IEC/TR 62471-2

Edition 1.0 2009-08

TECHNICAL REPORT

Photobiological safety of lamps and lamp systems –
Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety

colour inside

IEC/TR 62471-2:2009(E)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE X

ICS 29.140

ISBN 2-8318-1057-6

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOBIOLOGICAL SAFETY OF LAMPS AND LAMP SYSTEMS –

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FOREWORD

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IEC 62471-2, which is a technical report, has been prepared by Technical Committee 76: Optical radiation safety and laser equipment

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
76/396/DTR	76/410/RVC

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

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

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

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

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- withdrawn,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

IMPORTANT – The "colour inside" logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

INTRODUCTION

Optical radiation hazards from all types of lamps or other broadband light sources are assessed by the application of IEC 62471:2006 (Edition 1), *Photobiological safety of lamps and lamp systems*. IEC 62471 covers LEDs as well as incandescent, low and high pressure gas-discharge, arc and other lamps. It also covers electrically-powered optical radiation sources that are not lamps. The standard provides a risk group classification system for all lamps and lamp systems, and the measurement conditions are well developed. IEC 62471 does not include manufacturing or user safety requirements that may be required as a result of a lamp or lamp system being assigned to a particular risk group. The safety requirements for lamp systems necessarily vary and are best dealt with in vertical standards. This Part 2 provides the basis for safety requirements dependent upon risk group classification and examples thereof. The assigned risk group of a product may be used to assist with risk assessments, e.g. for occupational exposure in workplaces. National requirements may exist for the assessment of products or occupational exposure.

NOTE 1 There are some instances where the IEC 60825 laser product standards may be useful for a nearly "point" source, as in an LED fibre source or a superluminescent diode (see 3.16).

NOTE 2 IEC 62471 is currently being revised and will be published as IEC 62471-1.

PHOTOBIOLOGICAL SAFETY OF LAMPS AND LAMP SYSTEMS –

Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety

1 Scope

This technical report provides the basis for optical radiation safety requirements of non-laser products, serving as a guide for development of safety requirements in vertical product standards and assisting lamp system manufacturers in the interpretation of safety information provided by the lamp manufacturers.

This report provides guidance on:

- requirements for optical radiation safety assessment;
- allocation of safety measures;
- labelling of products.

This technical report does not address safety requirements of intentional exposure to optical radiation from sun tanning equipment, ophthalmic instruments or other medical/cosmetic devices whose specific safety issues are addressed through appropriate standards.

2 Normative references

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

IEC 62471, *Photobiological safety of lamps and lamp systems*

IEC 60825 (all parts), *Safety of laser products*

IEC 60050-845, *International Electrotechnical Vocabulary – Chapter 845: Lighting*

IEC 60417, *Graphical symbols for use on equipment*

3 Terms and definitions

For the purposes of this document, the terms and definitions of IEC 62471 and the following additional terms and definitions apply.

3.1
controlled access location
location where an engineering and/or administrative control measure is established to restrict access except to authorised personnel with appropriate safety training

3.2
exposure hazard value
EHV
value defined as follows:

$$EHV\ (distance, exposure\ \ time) = \frac{Exposure\ level\ (distance, exposure\ time)}{Exposure\ limit\ value}$$

The EHV is greater than 1 when the exposure level (3.3) exceeds the exposure limit value (3.4)

3.3
exposure level
EL
level of exposure from a source at a location in space for a stated duration

3.4
exposure limit value
ELV
maximum level of exposure of optical radiation to the eye or skin that is not expected to result in adverse biological effects. These ELVs are used to determine hazard distances in respect to foreseeable photobiological effects

3.5
hazard distance
HD
distance from the source at which the EL equals the appropriate exposure limit value (ELV)

3.6
intended viewing
deliberate act of an individual to either look at a source of optical radiation or at a virtual source, such as a reflection

3.7
intended use
usage of a product, process or service in accordance with specifications, instructions and information provided by the manufacturer or supplier

3.8
lamp
electrically powered device emitting optical radiation in the wavelength range between 200 nm and 3 000 nm, with the exception of laser radiation

3.9
lamp system
electrically operated product incorporating a lamp or lamps, including fixtures and incorporated electrical or electronic components, generally as intended by the manufacturer to be used (for illumination purposes - luminaire)

NOTE 1 Lamp systems may include diffusers, enclosures and/or beam modifying optics.

