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Optimized Design of Low Cost Light Guides for Plasic Scintillators*

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Introduction

Comparative tests have been carried out on light guides proposed for use on plastic scintillation counters. The original study was motivated by the need for 1300 light guides intended for use in the CLAS Electromagnetic Shower Calorimeter. Five lucite light guide types (see Fig. 1) have been tested to determine the light transmission characteristics of various designs. These tests have been performed with two different types of scintillator, one emitting light in the blue and a second, NE 172 which is often used as a wave-shifting material, with emission centered in the green. The possible effects of yellowing or of reduced transmission of blue light thus have been studied also. The principal goal of these tests has been to compare the light-gathering efficiency of the generally used "adiabatic" light guide with a much simpler design suggest by one of the authors (T.J.H.) This design (see Fig. 1.) utilizes a single rectangle of plastic material bent to provide optical coupling to scintillator at one end and to a photomultiplier (PMT) at the other. As can be judged from Fig 1, it is much simpler to fabricate than lightguides which use several polished and bent pieces.

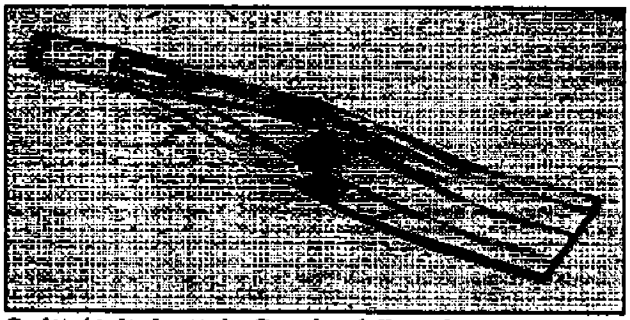
As this work was motivated by design considerations for the CLAS-EGN calorimeter, we describe here the principal aspects of that design. The light guides tested here were to view a green wave-shifter bar scintillator bonded to the edges of blue scintillator strips located within a Pb-scintillator calorimeter stack. A general description of the proposed EGN calorimeter has been given by Minehart et al.[1] The CLAS detector consists of six symmetric sectors around the beam line. Sectors will be separated by the superconducting coils of the toroidal magnet.

Each of the six CLAS sectors will be equipped with an independent electromagnetic shower calorimeter [ESC] with an approximate triangular shape. One ESC will consist of 13 identical submodules (SM), each submodule having 3 layers of 2 mm thick lead plates interleaved with 10 mm thick, 10 cm wide scintillators. Each SM is thus 1.14 radiation lengths thick. The scintillator strips in one layer are rotated by 120° relative to the previous plane such that they are parallel to the 3 sides of the triangle (U-, V-, and W-strips). This will provide the possibility of a stereo

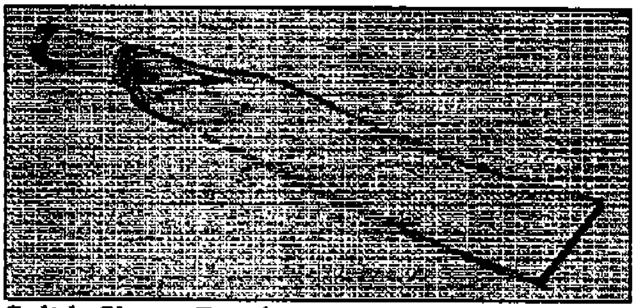
Fig 1. Light Guides

The five types of light guides, fabricated by the William and Mary Physics Machine Shop, are shown below:

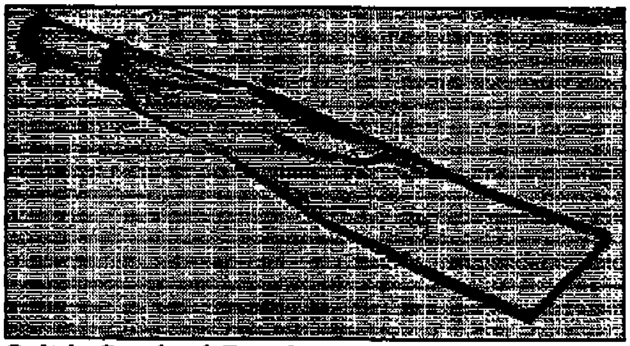
Split (Adiabatic), Sharp Bend



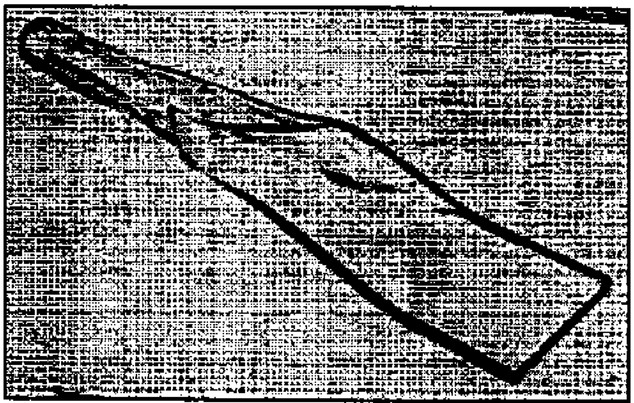
Split (Adiabatic), Gradual Bend



Solid, Sharp Bend



Solid, Gradual Bend



Solid, No Cylinder at PMT

readout, which is necessary to resolve multiple particles in the ESC. The scintillation light was originally to be converted into green light by wavelength shifter bars attached to one end of the strips and viewed by the light guides tested here.[2] The proposed design required approximately 1300 light guides and photomultiplier tubes to collect the light from the wavelength shifter bars. Minehart and collaborators have built and tested at BNL a prototype lead/scintillator sandwich calorimeter with a stereo read-out geometry. It measures electron shower energies with a resolution of $9.3\%/E^{1/2}$. Its front-rear segmentation rejected more than 98% of the pions at 2 GeV. The purposes of the tests made here were to choose an efficient, easily fabricated light guide similar to that needed in such a calorimeter that would simultaneously satisfy the requirements of uniform light collection and good timing.

Light Guide Test Procedure

The test apparatus consisted of a 2" photomultiplier (56AVP) tube and base, the five light guides, and a small square of Pilot-B scintillator measuring 10 x 10 x 1 cm. Devcon five-minute epoxy was used to fasten the scintillator to the flat end of a light guide and the PMT to the cylindrical end. The scintillator was wrapped with a layer of Al foil and two layers of black electrical tape. Each guide was wrapped with a layer of Al foil to within about two inches of the PMT, and black plastic was wrapped around the guide three or more layers thick. The PMT was seated in the base with an iron shield, and black plastic covered the opening between the shield and the light guide. Electrical tape was used to seal all seams. The base and PMT were elevated to permit the scintillator to rest flat on the test bench so that a radioactive test source (^{90}Sr) could be placed on top. In setting up the equipment, an optimum high voltage for the PMT was chosen, and a gain and DC offset for the spectroscopy amplifier determined. The DC offset was varied so as to exclude most of the low-level noise from the accumulated spectra.

With the setup shown in Fig. 2, two to four groups of pulse-height data were taken for each of the light guide configurations shown in Fig. 1. Each group consisted of 10 or 11 ten-minute data sets, corresponding to 9 (10 in a few cases) positions of the source on the face of the scintillator, and one background measurement without the source. The tenth position on the face of the scintillator, point E, was used to test the behavior of the "adiabatic" light guides (each formed of four strips of lucite) at the middle seam. Points 2, 5, and 8 were in line with the middle seam in each adiabatic light guide, so point E, slightly off center and not in line with a seam, was used to determine whether a source position in line with the seam was affected by it. For each light guide tested, a photo of the pulse height and shape on the oscilloscope was taken with the source at point 5 for subsequent comparison.

Interpretation of the Data

An example of a group of pulse-height data sets is shown in Fig. 3. The horizontal axis shows channel number, 0 to 511 from left to right, and the vertical axis is counts per channel. The pulse height from the amplifier is proportional to the number of photons striking the PMT. A test was run with thin plastic absorbers between source and scintillator to assure that the PMT was operating in a reasonably linear range and the signal was not saturating. As the middle section of each histogram is fairly linear, the X-intercept and slope of an unweighted linear fit in this range were used to characterize each data set. The X-intercept is a measure of the higher energies detected by the PMT, and the slope indicates the distribution of counts among energies in a histogram. A good light guide should have a spectrum with large X-intercept, indicating that high light output was detected, and a small slope, indicating that the higher energy pulses were abundant in the spectrum.

Results

Using Graphit, a program written by one of the authors [2], the data sets were displayed and overlapped to compare their shapes. Figure 4 shows overlapped data sets taken for point 5 for each of the five light guides. Linear fits were made to the data and the results were imported into a spreadsheet program. Graphs of the X-intercepts and slopes are shown in Figures 4 through 14.

From the graphs, it appears that the Solid-(Sharp Bend) and Split-(Gradual Bend) light guides yielded the best results, having higher X-intercepts and lower slopes. Close in performance are the Split-(Sharp Bend) and the Solid-(No Cylinder at

PMT). The latter appeared to favor one side in one test suggesting a possible uneven glue joint. The Solid-(Gradual Bend) gave the poorest performance. This was not expected, and upon very close observation, that light guide was seen to have a slight yellowish tint indicating that it might have been constructed of UV-absorbing (or perhaps old) lucite, thus reducing the light transmitted from the scintillator.

The unexpected discovery that one of the light guides was slightly yellowed and that that particular guide was poorest in light transmission motivated us to repeat these measurements with NE 172, a green-yellow scintillating plastic often used as a wave-shifter. If was felt that a yellowing of the lucite should most clearly affect the blue light and thus might not be as evident in tests with scintillator which emits light at longer wavelengths. These tests indicated that the Solid-(Sharp Bend), the Split-(Gradual Bend), and the Solid-(Gradual Bend) light guides are the best. Close behind is the Split-(Sharp Bend), and last is the Solid-(No Cylinder) light guide. Initial tests, performed by shining a laser into each lightguide and observing the amount of light scattered from the surfaces, indicated that the solid sheet, bent to a self-formed cylinder at one end, exhibited the greatest light losses in agreement with these test results.

