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# HIGH QUALITY DOMESTIC ACRYLIC SCINTILLATOR AND WAVEBAR

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## INTRODUCTION

As the energies of modern accelerators have increased, calorimeters have become an increasingly important part of the detectors used in experiments. The statistical fluctuations which limit the inherent energy resolutions of these detectors become smaller as the energies of detected particles increases.

A major fraction of modern calorimeters have used light emitting materials (scintillators) and photomultiplier tubes to generate signals for processing. At low energy, the light emitted in a calorimeter limits the attainable energy resolution. For this reason, a premium has been paid for the amount of light emitted by the shower of a particle in the calorimeter. However, at high energies, the total light output has been less important and it has become possible to sacrifice light for other features; uniformity of response, ease of light collection, and cost as examples. In order to reduce cost, a number of acrylic (methyl methacrylate polymer) based materials have been developed by CERN with the chemical firm Röhm, GBMH Chemische Fabrik (Darmstadt, Germany). Until recently, these materials have not been available from domestic producers in the quality which has been achieved in Europe. We report here on materials which have been produced domestically by two fabricators and which are equal in quality to the Röhm product.

We will report on two characteristics of the new domestic acrylic scintillator. These are 1). Initial light output and 2). Reabsorption of light (as indicated by attenuation lengths measured in long test samples). All tests have been performed using the CERN formula for PLEXIPOP I (1% PPO, 0.01% POPOP, and 1% Naphthalene by weight).

In addition to the acrylic scintillator, one vendor has been asked to produce another doped acrylic material. This material, used as a 'wavebar' to collect light from primary scintillators and transport it to photomultiplier tubes, is doped with 90 mg/ℓ BBQ. This wavebar material can be used to reduce the number of photomultiplier tubes in an experiment or to transport light from otherwise inaccessible locations to photomultiplier tubes. We also report on the attenuation length of this material.

The two manufacturers referred to are Polycast Technology, Inc. of Stamford, Connecticut, and Polytech, Inc. of Owensville, Missouri. The latter produced the BBQ doped acrylic sheet.

## TEST SETUP

In all tests, a number of layers of ¼ inch thick scintillator material were viewed by an RCA 8055 photomultiplier (S-11 photocathode). Signals were collected when cosmic rays traversed these layers as indicated by a coincidence of two scintillation counters placed on opposite sides of the test sample. The two trigger counters extended past the test sample allowing simultaneous determination of the pedestal (no light output from the test sample). Anode signals from the 8055 were integrated and histogramed by standard electronic circuitry (LRS qVt 3001 module).

In all tests each layer of scintillator was separately wrapped in aluminum foil. All edges of scintillator were machined on the Fermilab Physics Department P4 diamond headed flycutter and no additional hand buffing of the edges was performed. All other surfaces were as received from the manufacturer except for removal of protective paper and a dry wipe to remove the residue from machining. No chemical solvents were applied.

Figure 1 indicates the test setup for each of the two tests performed on the acrylic scintillator. In the relative initial light output test, comparisons were made against a Pilot F sample. Pilot F scintillator has light output nominally 64% of anthracene and 107% of NE110. Particles entered each sample at 10 cm from the edge of the scintillator near the photomultiplier tube and no attenuation corrections were applied. In this test, all sides were covered with aluminum foil except the side facing the photomultiplier. In the attenuation length measurements, the trigger coincidence counters were moved to various positions along the long test samples (each ¼ X 4 X 100 inches³). The phototube and test sample remained in fixed positions. In no test was any special optical coupling applied between the photomultiplier and test strips. A small air gap always existed. In those tests where filters are indicated, Wratten filters were placed between the photomulitplier tube and the test scintillator with no added optical coupling.

Figure 2 indicates the test setup for determining the attenuation length of acrylic wavebar. Light from five pieces of Pilot F scintillator (total thickness = 1 3/8 inches) was directed into the wavebar at various positions along its length. Each scintillator was wrapped in black felt and no reflector was used. A small air gap was left between the scintillator and wavebar and photomultiplier as before. The back side and edges of the wavebar were covered with aluminum foil while the front face was left open along its entire length. The wavebar sample as ¼ X 4 X 100 inches³.

## DATA

A typical distribution of data is presented in Figure 3. The lower peak is that for particles which pass through the trigger counters but completely miss the test sample. The higher peak is due to light from the test sample itself.

