Scintillator Light Yield Variation due to the Reflective Wrapping

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1 Abstract

During calibration of an X-ray spectrometer composed of rails of scintillator blocks, Dasgupta et. al. [1] observed large discrepancies between each scintillator blocks' light yield when radiated by a Sodium-22 (Na-22) source. Forty individual scintillator blocks of the same shape and type collectively constituted the yield data set with a variation of 16.7%. We demonstrate using Monte Carlo simulations of light transport in scintillators, that the cause of this high variance could be accounted for in variations of thickness of the reflective material on the scintillators' surface. Literature figures that related the number of layers of reflector tape to the reflectance coefficient were employed to then produce a distribution of reflectance coefficients that fully justify variations in the reflectivity as the source of light yield variation.

2 Introduction

Dasgupta et. al. wrapped fifty individual blocks of Lutetium Ytterbium Oxyorthosillicate (LYSO) with Polytetrafluoroethylene (PTFE) tape. Each scintillator was of dimension $2 \times 10 \times 30\text{mm}^3$, and sourced from Saint-Gobain [2]. The fifty scintillator blocks were divided into sets of ten, and each set was irradiated with Na-22, as shown in Fig.1. Ideally all scintillator blocks would perform consistently when exposed to the same amount of ionising radiation, with anticipated marginal variation due to manufacturing constraints. However in the report large variations were shown in the light yield of each scintillator, greater than expected from a manufacturing fault alone, as can be seen from four of the sets as shown in Fig.2. A fifth (Rail C) was excluded due to the raw data being lost.

2.1 *Simulating Light Transport*

A Monte Carlo simulation was employed to model the light transport in a scintillator with the same properties. One of the faces was assigned as the detector face; where the light exits the scintillator to be captured by a photo-detector. The remaining faces acted as diffuse reflectors of the light inside the medium, with a reflectance coefficient that determined the amount of light internally reflected. This simulation has accurately reproduced trends in light yield when the dimensions of the

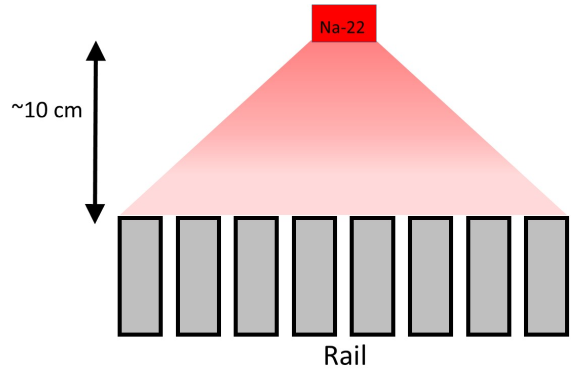

Figure 1: Calibration setup of X-ray spectrometer. The distance of the radiative source was much larger than the width of the rail, and so the amount of radiation incident on each block can be considered uniform.

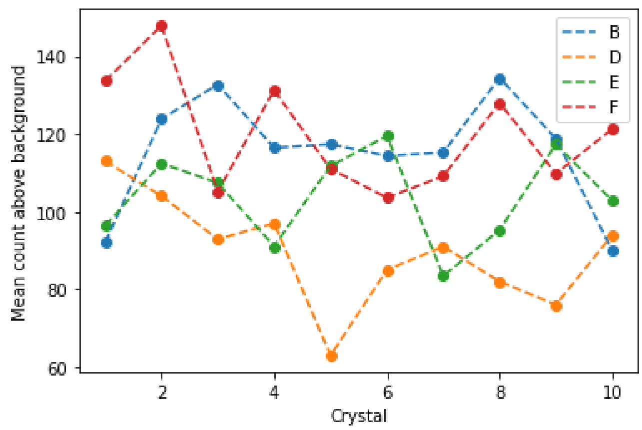

Figure 2: Dasgupta's results of each rail measured. The large discrepancies between each scintillator block are greater than expected, with a coefficient of variation of 16.7%.

Layer(s)	Reflectance Coefficient (%)
1	85
2	92.6
4	94.4
8	96.2

Table 1: Findings from Janecek [4] of the reflectance coefficient of PTFE tape. The thickness of the tape was 0.06mm. More layers of PTFE tape correspond to a higher reflectance coefficient.

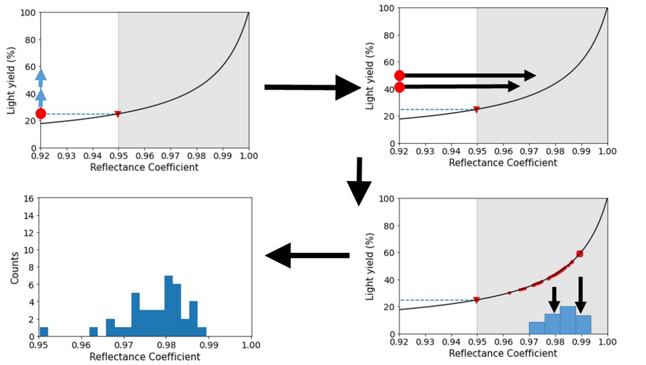

Figure 3: Graphical representation of the light yield model being used to find the effective reflection coefficients of each data point.

scintillator vary, with a Pearsons $R > 0.96$.

