

INTERNATIONAL STANDARD

**Nuclear instrumentation – Housed scintillators – Test methods of light output
and intrinsic resolution**

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TEST METHODS OF LIGHT OUTPUT AND INTRINSIC RESOLUTION**

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International Standard IEC 62372 has been prepared by IEC technical committee 45: Nuclear instrumentation.

This second edition cancels and replaces the first edition published in 2006. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- Title has been modified.
- To review the existing requirements and to update the terminology, definitions and normative references.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
45/913/FDIS	45/915/RVD

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

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

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

- reconfirmed,
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NUCLEAR INSTRUMENTATION – HOUSED SCINTILLATORS – TEST METHODS OF LIGHT OUTPUT AND INTRINSIC RESOLUTION

1 Scope

This document is applicable to housed scintillators for registration and spectrometry of alpha-, beta-, gamma-, X-ray and neutron radiation.

The main parameters, such as a light output and intrinsic resolution are established. This document specifies the requirements for the testing equipment and test methods of the basic parameters of housed scintillators, such as:

- the direct method is applicable to measure the light output of housed scintillators based on scintillation material. The housed scintillators certified by this method can be used as working standard of housed scintillators (hereinafter: working standard) when performing measurements by a relative method of comparison.
- the relative method of comparison with the working standard is applicable to housed scintillators based on the same scintillation material as the working standard.

This document does not apply to gas or liquid scintillators and scintillators for counting and current modes.

The numerical values of the parameters are set to the specific type of scintillators in the specifications.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1

scintillator

luminescent material, usually liquid or solid, showing radioluminescence with a short afterglow

[SOURCE: IEC 60050-845:1987, 845-04-37]

3.1.2

housed scintillator

scintillator, housed in a container with a reflector and optical window

3.1.3

scintillation detector

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

Note 1 to entry: The scintillator consists of a scintillating material in which the ionizing particle produces a burst of luminescence radiation along its path. A common scintillator is NaI(Tl).

[SOURCE: IEC 60050-395:2014, 395-03-01]

3.1.4

assembly

light protective chamber containing a housed scintillator, photomultiplier (PMT), PMT voltage divider

Note 1 to entry: Assembly is used for testing of the housed scintillator.

3.1.5

light yield

η

ratio of scintillation photons summed energy (E_p) to energy (E) lost by ionizing particles in the scintillator

$$\eta = \frac{E_p}{E}$$

Note 1 to entry: Value of η depends on type and energy of ionizing particle.

3.1.6

light output

C

ratio of total energy (L_{ph}) of scintillation photons, which pass through the output window of the housed scintillator of ionizing radiation, to energy (E), lost by ionizing particles in the scintillator

$$C = \frac{L_{ph}}{E}$$

3.1.7

intrinsic resolution of housed scintillator of ionizing radiation

R_d

component, given by housed scintillator of ionizing radiation to energy resolution of the scintillation detector

Note 1 to entry: The intrinsic resolution R_d is defined from the relation:

$$R_d = \sqrt{R_a^2 - R_{pm}^2},$$

where

R_a is the energy resolution of the scintillation detector;

R_{pm} is PMT intrinsic resolution.

3.1.8

total absorption peak

portion of the spectral response curve corresponding to the total absorption of photon energy in a radiation detector

Note 1 to entry: This peak represents the total absorption of photon energy from all interactive processes, namely, a) photoelectric absorption, b) Compton effect, and c) pair production.

[SOURCE: IEC 60050-395:2014, 395-03-94]

3.1.9

photomultiplier tube spectrometric constant

A

parameter, characterizing properties of the photomultiplier tube

Note 1 to entry: Defined by the following formula:

$$A = (R_a^2 - R_d^2) \times C_{ph}$$

where C_{ph} is light output, photons/MeV.