NOTE 2 For the purpose of this technical report, a lamp system may incorporate a lamp that does not serve as the primary function of the product, e.g. an indicator lamp or an illumination lamp inside a refrigerator.

3.10
modifying optics
optical components, such as filters, lenses and reflectors, which change the characteristics of the optical radiation from a lamp when incorporated into a lamp system

3.11
non-laser optical radiation
incoherent optical radiation generated by a process other than stimulated emission

3.12
restricted access location
location which is normally inaccessible by the general public, including workers, visitors and residents in the immediate vicinity, by means of engineering or administrative control measures but is accessible to authorised personnel that may not have specific safety training

3.13
small source
source or apparent source with an angular subtense smaller than the angle of acceptance γ that should be applied according to a risk assessment or classification.

NOTE This may result in the spatially averaged radiance (3.15) of a source or apparent source being averaged over a larger area than would be applied for the source radiance (3.14).

3.14
source radiance
radiance of the emitting element of the source (see IEV 845-01-34). However, the applicable acceptance angle should not be smaller than 1,7 mrad

Symbol: L

NOTE It is defined to differentiate from spatially averaged radiance (3.15).

3.15
spatially averaged radiance
radiance spatially averaged over a given angle of acceptance to account for physiological factors such as eye-movements (sometimes referred to as “physiological radiance”). The spatially average radiance may be lower than the source radiance (see 3.14)

Symbol: L_{sa}

3.16
superluminescent diode
edge-emitting semiconductor light source based on superluminescence. It combines the high power and brightness of laser diodes with the low coherence of conventional light-emitting diodes. Its emission band is 20 nm to 100 nm wide

3.17
unintentional viewing
condition when eye exposure to optical radiation is not intended

3.18
unintentional skin exposure
condition when skin exposure to optical radiation is not intended

3.19
viewer-related risk
risk for intended or unintended viewers of a source under application-specific realistic conditions

NOTE In order to be independent of the use condition, the risk group classification of lamps and lamp systems is based on worst case assumptions of exposure duration, pupil size and viewing distance. However, the emission of lamps is often divergent and when a lamp is integrated into a product, depending on product design and its application, these assessment conditions may become inappropriate. In this case, the product may be assessed at the minimum distance and maximum exposure duration representative for the application-specific conditions of foreseeable access.

4 Risk groups applied for optical radiation safety assessments

4.1 Basis for optical radiation safety classification

IEC 62471 provides the method to determine the risk group of any lamp or any product incorporating a lamp. The risk groups in IEC 62471 indicate the degree of risk from potential optical radiation hazards and minimise the need for further measurements. The risk groups were developed based upon decades of lamp use experience and the analysis of accidental injuries related to optical radiation emission (where injuries were, generally, quite rare except from ultraviolet-emitting lamps or arc lamps). There are four basic risk groups:

- Exempt Group (RG 0), where no optical hazard is considered reasonably foreseeable, even for continuous, unrestricted use. Typical examples are most frosted incandescent lamps and fluorescent lamps used in domestic applications;
- Risk Group 1 (RG 1) products are safe for most use applications, except for very prolonged exposures where direct ocular exposures may be expected. An example of a Risk Group 1 product is a domestic battery operated torch (flashlight);
- Risk Group 2 (RG 2) products generally do not pose a realistic optical hazard if aversion responses limit the exposure duration or where lengthy exposures are unrealistic;
- Risk Group 3 (RG 3) products pose a potential hazard even for momentary exposures, and system safety requirements are generally essential.

IEC 62471 does not provide manufacturing requirements and control measures. These issues should be addressed in application-specific vertical standards (see 4.3.3). However, in order to provide a consistent approach across products, the (non-normative) labelling requirements are outlined in this technical report (see 5.4).

4.2 Assessment criteria

The standard measurement conditions consider the emission spectrum and, depending on the type of hazard, either irradiance or spatially averaged radiance to determine risk to the eye and/or the skin. The measurement conditions are related to potentially hazardous viewing conditions and take into consideration physiological factors of the eye, such as accommodation, pupil size, the aversion responses and eye movements (saccades).