The raw data for relative light output are given in Table I for the acrylic scintillator. We report the pedestal subtracted channel of the peak of the distribution and channels of the half peak values of the distribution. From the lower half height location, we calculate a nominal number of photoelectrons, N defined as:

$$N = \left[\frac{2(\text{peak - half height})}{2.36\ \text{peak}}\right]^{-2}$$

We scale this number for thickness and quote all numbers per 3/8 inch thickness. Although it is not as precise a measurement, it is an indication of the reliability of the data and provides a number which can be used to estimate the photostatistical contribution to the resolution of a particular calorimeter design. In principle, the number N, should scale as the peak location. Such a scaling is given in the last column.

We repeat this format in reporting the raw attenuation data in Table II. However, Table II is divided into six sections, one each for strips with blackened far ends from each manufacturer, one each for strips with aluminum foil at the far ends from each manufacturer, and one each for Polytech strips with Wratten 2E and 4 filters between scintillator and photomultiplier tube. The data is also graphed in Figure 4.

Table III and Figure 5 present similar data for the wavebar material.

RESULTS

The relative light outputs for a near position of the domestic products can be compared against a sample received directly from Röhm. The attenuation length results for long samples are compared to a description of the Röhm product given by W. Kienzle, et al.[1] for their samples. Table 1 in their report indicates a relative light output for Plexipop I of 21% of NE110 (corresponding to 20% of Pilot F, nominally). The attenuation length is reported as 2.0m without filtering the light to the photomultiplier tube and 2.8m when a filter with a cutoff of 4350 A was used.[2]

In order to be quantitative, our data were fit to an attenuation curve described by a single exponential. As can be seen in Figure 4, some of the data is not well fit by such a single exponential. In order to help in comparisons with data from CERN, fits were obtained over a number of ranges. The results of the fits as well as the fitting function are given in Table IV.

CONCLUSIONS

In absolute light output, the two domestic samples compare closely to the

European sample. The values relative to Pilot F (or NE110 by extrapolation) are larger than quoted by Kienzle, et al. However, we do not attach any particular significance to this. The Pilot F samples are of unknown origin and were used only to monitor the stability of the test results. We, as Kienzle, et al. quote 10% uncertainties on the results based on their reproducibility. One additional measure of relative light output can be obtained by comparing $N_0$, the extrapolations of the attenuation formulae to zero length. In these values, we do not see much difference between the two domestic products. It should be noted that these extrapolations are a factor of two lower than the direct measurement of photostatistics. This is due to the differences in geometry and contribution of very short wavelength light.

The attenuation length data are difficult to compare because of differences in geometry, surface quality, and other details.[3] Nevertheless, the tests of Kienzle, et al. compare most directly with our fits for the range (0.5 to 2.0) meters. Since they appear to have corrected for the reflector at the far end, their attenuation lengths should be compared to our values obtained with the blackened far end. In comparison, the domestic product seems to be at least as good as the results reported from CERN.

The conclusion of these comparisons is that the currently available domestic production of acrylic scintillator matches the products available in Europe. The samples taken for testing were selected at random from a much larger order (30 sheets of 4 X 8 $feet^2$ material from each manufacturer). We have some reason to believe, therefore, that quality control can result in reproducible and high quality production. It is our experience that this is a recent achievement domestically.

Perhaps the most striking result in this work is the very long attenuation length attainable with filtering - as much as 16m when a #4 Wratten filter is used. However, this requires a serious loss of light. There is factor of nearly 3.5 loss of light even at the far end of our 2.5m samples. For a smaller loss of light ( a reduction of 25% at the far end), a Wratten #2E filter gives attenuation lengths approaching five meters.

TABLE I

RELATIVE LIGHT OUTPUT

| Material | Channel Number | | | N per 3/8 Inch | |
|---|---|---|---|---|---|
| | Peak | ½ Height$_{lo}$ | ½ Height$_{hi}$ | Calculated | 1.0 X Peak |
| Pilot F | 100 | 89½ | 121 | 47½ | 100 |
| Polycast Material | 26 | 22 | 31½ | 22 | 26 |
| Polytech Material | 22 | 19 | 27¼ | 28 | 22 |
| Rőhm Material | 26 | 22 | 31½ | 22 | 26 |

TABLE II

RAW ATTENUATION LENGTH DATA

A). Blackened Far End, Polycast Material

| Distance From PM | Channel Number | | | N per 3/8 Inch | |
|---|---|---|---|---|---|
| (Inches) | Peak | ½ Height$_{lo}$ | ½ Height$_{hi}$ | Calculated | 0.25 X Peak |
| 19½ | 37 | 31 | 44 | 13 | 9 |
| 33½ | 31½ | 25 | 39¼ | 8 | 8 |
| 47½ | 27 | 21¼ | 34½ | 7½ | 7 |
| 61½ | 24 | 18 | 32 | 6 | 6 |
| 75½ | 20 3/4 | 15 3/4 | 27½ | 6 | 5 |
| 89½ | 18 3/4 | 14½ | 24¼ | 6 | 4½ |

TABLE II (CONT.)

