Evaluation of the optical transmission of Schott glass

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1 Introduction

The Schott glass to be used by Hamamatsu for SNO PMT's must have a bulk light absorption coefficient of better than 0.5 cm^{-1} at 320 nm. This was checked by Schott during the production of the bulbs and the results of their measurements on daily extraction from the glass melt are shown in Fig. 1 & 2. Fig. 1 shows the transmission at 320 nm and 587 nm, and Fig. 2 the absorption coefficients at 320 nm. Glass samples from the melt were also sent to CRL for confirmation of this specification. The dots in Fig. 2 are the values obtained at CRL. We report here the light transmission measurements made at CRL.

2 Measurements

Seven envelopes of glass pieces were sent to CRL in two shipments. These envelopes contained 1 mm and 3 mm thick samples. Some samples were broken in shipment and were not used. The table below lists data on the samples received. Batch # is our identification, Date is Schott production date and Contents is the thickness and number of samples in each batch.

Batch #	Date	Contents
1	Mar 5-91	1 @ 1 mm , 1 @ 3 mm
2	Mar 11	1 @ 3 mm
3	Mar 18	1 @ 1 mm , 1 @ 3 mm
4	Mar 30	3 @ 1 mm , 3 @ 3 mm
5	Apr 20	2 @ 1 mm , 2 @ 3 mm
6	Mar 13	1 @ 1 mm , 1 @ 3 mm
7	Mar 6	1 @ 1 mm , 1 @ 3 mm

The light transmission through the samples were measured from 250 to 600 nm, in 0.2 nm steps, using a spectrophotometer (Spectronic 1201, from Milton Roy Co.) with the samples placed in air. The measured transmission through two samples (1 mm & 3 mm) from batch 5 are shown in Fig. 3. Since the transmission above 400 nm is the same for different thicknesses, it is assumed that all losses above 400 nm are reflective losses at the glass-air interfaces. These losses are about 8% and are independent of wavelength. The reflective losses will be negligible when the PMTs are immersed in water because the refractive indices of glass and water are similar.

3 Absorption Coefficients

The bulk absorption coefficient $\alpha(\lambda)$ in cm^{-1} is obtained using the formula

$$\alpha(\lambda) = \frac{ln(T(587nm) - \Delta(\lambda)) - ln(T(\lambda))}{t}$$

where T is the light transmission, t is the sample thickness and $\Delta(\lambda)$ is a correction term for the dispersion ($\Delta(320\text{nm}) \approx 0.005$). The α's for the best (batch 1) and worst (batch 5) samples are shown in Fig. 4 & 5 from 250 nm to 400 nm. The best and worst samples measured are shown together in Fig. 6. All samples are better than the specification (0.5 cm^{-1} at 320 nm). Fig. 2 shows the absorption coefficients at 320 nm measured by Schott as the glass production went on. A decline of the transmission was observed after March 10, however all their data are still within the specification.

For completeness, Fig. 7 to 13 show the α's for all seven batches from 280 to 400 nm and Fig. 14 shows the actual measured transmission for the best and worst samples used to obtain the curves in Fig. 6. Also shown in Fig. 14 is the transmission expected through 5 cm of acrylic with the absorption coefficients assumed in the vessel design criteria document.

4 Relevence to SNO

To quantitatively study the consequence to SNO of the optical transmission through the various materials in SNO, a computer program has been written. It folds together the Čerenkov spectrum emitted from randomly distributed vertices inside the D_2O, the light transmissions through the D_2O, the acrylic and the H_2O and the PMT quantum efficiency. It calculates, for the different glass samples, the fraction of Čerenkov photons which finally produce photoelectrons. The PMT quantum efficiency (probability to produce a photoelectron for a photon striking the glass) is assumed to be the product of the light transmission through the glass and the internal quantum efficiency (probability to produce a photoelectron for a photon striking the photocathode). The quantum efficiency is as provided by Queen's for Tube R1408, Serial # ZW535. The water absorption coefficients are as reported in the white book SNO-87-12, measured at NRC, and the acrylic coefficients are as in the vessel design criteria document.

The bulk of the Čerenkov light is lost at the shorter wavelengths and the acrylic has a much more severe cut-off then the glass as illustrated in Fig. 14, therefore the importance of the glass optical transmission becomes relatively insignificant for SNO. In fact, only 1% of the detectable light is lost going from the best glass sample to the worst. An additional 2% of the light is lost going from 1.5 mm thick glass to 3.5 mm thick glass, as allowed for in the specifications.

We can hope that much better acrylic will be obtained and, if so, the glass attenuation may become relatively more significant. Assuming no acrylic in the way but with the same water thicknesses, 3% of the detectable light is lost going from the best glass sample to the worst and the additional losses due to 2.5 mm thicker glass could be as high as 5%.

5 Conclusions

The bulk absorption coefficients of the Schott glass samples are within the specifications. The variations in the light transmission between samples are small, as also are the variations expected due to different glass thicknesses. Because of the other factors affecting light transmission in the SNO detector, the light absorption of the glass is unimportant. However in some other application, variations in α and thickness from tube to tube could be relevent in tube selection.