3.1.10

working standard

working standard of housed scintillator that is used to check the measuring system and to measure the light output by a method of comparison

3.1.11

full width at half maximum

FWHM

in a distribution curve comprising a single peak, the distance between the abscissa of two points on the curve whose ordinates are half of the maximum ordinate of the peak

Note 1 to entry: If the curve considered comprises several peaks, a full width at half maximum exists for each peak.

3.1.12

expanded uncertainty

expanded uncertainty quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

Note 1 to entry: The fraction may be viewed as the coverage probability or level of confidence of the interval.

Note 2 to entry: To associate a specific level of confidence with the interval defined by the expanded uncertainty requires explicit or implicit assumptions regarding the probability distribution characterized by the measurement result and its combined standard uncertainty. The level of confidence that may be attributed to this interval can be known only to the extent to which such assumptions may be justified.

[SOURCE: JCGM 100:2008, 2.35]

3.1.13

relative expanded uncertainty

ratio of the expanded uncertainty of a measurement to average value of quantity. It expresses the relative size of the uncertainty of a measurement (its precision)

3.2 Symbols and abbreviated terms

A	the photomultiplier tube spectrometric constant;
a	the assembly conversion factor with the housed scintillator;
a_i	the value of conversion response, measured at energy value of E_i ;
$a_{\max}$	the maximal value of a ;
$a_{\min}$	the minimal value of a ;
Δa	the value of nonlinearity;
C	the light output, in relative units;

C_{ph}	the light output, photons/MeV;
C_{pho}	the light output of the working standard, photons/MeV;
FWHM	the full width at half maximum of peak;
E	energy lost by ionizing particle in the scintillator;
E_{max}	the maximum gamma radiation energy;
E_p	summed energy of scintillation photons, which have arisen in scintillator;
eps	the initial point of housed scintillator conversion response, in energy units;
k	the coverage factor;
k_a	the assembly conversion factor;
L_{ph}	total energy of scintillation photons;
m	coefficient of spectral matching;
n	the number of energy values used;
N	the average value of conversion factor;
PMT	a photomultiplier tube;
Q	the PMT photocathode quantum sensitivity;
$S(\lambda)$	the PMT photocathode spectral characteristic;
R_a	the energy resolution of the scintillation detector;
R_{ao}	the energy resolution of scintillation detector with working standard;
R_d	the intrinsic resolution of the measured housed scintillator;
R_{et}	the intrinsic resolution of the working standard;
R_{pm}	the PMT intrinsic resolution;
U_p	the expanded uncertainty;
u_c	the combined standard uncertainty;
V	the value of pulse height corresponding to total absorption peak maximum of the measured housed scintillator;
V_d	the initial point of housed scintillator conversion response;
V_{et}	the value of pulse height corresponding to total absorption peak maximum of the working standard;
V_i	the value of pulse height corresponding to total absorption peak maximum for single measurement;
V_{in}	pulse height at the input of the assembly, the number of channels;
V_{max}	the value of pulse height which corresponds to E_{max} , the number of channels;
V_o	the initial point of assembly conversion response;
V_{od}	the initial point of assembly conversion response with the housed scintillator;
V_{out}	pulse height at the output of the assembly, the number of channels;
ΔV	the value of FWHM;
y_1	the average value of the controlled parameter at the beginning of the measurement;
y_2	the average value of controlled parameter at the end of the measurement;
$y(\lambda)$	the scintillator spectral characteristic;
Δy	the instability value;
η	light yield.

4 Test methods of basic parameters of housed scintillators

4.1 General

4.1.1 Test conditions

Measurements shall be made under normal conditions, unless otherwise specified in the specifications of the manufacturer of housed scintillators.

Measurements should start at least 0,5 h after the last device has been switched on, unless otherwise specified by the manufacturer specifications.

Before measuring, the housed scintillator and the PMT is kept under high voltage for the time necessary for getting to the operation condition. Before measuring, the PMT is kept under high voltage for the time necessary for getting to the operation condition.

All parameters are measured during the complete blackout of the housed scintillator and PMT.

Optical contact between the housed scintillator and the PMT is provided by the material specified in the manufacturer specifications of the housed scintillator.

