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CALIBRATION OF AN AEROGEL COUNTER OF INDEX 1.1 AT THE BEVALAC

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ABSTRACT

A Cerenkov counter consisting of a mosaic with 48 aerogel pieces having refractive indices $n \approx 1.1$ has been exposed to sea level muons, and to a beam of relativistic ^{55}Mn at the Berkeley Bevalac. The counter is 6 cm thick and approximately 60 cm in diameter, and is viewed by twelve 12.7 cm diameter photomultipliers. A relativistic muon produces typically 23 ± 4 photoelectrons. The light yield has been mapped as a function of position and has an r.m.s. variation less than 1%/cm. Analysis of the light yield indicates that absorption is important at short wavelengths. The calibration shows that the light yield and uniformity of the counter suffice to determine particle velocity in the γ range from 2.4 to 3.1 precisely enough to achieve a mass resolution of 0.3 a.m.u. for the instrument described in paper OG2-7 of this conference.

1. INTRODUCTION

Silica aerogels have been used as radiators in many Cerenkov counters with refractive indices between 1.015 and 1.055 (Bouffard et al. 1982; Henning et al. 1981). The refractive index of the aerogel material can be increased by heating to a temperature near 900°C (DeBrion et al. 1981). An oven has been constructed at D.S.R.I. for this purpose, and aerogels with indices in the range 1.07 to 1.25 have been produced. In this paper we report on the fabrication and performance of a Cerenkov counter with $n \approx 1.1$ to be used in a cosmic-ray isotope experiment (Buffington et al. 1983).

2. FABRICATION OF THE COUNTER

As shown in figure 1, the radiator is fabricated from aerogel blocks 140 mm square and 20 mm thick to form a mosaic 60 mm thick and more than 580 mm in diameter. Triangular pieces fill in the corners. The individual blocks were precision machined to within 50μ of the desired size using a fly-cutting technique. The mosaic was then pressed together within a light integration box, using an array of small pressure plates around its periphery. The air gaps between the pieces of the mosaic are $< 100\mu$ everywhere. The raw material consisted of aerogel blocks 190 mm square and 30 mm thick, with $n = 1.05$, which were recycled from a CERN ISR experiment. The blocks were originally produced by the University of Lund, Sweden (Henning and Svensson 1981). No detailed production history is available. This is unfortunate, as the response of the aerogel to heat treatment varies between production batches far more than for the 18 pieces within each batch. The variations are typically $\Delta n < 0.005$ within a batch, but frequently $\Delta n > 0.05$ between batches. Of 85 blocks obtained from the CERN experiment, 48 are employed in constructing the mosaic. The selected blocks are closely matched in groups of three, having indices within 0.005, to ensure uniformity throughout the 6 cm total thickness.

Figure 2 shows the average index of refraction of the 16 groups of three blocks each, displayed versus the light yield for a $\gamma = 2.75$ ^{55}Mn beam passing through the center of each group. The index is determined from the increase, during the heating process, in density ρ as the volume of the blocks decreases. The relationship used is that for amorphous silica aerogel:

$$n - 1 = 0.21\ \rho$$

If unconstrained, the blocks become curved during the heating process as residual stresses are released during its plastic phase (~950° to 1000°C). This curvature is reduced by loading the blocks with 8 to 11 gm/cm^2 during heating. Any remaining departure from the desired rectangular shape can then be removed during the final machining of the blocks.

3. PERFORMANCE OF THE COUNTER

The light integration box is viewed by twelve 12.7 cm diameter photomultipliers. As shown in the inset of figure 2, the refractive index of the block in position #5, which occupied one of the center positions, is determined to be 1.094±0.001, using Bevalac data with several values of γ. This is in good agreement with the average value of 1.096 obtained from the density of the blocks. The fit to these data points also shows that the light produced by passage of a relativistic muon normal to the mosaic plane yields 23±4 photoelectrons.

As the counter is to be used in an isotope experiment, the errors introduced by the uncertainty in particle trajectory (see Schindler et al. 1983) sets an upper limit on the amount of allowable variation in light collected as a function of position. A preliminary analysis of the Bevalac exposure covering ~90% of the counter surface shows that >75% of the area has variations below the design limit of 2%/cm. This specification follows from the expected ±2 mm trajectory accuracy together with a permissible light output uncertainty of 0.4%.

As can be seen from figure 3, the variations in light yield are largest at the edges of the blocks. In principle, this effect could be caused by either a loss of light at the interfaces between the blocks, or variations in refractive index with position in the block. That the latter explanation is probably dominant can be seen from figure 4, which compares the block index as determined from the decrease in volume during heating (i.e. as a function of density), and the index determined from the deflection of a laser beam through a 90° corner of the block. The index is consistently lower in the corners, and although most of the edge material is removed during machining, enough remains to make the edges of the blocks fall outside of the design specification for the experiment. The decrease in light yield determined from the calibration map indicates that the average difference in refractive index from center to edge of the blocks is $\Delta n = 0.003$. Part of this area would be unusable anyway, since particles passing through the vertical interstices will probably have to be rejected in the data analysis.