B). Blackened Far End, Polytech Material

| Distance From PM | Channel Number | | | N per 3/8 Inch | |
|---|---|---|---|---|---|
| (Inches) | Peak | ½ Height$_{lo}$ | ½ Height$_{hi}$ | Calculated | 0.25 X Peak |
| 19½ | 33 | 25½ | 42 | 8 | 8 |
| 33½ | 26½ | 19½ | 35 | 6 | 6½ |
| 47½ | 22 | 16 | 27 | 5½ | 5½ |
| 61½ | 19½ | 14 | 26 | 5 | 5 |
| 75½ | 18 | 12½ | 23½ | 4½ | 4½ |
| 89½ | 16½ | 11 | 22 | 4 | 4 |
| **C). Aluminum Foil Far End, Polycast Material** | | | | | |
| 19½ | 39¼ | 31 3/4 | 52½ | 9½ | 10 |
| 33½ | 36¼ | 30 | 46 3/4 | 11½ | 9 |
| 47½ | 33 | 26¼ | 41¼ | 8 | 8 |
| 61½ | 29¼ | 23¼ | 37½ | 8 | 7½ |
| 75½ | 26¼ | 20 3/4 | 35 | 8 | 6½ |
| 89½ | 26¼ | 21¼ | 34½ | 9½ | 6½ |
| **D). Aluminum Foil Far End, Polytech Material** | | | | | |
| 19½ | 29½ | 31¼ | 51¼ | 9½ | 10 |
| 33½ | 33 | 26 | 40 | 9½ | 8 |
| 47½ | 28¼ | 22 | 38 | 8½ | 7 |
| 61½ | 27 | 20½ | 36 | 7 | 7 |
| 75½ | 24½ | 17½ | 31 | 5 | 6 |
| 89½ | 25 | 19 | 33 | 7 | 6 |

TABLE II (CONT.)

E). Wratten 2E Filter Between Polytech Material And Photomultiplier Tube

| Distance From PM | Channel Number | | | N per 3/8 Inch | |
|---|---|---|---|---|---|
| (inches) | Peak | ½ Height$_{lo}$ | ½ Height$_{hi}$ | Calculated | 0.25 X Peak |
| 10 | 35 | 28 | - | 10½ | 8 3/4 |
| 20 | 34 | 27¼ | - | 10½ | 8½ |
| 34 | 30½ | 23½ | - | 8 | 7½ |
| 62 | 26 | 19 | - | 5 3/4 | 6½ |
| 90 | 24 | 16 3/4 | - | 4½ | 6 |
| F). Wratten 4 Filter Between Polytech Material and Photomultiplier Tube | | | | | |
| 20 | 8¼ | 4½ | 16½ | 2 | 2 |
| 34 | 7½ | 4½ | 12 | 2½ | 1 3/4 |
| 62 | 7½ | 3 3/4 | 12½ | 1 3/4 | 1 3/4 |
| 76 | 7½ | 3½ | 11½ | 1½ | 1 3/4 |
| 90 | 7¼ | 3½ | 13 | 1½ | 1 3/4 |

TABLE III

WAVEBAR ATTENUATION LENGTH DATA

| Distance From PM | Channel Number | | | N Per 1 3/8 Inch | |
|---|---|---|---|---|---|
| (Inches) | Peak | ½ Height$_{lo}$ | ½ Height$_{hi}$ | Calculated | .45 X Peak |
| 15½ | 31.7 | 21.9 | - | 14½ | 14¼ |
| 27½ | 26.5 | 14.6 | - | 7 | 12 |
| 39½ | 22.5 | 14.4 | - | 10 3/4 | 10 |
| 51½ | 18.6 | 10.5 | - | 7¼ | 8¼ |

TABLE IV

ATTENUATION LENGTH FIT PARAMETERS

| Material | Attenuation Formula $N_0 e^{-x/\lambda}$ | | | | | |
|---|---|---|---|---|---|---|
| | Range: (0.5 - 1.5)m | | Range: (0.5 - 2.0)m | | Range: (0.5 - 2.3)m | |
| | $N_0$ | $\lambda$(m) | $N_0$ | $\lambda$(m) | $N_0$ | $\lambda$(m) |
| Polycast, Black @ Far End | 11.2 | 2.5 | 11.2 | 2.5 | 11.1 | 2.5 |
| Polycast, Al @ Far End | 11.3 | 3.7 | 11.4 | 3.6 | 11.1 | 4.0 |
| Polytech, Black @ Far End | 11.9 | 1.9 | 10.2 | 2.1 | 10.0 | 2.3 |
| Polytech, Al @ Far End | 10.6 | 2.5 | 11.5 | 2.8 | 11.1 | 3.3 |
| Polytech, Wratten #2E Filter | 9.4 | 4.3 | - | - | 9.2 | 4.9 |
| Polytech, Wratten #4 Filter | 2.1 | 12.5 | - | - | 2.1 | 15.8 |
| Polytech Wavebar | 39.8 | 1.7 | | | | |

