IEC TR 62471-4

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TECHNICAL REPORT

colour inside

Photobiological safety of lamps and lamp systems –
Part 4: Measuring methods

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Photobiological safety of lamps and lamp systems –
Part 4: Measuring methods

INTERNATIONAL
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PHOTOBIOLOGICAL SAFETY OF LAMPS AND LAMP SYSTEMS –

Part 4: Measuring methods

FOREWORD

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IEC TR 62471-4 has been prepared by IEC technical committee 76: Optical radiation safety and laser equipment. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
76/654/DTR	76/707/RVDTR

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

The language used for the development of this Technical Report is English.

A list of all the parts in the IEC 62471 series, under the general title *Photobiological safety of lamps and lamp systems*, can be found on the IEC website.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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

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- withdrawn,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

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INTRODUCTION

Most lamps and lamp systems are safe and do not pose photobiological hazards except under unusual exposure conditions, whilst a full photobiological safety assessment requires sophisticated instrumentation and detailed analysis.

In order to provide a framework for the application of detailed measurement only where such is necessary, this document introduces two measurement approaches. Level A encompasses high accuracy, laboratory-based techniques whilst level B represents an estimation of the accessible emission using readily available instrumentation.

PHOTOBIOLOGICAL SAFETY OF LAMPS AND LAMP SYSTEMS –

Part 4: Measuring methods

1 Scope

This part of IEC 62471, which is a Technical Report, provides manufacturers, test houses, safety personnel and others with practical guidance on methods to perform radiometric and spectroradiometric measurements to determine the level of accessible optical radiation emitted by lamps and lamp systems in accordance with IEC 62471.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 62471:2006, *Photobiological safety of lamps and lamp systems*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62471 and the following 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
accessible emission
level of radiation determined at a given distance and under measurement conditions defined in IEC 62471

Note 1 to entry: The accessible emission is compared with the accessible emission limits to determine the applicable risk group.

3.1.2
angular response
detector output signal as a function of input beam angle

3.1.3
aperture stop
opening that defines the area over which average optical emission is measured

3.1.4
entrance pupil
image of the aperture stop as seen through the object space in an optical system

Note 1 to entry: The entrance pupil defines the acceptance cone in the object space.

Note 2 to entry: If there is no lens in front of the aperture stop, the location and size of the entrance pupil are identical to those of the aperture stop. Optical elements in front of the aperture stop can either magnify or diminish the image and modify the location of the entrance pupil with respect to the physical aperture stop.

Note 3 to entry: The entrance pupil is important since the amount of optical radiation collected from the source depends on this cone angle.

3.1.5
exit pupil
image of the aperture stop as seen through the image space in an optical system

Note 1 to entry: The exit pupil defines the acceptance cone in the image space.

Note 2 to entry: If there is no lens behind the aperture stop, the location and size of the exit pupil are identical to those of the aperture stop.

Note 3 to entry: The exit pupil is important since the amount of optical radiation falling on the detector depends on this cone angle.

Note 4 to entry: The cone angle is held constant in the luminance or radiance measurement at different object distances.

3.1.6
field stop
opening that defines the solid angle over which average optical emission is measured

3.1.7
level A assessment
accurate determination of the accessible emission using sophisticated instruments in laboratory conditions, performed by a trained operator

3.1.8
level B assessment
estimation of the accessible emission using readily available broadband radiometers or photometers with minimum training

Note 1 to entry: Level B assessment can be used as a screening method to determine where further detailed analysis is required without leading to the burden of measuring all sources.

3.1.9
measurement distance
<radiance measurement system> distance between the (apparent) source or the closest point of human access of the source under test and the entrance pupil

Note 1 to entry: If projection optics generate a virtual image of the emitter, the radiance measurement system images the plane of this apparent source and not the plane of the closest point of human access.

3.1.10
measurement distance
<irradiance measurement system> distance between the (apparent) source or the closest point of human access of the source under test and the aperture stop

3.1.11
spectral weighting function
function of the relative spectral effectiveness of optical radiation for a specified photobiological effect in consideration of calculation of a weighted quantity, such as weighted radiance or weighted irradiance

3.1.12
weighted irradiance
radiometric quantity obtained by multiplying spectral irradiance by a spectral weighting function and integrating over the limits of the weighting function

3.1.13
weighted radiance
radiometric quantity obtained by multiplying spectral radiance by a spectral weighting function and integrating over the limits of the weighting function

3.2 Abbreviated terms

CCD charge-coupled device

CCT correlated color temperature

CMOS complementary metal–oxide–semiconductor

CW continuous wave

FOV field of view

GLS general lighting service

HID high-intensity discharge

LED light-emitting diode

NMI national metrology institute

PMT photomultiplier tube

4 Application

4.1 General

This document is intended to be used as a reference guide by (but not limited to) manufacturers, testing laboratories, safety officers and officials of industrial or governmental authorities. It contains interpretations of IEC 62471 and supplementary information relating to the practical realization of radiometric measurements of lamps and lamp systems.

The procedures described in this document are adequate to meet the measurement requirements of IEC 62471 where measurements are deemed to be required. The existence of other equivalent measurement techniques, yielding results as valid as those described in this document, is acknowledged.

In many cases, measurement may not be necessary. Compliance with the requirements of IEC 62471 can be determined from an analysis of reported characteristics of the source and the design of the product.

4.2 Safety precautions

Optical radiation emitted from a test lamp or lamp system may be potentially hazardous to the operator's eyes and skin during the measurement. The existence of these hazards may be unknown in advance of the measurement results, especially for UV and infrared sources. If in doubt, it is recommended that the operator wear personal protection equipment to avoid damage to eye or skin during measurement, e.g. gloves, goggles, protective clothing or masks.

In the special case of vacuum-UV sources, the formation of ozone in the measurement path may produce additional hazards, so the test room should be appropriately ventilated.

It should be noted that the optical emission from the lamp or lamp system may be sufficiently intense to cause damage to instrumentation and black (absorbing) material in the laboratory. The risk of deterioration of non-metallic safety critical components, such as electrical wires, due to long term exposure to UV, should be assessed.

4.3 Hazard assessment overview

IEC 62471 provides an assessment and classification scheme for the photobiological safety of all electrically powered lamps and lamp systems emitting optical radiation in the wavelength range from 200 nm to 3 000 nm. The assessment of optical radiation hazards considers exposure of the skin, the anterior elements of the eye (cornea, conjunctiva and lens) and the retina as detailed in Table 1. Lasers are excluded from this scope except laser products designed to function as conventional light sources that meet the relevant criteria in IEC 60825-1:2014, Clause 4.4.

Each hazard is accompanied with a measurement type, spectral range and, where applicable, a hazard weighting function to account for the wavelength dependence of the hazard.

Table 1 – Optical radiation hazards considered by IEC 62471

Hazard	**Action spectrum**	**Wavelength range** (nm)	**Measured quantity**	**Symbol for emission level**	**Units**
Actinic UV	$S_{UV}(\lambda)$	200 to 400	Irradiance	E_s	W·m^{-2}
Near UV	N/A	315 to 400	Irradiance	E_{UVA}	W·m^{-2}
Blue light	$B(\lambda)$	300 to 700	Spatially-averaged radiance	L_B	W·m^{-2}·sr^{-1}
Blue light, small source	$B(\lambda)$	300 to 700	Irradiance	E_B	W·m^{-2}
Retinal thermal	$R(\lambda)$	380 to 1 400	Spatially-averaged radiance	L_R	W·m^{-2}·sr^{-1}
Retinal thermal, weak visual stimulus	$R(\lambda)$	780 to 1 400	Spatially-averaged radiance	L_{IR}	W·m^{-2}·sr^{-1}
IR radiation, eye	N/A	780 to 3 000	Irradiance	E_{IR}	W·m^{-2}

NOTE The naming of hazards differs between IEC 62471 and IEC 62471-5.

The methods employed to measure these quantities (described in Clause 5) are designed to account for biophysical phenomena, including averaging over apertures or fields of view (FOVs) which may be considered inappropriate for general radiometric measurements. Without taking these measurement conditions into account, hazards may be overestimated.

This assessment may be performed on both lamps and lamp systems. IEC 62471 provides guidance on the conditions under which the risk group classification may be transferred from lamps to lamp systems.

4.4 Selection of hazards

Given prior knowledge of the source type, one can select which of the hazards presented in Table 1 should be assessed for a particular product. The potential hazard categories relating to a range of typical sources are listed in Table A.1 in Annex A.

If in doubt, the full spectral range of emission can be measured before performing more detailed analysis.

4.5 Assessment levels

Most lamps and lamp systems are safe and do not pose photobiological hazards except under unusual exposure scenarios. There remain, however, some lamps and lamp systems for which the emitted optical radiation has the potential to pose adverse health effects. It follows that the most detailed measurement need only be performed in the latter case. The assessment approach recommended in this document is based on two assessment levels, termed level A and level B.

Level A represents the most accurate determination of the accessible emission using sophisticated spectroradiometric equipment and can be used in all cases. The instrumentation description is given in Annex B.

Level B measurements are made with readily available instruments, such as broadband radiometers or photometers with minimum training. Level B may then be considered as an initial screen to determine where detailed analysis is required. The application of level B is not suitable for those sources known to be potentially hazardous (including UV lamps) nor for consideration of the retinal thermal hazard, where required.

As with all measurements, a consideration of measurement uncertainty is important, particularly in the case of a level B assessment if the estimated accessible emission is close to the accessible emission limit. If a level B assessment does not clearly designate the risk group, then proceeding to a level A assessment is recommended.

Examples of the risk group determination of several lamps are shown in Annex F.

4.6 Initial filtering

In the case of sources emitting white light, if the luminance of the source is below 10^4 cd·m^{-2}, detailed analysis is not required. The luminance of the source can be obtained by measurement or calculation of reported parameters.

A luminance meter, with the FOV selected to be smaller than the emission area of the source, will report the value directly.

Luminance can be estimated from the illuminance, E_v, measured at a distance, D, from the source and the estimated luminous area of the source, A.

$$L_v = \frac{E_v \cdot D^2}{A} \quad (1)$$

Using data sheet values, luminance can be computed from luminous intensity, I_v (cd) by Equation (2) and from luminous flux, Φ_v (lumen), luminous area, A and beam half emission angle, θ, from Equation (3).

$$L_v = \frac{I_v}{A} \quad (2)$$

$$L_v = \frac{\Phi_v}{2\pi \cdot A \cdot (1-\cos\theta)} \quad (3)$$

4.7 Measurement quantities

4.7.1 Emission wavelengths

Given the wide spectral range over which photobiological safety hazards are considered and the wavelength dependence of those hazards, spectral analysis of the emission of lamps and lamp systems is recommended. In the case of the UV, blue light and retinal thermal hazards for which the spectral weighting functions are strongly wavelength dependent, detailed spectral measurements may be required.

Whilst the spectral range of application of IEC 62471 is 200 nm to 3 000 nm, spectral measurements beyond 1 400 nm are not required, but may be used.

The range of hazards considered for a particular product can be reduced given prior knowledge of the source type.

The potential hazard categories relating to a range of typical source types are listed in Table A.1.

4.7.2 Irradiance

The following description applies both to broadband irradiance and spectral irradiance measurements.

Measurement of the irradiance produced at a given distance by a lamp or lamp system is required to assess the following hazards:

- actinic UV hazard, E_{S};
- near UV hazard, E_{UVA};
- retinal blue light hazard (small source), E_{B};
- IR radiation eye hazard, E_{IR}.

The instrument should:

a) have a plane circular entrance aperture of diameter between 7 mm and 50 mm;
b) accept radiation within a circular cone whose centreline is normal to the plane of the entrance aperture;
c) have an angular spatial response varying as the cosine of the angle (up to the acceptance angle) from the normal to the detector area.

Whilst in general radiometry, the irradiance geometry requires a hemispherical cosine response, in consideration of biophysical phenomena the full acceptance angle (γ) is limited to 1,4 rad.

Where a source subtends an angle greater than 1,4 rad at the measurement distance, a field stop should be placed at the source to ensure measurement under 1,4 rad. Where the source cannot be accessed, the aperture can be moved toward the entrance aperture, as in Figure 1.

The entrance aperture of the optic serves as an averaging aperture and should be selected in consideration of the spatial uniformity of irradiance in the measurement plane. For sources that do not produce a spatially uniform irradiance, for example narrow beam reflector lamps, the peak irradiance may be significantly higher than that obtained by measurement using a wide entrance aperture. In such cases, a 7 mm entrance aperture diameter should be used.

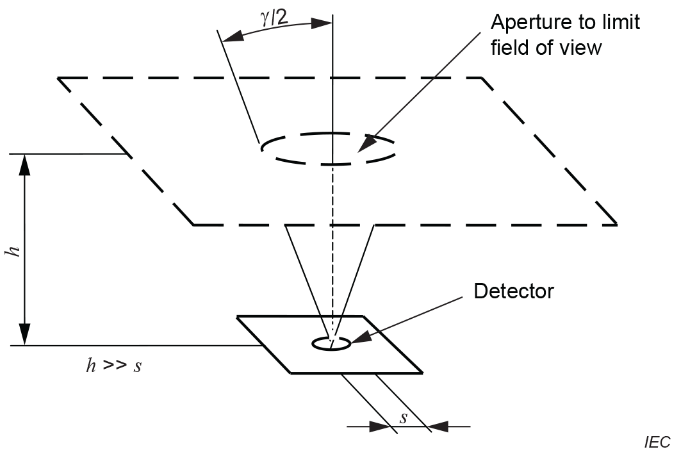


Figure 1 – Schematic representation of irradiance measurement

4.7.3 Radiance

The following description applies both to broadband radiance and spectral radiance measurements.

