FEASIBILITY STUDIES FOR A POSITION SENSITIVE DETECTOR USING PLASTIC SCINTILLATION DETECTORS

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ABSTRACT

Position sensitive detectors have many possible applications, either in industry, medicine, physics, etc. In plastic scintillation detectors, the light from the scintillating material is partially absorbed in the plastic bulk. Then, in principle one can determine the position of a radioactive source using the difference between the signals coming out from two opposite edges of the detector.

In this work, the variation in the signals collected in two photomultiplier tubes placed in the edges of a plastic scintillator detector is studied. The spectrum from each of the PM's is digitized, and then we study how they change when the source position changes. The plastic scintillator detector used, measuring 2x2x20 cm^3, was developed by IPEN's Nuclear Applications in Industry Department, made with styrene polymer added with 0,5% PPO - "1,4 difenyl-oxazol" and 0,05% POPOP - "1,4-di-2-(5-fenyl-oxazolyl)-benzene". The main reason for using a plastic scintillator detector comes from the ease for making this kind of detector and its low price.

The results show that the system is, indeed, position sensitive, and that further efforts should be made to enhance its sensitivity and resolution.

I. INTRODUCTION

Light Attenuation On Plastic Scintillators & The Detection Concept. On plastic scintillators, the spectrum of the emitted light partially superposes with the light absorption spectrum of the plastic bulk; as a consequence, the light intensity decreases while it propagates through the detector. Depending on the scintillator-bulk composition, the length for which the light intensity decreases to half of the initial one (we'll call it half-distance on the remaining of this paper) varies from tenths of centimeters to several meters. This phenomenon, known for years as one of the drawbacks of plastic scintillation detectors, could, in principle, be used to determine the position of a radioactive source; the idea is quite simple: if the light emitted in the scintillation process is progressively absorbed as it travels through the plastic, so one could measure the difference in pulse height on two opposite edges of a long (i.e., with a length of the same order as the half-distance) plastic scintillator, and from this determine the position of the source.

The advantage of this method of position determination consists in the very low price of the plastic scintillator and in the feasibility to build these detectors in different shapes and sizes to suit different applications. Also, the reduction in the number of photomultipliers needed in this kind of assembly (basically two PMT's are needed for each dimension, i.e., 6 would be needed to assemble a 3-dimensional system) in comparison to the most common NaI-based system, where at least 9 PMT's are needed, shall reduce the cost of the electronic system required to build a three-dimensional radioactive source mapping system.

Possible Uses. The development of this detector is part of a bigger project, where we intend to develop a detector specifically designed for breast cancer diagnosis. In this project, 2 large detectors would be employed to determine the spatial position of the emitting source. In the first stage, we shall determine (using a one-dimensional detector) if the plastic scintillator detector meets the minimum requirements of this use, i.e., if it can determine the source's position within a 5mm uncertainty; The following step consists of the development of a larger, 2-dimensional detector, which shall be employed in the final detection system. The final step consists in mounting the final prototype, joining 2 of such detectors in order to allow 3-dimensional position determination.

On the other hand, position sensitive detectors may also be used in a large number of applications, specially in industry. These uses, although not part of the primary scope of this project, shall also be studied if the detector proves useful.

Experimental Procedure. In order to study the dependence of the detector's output with respect to the position of the radioactive source, we started with a very simple spectroscopic equipment arrangement, and then introduced several stages of signal treatment; also, studies were made for two different detectors in order to analyze the influence of the detector polishment in the final results. These studies, together with its results, are presented in the next section.

II. EXPERIMENTAL SETUP & RESULTS

The Detector. The plastic scintillator used in this research was produced by the Nuclear Applications in Industry Department of IPEN (0.5% PPO and 0.05% POPOP in polymerized styrene), and was 20 cm long, 2 cm wide and 2 cm tall; the 2 square faces would each be coupled with a 14-pin photomultiplier tube (Amperex XP2202B). Experiments made by Mesquita *et al* [1] showed that for this particular type of plastic scintillator the dependence of the light intensity with the detector thickness consists of the sum of two exponential factors, as seen in Eq. (1):

$$I(x) = I_0 \cdot (0.481 \cdot e^{-0.02112 \cdot x} + 0.519 \cdot e^{-0.0016 \cdot x}) \quad (1)$$

In the first assembly tested, the two square faces were polished and the other four were only wrapped with Teflon tape.

