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# COPING WITH PLASTIC SCINTILLATORS IN NUCLEAR SAFEGUARDS*

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## Summary

Plastic scintillators offer several advantages for nuclear safeguards research and technology to those who design, assemble, encapsulate, and calibrate detectors from raw materials that are commercially available. These large, inexpensive detectors have good spatial uniformity and good high-energy gamma-ray response. Uniform light collection is obtained with a light pipe attached to a polished scintillator wrapped with aluminum foil. Best low-energy response is obtained by applying a variance analyzer to select the low-energy bias level.

## Introduction

Organic gamma-ray scintillators are characterized by their fast response, moderate gamma-ray interaction, and availability in a wide variety of sizes and shapes. These properties make organic scintillators, particularly solid organic-plastic scintillators, the best choice in nuclear safeguards for a number of applications ranging from assaying containers for fissile content to perimeter radiation monitoring of personnel and vehicles. Unfortunately, the appropriate plastic scintillator for the job often is commercially available only as raw material rather than as a finished radiation detector. Thus, a potential user must design his detector; purchase, assemble, and encapsulate the components; and then evaluate and calibrate the finished detector. As these steps are seldom required with other gamma-ray detectors, the potential user may not have the necessary information or experience to carry them out. The goal of this paper is to describe the properties of plastic scintillators that make them so useful and to outline a procedure for constructing detectors for gamma-radiation monitors.

## Perimeter-Monitoring Detectors

Perimeter monitors in nuclear safeguards must sense gamma radiation in the energy range 0.1 to about 1 MeV. In that range, gamma rays interact with plastic scintillators by Compton scattering, and the fraction of incident radiation detected (intrinsic detection efficiency) is smaller than would be the case for the same size inorganic scintillators—NaI(Tl), for example—where the gamma rays interact by the photoelectric effect. However, a low intrinsic detection efficiency can be tolerated in plastics because the low efficiency can be compensated for by the large detector area. The area is increased rather than the thickness because the improvement in performance is linear with area but saturates exponentially with thickness.

An example of the intrinsic detection efficiency and its variation with gamma-ray energy for our plastic scintillator, NE-102,** appears in Fig. 1. For comparison, the same information for a NaI(Tl) detector of identical thickness is shown; if this were the only basis for choice, the NaI(Tl) detector would be used exclusively. However, performance is based on total efficiency, which, in this case, is proportional to the product of intrinsic efficiency and area. An example of total efficiency for two perimeter monitors with similar performance (Fig. 2) shows the plastic to have greater total

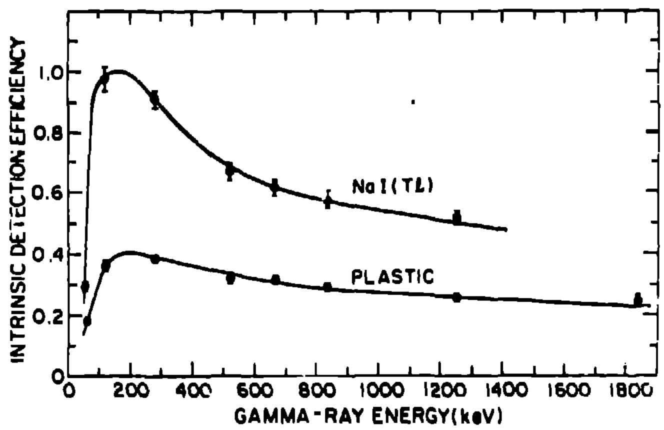


Fig. 1. The measured intrinsic gamma-ray detection efficiency of 3.8-cm-thick NE-102 plastic and NaI(Tl) scintillators illustrates that gamma-ray absorption is better in inorganic scintillators.