For the measuring, the following condition of choosing PMT should be reached: the working part of the photocathode shall overlap the output window of the scintillator.

It is allowed to apply a light guide or an assembly of several PMT, if technical characteristics and use conditions of light guide or assembly are specified in the specifications.

The measured housed scintillator is mounted on the PMT photocathode by optical contact, unless otherwise is specified in the manufacturer's specifications.

It is allowed to place a source of ionizing radiation inside the light protective chamber.

PMT voltage should correspond to its attached data for operation conditions.

The spectrum of pulse height should be measured to define operation conditions of the assembly.

4.1.2 The sources of ionizing radiation

Enclosed radioactive sources of alpha-, beta-, gamma-, X- and neutron radiation with known energies should be used. The source of radiation shall be selected depending on the application of measured housed scintillator according to Table 1.

Table 1 – Source of ionizing radiation

The application of housed scintillator	Source of radiation according to application
Alpha-radiation of radionuclides	^{239}Pu , ^{241}Am , ^{244}Cm or ^{237}Np
Beta- radiation	^{137}Cs or ^{207}Bi
Gamma-radiation of radionuclide	^{137}Cs
Low gamma- and X-radiation	^{55}Fe , ^{109}Cd , ^{241}Am and ^{57}Co
Neutron radiation	$^{239}\text{Pu}+\text{Be}$, $^{241}\text{Am}+\text{Be}$ or ^{252}Cf

For measurements with the gamma- or X-radiation sources, they should be placed along the scintillator axis at minimum distance of not less than two diameters or a diagonal of the scintillator.

For measurements with the alpha- or beta-radiation sources, they should be placed directly on the entrance window of the housed scintillator.

For measurements with the alpha- or beta- sources, it is allowed to use a single-hole or multi-hole collimator with a hole diameter less than the thickness of the collimator.

4.1.3 The assembly test conditions

The current of the divider should exceed the PMT average anode current more than 10 times.

PMT power supplies shall provide high voltage stability better than 0,05 % and divider current more than 0,5 mA.

At low-resistance inputs of subsequent stages of the measurement section the measurements may be performed without matching stage.

For a recording device providing a pulse heights spectrum suitable for further processing multi-channel pulse analyzers, which have an output recording device of any type that registers and allows to give the pulse height spectrum in form convenient for processing, should be used.

4.2 Test methods of nonlinearity and instability of the assembly

4.2.1 Nonlinearity measurement

4.2.1.1 General

The dependence of the pulse height (V_{out}) at the output of the assembly on the signal (V_{in}) at the input of the assembly (assembly conversion response) is defined according to formula:

$$V_{out} = k_a \times V_{in} + V_o,$$

where

k_a is the assembly conversion factor;

V_o is the initial point of assembly conversion response.

If conversion response of the housed scintillator is linear, the assembly conversion response with the housed scintillator is also linear:

$$V_{out} = a \times E + V_{od}$$

Then

$$V_{od} = V_o + V_d = V_o + a \times eps, \quad (1)$$

where

E is energy lost by ionizing particle in the scintillator;

a is the assembly conversion factor with the housed scintillator;

V_{od} is the initial point of assembly conversion response with the housed scintillator;

V_d is the initial point of housed scintillator conversion response;

eps is the initial point of housed scintillator conversion response, in energy units.

Nonlinearity (Δa) is determined by the deviation of measured points from assembly conversion response, in percentage, and calculated according to the formula:

$$\Delta a = \frac{(a_{\max} - a_{\min})}{(a_{\max} + a_{\min})} \times 100, \quad (2)$$

where

$a_{\max}$ is maximal value of a ;

$a_{\min}$ is minimal value of a .

V_{od} value is defined as the cutoff of the assembly conversion response with the housed scintillator on the coordinate axis. V_o value should be calculated according to formula (1).

For each value of energy, the position of a maximum of a peak of full absorption is defined.

