Properties of Injection-molding Plastic Scinillator for Fiber Readout

Yukihiro Hara

Jan. 31th, 2005

Abstract

Plastic-scintillator plates with grooves for fibers have been produced by the injection-molding technique. These are based on polystyrene derivative. This is an attempt to use the injection-molding technique of scintillator for lead-scintillator-sandwich-type sampling calorimeters used in photon veto counters of kaon decay-in-flight experiments. The samples have grooves engraved on their surface when they were produced without using any machine tool. These grooves are used for wave length shifting fibers to read out scintillation light. The samples produced this time are 150mm $\times$ 150mm which have parallel 15 grooves on the surface of one side. For measurements, electrons from a ^{90}Sr radioactive source were used. As a result, the light transmission of injection-molding scintillator for the direction across the grooves was as well as for the direction along the grooves in comparison with casting one. On the other hand, the light yield is 12pe/MeV for fiber readout by one fiber with injection-molding scintillator. It is 60% of that with the casting one. Also, about 100pe/MeV light yield would be expected in using all 15 grooves from a simple sammation of each measurement by one fiber. It will be compared to actual measurement in a future study.

1 Introduction

1.1 Motivation

Kaon decay-in-flight experiments require huge amount of photon counters to cover a long decay volume[1,2]. Commonly, lead-scintillator-sandwich-type calorimeter is selected for such photon counters. When a photon enters a lead-scintillator sandwich calorimeter, the photon is converted into an electron-positron pair and deposits energy in scintillators. The deposited energy in scintillators is observed as scintillation light. The emitted light from the scintillators is usually read out through wave-length-shifting (WLS) fibers with longer attenuation length to achieve uniforme responce of the detector.

Scintillator plates with grooves for WLS fibers have been produced by the injection-molding technique. These grooves were engraved on one side of each sample by the injection mold process. The sample is a 150mm square and 5mm thick in design. This size is much smaller than the size of the scintillators used in the real experiments. This size was selected to keep the cost of this test reasonable. These small samples with grooves were made to test the injection-molding technique. Their properties such as light yield and light transmission through WLS fibers were checked.

1.2 What is the injection-molding plastic scintillator?

The injection-molding process is the most popular method used in mass production of plastic products. Once a mold is made, plenty of plastic products in the same figure can be made at low cost. This is why the injection-molding process is used popularly. However, this process has a weak point. In this process plastic is heated, melted and injected into a mold. Therefore, the scintillation material tend to be damaged because the material is treated at high temperature in this process. The properties of the plastic such as light emission and light transmission are said to be worse in general. Casting process is used generally in making plastic scintillator. In this process, plastic material is polymerized between two glass plates[3]. Compared with the injection-molding process, the material is treated at lower temperature in this process. Being at low temperature, the casting process keeps quality of plastic better than injection molding. Both light emission and transmission are better than those of injection-molding plastic. However, casting scintillator is expensive because the casting process requires more time and effort to make.

1.3 Test samples

Test samples of injection-molding scintillator were based on polystyrene derivative (Methyl methacrylate and Styrene :MS resin). The material was melted and injected into a mold. The temperature of the material was about $200°C$ in this process. The casting sample, which was made of Bicron BC-400 plastic scintillator based on polyvinyltoluen, was also prepared for comparison with the injection-molding sample.. The softening point of the plastic was $70°C$. The design of both test samples is shown in Fig.1 and Fig.2. Values show nominal dimensions in these figures. The actual size of the injection mold sample was 150.4mm $\times$ 150.3mm $\times$ 5.3mmt and that of the casting sample was 150.0mm $\times$ 150.0mm $\times$ 5.1mmt. Accuracy of the form of the casting sample was higher than that of injection mold sample because the shape of casting samples was machined.

