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A PRECISION BETA-GAUGE USING A PLASTIC SCINTILIATOR AND PHOTOMULTIPLIER DETECTOR

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January 1982

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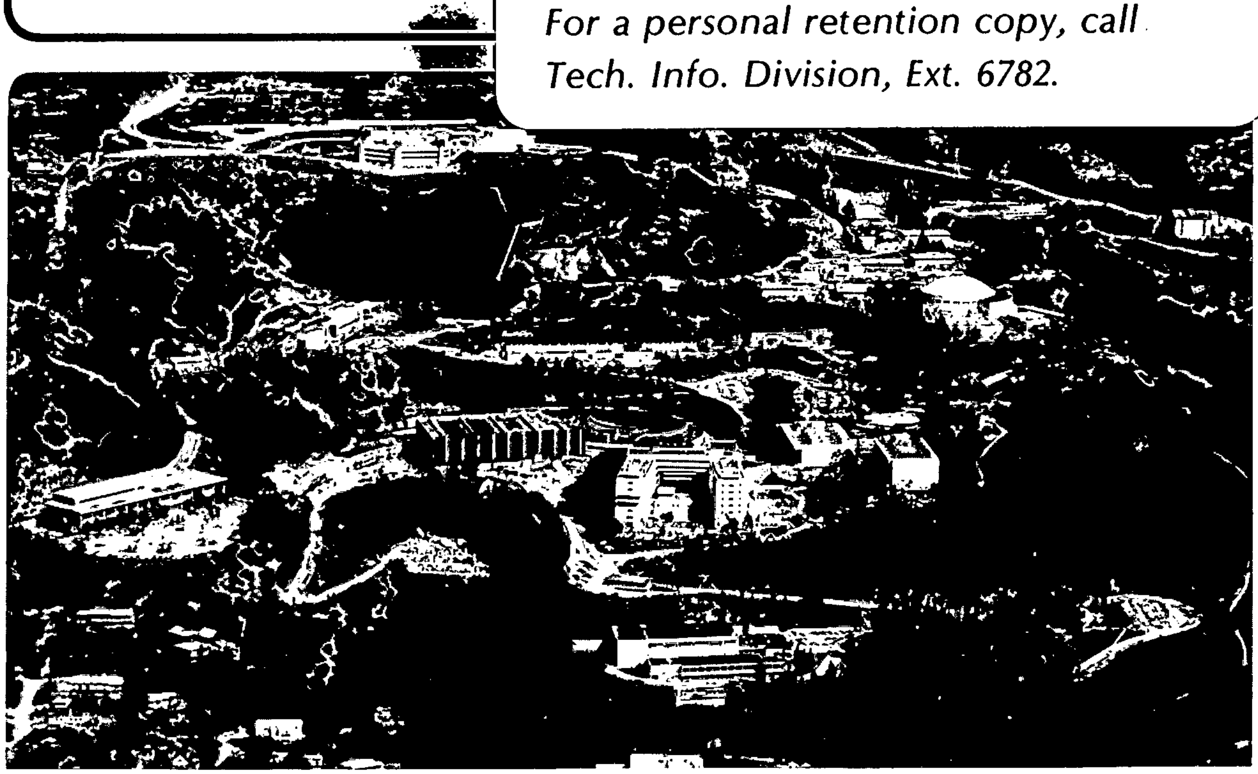

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A PRECISION BETA-GAUGE USING A PLASTIC SCINTILLATOR AND PHOTOMULTIPLIER DETECTOR

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1. Abstract

We describe the use of a plastic scintillator photomultiplier detector combination in applications involving the precision beta-gauge measurement of small mass deposits on thin substrates. The requisite precision (± 2 $\mu g/cm^2$) places stringent requirements on the beta-particle counter and associated electronics. The scintillator based system is shown to be equivalent if not superior to previously employed semiconductor detectors with respect to long-term counting stability.

2. Introduction

An interesting example of the application of nuclear methods to environmental research is the use of β-particle attenuation for the measurement of thin aerosol particle deposits collected on filter substrates[1]. Recent work has resulted in the design and widespread use of automated β-gauge devices for the rapid determination of aerosol particle mass to a precision of ± 3 $\mu g/cm^2$[2]. In our earlier designs, we have employed a silicon surface barrier detector operated at room temperature as the monitor of the transmitted β-spectrum intensity[3]. In the present work, we report the use of a plastic scintillator and fast photomultiplier in the same application and discuss its several advantages.