It seems worth reiterating that the need to have each of the CLAS scintillation detectors assembled and operating stably for many years in a radiation environment and under ambient temperature and humidity conditions suggests that the potential effects of yellowing caused by aging plastic or glue joints or the effects of radiation on either or both must be considered carefully.

Conclusions

Since the inception of this work, collaborators from Russia and Armenia have designed a more complex, more costly lightguide which is formed of dozens of optical fibers. Instead of connecting the PMT to the blue scintillator strips via a green NE-172 wave-shifter bar, each individual strip is connected to the PMT with a fraction of the fibers in the bundle. That innovative design is worthy of note for many similar applications. Still, the work reported here has shown that an excellent lightguide can be fabricated from a single rectangle of plastic sheet, one end of which is heated and formed into a curved shape which is glued to a plastic cylinder for matching to the PMT. It is estimated that for a plastic scintillator of edge dimensions 1 x 10 cm, such a light guide will always be far simpler and less costly to fabricate than the typical "adiabatic' guide which, in the example given, would be bent from four individually cut and polished strips of plastic 1 x 2.5 cm on an edge. In most applications, the new design tested here will also prove more rugged.

References

1. R. Minehart et al, Lead-scintillator Electromagnetic Calorimeter with Stereo Readout, CEBAF PR-90-026, November 1990.
2. Conceptual Design Report, CEBAF Basic Experimental Equipment, April 13, 1990.
3. R. Minehart, et al., Presented at October, 1990 Crystal City Meeting of the IEEE