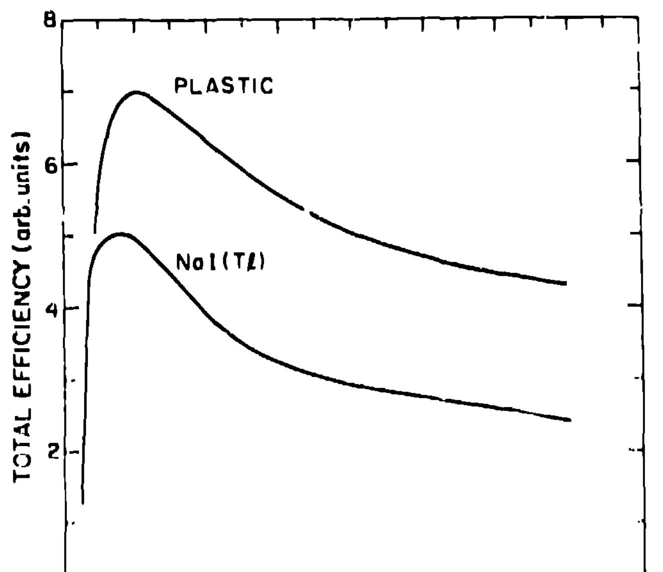


Fig. 2. The total gamma-ray detection efficiency of monitors having 3.8-cm-thick detectors with detector areas in the ratio of 3.5 to 1 shows an advantage for the larger plastic detectors. The detector cost for the plastic monitor is also favorable, about half that for the NaI(Tl) monitor.

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**Nuclear Enterprises Ltd., Reading, England. Similar material is available in the US from Bicron Corp., Newbury, Ohio.

efficiency over most of the gamma-ray energy region, yet the total detector cost for the plastic monitor is about half the NaI(Tl) detector cost. Other advantages of plastic scintillators are better area coverage by the larger detectors and relative freedom from temperature and mechanical shock.

## Detector Design and Construction

The large size of plastic scintillators causes light collection to be more variable than in smaller inorganic scintillators where direct or diffuse reflected light collection can provide good uniformity. Total internal reflection is necessary in large scintillators; however, it can transmit only part of the light from a distant cintillation,[1] usually less than 50%; a single photomultipli· at the end of a long narrow scintillator can collect light only at its attachment point. However, scintillations in a large detector that are near the photomultiplier allow direct light collection and result in a much larger response. The extremes are illustrated in Fig. 3(a) and (b). Adding a light pipe between photomultiplier and scintillator serves to reduce direct light collection and improve the homogeneity of the detector,[2] Fig. 3(c) and (d).

With light collection depending on total internal reflection, plastic scintillators must be fabricated and assembled to assure a smooth interface between the scintillator and the surrounding air. Techniques developed for optimizing cosmic-ray detectors apply here and result in four general rules.

1. The scintillator should be a polished rectangular phosphor with a uniform cross section, a polished light guide, and a mirror on the surface opposite the photomultiplier.[1]

2. The sides of the scintillator should be made totally reflecting by loosely wrapping them with aluminum foil.[2]

3. An original glass-cast surface is better for total internal reflection than a good polished surface.[2]

4. The light pipe length is determined from the scintillator cross section and the critical angle at the scintillator-air interface. The product of the cross-section diagonal and the tangent of the critical angle is a minimum length for the light pipe.[2]

