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A COMPARISON OF THE RUGGEDIZED ZnS(Ag)/EPOXY AND MYLAR–BASED ALPHA DETECTORS FOR WASTEWATER STREAMS

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Introduction

A low-level alpha radiation sensor has been designed and developed at Oak Ridge National Laboratory (ORNL) for monitoring process wastewater streams at the Westinghouse Savannah River Site (SRS). This new Ruggedized Contamination Detector (RCD) is intended to replace the fragile, mylar-based scintillators and has improved sensitivity and reliability for detecting alpha contamination.

The unique entrance window invented for this sensor has considerably less mass per unit area than conventional Mylar windows currently used in wastewater streams. The thin layer deposited between the radiation detection medium and potentially contaminated wastewater makes it much easier to detect short-range alpha particles. Compared to the conventional Mylar-based detectors, the new design allows for eight times the number of ^{238}U alphas to penetrate the entrance window and reach the scintillation material and eliminates the need for routine replacement of the Mylar entrance window.

Experimental Results

The RCD sensor is formed by settling a thin-layer of ZnS(Ag) scintillation powder onto the front edge of an optically-transparent epoxy lightpipe (1), shown in Fig. 1. This encapsulation of the alpha detection material provides distinct advantages over current technology. First, it fixes the scintillation powder at the very edge of the lightpipe for maximum alpha detection efficiency. Second, encapsulating the scintillating powder makes it virtually immune to environmental conditions of washing, dissolution, or simple removal by rubbing. Third, by settling the powder into the surface of epoxy poured onto an optical surface, a microscopically smooth front face is produced. This face allows for a thin, low-mass aluminum overcoat and protective cyanoacrylate hardcoat to be evaporated onto the surface. The final, monolithic structure and evaporated radiation entrance window are capable of withstanding both physically and chemically challenging environments encountered in wastewater streams.

Theoretical Model

The maximum water depth that an alpha particle can permeate and still be detected in the detection medium is a function of the angle between the emitted particle's direction and the plane normal to the phosphor or plastic layer. The particle will also experience energy lose in the protective entrance window layer separating the water and detection medium. We can calculate the number of alpha particles striking the detection medium by knowing the specific activity of a sample and integrating over the solid angle of emission.

Figure 2 shows the geometric diagram for an alpha particle emitted from a depth in the water and striking the detection medium. The range (r) of an alpha particle in water equals the maximum range (R_m) minus the absorption in the protective entrance window. For a 4.18 MeV ^{238}U alpha particle, the maximum range in water (R_m) is 2.2 mg/cm^2 (2). The thickness of the entrance window is 200 Å (0.005 mg/cm^2) of aluminum and < 0.24 mg/cm^2 of cyanoacrylate. To maintain units, the Bragg-Kleeman Rule (3) is used to convert the alpha absorption in the materials into water equivalent absorption. The absorption then becomes 0.003 mg/cm^2 and 0.23 mg/cm^2, respectively. The range of the alpha particle is then

$$r = R_m\,(\mathrm{mg/cm^2}) - \frac{(0.003 + 0.23)\mathrm{mg/cm^2}}{\cos\theta}. \qquad (1)$$

The equation for the actual depth in water (X) of the emitted alpha particle is

$$\cos\theta = \frac{X}{r}. \tag{2}$$

Solving for X and substituting Eq. (1) into Eq. (2) yields

$$X\,(\mathrm{mg/cm^2}) = \cos\theta\,(2.2\ \mathrm{mg/cm^2} - 0.233/\cos\theta), \tag{3}$$

or converted to linear dimensions

$$X\,(\mathrm{cm}) = (2.2\ \mathrm{mg/cm^2}\cos\theta - 0.233\ \mathrm{mg/cm^2})\ 0.001\ \mathrm{cm^3/mg} \tag{4}$$

The angle θ becomes a maximum when all the alpha energy is absorbed in the entrance window and the depth in water (X) is zero and a minimum when the particle is emitted normal to the detection medium layer. Therefore,

when $X = 0$ cm, $\theta_{max} = 83.9°$,

and when $X = 0.00197$ cm $\theta_{min} = 0°$.

