Light Attenuation in Large Plastic Scintillators

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We have measured the attenuation lengths of three scintillators: NE-110 from NE Technologies [3], BC-408 from Bicron [2] and SCSN-38 from Kuraray [4]. The primary goal was to understand the light attenuation in relatively long scintillator pieces. Roughly 80% of the area covered by the CLAS TOF [1] system requires scintillators which are longer than 300 cm in length, so the light attenuation and the limitations due to fabrication of long pieces are important considerations. Bicron is able to fabricate scintillator bars up to 450 cm. The ovens at NE technologies limit the lengths of scintillator they produce to 320 cm and Kuraray can produce pieces up to 280 cm. Kuraray provided us with several scintillators bonded together at the center to test their ability to fabricate composite pieces.

1 Procedure

The measurements were performed on 5-cm thick scintillators, 10 to 20 cm wide, and typically 300 cm long. However both shorter and longer pieces were tested. The scintillators were balanced on the 5-cm side so that the width could be irradiated by a horizontal 8 KeV X-ray tube which moved along the length of the piece. The X-ray source was about 1-cm wide, but for finer scans a slit was built which collimated the X-rays within 0.25 mm. A single XP2262 photomultiplier tube was attached through an air gap to one side of the scintillator. The entire assembly was placed inside a dark box. The photomultiplier anode current was read with a digital multimeter (Keithley 197A Autoranging Microvolt DMM) and transmitted to a PC via a GPIB connector. The position of the X-ray tube was controlled by the PC, so fine position scans could be taken quickly by programing the computer to record the photomultiplier current as the X-ray generator moved along the length of the scintillator. The "dark current," or current measured when the X-ray generator was off, was monitored, but typically less than 10 nA, as compared to the 200-1000 nA signal currents.

2 BC-408 and NE 110

Bicron and NE Technologies have produced large quantities of BC-408 and NE 110 scintillators and our tests of these scintillators make it simple to compare our results with other measurements. Both scintillators use polyvinyltoluene (PVT) as a base material. Figure 1 shows the attenuation measurement for BC-408 and Figure 2 shows the measurements for NE 110. Both scintillators were of the same dimensions ($300\times20\times5$ cm^3). The Bicron scintillator yields a relatively uniform attenuation length of 500 cm. The attenuation of the NE 110 piece has two components, 180 cm for the first half and 400 cm for the last half of the piece.

3 SCSN-38

Kuraray produces scintillators which use polystyrene as a base material. These scintillators have been used successfully in other applications and we wished to measure their performance. The attenuation in the 300-cm piece was measured (Figure 3) and compared with the NE 110 and BC-408 scintillators. The attenuation curve of the SCSN-38 piece was almost identical to the one measured for NE 110. This verified claims by Kuraray that the attenuation characteristics of SCSN-38 were similar to the NE 110 scintillator. (No measurements of absolute light output were made).

3.1 Bonded Joint

Due to the limitation on the length of pieces which can be manufactured, we were particularly interested in testing pieces composed of two bonded scintillators. Kuraray made available to us four pieces of SCSN-38 scintillators joined at the center. The pieces were joined together with a third piece, approximately 2 mm thick. This transition piece appeared to be active scintillator material and was used to "fuse" the two major scintillator pieces together. On first inspection, the transition piece could be felt as a slight bulge on the scintillator. The two joints between it and the rest of the scintillator were bearly visible, but could be seen as shadows when light illuminated the piece.

Consistent with our visual assessment, the first measurements of the attenuation and absolute output at the joint were quite satisfactory. The attenuation curve did not show any indication of distortion due to the bond. The light output was reduced by about 12% in a region of about 6 mm centered on the joint (Figure 4a). The width of this region is believed to be due to surface conditions, as the 8 KeV X-ray penetrates only 5 mm into the scintillator. This small loss of light over such a small area would not have a significant effect on the measurement of minimum ionizing tracks in these detectors.

Immediately after the first tests, the scintillators were wrapped in special masking tape (BC-460 from Bicron Corporation) and stored in their original shipping wooden containers for protection. No other special precautions were taken to guarantee the quality of the scintillator, but the pieces were always handled with care. We followed the initial measurements with data taken a little over a month later. The scintillators were unwrapped. Visual inspection of all four pieces showed crazing along the joined surfaces of the scintillator. Quantitatively the crazing had two important effects. First, the loss of light was not limited to the region of the joint, but persisted for all measurements of the source positioned on the far side of the joint relative to the photomultiplier. This deterioration is shown in Figure 4, where we plot an expanded view of the joint as measured by the current in the photomultiplier tube. Secondly, the measured attenuation showed deterioration of 10-15%. This is shown in Figure 5, where we overlay two attenuation measurements of the 350 cm piece made a month apart.