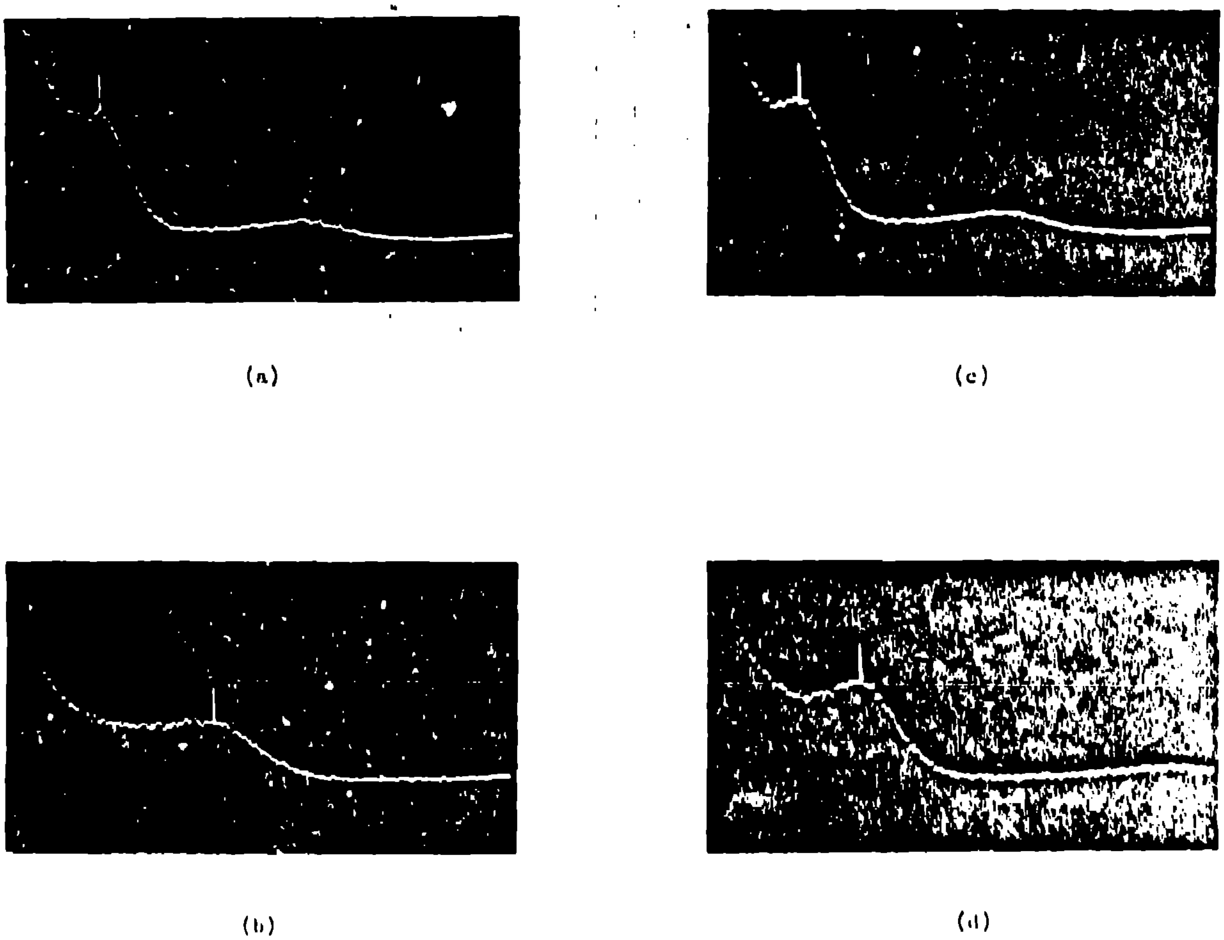


Fig. 3. The pulse-height response of a plastic scintillator (7.6-cm wide, 3.8-cm thick, and 91-cm long NE-102) to a $^{22}$Na source placed at (a) the scintillator foot and (b) the opposite (photomultiplier) end. Direct light collection contributes more in (a) and (b) than in (c) and (d) where a 12.7-cm-long rectangular light pipe has been added.

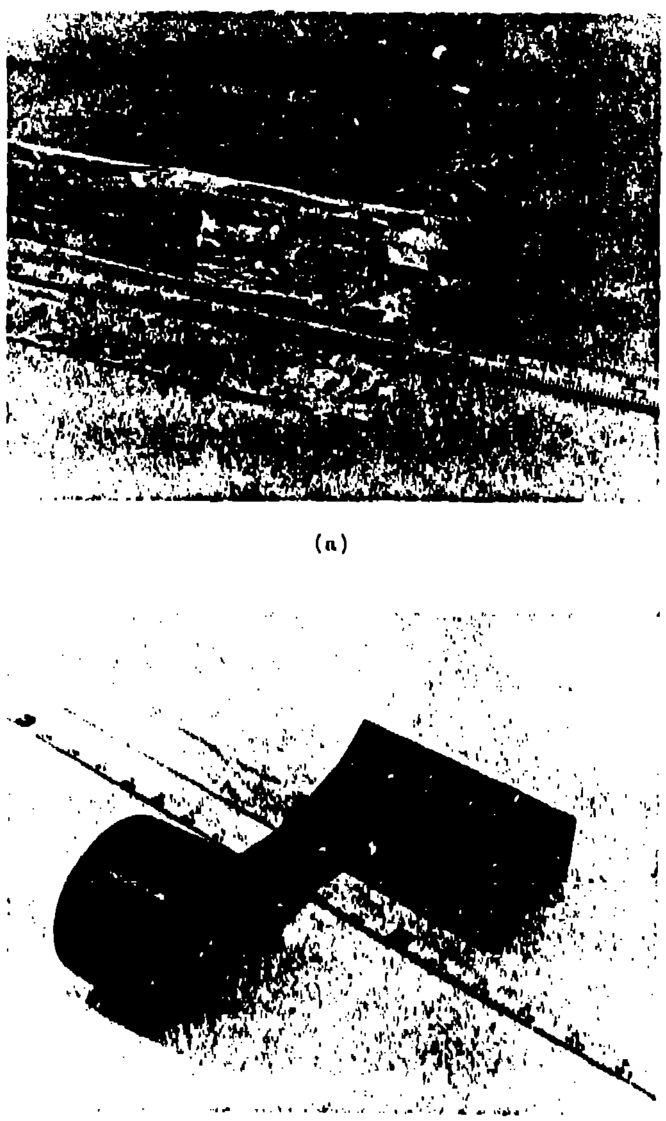
The aluminum foil wrapping can be household foil held in place with black polyvinylchloride (PVC) tape. The black tape forms a lighttight enclosure when applied in multiple layers with adequate care to completely cover the edges and joints (Fig. 4).

