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A NEW SCINTILLATOR AND WAVELENGTH SHIFTER

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ABSTRACT

We have developed a new type of scintillator and a wavelength shifter to be used for high energy particle calorimeters. To obtain a long attenuation length, two kinds of fluors are mixed in a polystyrene base. The wavelength shifter has a new material matching its absorption spectrum to the wavelength of the scintillation light. Their common characteristics are a relatively high light output and a long attenuation length with a reasonable cost.

1. INTRODUCTION

In high energy physics, the calorimetric method for particle identification and energy measurement becomes more important as the energy of the particles increases. Calorimeters to be used for experiments, in particular for collider experiments, often require the use of a large amount of scintillator. Inexpensive acrylic and polystyrene scintillators have been developed at the request of the CERN proton-antiproton collider experiment UA1.[1),2)]

In this paper we describe a new type of polystyrene scintillator and a wavelength shifter which have been developed primarily for the electromagnetic shower calorimeter for the proton-antiproton Collider Detector Facility at Fermilab.[3)] The shower calorimeter employs a scheme of lead-scintillator arrays where the light from scintillator is wavelength converted by wavelength shifters placed at the edges of scintillators, and transmitted to photomultipliers through light guides.[4)]

Important properties which are relevant to the energy resolution of a lead-scintillator shower calorimeter are the light yield and the attenuation length of the scintillator. A greater light output from the scintillator gives less fluctuation, and a longer attenuation length results in a more uniform sensitivity. The primary scintillation light from the base resin of the scintillator is ultraviolet, while the spectral transmittance of the resin increases with wavelength in the region where the ordinary fluorescent materials have their emmission peaks. This consideration suggests that an improvement of the scintillator can be made by converting shorter wavelength components to longer wavelength.

For the scintillator-waveshifter scheme, this means one needs a waveshifter whose absorption spectra has a peak at a longer wavelength than that of conventional ones, e.g. BBQ.

According to this basic consideration, we have developed a new scintillator-waveshifter system which is more favorable than the previously considered extruded polystyrene scintillator, KSTI-390 coupled with BBQ.[5)]

The improvement of the light output and the attenuation length of the scintillator has been achieved practically by mixing two fluors into a polystyrene base. The primary ultraviolet light emitted by the base is wavelength shifted by the first fluor to a longer wavelength (about 360 nm at the emission peak), which in turn is converted into a still longer wavelength (about 430 nm) by the secondary fluor. The chemicals of the first kind we have tried are b-PBD, DPO and P-TP, while those of the second kind are BBOT, POPOP, bis-MSB and BDB.

The scintillator adopted is one of modified polystyrene scintillators; some optical and mechanical properties and durability have been reported by T. Inagaki et al.[6)] The characteristics of the scintillator are summarized as follows:

(a) similar performance to NE 110 in light output, radiation resistance and decay time,

(b) comparable mechanical properties to plexipop.

Measurements on light output and attenuation length were made on samples of scintillators with different fluorescent chemicals with various concentrations, and the most suitable one for our purpose was selected. We obtained the rusult that both attenuation length and light output represent a significant improvement over previous optimal materials.[5)]

To make a waveshifter which matches a longer wavelength of light from the new scintillator, a chemical which is commercially called "Y-7" was put into an acrylic base. The Y-7 converts the scintillation light of about 430 nm wavelength into green light of about 490 nm wavelength. The attenuation length and the conversion efficiency of a 3 mm thick Y-7 waveshifter have been measured for different concentrations of Y-7 to obtain the optimum.

In Sec. 2 of this paper we describe the light yeild of various samples of scintillators with different combinations and concentrations of the first and second kind of fluors. In Sec. 3, the optical properties relevant for application to calorimeters are discussed on the selected sample of the scintillator. The properties of wavelength shifter Y-7 are described in Sec. 4. A conclusion is given in Sec. 5.

2. LIGHT YIELD IN SCINTILLATOR

Samples of scontillator with two fluors with different species and concentration were prepared. The fluor of the first kind was chosen from b-PBD, DPO and P-TP, and that of the second kind from BBOT, POPOP, bis-MSB and BDB.

A typical example of the absorption and emission spectra of the two kinds of solute are shown in Fig. 1. It is evident from the figure that the emission band of the primary fluor b-PBD matches the absorption band of the secondary fluor BDB.

The concentration of the primary fluor is 0.5 ∿ 3.0%, while that of the secondary fluor is 0.01 ∿ 0.03%. The range of concentration was chosen on the basis of measurements of the light-absorption coefficient of these materials. The concentration of the secondary fluor is small, but it is effective enough to convert light from the primary fluor. For example, the polystyrene with 0.02% BDB has an estimated absorption length less than 30 μm for light with wavelength 350 nm.

The light output from samples with different chemicals and concentration was measured and is listed in Table 1. The measurement was made by using a photomultiplier tube R329 (Hamamatsu) and an α-ray source $^{241}_{95}Am$. The size of each sample was 90 × 100 × 10 mm^3. The sample was attached flat to the head of the phototube and the α-ray source was set on the surface of the sample.

The measured light yield from various samples was normalized to that from a reference piece of NE 110. For a few kinds of scintillator with high light output, SCSN-28, 31, 38, 56, 57, and

58, we measured the attenuation and found no significant difference. Considering that the cost of the scintillator is primarily determined by the amount of the primary fluor, we selected SCSN-38 as the best candidate for our shower calorimeter.

3. SCINTILLATOR SCSN-38

3.1. Optical properties

The attenuation length of the new scintillator SCSN-38 (1% buthyl-PBD and 0.02% BDB in polystyrene base) was measured with the setup shown in Fig. 2. The photomultiplier and the radioactive source were R329 (Hamamatsu), and ^{106}Ru (β-ray source), respectively. Each sample sheet in the test had the dimensions $500 \times 50 \times 6$ mm^3 and was well polished on the edges and was wrapped with aluminum foil. The edge facing the waveshifter is optically open, while the opposite edge is blackened in order to prevent reflection. To obtain the light output from the test material, a neutral density filter was inserted between the waveshifter and the photomultiplier, and the photoelectron yeild was estimated by carefully measuring the counting inefficiency. As a reference material, a scintillator from KSH(KSTI-390) was tested in the same setup.

Each sample of the waveshifter "Y-7", whose size is $400 \times 50 \times 3$ mm^3, was wrapped with aluminum foil. The scintillator was attached to a window in the foil with a small air gap. A light guide ($400 \times 50 \times 3$ mm^3) and the waveshifter were attached with an optical cement. As a reference waveshifter material, we used BBQ in acrylic base (90 mg/l). The emission and absorption spectra of the Y-7 and BBQ are shown in Fig. 1 and Fig. 3, respectively.

The results of the measurements of the attenuation lengths are shown in Fig. 4 and Table 2.

3.2. Edge effect

When the β-ray source is placed very close to the edge of the waveshifter side, we observe an edge effect, a rise of light yield with an attenuation length of a few centimeters. The edge effect is more pronounced in SCSN-38 than in the KSTI-390. As shown in Fig. 5 the light output increases considerably within about 5 cm.

To prevent this effect, we wrapped the scintillator near the edge facing the waveshifter with a black tape, leaving a thin air gap (Fig. 6). The width of the tape was 1 cm, 2 cm, or 3 cm. The measured attenuation curves are shown in Fig. 7. As one notices from the figure, the optimum width of the black tape to get a smooth attenuation curve was 1 cm.

3.3. Uniformity of Scintillator Plates

To achieve a uniform sensitivity over the whole volume of a large scale calorimeter in the collider detector, good uniformity is required for thickness and optical properties of the scintillator plates. The new type of scintillator described in this paper is molded by casting rather than extrusion, so that a cross-link molecular structure is kept and mechanical strength maintained.[6] Casting, however, is less advantageous for obtaining good uniformity in thickness. Thus, a careful control has been required to keep the gap widths of casting boards uniform in the production process.