Measurement of the spatially averaged radiance in a defined FOV and at a given distance of a lamp or lamp system is required to assess the following hazards:

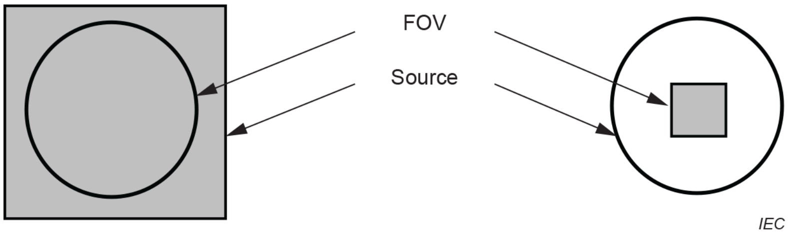
- retinal blue light hazard, L_B;
- retinal thermal hazard, L_R;
- retinal thermal hazard (weak visual stimulus), L_{IR}.

This measurement accounts for biophysical phenomena including pupil constriction and eye movements. With increasing exposure time, the image produced on the retina is spread over a larger area, defined by a time-dependent angular subtense of the area of the retina irradiated. The retinal irradiance for a given exposure time can be obtained from a radiance measurement in a FOV that matches the time-dependent angular subtense.

Specific FOVs are specified in IEC 62471 according to hazard and risk group and for pulsed sources.

The measurement FOV is independent of the size of the source.

For sources that subtend an angle smaller than the specified FOV, as depicted in Figure 2 b), the spatially averaged radiance value might be smaller than the radiance of the source. This biologically effective value of spatially averaged radiance is the appropriate value to be compared to the emission limits. Since the spatially averaged radiance is dependent on the overlap of the measurement FOV with the spatial radiance profile in the plane of the source, care should be taken when measuring at a different distance than the assessment distance. Further guidance is provided in 5.5.3, and further information in Annex I.



a) Source size larger than the FOV (over-filled) b) Source size smaller than the FOV (under-filled)

Figure 2 – Consideration of filling of FOV

Radiance can be measured in one of two ways: using a direct imaging technique or indirectly through a measurement of irradiance under defined geometry to set the FOV.

Direct radiance measurements are performed with an optical system similar to that in Figure 3.

The instrument should:

- have a plane circular entrance pupil of diameter between 7 mm and 50 mm;
- image the radiant source onto a detector;
- have a circular field stop of diameter, d, to establish the specified averaging FOV;
- have a means of accommodating the image distance, H, according to measurement distance.

The entrance pupil of the optic serves as an averaging aperture and should be selected in consideration of the spatial uniformity of irradiance in that plane. For sources that do not produce a spatially uniform irradiance, for example narrow beam reflector lamps, the peak radiance may be significantly higher than that obtained by measurement using a wide entrance pupil. In such cases, a 7 mm entrance aperture pupil should be used.

The entrance pupil might be a real or virtual image when the aperture stop is located behind the imaging lens. See B.6.2 for further details.

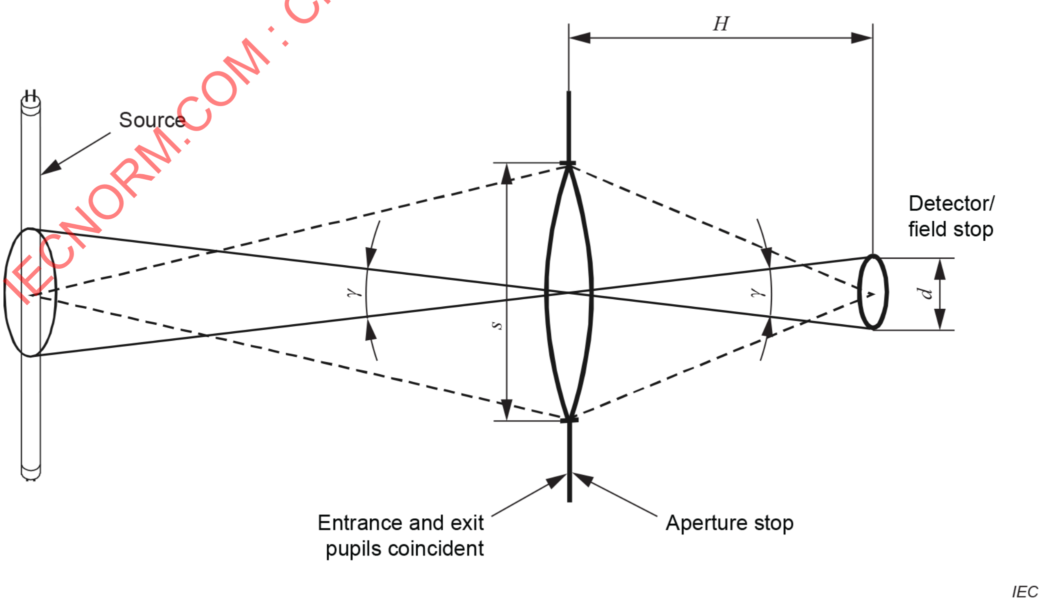


Figure 3 – Example of a direct measurement of radiance using a lens and aperture

Indirect radiance measurements are performed using an irradiance entrance optic as described in 4.7.2 and B.6.1, the FOV being defined by placing an aperture (serving as field stop) sufficiently close to the apparent source to produce the required FOV (see Figure 4).

The diameter, f, of the field stop is computed from:

$$f = 2 \cdot D \cdot \tan\left(\frac{\gamma}{2}\right) \approx D \cdot \gamma \text{, for small } \gamma \tag{4}$$

Where

D is the measurement distance;

γ is the specified averaging FOV (in rad).

The radiance, L, is then computed from the measured irradiance, E, from:

$$L = \frac{E}{\Omega} \tag{5}$$

Where the solid angle, Ω, corresponding to the FOV planar angle, γ, is computed from:

$$\Omega = \frac{\pi \cdot f^2}{4D^2} \approx \frac{\pi \cdot \gamma^2}{4} \text{, for small } \gamma \tag{6}$$

This method can only be applied for narrow FOVs (as is the case in the IEC 62471 assessment) and where the (apparent) source can be accessed directly, otherwise the physical aperture acts as an aperture stop rather than a field stop.

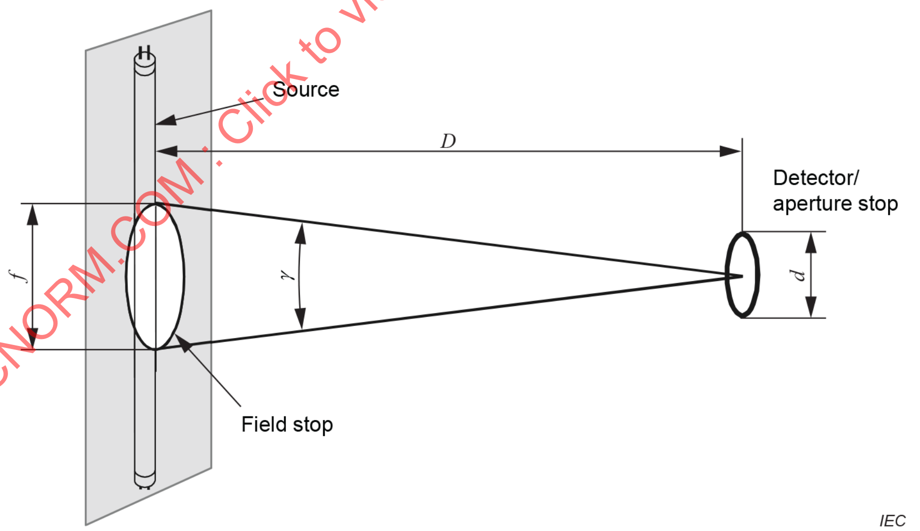


Figure 4 – Indirect measurement of radiance

4.7.4 Source size and location

4.7.4.1 General

Measurement of the (apparent) source size at the measurement distance and location with respect to the closest point of human access may be required to assess the following hazards:

- retinal blue light hazard, L_B;

- retinal thermal hazard, L_R;
- retinal thermal hazard (weak visual stimulus), L_{IR}.

In consideration of the blue light hazard, if the source is entirely over-filled by the 0,011 rad FOV at the given measurement distance, the simpler irradiance-based blue light small source criteria should be applied. This does not require specific measurement of the source size.

In consideration of the retinal thermal hazard, the angular subtense of the source at the measurement distance is required to compute the accessible emission limit.

If projection optics generate a virtual image of the emitter, the size of the apparent source should be considered, and the radiance measurement system should image the plane of this apparent source.

4.7.4.2 Determination of source location

An imaging technique should be applied to determine the position of the apparent source with respect to the closest point of human access, achieved by fixing the camera focus and translating the camera between two positions to image the apparent source or the closest point of human access.

4.7.4.3 Determination of source size

An imaging technique should be applied to determine the (apparent) source size and location, ensuring the resulting image is not saturated.

The average angular subtense, α, is computed from the dimension of the 50 % of the peak emission points of the source (physical or apparent) and the assessment distance, subject to limiting angular subtense, α_{min} and α_{max}, for continuous wave and pulsed sources.

Where the source subtense is less than α_{min} it should be set to equal α_{min}; likewise, where the source subtense is greater than α_{max} it should be set to equal α_{max}.

Where the source is spatially uniform, the dimensions of the 50 % emission points can be determined and the angular subtense computed from Equation (7) for circular sources and Equation (8) for oblong sources.

$$\alpha = 2\tan^{-1}\left(\frac{d}{2D}\right) \approx \frac{d}{2D} \quad \text{for small } (d/2D) \tag{7}$$

$$\alpha = 0{,}5 \times \left[(2\tan^{-1}\left(\frac{a}{2D}\right) + 2\tan^{-1}\left(\frac{b}{2D}\right)\right]$$

$$\approx 0{,}5 \times \left[\left(\frac{a}{D}\right) + \left(\frac{b}{D}\right)\right] \quad \text{for small } (a/2D), (b/2D) \tag{8}$$

Where

d is the diameter of the (apparent) source normal to the measurement direction;

D is the measurement distance with respect to the (apparent) source;

a, b are the orthogonal dimensions of the (apparent) source normal to the measurement direction.

NOTE 1 Any angular dimension that is greater than α_{max} or less than α_{min} is limited accordingly prior to determining the mean; see example in Figure 5.

NOTE 2 Where an apparent source is considered, the distance from the apparent source to closest point of human access is added to the measurement distance to determine D.

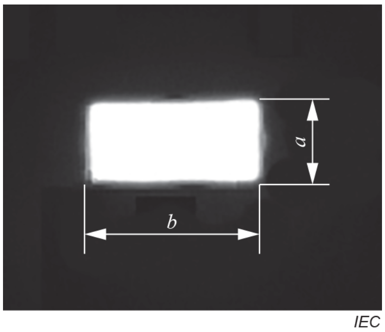
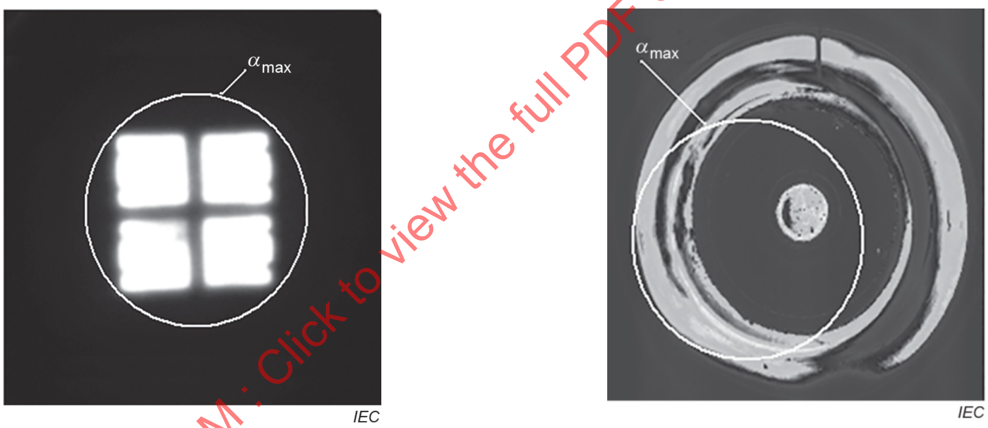


Figure 5 – Example of a rectangular source

For a non-uniform source, the relative radiance profile of the source can be captured using an imaging technique. The equivalent circle based on the effective hot spot over 50 % of the peak intensity of the source within α_{max} is determined by image calculation, and the angular subtense computed from Equation (7) as shown in Figure 6.



a) b)

Figure 6 – Example of the non-uniform radiance distribution

4.7.5 Temporal emission

A pulsed lamp or lamp system is one that delivers its energy in the form of a single pulse or a train of pulses where each pulse is assumed to have a duration of less than 0,25 s.

Time-averaged values are reported for all hazards except the retinal thermal hazard which requires additional analysis of the peak radiance.

Detailed information on the determination of time-averaged radiance and time-averaged irradiance is provided in Annex D.

4.8 Measurement uncertainty

It is important to consider potential sources of error in the measurement of optical radiation emitted by a light source as explained in Annex E. High measurement uncertainties are acceptable if this is taken into consideration in the risk group classification. This is particularly important in employing level B assessment.

5 Test conditions

5.1 General

Whilst the product should be configured to represent highest-level optical emission, environmental test conditions depend on the assessment level adopted. The laboratory conditions described in Clause 5 are a requirement for the level A assessment only. Whilst a level B assessment may be performed under ambient light conditions (subtracting the ambient light contribution from the measurement result), the use of a darkened room or enclosure is recommended.

The measurement and associated uncertainty of the emission of the sources under test are affected by environmental factors. The ambient temperature may influence the optical emission of most types of sources, especially discharge lamps and LED products (except for temperature-controlled LEDs). The formation of ozone (e.g. from UV-C) in the measurement path may compromise accuracy and may present a safety hazard. The measured optical radiation output in certain portions of the infrared spectrum may have fluctuations caused by atmospheric absorption.

The test conditions should be recorded in the report as described in Annex H.

5.2 Dark room (level A)

Measurements should be performed in a dark room where the environmental factors are negligible to the measured quantities (e.g. light, smoke, dust, mist, vibrations). Careful checks should be made to ensure that extraneous radiation and reflections from room surfaces, such as wall, floor and ceiling, do not add significantly to the measurement results. Baffles are often used to reduce extraneous radiation. Note that visually black surfaces can be reflective to UV and IR radiation.

5.3 Environmental conditions (level A)

The following environmental conditions should be applied.

- Temperature: 25 °C ± 2 °C.
- Relative humidity: up to 65 %.