4 Conclusions

We have measured the attenuation length of Bicron, NE Technologies and Kuraray scintillator. The effective attenuation length in BC-408 is 60% longer than the attenuation length of NE 110 or SCSN-38. Assuming that the time resolution scales like the inverse square of number of photoelectrons, we can estimate the resolution as a function of counter length (Figure 6). In this approximation, a piece of BC-408 scintillator 350 cm in length can achieve 50% better time resolution than NE 110 or Kuraray SCSN-38.

Four pieces of SCSN-38 scintillator fabricated of two sheets joined at the center were tested for light transmission. We found crazing at the joints one month after first inspection of the pieces. The crazing resulted in significant deterioration of the light output at the joint itself and of the light transmission across the joint.

References

[1] "Conceptual Design Report — Basic Experimental Equipment," CEBAF April 13, 1990.

[2] Bicron Corporation, 12345 Kinsman Road, Newbury, OH 44065-9677.

[3] NE Technology, Inc., Princeton Corporate Plaza, 9 Deer Park Dr., Suite 110, Monmouth Junction, NJ 08852.

[4] Mitsui Plastics, Inc., 11 Martine Ave., White Plains, NY 10606.

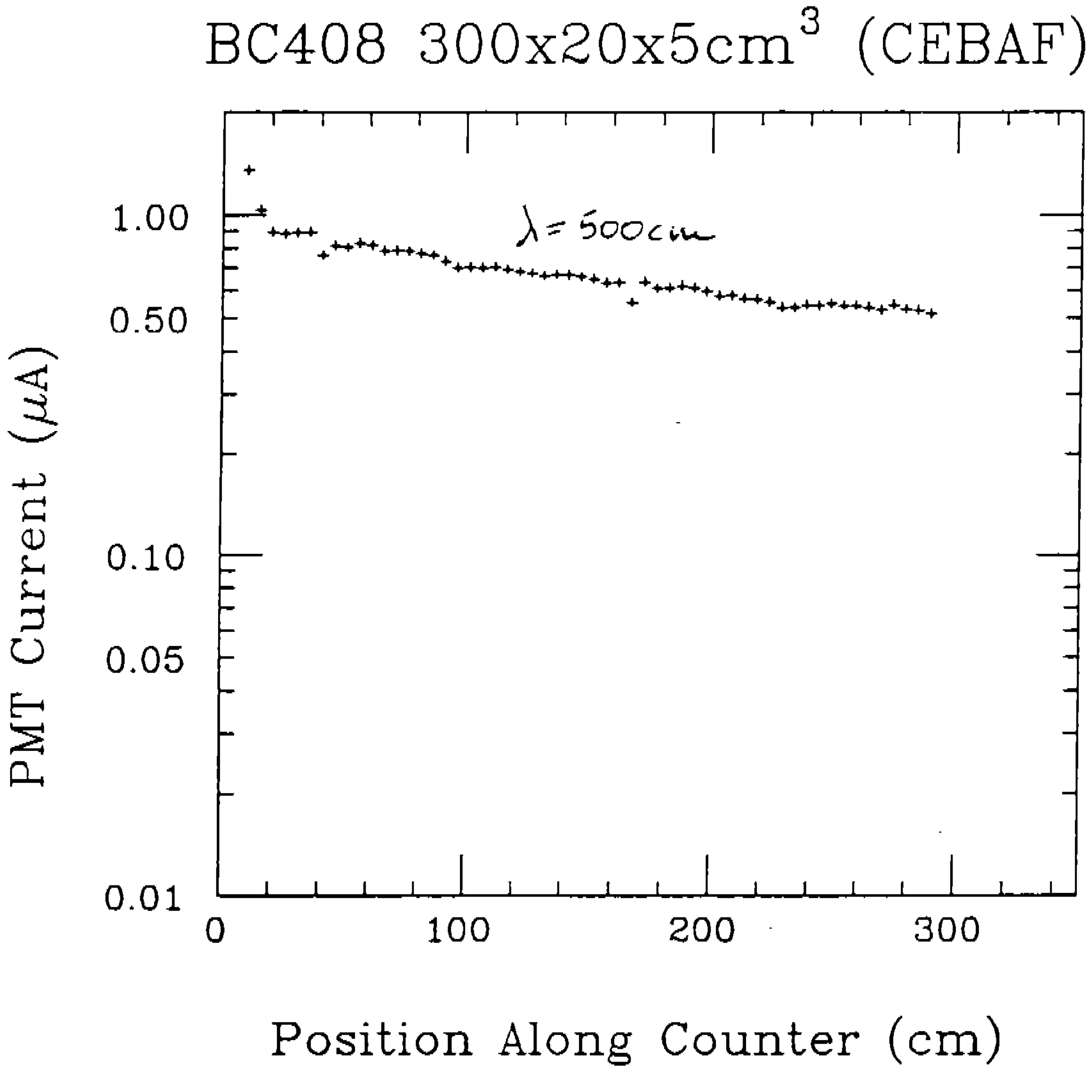

Figure 1: The light attenuation curve in a 300×20×5 cm^3 piece of BC-408 scintillator.