Figure 1

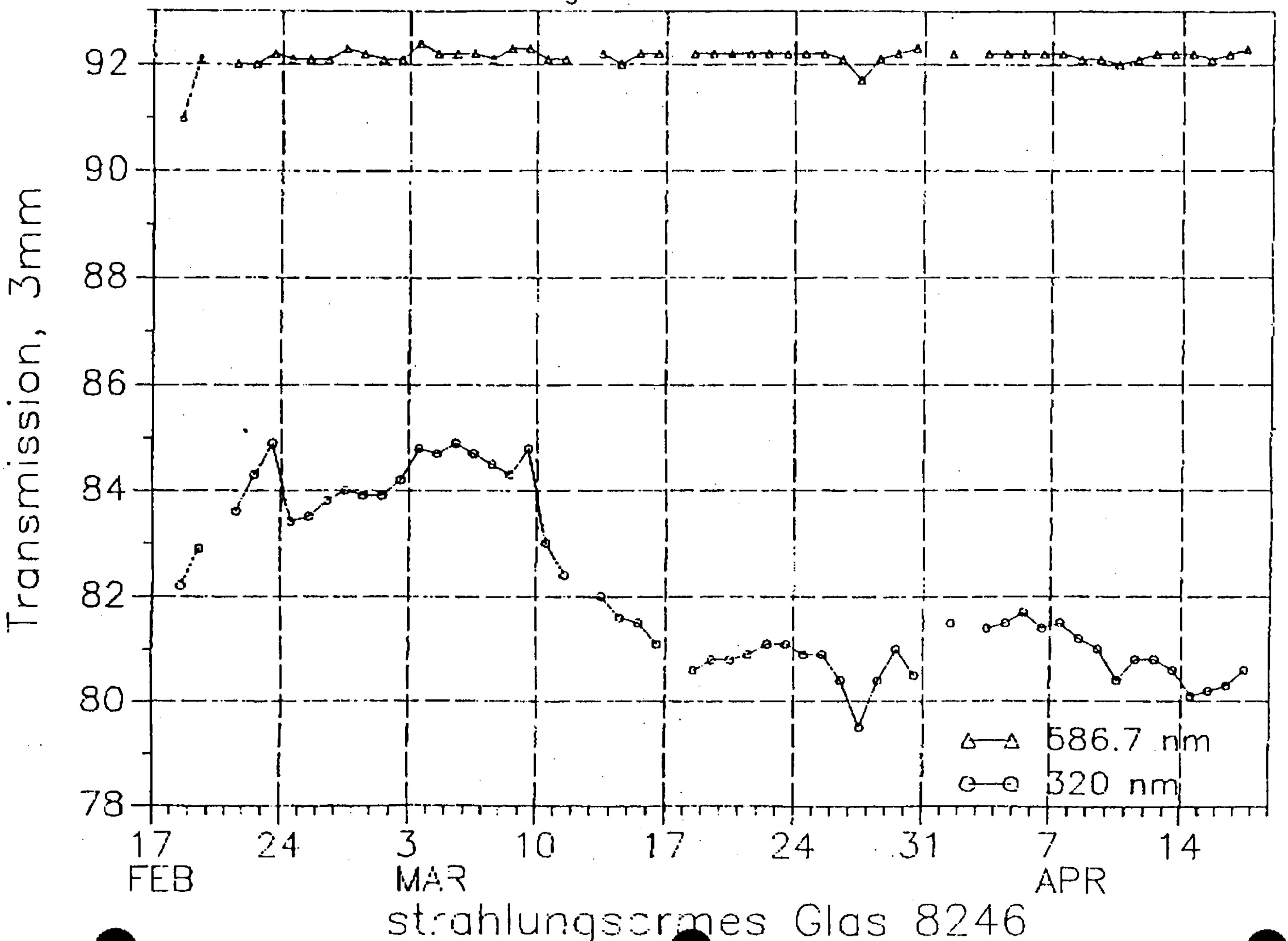