The applied environmental conditions should be noted in the test report.

NOTE The relative humidity can be disregarded when it has no influence on the measurement results.

5.4 Power supply

The lamp or lamp system is supplied by a power source given in the relevant product standard. If no standard exists, the recommendation provided by the product manufacturer should be applied. Allowable power supply tolerances are specified and used for maximum radiation output determination.

A lamp that needs external control gear or ballast, and reference power source, should be operated under the product specification.

5.5 Product configuration

5.5.1 General

Where measurements are being made for the purpose of classification, all controls and setting listed in the operation, maintenance and service instruction needs to be adjusted in combination to result in the maximum accessible emission. For any lamp or lamp system with dimming control, the measurement should be operated at maximum output.

Measurements are also required with the use of accessories that may increase the radiation hazard, such as collimating optics which are supplied or offered by the manufacture for use with the product. Vertical standards will include guidance on the assessment of specific elements.

5.5.2 Warm up

The measurements of optical radiation are carried out at the maximum radiation output condition. Should the radiation output vary significantly at the maximum level, the measurements may be carried out at the steady state, adjusting for the maximum optical radiation output. It should be noted that the relative spectral distribution may be different at the steady state and the maximum level.

A warm-up is normally not needed for a pulsed lamp or lamp systems unless specified by the product specification. Pulse-to-pulse repeatability should be considered.

Measurements are made with the instrument measurement aperture so positioned and so orientated with respect to the lamp or lamp system as to result in the maximum detection of optical radiation. The measurement instrument may have to be moved or the angle changed to obtain a maximum reading. Appropriate provision is to be made to avoid or to eliminate the contribution of collateral radiation to the measurement.

5.5.3 Measurement distance

5.5.3.1 General

The photobiological safety evaluation of a product should ideally be performed at a distance which reflects normal use of the product. Such information should be provided in product-specific standards. In the absence of product-specific standards, IEC 62471 provides specific measurement distances for irradiance- and radiance-based hazards.

The measurement distance need not be the same as the assessment distance. Where the source is too intense and would damage the instrument, a larger measurement distance may be employed. On the other hand, where the measurement signal is very weak at the assessment distance, a shorter distance can be applied to improve the measurement signal to noise ratio.

Care should be taken in converting results between the measurement distance and the assessment distance.

5.5.3.2 Irradiance-based hazards

The irradiance at the assessment distance may be computed from the product of the result at the measurement distance and one of the following:

- the ratio of the signal measured at a single wavelength at the assessment distance to that at the measurement distance;
- the ratio of the irradiance or illuminance measured with a suitable radiometer or illuminance meter at the assessment distance to that at the measurement distance.

An illuminance meter can be used freely when measuring white light sources. For other sources emitting in the visible including some UV and colored light sources, the illuminance reported by the illuminance meter may be incorrect. This process can nevertheless be applied, in considering the ratio of the relative illuminance values recorded by the illuminance meter at both distances.

Alternatively, the inverse square law may be applied. The inverse square law relates the irradiance E_1 at a source distance r_1 and the irradiance E_2 at source distance r_2 by

$$E_1 \times r_1^2 = E_2 \times r_2^2 \qquad (9)$$

Care should be taken when considering sources with beam-shaping optics since the far-field condition, where the inverse square law applies, starting from a greater source distance (sometimes called the "flash distance").

This flash distance, r_f, of projection systems can be estimated if the focal length of the reflector or lens f, the diameter of the source D and the reflector (or lens) aperture diameter, a, are known:

$$r_f \approx a \times f / D \quad (10)$$

In practice, the value of the aperture is normally 50 % to 70 % of the full reflector diameter.

5.5.3.3 Radiance-based hazards

The spatially averaged radiance is dependent on the overlap of the measurement FOV with the spatial radiance profile in the plane of the source.

A result at the assessment distance can only be inferred from one at the measurement distance where the FOV is modified, according to Equation (11) to ensure that the same area of the source is measured.

$$\gamma_1 = \gamma_0 \times \frac{D_0}{D_1} \quad (11)$$

where

γ_1 is the modified FOV to measure at the modified distance;

γ_0 is the required FOV at the assessment measurement distance;

D_1 is the modified measurement distance;

D_0 is the assessment measurement distance.

If it is not possible to modify the FOV to γ_1, but to reduce to a FOV which ensures that the "true" radiance (FOV fully over-filled), L, can be measured, the spatially averaged radiance, L_1, at the assessment distance can be estimated from the luminous area of the emitter and making the assumption of spatially uniform radiance over the luminous area using Equation (12).

$$L_1 = \frac{L \times A_s}{A_{FOV}} \quad (12)$$

where

A_s is the luminous area of the source in the FOV;

A_{FOV} is the area encompassed by the FOV at the assessment distance.

Where it is not possible to modify the FOV, the spatially averaged radiance at the assessment distance, L_1, can be estimated from the result at the measurement distance, L_0, from Equation (13).

$$L_1 = \frac{L_0 \times A_{FOV,0} \times A_1}{A_0 \times A_{FOV,1}} \quad (13)$$

where

A_0 is the luminous area of the source in the FOV at the measurement distance;

A_1 is the luminous area of the source in the FOV at the assessment distance;

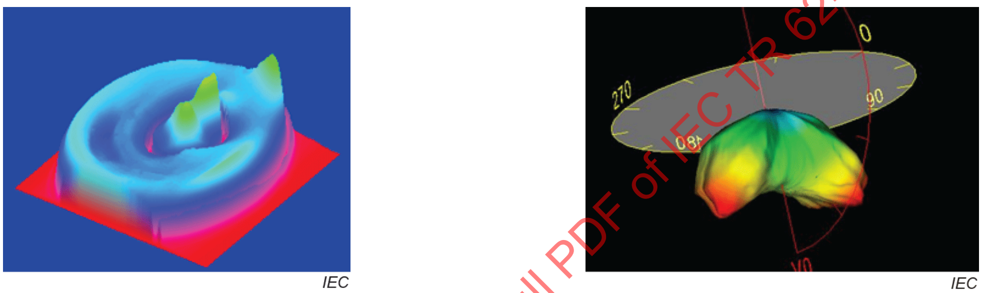
$A_{FOV,0}$ is the area encompassed by the FOV at the measurement distance;

$A_{FOV,1}$ is the area encompassed by the FOV at the assessment distance.

5.6 Optical alignment

The source under test should be orientated in such a manner that the maximum accessible emission is recorded, considering the angular and spatial variation of optical emission as depicted in Figure 7.

Where a lamp or lamp system comprises a range of source types, the source should be aligned to the source representing worst case for a given hazard. For example, for the consideration of the blue light hazard of an RGB LED, the measurement FOV should be aligned with the blue emitter.



a) Spatial radiance variation   b) Angular intensity variation

Figure 7 – Example of the emission profiles

For hazards expressed in irradiance, measurements should be performed in the direction of peak irradiance except in the case of lamp systems comprising a plurality of sources converging on a cross-over point (such as a ring light) at which cross-over point measurements should be performed.

For hazards expressed in radiance, in addition to the direction of the peak intensity, the spatial variation across the source should be considered with respect to the FOV of the measurement.

For luminaires, the direction of peak luminous intensity may be obtained from existing data on the source under test or determined by using a goniophotometer. The angle interval for the measurement should be at least one twentieth of the beam angle.

The spatial variation may be assessed by scanning the radiance entrance optic across the plane of the source or by prior assessment using an imaging radiance meter and the "hot spot" position determined by image analysis. The pixel resolution of the imaging radiance meter should be high enough to enable locating hotspots over the narrow FOVs in consideration.

6 Performance characteristics: level A instruments

6.1 General

Since level A represents the most accurate determination of the accessible emission of sources under test, spectroradiometric equipment and accessories should be used alongside NMI traceable calibration, laboratory procedures and a detailed evaluation of measurement uncertainty.

The combination of broadband detectors and a spectroradiometer can improve the measurement process in many instances. A survey of spatial, temporal, or variations of a source type can be rapidly accomplished using the filtered detector. This applies also to pulsed sources which may be difficult to measure spectrally.

The measurement of optical radiation for classification of lamps and lamp systems with respect to photobiological safety deals with radiometry or spectroradiometry in the wavelength range from 200 nm to 3 000 nm. Special attention is required not only on measurement methods but also on instruments to be used because of specific considerations of hazard weighting functions and optical geometries to accept the emission of the sources relating to risk classification. The result of hazard evaluations may be influenced by the instrument's characteristics.

Accurate assessment of accessible emission does not mean that the highest performance spectroradiometer available need be used.

In consideration of potential measurement difficulties in measuring the spatially averaged radiance of a source, cameras can be used to assist in determining the radiance profile of the source, from which spatially averaged radiance can be computed.

Further details can be found in IEC 62471 and CIE 063.

6.2 Spectral irradiance and radiance

6.2.1 Spectral analysis

6.2.1.1 General

The assessment of photobiological safety potentially involves measurement in a wide spectral range and in the consideration of the UV, blue light and retinal thermal hazards includes spectral weighting functions which are strongly wavelength dependent.

A monochromator (and associated detector), spectrograph or array spectrometer should be used to determine the spectrum of the source. An overview of these instruments is provided in Clause B.1.

In selecting an instrument, the key parameters to be considered are as follows:

1) spectral range, accuracy and bandwidth;
2) sensitivity;
3) stray light;
4) linearity.

6.2.1.2 Spectral range, accuracy and bandwidth

Whilst the full spectral range covered by IEC 62471 is 200 nm to 3 000 nm, the range can be limited in accordance with Annex A as a function of source type.

Having defined the wavelength range over which measurements are to be made, the wavelength accuracy of the instrument should be considered. Wavelength errors can have a significant impact, particularly on weighted values where the spectral weighting function is strongly wavelength dependent. To minimize this effect, IEC 62471 provides a recommendation of wavelength accuracy as a function of wavelength region under consideration, reproduced in Table 2. Note that beyond 1 400 nm, spectral measurements are not required.

Table 2 – Recommended wavelength accuracy

Range (nm)	Wavelength accuracy (nm)
200 to 300	0,2
300 to 325	0,1
325 to 600	0,2
600 to 1 400	2

In a similar manner to wavelength accuracy, the instrument spectral bandwidth, defined as the full width at half maximum (FWHM) of the spectral band-pass function of the instrument, might change the weighted results of a spectrum with varying levels. A broader bandwidth would average the incident radiometric power over a wider spectral range, but the energy of spectral lines would still be completely captured. In contrast, for action spectra with strong curve slopes such as the actinic UV weighting function or the UVA action spectrum, the bandwidth should be small enough to allow a precise actinic weighting of the radiometric value.

To minimize this effect, IEC 62471 provides a recommendation of FWHM bandwidth as a function of wavelength region under consideration, reproduced in Table 3. It should be noted that small bandwidth reduces the sensitivity of the instrument (as reflected in a higher noise equivalent irradiance or radiance) which should also be avoided.

Table 3 – Recommended bandwidths

Range (nm)	Bandwidth (FWHM) (nm)
200 to 400	≤ 2
400 to 600	≤ 8
600 to 1 400	≤ 20
1 400 to 3 000	no bandwidth limitation

It is generally recommended that measured wavelength interval or step width $\Delta\lambda$ be equal to, or an integer divisor of, the bandwidth when measuring the spectral properties of sources with rapidly varying spectral characteristics. It should be noted that bandwidth may not be adjustable for a given instrument.

The shape of the band-pass, the slit function, can be determined by measurement of a laser having a single lasing mode. Since the line width of the laser is significantly less than the instrument band pass, the resultant spectrum demonstrates the instrument band pass.

6.2.1.3 Sensitivity

All instruments have a signal-to-noise-dependent limit below which measurements are not possible, even with longest integration times. For hazard analysis, it is not sufficient to report zero signal when the only known fact is that the measurement is below the instrument's limit. The instrument used for hazard testing should be characterized to determine the measurement limit levels. Whenever the instrument reading is zero, or below the measurement limit, the noise equivalent irradiance or radiance should be reported.

The instrument should respond over the full emission range of the source and the noise equivalent irradiance or radiance, reported by a calibrated spectroradiometer measuring a covered entrance optic, should not be more than 10 % of the risk group emission limit considered.

6.2.1.4 Stray light

Stray light performance is a measure of the rejection of wavelengths other than that in consideration. Poor stray light rejection may give rise to a signal in excess of the true signal at that wavelength and thus may give rise to an error during calibration, measurement or both.

Stray light is generally limiting only for the actinic UV hazard for which detection of trace levels of optical radiation are to be measured and can potentially give rise to significant errors. To obtain 1 % accuracy, rejection of out-of-band radiation needs to be on the order of 10^{-6}. This can be easily achieved using double monochromators but can be obtained with single monochromators and array spectrometers providing that filters are used to improve the suppression of out-of-band radiation.

The influence of stray light on the measurement of both the lamp that is used to calibrate the spectroradiometer and the lamp under test can be estimated by inserting a long-pass filter before the entrance optic. Signal recorded in the blocking region, and above the blocking level, is a stray light contribution. The ratio of stray light compared to the measurement without long-pass filter in this spectral region gives an estimate for the stray light level. If no correction is applied, this ratio fully accounts for the resulting measurement uncertainty contribution from stray light.

Further information is provided in Annex G.

6.2.1.5 Linearity

When the individual sources under test have wide range in light output compared with the source used to calibrate the measurement system, linearity of the measurement system would affect the measurement result. The linearity of the system should be evaluated, and the measurements should be performed within the range that the linear response is confirmed. Any non-linearity corresponding to the difference of the power levels should be corrected.

6.2.2 Entrance optics

6.2.2.1 General

The entrance optics defines the geometry over which light is collected. Due to the biophysical phenomena considered in this photobiological safety evaluation, this geometry may differ from those typically considered in general radiometry.

Characteristics of entrance optics might be determined according to the requirements in appropriate standards such as ISO/CIE 19476.

6.2.2.2 Irradiance entrance optic

The entrance optic should:

- have a plane circular entrance aperture of diameter between 7 mm and 50 mm;
- accept radiation within a circular cone whose centreline is normal to the plane of the entrance aperture;
- have an angular spatial response varying as the cosine of the angle (up to 0,7 rad) from the normal to the detector area;
- be polarization insensitive.