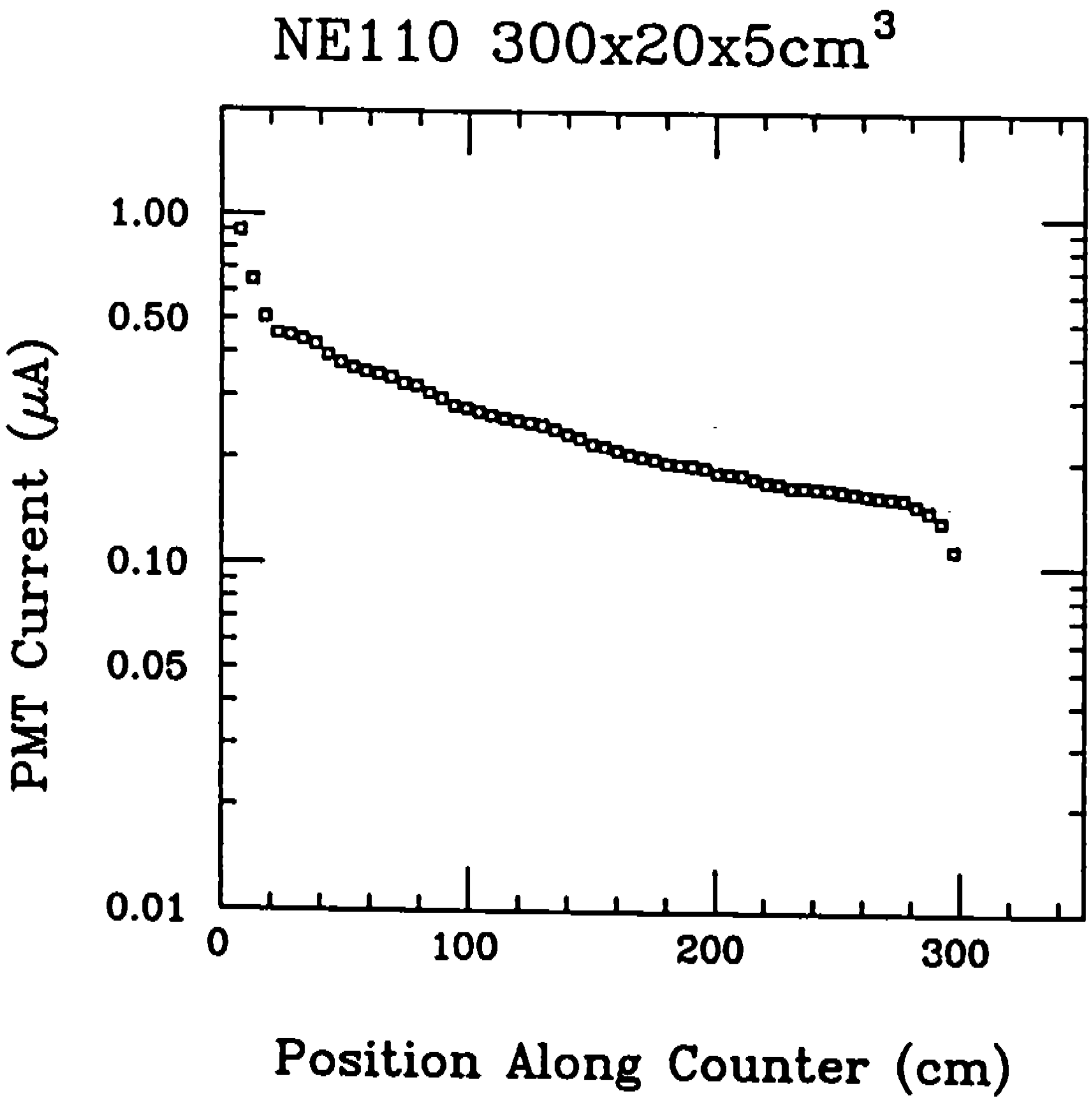

Figure 2: The light attenuation curve in a $300\times20\times5$ cm^2 piece of NE 110 scintillator.

