tiles to phototubes. A technique to connect (splice) WLS fibers to clear fibers has been developed [10]. The average fraction of light transmitted across the splice is 92% with a splice-to-splice spread of about 6% .

LIGHT YIELD OF TILE/FIBER ASSEMBLIES

We have studied the light yield of tile/fiber assemblies as a function of the tile thickness. As shown on Fig. 5, light yield increases linearly with tile thickness. One can also increase

the light yield of a tile by increasing the number of the WLS fibers embedded in the tile. The results shown in Fig. 6 indicate that the light yield increases with the density of fibers (total length of fibers per unit area of the tile) embedded in the tile. We have also investigated the light yield of tiles with the different fiber layout patterns shown in Fig. 7. The data in Fig. 8 show that tiles with fibers laid out in a spiral pattern have 1.4 times the light yield of tiles with fibers laid out in U-pattern.

In order to improve hermeticity of a calorimeter, we have studied a possibility of limiting the number of readout fibers without significant reduction of the light yield of the tile/fiber assemblies. Our preliminary results indicate that tiles with only single readout fiber connected to a phototube, (σ pattern, shown on Fig. 7a, with the other end of the fiber aluminized) have light yield of about 80% relative to the tiles with standard U-pattern fiber layout. The reflectivity of the fiber mirroring, measured with a UV light source and photodiode setup, is 84% $\pm$ 3%.

SPATIAL RESPONSE UNIFORMITY

We have studied the spatial uniformity of light collection of different tile/fiber assemblies using a electron beam device. This device, constructed at Argonne National Laboratory, uses a Ru^{106} β source and a set of permanent magnet dipole and quadrupole elements that momentum select and focus electrons into 2 mm by 5 mm beam spot [11].

Good spatial uniformity of the light collection of tile/fiber assemblies can be achieved by the appropriate use of surface masks. Figure 9 shows a comparison of light collection uniformity for unmasked and masked 4mm PVT U-pattern tile. The masked tile response has a spread of about 2%. The interesting feature of σ pattern tiles (Fig. 7a) is that their unmasked spatial uniformity of the light collection, shown on Fig 10, has a spread of about 2% and therefore tiles with such fiber layout pattern do not require selective masking.

TILE-TO-TILE UNIFORMITY

We have studied the tile-to-tile uniformity of light collection as a part of quality control program during the production of the large-scale prototype electromagnetic and hadronic calorimeter for the CDF end-plug and forward regions. The tile-to-tile light yield variations of 7-9% have been achieved for sets of tiles (towers) connected to a single phototube. A technique of reduction of the tile-to-tile light yield variations after tower assembly has been developed. In addition, we have performed a Monte Carlo study [12] in order to determine the effects of tile-to-tile light yield variations on the energy resolution of the calorimeter. Our results indicate that if each tower is properly calibrated with high energy electrons, the tile-to-tile variations in a tower do not cause a significant deterioration in the energy resolution of the calorimeter.

RADIATION HARDNESS ISSUES

We have studied effects of radiation damage on the light yield of tile/fiber assemblies using a Co^{60} source. Figure 11 shows the relative light yield of a SCSN-81 tile with BCF-91 fiber as a function of the radiation dose. The light yield of the tile/fiber assembly is reduced to about half of its original level for a 3 Mrad radiation dose.

SUMMARY AND OUTLOOK

The recent R&D effort has resulted in the increased light yield and improved uniformity of light collection for the component elements of tile/fiber calorimeters. Light yields of more than 4 photoelectrons per tile per minimum ionizing particle have been achieved for 4 mm thick PVT tiles coupled to a 4 m long clear readout fiber. A uniformity of light collection at the level of 1-2% has been achieved by selective masking of tile surface.

The above results have been used in the design and construction of a large-scale engineering prototype electromagnetic and hadronic calorimeter modules for the CDF and SDC detectors. These prototypes will be tested during the 1991 Fixed-Target Run at Fermilab.

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[10] G. Apollinari et al., to be published in NIM.