A range of entrance optics is available for the measurement of spectral irradiance as detailed in B.6.1.

In selecting an irradiance entrance optic, in addition to the above, performance parameters relative to a specific product should be considered as follows:

a) spectral range over which angular response specified;
b) transmission or reflectance mode;
c) impact of low throughput upon instrument sensitivity.

6.2.2.3 Radiance entrance optic

Subclause 6.2.2.3 refers to the optic used to measure radiance using the imaging technique. For the alternative technique, see 6.2.2.2.

The instrument should:

- have a plane circular entrance pupil of diameter between 7 mm and 50 mm;
- image the radiant source onto a detection plane;
- have a circular field stop to establish the specified averaging FOV;
- be polarization insensitive.

A range of entrance optics are available for the measurement of spectral radiance as detailed in B.6.2.

In selecting a radiance entrance optic, in addition to the above, performance parameters relative to a specific product should be considered as follows:

a) spectral range of transmission;
b) optical aberrations;
c) impact of high throughput upon instrument saturation;
d) ability to view measurement field for purposes of optical alignment;
e) location of entrance pupil.

An overview of these entrance optics is provided in B.6.2.

It is generally difficult to obtain aberration free optics, focusing at 200 mm and used over a wide spectral range. Whilst it is possible to modify the measurement distance according to spectral range, the FOV needs to be maintained and variations in the irradiance profile at the plane of the entrance aperture considered. It is recommended that this be considered in the uncertainty budget for the radiance measurement.

6.2.3 Calibration standards

6.2.3.1 Spectroradiometric calibration

The recommended sources for irradiance calibration are deuterium discharge lamp for the UV region and calibration-grade tungsten–halogen lamp for the near UV, visible and infrared regions. The deuterium lamp may vary in output level while maintaining its spectral shape. The calibration of the spectroradiometer in the 200 nm to 350 nm regions using the deuterium lamp should be adjusted in comparison to the calibration level from the tungsten–halogen lamp between 300 nm and 350 nm. The wavelength below which the deuterium shape is used should be at as short a wavelength as practical considering the noise in the tungsten (or tungsten–halogen) lamp calibration.

The recommended source for radiance calibration is a spatially uniform radiance standard, such as an integrating sphere-based standard including a calibration-grade tungsten–halogen lamp. The output window should fully over-fill the measurement FOV and have a radiance uniformity better than 10 %.

In all cases, the following apply.

a) The spectral range of the calibration sources should be not less than the wavelength range corresponding to risk categories;

b) The spectral power distribution should be continuous;

c) Output irradiance or radiance levels need not be close to the emission limits corresponding to risk group classification providing the spectroradiometer linearity is demonstrated;

d) The beam profile falling on the limiting aperture of the input optics of the measurement equipment should be uniform, e.g. non-uniformity over the aperture is less than 5 %;

e) The sources should have sufficient stability in light output;

f) The calibration should be traceable to a national metrology institute.

NOTE National metrology institutes currently offer a calibration of spectral irradiance to 2 500 nm. The spectral irradiance data in this case may be extrapolated to 3 000 nm in accordance with Annex C.

6.2.3.2 Wavelength calibration

The wavelength calibration of the spectroradiometer should be periodically verified against a suitable wavelength calibration standard, including, but not limited to atomic line sources for which the emission peaks are fixed and the positions of which can be obtained from sources such as the NIST standard reference database.

6.3 Imaging devices

In consideration of potential measurement difficulties in measuring the spatially averaged radiance of a source using the instruments detailed above, the use of imaging devices can be used to assist in determining the radiance profile of the source, from which spatially-averaged radiance can be computed.

Such devices, detailed in Clause B.7, are suitable only for the measurement of sources composed of a single type of emitter, thereby having a negligible variation in spectral distribution over the emission area of the source.

The imaging device should:

- have a plane circular entrance aperture of diameter 7 mm to 50 mm;
- image the full radiant source onto the image sensor;
- be polarization insensitive;
- have a known spectral responsivity.

6.4 Temporal emission

In the first instance, the temporal emission should be evaluated to determine whether or not pulsed or CW conditions apply; where a source is determined to be pulsed, the full analysis requires a spectral analysis of the pulsed emission.

Determination of temporal emission profile is typically performed using a fast response photodetector, sensitive to the spectral range considered. Care should be taken where a source includes multiple emitters pulsed at different rates. In this case a suitable filter, or a monochromator, can be used to isolate the wavelength under consideration.

Spectral analysis of single pulse sources is only practical with an array spectrometer or spectrograph triggered by an external synchronous signal from the lamp driver electronics.

Spectral analysis of continuous pulse sources may either be performed with an array spectrometer or spectrograph triggered by an external synchronous signal from the lamp driver electronics, or a scanning monochromator in conjunction with pulse-detection electronics. In parallel with this measurement, a fast response broadband detector is needed to operate synchronously together with the spectral sampling if the pulse-to-pulse variation is significant.

Care should be taken in considering the time basis of the risk group classification and any averaging introduced by the instrument (such as exposure duration or measurement integration time).

In consideration of radiance hazards only, an alternative approach is to use an imaging radiance meter (e.g. CCD camera), triggered by an external synchronous signal from the lamp driver electronics.

6.5 Source size and location

The determination of α, the angle subtended by a source, requires the determination of the effective area of the source where the emission level is more than 50 % of its peak value. The location of the apparent source with respect to the closest point of human access is required in the case of the use of projection optics. In both cases, an imaging technique can be employed.

Whilst the simplest method is to produce an image of the source with a suitable lens on a screen and, by manual or motorized means, displace a detector in the image plane to determine the 50 % emission dimensions, a more robust solution is to use solid-state cameras.

A silicon-based CCD or CMOS camera is sensitive only in the spectrum below 1 050 nm. For IR sources, an infrared sensitive camera may be used.

7 Performance characteristics: level B instruments

7.1 General

Level B measurements are made with readily available broadband radiometers or photometers with minimum training. Level B may then be considered as an initial screen to determine where detailed analysis is required. Level B instruments include illuminance meters, luminance meters, UV radiometers and thermal power sensors.

7.2 Irradiance or radiance

7.2.1 General

Whilst close match photometers are available, it is generally difficult to obtain radiometers having a flat spectral response over an extended spectral region or replicate accurately the cut-on and cut-off of even simple functions such as the UVA response let alone the more complicated hazard weighting functions required here. Flat-response thermal detectors are available, but their wide spectral response can complicate the assessment of broadband sources, without the use of filters which will compromise their flat spectral response.

There are a significant number of technical concerns in using such general-purpose radiometers including:

- radiometer spectral responsivity will not match that required for evaluation of given hazard;
- mismatch errors due to likely difference in spectral distribution between calibration source and source under test;
- difficulty in establishing correction factors without information on the spectral distribution of the source under test.

The application of level B is therefore not suitable for those sources known to be potentially hazardous (including UV lamps) nor for consideration of the retinal thermal hazard. Annex A provides guidance on source types for which a level B assessment may be used.

Level B instruments should be selected with care, ensuring that the selected instrument has a high sensitivity in the vicinity of the nominal emission of the source under consideration. As an example, it makes no sense to measure a violet (410 nm) LED with an illuminance meter which has minimal response at that wavelength.

There exist some radiometers designed to offer a relatively close match to the spectral weighting functions employed in the photobiological safety analysis, reporting weighted irradiance or radiance values. Where a radiometer is used that responds over the full range of a spectral weighting function but does not follow the spectral weighting factors of that function, un-weighted values should be used in this assessment.

Across the UV and IR spectral regions, radiometers are generally available only with entrance optics designed for the measurement of irradiance. Photometers are available both as illuminance meters (irradiance) and luminance meters (radiance).

Further details can be found in ISO/CIE 19476 (photometers) and CIE 220 (UV radiometers).

7.2.2 UV lines

Low-pressure mercury discharge lamps mainly produce spectral lines in the UV region at 253,7 nm, 297 nm, 313 nm, 365 nm etc. UV irradiance meters dedicated to detecting these spectral lines can be used to determine the weighted irradiance by applying the spectral weighting function for these wavelengths, according to CIE 220. It should be noted that relatively low amplitudes of some spectral lines may contribute highly to the weighted irradiance because of high spectral weighting factors.

7.2.3 Narrow band sources

The spectrum of narrow band sources such as single colour LEDs spans over some tens of nanometres only. A broadband detector, for example an optical power meter integrated with an input aperture or an irradiance meter, calibrated at relevant wavelengths by a reference source, can be used to determine the emission quantities.

7.2.4 Known spectral distribution

In some cases, the source under evaluation has a known spectral distribution other than the spectral irradiance (e.g. spectral power). Under those circumstances, the spectral distribution may be converted to spectral irradiance based on the result from a broadband measurement or a spectroradiometric measurement in a limited spectral range.

With a broadband radiometer, the spectral irradiance of the emitter, $E_\lambda(\lambda)$, can be calculated from Equation (14).

$$E_\lambda(\lambda) = \frac{E_{\text{rad}} \times X(\lambda)}{\int_{\lambda_1}^{\lambda_2} X(\lambda) \times R_{\text{rel}}(\lambda) \times \mathrm{d}\lambda} \qquad (14)$$

where,

E_{rad} is the irradiance recorded by the radiometer at the assessment distance;

$X(\lambda)$ is the relative spectral distribution of the source;

$R_{\text{rel}}(\lambda)$ is the nominal relative spectral responsivity of the radiometer.

λ_1, λ_2 define the spectral range over which the radiometer responds.

Where the measured source has emission in the visible region, the illuminance E_v can be measured with an illuminance meter to enable determination of the spectral irradiance of the emitter, $E_\lambda(\lambda)$ from Equation (15).

$$E_\lambda(\lambda) = \frac{E_v \times X(\lambda)}{683 \times \int_{380}^{780} X(\lambda) \times V(\lambda) \times d\lambda} \quad (15)$$

where

E_v is the illuminance measured by an illuminance meter at the assessment distance;

$X(\lambda)$ is the relative spectral distribution of the emission, at least covering the assessment wavelengths and visible region;

$V(\lambda)$ is the spectral luminous efficiency function for photopic vision.

With a calibrated spectroradiometer, the spectral irradiance may be measured at a single wavelength, λ_0 or over a limited range λ_1 to λ_2.The spectral irradiance of the emitter, $E_\lambda(\lambda)$ can be calculated either from a single value at λ_0 using Equation (16) or the integrated quantity over a range of wavelengths, using Equation (17).

$$E_\lambda(\lambda) = \frac{E_{meas}(\lambda_0) \times X(\lambda)}{X(\lambda_0)} \quad (16)$$

$$E_\lambda(\lambda) = \frac{\int_{\lambda_1}^{\lambda_2} E_{meas}(\lambda) \times X(\lambda) \times d\lambda}{\int_{\lambda_1}^{\lambda_2} X(\lambda) \times d\lambda} \quad (17)$$

where

$E_{meas}(\lambda)$ is the spectral irradiance recorded over λ_1 to λ_2;

$X(\lambda)$ is the relative spectral distribution of the emission.

It is presumed that the spectral irradiance $E_\lambda(\lambda)$ and the known spectral distribution $X_\lambda(\lambda)$ have a similar spectral shape and differ only by some sort of geometrical extent. This is usually not the case if the radiant source varies in radiance over the viewing angle or if the source is mounted into a lamp housing with reflecting elements.

7.2.5 Luminance-based

Due to their use in determining the visual perception of sources, radiometers configured for radiance geometry are limited to luminance meters, in which case the photometry-based approach highlighted above can be applied. In all other cases, the indirect method to determine radiance can be applied using an irradiance detector and by placing an aperture at the source to limit the FOV.

Where the measured source has emission in the visible region, the luminance L_v can be measured with a luminance meter:

$$L_\lambda(\lambda) = \frac{L_v \times X(\lambda)}{683 \times \int_{380}^{780} X(\lambda) \times V(\lambda) \times d\lambda} \quad (18)$$

where

L_v is the luminance measured by a luminance meter under defined FOV;

$X(\lambda)$ is the relative spectral distribution of the emission, at least covering the assessment wavelengths and visible region;

$V(\lambda)$ is the spectral luminous efficiency function for photopic vision.

The assessment of retinal hazards should be performed under specific FOV, which is typically not possible to realize with a luminance meter. Where possible, the luminance measurement should be performed by choosing a distance and FOV combination such that the measurement area under-fills the source. In this way, the spatially averaged radiance, $L_{act,av}$, can be computed from Equation (19).

$$L_{act,\,av} = \frac{L_{act} \times A_{source}}{A_{FOV}} \qquad (19)$$

In all other cases, the indirect method to determine radiance can be applied using an irradiance detector and by placing an aperture at the source to limit the FOV.

L_{act} is the weighted radiance obtained without spatial-averaging;

A_{source} is the estimated source area;

A_{FOV} is the area of the circular FOV considered.

7.3 Apparent source location and subtense

For level B assessment, measurement of this parameter is not appropriate. Assume worst-case angular subtense, 0,1 rad and ignore the effect of the location of the apparent source.

7.4 Temporal emission

For level B assessment, measurement of this parameter is not appropriate. Assumption can be made of a square wave profile and the duty cycle used to compute time-averaged values.

Annex A
(informative)

Hazard selection

Knowledge of the source type allows reduction of the number of hazards to consider, for example a blue-LED pump phosphor-coated LED emits no UV nor IR radiation. The following Table A.1 provides a non-exhaustive list of source types and the main hazards that should be considered.

