An Alpha/Beta/Gamma Health Physics Instrument With Pulse-Shape Discrimination

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Abstract

A recent breakthrough in alpha scintillation detector design supports the feasibility of extending this new technology to the development of a monolithic alpha/beta/gamma (a/β/γ) scintillation detector. The new scintillator is physically robust and chemically resistant to environmental conditions encountered in radiation monitoring, and yet inexpensive to manufacture. The use of pulse-shape discrimination electronics allows pulses from each scintillator to be separated for particle identification. An a/β/γ detector has a wide variety of possible applications including laundry monitoring, wastewater monitoring, air sampling, and health physics instrumentation.

I. INTRODUCTION

The purpose of a general radiation survey of an area, an item, or a person is to determine whether alpha, beta, and/or gamma (a, β, and/or γ) contamination is present and to what extent. The most reliable way of determining this information is to use separate detectors optimized for each specific type of radiation (a, β, and/or γ). However, this process requires at least three complete surveys and is very time-consuming. Combination detectors have been invented that allow surveyors the freedom of detecting more than one type of radiation with one detector, which reduces the amount of time involved. Currently, most surveys are conducted by using at least two detectors—one for detecting a radiation and one for determining the presence of β/γ radiations.

Another problem encountered with detectors currently used during field/laboratory surveys is the use of aluminized Mylar™ or mica entrance windows, which are easily torn, scratched, or punctured. When entrance windows are damaged, the detector is rendered inoperable and the unit must be shelved until the window is repaired or replaced. Also, neither Mylar nor mica can protect against hostile environments that attack the underlying detection medium. These detectors, when used to monitor either liquid or gaseous streams, experience damage to fragile entrance windows and possibly to the exposed gas, phosphor, or plastic detection medium.

II. DESIGN

The principle on which a rugged a scintillation detector was developed for health physics instrumentation was recently demonstrated at Oak Ridge National Laboratory[1]. The result was a new type of a detector resistant to scratches, punctures and corrosive chemicals that has >90% detection efficiency for 239Pu α particles. One key feature for manufacturing this detector was a novel technique developed for uniformly settling ZnS(Ag) particles into an optically transparent epoxy.

This same settling technique is applied in this design to settle α-sensitive scintillation particles into a curable-liquid, β-sensitive scintillator and then optically coupling a γ scintillator to the aβ unit (Fig. 1). Recently reported pulse-shape discrimination (PSD) techniques[2] will be expanded and used to separate pulses generated in each scintillator to determine the amount and type of each radiation present.

The settling technique used in forming the αβ scintillator unit provides a microscopically smooth surface that is easily overcoated with an e-beam evaporated, thin film of aluminum. This light-tight and pinhole-free aluminum entrance window is protected from physical and chemical damage by applying a thin layer of cyanoacrylate or other hardcoat material applied thin enough not to attenuate α particles but still remain resistant to physical and chemical damage.

An important criterion for developing such an αβ/γ detector involves choosing three scintillators with different decay time constants. By having a distinct decay time for the a, β, and γ responses, PSD electronics can be used to identify particles interacting in the sandwiched scintillators. Light pulses generated in each of the scintillators possess characteristic waveforms that, when processed through
timing filter amplifiers, will result in distinctive baseline crossover times. By electronically windowing these zero-crossing points, pulses are identified as being from either \( \alpha \), \( \beta \), or \( \gamma \) radiations and are directed into separate single-channel analyzers for counting.

With the availability of a single-unit \( \alpha/\beta/\gamma \) detector that is both chemically and physically resistant, several "problem" areas of environmental and health physics monitoring can be alleviated:

- **Laundry Monitoring:** A rugged \( \alpha/\beta \) scintillator can replace the conventional scintillators used in commercially available laundry monitors. The new scintillator will allow clothes to be pushed through, close to the scintillator, without damaging the radiation entrance window. Close contact with contaminated clothing would provide more accurate counting with the probability of detecting lower activity levels. Watertight scintillators could be placed inside washing facilities for further evaluation of possible radioactivity. This new scintillator is easily cleaned, if contaminated, by using a detergent and cloth.

- **Wastewater Monitoring:** An \( \alpha/\beta \) or \( \alpha/\beta/\gamma \) scintillator could be fabricated and placed directly into wastewater streams. Because no Mylar is required to protect the watertight scintillator assembly, water can flow across the surface of a scintillator without contamination or degradation. The scintillator is easily cleaned, if background buildup of dirt and contaminates occur, by using a detergent and cloth.

**Air Sampling:** For gross particle counting in air stacks or outside hoods and glove boxes, an \( \alpha/\beta \) or \( \alpha/\beta/\gamma \) detector can be used. The detector surface is chemically resistant and the cyanacrylate hardcoat used in the prototype rugged scintillation detectors showed that they are of withstanding 6-mol concentrations of nitric acid and various alcohols encountered in these environments.

**Health Physics Instrumentation:** An \( \alpha/\beta/\gamma \) survey instrument will allow health physicists to use only one instrument when surveying. Currently, several different instruments are required to achieve accurate information on amounts and types of radiation present. This new detector is robust (physically and chemically) and monolithic and could possibly lead to future development of dose information.