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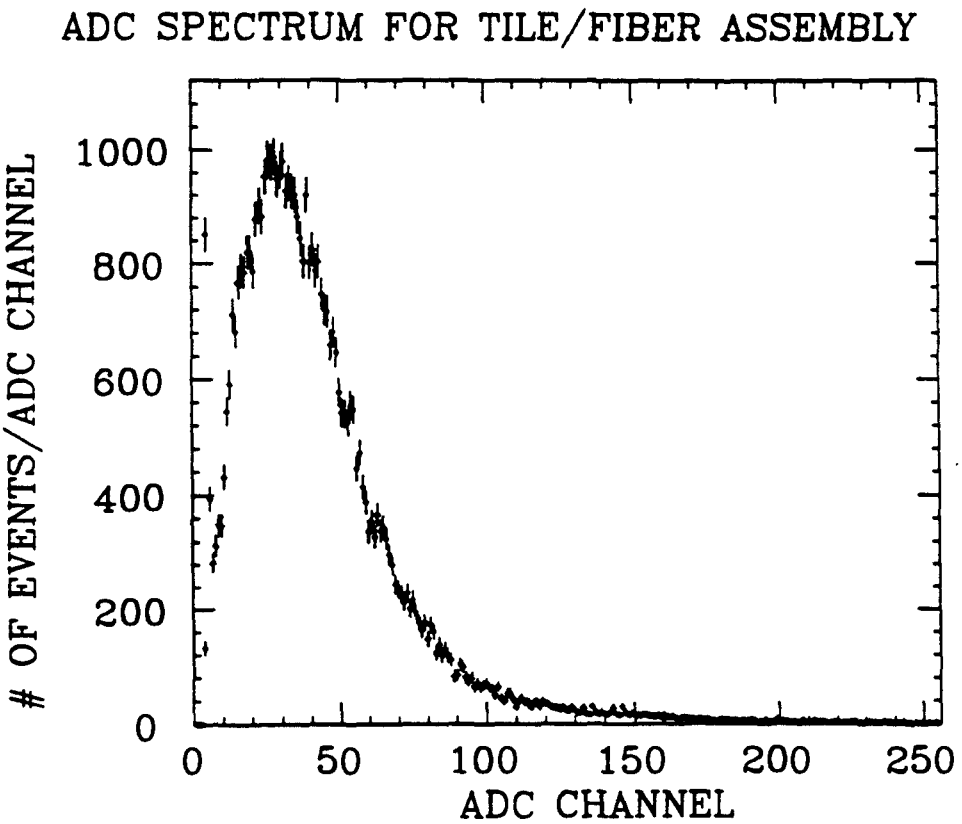
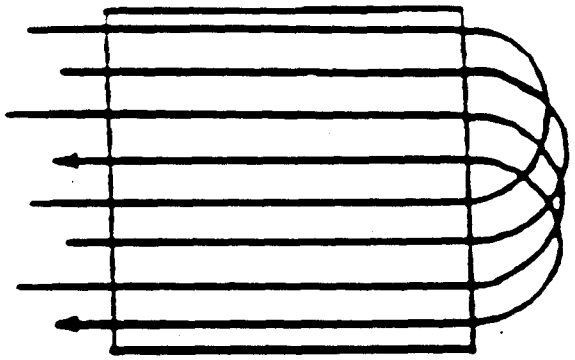
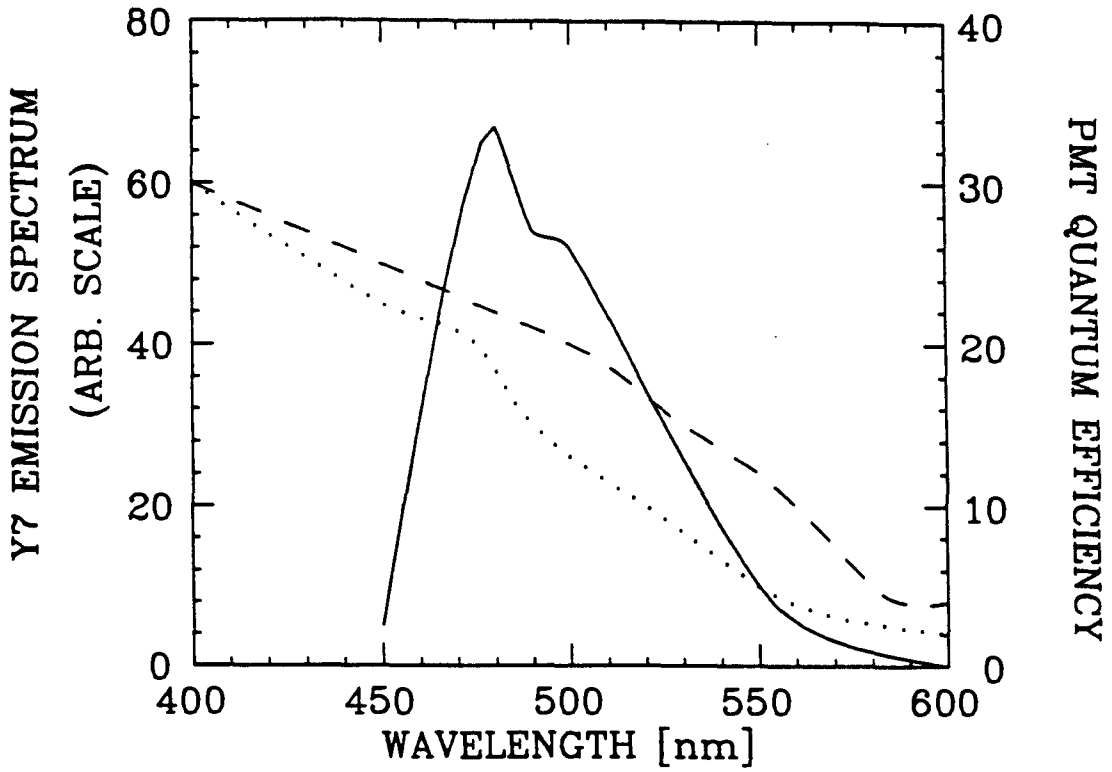