The values of the nonlinearity and the initial point of assembly conversion response shall be defined using a housed scintillator based on thallium-activated sodium iodide single crystal during irradiation by gamma-radiation.

Pulse height spectra are measured using monoenergetic gamma radiation with at least five energy values in the range from 300 keV to 1 500 keV.

For each energy value the total absorption peak maximum position should be defined.

The light output of a housed scintillator may be used to determine the nonlinearity and the initial point of assembly conversion response in cases where it is necessary to measure the parameters of housed scintillators with low light output. For that, light flux from housed scintillator is attenuated by a neutral light filter. The pulse heights obtained after attenuation should correspond to the working range of pulse heights of the tested scintillator.

Neutral light absorbers are added after the PMT power supply is turned off and the light protection chamber is opened. After setting the light absorber, the chamber is closed, the PMT power supply is turned on and measurements are taken after not less than half an hour's irradiation.

The values of nonlinearity and V_o are measured at the same gain factor which is used for measuring the parameters of tested housed scintillator. The nonlinearity and V_o should be measured once per month or more frequently, after PMT replacement or assembly repair.

4.2.1.2 Measurements

The test conditions and the order of measurements are in accordance with 4.1.

The value of pulse heights (V) corresponding to total absorption peak maximum is determined. The measurements are repeated three times and the average value V is calculated.

All above-mentioned procedures are repeated for each value of energy (E_i).

The pulse height spectra may be accumulated simultaneously from all the gamma-emitting sources during irradiation of the housed scintillator.

4.2.1.3 Processing of results

The values of the assembly conversion factor with the housed scintillator (a_i) for each energy range (E_i) are calculated according to the formula:

$$a_i = \frac{(V_{\max} - V_i)}{(E_{\max} - E_i)},$$

where

$E_{\max}$ is the maximum gamma radiation energy;

$V_{\max}$ is the pulse height, corresponding to the $E_{\max}$, the number of channels.

The minimal ($a_{\min}$) and maximal ($a_{\max}$) values from the set of values (a_i) should be selected.

The assembly nonlinearity (in percentage) is calculated in accordance with formula (2).

The average value of conversion factor (N) is calculated according to the formula:

$$N = \frac{1}{n-1} \sum_{i=1}^{n-1} a_i,$$

where

n is the number of energy values used;

a_i is the value of conversion response, measured at the energy value of E_i .

The value of the initial point of assembly conversion response with the housed scintillator (the number of channels) is calculated according to the formula:

$$V_{od} = \frac{1}{n} \left(\sum_{i=1}^n V_i - N \sum_{i=1}^n E_i \right)$$

The value of the initial point of assembly conversion response is calculated in accordance with the formula:

$$V_o = V_{od} + N \times eps,$$

Expanded uncertainty of assembly nonlinearity should not exceed $\pm 0,03$ with a level of confidence of 0,95 ($k = 1,96$).

Expanded uncertainty of the initial point measurement of assembly conversion response should not exceed two channels with a level of confidence of 0,95 ($k = 1,96$).

4.2.2 Instability measurement

4.2.2.1 General

The instability of the assembly should be calculated by the change in time of the determined parameter or an intermediate parameter which is used to calculate the defined parameter.

During measurement of the light output of the housed scintillators, the instability is determined by the change of pulse height over time.

During measurement of the intrinsic resolution of the housed scintillators, the instability is determined by the change of pulse height and energy resolution of the scintillation detector over time.

The instability of the assembly may be determined by using a housed scintillator based on the same scintillator material type and during irradiation by the same radiation type as for the tested housed scintillator.

The test conditions and the order of measurements are in accordance with 4.1.

Three measurements should be carried out before the start and at the end of the measurement.

4.2.2.2 Processing of results

The value of instability (Δy), in percentage, is calculated by the formula:

$$\Delta y = \frac{(y_1 - y_2)}{(y_1 + y_2)} \times 100,$$

where

y_1 is the average value of the controlled parameter at the beginning of the measurement;

y_2 is the average value of the controlled parameter at the end of the measurement.