Table A.1 – Examples of potential risk categories

Source type		**Hazard**				
		Actinic UV	**Near UV**	**Blue light**	**Retinal thermal**	**Infrared eye**
LED	UV LED (200 nm to 400 nm)	X	X			
	Colored LED (380 nm to 780 nm)			X		
	White LED (Violet LED pump)		X	X		
	White LED (Blue LED pump)			X		
	White LED (RGB)			X		
	IR LED (780 nm to 3 000 nm)				X	X
Laser generated	White Light Source (Blue laser pump)			X	X	
Incandescent	Incandescent lamp			X		X
	Halogen tungsten lamp	X	X	X		X
	IR heater			X		X
Discharge (GLS)	Fluorescent lamp for GLS	X	X			
	High-pressure sodium (HPS) lamp for GLS			X		
	High-pressure mercury (HPM) lamp for GLS	X	X	X		
	Metal halide (MH) lamp for GLS	X	X	X	X	X
Discharge (non-GLS)	Deuterium	X	X			
	High-pressure sodium (HPS)			X		
	High-pressure mercury (HPM)	X	X	X		
	Metal halide (MH)	X	X	X	X	X
	UV germicidal lamp	X	X			
	UV blacklight	X	X			
	Insect killer lamp	X	X			

Annex B
(informative)

Instrumentation description

B.1 Double monochromators

A double monochromator offers the highest stray light performance and is the recommended instrument particularly in the UV wavelengths. For the UV hazard measurement of GLS sources, the stray light caused by intense visible radiation may become a major source of error. A double monochromator system is recommended to eliminate this effect; however, sufficient signal-to-noise ratio (SNR) is needed because of the reduced throughput. The diffraction efficiency of the grating should be carefully designed to avoid signal too low in the shorter UV region. UV sensitive PMTs having higher sensitivity in UV region than that in visible region are appropriate to improve the SNR.

B.2 Single monochromators

A single monochromator can be used in the wavelength of visible to infrared region and in the UV spectrum only if the rejection of out-of-band stray light is sufficient, such as a visible blind photomultiplier or a UV band-pass filter is applied. Single monochromators can also be sufficient when the lamps to be measured have emission only in a limited spectral region and no significant emission contributing to possible stray light exists outside the region, such as single-colour LEDs.

B.3 Array spectrometers

An array spectrometer using photodiode arrays or CCD detectors can record spectral data in a specific spectral range almost simultaneously. The advantage of these is that the spectral information can be recorded in a fraction of a second compared to minutes for scanning instruments. The disadvantages of the array spectrometer are that there is only one grating so that the measurement is only applied in a specific spectral range, and for small array spectroradiometers with short focal length it is generally difficult to achieve the required low stray light especially in the UV measurement. The bandwidth and measurable wavelength range are preset by the manufacturer, which should be specified and matched with the requirements in IEC 62471.

Array spectrometers are generally useful for level B measurements. Note that most sources of error (such as stray light and detector noise) err in the direction of over-stating the potentially hazardous emissions. For CCD spectroradiometers, low sensitivity of the array detector in the short UV region may limit their application. Additional corrections to decrease the noise and stray light should be applied.

B.4 Detectors

The levels of spectral irradiance and spectral radiance encountered in a photobiological safety evaluation vary widely between sources. Detectors should be selected based on required sensitivity, SNR, dynamic range and spectral range. The spectroradiometer with a photomultiplier tube (PMT) should have a high sensitivity and a good SNR, which is suitable for the measurement of actinic hazard quantities in the UV and visible range. Meanwhile, for the measurement of the retinal thermal hazard radiance, a silicon photodiode is suitable to be used in the visible range. A GaAs photodiode is suitable for the near infrared measurements, while PbS and InGaAs detectors are suitable for infrared radiation measurements at the longer wavelength (up to 3 000 nm) range.

B.5 Entrance optics

In spectroradiometers, an optical fibre or/and a lens is usually used to converge the optical radiation of the source under test onto the entrance slit of the monochromator. However, the response of the monochromator to the spatial incident radiation might be very uneven, which may be caused by:

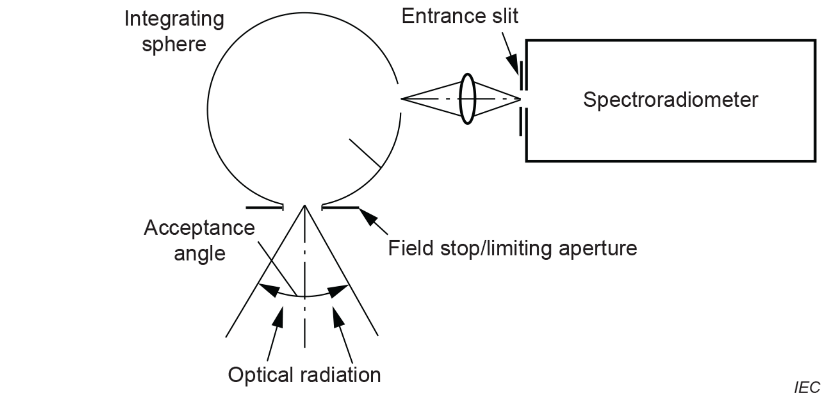
a) non-uniform response on the entrance slit of the monochromator;

b) angular response dependence to incident optical radiation, for example of the radiation from a large source;

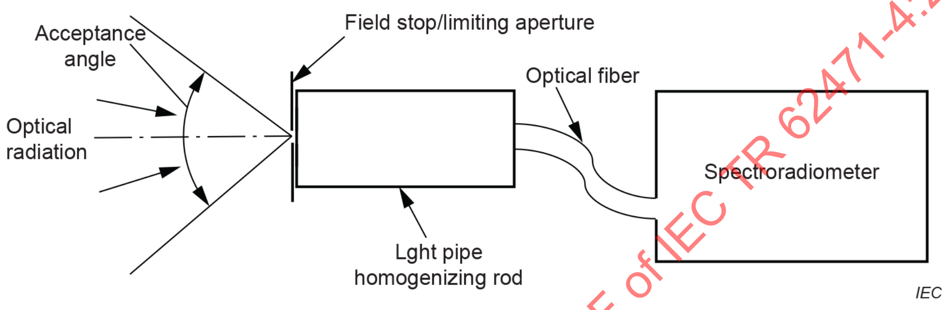
c) polarization effects of the radiation with different states.

When the measured beam profile on the entrance slit of the monochromator is not similar to that of the calibration source, it may cause unacceptable error, so it is necessary to add a diffuser in the input optics of the spectroradiometer.

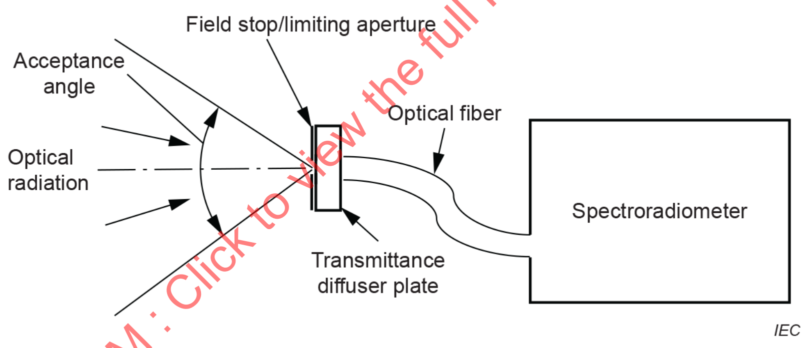
Several types of the diffusers can be used to average the incident radiation, such as integrating spheres, homogenizing rods, diffuse transmission plates, reflection diffusers and mixtures of those types. It is important that the entrance aperture of the diffuser matches with the field stop in radiance measurement, or the limiting aperture in irradiance measurement. The application examples are shown in Figure B.1.



a) Integrating sphere



b) Homogenizing rod



c) Diffuse transmission plate

Figure B.1 – Examples of the diffuser optics

The integrating sphere has excellent diffusing properties to average the radiation over the measurement field and is better used as the input optics. It should be noted that due to the multiple reflections inside the integrating sphere, even slight fluorescence caused by the coating layer material can be intensively amplified. This is often the case if a high content of UV radiation is present and if the coating material contains fluorocarbons.

For transmittance diffuser plates, the diffusing properties are dependent on the thickness and correct hemispherical cosine response. However, the transmittance will decrease quickly as the thickness increases. This diffuser is convenient to be integrated with an optical fibre or broadband detector compactly.

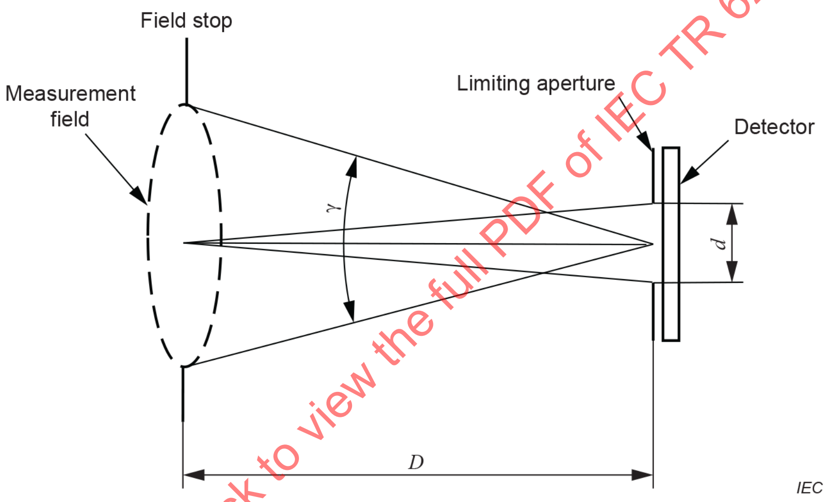
A light pipe homogenizing rod has very high radiation transmission efficiency. The substrate's refractive index of the light pipe is the only factor that influences its critical angle which defines the acceptance angle of the incident optical radiation.

A correctly designed reflection diffuser plate may also suffice as the input device connected to the spectroradiometer or broadband radiometer. An aperture apart from the reflection diffuser is set on the incident radiation path as the field stop. The incident radiation under a defined angle is directed perpendicular to the diffuser plate. Another aperture which is located on the reflection path is possible far away from the reflection surface for the homogenization of the incident radiation. The reflection radiation from this aperture is imaged on the entrance slit of the spectroradiometer. It should be noted that the imaging optics of the spectroradiometer does not shadow any radiation coming from the source to be measured.

B.6 Measurement geometries

B.6.1 Irradiance

For determination of irradiance and weighted irradiance of a given lamp or lamp system, Figure B.2 schematically shows the main concept structured by an irradiance detector and a field stop. The source emission under test is accepted within the acceptance angle (γ), which is implemented by placing a field stop at the source location to limit the measurement field. If it is difficult to achieve, as in the case of projector fixtures, this field stop could be set apart from the source but should be as close as reasonably possible to the source.



Key

d diameter of limiting aperture

D measurement distance

Figure B.2 – Schematic representation of irradiance measurement

A limiting aperture of diameter between 7mm for non-uniform beam profiles and 25 mm for a uniform beam profiles, is used in front of the detector surface. The measurement needs to be performed in that position of the beam giving the maximum reading.

If a spectral radiance measurement is applied, the detector is replaced by a spectroradiometer.

B.6.2 Radiance

The quantities obtained by the radiance measurement are used for assessment of retinal hazards. The emission of a source under test is measured by spatially averaging over the specified FOV.

An optical lens is generally used to collect the source emission onto the field of the detector. An aperture stop with 7 mm diameter (s) is needed for the sources that do not emit uniform beam profiles. In the case of the single lens, when the measurement distance (D') is different from the calibration distance (D), the area of the field stop is adjusted accordingly as in Figure B.3 from A to A' to keep the acceptance angle (γ) constant. In addition, the detector readings will change due to the variation of the detector angle (Ω), and recalibration should be applied.

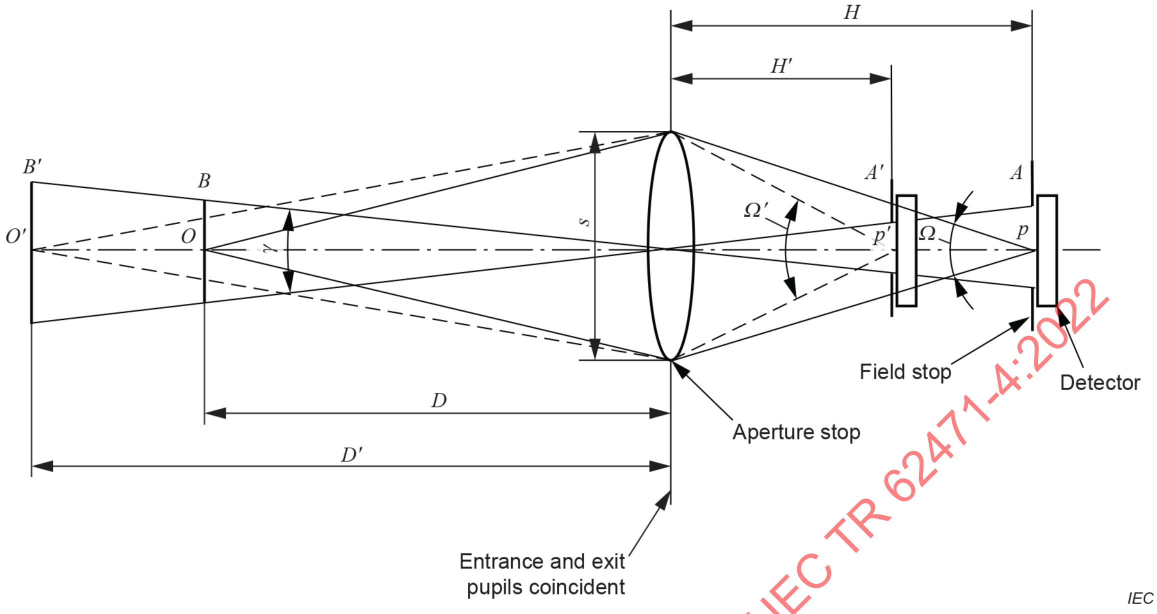


Figure B.3 – Geometry of radiance measurement with a single thin lens

A single thin lens is generally difficult to achieve with high imaging quality, especially for a large FOV. An optical system designed with multiple lenses is applied in common instruments, as shown in Figure B.4.