2 Measurements and Results

To know the property of the light transmission and the light yield with the combination of injection molding and WLS fibers, two measurement methods were used, namely "direct readout" and "fiber readout". Direct readout was the method to read out the light from the scintillator directly. On the other hand, fiber readout was the method to read out the light from the scintillator through WLS fibers. In both measurements, the injection-molding sample was compared with the casting sample. Two PMTs, which were used in both measurements for readout and trigger, were H3178-51 made by Hamamatsu. H3178-51 is a standard 1-1/2 inch PMT. The arrangement of instruments is shown in Fig.3. A box for light shield was used in all the measurements. A ^{90}Sr sealed radioactive source was used for electron source. Electrons was collimated with a 1mm thick brass collimator with a hole of 8mmϕ. Energy deposit in 5mm thick plastic was estimated to be 1.2MeV. In Fig.4, the electric circuit diagram for the measurement is shown. A divider was used in direct readout. A linear 9 times amplifier was used in fiber readout. Obtained values of ADC channel were converted to their equivalent in a photoelectron(pe) yield. A value of pe/channel was determined by measurement of single photon. In this measurement, an LED was used for a light source. Light emitted from the LED was weakened to less than single photon by passing through 20 layers of paper.

Direct readout had a purpose of checking the light transmission in the scintillator. To check the effect of the grooves for light transmission, light yield in two directions- along or across the direction of the grooves were measured as shown in Fig.5 and Fig.6. The source position was varied in each direction. For each direction, 8 points were selected as source positions. When the light yield was measured along the direction of the grooves, the source position was varied along a parallel line which was in the center between the center groove and the adjacent groove. When the light yield was measured across the direction of the grooves, the source position was varied along a perpendicular to the grooves. To avoid electrons passing through the grooves, which are thinner region, the source position was set between two adjacent grooves. The window of the readout PMT was attached to an end of the scintillator. The center of the window was aligned to the center of the source position. Sillicon greace(OKEN 6262A, Oken) was used to connect the scintillator end with the PMT window. Any refrective material was not used in the direct readout because of strong light emission.

Fiber readout had a purpose of checking the light yield through WLS fiber(PSFY-11 SJ, Kuraray). In fiber readout, the samples were measured by two means.

1. With fiber position fixed, source position was varied along the grooves as shown in Fig.10.
2. With source position fixed, fiber position was varied against the grooves as shown in Fig.11.

The WLS fiber has multi-cladding and was mechanically strengthened fiber(S type). The diameter was 1mm. The scintillation light, which has wavelength about 420nm, emitted in the scintillator is captured by WLS fibers. Then, the WLS fibers emit the light, which has wavelength about 500nm, radially. The light, which fulfill the condition of total reflection, transported to PMT window. The used fiber was 90cm long and was bended to make a loop. This length of 90cm was good to make a loop. One part of the fiber was in a groove and the other part was kept outside the reflector. To know the property of each groove, the same fiber was used. Also, to increase the light yield, silicon greace was rubbed in the groove and the fiber end and the sample was wrapped by polyethylene terephthalate(PET) sheets(E60L, Toray). The PET sheets was white and 0.2mm thick. These sheets covered whole region of the sample except for two sides perpendicular to the grooves.

2.1 Direct readout

In Fig.7-9, the results of direct readout are shown. For each direction, similar tendencies were observed for both samples. It was predicted that injection-molding plastics have worse property of light transmission especially in the direction across the grooves because of an optical distortion near the grooves caused by turbulent flow of melted material injected into a mold with the grooves. However, the tendencies of light attenuation of injection-molding scintillator were as much as the cast one in both directions. Therefore, it can be said that the effect of the grooves of injection molding to degrade the light transmission is nearly equal to casting.

2.2 Fiber readout

The results of fiber readout are shown in Fig.12-14. As shown in Fig.12 and 13, the fluctuation of light yield was very small. At the nearest point of 2.5cm from the end of the scintillator of PMT side in Fig.13, light yield seemed rather small. It is thought to be caused by smaller fiber-surface receiving light at this position which is near the boundary between the scintillator and air. The light yield with injection mold was 12pe/MeV on average. It was 60% of that

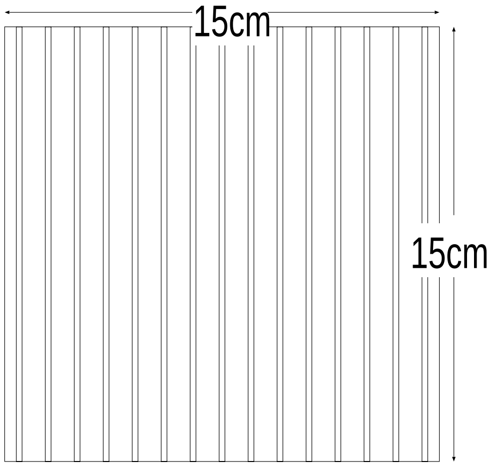

Figure 1: Plan view of the samples: Each sample has 15 grooves on one side of the surfaces. The other side is flat.