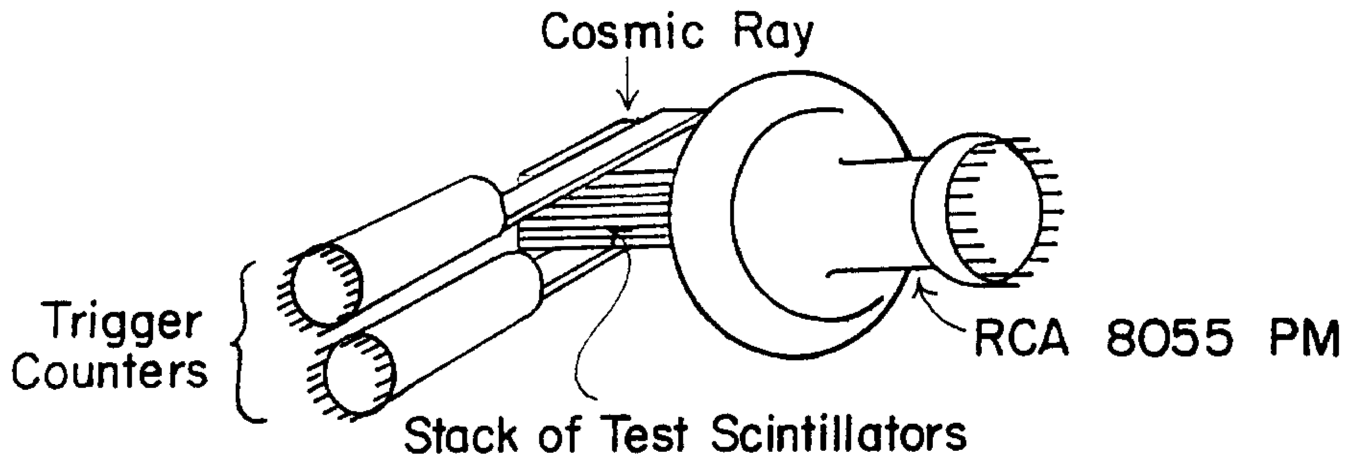


Fig. 1a

ABSOLUTE LIGHT TEST SETUP

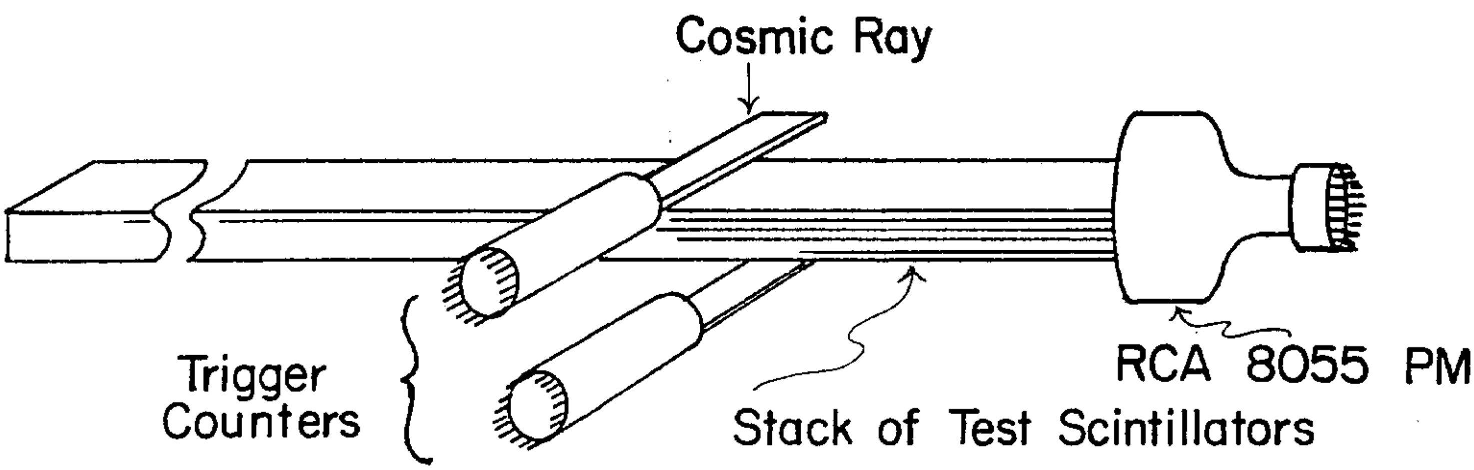


Fig. 1b

ATTENUATION TEST SETUP

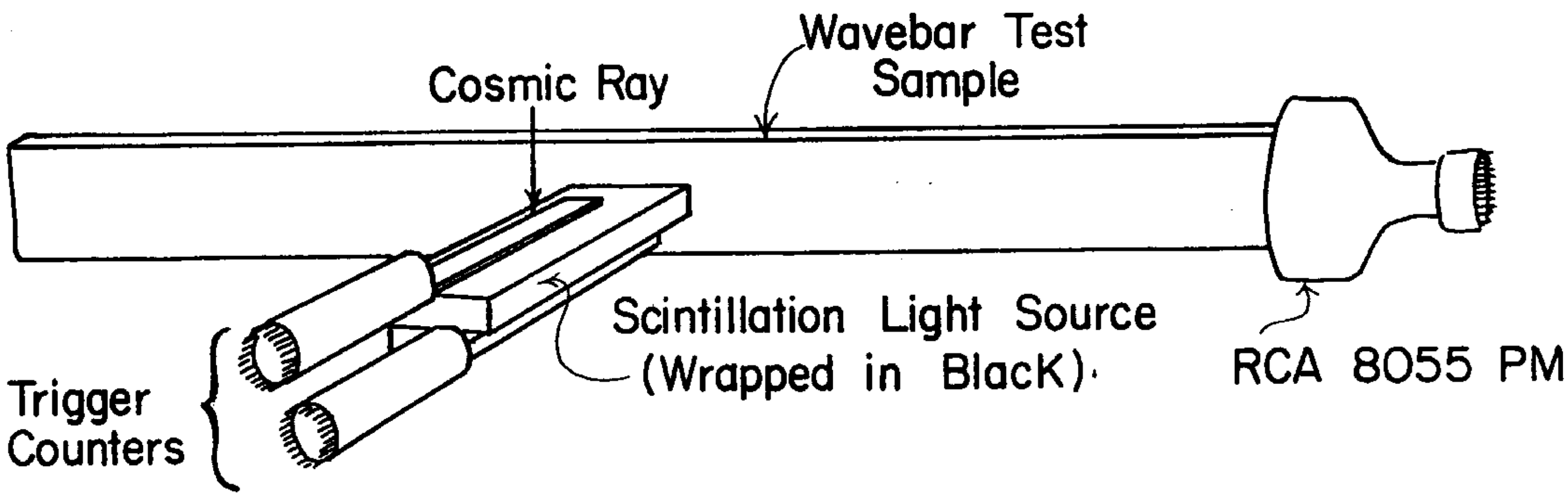


Fig. 2

SCHEMATIC DRAWING OF WAVEBAR TEST SETUP