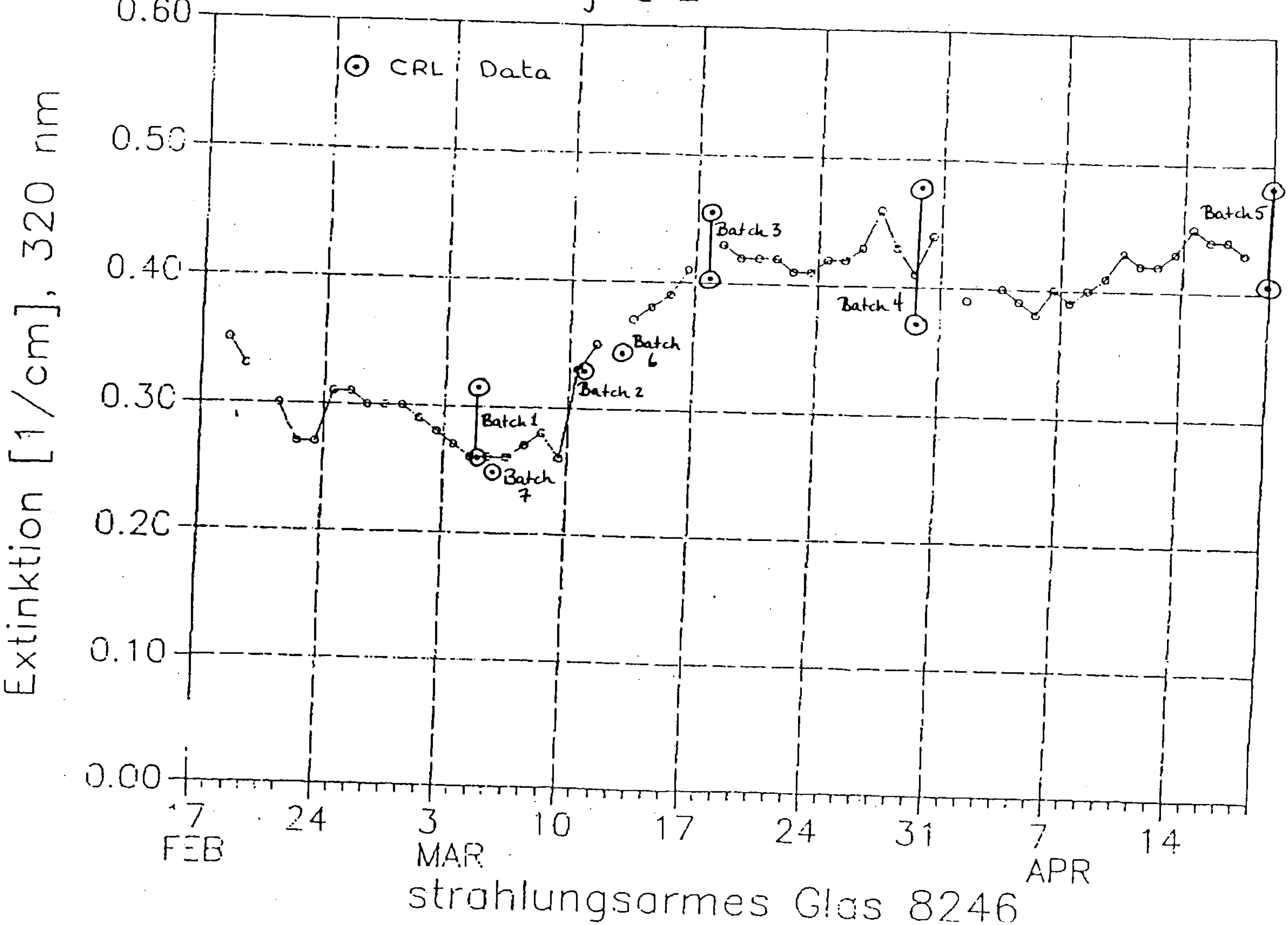