The next step in assembling a detector is to attach the photomultiplier tube. The photomultiplier tube selected may have its diameter equal to the scintillator thickness or it may be larger. The more photosensitive surface in contact with the scintillator, the larger the pulse height obtained. Usually a single photomultiplier will suffice, although more than one can be used. The photomultipliers are the end-window type and have bialkali photocathodes for minimum noise. A simple fixture [Fig. 5(a)] holds the photomultiplier in place at an opening cut in the foil-tape covering. The fixture can be attached with strapping tape and light sealed with PVC tape at its edges. The photomultiplier is coupled to the scintillator with optical coupling grease and light sealed with PVC tape at the fixture. Further mechanical attachment and magnetic shielding may be required, but is not shown on the assembled detector in Fig. 5(b).

## Detector Electronics

The signal-conditioning electronics for plastic scintillators in perimeter monitors consits of a bleeder string photomultiplier base (operating at about 1-kV high voltage for a Hamamatsu* 580 photomultiplier), a scintillation preamplifier, a pulse amplifier (with a gain of approximately 1280), and a single channel analyzer.

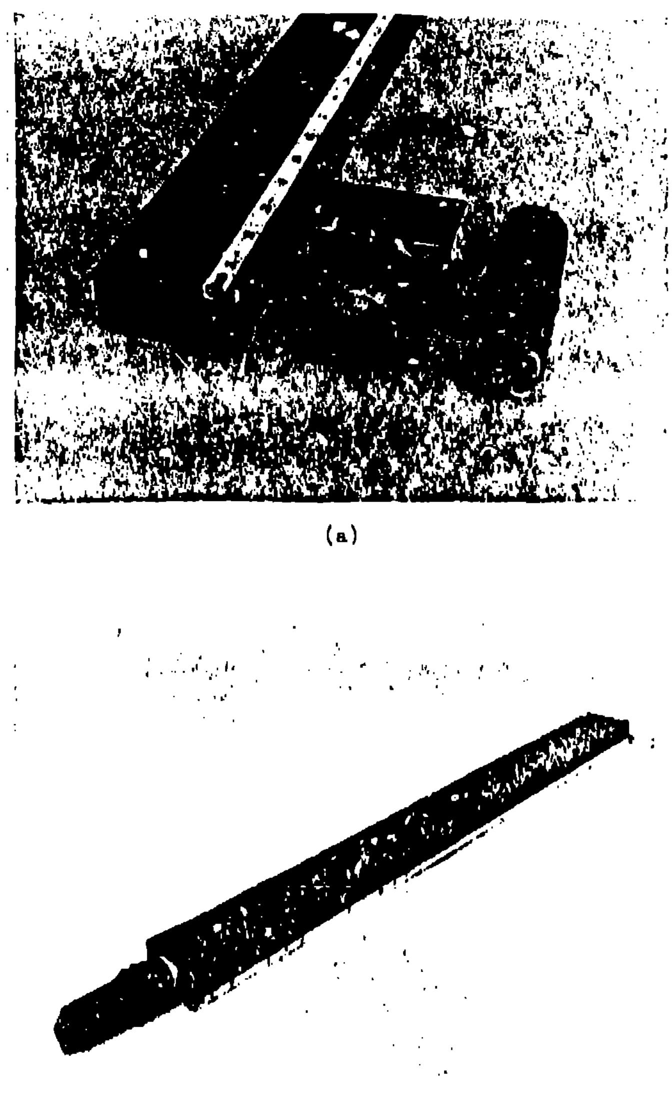
*Hamamatsu Corp., Middlesex, New Jersey.