The scintillator plates produced with the present casting device have a size of 2700×1900 mm^2. To examine the thickness distribution over this size of plates, a plate with nominal thickness 6 mm was cast and 14 pieces of 60×60 mm^2 were cut from various parts of the plate as shown in Fig. 8. Thickness was measured with a micrometer. The average thickness was 5.977 mm with a standard deviation of 4.8×10^{-2} mm.

The light output of these 14 pieces of scintillator was measured with a procedure as described in the preceeding section. To minimize errors in the measurement, the pieces of scintillator were mounted on a special jig equipped with a neutral density filter, a phototube, and a trigger system. Fig. 9 shows the light output measured for scintillator pieces of various thickness. One observes the thickness dependence of the light yield; a linear fit is given by

$$y = (0.118 \pm 0.040)x + (0.031 \pm 0.241),$$

where y is the number of photoelectrons and x is the thickness of the scintillator in mm.

The error in the measurement of light output comes from missetting of samples, instability of the photomultiplier, chemical non-uniformity and statistics. An upper limit of the chemical non-uniformity σ_{chem} is given by the relation,

$$\sigma^2_{chem} \leq \sigma^{cor^2}_{tot} - \sigma^2_{stat},$$

where σ^{cor}_{tot} is the standard deviaiton of the light output from pieces corrected for thickness;

$$\sigma^{cor}_{tot} = \frac{1}{y_0}\sqrt{\frac{\Sigma(y(x_i) - y_i)^2}{14 - 2}} = 0.935\%,$$

where y_0 is the average of the light outputs.

The statistical error for photon counting σ_{stat} is typically 0.41%, hence the upper limit of chemical non-uniformity σ_{chem} is 0.86%. In other words, chemical non-uniformity of the scintillator was not observed to an accuracy of 0.86%.

4. WAVE LENGTH SHIFTER Y-7

The new waveshifter is made of acrylic plate doped with a fluorescent material commercially called "Y-7". The absorption and emission spectra of the Y-7 together with those of BDB are shown in Fig. 1. The figure shows that the absorption spectrum matches the emission spectrum of BDB, the secondary fluor in the scintillator SCSN-38. Table 2 shows a comparison of the light yield of the scintillator-shifter combinations SCSN-38 and Y-7, SCSN-38 and BBQ, KSH and Y-7, and KSH and BBQ. The light output given in the table shows the excellent matching of Y-7 to SCSN-38.

Measurements were made on the attenuation length of a sheet of the Y-7 shifter with a size of $3 \times 50 \times 500$ mm^3 in the scintillator-shifter configuration. The arrangement for the measurement is shown in Fig. 10. The set up is essentially the same as that described in Sec. 3. (Fig. 4), except that the attenuation in the wave shifter was measured by moving the scintillator along the waveshifter. Fig. 11 shows typical attenuation curves for waveshifters, Y-7 and BBQ. The attenuation of the Y-7 and BBQ samples are similar and as expected for such pieces of acrylic.

Dependence of light output and attenuation length of 3 mm thick waveshifter on the concentraiton of Y-7 is shown in Fig. 12 and Fig. 13. The concentrations of samples were 0, 5, 10, 20, 30, and 40 ppm. The absorption length of Y-7 for light with the wavelength of 460 nm is 5.95 mm for 10 ppm. The saturation of the light yield with concentration as observed in Fig. 12 is consistent with this absorption length, if the reflection from the aluminum foil is taken into account. We selected a concentration of 30 ppm for our shower calorimeter.

To reduce the sensitivity of the waveshifter pieces to Cerenkov radiation from high energy particles passing directly through them, the waveshifter pieces can be made with a UV absorbing acrylic base. We have found no singificant degradation of the light yield or attenuation of Y-7 pieces with UV absorbing base.

5. CONCLUSION

This study was aimed to obtain a low cost and high light output shower counter with a uniform sensitivity using the scintillator-waveshifter technique.

We have obtained a sheme using a two fluor polystyrene scintillator with a long attenuation length and high light output coupled to an acrylic wavelength shifter with Y-7. The combined characteristics are more favorable than an acrylic scintillator or the polystyrene scintillator previously selected coupled to acrylic doped with BBQ.

AKNOWLEDGEMENTS

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TABLE CAPTIONS

Table 1. Fluorescent components in the scintillator SCSN series and the light output. The light output is normalized to that of NE110. The error of the measured value of the light output is typically less than ± 2%.

Table 2. Performance list of the scintillators (SCSN-38 and KSH) combined with two kinds of waveshifter Y-7 and BBQ.

REFERENCES

1). C. Aurouet et al, N.I.M. 169 (1980) 57.

2). J. C. Thevenin et al, N.I.M. 169 (1980) 53.

3). Design Report for the Fermilab Collider Detecter Facility, August, 1981, Fermilab internal note CDF-111.

4). W.B. Atwood, et al. SLAC TN-76-7 (1976).

5). B. Kustom et al, Fermilab internal note CDF-67 1980 (unpublished); L. Nodulman et al, ANL-HEP-PR-82-04, to be published in Nucl. Instr. & Meth. in Physics Research (1982).

6). T. Inagaki et al, KEK Preprint 81-18 Nov. 1981 I.

FIGURE CAPTIONS

Fig. 1. Absorption and re-emission spectra of typical fluorescent solutes, b-PBD, BDB and Y-7. The wavelengths for maximum emission are 366, 430 and 490 nm, while those for maximum absorption are 305, 430, and 460 (and 437) nm, for b-PBD, BDB and Y-7, respectively.

Fig. 2. Experimental setup for the attenuation test. The waveshifter (WLS) and the light guide are connected by an optical cement. Both are wrapped with aluminum foil. The other edge of the WLS is blackened. One side of the scintillator is attached to WLS bar with an air gap, while other is blackened to prevent reflection. The gain of the amplifier is 20 dB. A neutral density filter is set between the light guide and a photomultiplier PMT1, to attenuate the light quantity in half.

Fig. 3. Absorption and re-emission spectra for BBQ.[4)] The re-emission and absorption peaks are at 480 nm and 420 nm.

Fig. 4. Attenuation curves of scintillators. Experimental setup is shown in Fig. 2.

Fig. 5. A typical attenuation curve of SCSN-38. The curve is drawn by fitting the data to a function $F(x)= A_1\exp(-x/L_1) + A_2\exp(-x/L_2)$: where $A_1= 130$, $L_1 = 1.31$ cm, $A_2 = 105$, $L_2 = 97.0$ cm.

Fig. 6. A black tape remedy for the edge effect. The side edge near the waveshifter is wrapped with a black tape, while the other part of the scintillator is wrapped with aluminum foil.

Fig. 7. Edge effect of SCSN-38. At distances beyond 5 cm, the light output of three samples with different width of black tape coincide within the systematic error ($\lesssim 10\%$). The marks of ⊛ , ◐ , and ○ within 5 cm correspond to no tape, 1 cm wide tape, and 3 cm wide tape, respectively.

Fig. 8. Sampling figure for uniformity test. The circles with numbers indicate places where samples were cut.

Fig. 9. Thickness dependence of light output for SCSN-38 with a nominal thickness of 6 mm. The virtical error bars show 1 standard deviation of counting statistics, while the horizontal bars indicate errors in the thickness measurement. A fit is made to a strainght line, $y(x) = \alpha x + \beta$, with $\alpha = 0.118 \pm 0.040$, and $\beta = 0.031 \pm 0.241$.

Fig. 10. Experimental setup for the attenuation test of a waveshifters. The gain of the amplifier is 20 dB.

Fig. 11. Attenuation curves of waveshifters. The abscissa shows the distance of the scintillator from the photomultiplier PMT1 (See Fig. 10).

Fig. 12. Concentration dependence for light output from Y-7. The experimental setup is shown in Fig. 10. Marks of

○, △, X, □, ⊛, and ▲ correspond to the light output measured at 5 cm, 10 cm, 20 cm, 30 cm, 40 cm, and 45 cm from the junction point with the light guide, respectively. Curves are drawn to guide the eye.