IEC 62471 distinguishes between lamps intended for general lighting service (GLS) and lamps intended for use in other applications such as for germicidal use, heating, signalling, data transfer or others. Assessment and measurement conditions are different for these two groups:

- GLS - the hazard values should be quoted as irradiance or spatially averaged radiance values at a distance which produces an illuminance of 500 lux;
- other applications – the hazard values should be determined at a distance of 200 mm from the source.

Different application groups define a range of operational, maintenance and servicing conditions. If the assessment applied to different application groups in a vertical standard justifies it, the measurement conditions in IEC 62471 can be modified for specific application groups.

4.3 Application-related issues

4.3.1 Near-infrared sources

The limits set for the infrared (IR) spectral region were originally intended for applications of large IR-radiators with a significant amount of IR-A and IR-B radiation. The limits protect the cornea or lens of the eye against long-term thermal effects (e.g. cataract). Thus, the limits should be applied where the application is likely to result in chronic and lengthy exposures of the eye for periods greater than 1 000 s and the daily averaged irradiance is expected to be at least 100 W·m^{-2}. The primary objective is to minimise heating of the lens and cornea.

4.3.2 “Point sources”

There may be a small number of applications where an incoherent optical radiation source appears as a nearly monochromatic “point” source and should be considered within a laser safety standard framework. Generally, this will only apply to: superluminescent diodes (SLDs) (see 3.16), which resemble “point sources”; and LEDs which are employed in optical fibre communications, where the fibre source also resembles a very small, or “point” source. The user is referred to IEC 60825-1 for SLDs and to IEC 60825-2 for optical fibre communication systems.

4.3.3 Application-related vertical standards

The requirements in vertical standards may:

– limit the source risk group that can be used in a given application;

– require specific performance features based upon the risk group specifications; or

– specify application-specific control measures.

Basic guidance, based on the likelihood of direct source viewing, is provided in Clause 6. Vertical standards should be guided by the principle that it is not necessary to reduce optical radiation exposure to as low as reasonably achievable. However, as a general guideline, needless emissions that would produce unnecessary human exposure should be minimised. The hierarchy of applicable safety measures should follow the internationally accepted priority ranking of manufacturer safety measures. That is, engineering controls (e.g., filters, shielding, etc) are the highest priority, followed by administrative measures (such as warnings and labels, see 5.4) and then personal protective equipment as the last resort. Details should be provided in application-specific vertical standards.

5 Guidelines for lamp and lamp system manufacturers on how to apply IEC 62471

5.1 Limit values

5.1.1 General

It should be noted that the risk group classification system of IEC 62471 is primarily applied to lamps. However, in terms of product safety, the lamp system manufacturer has responsibility for assessing the final lamp system product. Because of different technical tasks and needs, manufacturers of lamp systems or luminaires might have limited capabilities for tests and measurements and they commonly rely on the lamp/LED data provided by the lamp/LED manufacturer. Therefore, guidance is provided on how and when lamp system manufacturers may rely on data provided by the lamp manufacturer.

There are many types of lamps for which the intended applications are known. For instance, for conventional light sources, the modifications of the safety-related optical features of the incorporated lamp by the lamp system manufacturer are generally not significant. In most cases there is a single conventional lamp type (light bulb) used for a luminaire and the lamp system manufacturer only adds a fixture and a power supply. In these cases, the lamp data are usually directly transferable to the lamp system. The assessment and risk group classification of the lamp can be used by the lamp system manufacturer for classification of the lamp system. However, other types of lamps may need detailed consideration.

The limit values of the safety standard are provided in two different quantities, which require separate consideration.

5.1.2 Limits provided in irradiance/radiant exposure

In the spectral ranges 200 nm to 400 nm and 1 400 nm to 3 000 nm where the emission limits in IEC 62471 are provided in irradiance or radiant exposure, the measurements of a single lamp can not simply be transferred directly to a lamp system but require an analysis of the optical additivity to determine the system risk group.

When a lamp is employed with additional integrated or attached modifying or projection optics, this lamp system should be considered as a different product and the lamp system manufacturer should provide the new risk group safety classification.

NOTE Additional optics primarily modify the irradiance of a source (i.e. may have a significant impact where the classification is based on irradiance or radiant exposure-criteria), whereas the radiance may remain unchanged (i.e. less impact where the classification is based on radiance-criteria).