92
90
88
86
84
82
80
78
Transmission, 3mm
17
FEB
24
3
MAR
10
17
24
31
7
APR
14
586.7 nm
320 nm
strahlungsarmes Glas 8246

Figure 2



CRL Data
Extinktion [1/cm], 320 nm
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Batch 1
Batch 2
Batch 3
Batch 4
Batch 5
Batch 6
Batch 7
17
24
3
10
17
24
31
7
14
FEB
MAR
APR
strahlungsarmes Glas 8246

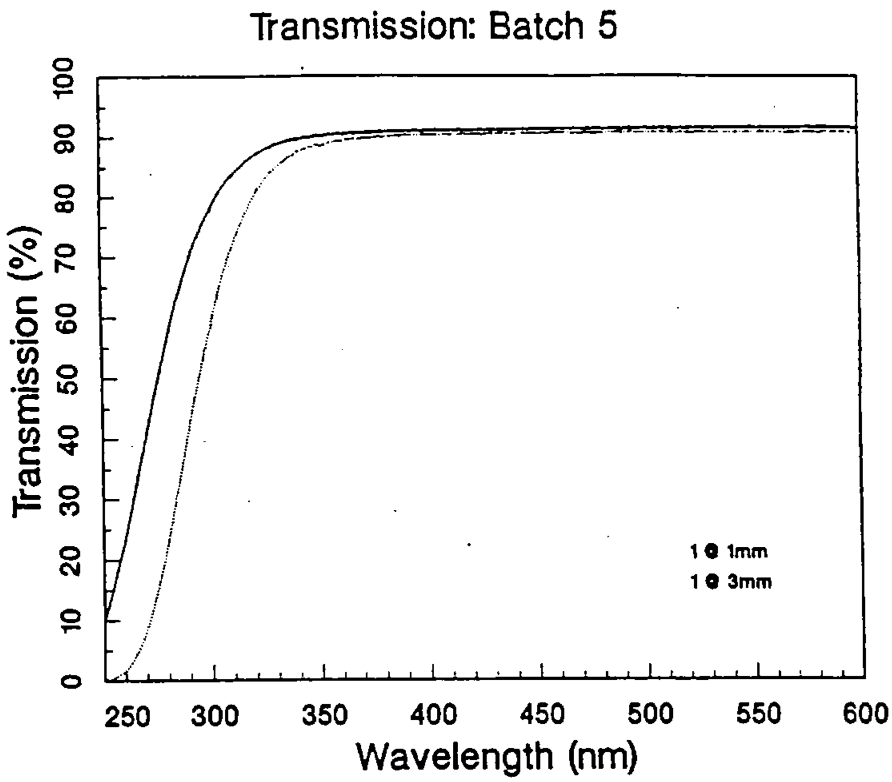


Figure 3

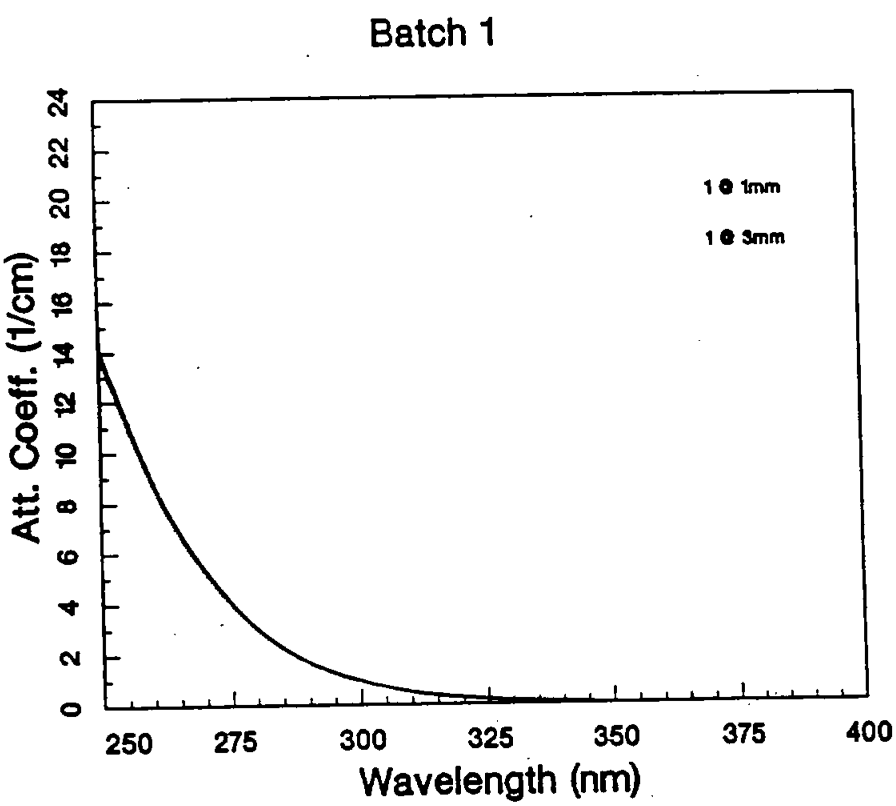


Figure 4

Batch 5