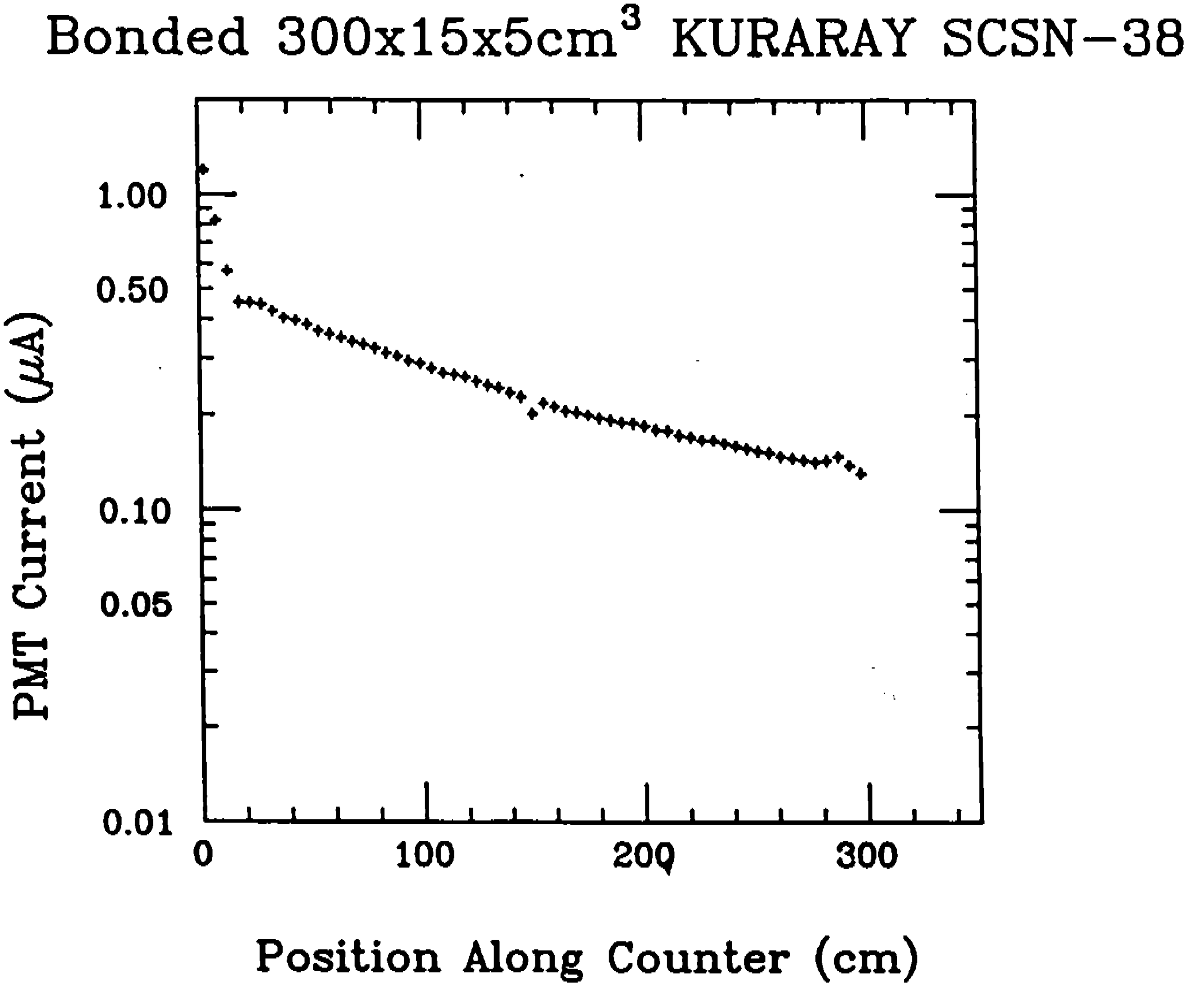

Figure 3: The light attenuation curve in a 300×15×5 cm^3 piece of SCSN-38 scintillator.