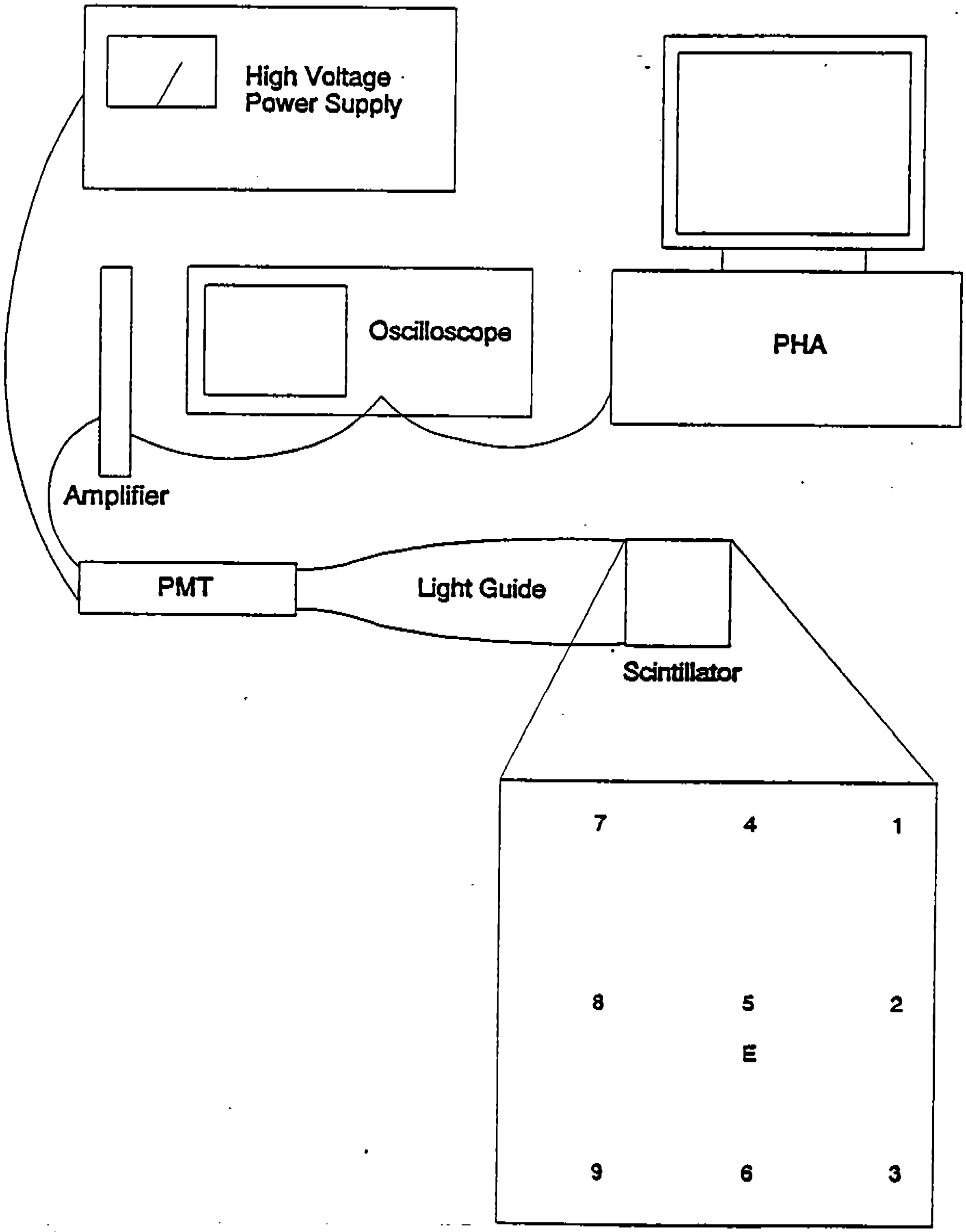


Figure 2. Experimental Setup

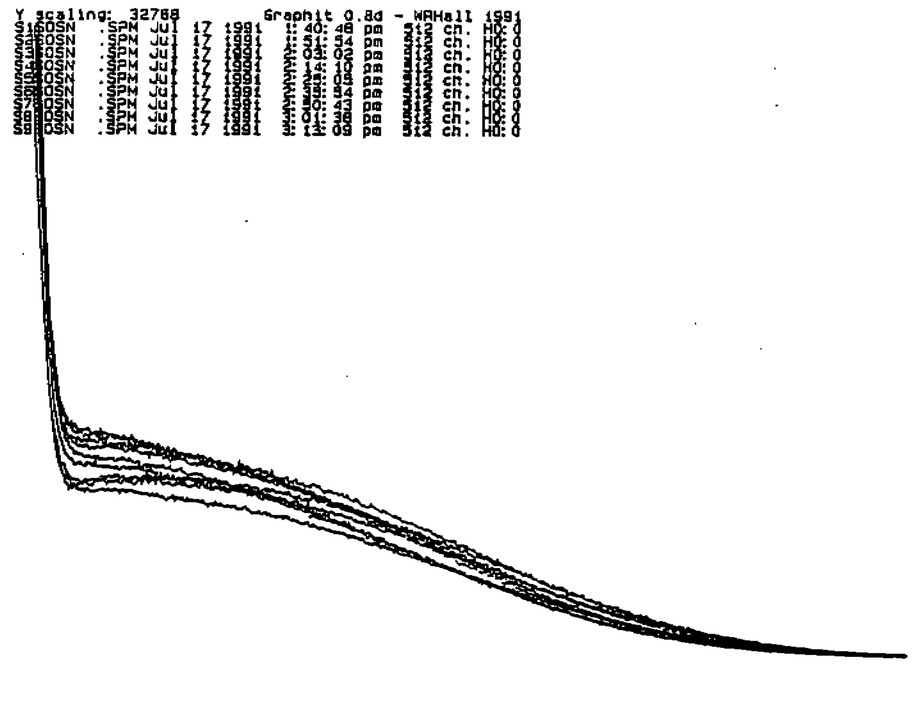


Figure 3. Group of nine data points taken with Solid, Sharp-Bend Light Guide.

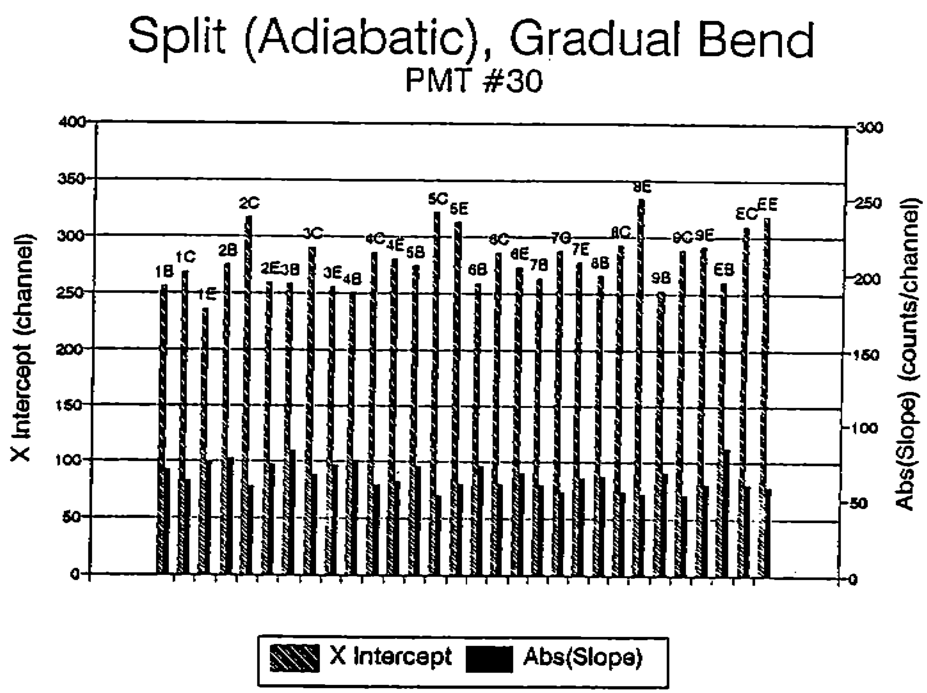


Figure 4.

X-intercepts and slopes for the Split (Adiabatic), Gradual Bend light guide. The first character represents the position of the source on the scintillator, and the second character indicates the data group. Group A is omitted from this graph to prevent clutter (data can be found in Table 1), and group D was not used (group E was really the fourth data group).