3. Description of β-Gauge

A β-particle thickness gauge is a simple instrument consisting of a radioactive source which emits a continuous β-particle spectrum and a suitable detector with which to measure the intensity of the β-spectrum after it has been transmitted through the sample. As the thickness of the sample is varied, the observed counting rate I is described by the exponential relationship:

$$I = I_o e^{-\mu x} \tag{1}$$

where I_o is the counting rate without sample, x is the sample thickness in $\mu g/cm^2$, and μ is a mass absorption coefficient characteristic of the energy of the beta spectrum. For optimum sensitivity in a given application, the energy endpoint of the β spectrum and the detector efficiency must be matched to the mass range of interest. For the present application either ^{147}Pm (E_{MAX} = 225keV) or ^{14}C (E_{MAX} = 156keV) was employed.

The difficulty in designing β gauges arises from the stability required to perform difference measurements to a precision of ± 5 $\mu g/cm^2$ on substrates with total mass of 5 mg/cm^2. The precision in the individual counting measurement must be one part in 10^4 or less over the period between instrument calibrations. Insofar as too frequent calibrations are undesirable, the measurements place stringent requirements on the stability of the detector and associated electronics.

The choice of semiconductor detectors for this application is influenced by their efficiency for counting low-energy beta particles and simplicity of operation. Their small size is a convenience for mounting in stable mechanical configurations. The normal energy resolution advantages of semiconductor detectors are not exploited in this application and, in fact, some price is paid in the limitation of maximum counting rate to approximately 10^5 counts/sec. This in turn extends the measurement interval such that long-term instabilities due to ambient temperature variations could become a limiting factor when processing large numbers of samples.

Although scintillation spectrometers are also susceptible to temperature induced instabilities, the fact that they exhibit negligible noise currents allows the setting of discriminator thresholds at very low levels relative to the minimum signal amplitude. This should minimize the effect of gain change on total count rate measurement as performed in the present measurements. A stable mechanical geometry using the glass tube and scintillator-light pipe combination is more difficult to achieve but not insurmountable.

Figure 1 is a schematic of the scintillation detector β-gauge system. The scintillation spectrometer consists of a 1.6 mm thick NE102* plastic scintillator optically coupled to a 18 mm diameter HAMAMATSU R1213* photomultiplier tube. The tube is operated with a grounded photocathode and employs a conventional dynode resistor string in the tube base. D MOS* source followers are used to buffer the last four stages of the dynode string. The pulse processing electronics are conventional wide-band counting electronics.

4. Results

Using this configuration, a series of measurements was performed to characterize the scintillation spectrometer for precise beta-gauge applications. These consisted in calibrating the beta gauge using thin film standards and then measuring a known sample repeatedly over a time span of several hours. The measured performance data are summarized in Table 1.

Over a span of 1.3 hours, a series of 40 measurements each of 100 secs was performed on the same sample. The counting rate for the particular thickness sample was 2.3×10^5 counts/sec. The mass calibration curve was obtained by fitting the relationship of Equation 1 to the results of measurements obtained from calibrated polycarbonate thin-film standards with masses ranging from 650 to 3000 $\mu g/cm^2$. The standard deviation calculated for the 30 determinations was only slightly larger than that expected if counting statistics were the only source of error. This indicates that the operation of the detector and counting system is stable to the required precision over the 1.5 hour duration of the test under normal ambient laboratory conditions.

Longer term measurements involving better statistics and lasting over ten hours indicate a precision which is approximately twice the statistical error but is still less than one part in 10^4 and corresponds to an error of less than 2 $\mu g/cm^2$. The average deviation of the ambient temperature over this time interval was ± 0.7°C. This precision is far less than the errors associated with systematic effect such as sample positioning errors. Furthermore, this precision is slightly better than that achieved by the previous semiconductor system.

5. Summary and Conclusion

A precision beta gauge has been designed using a plastic scintillator and photomultiplier tube combination as the detector. The measured precision has been shown to be better than that achieved with semiconductor detectors under equivalent conditions. The enhanced counting rate capability of the scintillation spectrometer allows precise measurement of larger batches of samples in shorter time intervals than was previously possible.

6. Acknowledgements

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7. References

[1] E.S. Macias and R.B. Husar, Proc. Int. Conf. Nucl. Methods Environ. Res., 2nd (1974) 413.

[2] J.M. Jaklevic, R.C. Gatti, F.S. Goulding, B.W. Loo and A.C. Thompson, U.S. Environmental Protection Agency Project Summary of Final Report, EPA-600/S4-81-006 (Mar. 1981).

[3] J.M. Jaklevic, R.C. Gatti, F.S. Goulding and B.W. Loo, Environ. Science and Tech., 15 (1981) 680.

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TABLE 1.

Parameters calculated from a least squares fit of seven mass standards to Equation 1.