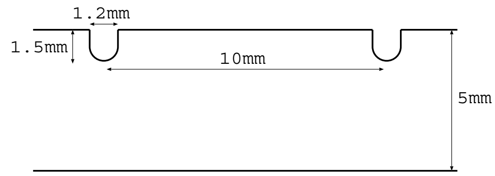

Figure 2: Magnified figure of cross section of the samples: Both samples -injection molding and casting- were made into the same figure. Injection-molding samples have grooves when they were made in the mold. BC-400 was used as a sample of casting plate. Machine tools were used to make grooves on this BC-400 plate.

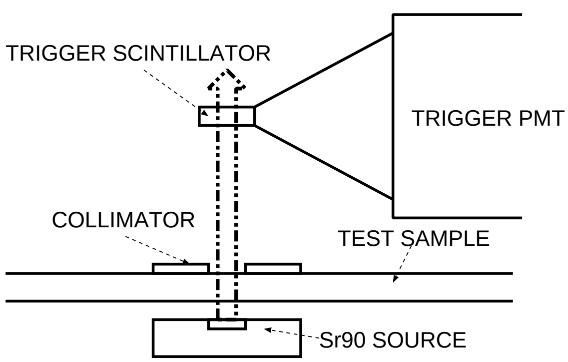

Figure 3: Setup for the measurement: Electron from the ^{90}Sr source deposits its energy in the test sample. Then, scintillation light is emitted and observed. To choose the emittion by the electrons, a trigger scintillator, which is 9mm $\times$ 9mm $\times$ 2mmt, was used.

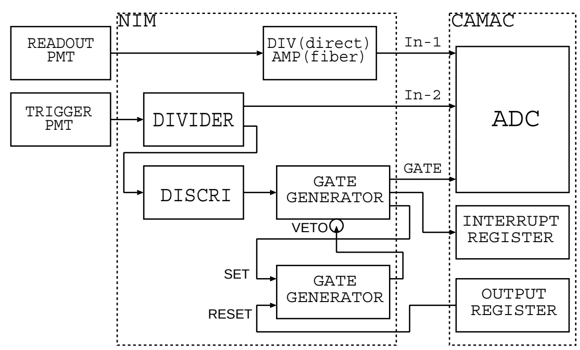

Figure 4: Electric circuit diagram: In this circuit, a divider was used for direct readout. An amplifier was used for fiber readout. This selection was done by the quantity of light emission.