5.1.3 Limits provided in (time integrated) radiance

In cases where the emission limits in IEC 62471 are provided in terms of spatially averaged radiance or time-integrated spatially averaged radiance, the principle of conservation of radiance may be used with caution. That is, if a lamp or single LED emits below the radiance level specified (per risk group), the final lamp system or LED-array also can not exceed the accessible emission limits. IEC 62471 requires measurements of spatially averaged radiance (3.15) values with the consequence that the relationship between the field of view and the source area, as it was used for the characterisation of a single component, may be changed by the integration of the single lamp or LED into luminaries (arrays) or with the attachment of beam-shaping optics.

Under specific conditions (see 5.2.2), the assessment of a single lamp/LED is directly transferable to the lamp system or luminaire. The risk group will remain the same, or may be reduced (e.g., by filters, etc.).

NOTE Since additional optics primarily modify (increase) the irradiance of a source rather than the radiance, an evaluation should verify that the most restrictive classification criterion of the lamp system has not been changed (from radiance to irradiance criterion).

5.2 Guidelines for lamp/LED manufacturers

5.2.1 General

The primary purpose of lamp risk-group classification by the lamp or LED manufacturer is to inform the user or final-product manufacturer of potential hazards that may need to be addressed in the safety design of the final product. Therefore, when a lamp is placed in Risk Groups 1, 2 or 3, it is important for the user to be informed of which potential hazards may require controls. If the manufacturer provides the EHV or HD for the lamp (see 5.3.4), the determination of appropriate controls can be simplified.

5.2.2 Measurement conditions

In the range 200 nm to 400 nm or 1 400 nm to 3 000 nm where the limits in IEC 62471 are provided in irradiance or radiant exposure, the measurements should be performed according to IEC 62471.

In cases where the limits in IEC 62471 are provided in spatially averaged radiance or time-integrated radiance, the source radiance (according to 3.14) data should be determined (LEDs: operating under maximum operating conditions, such as maximum current) according to IEC 62471. The angle of acceptance should be 1,7 mrad in any case.

NOTE These values should be compared with the risk group-specific limit values (rather than apply different angles of acceptance). Under these conditions it can be assured that the risk group allocation of the component in any case is directly transferable and useful to the characterisation of the final lamp system.

If the use of the product is known and unambiguous, the application-specific requirements (i.e. vertical standards) should be applied, where these exist, or subclauses 4.2 and 4.3 should be applied.

In case of multi-purpose lamps or if application-specific requirements (i.e. vertical standards) do not exist, the measurement of single lamps and components should be performed at a distance of 200 mm and the risk group and values should appear in the user information.

The assessment and risk group classification should be based on these values.

5.2.3 User information

The user information should include the risk group classification of the lamp that can be used for risk group classification of a lamp system.

Information on risk group classification should be given for the intended use. Information should be provided if application-specific conditions or requirements (as pointed out in 4.2 and 4.3 or as required by vertical standards) were applied. It should be noted that re-classification may be necessary if the lamp is used in other applications.

In the range 200 nm to 400 nm or 1 400 nm to 3 000 nm where the classification is based on irradiance or radiant exposure, it should be noted that the assessment of a single lamp can not be automatically transferred to the final lamp system. However, if the integration of the lamp into a lamp system does not change the accessible emission characteristics of the lamp, the risk group classification of the lamp system remains the same as the risk group of the lamp.

5.3 Guidelines for lamp system/luminaire manufacturers

5.3.1 General

The lamp risk group classification indicates necessary safety measures to reduce the risk group required for the application as specified in vertical standards. If the risk group of the lamp is below the maximum appropriate for the application (see Table 3), the manufacturer should assure that the risk group is directly transferable to the lamp system.

Lamp manufacturers produce some lamp types solely intended for specific applications (4.2 and 4.3, or as required by vertical standards) and these products should be classified by the lamp manufacturer only under the application-specific conditions, if they exist. If these sources are modified or marketed for use for other purposes, the lamp system manufacturer should perform the re-assessment and assign the appropriate risk group.