Fig. 13. Concentration dependence of the attenuation length. The solid line and dotted line correspond to samples with dimensions of $500 \times 50 \times 3\ mm^3$ and $1000 \times 50 \times 3\ mm^3$, respectively. The samples are wrapped with aluminum foil with the end blackened. Experimental setup is shown in Fig. 10. The errors are estimated from fitting attenuation curves with exponentials. The curves are simply drawn to guide the eye.

Table 1

Sample No.	Concentration of Fluorescent Material							Light Output
	Primary fluor			Secondary fluor				% NE110
	b-PBD	DPO	p-TP	BBOT	POPOP	bis-MSB	BDB	
SCSN-01		1.0		0.01				81
02		2.0		"				75
03			2.0	"				88
04			1.0	"				85
05			0.5	"				73
06		3.0		0.01				71
07	1.0			"				88
08	2.0			"				88
09		0.5		"				77
10	0.5			"				81
11	1.0						0.01	100
12		1.0			0.01			88
13		"			0.02			92
14		"			0.03			92
15		"					0.01	96
16		1.0					0.02	92
17		"					0.03	96
18		0.5		0.02				77
19		"		0.03				81
20		1.0		0.02				81
21		1.0		0.03				73
22		2.0		0.02				77
23	2.0			"				100
24	"					0.02		108
25	"						0.02	112
26			0.5	0.02				81
27			"			0.02		88
28	1.0					"		112
29		1.0				0.01		92
30		"				0.02		95
31	1.0					0.01		108
32		0.5					0.01	96
33		"					0.02	96
34		"					0.03	92
35		2.0					0.01	88
36		"					0.02	85
37		"					0.03	88
38	1.0						0.02	112
39	"						0.03	104
40	0.5						0.01	96
41		0.5			0.01			90
42		"			0.02			92
43	0.5						0.02	100
44	"						0.03	92
45	"			0.02				87
46	1.0			0.02				88
47	0.5				0.01			88
48	"				0.02			92
49	1.0				0.01			104
50	2.0						0.01	100
51	2.0						0.03	100
52	3.0						0.01	100
53	0.5					0.01		92
54	"					0.02		92
55	"					0.03		92
56	1.0				0.02			96
57	2.0				0.01			100
58	"				0.02			100
59	"					0.01		100

Table 2

Combination	Attenuation Length of Scintillator (cm)	Light output[1)]
SCSN-38 + Y-7(30ppm,UVT)	91.0 ± 11.5	164
SCSN-38 + BBQ(90 mg/l)	55.5 ± 1.6	99
KSH390 + Y-7(30ppm,UVT)	42.9 ± 2.2	89
KSH390 + BBQ(90 mg/l)	38.2 ± 1.4	100

1) The light output was measured by setting the β-ray source at 25 cm from the waveshifter bar. The values are normalized to the light yield from the KSTI-390-BBQ combination.

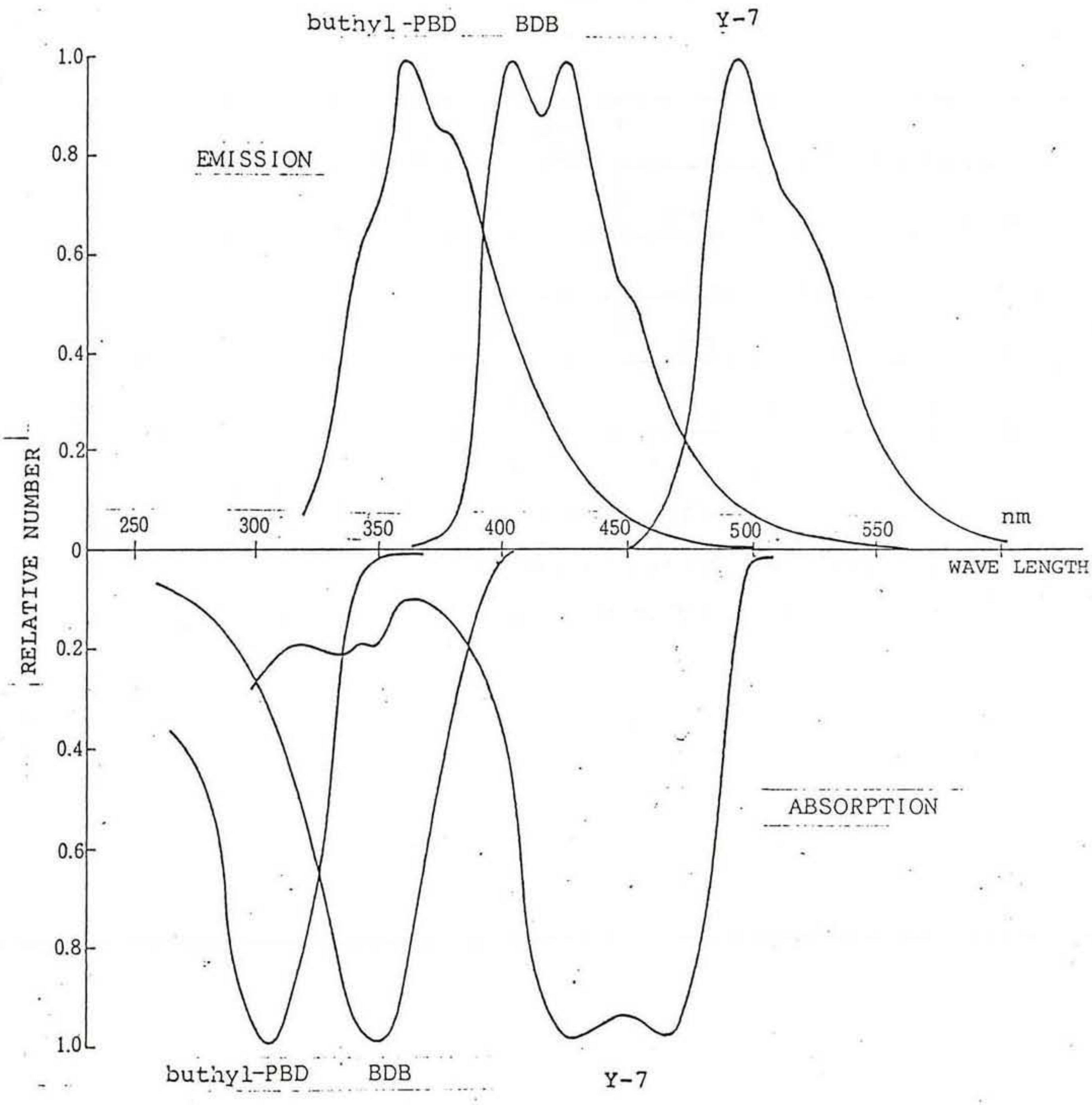

buthyl-PBD
BDB
Y-7
1.0
0.8
EMISSION
0.6
0.4
0.2
RELATIVE NUMBER
0
250
300
350
400
450
500
550
nm
WAVE LENGTH
0.2
0.4
ABSORPTION
0.6
0.8
1.0
buthyl-PBD
BDB
Y-7

Fig. 1.