The acceptance angle (γ), entrance pupil size and measurement distance is consistent with the assessment requirements in IEC 62471 and application standards. The output (V) of the detector is as follows:

$$V = R_{\text{ph}} \times L \times T \times A \times \Omega \tag{B.1}$$

where

R_{ph} is the responsivity of the detector;

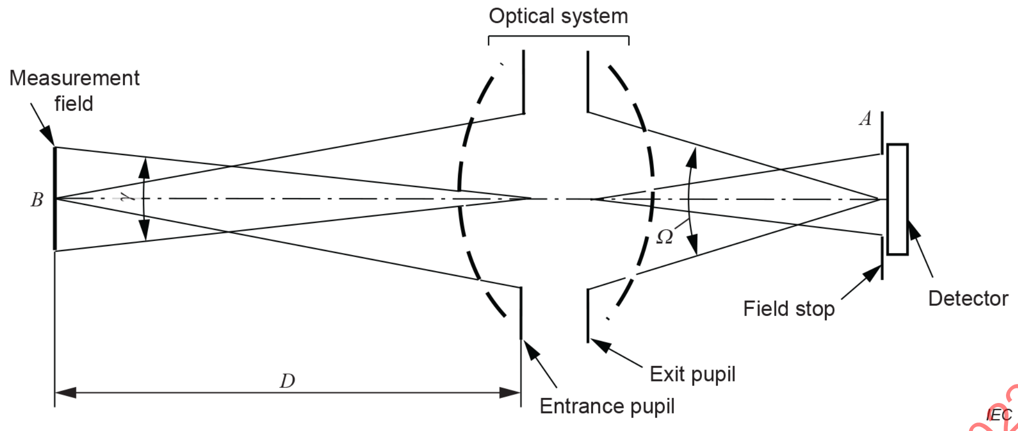
L is the averaged radiance over the measurement field of the source under test;

T is the transmittance of the optical system;

A is the area of the field stop;

Ω is the aperture solid angle of the detector.

In order to achieve repeatable readings, the aperture solid angle (Ω) and field stop (A) of the detector needs to be constant, otherwise a correction or/and recalibration should be applied.

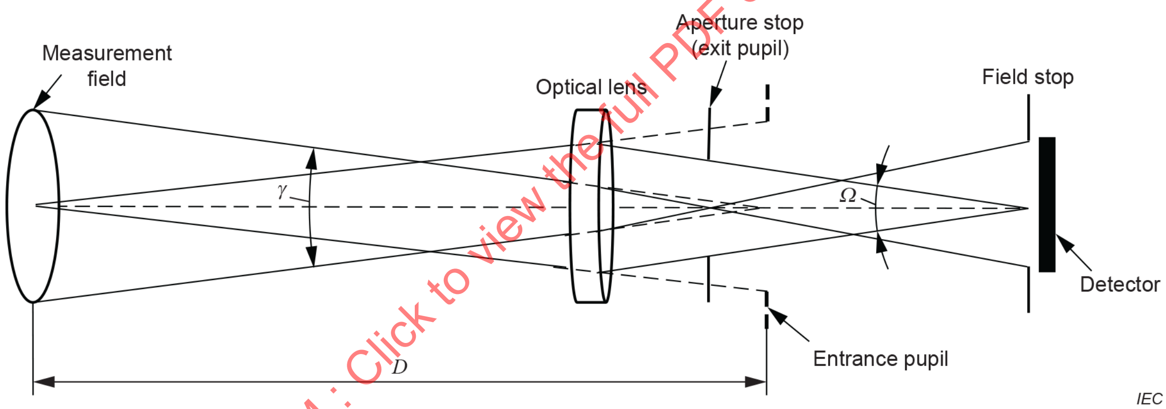


Key

D measurement distance

Figure B.4 – Geometry of a general radiance measurement

A typical geometry of the radiance measurement is shown in Figure B.5. The aperture stop is settled behind the optical lens to form a constant aperture solid angle of the detector. Whenever focusing the target source at different distances by moving the lens, the radiance readings remain constant.



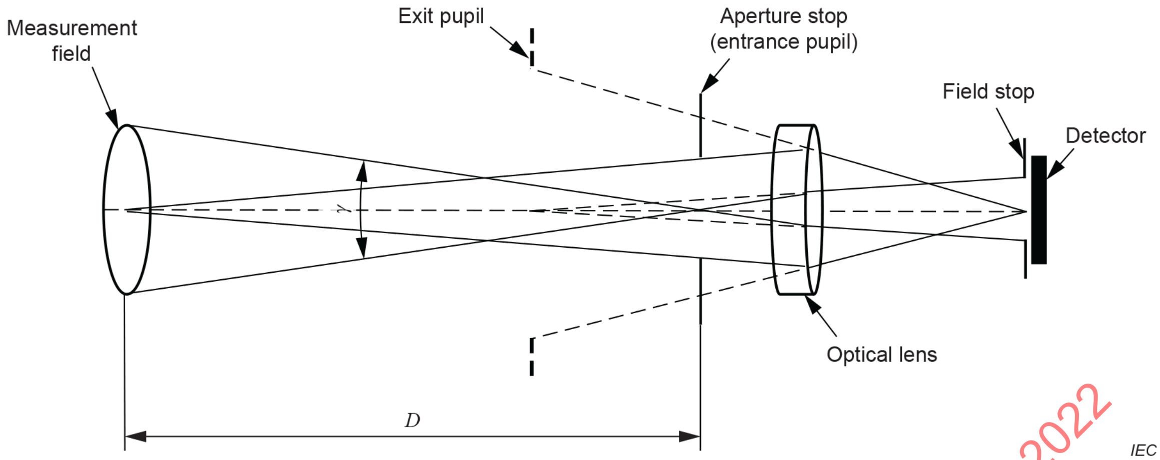
Key

D measurement distance

Figure B.5 – Setup of the aperture stop behind the lens

However, in this situation, the entrance pupil is an image of the aperture stop formed by the frontal lens, usually a virtual image behind the lens. The measurement distance is scaled from the virtual entrance pupil to the apparent source. Also, when the measurement is taken at a different distance, the position as well as size of the entrance pupil will change, and a correction should be applied.

For the convenience of determining the entrance pupil, an aperture stop can be in front of the optical lens, and the measurement distance is taken from this aperture to the source under test, as shown in Figure B.6. However, the variation of the exit pupil which defines the aperture solid angle of the detector needs to be corrected for the measurements at different distances. In the situation that the aperture stop is located at the front focal point, the acceptance angle of the measurement and the aperture solid angle of the detector will remain constant.



Key

D measurement distance

Figure B.6 – Setup of the aperture stop in front of the lens

In the case of radiance measurement for retinal hazard assessment, when the source size is smaller than the measurement field, the irradiance measurement could be applied instead of radiance measurement.

An alternative approach of radiance measurement can be adopted, by placing an aperture at the source to define the measurement field of view and performing a measurement of irradiance. This can only be applied where the apparent source can be accessed directly. Otherwise, an imaging lens is applied to image the source profile and placing an aperture at that image plane through which to measure. The field of view of measurement is defined by diameter of the aperture.

For spectral radiance measurement, it can be implemented by replacing the detector above with a spectroradiometer.

B.7 2D imaging detector

A linear 2D imaging detector such as a CCD camera is generally used to determine the maximum emission within a defined measurement field over a larger source, and the angular subtense of an apparent source for retinal thermal hazard assessment. For the measurement of the maximum emission of an extended source with a uniform spectrum, it can be achieved by integration of a spectral radiance meter with a spectrally uncorrected imaging CCD camera. The spectrally weighted radiance measured by the spectral radiance meter within the same measurement field can be used to correct the readings of the CCD camera, and the maximum radiance under the required acceptance angle according to risk group classification can be determined by calculation of the digital image. However, for a spectral non-uniform source, such as a multiple colour LED-chip lamp, a spectrally corrected CCD camera which is matched with the relevant spectral weighting function is required. Otherwise, the different colour chips are handled separately.

For the evaluation of retinal thermal hazard, the emission limits are dependent on the angular subtense of the apparent source. The dimension of luminous area of the source can be determined by the CCD camera based on the radiance profile of the source.

For a source which only emits infrared radiation, that is a weak visual stimulus, there would be no response for a silicon-based camera. In this case, an infrared sensitive camera in the wavelength range up to 1 400 nm is applied.

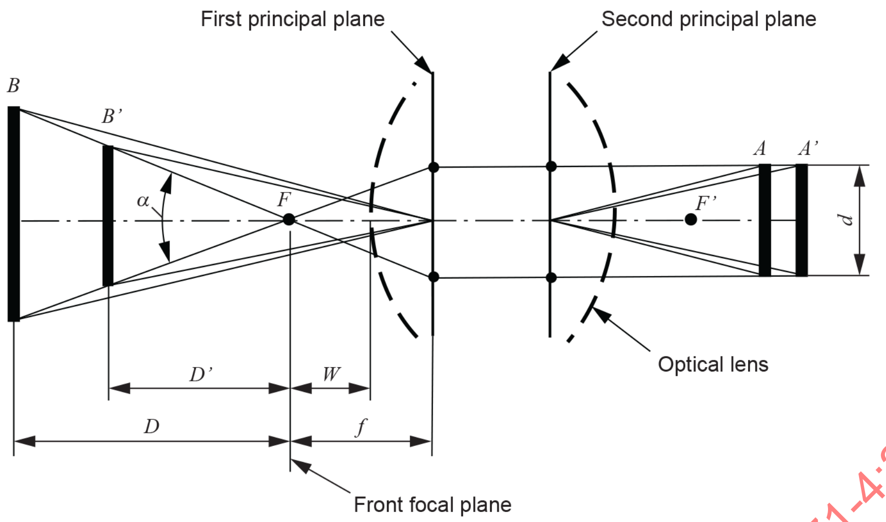


Figure B.7 – Example of a 2D imaging detector

An example of a 2D imaging detector with a optical lens is shown in Figure B.7, when the measurement distance D is counted from the apparent source (B) to the front focal plane of the optical lens, the angular subtense α is determined by Equation (B.2):

$$\alpha = 2\ \arctan(d/2f) \cong d/f \qquad \text{(B.2)}$$

where

d is the diameter of the source image on the CCD detector;

f is the focal length of the optical lens.

NOTE The working distance W from the front lens surface to the focal plane is provided by the manufacturer.

Annex C
(informative)

Extrapolation of spectral irradiance for thermal radiators

In some cases, the spectral irradiance in the infrared is determined up to a wavelength limit where the weighted irradiance has to be calculated over an extended spectral range given by the weighting function. If the examined radiant source is a thermal radiator mainly following Planck's radiation law, the spectral irradiance can be extrapolated by calculating the ratio temperature T_r from two known spectral irradiances $E_\lambda(\lambda_1)$ and $E_\lambda(\lambda_2)$.

Following Planck's law, the spectral irradiance of a temperature radiator is of the form of Equation (C.1).

$$E_\lambda(\lambda,T) = f_G \times \varepsilon \times \frac{c_1}{\pi \times n^2 \times \lambda^5} \times \frac{1}{\exp\left(\frac{c_2}{n \times \lambda \times T}\right) - 1} \tag{C.1}$$

where

T is the radiant temperature in kelvin;

n is the refractive index of air;

c are the Planck constants with c_1 = 3,741 771 85 × 10^{-16} kg·m⁴·s⁻³ and c_2 = 0,014 387 768 78 K·m;

λ is the wavelength in m;

ε is the effective emissivity of the temperature radiator;

f_G is a geometric extend factor of the source.

With two known spectral irradiances $E_\lambda(\lambda_1)$ and $E_\lambda(\lambda_2)$ the ratio temperature can be calculated in a first approach by

$$T_r(\lambda_1,\lambda_2) = \frac{c_2}{n} \times \frac{\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)}{\ln\left(\frac{E_\lambda(\lambda_1)}{E_\lambda(\lambda_2)}\right) + 5 \times \ln\left(\frac{\lambda_1}{\lambda_2}\right)} \tag{C.2}$$

where λ_1 and λ_2 are two different wavelength values close to the region which should be extrapolated with $\lambda_1 < \lambda_2$.

The geometric extend factor combined with the effective emissivity can be combined to a general extrapolation factor $f_e = f_G \times \varepsilon$, which can then be calculated as

$$f_e = E_\lambda(\lambda_2,T_r) \cdot \left[\frac{c_1}{\pi \times n^2 \times \lambda_2^5} \cdot \frac{1}{\exp\left(\frac{c_2}{n \times \lambda_2 \times T_r}\right) - 1}\right]^{-1} \tag{C.3}$$

using the calculated ratio temperature T_r and the wavelength λ_2 (or λ_1 respectively).

With these results, the extrapolated spectral irradiance $E_{\lambda,e}(\lambda,T_r)$ can be estimated:

$$E_{\lambda,\mathrm{e}}(\lambda,T_\mathrm{r}) = f_\mathrm{e} \times \frac{c_1}{\pi \times n^2 \times \lambda^5} \times \frac{1}{\exp\left(\frac{c_2}{n \times \lambda \times T_\mathrm{r}}\right) - 1} \quad \text{(C.4)}$$

Using this extrapolation, the required calculations for a weighted irradiance can be performed.

EXAMPLE The spectral irradiance of a 1 000 W tungsten halogen lamp is known up to 2 400 nm. The spectral interval from 2 400 nm to 3 000 nm is extrapolated. The following spectral irradiance values are given for λ_1 = 1,6 × 10^{-6} m and λ_2 = 2,3 × 10^{-6} m:

$E_\lambda(\lambda_1)$ = 0,052 2 W·m^{-2}·nm^{-1} and $E_\lambda(\lambda_2)$ = 0,020 6 W·m^{-2}·nm^{-1}.

This leads to a ratio temperature of T_r = 3 093 K and a mean extrapolation factor f_e = 7,62 × 10^{-14}.

Using Equation (C.4) to extrapolate up to 3 000 nm, the extrapolated irradiance from 2 400 nm up to 3 000 nm leads to a total irradiance of $E_{(2400-3000)\ \mathrm{nm}}$ = 8,4 W·m^{-2} and, extrapolating down to 780 nm, the overall infrared irradiance, over the range 780 nm to 3 000 nm is E_{IR} = 95,1 W·m^{-2}.

Annex D
(informative)

Temporal emission measurement

D.1 General

When the pulse duration of a tested source is less than 0,25 s, the pulsed source assessment procedure is applied. The time-averaged irradiance and/or time-averaged radiance on relevant criteria time bases according to IEC 62471 should be measured. If the pulse information is unknown, the pulse wave of the source is measured in advance.