For modelling the wrapping material, a reflectance coefficient range of 0.8 - 1.0 was used to show how the light yield varied with respect to the reflectance coefficient. The reflection regime was diffuse. The Fresnel equations and total internal reflection were also implemented in the simulation to replicate light interaction at the detector face.

Typical values of the reflectance coefficient for PTFE vary with respect to thickness and density [3] but are generally found to be ≥ 0.97 for thicknesses ≥ 1.59mm. In experiments, scintillators are wrapped with PTFE tape, which is much thinner than this figure, and so extra layers are wrapped over the scintillator body to compensate. Janecek [4] found the reflectance coefficient of 1,2,4, and 8 layers of PTFE tape, each layer of thickness 0.06mm. These coefficients are shown in Table.1, and will be used throughout this report.

We assume an attempt was made to wrap each scintillator consistently, but it is unknown how many layers or what thickness of PTFE tape was used by Dasgupta et. al. As of such, the reflectance coefficients in Table.1 were substituted, each representing a number of wrapped layers. We intended to map these reflectance coefficients to both the mean light yield, and the minimum light yield that Dasgupta measured. This is due to the fact that the parameters of how the PTFE was wrapped is also unknown.

Normally, the thickness of PTFE wrapped is not homogeneous, and so there will be zones on the surface area of a higher and lower reflectance coefficient. If this alone determined the variation in light yield, and the entire surface area is wrapped, then there is only a lower limit applied onto the range of reflectance coefficients. It thus is logical to map each reflectance coefficient from Table.1 to the lowest yield Dasgupta measured (Found for rail D on Fig.2), as any variation will only increase the yield.

However, this fails to treat losses of light yield that can occur through grains of dust found between the PTFE tape and the scintillator that could disrupt the light scattering process. Although unlikely, it also fails to treat the case that some surface area of the scintillator is left bare. These two conditions allow for the effective reflectance coefficient of the wrapped PTFE to be less than that prescribed in Table.1 for the given thickness. If this is the case, then it would be logical to map the reflectance coefficients listed in Table.1 to the mean light yield found by Dasgupta in Fig.2.

The technique of mapping the minimum reflectance coefficient is highlighted in Fig.3 as to how the light yield - reflectance coefficient function is used a mapping tool, to find the respective reflectance coefficients of all the other scintillator crystals Dasgupta used. The process in which the coefficients are mapped to the mean light yield is equivalent, but its starting value is at the mean light yield instead of the minimum light yield data point found by Dasgupta.

3 Results

If the reflectance coefficient from Table.1 corresponds to the minimum or mean light yield data point in Dasgupta's report then every single data point can be justified by variations in their effective reflectance coefficient. Fig.4 shows the minimum and maximum yields and their corresponding reflectance coefficients on the line plot of the simulations light yield - reflectance coefficient relation.

The distributions in Fig. 5 shows the frequency of scintillators wrapped to an effective reflectance coefficient for each mean/minimum reflectance coefficient in Table.1.

4 Discussion

The four graphs in Fig.5 illustrate the distribution of reflectance coefficients that Dasgupta may have effectively wrapped the scintillators to. As predicted, the figure shows a distribution typical of measurements affected by human error. The minimum regime data points map to higher reflectance coefficients on average, as the reflectance coefficients from Table.1 are mapped to the minimum light yield data points, as described in section. 2.1. Because the range of reflectance coefficients used in the simulation was restricted between 0.8 - 1, the minimum value for $R = 0.85$ found in Fig.4 for the mean regime is not displayed.

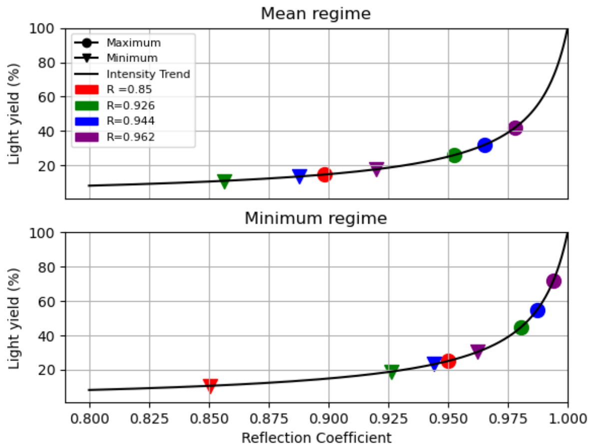

Figure 4: Of the distribution of reflectance coefficients that result from the mapping process described, the minimum (triangles) maximum (circles) and maximum (circles) mapped coefficients are shown here. For the minimum regime, the prospective coefficients in Table.1 are mapped to the minimum yield data point. For the mean regime, the coefficients are mapped to the mean light yield of the Dasgupta's data. These markers are placed onto the intensity trend that was found through simulating photon transport within a scintillator, the reflector of which is modelled from PTFE's reflective properties. The minimum data point found on the mean regime for R=0.85 is outside of the range R= 0.8 - 1, and so could not be mapped.