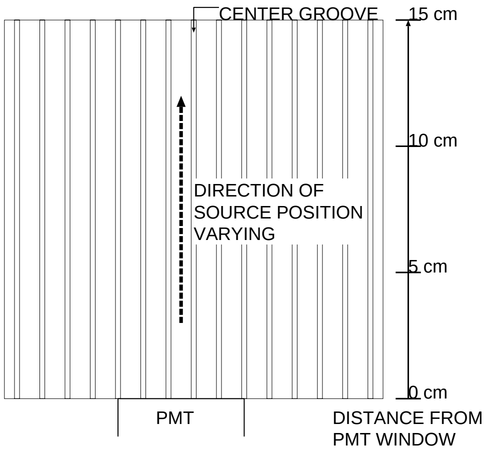

Figure 5: Variation of source position along the direction of the grooves

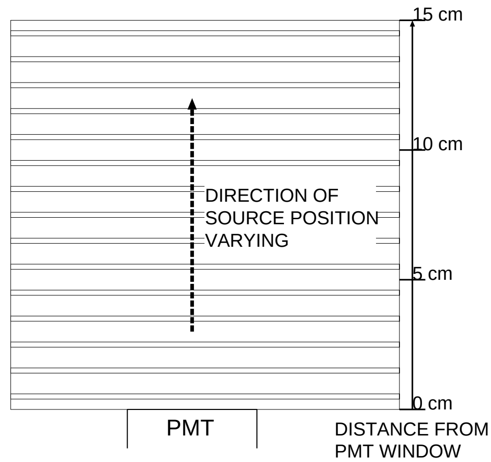

Figure 6: Variation of source position across the direction of the grooves

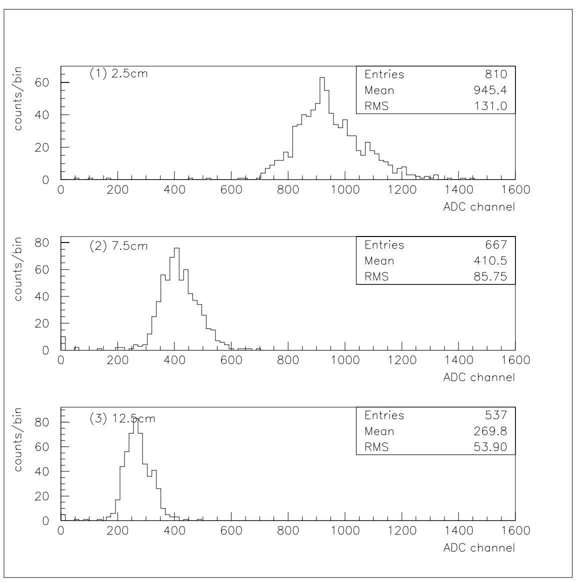

Figure 7: ADC distributions with varying source position by direct readout with injection mold plastic: The distance from source to PMT window is shown on top-left of each frame.

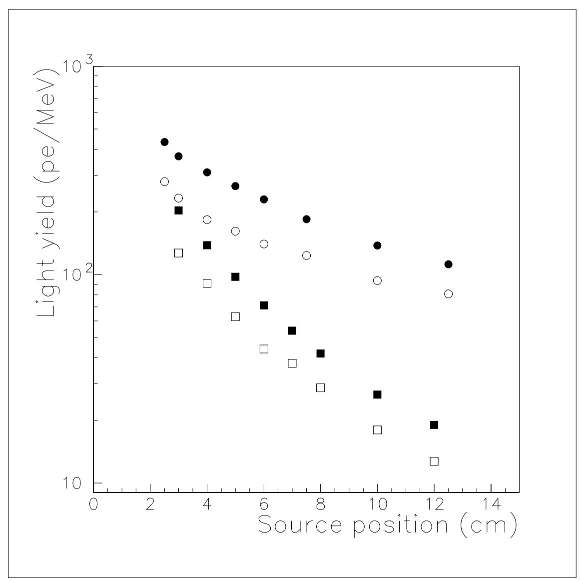

Figure 8: Light yield by direct readout from varying positions of source :Circles show along the direction of the grooves and squares show across the direction of the grooves. Each filled symbol shows injection molding and each open symbol shows BC-400.

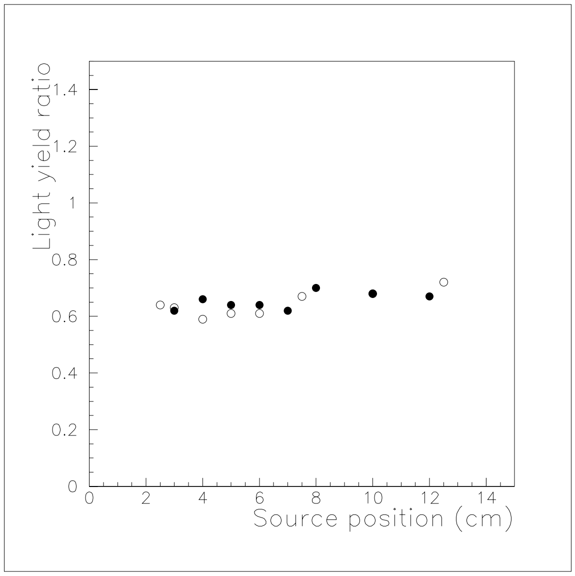

Figure 9: Light yield ratio of injection-molding to casting by direct readout with varying source: Open circles show along the direction of the grooves.On the other hand, filled circles show across the direction of the grooves.

with BC-400(20pe/MeV). Fig.14 shows the relation between the distance from light source to the fiber and the number of photoelectron.