5.3.2 Sources for general lighting service (GLS)

IEC 62471 states that for lamps and lamp systems used for GLS the hazard values should be reported as irradiance or spatially averaged radiance values at a distance which produces an illuminance of 500 lux. Only lamps and lamp systems which are classified as Exempt Group with respect to the skin hazard when assessed at the location of the 500 lux illuminance level, should normally be used for GLS applications. In addition, if the application requires skin access to the optical radiation from the source where the illuminance is likely to exceed 500 lux for periods of exposure longer than 1 h, the user should be warned that an exposure assessment may be required.

NOTE The above is intended to ensure that applications are considered where, for example, the UV emission limits may be exceeded. This may be of concern for some lamps where the emission limits are not exceeded at 500 lux, but may be exceeded at a higher illuminance level where the hands, for example, may be located during fine detail task illumination, or where the head is closer to the source than the surface illuminated at 500 lux.

The required illuminance measurement of the GLS lamp systems takes into account contributions from all the elements of the lamp system. In contrast to the radiance measurement for risk group determination, the acceptance angle for the illuminance measurement of GLS sources is not limited. When multiple lamps or modifying optics are applied to a GLS product, the ultraviolet and infrared emission of the product in many cases may be reduced; thus, the corresponding risk is reduced. Furthermore, if lenses or arrays increase the 500 lux distance, the angular subtense of the component sources decrease (and the spatially averaged radiance decreases), so that the risk remains essentially the same.

In cases where the classification by the lamp manufacturer is based on radiance or time-integrated radiance and where irradiance-dependant hazards can be neglected (LEDs or by the use of appropriate filters), the GLS-classification of the lamp can directly be transferred to the lamp system/luminaire.

5.3.3 Multi-purpose lamps

The following general approach should be followed in the course of risk group determination of lamp systems. In cases where the risk classification of the lamp is based on the most restrictive radiance or time-integrated radiance criteria, these values remain unchanged or are decreased by integration of the lamp into a system or by adding optical elements. Such measures or elements, in contrast, may change the irradiance or radiant exposure produced by a source and should be considered in cases where the risk grouping of the incorporated lamp is based on those criteria. However, the possible variation of the most restrictive classification criterion, i.e. from radiance to irradiance, should be considered in case of radiance-based classification of the incorporated lamp.

5.3.4 Determination of the hazard distance

In order to be independent of the use condition, the risk group classification of lamps and lamp systems is based on worst case assumptions of exposure duration, pupil size and viewing distance. However, the emission of lamps is often divergent and the viewer-related risk at a reasonable distance may not be adequately reflected by the risk classification of the equipment, i.e. the real risk is lower.

The exposure hazard values (EHV), i.e. the excess over the applicable exposure limits, have significant practical relevance (see 3.2). This concept can be helpful when considering appropriate control measures: to limit either the exposure duration or the accessibility of a source as applicable.

The EHV may be graphically presented as distance-dependent values: with increasing distance from a lamp or lamp system the applicable hazard values decrease - see Figure 1. At the distance X_1, EHV = 1, i.e. the EHV equals the applicable emission limit value. Distance X_1 is the hazard distance (HD) for this lamp system. At distance X_2, the optical radiation hazard value exceeds the applicable emission limit value by a factor of A. At this distance, excessive exposure to optical radiation may be reduced either by restricting exposure time by a factor of A (if the emission limit values are expressed in terms of radiant exposure or time integrated radiance), or by using engineering controls (such as filters) which attenuate the accessible emission and/or personal protective means (such as eyewear, clothing) which would limit the potential exposure to the emitted energy.

