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IEEE Standard Test Procedures for Photomultipliers for Scintillation Counting and Glossary for Scintillation Counting Field

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Institute of Electrical and Electronics Engineers

Sponsor

Nuclear Instrumentation and Detectors Committee
of the
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Foreword

(This Foreword is not a part of IEEE Std 398-1972, Test Procedures for Photomultipliers for Scintillation Counting and Glossary for Scintillation Counting Field, ANSI N42.9-1972.)

Photomultipliers are extensively used in scintillation counting for the detection and analysis of ionizing radiation. The utilization of these detectors in a variety of technical disciplines have made standard test procedures desirable so that measurements may have the same meaning to all manufacturers and users.

This standard is not intended to imply that all tests and procedures described herein are mandatory for every application, but only that such tests as are carried out on photomultipliers for scintillation and Cerenkov counting should be performed in accordance with the procedures given in this document.

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An American National Standard

IEEE Standard Test Procedures for Photomultipliers for Scintillation Counting and Glossary for Scintillation Counting Field

1. General

The photomultiplier is an essential component in scintillation and Cerenkov counting. In these applications there are special requirements with regard to pulse-height characteristics, spurious pulses, and timing.

1.1 The Scintillation Counter

The scintillation counter is a radiation detector that consists of three major components: a scintillating medium that produces a flash of light when ionizing radiation interacts with it; one or more photomultipliers, optically coupled to the scintillator, which converts the light flash to an amplified electrical impulse; and associated electronic instrumentation which powers the photomultiplier and processes the output signal.

1.2 The Cerenkov Counter

The Cerenkov counter is a radiation detector that consists of three major parts: a medium in which light is produced by the Cerenkov effect; one or more photomultipliers, optically coupled to the Cerenkov medium; and the associated electronic instrumentation which powers the photomultiplier and processes the output signal.

2. Photomultiplier Characteristics

2.1 General Characteristics

The tests herein described for photomultipliers to be used in scintillation counters are supplementary to those tests described in IEEE Std 158-1962, Methods of Testing Electron Tubes, which covers the following basic characteristics commonly requiring specification for photomultipliers (numbers in brackets refer to section numbers of IEEE Std 158-1962, Part 5.):

- Radiant sensitivity [2.4]
- Uniformity of sensitivity [2.7]
- Current amplification [3.2]
- Current-voltage relationship [4.2]
- Dynamic performance, pulse performance [5.2]

Electrode dark current [6]
Noise [7]
Peak-output-current limitations [9]

2.2 Additional Characteristics Specific to Scintillation and Cerenkov Counters

Additional specifications and tests required for photomultipliers used in scintillation and Cerenkov counting in connection with the preceding basic characteristics are the following:

- 1) Pulse-height characteristics
- 2) Spurious-pulse characteristics
- 3) Pulse-timing characteristics

3. Testing of Photomultiplier Characteristics

3.1 Pulse-Height Characteristics

The following sections deal with pulse characteristics of photomultipliers used in counting applications. Throughout this section it is assumed that the pulse-height analyzer is linear and that channel numbers are with respect to the extrapolated pulse-height analyzer zero.

3.1.1 Pulse Height.

A photomultiplier consists of a photocathode which produces photoelectrons and an electron multiplier structure which provides gain by secondary electron multiplication. For a given number N of photoelectrons emitted from the photocathode, a number $G \times N$ electrons are observed at the anode. The factor G is the multiplier gain, which depends upon the interstage potential differences applied to the electrodes. The counting rates and resolving times shall be such that pulse pileup is sufficiently low so as not to significantly affect the accuracy of the results.

When the input consists of photon packets sufficiently well spaced in time, the photomultiplier can resolve them as separate events, and the output signal consists of separate charge pulses. These pulses can be amplified with a charge-sensitive preamplifier, followed by a main amplifier, and sorted with a pulse-height analyzer. The term pulse height is commonly used to designate the charge associated with a PMT (photomultiplier tube) output pulse.

Pulse height is measured with a charge-sensitive preamplifier and a pulse-height analyzer. The system can be calibrated in terms of coulombs per channel with a precision pulser. The slope and zero intercept shall be determined.

3.1.2 Pulse-Height Resolution.

A photomultiplier produces a charge output proportional to the number of photons incident on the photocathode. Because of the statistical variations inherent in the conversion of photons to photoelectrons, together with the statistical nature of the secondary emission process, the output-signal charge varies from one pulse to the next even for equal numbers of incident photons. The resulting distribution in pulse height limits the photon resolution of the device and hence limits the energy resolution of a scintillator-photomultiplier combination. For this reason a figure of merit called PHR (pulse-height resolution) is introduced to characterize the device's ability to discriminate between slightly different input-signal amplitudes.

PHR is the fractional full width at half maximum of the pulse-height-distribution curve (FWHM/ A_1) of the peak of interest, where A_1 is the pulse height corresponding to the maximum of the distribution curve. It is customary to state PHR in units of percent. The following discussion outlines several kinds of PHR measurements that are used to characterize photomultipliers.

In general there are five distinct PHR measurements that serve to define the photon-and-electron resolution of photomultipliers and photomultiplier-scintillator combinations.