### III. THEORETICAL AND EXPERIMENTAL

A crucial part of developing the \( \alpha/\beta/\gamma \) scintillator involves the \( \beta \) scintillator. The \( \beta \) scintillator must have a low viscosity to allow for uniform settling of the \( \alpha \)-scintillator particles, curable to a Shore D hardness of \( \sim 80 \), low \( Z \) for minimum backscatter, and a high light output and conversion efficiency.

Other considerations that must be addressed to develop an \( \alpha/\beta/\gamma \) scintillator detector are:

1. identifying three scintillators to use in the \( \alpha/\beta/\gamma \) sandwich that demonstrate good separation of decay constant pulses [one possibility would use ZnS(Ag) for \( \alpha \) detection (0.2 \( \mu s \)), NE-120\(^1\) or BC-490\(^2\) plastic for \( \beta \) detection (2.4 \( ns \)), and CsI(Na) for \( \gamma \) detection (0.65 \( \mu s \))]; and

2. optimizing the thickness of each scintillator layer to ensure maximum energy range detection while minimizing the possibility of erroneously detecting radiation particles in the other scintillators.

Theoretical calculations indicate that one possible sandwich configuration would be 8 mg/cm\(^2\) ZnS(Ag) for detecting \( \alpha \) particles; 6-mm-thick NE-120, BC-490, or other plastic for detecting the \( \beta \) particles; and a 5-in.-thick CsI(Na) crystal coupled to the \( \alpha/\beta \) unit. This assembly would provide no detection of \( \beta \) or \( \gamma \) interactions within the ZnS(Ag) phosphor and a 5% probability of detecting \( \gamma \) rays < 50 keV within the \( \beta \) scintillator, and \( \beta 's \) with energies > 3 MeV might be detectable in the CsI(Na) scintillator used for \( \gamma \) interactions. The ultimate detectable energy ranges for this configuration would be \( \alpha \)'s > 1 MeV, and \( \beta 's \) and \( \gamma 's \) between 50 keV and 3 MeV.

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\(^1\)NE-120 plastic scintillator is manufactured by Nuclear Enterprises, Inc., 7 Deer Park Drive, Suite A2, Monmouth Junction, NJ 08852.

\(^2\)BC-490 plastic scintillator is manufactured by Hiltron Corporation, 12345 Kinsman Road, Newbury, OH 44065.
Preliminary experimental tests have been conducted for several $\alpha/\beta$ units by using various thicknesses of curable plastic scintillator (both NE-120 and BC-490). Results from samples ABG7271 (2 mm thick) and ABG7272 (3 mm thick) are shown in Figs. 2 and 3 respectively. A $^{239}$Pu source and a $^{137}$Cs $\beta$/$\gamma$ source were used to test the samples shown in these figures. No discrimination of different raditions by pulse-shaping was used in these tests. Instead, the signal from an RCA 4523 photomultiplier tube was fed into a scintillation preamplifier and then into a linear amplifier. An amplifier time constant of 0.25 $\mu$s was determined best for detecting both $\alpha$ and $\beta$ particles without reducing pulse amplitudes. Sources were spaced 1.8 in. from the scintillator.

As shown in Figs. 2 and 3, this $\alpha/\beta$ unit is capable of detecting both $\alpha$ and $\beta$ particles. Samples ABG7271 and ABG7272 also indicated a 5$\%$ detection efficiency for 0.662-MeV $\gamma$'s from the $^{137}$Cs source. These samples were also tested with an $^{241}$Am disk source, a $^{40}$K $\beta$ source, and a $^{208}$Tl $\beta$ source. Efficiency results for both samples are tabulated below. Even though these results are not expected for the final configuration of an $\alpha/\beta/\gamma$ detector, these preliminary numbers indicate the capability of detecting $\alpha$ and $\beta$ particles within a monolithic unit developed by using the settling technique.

IV. CONCLUSIONS

It has been demonstrated that a monolithic $\alpha/\beta$ unit can be developed that is capable of detecting both $\alpha$ and $\beta$ particles with reasonable efficiencies. However, this development is still in the preliminary stages and further testing is required to optimize the thickness of the $\beta$ scintillator, increase the efficiency of the scintillators by improving the settling technique of the phosphor and curing of the plastic, and develop a set of pulse-shape discrimination electronics that will allow for separation of all the radiations interacting within the scintillators.

Currently, we are working with manufacturers to lower the viscosity of the $\beta$ scintillator to improve settling of the phosphor and to decrease the amount of time required for the scintillator to cure. We are also working to optimize all the scintillators for increased efficiency and lowered crossover detection. It is anticipated we will begin developing the electronics for this unit in the near future.

DISCLAIMER

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ABG7271 (2 mm thick)

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<th>Source</th>
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<th>Number reaching surface of scintillator</th>
<th>Number detected</th>
<th>Efficiency</th>
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<td>2363</td>
<td>1371</td>
<td>58%</td>
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<td>14450</td>
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<td>41%</td>
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ABG7272 (3 mm thick)

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<th>Number detected</th>
<th>Efficiency</th>
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V. REFERENCES


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