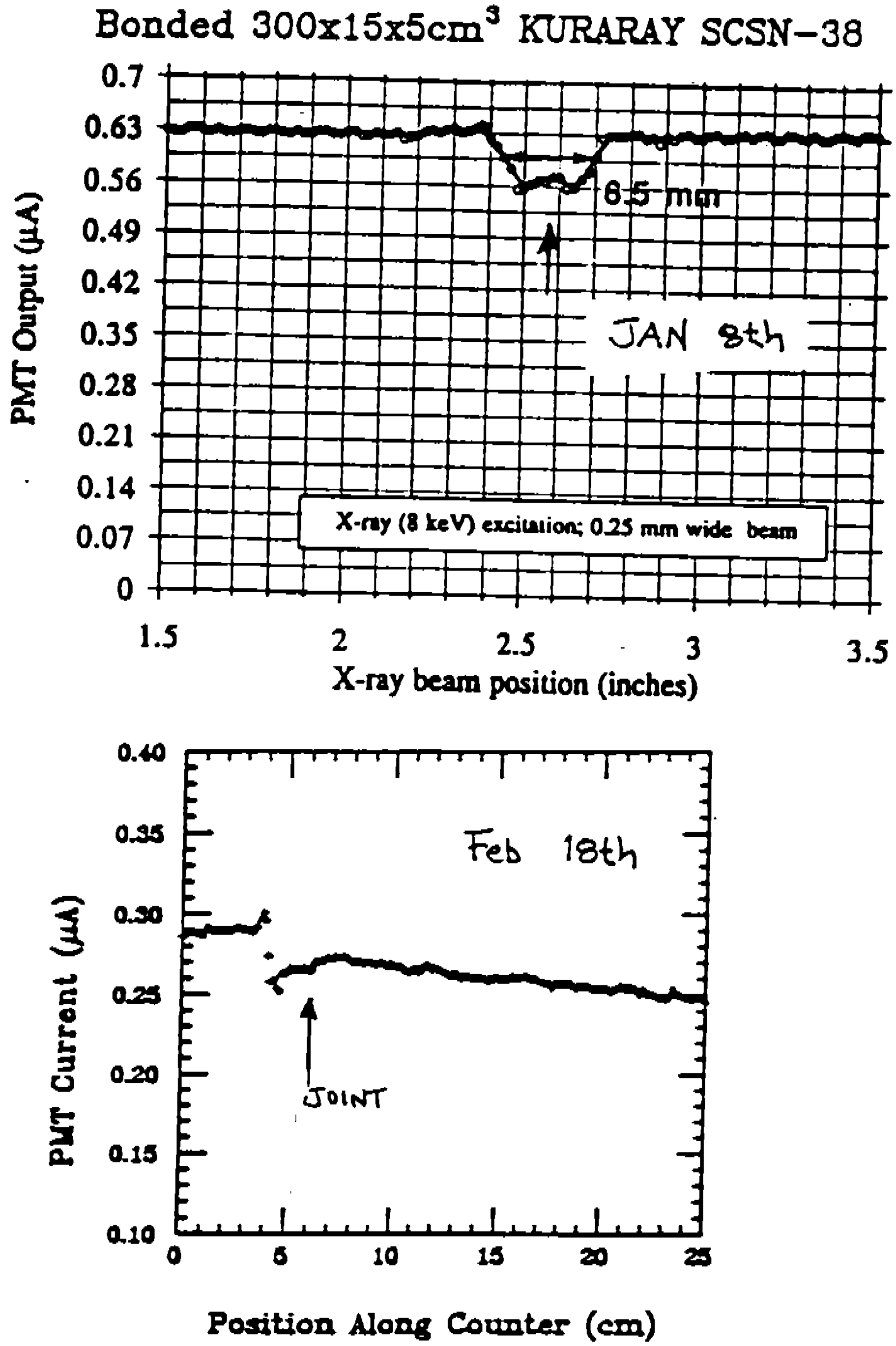

Figure 4: Fine scan along joint in a 350×15×5 cm^2 piece of SCSN-38 scintillator. a) Data taken January 8, 1992. (Note the axis is in inches). Light reduction occurs only around the joint. b) Data taken February 18, 1992. Light reduction occurs for all measurements taken on the far side of the joint.