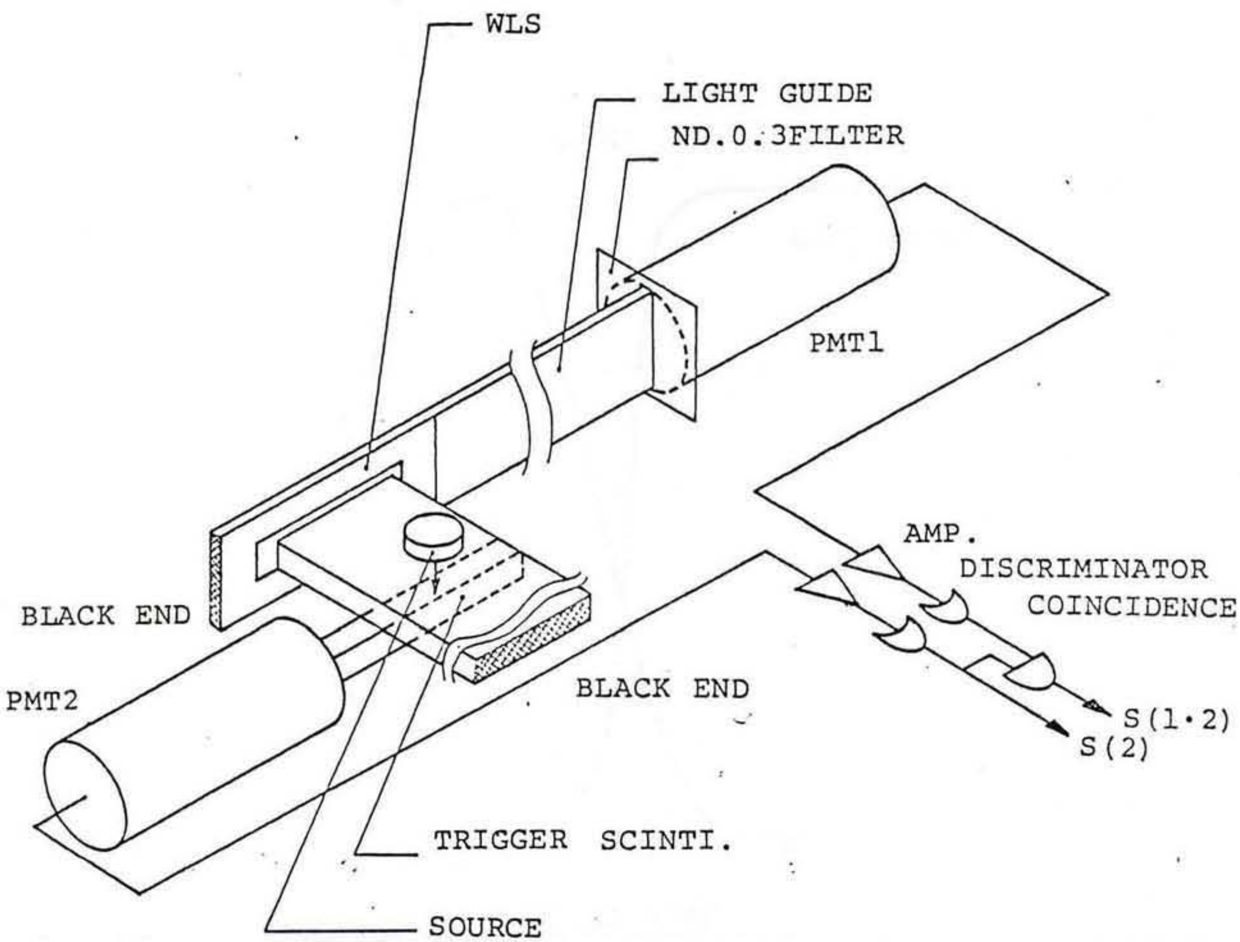

WLS
LIGHT GUIDE
ND.0.3FILTER
PMT1
AMP.
DISCRIMINATOR
COINCIDENCE
BLACK END
BLACK END
PMT2
S(1·2)
S(2)
TRIGGER SCINTI.
SOURCE

Fig. 2.

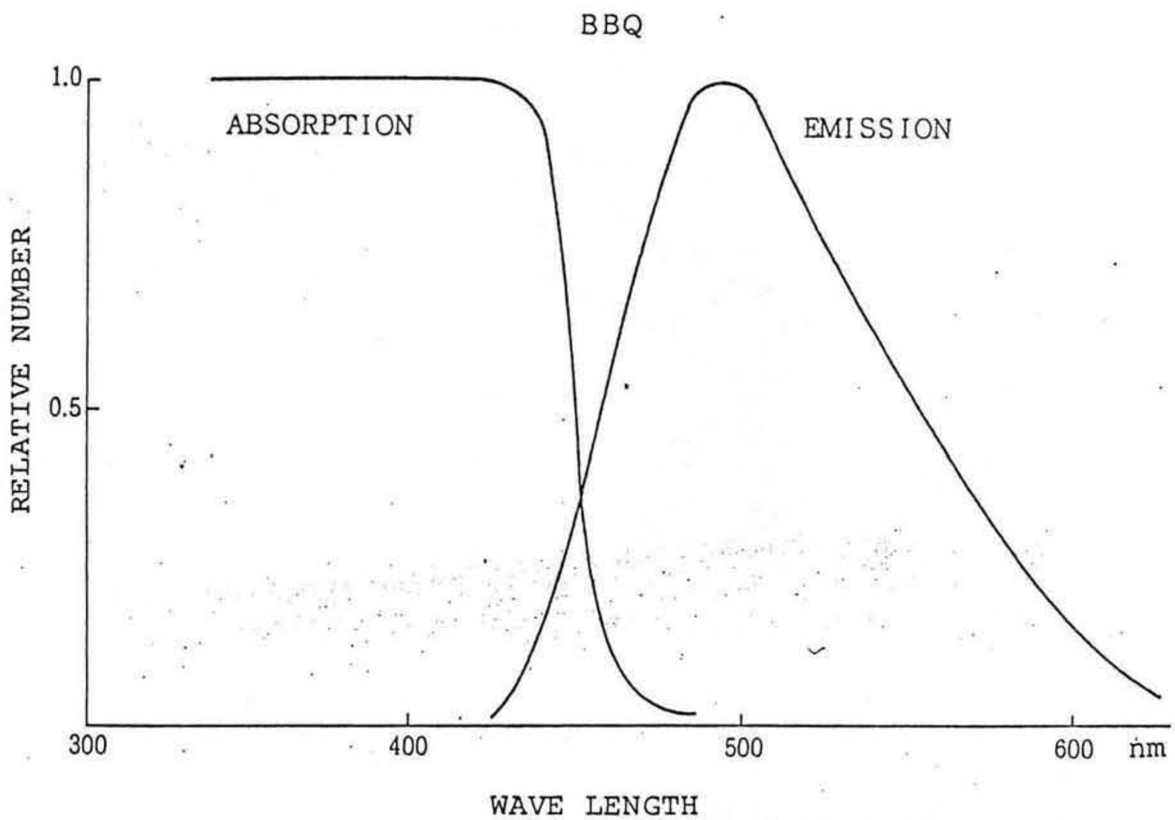

BBQ
1.0
0.5
RELATIVE NUMBER
ABSORPTION
EMISSION
300
400
500
600
nm
WAVE LENGTH

Fig. 3.