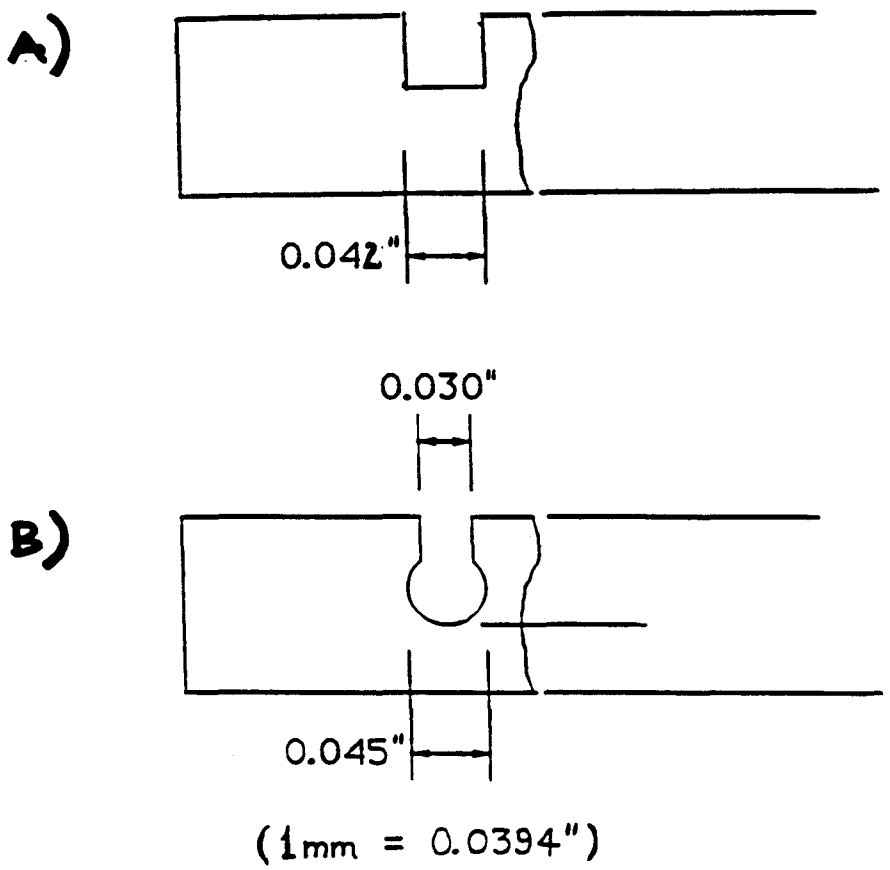
1. Figure 1: The ADC pulse-height spectrum for cosmic ray muons passing through a reference tile. The fraction of triggers with no ADC deposition is equal to 2.3% corresponding to the average light yield of 3.3±0.1 photoelectrons per minimum ionizing particle.



2. Figure 2: A diagram of the fiber geometry in a reference tile. WLS fibers were epoxied into the grooves and spliced to a 60 cm long clear fibers.