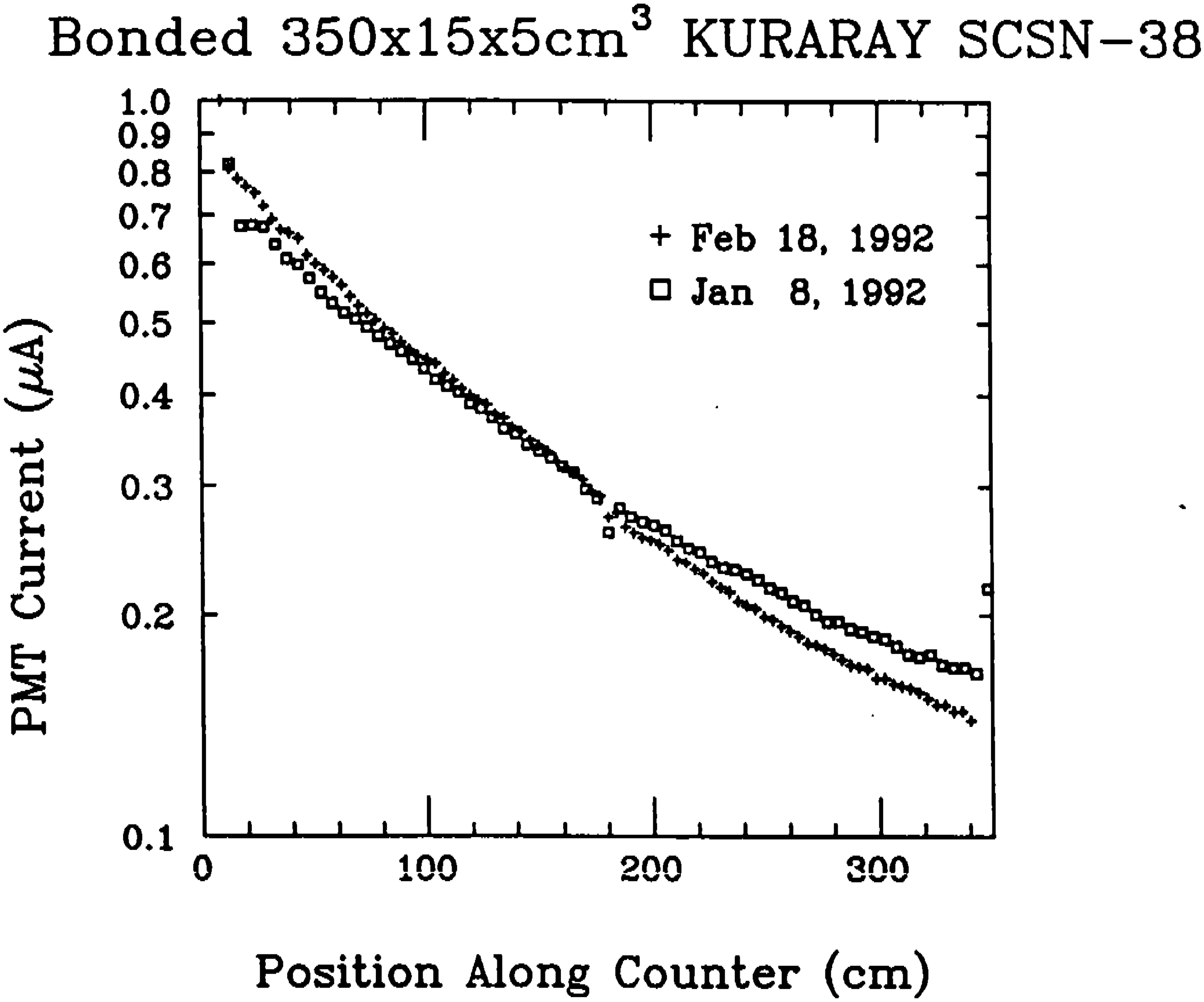

Figure 5: The light attenuation curve in a $300 \times 15 \times 5$ cm^3 piece of SCSN-38 scintillator. We compare two measurements taken a month apart. There is a 10-15% reduction in the attenuation length past the joint, indicating deterioration of the performance due to the scintillator bond.