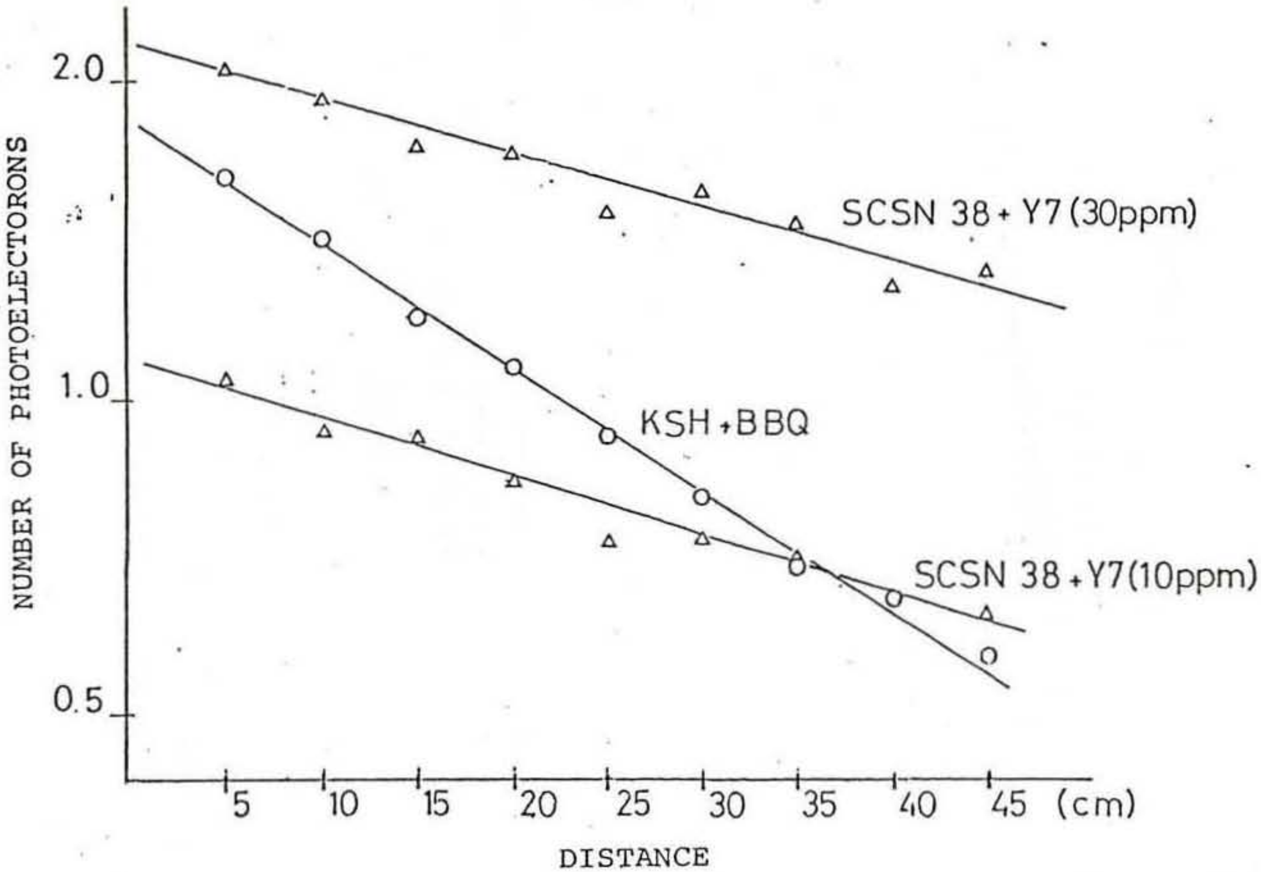
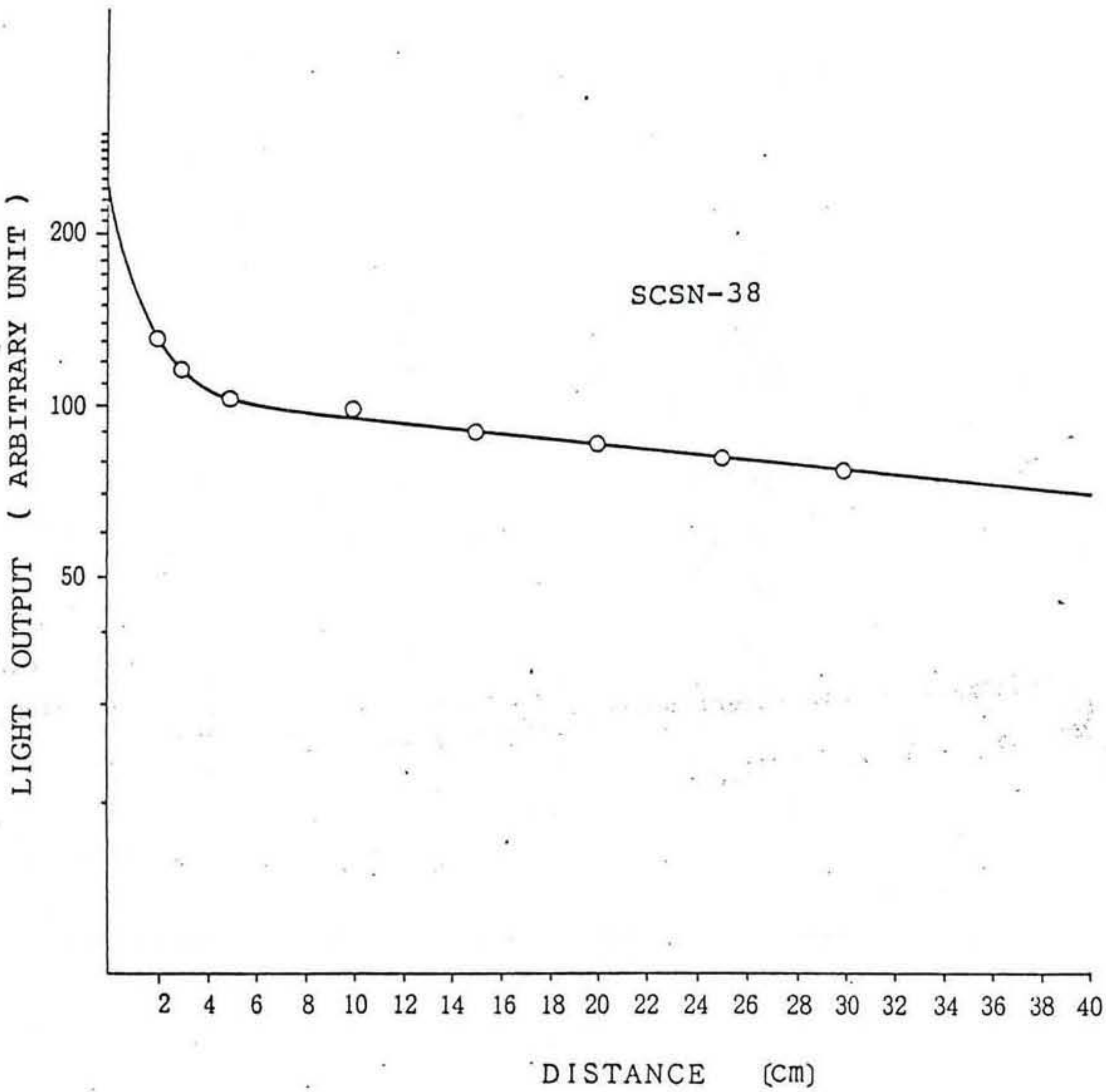

2.0
1.0
0.5
NUMBER OF PHOTOELECTORONS
SCSN 38 + Y7 (30ppm)
KSH + BBQ
SCSN 38 + Y7(10ppm)
5
10
15
20
25
30
35
40
45 (cm)
DISTANCE

Fig. 4.



LIGHT OUTPUT (ARBITRARY UNIT)
200
100
50
SCSN-38
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
DISTANCE (Cm)

Fig. 5.

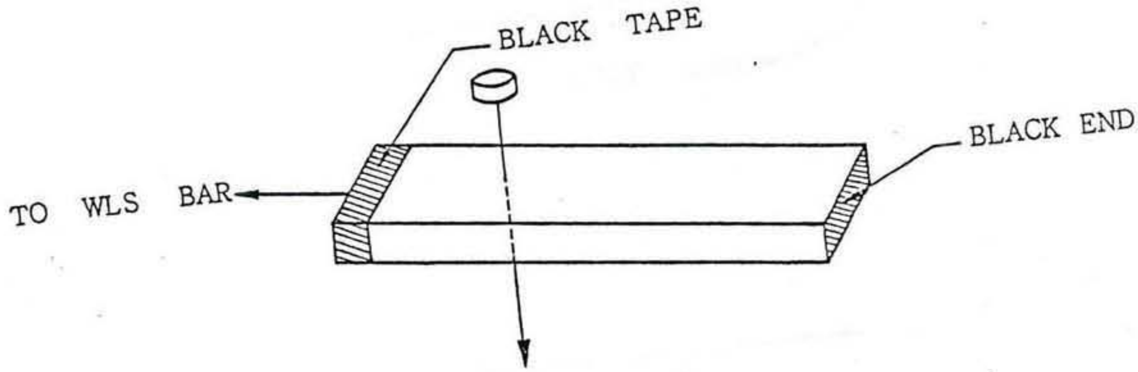


Fig. 6.