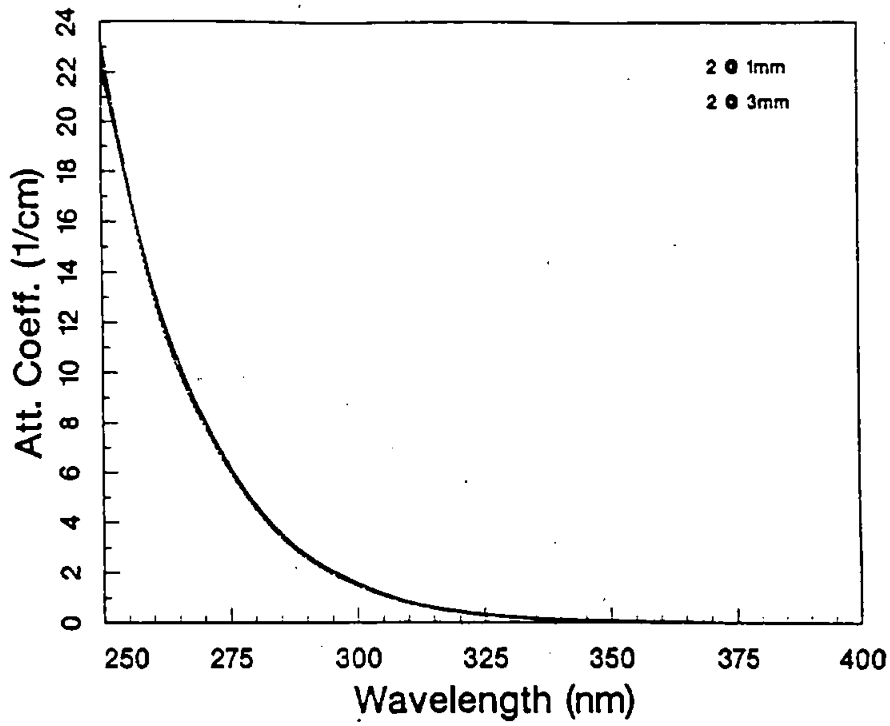


Figure 5

Best and Worst Curves

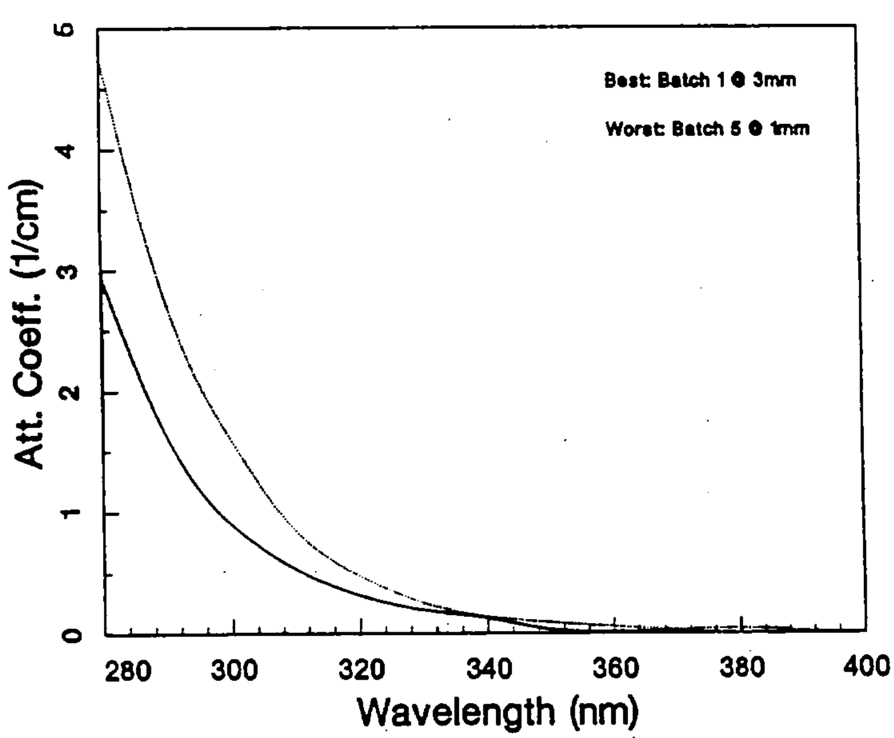


Figure 6

Batch 1

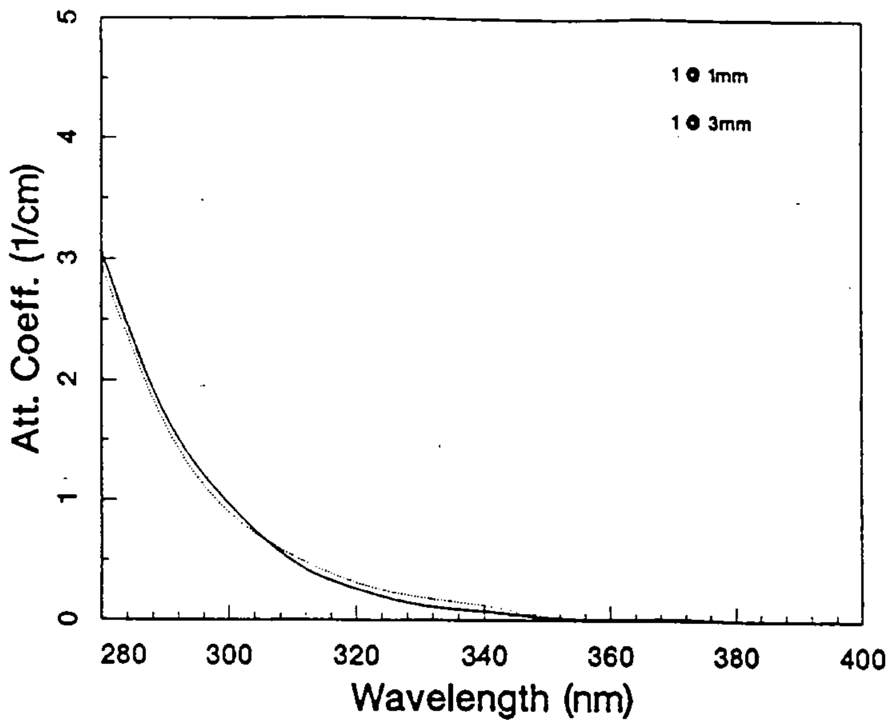


Figure 7

Batch 2

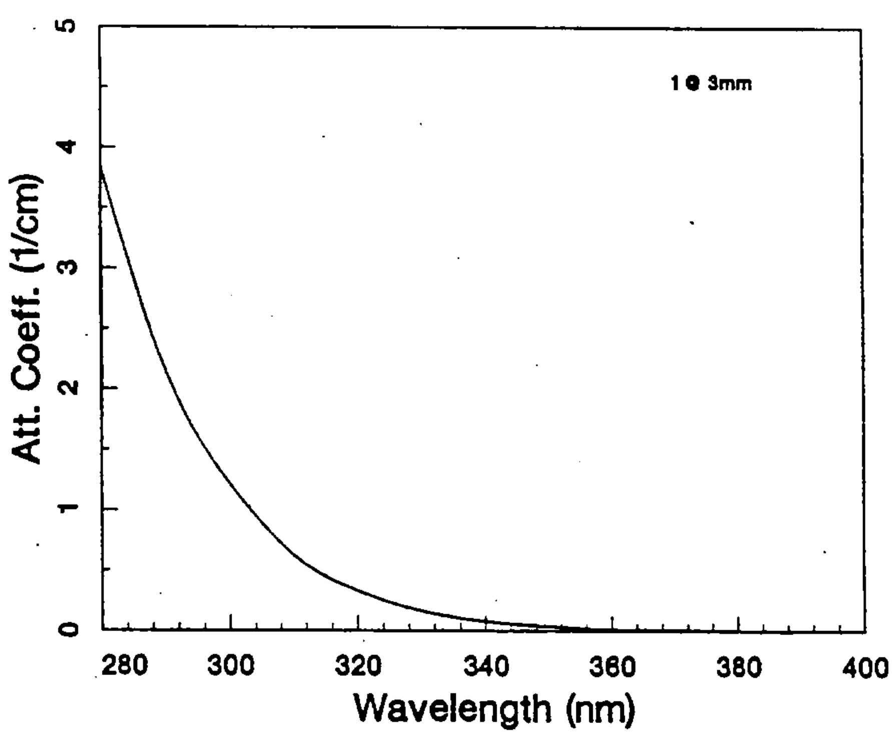