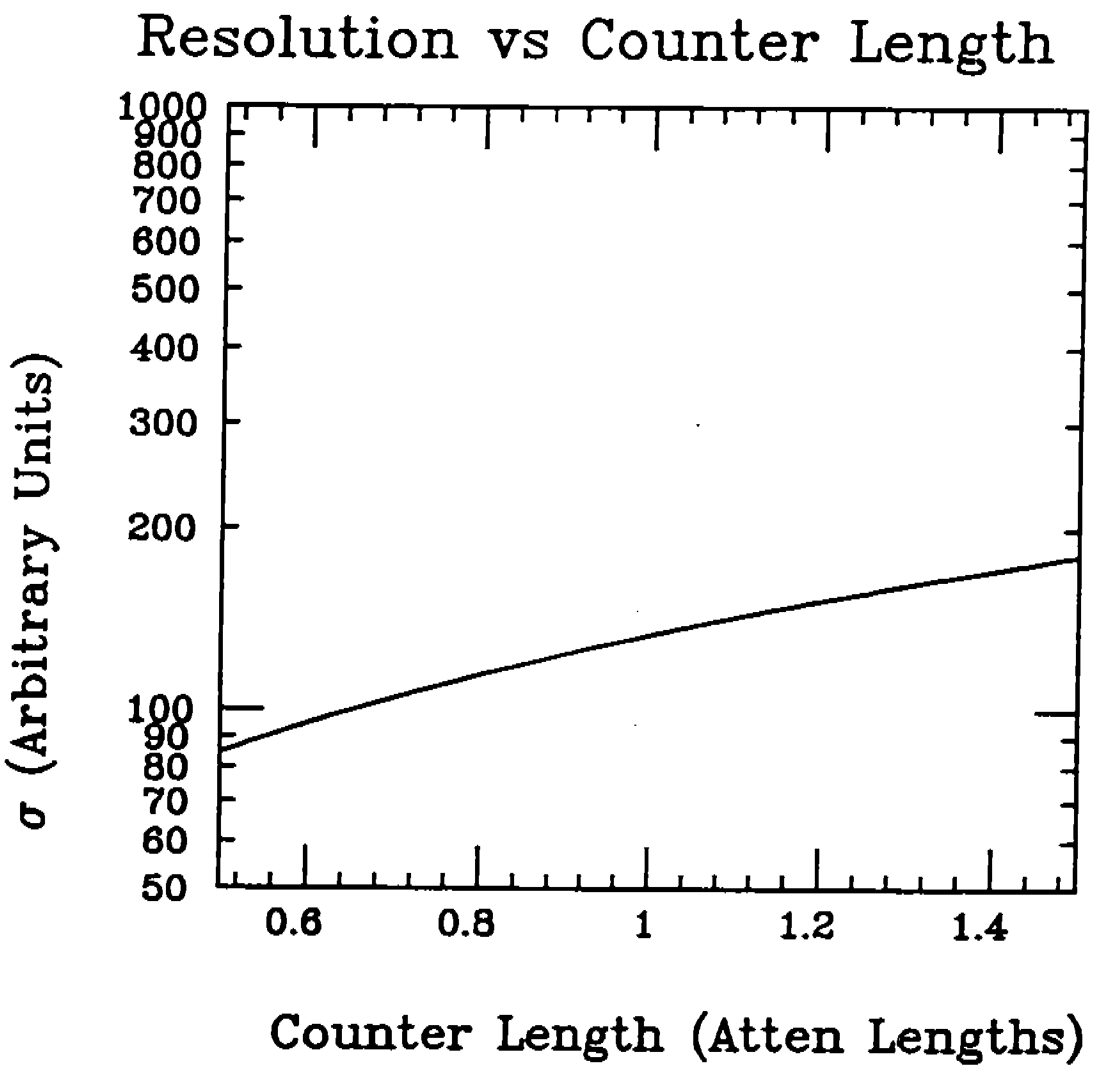

Figure 6: Assuming that the time resolution varies as the inverse of number of photons, we plot the time resolution as a function of counter length. The counter length is measured in units of the scintillator attenuation length.