The instability of the pulse height should not exceed 2 %. The instability of the energy resolution should not exceed 3 %.

4.3 Test methods of the intrinsic resolution, light output of the housed scintillator and PMT spectrometric constant

4.3.1 Equipment

The test conditions and the order of measurements are in accordance with 4.1.

A PMT with the known spectral characteristic $S(\lambda)$ and quantum sensitivity Q is used.

The nonlinearity and the initial point of assembly conversion response is measured as specified in 4.2.1.

The assembly is qualified for making measurements if its nonlinearity does not exceed 3 %.

The instability of the assembly is assessed as specified in 4.2.2. The assembly is qualified for making measurements if its instability does not exceed 2 %.

4.3.2 Measurements

The tested housed scintillator is mounted on the PMT photocathode by optical contact and the pulse height spectrum is measured as specified in 4.1.1.

The number of channels (V) corresponding to total absorption peak maximum is determined taking into account the initial point of assembly conversion response.

The value of FWHM (ΔV) is determined.

The measurements are carried out, as described above, each time installing neutral light filters of different optical density between the housed scintillator output window and PMT photocathode and obtaining the values of V and ΔV .

4.3.3 Processing of results

The value of the energy resolution of the scintillation detector (R_a) for each of n measurements (n is the number of filters for different optical density, at least 5) is calculated according to the formula:

$$R_a = \frac{\Delta V}{V} \quad (3)$$

Based on the results of n measurements, a characteristic curve $R_a^2 = f\left(\frac{1}{V}\right)$ is plotted. A straight line is fitted through the experimental points, which can be approximated by the dependence:

$$R_a = \sqrt{R_d^2 + \frac{A}{V}},$$

where the value R_d^2 is the value which the curve cuts off on the y-axis that corresponds to the intrinsic resolution of the measured housed scintillator (R_d).

The PMT intrinsic resolution is calculated by the formula:

$$R_{pm} = \sqrt{(R_a^2 - R_d^2)}$$

Light output, photons/MeV, is defined using the formula:

$$C_{ph} = \frac{2,36^2}{R_{pm}^2 \times Q \times m \times E},$$

where

Q is the PMT photocathode quantum sensitivity;

m is the coefficient of spectral matching which is calculated according to the formula:

$$m = \frac{\int S(\lambda) \times y(\lambda) d\lambda}{\int y(\lambda) d\lambda},$$

where

$S(\lambda)$ is the PMT photocathode's spectral characteristic;

$y(\lambda)$ is the housed scintillator spectral characteristic.

The scintillators certified using this method can be considered a working standard of housed scintillators when performing measurements by the relative method of comparison.

4.4 Test methods of the light output

4.4.1 General

The relative method of comparison with the working standard may be applied if the tested housed scintillator and working standard are made of the same scintillation material.

The test conditions and the order of measurements are in accordance with 4.1.

The nonlinearity and the initial point of assembly conversion response is measured as specified in 4.2.1.

The assembly is qualified for making measurements if its nonlinearity does not exceed 3 %.

The instability of the assembly is calculated as specified in 4.2.2. The assembly is qualified for making measurements if its instability does not exceed 2 %.

The difference between the diameters of the working standard and tested housed scintillators should not exceed 25 %. Also, the sensitivity non-uniformity of PMT photocathode for the larger housed scintillator should not exceed 20 %.

NOTE Sensitivity non-uniformity of PMT photocathode is measured using the housed scintillator with 10 mm diameter as the light source.

The working standard is calibrated according to 4.3.

The working standard and tested housed scintillator are irradiated by ionizing radiation of the same type and energy.

The type of ionizing radiation source is selected according to 4.1.2 or as specified in the manufacturer's specifications.

4.4.2 Measurements

At first the working standard is tested.

The order of measurements is in accordance with 4.1.

The PMT operative voltage and the gain of data processing unit are selected in such a way that the maximum of distribution curve for the used source should be within the last quarter of the pulse analyzer scale.