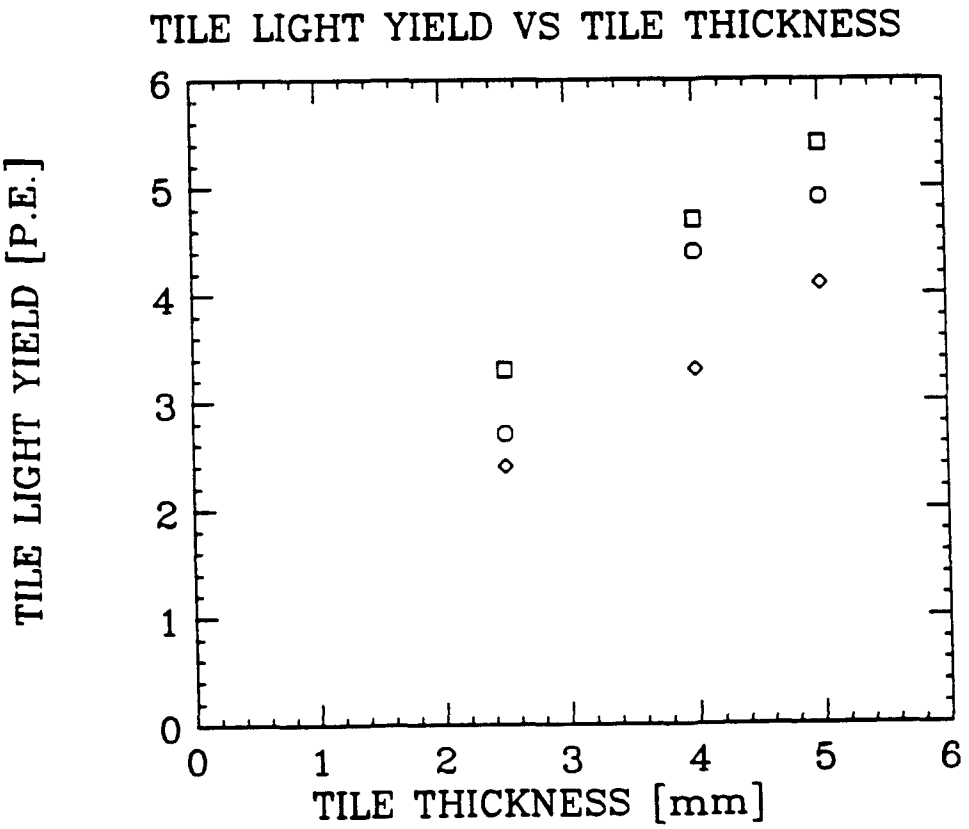
3. Figure 3: A comparison of the emission spectrum [8] of BCF-91 green WLS fiber with Y7 dye (solid line) with the quantum efficiency [7] of a standard bialkali photocathode (dotted line) and the quantum efficiency of a "green-extended" bialkali photocathode (dashed line).



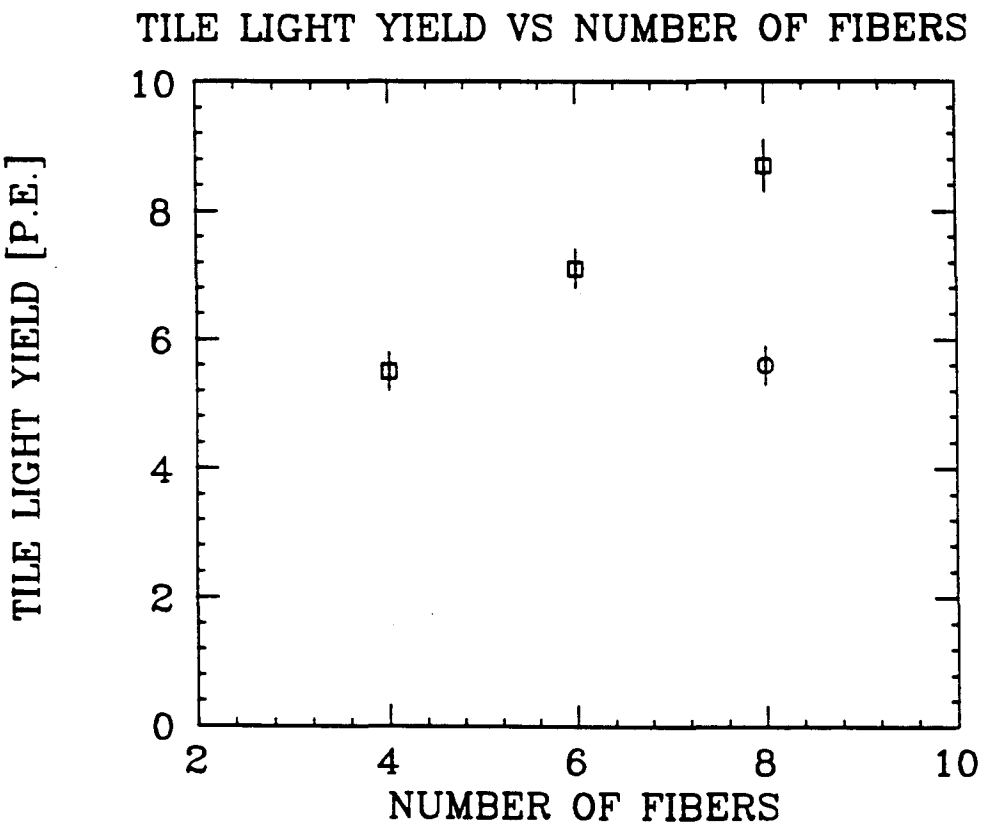
4. Figure 4: A comparison of two alternative techniques of building tile/fiber assemblies:

   a) the fiber is loaded into a square shaped groove and glued;

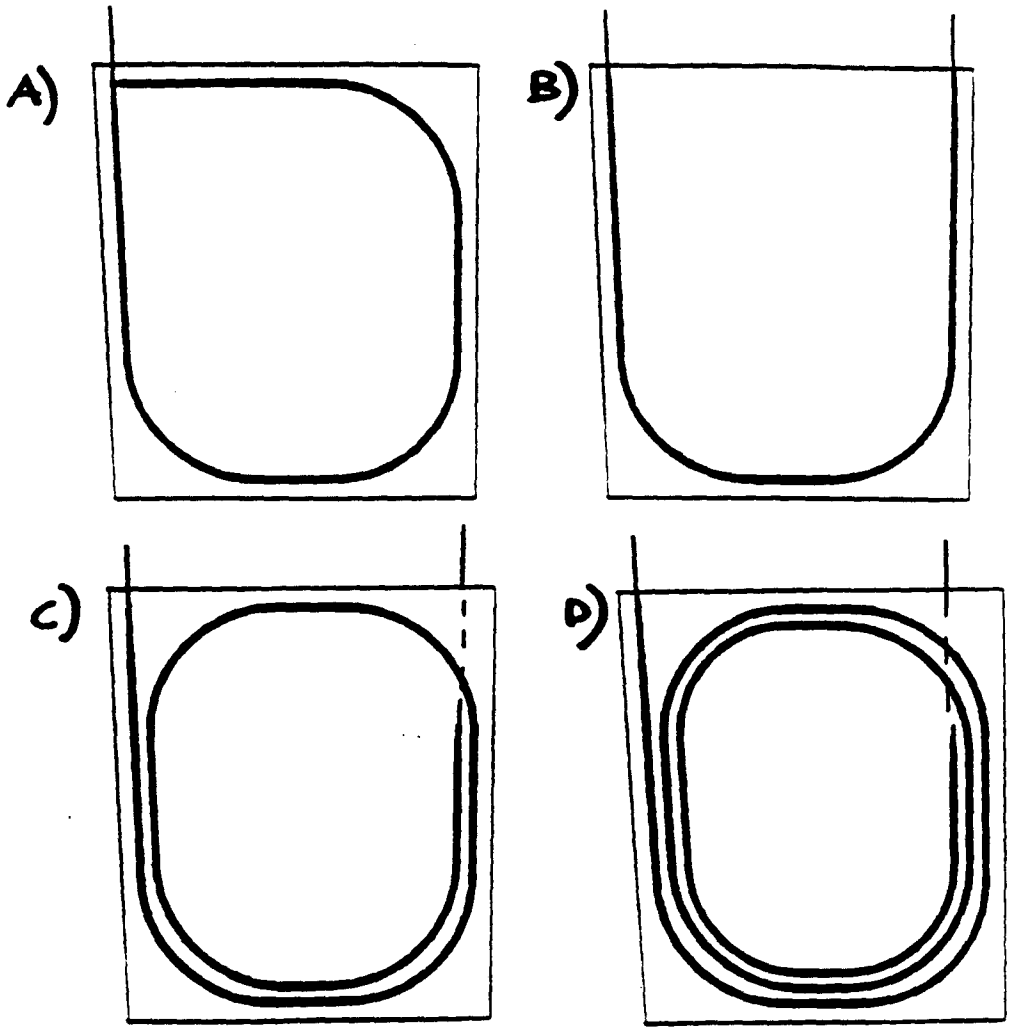
   b) the fiber is loaded into a ball groove; no glue is needed.