Solid, No Cylinder at PMT
PMT #30

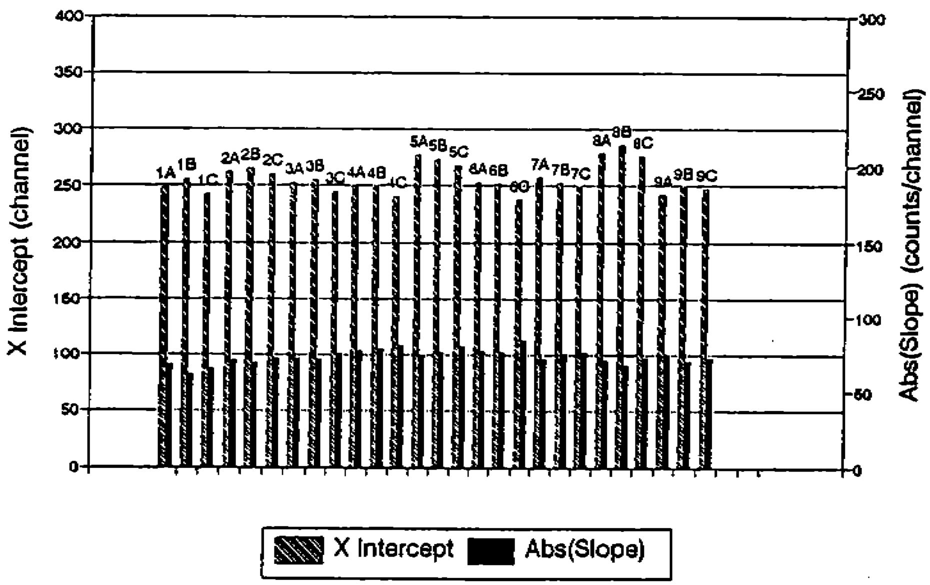


Figure 6.

Group D is not shown because it contains only one data set (see Table 1).

Solid, Sharp Bend
PMT #30

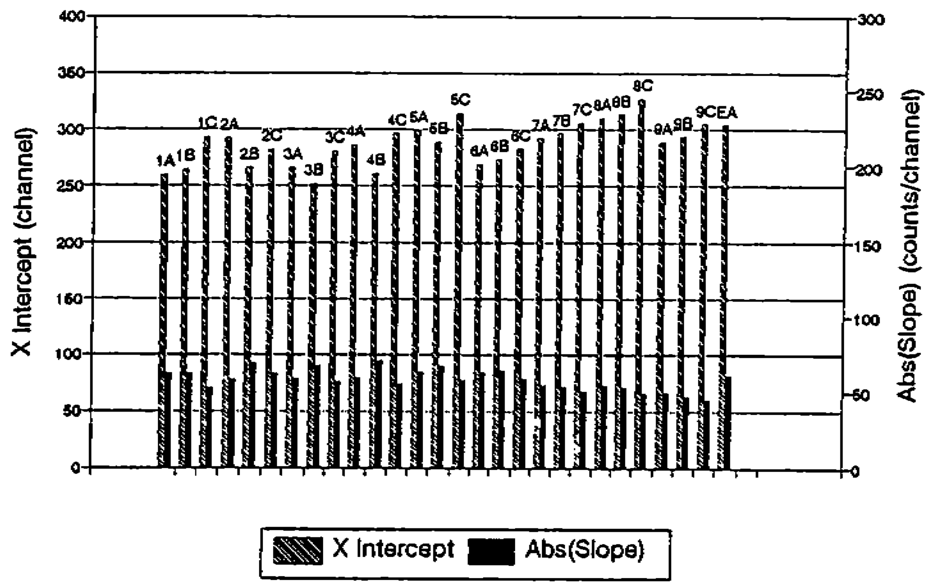


Figure 5.

The data set for point E in group A was taken by mistake.

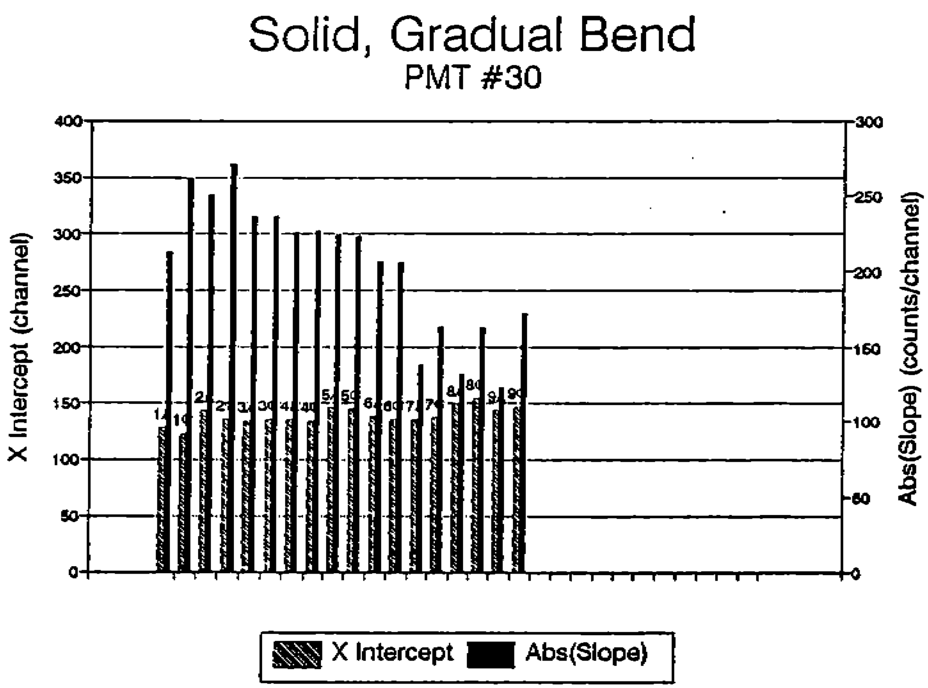


Figure 8.