Source Intensity

$I_0 = 2.6514 \times 10^5$ cts/sec

Mass absorption coefficient

$\mu = 1.3498 \times 10^{-4}$ cm^2/gm

Average deviation of 30 measurements of 100 secs each

Mass

$x = 1085.3$ μg/cm^2

Deviation

$\sigma(x) = 1.54$ μg/cm^2

Long-term, high-rate stability test (2000 sec runs, 10 hour total interval)

Average counting rate

$I = 5.3713 \times 10^5$ cts/sec

Average deviation of 18 consecutive runs

$\sigma(I) = 48.5$ cts/sec

Statistically derived error

$\sigma(I) = 23.2$ cts/sec

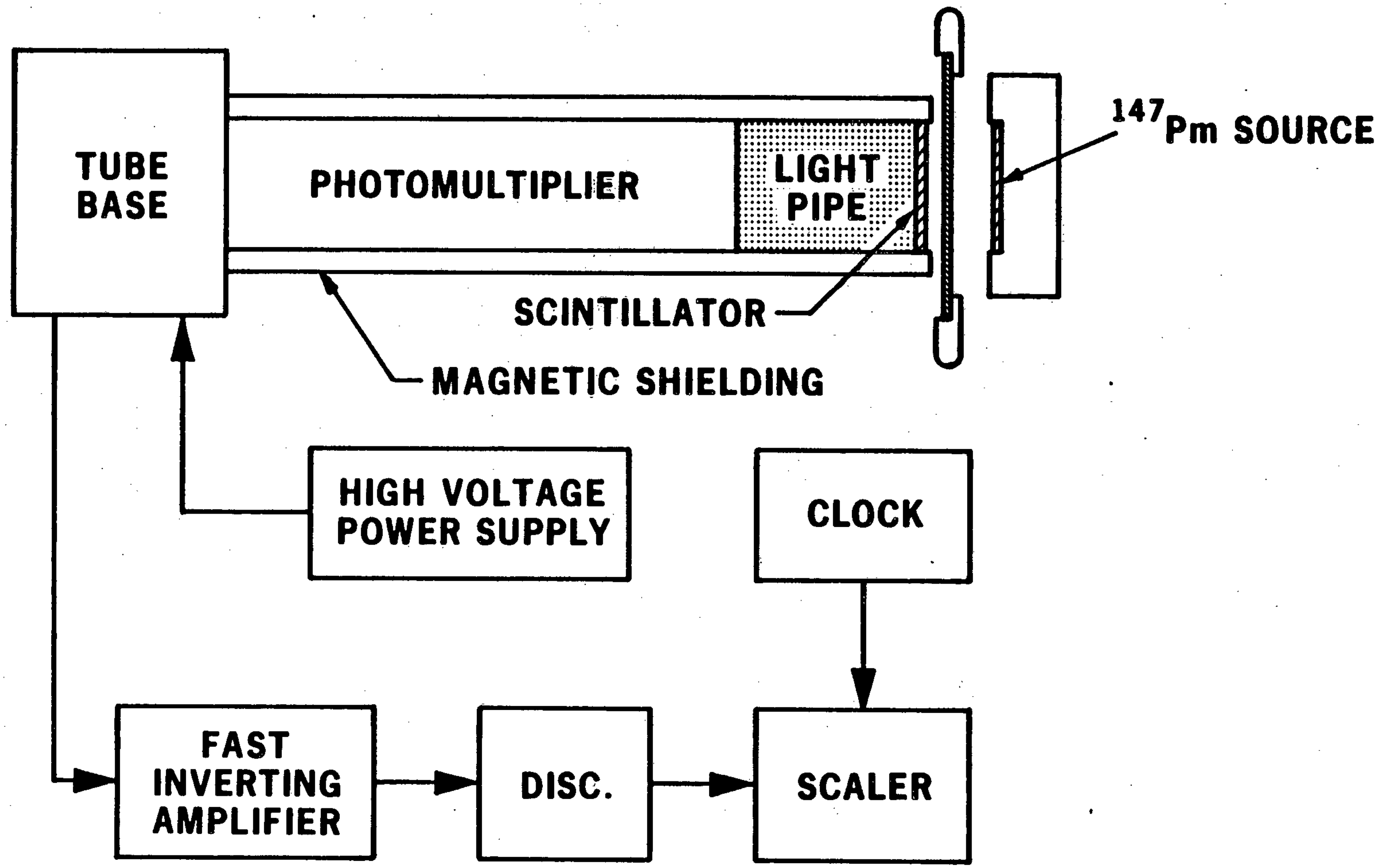

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Fig. 1. Schematic diagram of scintillator/photomultiplier beta-gauge system.

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