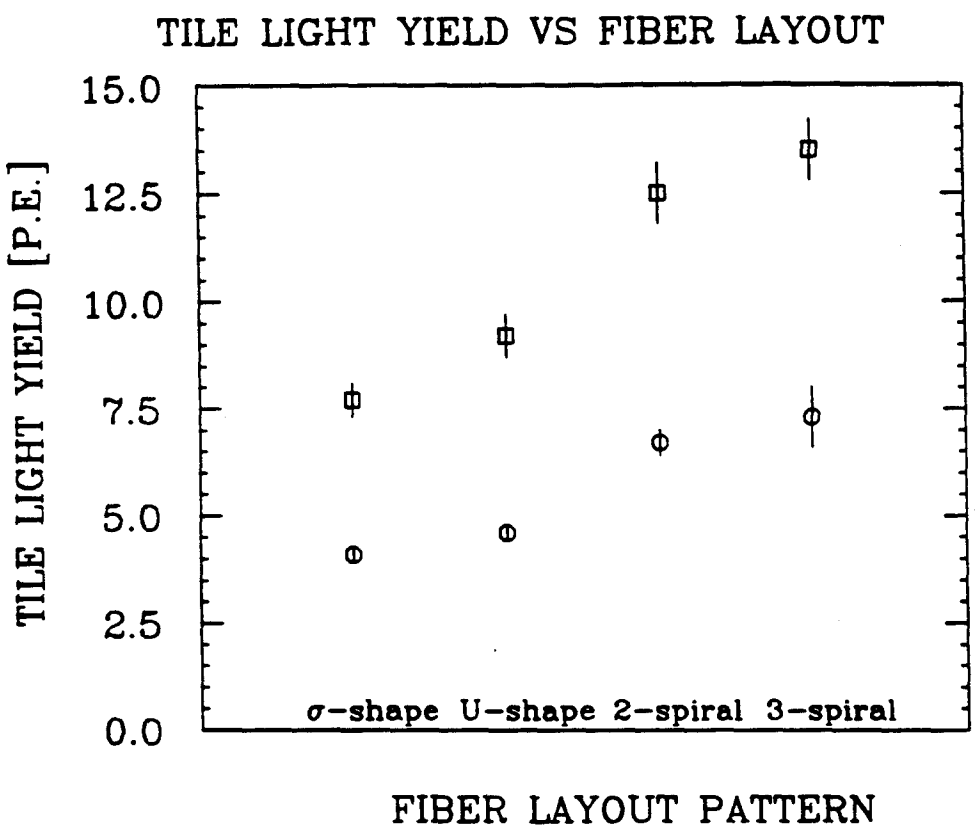
5. Figure 5: The light yield of SCSN-81 tiles as a function of tile thickness: the squares correspond to the light yield for 10 cm×10 cm tiles, the circles correspond to the light yield for 10 cm×20 cm tiles, and diamonds correspond to the light yield for 15 cm×25 cm tiles. Measurements were done using a EMI 9839B phototube with standard bialkali photocathode.