The number of alphas striking the detection medium (N) can be determined by

$$N = (\text{specific activity}) \times (\text{area}) \times dX. \tag{5}$$

By integrating over all increments of thickness of water dX and including the solid angle geometry between θ = 0° and 83.9° (4),

$$N = (SA)\,(A)\int_{0}^{1.97\times10^{-3}}(\text{geometry fraction})\,dX, \tag{6}$$

where SA is the specific activity and A is the area of the detection medium. The geometry fraction varies with θ as 0.5 (1 – cos θ), where θ equals one-half the total angle of emission (5). Differentiating Eq. (4) and subsituting it into Eq. (6) yields

$$N = (SA)\,(A)\,(0.001)\int_{83.9}^{0} 0.5\,(1 - \cos\theta)\,(-2.2\sin\theta\,d\theta). \tag{7}$$

After integrating, Eq. (7) becomes

$$N = (SA)\,(A)\,(0.0011)\,[\cos\theta + \sin^2\theta/2]. \tag{8}$$

This number actually indicates a minimum number of alpha particles that would strike the surface of the detection medium since the precise thickness of the cyanoacrylate is not know. Therefore, Eq. (8) should be written as

$$N \geq (SA)\,(A)\,(0.0011)\,[\cos\theta + \sin^2\theta/2] \geq (SA)\,(A)\,(0.0011)\,[0.6006] \tag{9}$$

Sensitivity

Several RCD samples were fabricated for testing at the SRS in their On-Line Alpha Monitors (OLAMs). The samples were 15.08 cm in diameter with 7.5 mg/cm² ZnS(Ag), 200 Å of aluminum and < 0.24 mg/cm² cyanoacrylate. The SRS currently uses a xx µm layer of Mylar covering a polyvinyltolune (PVT) scintillator. All samples, excluding SR-4 with no reflective entrance window, were comparable in sensitivity to the PVT-based detector (Table 1) when tested with a 1200 dpm and a 1500 dpm ^{239}Pu alpha source. The Mylar-based ZnS(Ag) detector was not available for comparison to the RCD in this experiment.

Acid Test

To test the ruggedness of the new alpha water monitor, samples were subjected to various solutions of nitric acid. Three solutions were prepared with the following compositions:

0.57 g/l ^{238}U in 0.015 $\underline{M}$ HNO_3,
5.7 g/l ^{238}U in 0.15 $\underline{M}$ HNO_3, and
34.2 g/l ^{238}U in 1 $\underline{M}$ HNO_3.

The samples were coated with an entrance window thickness of 200 Å (0.005 mg/cm^2) of aluminum and < 0.24 mg/cm^2 of cyanoacrylate. They showed no degradation or reduction in performance after three months exposure, when the experiments were terminated.

Linearity of Response

Figures 3 and 4 show the linearity of the detector response versus activity. In Figure 3, the theoretical calculations for the various activities given for the acid tests are plotted. The actual experimental data for these activities are also shown. The experimental data was lower than the theoretical by a factor of approximately 1.5. This variation is thought to be caused by a slight attenuation of the alpha particles within the epoxy base. A comparison of the RCD and the Mylar-based ZnS(Ag) detector is given in Figure 4. The comparison was done for actual ^{238}U alpha particles penetrating the entrance window to the phosphor layer. The RCD allowed eight times the number of alpha particles to penetrate to the detection medium. This difference is entirely due to the amount of material used in the entrance window.

Conclusions

The real advantage of the RCD is the improved reliability. Conventional on-line water monitors have a layer of protective Mylar that can be easily torn or contaminated by the flowing water. The RCD, because of the special epoxy encasement, has an evaporated aluminum layer with a protective coating. This unique entrance window provides a watertight layer resistant to physical and chemical damage. This layer also allows for easy cleaning with a cloth if contaminated.

The advent of the special entrance window also increases the sensitivity of the RCD because of the small amount of material required to protect the phosphor surface. In fact, it was discovered that the RCD could be used in an on-line water monitor without any entrance window. However, some sensitivity is sacrificed because there is not a layer of light-reflecting material to direct the scintillation events toward the photomultiplier tube.