(a)

(b)

Fig. 4. (a) Household aluminum foil loosely wrapped around the scintillator provides an air interface for the scintillator and serves as a mirror, particularly at the foot of the detector. (b) A black tape wrapping secures the foil and forms a lighttight enclosure.



(a)

(b)

Fig. 5. (a) A simple holding fixture for the photomultiplier is attached over an opening in the scintillator covering. (b) The photomultiplier is coupled to the scintillator and light sealed with a final layer of tape.

The operating parameters for plastic scintillators are much like inorganic scintillators except that, for plastic, the intrinsic detection efficiency is greatly dependent on the lower level discriminator (LLD) bias level. The family of curves in Fig. 6 illustrates the influence of bias level on efficiency over a wide gamma-ray energy range. The maximum efficiency is obtained for the lowest bias voltage; however, it is possible to lower the bias to the point that more than just gamma-ray scintillations are counted. Then, the statistics of counting can change, resulting in a larger variance in the signal-count distribution and a correspondingly higher perimeter monitor false-alarm rate. An acceptable bias level can be achieved most readily by direct examination of the counting statistics. If the count distribution is Poisson, as it should be for proper operation, the variance will equal the mean. An instrument that does the necessary counting and calculating (Fig. 7) is described in another paper submitted to this conference.[7] The instrument, called a variance analyzer, counts the single channel analyzer output and carries out a continuing sequence of repetitive samples. Each group of 30 samples is analyzed to determine its mean and variance and these values in turn determine a result R.

$$R = \frac{(\text{variance})^{0.5} - (\text{mean})^{0.5}}{(\text{mean})^{0.5}} \quad .$$

Both individual results and a running average of result values are displayed. A result average between -0.1 and +0.1 is acceptable and a procedure of varying the LLD voltage and restarting the variance analyzer is followed until the desired result appears.

With the variance analyzer available, plastic scintillators become as easy to use as inorganic scintillators whose photoelectric peaks aid calibration. The variance analyzer offers an additional advantage because it is sensitive to electrical noise originating in any part of the signal-conditioning electronics; thus, achieving an adequate result verifies the entire system and assures that the monitor will perform as expected.

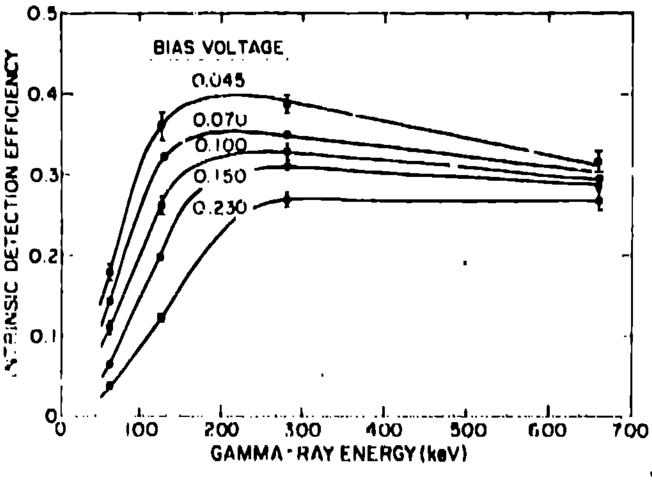



Fig. 6. The bias voltage of the lower level discriminator has a pronounced influence on the intrinsic efficiency of a plastic scintillator over a wide gamma-ray energy range. Best performance is obtained at the lowest practical voltage.


Fig. 7. The variance analyzer permits the proper LLD voltage to be rapidly determined.

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