Later, the remaining four faces were also polished and then painted with reflexive paint (The Harshaw Chemical Co.) in order to verify the influence of this parameter in the system's response.

Initial Instrumentation Setup. In the first detection system assembled, the data from one photomultiplier was amplified and then collected in an MCA (fig 1); the typical results obtained using this system are shown in Fig.2, where one can notice that the count rate for every position is too high in the first channels and that, although one can notice some differences on the various spectra, this difference isn't really easy to see.

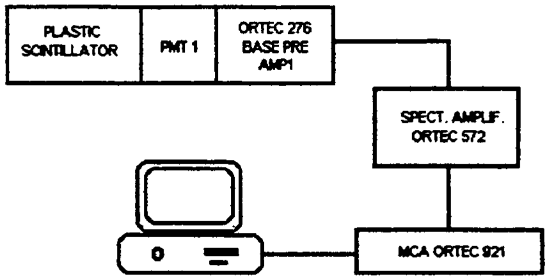

Figure 1. Initial Instrumentation Assembly.

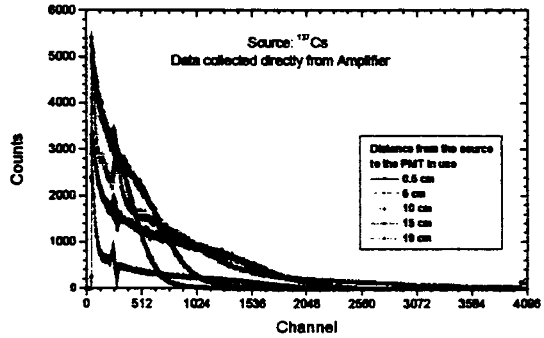

Figure 2. Spectra Collected Using the System of Fig.1 For 5 Different Source Positions.

In order to increase the detector's resolution, the system shown in Fig.3 was assembled; in this case, a pulse is counted only when there are pulses reaching from both photomultipliers at the same time and the sum of the amplitudes of both exceeds some fixed value (this value was experimentally set for each source type). The coincidence requirement was set only to reduce the noise level, "cleaning up" the spectrum. The second condition, on the other hand, had the objective of removing the low-energy Compton events (due to the absence of high-Z materials in the plastic scintillator used, the probability for photoelectric absorption in this detector was very small) which were responsible for a high count rate in the first channels that would "mask" any peaks that should arise. With the introduction of this system, the experimental results were greatly improved and we were able to collect spectra like the one in Fig.4. To analyze these data, a gaussian peak was fitted to each of the positions' spectra; the results for one of the PMT's are shown in Fig.5, where the error bars represent the standard deviation of the gaussian peak fitted; here it is more easily noticed that the detector's output differs for each different source position. Based on these promising results, we've decided that the detector was indeed position sensitive, but that further improvements would be needed in order to enhance the (still far from satisfactory) results.

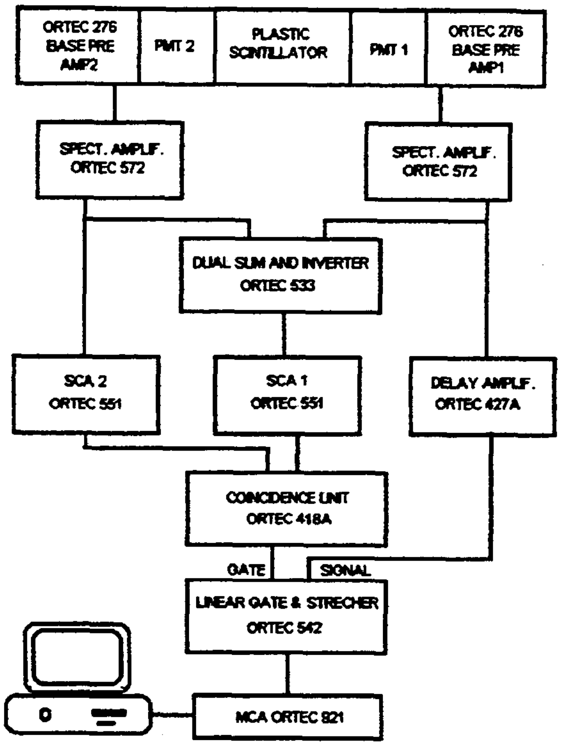

Figure 3. Instrumentation Assembly Using Coincidence.