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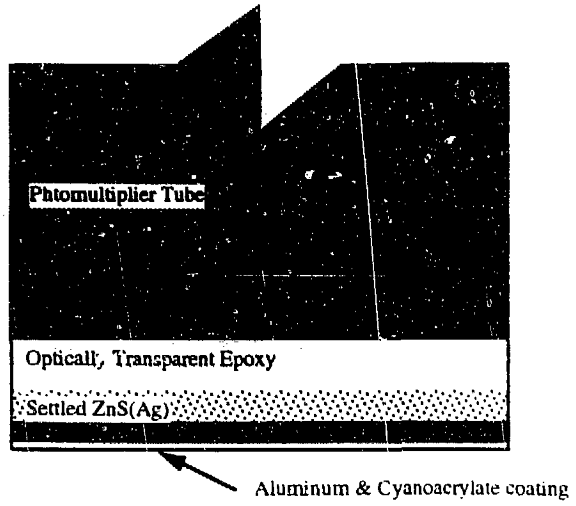

Fig. 1. Cross-sectional view of the ruggedized contamination detector.

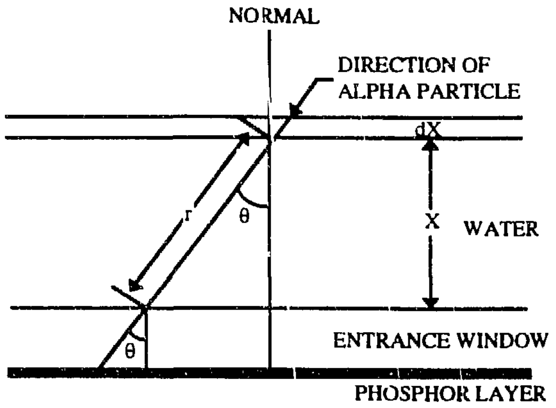

Fig. 2. Geometric diagram illustrating the passage of an alpha particle through water and an entrance window to reach the phosphor layer.

Table 1. Sensitivity of the SRS PVT Monitor and the RCD Monitor

Sample	1200 dpm	1500 dpm
PVT	22%	24%
SR-4	19%	20%
SR-5	24%	27%
SR-6	27%	26%
SR-7	25%	26%
SR-8	24%	24%

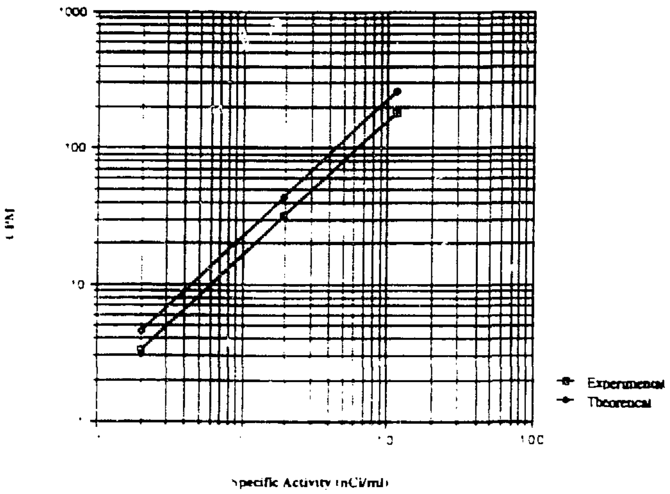

Fig. 3. Theoretical and experimental data for the RCD monitor.

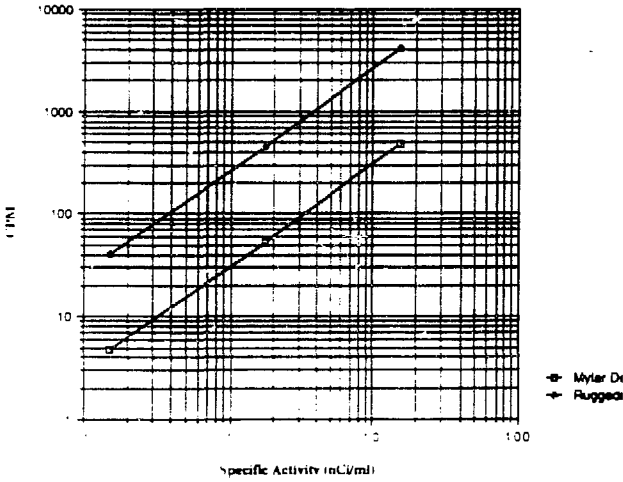

Fig. 4. Comparison of the RCD and Mylar-based ZnS(Ag) monitors.