The value of pulse height (V_{et}) corresponding to total absorption peak maximum is obtained.

NOTE For organic scintillators the pulse height corresponding to Compton absorption edge at half-height of the distribution edge is determined.

The measurements are carried out three times and the average value V_{et} is calculated for the working standard.

All above-mentioned procedures are repeated for the tested housed scintillator and the average value of pulse height V corresponding to total absorption peak maximum or Compton distribution edge is calculated.

4.4.3 Processing of results

For the tested housed scintillator, the value of light output (C_{ph}), photons/MeV, is calculated by the formula:

$$C_{ph} = \frac{C_{pho} \times (V_a - V_o)}{(V_{et} - V_o)},$$

where C_{pho} is the value of the light output of the working standard (photons/MeV).

Relative expanded uncertainty ($\frac{\Delta C_{ph}}{C_{ph}}$) of light output measurement, in percentage, at level of confidence of 0,95 should not exceed the value calculated by the following formula:

$$\frac{\Delta C_{ph}}{C_{ph}} = 1,1 \times \sqrt{\left(\frac{\Delta C_{pho}}{C_{pho}}\right)^2 + 4},$$

where $\frac{\Delta C_{pho}}{C_{pho}}$ is the relative expanded uncertainty, in percentage, for light output measurement of the working standard.

Relative expanded uncertainty, in percentage, for light output measurement with a level of confidence of 0,95 should not exceed ± 2 % ($k = 1,96$).

4.5 Test methods of the intrinsic resolution

4.5.1 Determination of PMT spectrometric constant

4.5.1.1 General

The test conditions and the order of measurements are in accordance with 4.1.

The nonlinearity and the initial point of assembly conversion response is measured as specified in 4.2.1.

The assembly is qualified for making measurements if its nonlinearity does not exceed 3 %.

The instability of the assembly is assessed as specified in 4.2.2. The assembly is qualified for making measurements if its instability does not exceed 2 %.

4.5.1.2 Measurements

The measurements are carried out three times according to 4.3.2.

The spectrometric constant (A) is obtained from the energy resolution of the scintillation detector with the working standard (R_{a0}) and the intrinsic resolution of housed scintillator (R_{et}) according to the formula:

$$A = (R_{a0}^2 - R_{et}^2) \times C_{pho} \quad (4)$$

The energy resolution of the scintillation detector with the working standard, intrinsic resolution and light output of the working standard are determined for radiation of the same type and energy.

4.5.1.3 Processing of results

The energy resolution (R_{ao}) value of the scintillation detector with working standard is calculated by the formula:

$$R_{ao} = \frac{\Delta V}{V}$$

The average value of the three measurement results is obtained. The value of PMT spectrometric constant is calculated according to formula (4).

The values of intrinsic resolution and light output of working standard are used for calculations.

Relative expanded uncertainty, in percentage, of spectrometric constant with a level of confidence of 0,95 should not exceed $\pm 10\%$ ($k = 1,96$).

4.5.2 Test method of the intrinsic resolution for housed scintillator

4.5.2.1 General

The test conditions and the order of measurements are in accordance with 4.1.

The nonlinearity and the initial point of assembly conversion response is measured as specified in 4.2.1.

The assembly is qualified for making measurements if its nonlinearity does not exceed 3 %.

The instability of the assembly is assessed as specified in 4.2.2. The assembly is qualified for making measurements if its instability does not exceed 2 %.

Sources should be selected according to 4.1.2.

4.5.2.2 Measurements

The light output (C_{ph}) of tested housed scintillator shall be measured in accordance with 4.4.

The PMT spectrometric constant (A) shall be measured according to 4.5.1.

For measurement of energy resolution of the scintillation detector (R_a), the tested housed scintillator is placed on the PMT photocathode by optical coupling, the pulse height spectrum measurements are carried three times according to 4.3.2.

The energy resolution of the scintillation detector and the housed scintillator light output are measured for radiation of the same type and energy as for the housed scintillator intrinsic resolution.