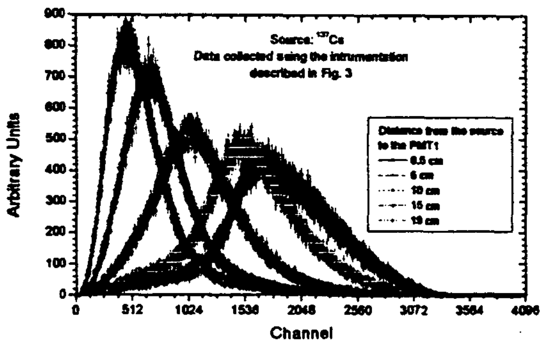

Figure 4. Spectra Collected for 5 Different Source Positions Using the System Shown in Fig.3 and a ^{137}Cs Radioactive Source

In a different approach to the analysis of the dependence of the detector's response in respect to the source's position, we can define the "average channel" of the spectrum as:

$$f(x)=\frac{\sum_i C_i(x)\cdot i}{\sum_i C_i(x)} \tag{2}$$

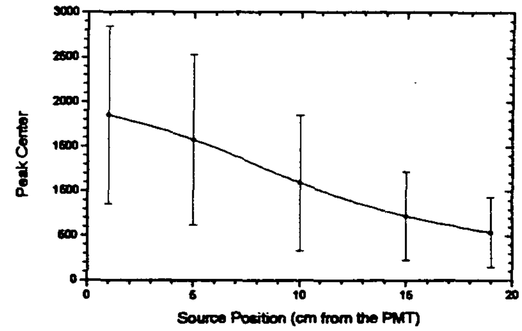

Figure 5. Peak Center vs. Source Position for the Same Data Shown in Fig.4.

Also, in order to join the information from both photomultipliers in a consistent way, we can calculate the ratio

$$R(x)=\frac{f(x)_{PMT1}}{f(x)_{PMT2}} \tag{3}$$

and analyze how it changes with the position of the radioactive source. In Fig.6 one can observe the dependence of these ratios with respect to the source position, for the same data shown in Figs.4 and 5 (only using the data from both PMT's).

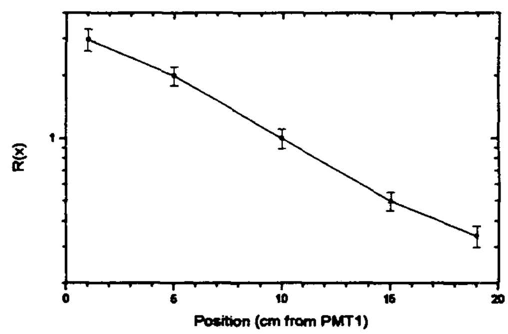

Figure 6. Ratios Calculated According to Eq.(3) for the Same Experimental Results Shown in Figs. 4 and 5.

At this point, it can be noticed that all measurements so far were made with the detector polished only on the square faces coupled to the PMTs and, in order to analyze the influence of the detector polishment on the result, we decided to polish all six faces of the detector, painting the four rectangular ones with reflexive paint, and repeat all measurements.

The results obtained with the polished detector are shown in Figs.7 and 8. The main difference to the previous results is that the dependence of the spectra with the source position was increased. This phenomenon can be understood as a consequence of the coincidence requirements, as there's some distortion in the edges of the detector, due to the fact that many pulses that travel a long way inside it are "lost", not reaching any PMT; when the source is near to the PMT that's counting, some of the strong pulses aren't be counted because the weak pulse that headed towards the other PMT is lost before getting there, thus decreasing the average light intensity for this position; on the far edge, on the other way, the weak pulses would be absorbed before getting to the counting PMT, increasing the average light intensity for that particular PMT.

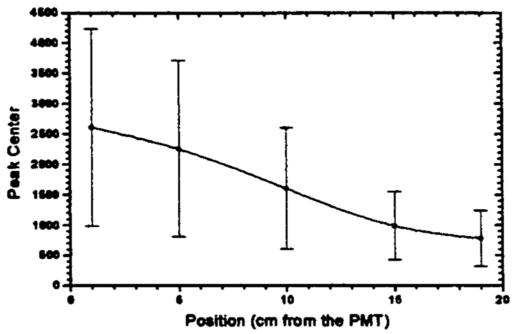

Figure 7. Peak Center vs. Source Position for the Polished Detector.