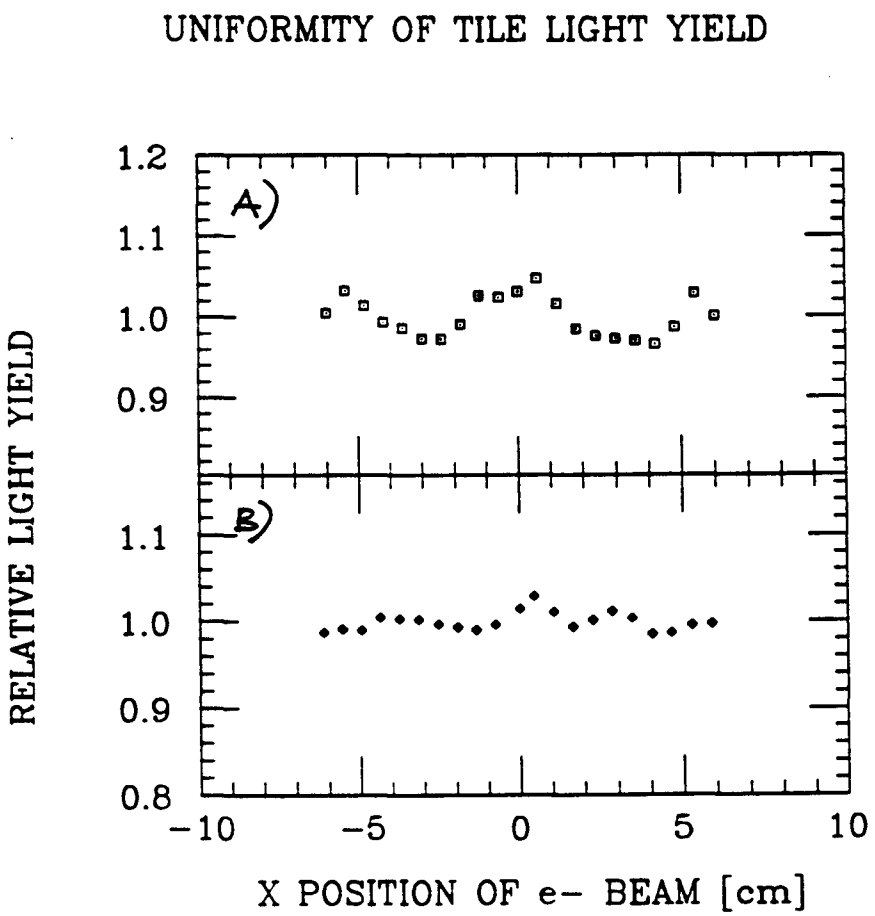
6. Figure 6: The light yield of a 30 cm×30 cm, 5 mm thick SCSN-81 tile as a function of number of WLS fibers embedded in it. The squares correspond to light yield of tiles with fibers glued into the grooves ; the circle corresponds to the light yield measurement of a tile with fibers embedded into the tile using the "ball groove" method. Measurements were done using a EMI 9839B phototube.



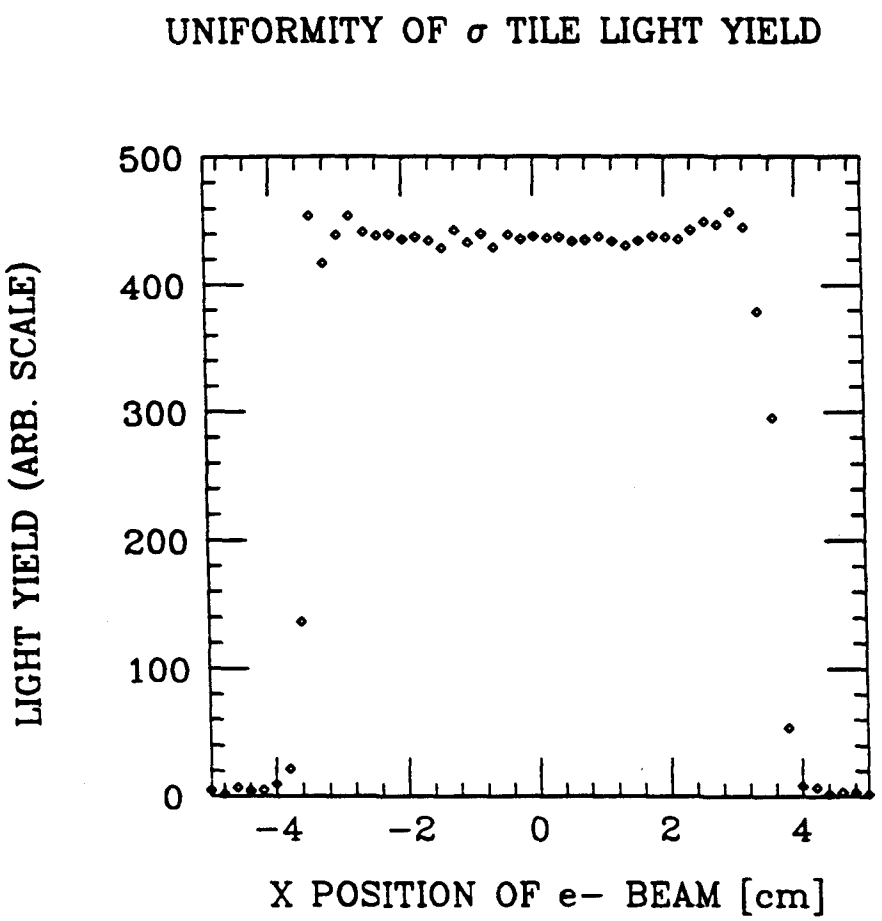
7. Figure 7: Different layout patterns of fibers in the tile that were examined: a) σ pattern with single fiber connected to photomultiplier. The end of the fiber remaining in the tile has been aluminized; b) U-shaped pattern, with 2 readout fibers; c) 2-spiral pattern with 2 readout fibers; d) 3-spiral pattern with 2 readout fibers.