The amount of light below threshold in position #5 is 3.6% of the relativistic light yield. Of this, 2.6% is due about equally from delta rays and Cerenkov light from the $BaSO_4$ paint grains on the surface of the diffusion box covers (Ahlen and Salamon 1979). This allows us to place an upper limit of 1% on the amount of scintillation produced in the aerogels.

Since the light yield near threshold varies rapidly with small changes in refractive index, it is important to ensure that the aerogel material is homogeneous so the errors from this effect will be small enough to allow good mass resolution (Meyer and Gaulier 1975). After photoelectron statistical fluctuations and δ-ray fluctuations are removed from the observed distribution, the residue can be explained by small-scale variations in the index of refraction, $\Delta n \approx 0.00025 \pm 0.00005$. Fluctuations of this size introduce an error $\delta M \approx 0.08$ a.m.u. for the ^{55}Mn mass determination. This error depends little on γ, but reduces to 0.03 a.m.u. for ^{20}Ne.

The 23 ± 4 photoelectrons for a relativistic muon is somewhat lower than the $\sim$40 theoretically expected for a 0.35 to 0.53μ bandpass. This suggests the presence of absorption at small wavelengths, probably in the aerogel; the short wavelength cutoff for the observed amount of light in this case would be 0.42μ, assuming a sharp cutoff. Partially supported by NASA grant NGR 05-002-160.

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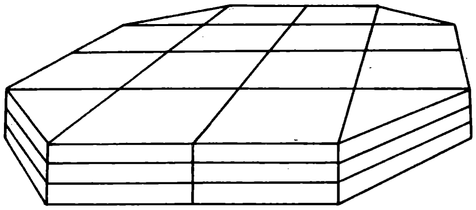

Fig. 1. Schematic diagram showing the placement of individual aerogel blocks to make up the fabricated mosaic.

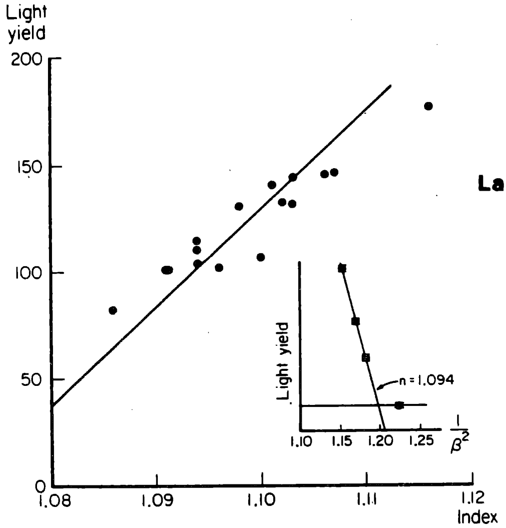

Fig. 2. Light yield versus refractive index as determined by the density method. Straight line indicates expected relationship. *Inset*: Light yield versus $1/\beta^2$ for data with upstream material, for aerogel block #5, one of the four center blocks. The intersection of the sloping line with the flat line (residual light other than aerogel Cerenkov, as determined by the data point below threshold) fixes the index of refraction for this block.

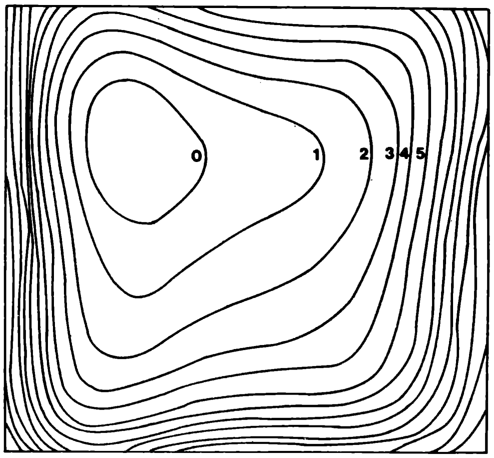

Fig. 3. Contours of equal response for aerogel block #5. The curves mark 1% intervals, which *decrease* from the "0" contour above and to the left of center.

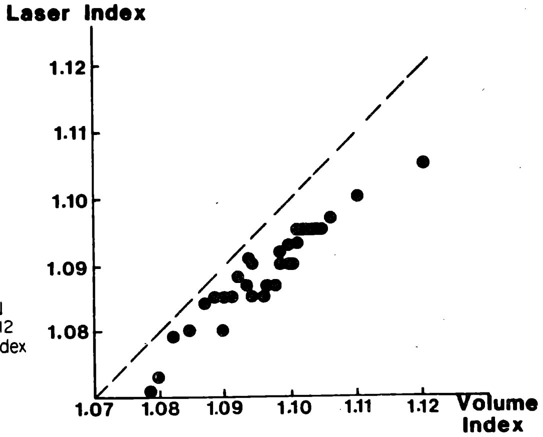

Fig. 4. Comparison of the index of refraction as determined by the volume (density) method, and by the laser method. Dashed line indicates a perfect correlation. The laser index is systematically smaller than the volume index by about 0.005. This is attributed to a smaller index of refraction near the edges, which is the region measured by the laser method.