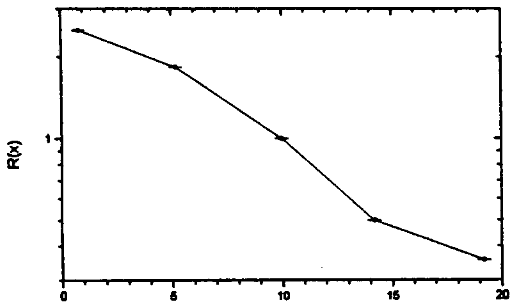

Figure 8. Ratios Calculated According to Eq.(3) for the Same Experimental Results Shown in Fig.7.

After the measurements with the polished detector, the next step was to install it inside a collimator, in an attempt to improve both the light collimation and the optical coupling stability. The results, shown in Figs. 9 and 10, show that the new system, as expected because of the better γ-ray collimation, had its resolution increased.

Finally, to analyze the dependence of the system's response with respect to the energy of the γ-ray, experiments with a ^{99m}Tc source ($E\gamma$=140.5keV) were performed. It must be noted that some of the system's setting, like amplifier gains and the value of the threshold on the summation, had to be changed in order to make the detection feasible. The comparison of these results with the previous ones (made with a ^{137}Cs source, with $E\gamma$=661.7keV), shown in Fig. 11, shows that the ratios, calculated using the formula given in Eq.3, appear to be almost independent of the source energy.

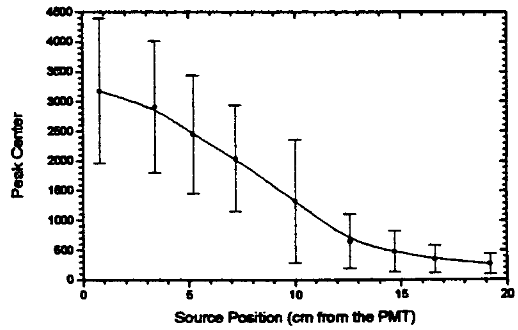

Figure 9. Peak Center vs. Source Position for the Polished Detector Inside the New Collimator.

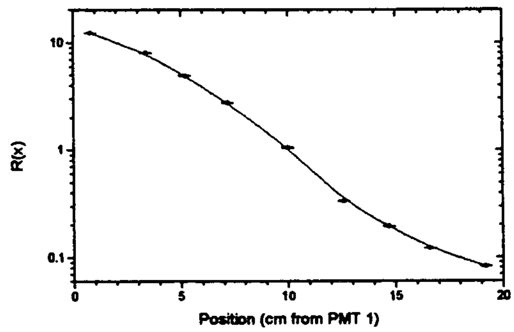

Figure 10. Ratios Calculated According to Eq.(3) for the Same Experimental Results Shown in Fig.9.

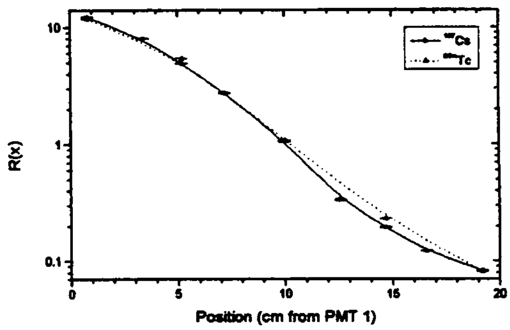

Figure 11. Comparison of the Ratios Calculated According to Eq.(3) for two γ Sources With Different Energies.

III. CONCLUSIONS

The experimental results presented in this paper show that the response of a plastic scintillator detector changes significantly when the position of the radioactive source is changed. In order to prove useful for the intended use (the development of a detector for breast scintillography), the detector's response should be enhanced, either by means of new hardware (a new system arrangement) or through a different approach to the analysis of the experimental results. Also, some reverse-calculation studies are being made to allow to the determination of the exact spatial resolution, and some theoretical models are being developed in an attempt to find ways to improve even further the detector's performance.

REFERENCES

[1] Martini, E.; Hamada, M. M. & Mesquita, C. H. **Light attenuation studies in the plastic scintillator detector**, Revista Brasileira de Pesquisa e Desenvolvimento, vol. 1, p. 73-77, 1996.