Suppose that there is no difference in the light yield among all fibers enbedded in the 15 grooves. In this case, about 100pe/MeV light yield would be expected by simple interpolation. However, it is thought to be too much in another respect. Typically 10,000 photons of scintillation light are emitted per 1MeV of depositted energy[4]. On the other hand, trapping efficiency of both sides of WLS fibers' end was 10% and quantum efficiency of photocathode of the PMT was also 10%. Thus, a ratio of photons to get to photocatode of PMT would be expected to be about 1% = 10% $\times$ 10% through WLS fibers. The trapping efficiency is decided by the type of the WLS fibers and the quantum efficiency is decided by the type PMT. If other factors such as attenuation in the scintillator and WLS fibers, uptake ratio of photons into WLS fibers, and efficiency of wavelength conversion of WLS fibers are contained, the value of estimation will reduce. This difference between the two estimations will be considered in future study.

3 Summary

There are two conclusions. The first is that effect of the grooves to prevent the light transport was almost same between injection molding and casting. The second is that the light yield was 12pe/MeV by the fiber readout with injection mold. It was 60% of that of 20pe/MeV light yield of BC-400 casting scintillator. It was also observed that fiber readout has good uniformity along the direction of fiber. Incidentally, expected light yield by all the 15 grooves filled with fiber would be about 100pe/MeV by simple estimation from one-fiber readout. A comparison between the expectation and a measurement will be studied in the future test.

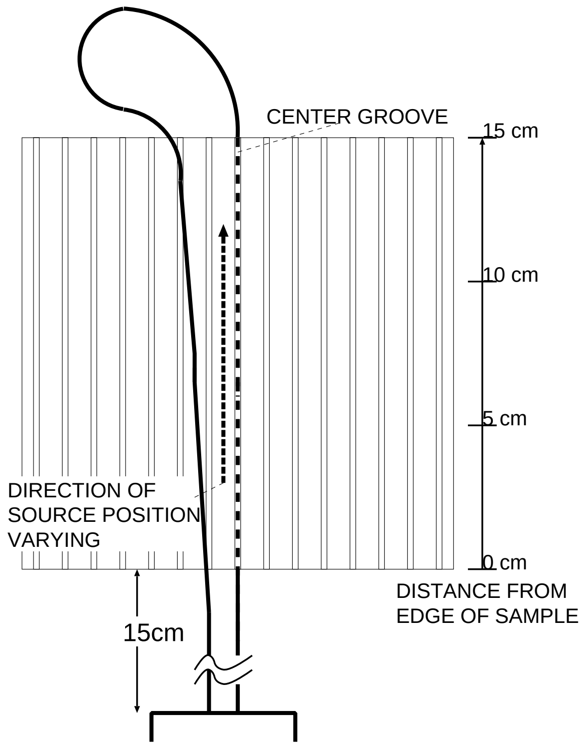

Figure 10: Variation of source position: Fiber was fixed on the center groove

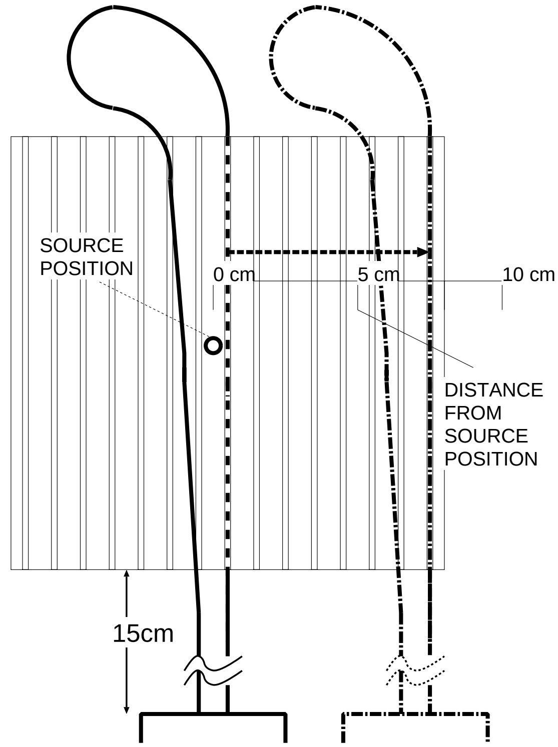

Figure 11: Variation of fiber position: Source was fixed on the center of the sample