Figure 8

Batch 3

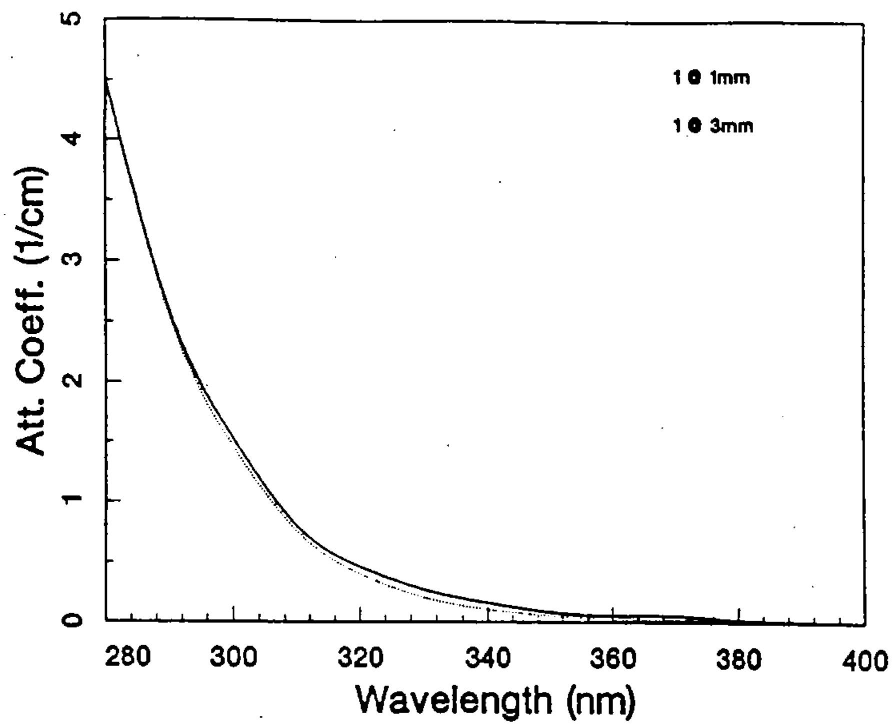


Figure 9

Batch 4

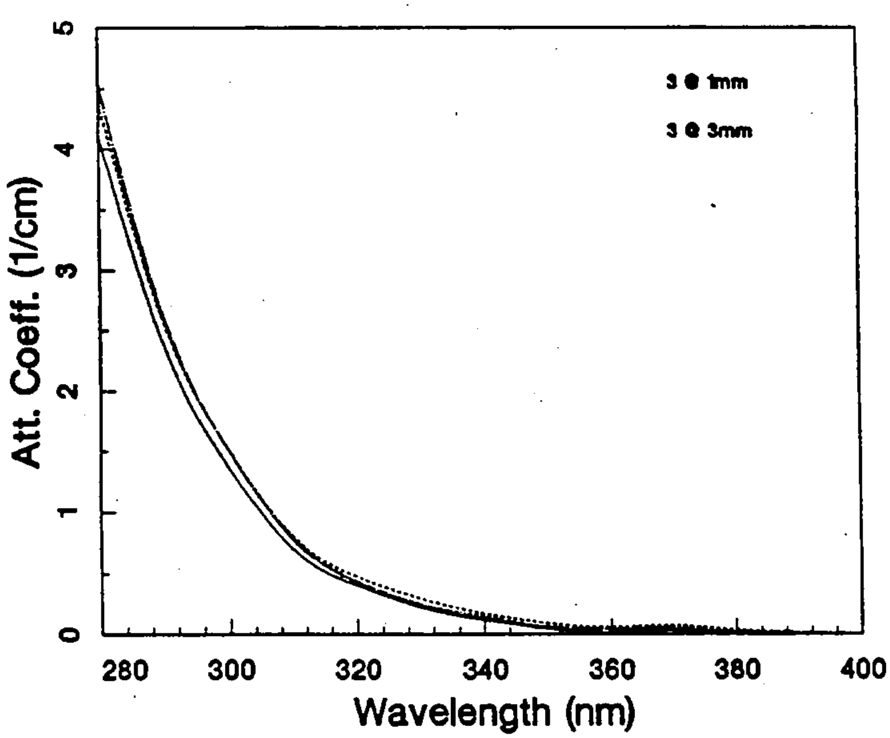


Figure 10

Batch 5

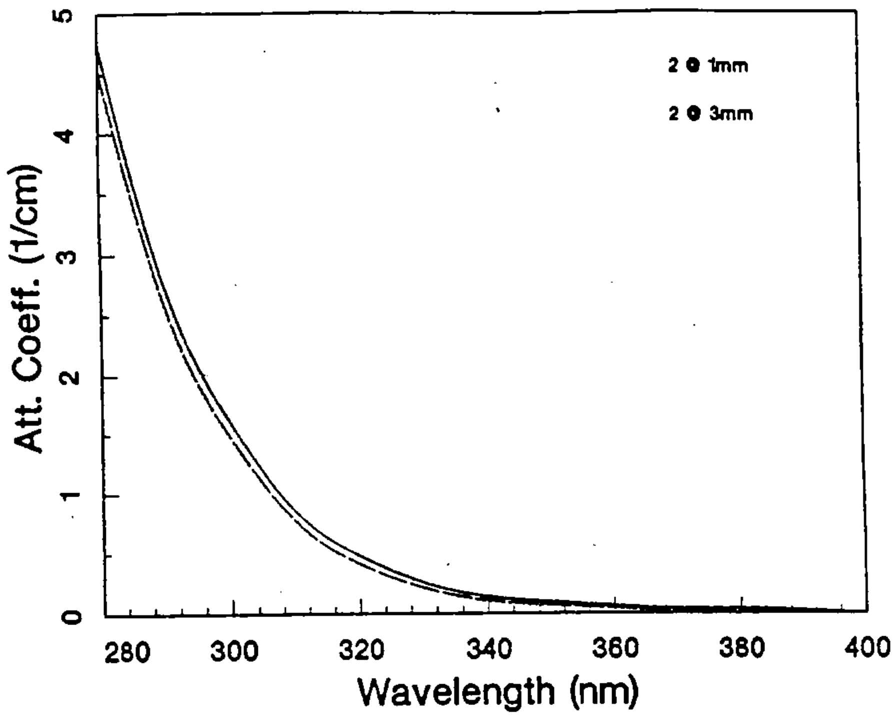


Figure 11

Batch 6