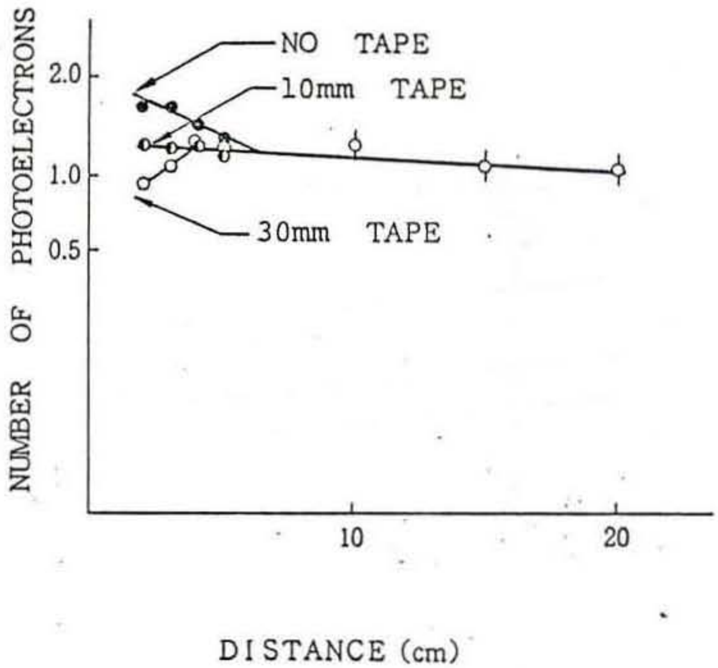

NO TAPE
10mm TAPE
30mm TAPE
NUMBER OF PHOTOELECTRONS
2.0
1.0
0.5
10
20
DISTANCE (cm)

Fig. 7.

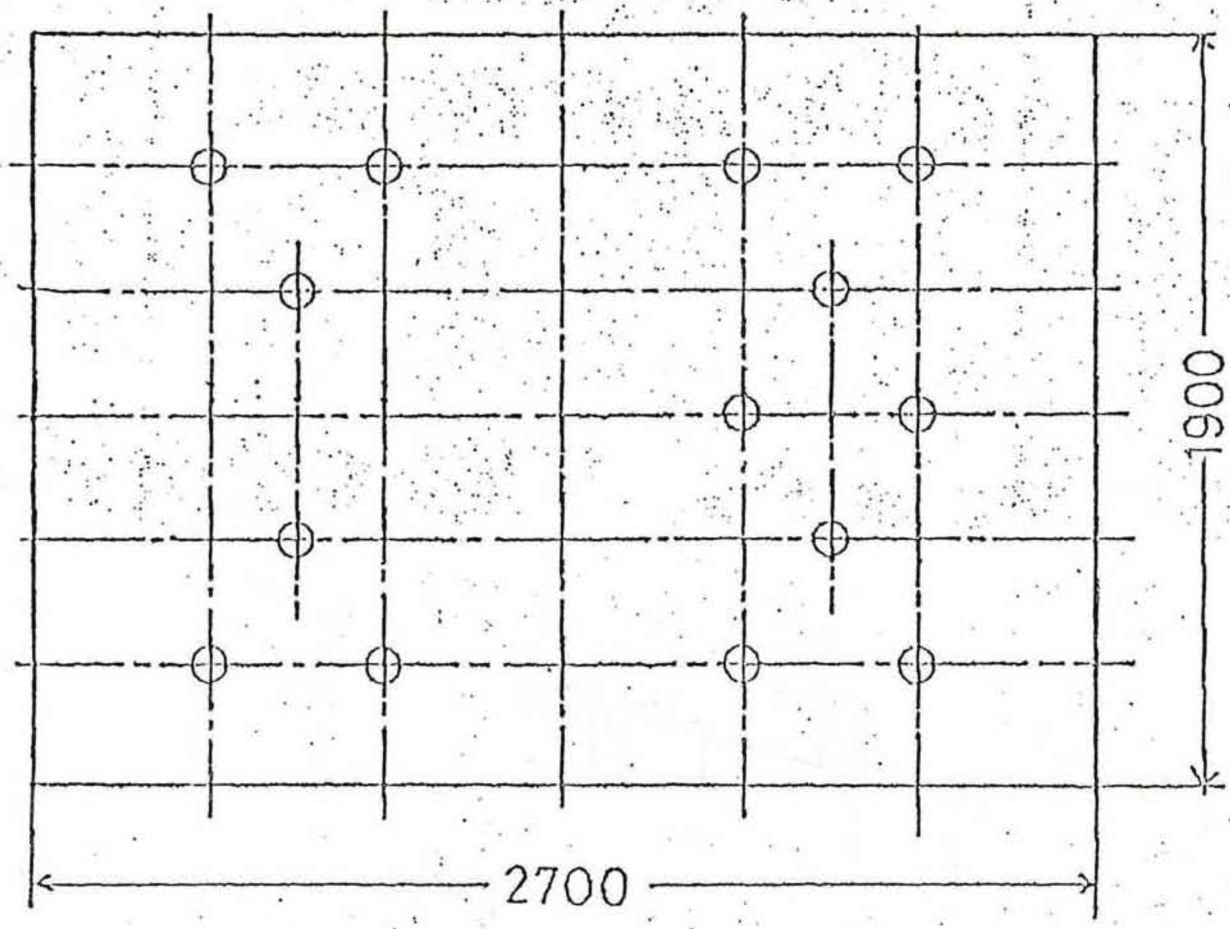


Fig. 8.

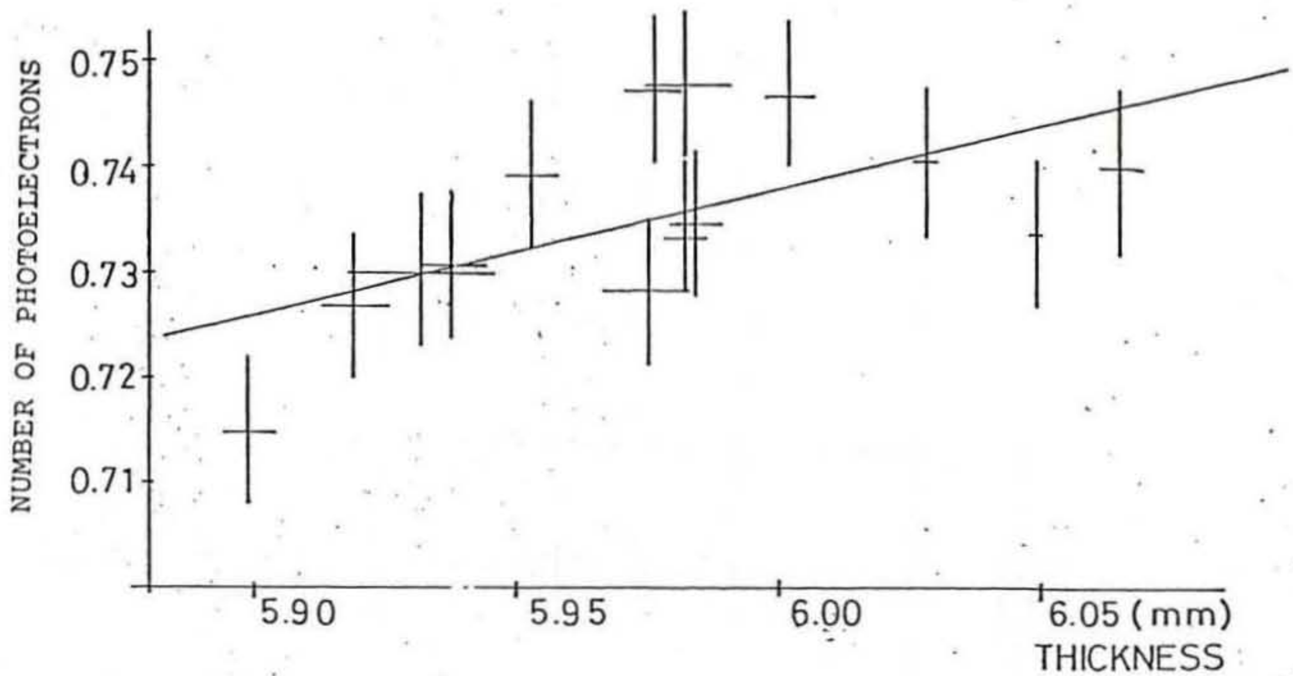

NUMBER OF PHOTOELECTRONS
0.75
0.74
0.73
0.72
0.71
5.90
5.95
6.00
6.05 (mm)
THICKNESS

Fig. 9.