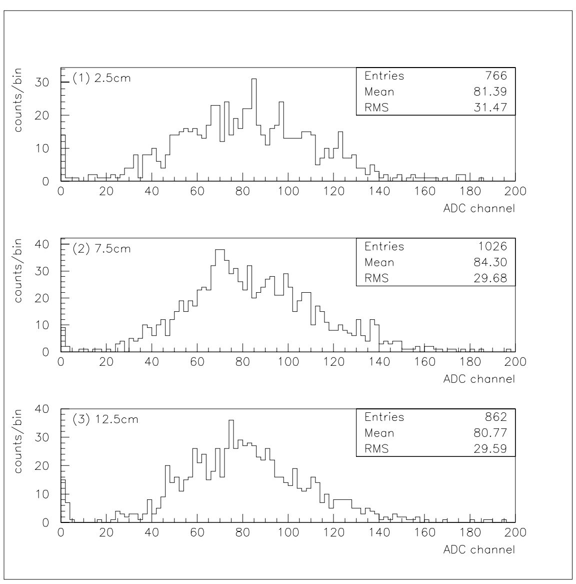

Figure 12: ADC distributions with varying source position by fiber readout with injection mold plastic: The distance from source to the edge of scintillator near to PMT is shown on top-left of each frame.

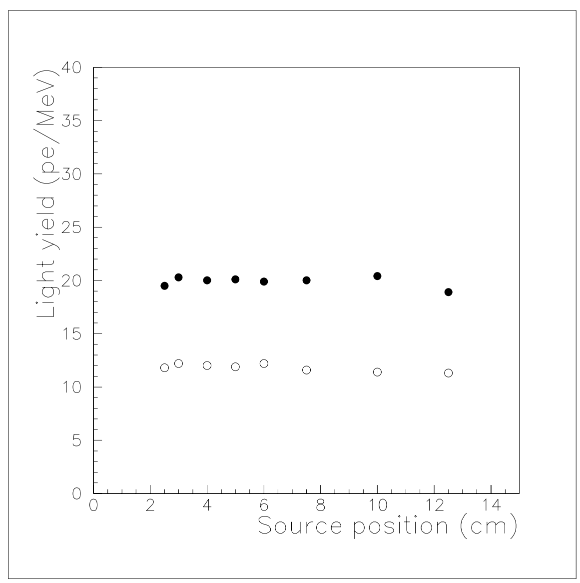

Figure 13: Light yield by fiber readout with fiber position fixed and source position varied: Filled circles show for BC-400 and open circles show for injection mold. Light yield varied little.

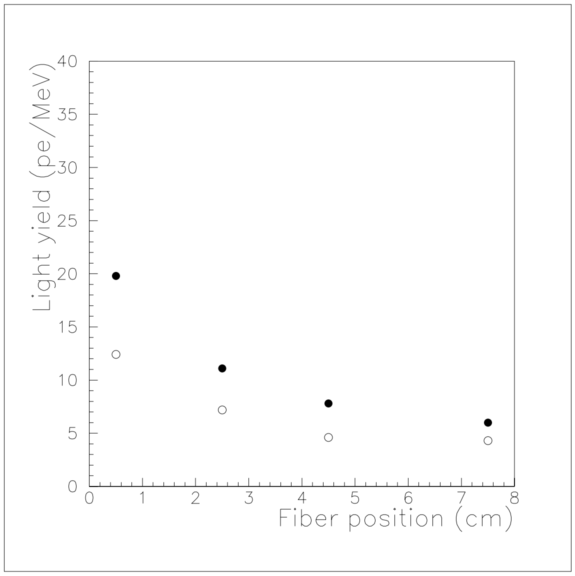

Figure 14: Light yield by fiber readout with source position fixed and fiber position varied: Filled circles show for BC-400 and open circles show for injection mold.

References

[1] T. Inagaki et al., KEK Internal:96-13: Proposal of an Experiment at the KEK 12 GeV Proton Synchrotron, Nov. 1996

[2] J. Frank et al., Charged Kaons at the Main Injector: A Proposal for a Precision Measurement of the Decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ and Other Rare K^+ Processes at Fermilab Using the Main Injector, Jun. 2001

[3] Y. Yoshimura et al., Nucl. Instr. and Meth. A406 (1998) 435-441

[4] R.C.Fernow, Introduction to experiment particle physics