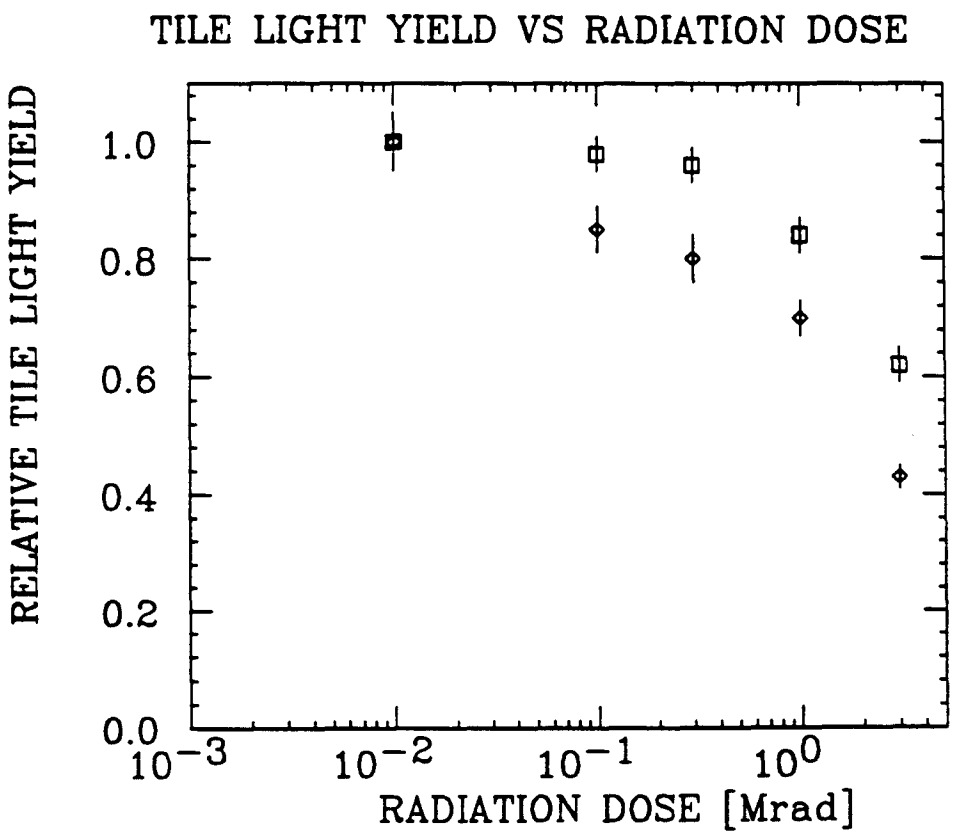
8. Figure 8: The light yield of tile/fiber assemblies as a function of different fiber layout pattern: tile/fiber assemblies were built with 4mm thick BC-408 scintillator. BCF-91 WLS fibers were air coupled to the tiles. The squares correspond to the light yield of the tiles with 30 cm long WLS fibers connected directly to the photomultiplier; the circles correspond to the light yield of tiles with WLS fibers (10 cm long) spliced to 4 m of clear fiber. Measurements were done using a Hamamatsu R329 phototube.



9. Figure 9: The spatial uniformity of light collection for 4 mm thick PVT tiles with U-shaped fiber layout pattern a) a scan across two unmasked tiles, and b) a scan across two tiles, selectively masked tile, resulting in the spatial uniformity of $\approx 2\%$.



10. Figure 10: Spatial uniformity of the light collection of unmasked 4mm thick PVT tile with σ pattern of fiber layout. A scan across the tile. The signal fall-off at x=± 3.5cm corresponds to the edges of the tile. The spread of the response is $\approx$ 2%.



11. Figure 11: The relative light yield of SCSN-81 tiles with BCF-91 fiber assembled using ball groove technique, as a function of radiation dose. Tile/fiber assemblies were exposed to Co^{60} source at a rate of $\approx$ 1 Mrad/hour. Circles correspond to the relative light yield of the tiles measured 1 week after irradiation, squares correspond to the relative light yield of the tiles measured 2 weeks after irradiation. Measurements were done using a Hamamatsu R329 phototube.