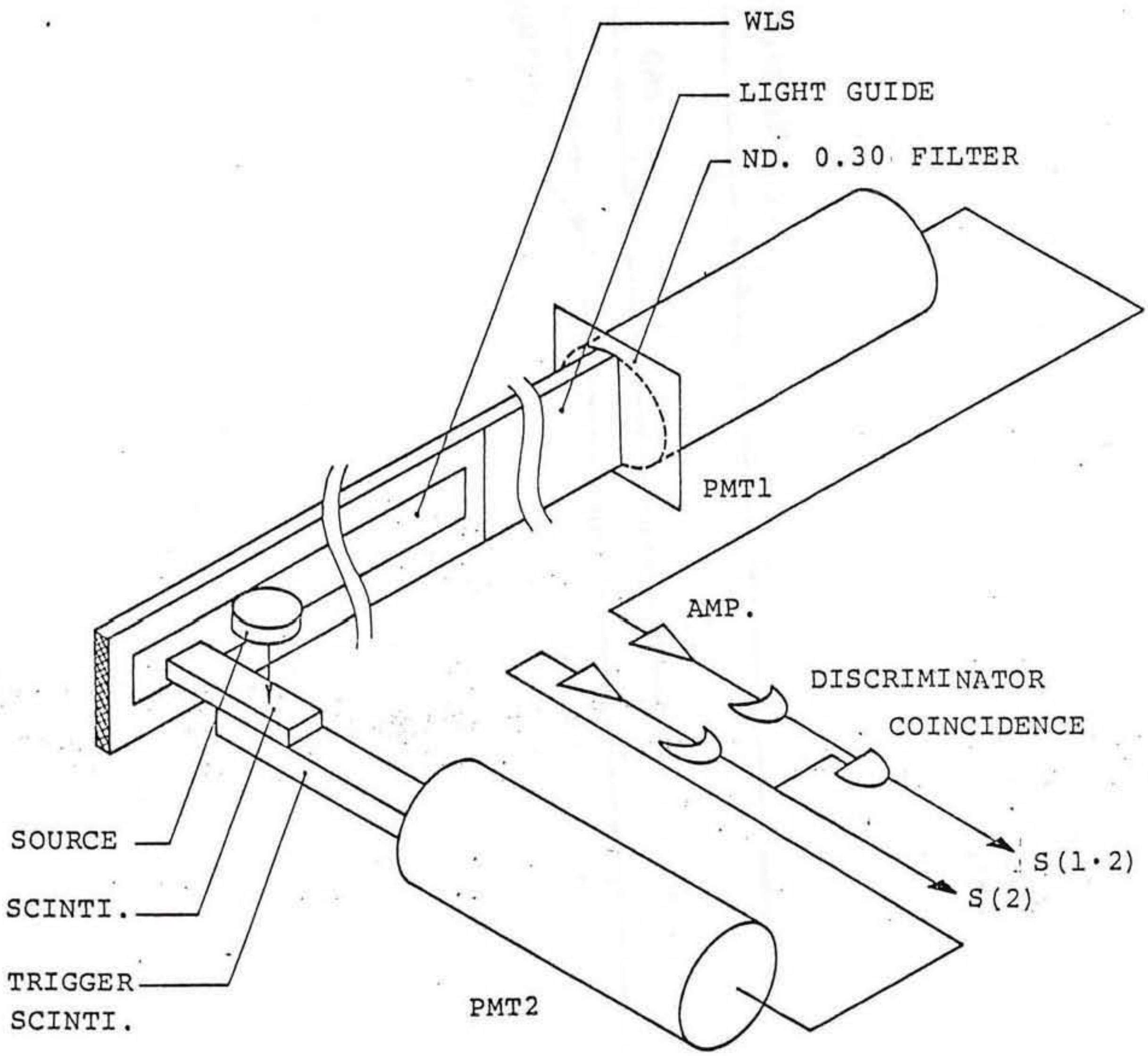

WLS
LIGHT GUIDE
ND. 0.30 FILTER
PMT1
AMP.
DISCRIMINATOR
COINCIDENCE
SOURCE
SCINTI.
TRIGGER
SCINTI.
PMT2
S(1·2)
S(2)

Fig. 10.