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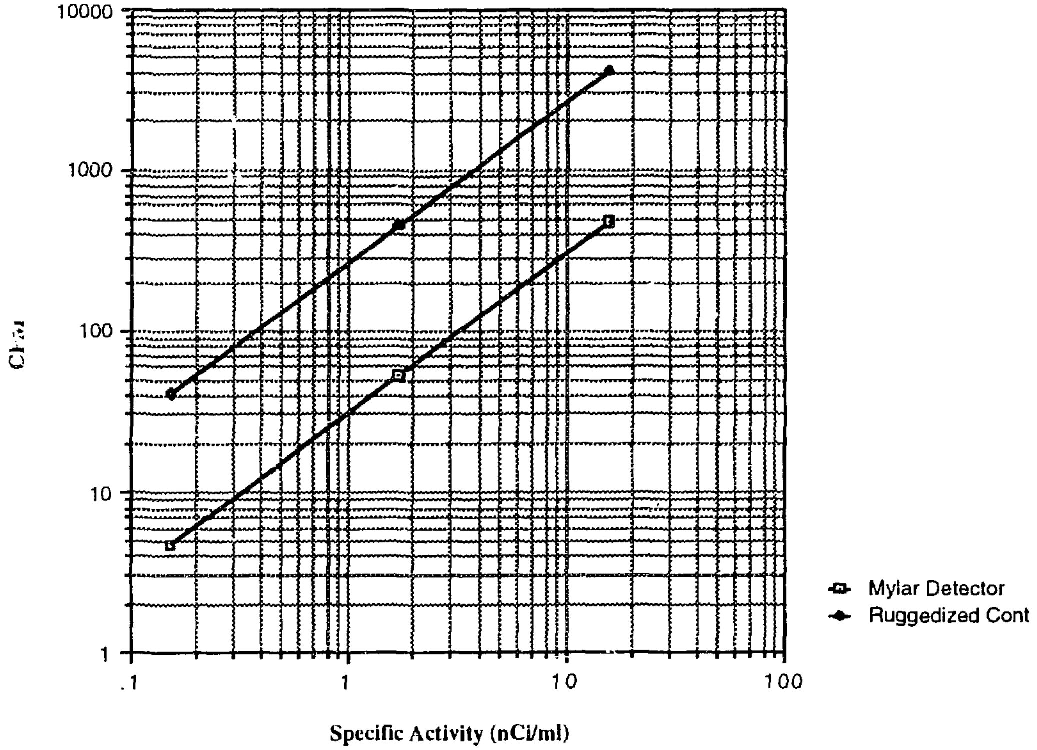
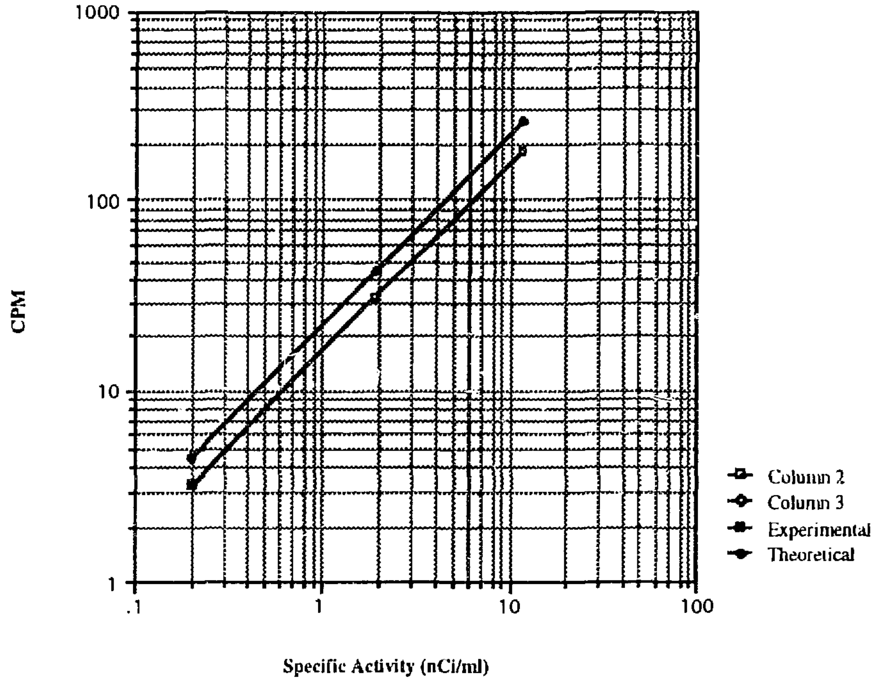
SRS

