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# INTERNATIONAL STANDARD

## Nuclear instrumentation – Photomultiplier tubes for scintillation counting – Test procedures



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# NUCLEAR INSTRUMENTATION – PHOTOMULTIPLIER TUBES FOR SCINTILLATION COUNTING – TEST PROCEDURES

## FOREWORD

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International Standard IEC 60462 has been prepared by IEC technical committee 45: Nuclear instrumentation.

This second edition cancels and replaces the first edition published in 1974 and constitutes a technical revision.

The main technical changes with regard to the previous edition are as follows:

- to review the existing requirements and to update the terminology, definitions and normative references.

The text of this standard is based on the following documents:

| FDIS | Report on voting |
|---|---|
| 45/706/FDIS | 45/711/RVD |

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

# NUCLEAR INSTRUMENTATION – PHOTOMULTIPLIER TUBES FOR SCINTILLATION COUNTING – TEST PROCEDURES

## 1 Scope and object

This International Standard establishes test procedures for photomultiplier tubes (PMT) for scintillation and Cherenkov detectors.

This standard is applicable to photomultiplier tubes for scintillation and Cherenkov detectors.

Photomultiplier tubes are extensively used in scintillation and Cherenkov counting, both in the detection and analysis of ionizing radiation and for other applications. For such uses, various characteristics are of particular importance and require additional tests to those conducted to measure the general characteristics of PMT. This has made desirable the establishment of standard test procedures so that measurements of these specific characteristics may have the same significance to all manufacturers and users.

The tests described in this standard for PMT to be used in scintillation detectors are supplementary to those tests described in IEC 60306-4, which covers the basic characteristics commonly requiring specification for photomultiplier tubes.



This recommendation is not intended to imply that all tests and procedures described herein are mandatory for every application, but only that those tests carried out on PMT for scintillation and Cherenkov detectors should be performed in accordance with the procedures given in this standard.



## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60306-4, *Measurement of photosensitive devices – Part 4: Methods of measurement for photomultipliers*

## 3 Terms, definitions, symbols and abbreviations

### 3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

**3.1.1**
**photomultiplier tube**
**multiplier phototube**
**PMT (abbreviation)**
vacuum tube consisting of a photocathode and an electron multiplier intended to convert light into an electric signal

[IEC 60050-394:2007, 394-30-12]

**3.1.2**
**Cherenkov detector**
radiation detector designed to detect relativistic particles, using a medium in which the Cherenkov effect is produced

NOTE The medium is optically coupled to a photosensitive device, either directly or through light guides.

[IEC 60050-394:2007, 394-29-17]

**3.1.3**
**scintillation detector**
radiation detector consisting of a scintillator that is usually optically coupled to a photosensitive device, either directly or through light guides

NOTE The scintillator consists of a scintillating material in which the ionizing particle produces a burst of luminescence radiation along its path.

[IEC 60050-394:2007, 394-27-01]

**3.1.4**
**light guide**
optical device designed to transmit light without significant loss

NOTE It may be placed between a scintillator and a photomultiplier tube.

[IEC 60050-394:2007, 394-30-15]



**3.1.5**
**dark current (of a photomultiplier tube)**
electric current flowing from the anode circuit in the absence of light on the photocathode

[IEC 60050-394:2007, 394-38-14]



**3.1.6**
**gain (of a photomultiplier tube)**
ratio of the anode output current to the current emitted by the photocathode at stated electrode voltages

[IEC 60050-394:2007, 394-38-15]

**3.1.7**
**collection efficiency (of a photomultiplier tube)**
ratio of the number of measurable electrons reaching the first dynode to the number of electrons emitted by the photocathode

[IEC 60050-394:2007, 394-38-16]

**3.1.8**
**light sensitivity (of a photomultiplier)**
ratio of a photomultiplier cathode current by the corresponding incident light flux of a given wavelength

[IEC 60050-394:2007, 394-38-62]

**3.1.9**
**spectral sensitivity (of a photomultiplier)**
light sensitivity as a function of wavelength

[IEC 60050-394:2007, 394-38-63]

**3.1.10**
**light sensitivity non-uniformity (of a photomultiplier)**
variation of the light sensitivity over the photocathode surface

[IEC 60050-394:2007, 394-38-64]

**3.1.11**
**transit time (in a photomultiplier tube)**
time interval between the emission of a photo-electron and the occurrence of a stated point on the output current pulse due to that electron

[IEC 60050-394:2007, 394-38-12]

NOTE For example, peak maximum.

**3.1.12**
**transit time jitter (in a photomultiplier tube)**
variation in the transit times corresponding to different photoelectrons

[IEC 60050-394:2007, 394-38-13]