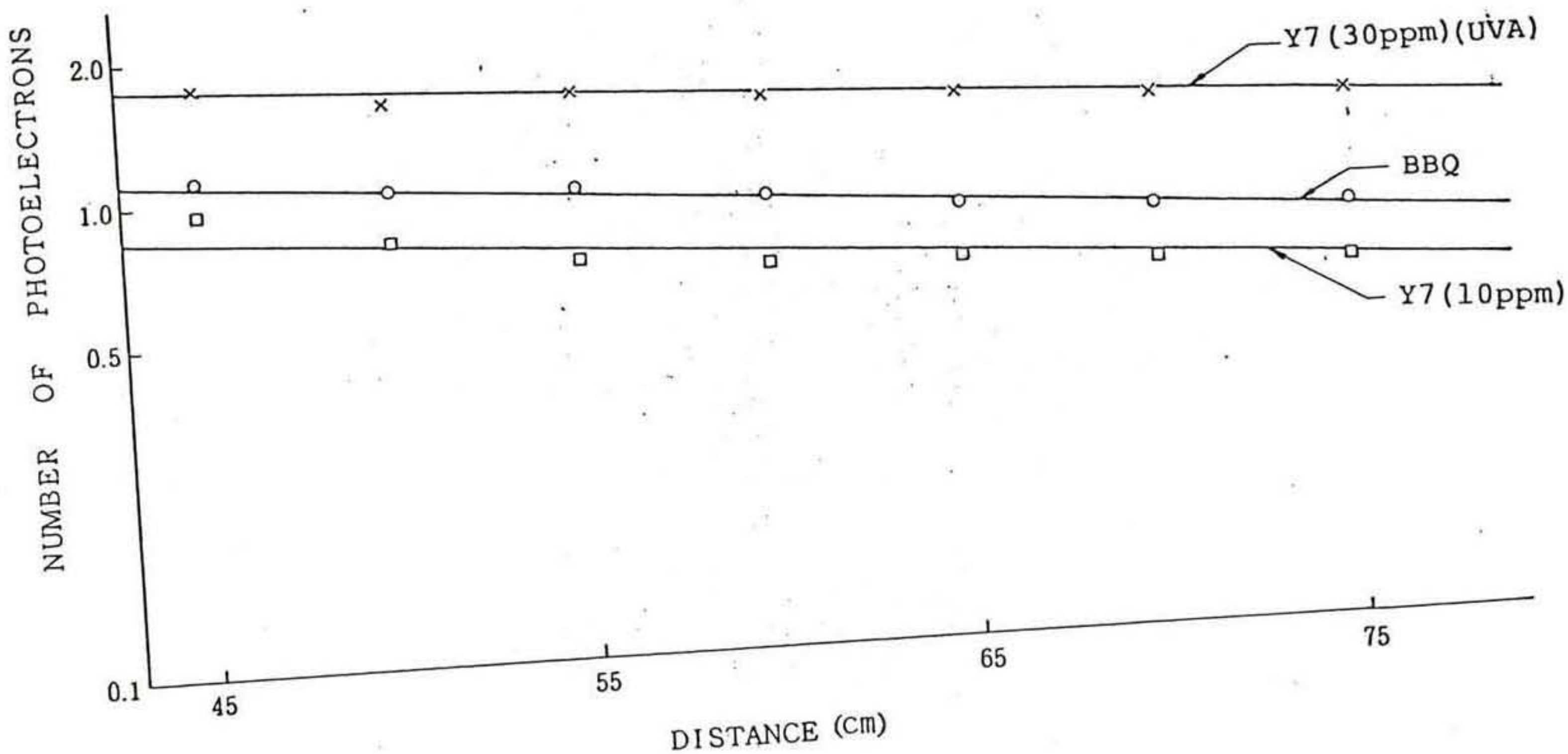
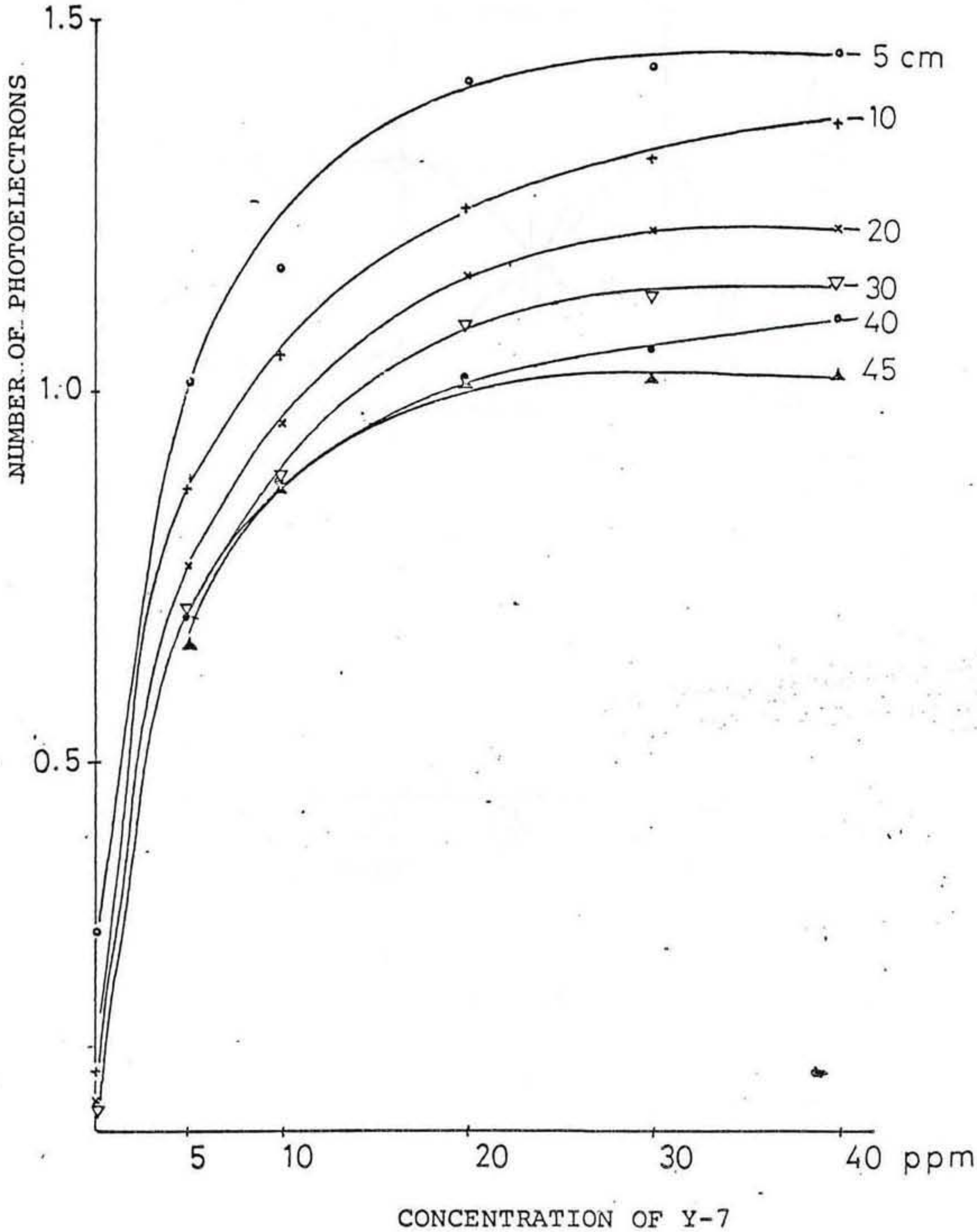

NUMBER OF PHOTOELECTRONS
2.0
1.0
0.5
0.1
45
55
65
75
DISTANCE (cm)
Y7(30ppm)(UVA)
BBQ
Y7(10ppm)

Fig. 11.



1.5
1.0
0.5
NUMBER OF PHOTOELECTRONS
5 cm
10
20
30
40
45
5
10
20
30
40 ppm
CONCENTRATION OF Y-7

Fig. 12.

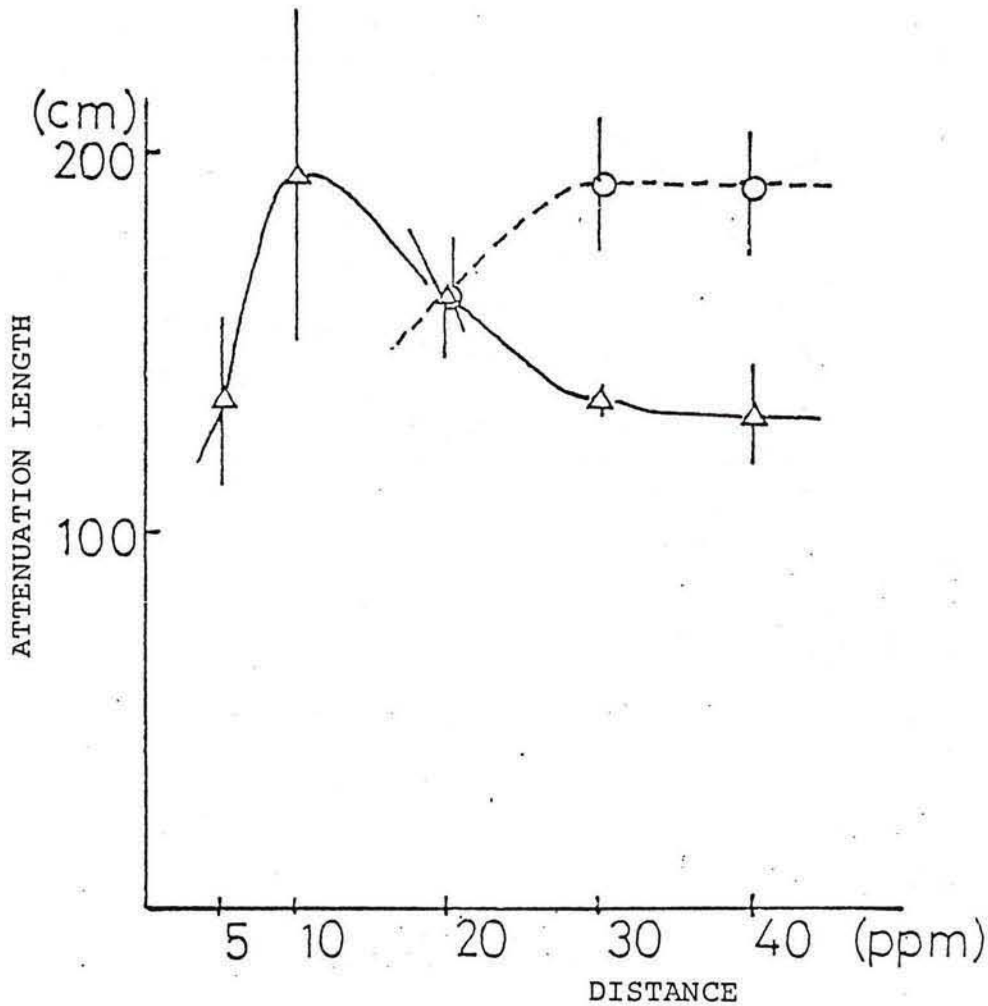


Fig. 13.