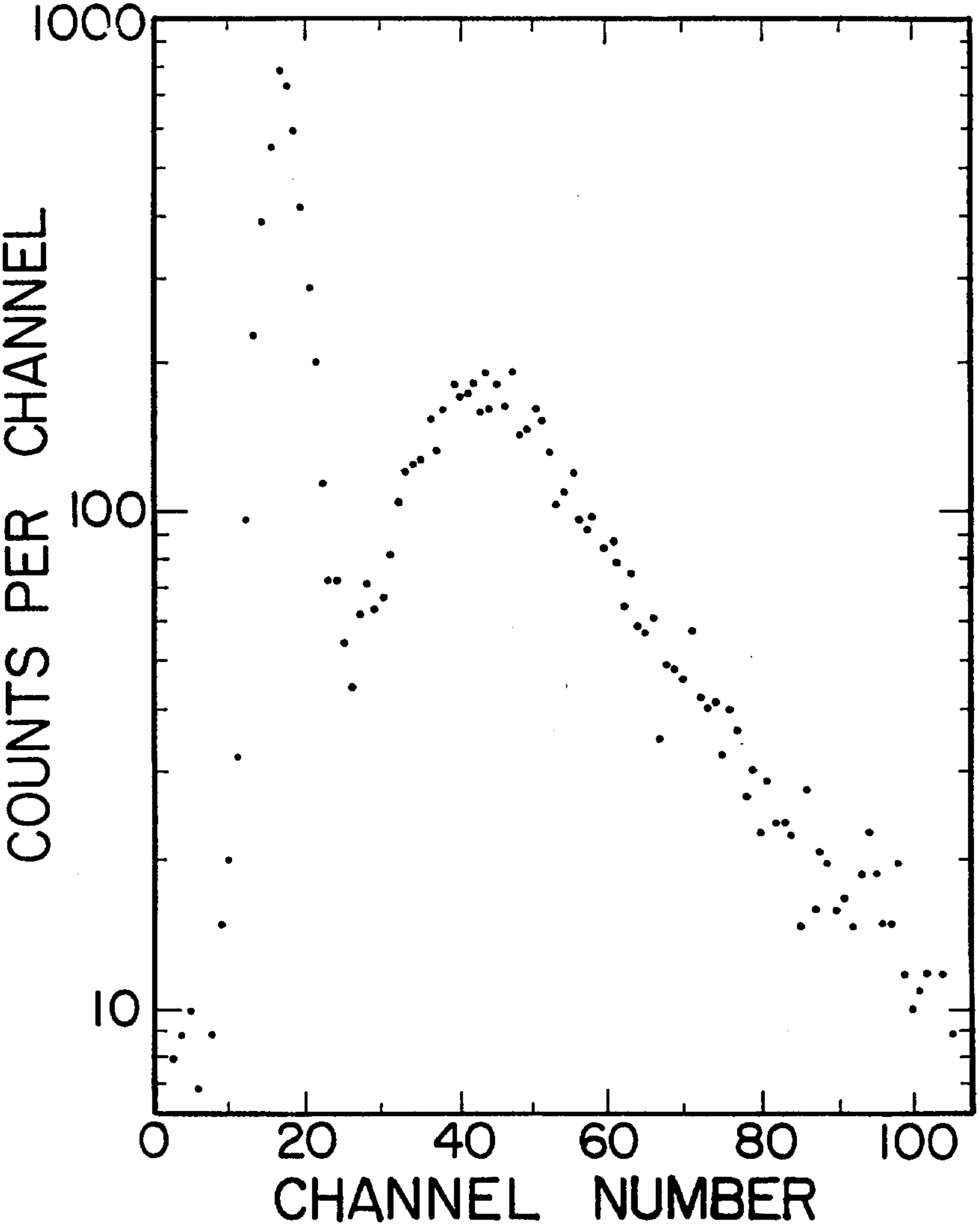


Figure 3. TYPICAL DATA

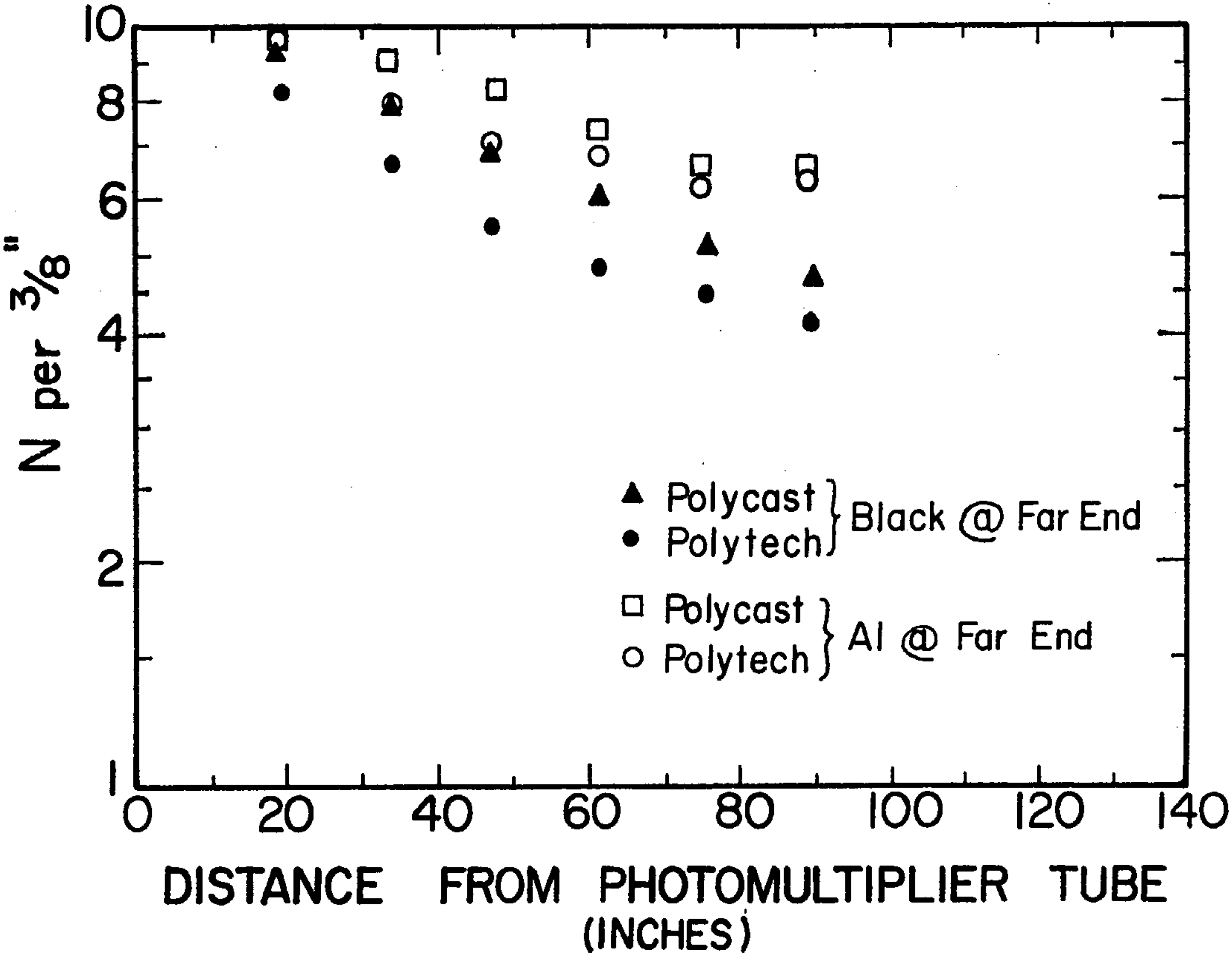


Figure 4a. ATTENUATION IN SCINTILLATOR

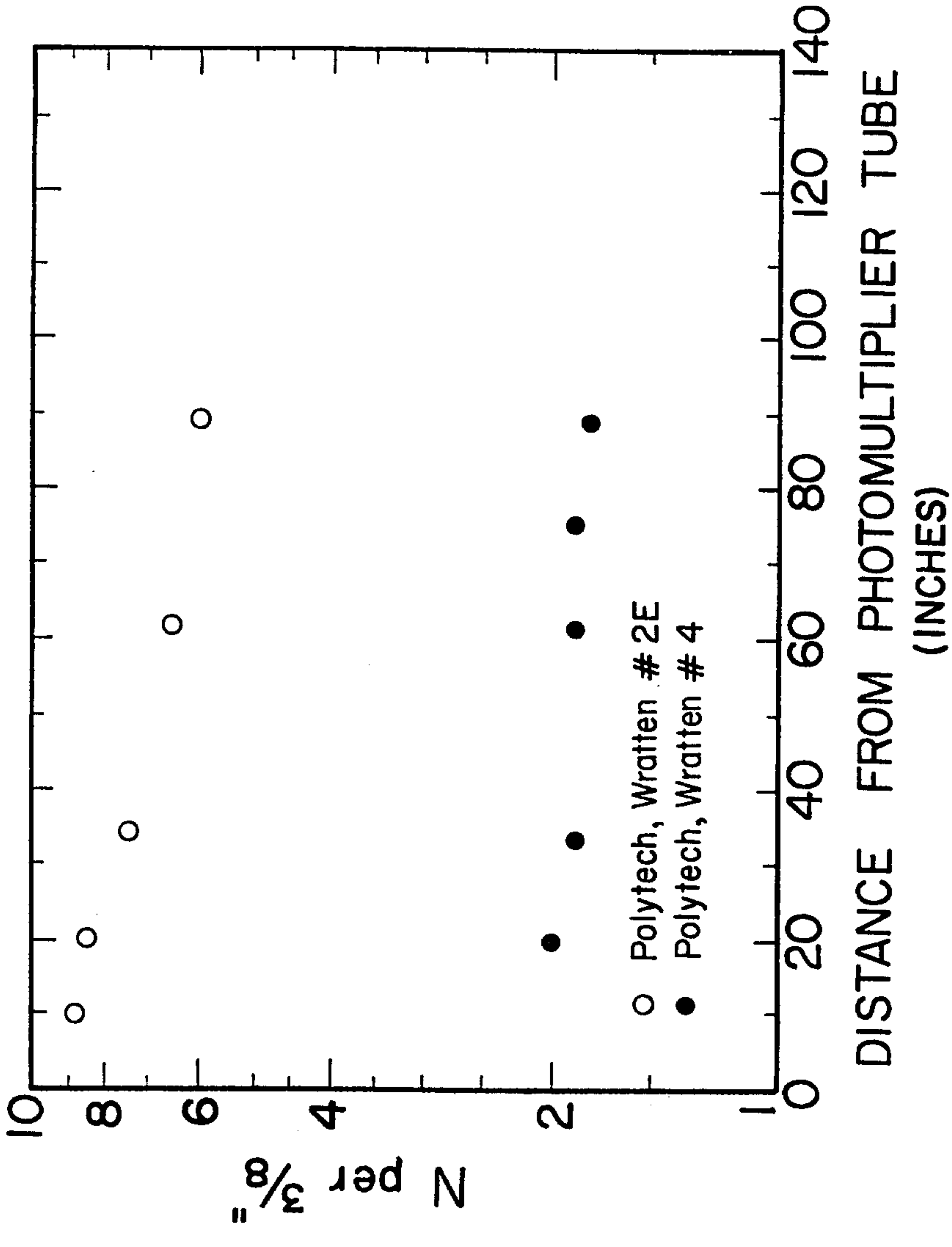


Figure 4b. ATTENUATION IN SCINTILLATOR