- 1) *^{137}Cs PHR for a Scintillation-Crystal PMT Combination.* This PHR is principally a function of the photocathode quantum efficiency and spatial uniformity, as well as the resolution of the scintillation crystal.
- 2) *Light-Emitting Diode PHR.* This PHR is obtained with an LED (light-emitting diode) calibrated to provide a ^{137}Cs -equivalent signal (or stated number of photoelectrons per pulse). The LED PHR is numerically smaller than the scintillator-PMT PHR because the contribution of the crystal is not present. (See Fig. 1.)
- 3) *^{55}Fe PHR for a Scintillation-Crystal-PMT Combination.* This is the PHR obtained from a scintillation crystal and an ^{55}Fe source. This PHR depends on both the crystal and the photomultiplier.
- 4) *Single-Electron PHR.* The PHR of the SEPHR (single-electron spectrum) has significance only for those photomultipliers that can resolve a single-electron peak. A weak dc light is used as the source of single electrons from the photocathode. (Note that this measures only the resolution of the electron multiplier section of the device.)
- 5) *Electron Resolution.* Electron resolution is a measure of the ability of the electron multiplier section of the device to resolve inputs consisting of either one or two electrons. The measurement applies only to those photomultipliers that can resolve one- and two-electron events. As an alternative to measuring the FWHM of the electron peak, the peak-to-valley ratio can be measured. (See Fig. 2.)

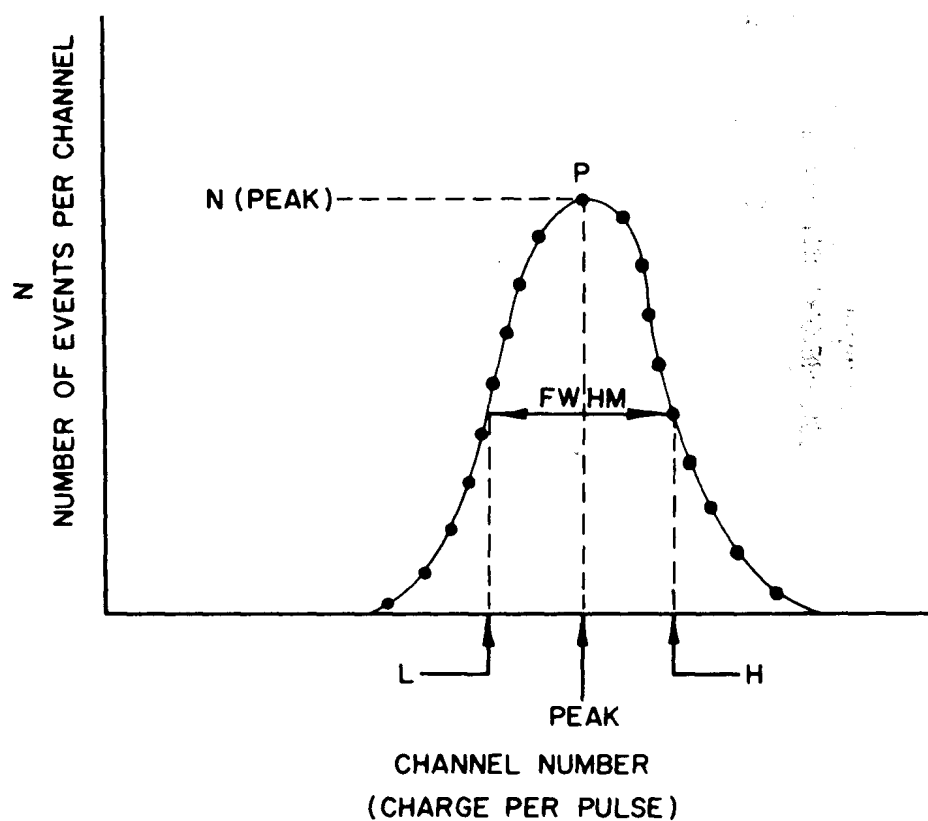
Measurement of ^{137}Cs PHR requires a ^{137}Cs source, an NaI(Tl) scintillation crystal of approximately the same diameter as the photocathode, a pulse-height analyzer, and the photomultiplier to be tested. The PMT is optically coupled to the scintillation crystal, for example, with the aid of silicone grease or viscous oil. The crystal housing must be at photocathode potential. The source is placed in contact with the crystal housing.

The PMT should be operated at a voltage such that linear response is obtained; that is, output is proportional to input intensity. Improper anode bias, excessive gain (and thus excessive anode current), or improper voltage divider circuits may give rise to a compression of the output-pulse distribution, yielding an incorrect (low value) of PHR.

The scintillation-crystal-PMT combination must operate for several hours to obtain optimum PHR.

Phosphorescence of the crystal and PMT faceplate may require several hours to decay to a low enough level to permit accurate measurements to be made. Therefore, photomultipliers and crystals should not be exposed to ambient laboratory light for some time before measurements are made.

The test enclosure must be designed to avoid high electric fields in the region of the photocathode. If the PMT is operated at photocathode ground (positive high voltage), there is little problem with external electric fields at the photocathode. If negative high voltage is used, electric fields near the photocathode must be low. This may be accomplished by an electrostatic shield having the same potential as the photocathode. Otherwise, excessive noise on the output signal and electrolysis, followed by eventual loss of photosensitivity, may develop. As with other PMT measurements, a magnetic shield is required.



THE VALUES OF H AND L SHOULD BE INTERPOLATED AND NOT RESTRICTED TO INTEGER CHANNEL VALUES. $(H-L) \geq 8$
 $R = 100(H-L)/P$ IN PERCENT, WHERE : $R = PHR$

H = CHANNEL HIGH

L = CHANNEL LOW

P = PEAK

Figure 1 — ^{137}Cs Equivalent LED spectrum