For the pulsed source measurement, the following apparatus can be applied.

a) A fast response photodetector is required to record temporal emission wave of a pulsed source. The sensitive wavelength of the detector should cover the spectrum region to be measured. A method using a silicon photodiode can be applied only after verifying that the spectral uniformity is enough to ensure that the measurement of the visible region is equivalent to that of the IR or UV.

b) An array spectroradiometer can be applied to determine averaged irradiance or radiance of the pulsed source within a given exposure time. However, the exposure duration which is set to achieve an appropriate signal level to improve the SNR, different to the criteria time base of the risk classification, should be carefully designed. For an intense pulsed source, a light attenuation is necessary to integrate the emission signal in the whole duration of a single pulse, or integral number of the cycle for a pulse train.

c) A time-resolved spectroradiometer, composed of a monochromator and one or several fast response photodetectors together with high-speed electronics, can be applied to measure temporal spectral irradiance (or radiance) distribution at each wavelength setting.

d) An imaging radiance meter (e.g. CCD camera) can be used to measure the relative radiance profile of an extended source for determination of the maximum emission region. The exposure of the camera needs to be triggered by an external synchronous signal.

D.2 Pulse duration

a) For a source emitting pulse wave or modulated wave, it is necessary to determine the pulse duration. If the duration is larger than 0,25 s it can be treated as a CW source. Otherwise, the pulse width is determined and then α_{max} is calculated.

b) The temporal emission intensity of a pulsed source can be measured by using a fast response photodetector, or a time-resolved spectroradiometer at a specific wavelength.

c) The nominal pulse width of a source Δt is determined in terms of the measured temporal emission wave, where the emission intensity is higher than 50 % of its peak value.

d) When the retinal thermal limit for emission durations less than 0,25 s is expressed in terms of peak radiance (such as the case in IEC 62471-5) and not in terms of radiant exposure, the pulse duration t_p is determined according to the time increment which is calculated by Equation (D.1),

$$t_p = D/L_{max} \tag{D.1}$$

where L_{max} is the peak radiance of the pulse, and D is the total radiance dose of the whole pulse in the time T and determined by integrating the temporal radiance with time increment (Δt) from t_1 to t_2, as in Figure D.1.

$$D = \sum_{t_1}^{t_2} L(t) \times \Delta t \tag{D.2}$$

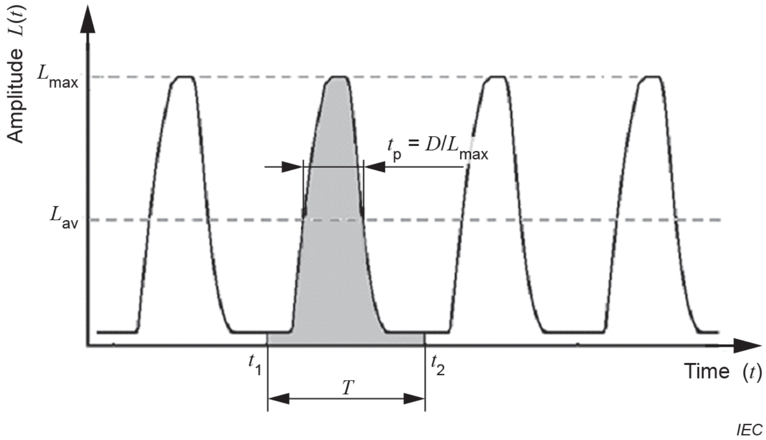


Figure D.1 – Example of temporal pulse wave

In Figure D.1, D is also calculated as $L_{av} \cdot T$. Here L_{av} is the averaged value of the pulse emission in the cycle T.

1) For multi-colour sources, for example of a colour-tunable white LED lamp which consists of low CCT (A) and high CCT (B) LEDs as in Figure D.2, the spectral sensitivity function of the detector would significantly affect recorded waveform of the emission. The solid line represents the signal curve measured by a photometric detector, and the spectrally weighted radiance wave for blue light hazard is represented by the dashed line.

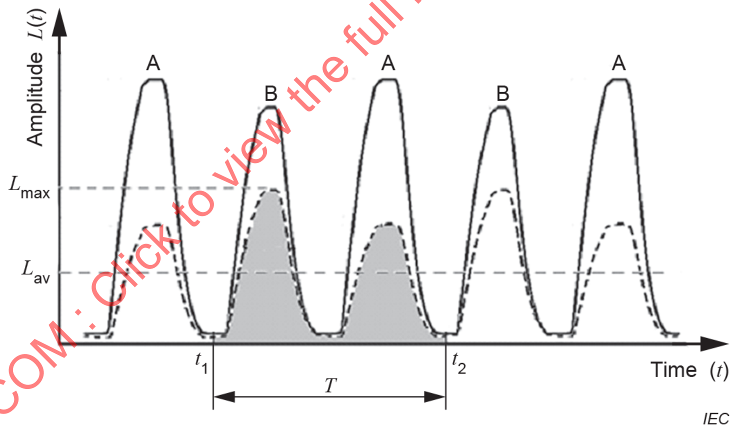


Figure D.2 – Example of a colour-tunable white LED lamp

In this case, the emission waves of different colour components could be measured separately, and the spectral weighting functions should be considered.

2) The pulse wave can be either a temporal pulse wave or a spatial scanning pulse wave.

In the case of spatial scanning pulse, an input optics consisting of a 7 mm entrance pupil to average the scan beam is necessary. The pulse duration should be determined at all accessible positions in the whole scan pattern.

NOTE For scanning sources that incorporate a source operating in continuous wave (CW) mode, the pulse duration could be determined by calculation of the scanning speed and diameter of the beam spot.

D.3 Averaged irradiance and averaged radiance

The averaged irradiance for a pulsed source can be determined by time integrating the irradiance for near UV hazard and infrared radiation hazard, or spectrally weighted irradiance for UV hazard on the criteria time bases of the classification.

The averaged radiance for a pulsed source can be determined by time integrating the spectrally weighted radiance for blue light hazard and retinal thermal hazard on the criteria time bases of the classification.

a) Fast response broadband detectors can be used for level B method to record the temporal irradiance or radiance wave of the pulse emission. The averaged radiance for blue light hazard and retinal thermal hazard is calculated by averaging the spectrally weighted radiance over a given 0,25 s duration which achieves a maximal reading.

   The averaged irradiance for UV hazard, UV-A hazard, or infrared radiation hazard is calculated by averaging the temporal wave in a criteria time base of the classification.

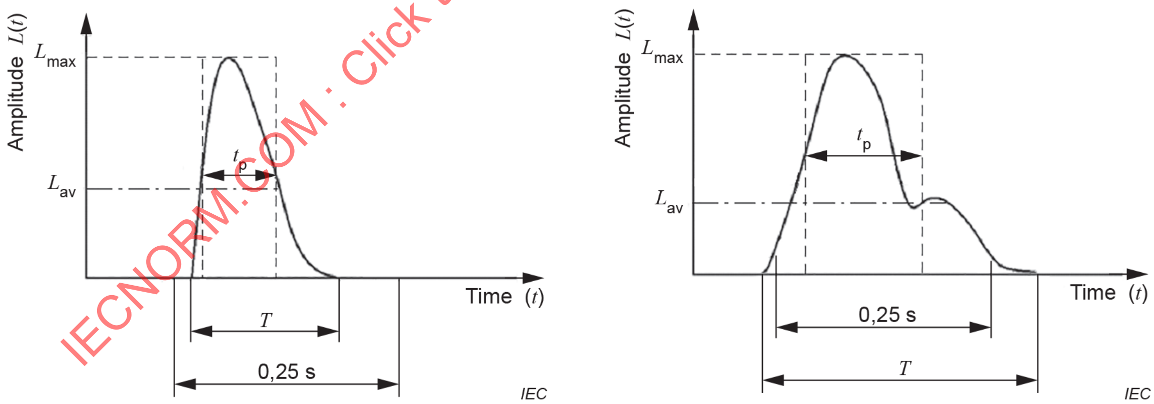
   NOTE 1 If the detector is connected to a photocurrent time-integration electronics, the weighted radiant exposure and weighted radiance dose could be obtained directly.

b) An array spectroradiometer triggered by an external synchronous signal from the lamp driver electronics is appropriate to measure the time-averaged spectral irradiance or spectral radiance of the pulsed source which emits the spectrum in near UV, visible and near infrared radiation.

   1) The averaged irradiance for near UV hazard is calculated by the summation of the time-averaged spectral irradiance from 315 nm to 400 nm.
   2) The averaged radiance for blue light hazard is calculated by integrating the time-averaged spectral radiance from 300 nm to 700 nm with the spectral weighting function, B(λ).
   3) The averaged radiance for retinal thermal hazard is calculated by integrating the time-averaged spectral radiance from 380 nm to 1 400 nm with the spectral weighting function, R(λ).

NOTE 2 The integration time of the array spectroradiometer is set to include the whole pulse wave or an integral number of cycles.

NOTE 3 For a single pulse, when the whole duration is less than 0,25 s as in Figure D.3 a), the radiance values for blue light hazard and retinal thermal hazard are calculated by averaging over 0,25 s. However, when the whole duration is wider than 0,25 s as in Figure D.3 b), a reference photodetector is needed to record the wave profile, and the averaging time (0,25 s) is determined through this profile to achieve maximum reading.



a) Whole duration is less than 0,25 s **b) Whole duration is wider than 0,25 s**

Figure D.3 – A single pulse wave

c) A time-resolved spectroradiometer triggered by an external synchronous signal can be used to measure the temporal spectral irradiance or radiance wave by setting at each wavelength scale.

   In order to minimize the measurement uncertainty caused by the pulse-to-pulse variation, the use of a reference photodetector is recommended for compensation of the output variation of the pulsed source during the measurement.

   For a single pulse wave, in order to obtain the complete time-averaged spectral irradiance or radiance, it is necessary to operate the pulsed source repetitively, the measurement is implemented at a series of discrete wavelength settings until the desired spectral range has been covered.

For a modulated pulse wave, the time-averaged spectral irradiance or radiance is calculated among several cycles of the pulse wave.

1) The averaged irradiance for UV hazard is calculated by integrating the time-averaged spectral irradiance from 200 nm to 400 nm with spectral weighting function, $S_{UV}(\lambda)$.
2) The averaged irradiance for near UV hazard is calculated by summation of the time-averaged spectral irradiance from 315 nm to 400 nm.
3) The averaged radiance for blue light hazard is calculated by integrating the time-averaged spectral radiance from 300 nm to 700 nm with the spectral weighting function, B(λ).
4) The averaged radiance for retinal thermal hazard is calculated by integrating the time-averaged spectral radiance from 380 nm to 1 400 nm with the spectral weighting function, R(λ).
5) For a weak visual stimulus radiation, the retinal thermal hazard radiance is calculated from 780 nm to 1 400 nm.
6) The averaged irradiance for IR radiation hazard is calculated by integrating the time-averaged spectral irradiance from 780 nm to 3 000 nm.

For a spectrally variable pulse, as an example shown in Figure D.4, a time-resolved spectroradiometer can be used to measure temporal spectral irradiance or radiance waves of the pulsed source at each wavelength setting. At the same time, a fast response broadband detector operates synchronously to record the temporal intensity distribution of the wave, which is applied to compensate for the variation of pulse-to-pulse wave.

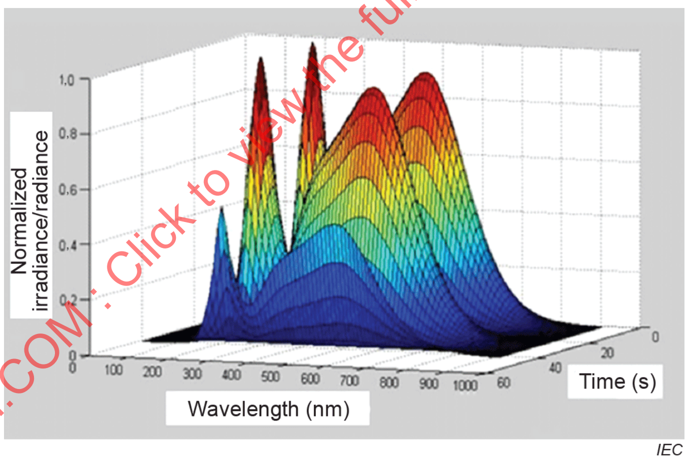


Figure D.4 – Example of a spectrally variable pulse

Annex E
(informative)

Uncertainty analysis

The analysis of overall uncertainty of a measurement result should follow ISO/IEC Guide 98-3 and its supplements. The uncertainties in measured quantities should be reported as an expanded uncertainty with a coverage factor that corresponds to a 95 % confidence level. Most uncertainty estimates in the field of photometry and radiometry assume that the appropriate coverage factor is $k = 2$.

Uncertainty associated with a measurement result is a function of the method used and the model of evaluation. It is generally determined by the uncertainty in the measurement process and the uncertainty of the calibration standards. The first step in uncertainty analysis is identifying the uncertainty components. Below is a list that can be the start of the evaluation of uncertainty for measurements used in classifying lamps and lamp systems.

- Instrument:
  - wavelength;
  - bandwidth;
  - linearity;
  - stability;
  - spatial uniformity in responsivity;
  - stray light;
  - out-of-band;
  - entrance aperture;
  - polarization;
  - response time.
- Calibration:
  - standards (assigned uncertainty);
  - alignment;
  - distance;
  - electrical operation.
- Measurement:
  - alignment;
  - distance;
  - source under test;
    - stability;
    - temperature;
    - size;
    - electrical operation.

All the uncertainty components that contribute to the measurement results should be examined and included in the model and the related uncertainty budget. For all measurements, not only the contributions from the measurement system and procedures, but also the contributions from the measurement specific to a lamp or lamp system to be evaluated, should be taken into account.

Procedure in details for the determination of measurement uncertainties in the field of radiometry and photometry is specified in CIE 198-2011, "Determination of Measurement Uncertainties in Photometry".