## 3.2 Symbols and abbreviations

### 3.2.1 Symbols

| | |
|---|---|
| $A$ | photomultiplier tube spectrometric constant; |
| $C_{pho}$ | light output of the working standard in photon/MeV; |
| $H$ | pulse height or peakposition without filter; |
| $H'$ | pulse height or peak position with filter; |
| $k$ | absorption factor of the filter; |
| $n$ | total number of readings; |
| $P$ | P is the pulse height corresponding to the peak-value of the distribution; |
| $\overline{P}$ | mean pulse height averaged over $n$ readings; |
| $P_i$ | pulse height at the $i^{th}$ reading; |
| $P_{max}$ | maximum pulse height, recorded during the 16 h test interval; |
| $P_{min}$ | minimum pulse height; recorded during the 16 h test interval; |
| $P_T$ | pulse height at temperature $T$; |
| $P_N$ | pulse height at temperature $T$ = 20 °C; |
| $P_{UP}$ | pulse height when PMT stands upright; |
| $P_{NS}$ | pulse height when PMT lies along north-south direction; |
| $R$ | pulse height resolution (*PHR*); |
| $R_a$ | energy resolution of the scintillation detector; |
| $R_d$ | intrinsic resolution of the measured housed scintillator; |
| $R_{et}$ | intrinsic resolution of the working standard; |
| $t$ | observed time; |
| $t_r$ | photomultiplier rise time; |
| $t_s$ | rise time of the source pulse; |
| $t_{scp}$ | oscilloscope rise time; |
| $X$ | pulse height linearity; |
| $V$ | value of pulse height corresponding to total absorption peak maximum of the measured housed scintillator; |

| | |
|---|---|
| $\Delta$ | mean pulse height deviation; |
| $\Delta_{max}$ | maximum pulse height deviation, in percent; |
| $\Delta P$ | full-width at half-maximum (*FWHM)*; |
| $\Delta_T$ | pulse height shift, in percent; |
| $\Delta_{\mu\text{-metal}}$ | deviation of pulse-heights. |

### 3.2.2 Abbreviations

| | |
|---|---|
| CFTD | constant fraction timing discriminator; |
| *FWHM* | full-width at half-maximum; |
| LED | light emitting diode; |
| MCA | multichannel analyzer; |
| *PHD* | pulse height distribution; |
| *PHR* | pulse height resolution; |
| PMT | photomultiplier tube; |
| $s^{-1}$ | counts per second; |
| *SPEPHR* | single photo-electron pulse height resolution; |
| *SPERT* | single photo-electron rise time; |
| TAC | time-to-amplitude converter; |
| TTS | transit-time spread. |



## 4 Test conditions



Test conditions for photomultipliers are specified in terms of environmental conditions that shall be met to enable accurate measurements of the photomultiplier parameters discussed in this standard.

Power supplies should be stabilized and, in particular, high-voltage power supplies should have regulations of 0,01 % or better, and ripple and noise should be not more than 10 $mV_{pp}$.

The test enclosure shall be free of detectable light leaks. This can be verified by half-hour photon counting periods, with and without bright ambient light incident on the enclosure.

The PMT should be stored in darkness for 1 h prior to measurement to avoid phosphorescence effects. Cleanliness of the PMT glass and sockets is essential in preventing external noise effects. Any material near the photocathode should be at photocathode potential to prevent electro-luminescence of the envelope and electrolysis or charge accumulation of the glass. To obtain the best conditions for reproducibility of tests, it is recommended that where feasible, a shield connected to cathode potential, be placed around and in contact with the glass envelope of the photomultiplier.

The PMT should be degaussed before using, and a magnetic shield should be employed. Note that even the earth's magnetic field is of sufficient strength to influence measurements. Tube temperature should preferably be maintained constant at ± 2 °C within the limits from 19 °C to 25 °C. This is important in instances where the voltage divider may raise the temperature of the test enclosure.

Caution should be used to avoid drifts or base line shifts in the electronic circuitry that significantly affects the measurements.

To prevent drifts or base line shifts in potentials between dynodes resulting from the electron multiplier current, the quiescent current drawn by the resistive voltage divider should be at least 20 times the DC anode current. Alternatively, the potentials between dynodes for the dynodes drawing the greatest current may be individually stabilized (as with separate power supplies).

Charge-storage capacitors may be effectively used across the dynodes or from the dynodes to ground when the ratio of the peak anode current to the average anode current is large and the capacitor can maintain the required dynode potentials for the duration of the pulse.

Pulse shaping methods and time constants suitable for optimum performance should be used and should be stated.

# 5 Test procedures for photomultiplier characteristics

## 5.1 General

In addition to the specifications and test methods of IEC 60306-4, complementary or extended specifications and tests required for photomultipliers used with scintillation and Cherenkov detectors are:

a) Pulse height characteristics[1].

b) Dark current.

c) Pulse timing characteristics.

## 5.2 Pulse height characteristics



### 5.2.1 General

Pulse height is used in counting and spectrometric applications.



### 5.2.2 Pulse height resolution measurement

#### 5.2.2.1 General

In general there are four distinct *PHR* measurements to define the photon-and-electron resolution of PMT and scintillator/PMT combinations. These resolutions may be used separately or together.

#### 5.2.2.2 $^{137}$Cs PHR for a scintillator/PMT combination

This *PHR* is a function of the photocathode quantum efficiency, collection efficiencies of the dynodes and spatial uniformity, as well as the resolution of the scintillator.

For standard cases, measurement of $^{137}$Cs pulse height resolution requires a $^{137}$Cs source, a NaI(Tl) scintillator of 50 mm height and approximately the same diameter as the photocathode, a pulse height analyzer and the photomultiplier to be tested. The photomultiplier tube is optically coupled to the scintillator - for example, with the aid of silicone grease or viscous oil. The crystal housing should be at photocathode potential. The source is placed at a distance from the scintillator such that less than 1 000 pulses/s are encountered.

The PMT should be operated at a voltage such that a linear response is obtained, i.e. the output pulse height is proportional to input light 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 tube/scintillator combination should warm-up for 1 h to obtain optimum *PHR*.

1 The terms “pulse amplitude” and “pulse height” are commonly used to designate the charge associated with a PMT output pulse.