Only two groups of data, A and C, were taken. Group B was not used (group C was really the second data group).

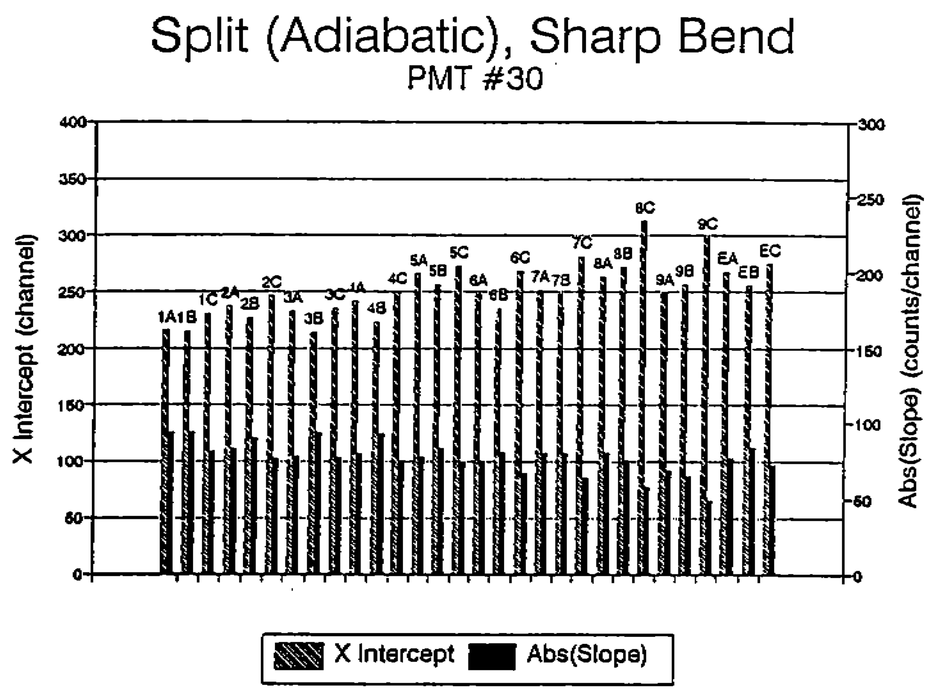


Figure 7.

Group D is not shown because it only contains three data sets (see Table 1).

Split (Adiabatic), Gradual Bend
PMT #42

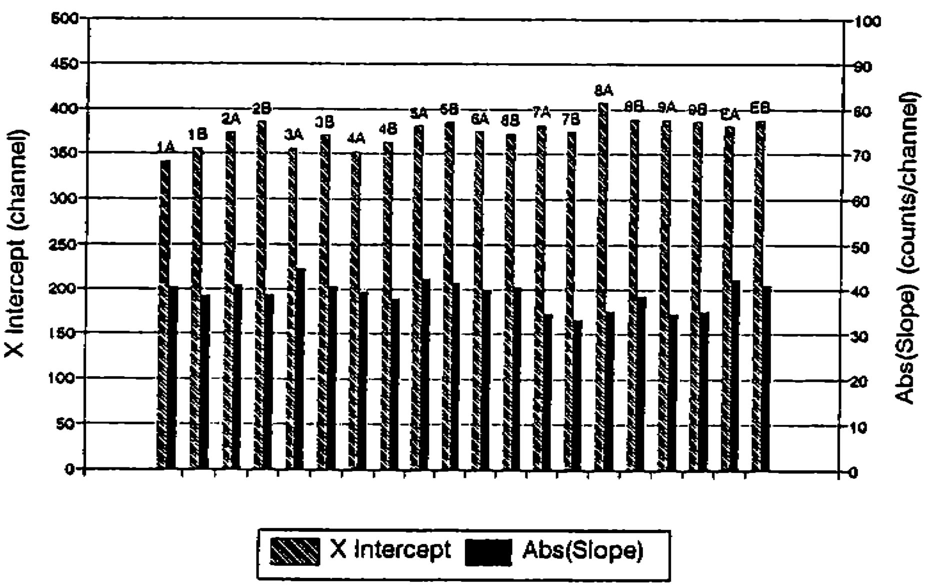


Figure 10.