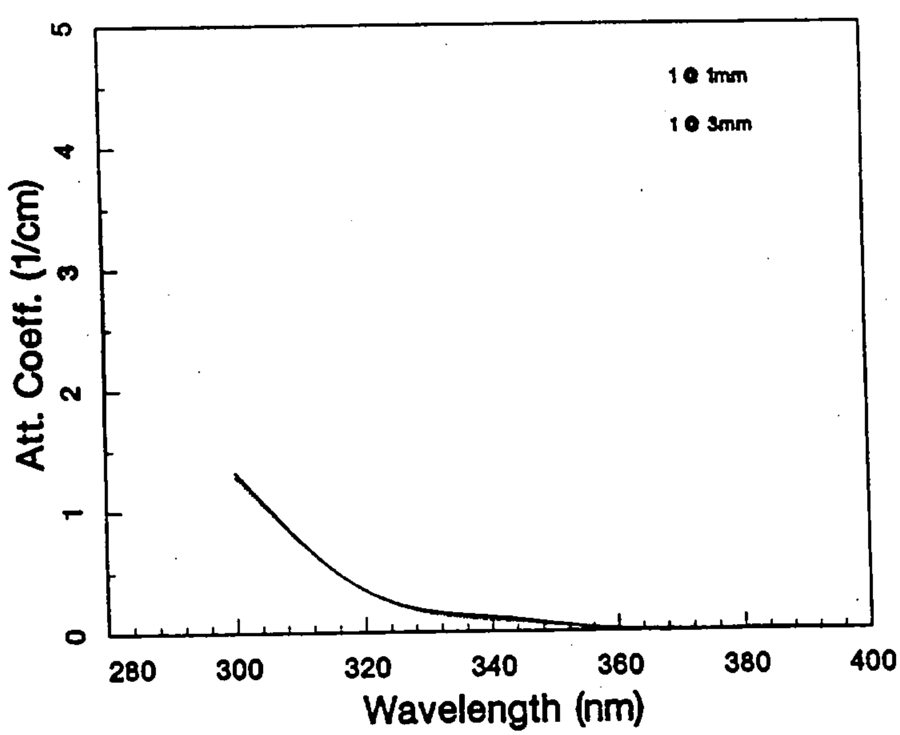


Figure 12

Batch 7

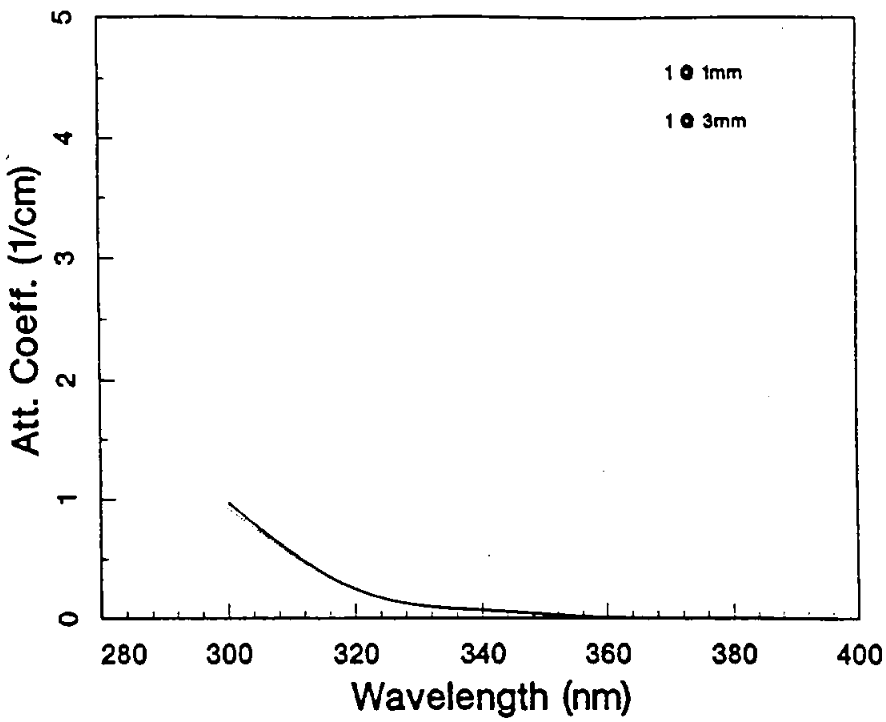


Figure 13

Transmission for Pmt Best and Worst Curves and for 2 Inch Acrylic

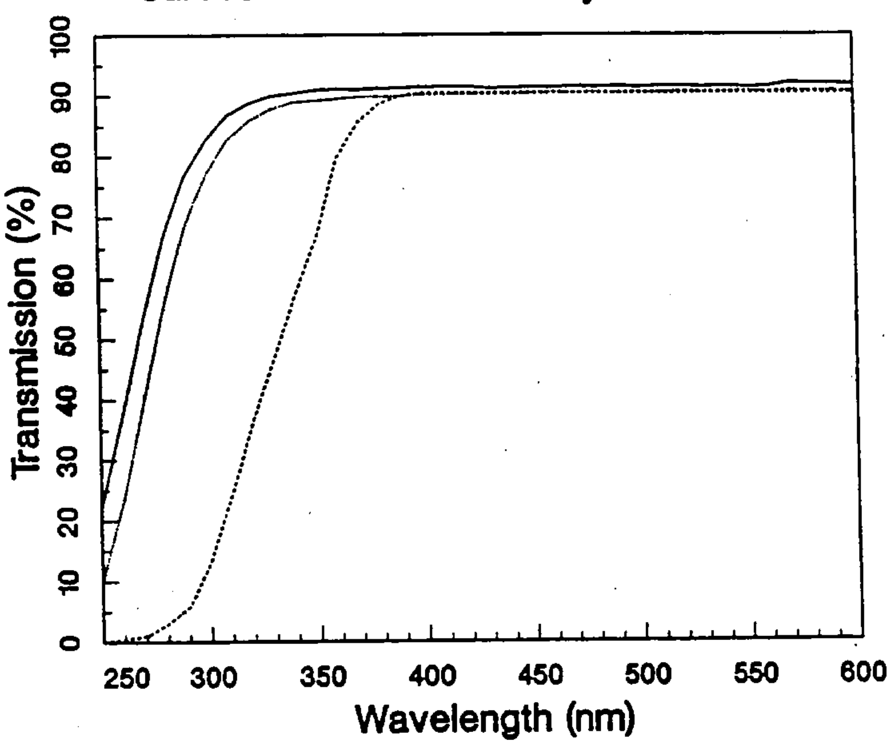


Figure 14