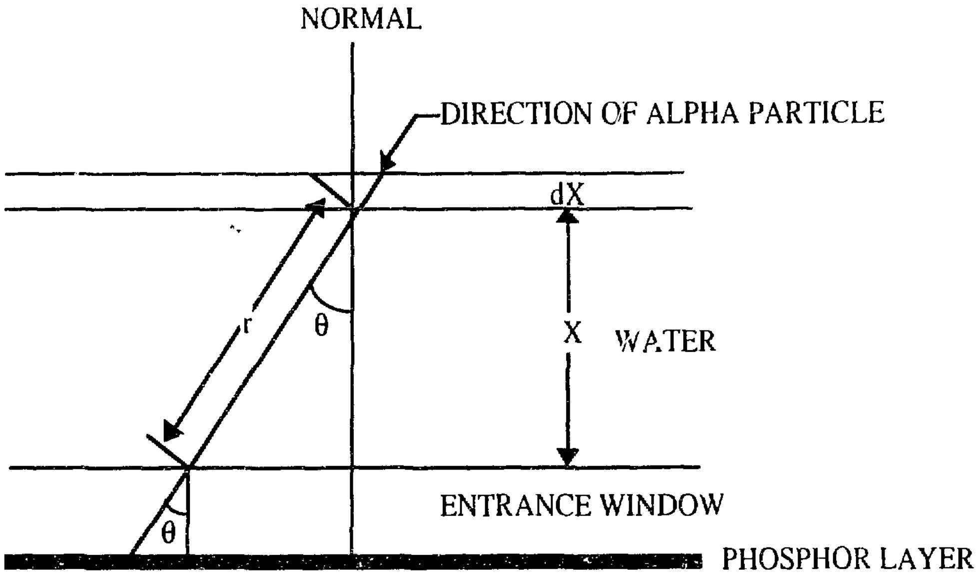
Comparison Of The Mylar-Based and RCD Monitors



Comparison Of RCD Theoritical and Experimental Data



Geometric Diagram of On-Line Alpha Monitor



Sensitivity of PVT v. RCD Monitor

Sample	1200 dpm	1500 dpm
PVT	22%	24%
SR-4	19%	20%
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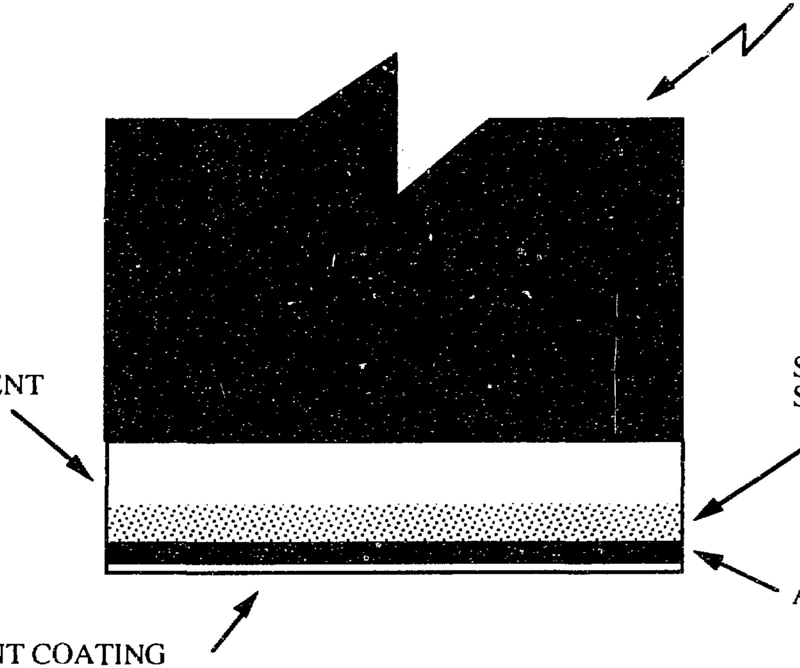
The Ruggedized Contamination Detector (RCD)



PHOTOMULTIPLIER TUBE

OPTICALLY TRANSPARENT
EPOXY

SETTLED ZnS(Ag)
SCINTILLATOR

ALUMINUM COATING

SCUFF-RESISTANT COATING