Solid, Sharp Bend
PMT #42

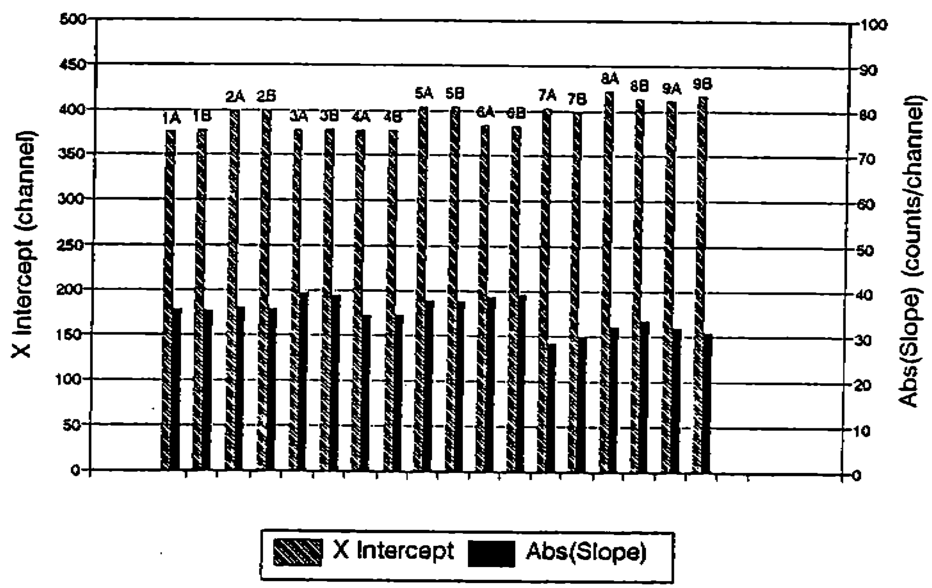


Figure 9.

Note: The X-intercept and slope scales on the following graphs are different from those for PMT #30.

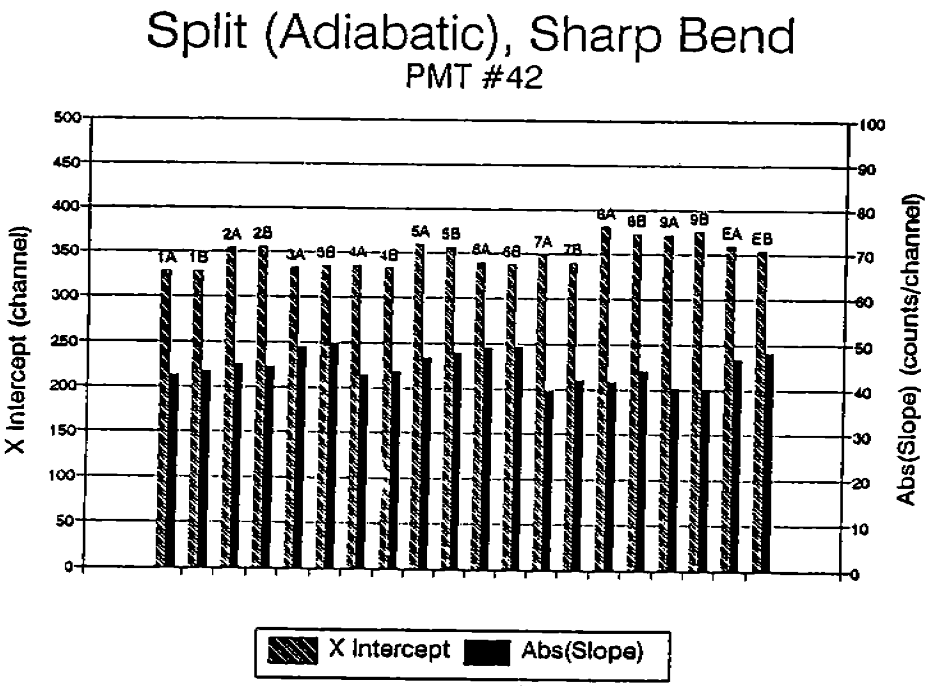


Figure 11.

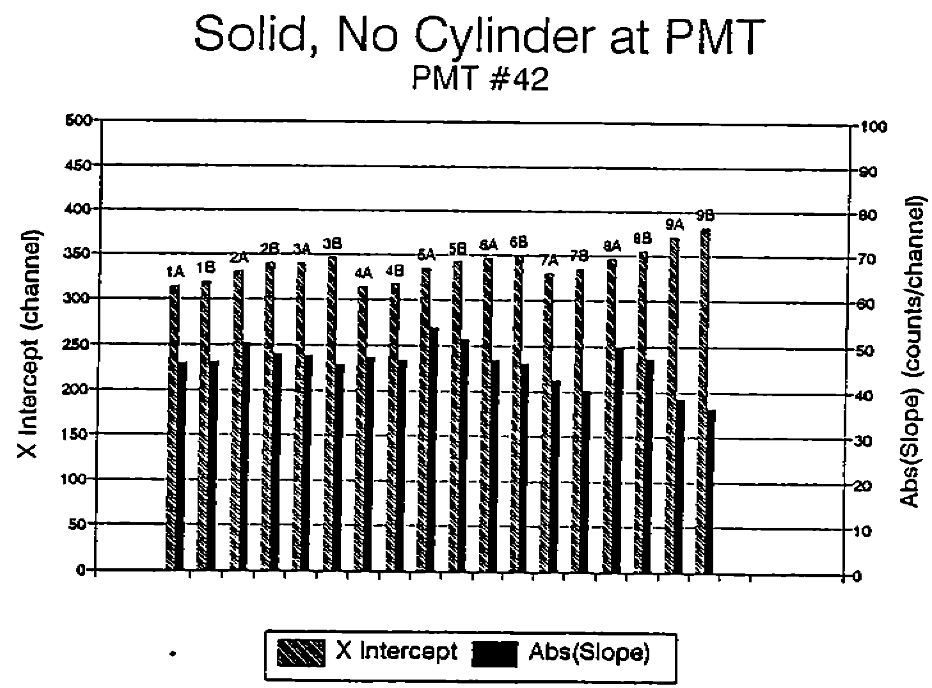


Figure 12.