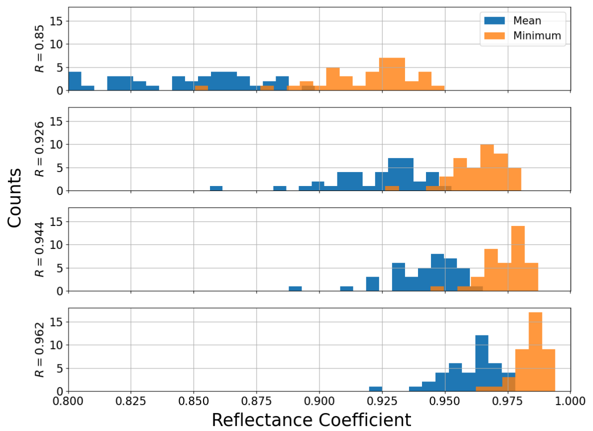

Figure 5: Distribution of effective reflectance coefficients from Dasgupta et. al's report, where each row signifies where the minimum (green) or mean (blue) reflectance coefficient corresponding to Dasgupta's data points. All data points satisfy the condition $R < 1$.

This evaluation was carried out with the assumption that the reflectance coefficient solely can explain the variation observed in the light yield. However other parameters will give room for statistical fluctuation, such as the manufacturing faults that could cause the yield to vary between each scintillators light yield. As the measured data from Dasgupta's report is averaged over a five minute minute exposure the stochastic nature of radioactive decay - both within in the scintillator as self emission, and the Na-22 source is not likely to be a main contributor of variance in the yield.

Variability in PTFE reflectivity has been observed by Ghosh et. al [5] for the same sample, demonstrating further that human error is not the only factor in light yield variation. This variability in reflectivity generally reduced as the wavelength changed from UV to visible light, for PTFE of thicknesses 5-10mm. The emission spectra of LYSO is generally larger than 350nm, with a peak emission at 420nm [6]. Within this spectrum the variability in reflectivity found by Ghosh et. al appeared to remain below 2%, however these are for thicknesses much higher than those used in scintillator experiments. The exact variability was shown to change indiscriminate of the PTFE thickness.

Cuboids can be wrapped in different ways, each with a necessary amount of overlap to ensure that no part of the scintillator is unwrapped. Because the reflectance coefficient of PTFE depends on the thickness, this causes the reflectance coefficient to vary depending on the surface region of interest. One layer of overlapping PTFE should in principle perform marginally better than with no overlap in reflecting light, and result in an 'effective' reflectance coefficient - the equivalent reflectance coefficient of the scintillator if it were wrapped homogeneously. If further developments were made to justify this conclusion further it would be to observe how much the effective reflectance coefficient would change with small and large overlaps, and whether this supports the variance in the reflectance coefficient we see in Fig. 5.

5 Conclusion

By using a Monte Carlo simulation of optical light transport within a scintillator, we show that the wide discrepancies noted by Dasgupta can be wholly explained if the range of reflectance coefficients 0.95-0.97 are assigned to the minimum light yield data point. This does not presume any margin of error incurred on Dasgupta's data set from manufacturing faults. If it did, a larger range of reflectance coefficients would be permitted, strengthening the likelihood of variation in PTFE thickness being the source for the large variation.

References

[1] A. Dasgupta, C.D Armstrong, D.Neely, D.R. Rusby, G.G. Scott - *Calibrating LYSO crystals part of a hard X-ray spectrometer* CLF Annual Report 2019

[2] Saint-Gobain LYSO Datasheet, Accessed 03/2021 `https://www.crystals.saint-gobain.com/sites/imdf.crystals.com/files/documents/lyso-material-data-sheet.pdf`

[3] B.K. Tsai, D.W. Allen, L. M. Hanssen, B. Wilthan, J. Zeng - *A Comparison of Optical Properties between High Density and Low Density Sintered PTFE*, SPIE Vol. 7065, 70650Y, (2008)

[4] M. Janecek - *Reflectivity Spectra for Commonly Used Reflectors*, IEEE Transactions on Nuclear Science, Vol. 59, No. 3, (2012)

[5] S Ghosh -*Dependence of polytetrafluoroethylene reflectance on thickness at visible and ultraviolet wavelengths in air*, Journal of Instrumentation, Vol. 15, P11031, (2020)

[6] C.M Pepin et. al *Properties of LYSO and recent LSO scintillators for phoswich PET detectors*, IEEE Transactions on Nuclear Science 51(3):789 - 795 (2004)