Annex F
(informative)

Application examples

F.1 General

Photometric and radiometric data on lamps and lamp systems are available in the form of manufacturer's specifications or testing laboratory report, for example as luminous flux and radiant flux, luminance and luminous intensity, as well as spectral power distribution, etc. In the photobiological safety assessment, such data could be used for initial screening to avoid additional measurements. Several examples will be given to indicate the possible approach for calculation and measurement.

F.2 Example 1 – LED flashlight

An LED flashlight is shown in Figure F.1.

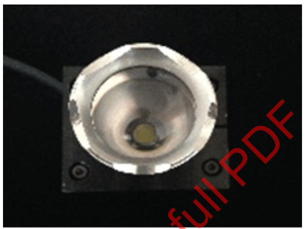


Figure F.1 – Example of a LED flashlight

a) Level B measurement

1) Check the spectral range, luminance and other parameters of the tested source according to the product specifications and other information.

   Spectral range: 380 nm to 750 nm.

   Luminance: L = 1,698 × 10^7 cd·m^{-2}.

2) Determine the potential hazard category, and measurement quantities according to the known information. For a typical white light LED lamp, the blue light hazard is the dominant effect.

   A known luminance L > 10^4 cd·m^{-2} means a further measurement is necessary. So the weighted radiance of blue light hazard needs to be measured by using Level A method.

b) Level A measurement

1) A CCD camera is used to measure the radiance profile of the tested source. The measurement geometry structure is as shown in Figure B.7. An aperture with 7 mm diameter is set on the front focal plane of the optical lens, and the measurement distance is at 200 mm. The radiance profile is shown in Figure F.2.

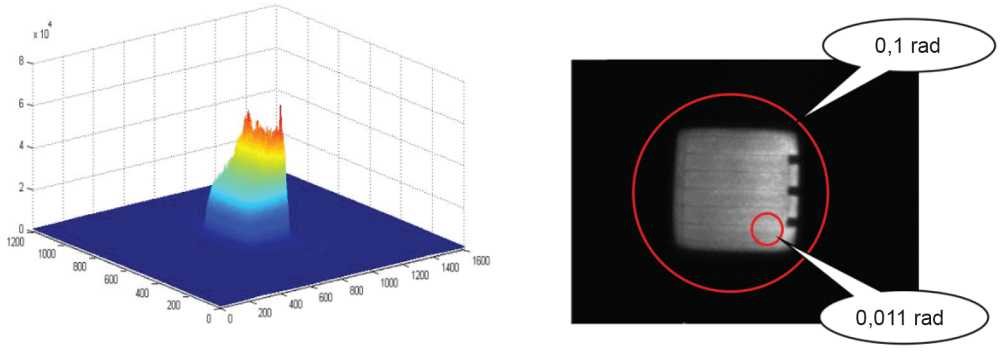


Figure F.2 – Example of a radiance profile

2) A spectroradiometer coupled to the CCD camera is used to measure the spectral radiance averaged over an angle of acceptance (0,1 rad), and the spectral radiance distribution from 300 nm to 750 nm is shown in Figure F.3.

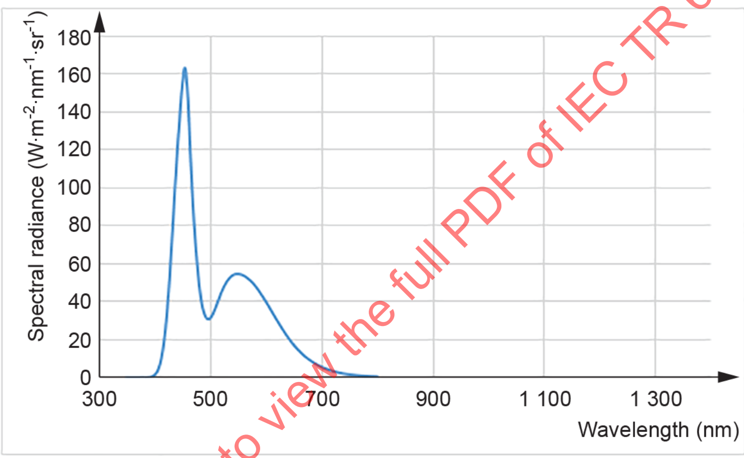


Figure F.3 – Spectral radiance distribution

3) The dimension of the apparent source can be determined (see Figure F.2), and then the angular subtense is calculated, α = 0,03 176 rad.

4) Searching of the hot spot with 0,1 rad (for exempt group) is done through an image process to scan across the full radiance profile of the source. The blue light hazard weighted radiance is calculated by integration of the spectral radiance multiplied by the spectral weighting function for blue light hazard, and L_B (0,1 rad) = 4,834 × 10^3 W·m^{-2}·sr^{-1}.

   If the accessible emission is over the limit of the exempt group, then 0,011 rad (risk group 1) is used to search for the hotspot, to determine the weighted radiance, and L_B (0,011 rad) = 2,824·10^4 W·m^{-2}·sr^{-1}.

5) The accessible emission is over the limit of risk group 1, but below that of risk group 2. Therefore, the source under test is assigned to risk group 2 for blue light hazard.

F.3 Example 2 – Infrared tungsten filament lamp

An infrared tungsten filament lamp is shown in Figure F.4.

IEC

Figure F.4 – Example of an infrared tungsten filament lamp

a) Level B measurement

1) Check spectral range, luminance and other parameters of the tested source according to the product specifications and other information.

Spectral range: 380 nm to 3 000 nm.

Luminance: L = 2,638 × 10^4 cd·m^{-2}.

2) Determine the potential hazard categories and the measurement parameters. Because the glass bulb blocks UVB emissions, only there are very low UVA emissions. Therefore, the retinal blue light hazard, retinal thermal hazard and IR radiation hazard will be considered.

Moreover, the luminance L (2,638 × 10^4 cd·m^{-2}) is over the luminance criterion (10^4 cd·m^{-2}) for the exempt group, the measurement of blue light hazard weighted radiance is necessary, and Level A measurement is applied.

b) Level A measurement

1) A CCD camera is used to determine the radiance profile of the tested source (see Figure F.5).

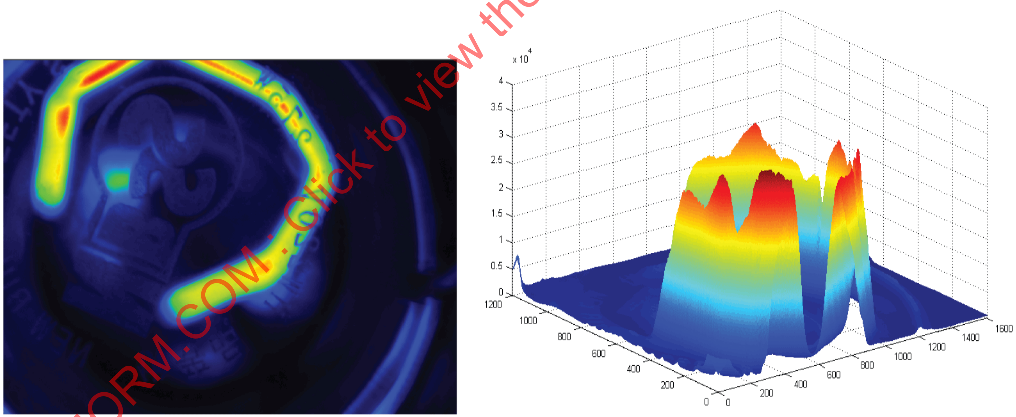


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Figure F.5 – Example of a radiance profile

2) A spectroradiometer with radiance geometry and irradiance geometry is used to measure the spectral radiance from 380 nm to 1 400 nm and spectral irradiance from 380 nm to 3 000 nm, respectively (see Figure F.6).

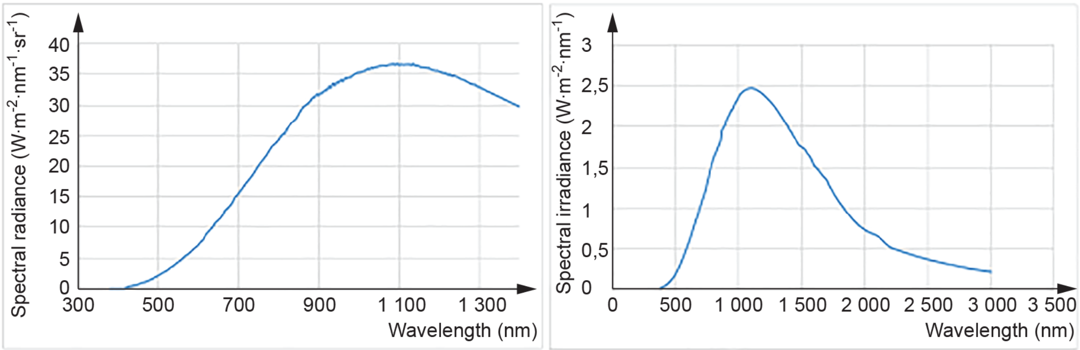

Figure F.6 – Spectral radiance and irradiance distributions

3) The dimension of the apparent source can be determined (see Figure F.7), and then the angular subtense is calculated, α = 0,011 rad, which means the limit for retinal thermal hazard is equal to 2,5 × 10^6 W·m^{-2}·sr^{-1}.

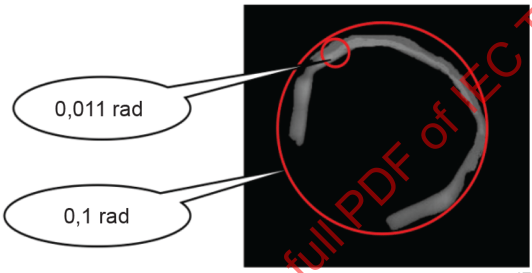

Figure F.7 – Radiance profile of the lamp

4) Searching of the hot spot over an angle of acceptance is done through an image process to scan across the full radiance profile of the source, to determine the blue light hazard weighted radiance and the thermal hazard weighted radiance.

Blue light hazard weighted radiance L_B (0,1 rad) = 14,7 W·m^{-2}·sr^{-1} is below the limit of the exempt group.

Retinal thermal hazard weighted radiance L_R (0,011 rad) = 8,04 × 10^4 W·m^{-2}·sr^{-1} is below the limit of the exempt group.

F.4 Example 3 – Compact fluorescent lamp (CFL)

A compact fluorescent lamp (CFL) is shown in Figure F.8.

Figure F.8 – Example of a compact fluorescent lamp (CFL)

a) Level B measurement

1) Check spectral range, luminance and other parameters of the tested source according to the product specifications and other information.

Spectral range: 300 nm to 750 nm, the tube glass blocks the short UV radiation below 300 nm.

Luminance: L = 3,568 × 10^4 cd·m^{-2}.

2) Determine the potential risk categories. Here, the retinal blue light hazard and UV-A hazard are considered.

Moreover, the luminance L = 3,568 × 10^4 cd·m^{-2} is over the luminance limit (10^4 cd·m^{-2}) of exempt group for GLS sources, so the measurement of blue light hazard weighted radiance is necessary, and Level A measurement is applied.

b) Level A measurement

1) A CCD camera is used to determine the radiance profile of the tested source (see Figure F.9).

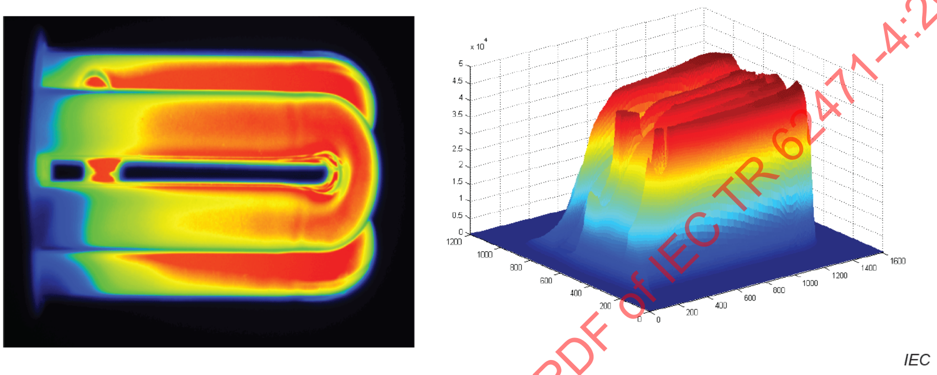

Figure F.9 – Example of a radiance profile

2) A spectroradiometer coupled to the CCD camera is used to measure the spectral radiance averaged over an angle of acceptance (0,1 rad), and the spectral irradiance distribution from 300 nm to 750 nm (see Figure F.10).

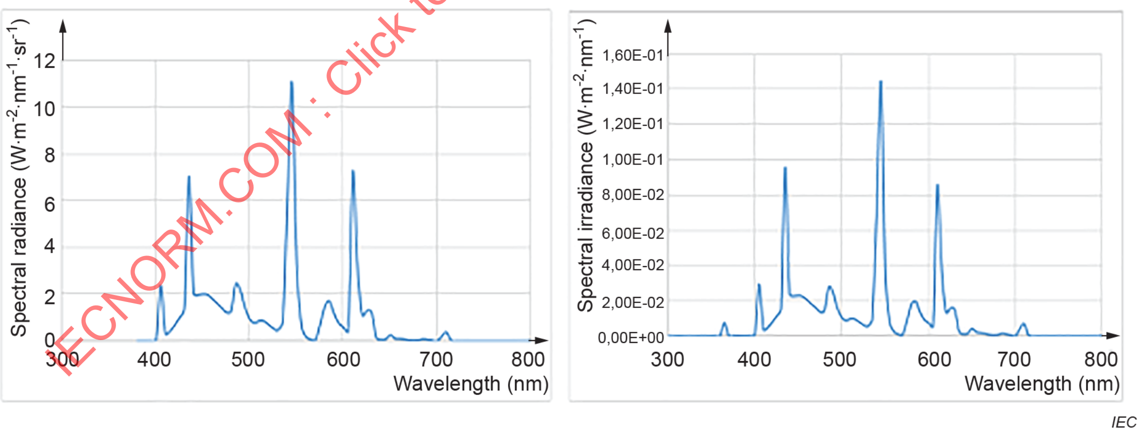

Figure F.10 – Spectral radiance and irradiance distribution