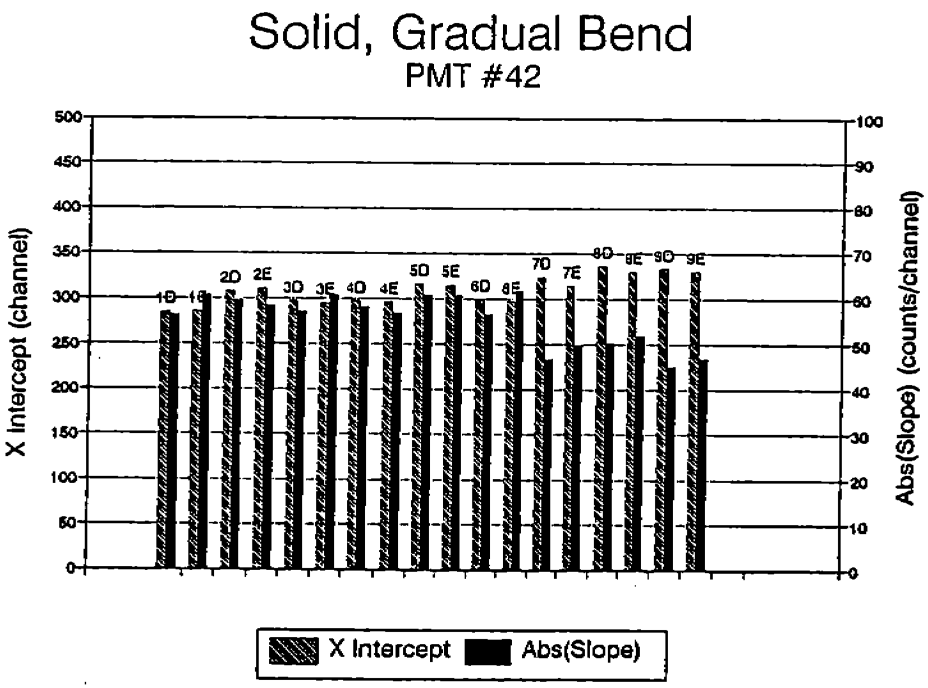


Figure 14.

These two additional data groups were taken after breaking and regluing this light guide. Group C is not shown because it only contains one data set (see Table 1).

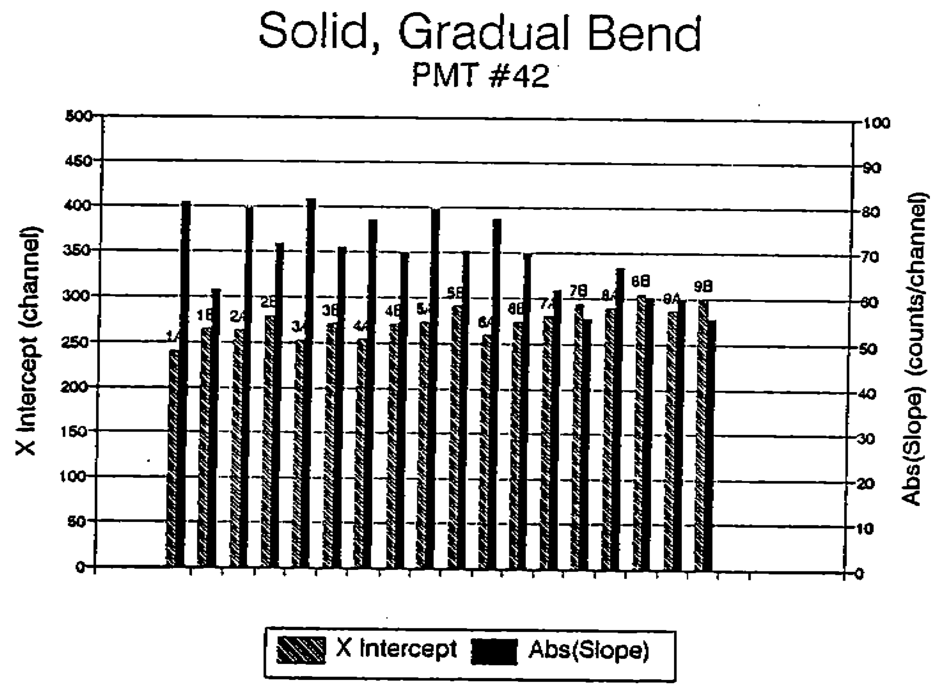


Figure 13.