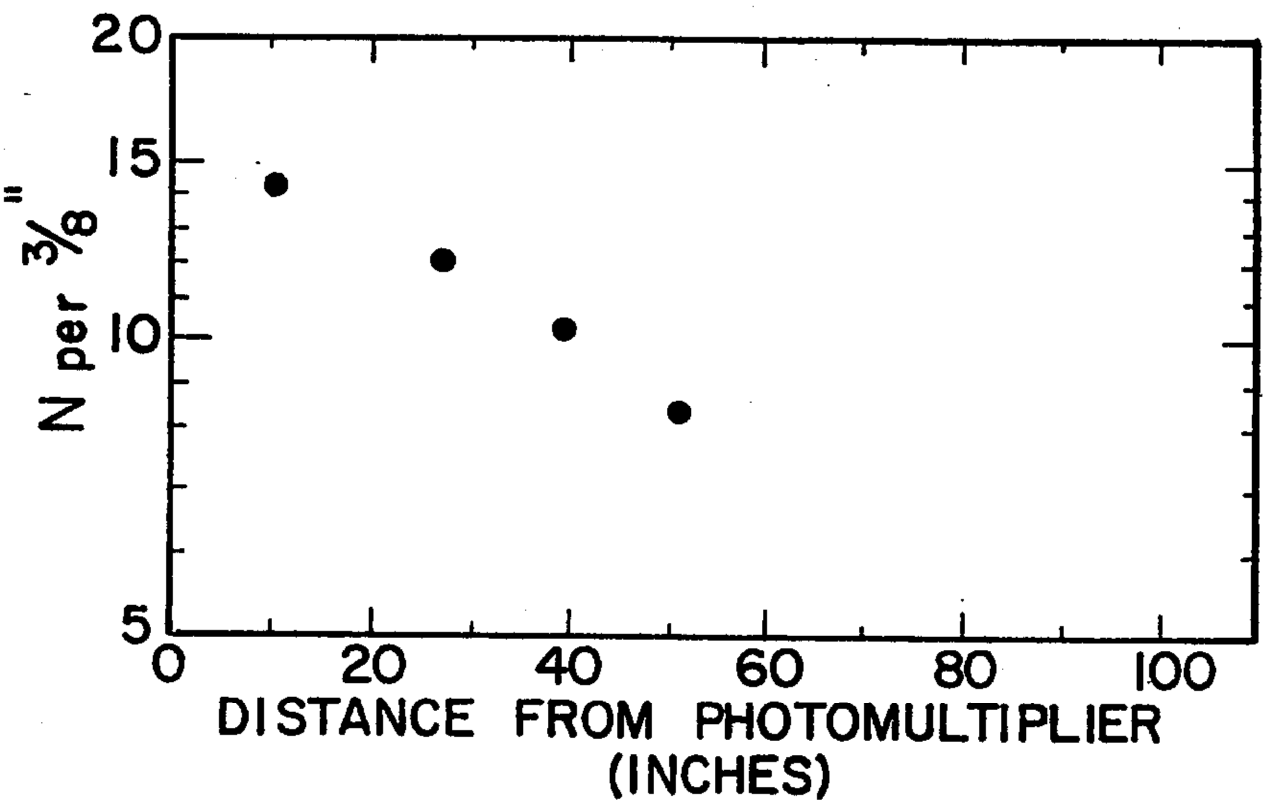


Figure 5. ATTENUATION IN WAVEBAR

## FOOTNOTES

[1] W. Kienzle, G. Matthiae, R. Vanderhagen, S. Weisz, and S. Burgun, "Scintillator Developments at CERN", NP Internal Report 75-12, October 6, 1975.

[2] The attenuation length values are obtained by setting the mirror reflectivity = 1; a more realistic value is probably 0.9, for which all the values of $\lambda$ must be increased by $\sim$ 10%.

[3] In other tests (not reported here), six inch wide samples from Polytech gave attenuation lengths of three meters for the shortest range and five meters for the longest range (with aluminum foil as a far end reflector). Kienzle, et al. were using samples approximately twice as thick as our and use an acrylic light guide.