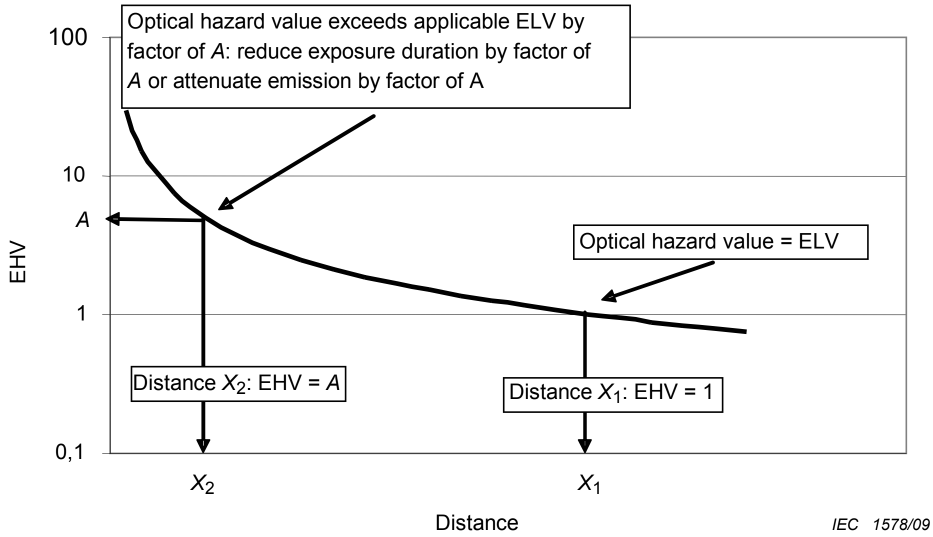


Figure 1 – Example of graphic presentation of distant dependent emission hazard values

Similar to the risk group allocation of the lamp or lamp system, these hazard distance values can also be categorized in order to determine the effective viewer-related risk (3.19) under realistic use conditions. For instance, with increasing distance from a Risk Group 3 lamp system (as categorised at a measurement distance of 200 mm) the risk for the viewer stepwise decreases from Risk Group 2 (e.g. at X_2 in Figure 1) to Risk Group 1 and to Exempt (e.g. at X_1 in Figure 1), at the distances where the irradiance, or from where the measured radiance, falls below the applicable risk-group-specific emission limit.

Therefore, in addition to assigning a lamp system to a risk group, the lamp system manufacturer should also provide such data. Where the lamp system is assigned to a risk group above Exempt, the manufacturer should, at least, provide the hazard distance (HD) for all risk groups below the assigned one. These risk group-related hazard distances can be used for the determination of applicable safety measures, see Table 3.

NOTE The above example and Figure 1 apply to one limit ("hazard") and to a specific exposure duration. Similar data are needed for all relevant limits ("hazards") as well as for different exposure durations.

5.4 Labelling

Usually, primary engineering control measures need to be used by the manufacturer to make the product "safe by design". Specific details depend upon the application and should be specified in application-specific vertical standards. To provide a common approach across applications, this technical report specifies the labelling requirements as a main part of the secondary (administrative) control measures. Lamp systems should be marked by the manufacturer in accordance with the requirements of Table 1.

The following guidance is given for products not covered by existing application-specific vertical standards. Except for an Exempt Risk Group and a Risk Group 1 lamp system emitting only in the wavelength range 400 nm to 780 nm, the risk group should be marked on the product. If the size or design of the product makes labelling impractical, the label should be included in the packaging and included in the user manual. Warning symbols should be in accordance with IEC 60417-1.

Labels on the housing should be permanently fixed, legible, and clearly visible during maintenance and service. They should be positioned so that they can be read without the necessity for human exposure to optical radiation in excess of the applicable ELVs. Text and borders should be black on a yellow background. The label size should be adapted to the size of the product. Reproductions of all required labels should be included in the user manual.

Table 1 – Hazard-related risk group labelling of lamp systems

Hazard	Exempt Risk Group	Risk Group 1	Risk Group 2	Risk Group 3
Ultraviolet hazard 200 nm to 400 nm	Not required	NOTICE UV emitted from this product	CAUTION UV emitted from this product.	WARNING UV emitted from this product.
Retinal blue light hazard 300 nm to 400 nm	Not required	Not required	CAUTION Possibly hazardous optical radiation emitted from this product	WARNING Possibly hazardous optical radiation emitted from this product
Retinal blue light or thermal hazard 400 nm to 780 nm	Not required	Not required	CAUTION Possibly hazardous optical radiation emitted from this product	WARNING Possibly hazardous optical radiation emitted from this product
Cornea/lens infrared hazard 780 nm to 3 000 nm	Not required	NOTICE IR emitted from this product	CAUTION IR emitted from this product	WARNING IR emitted from this product.
Retinal thermal hazard, weak visual stimulus 780 nm to 1 400 nm	Not required	WARNING IR emitted from this product	WARNING IR emitted from this product.	WARNING IR emitted from this product.

5.5 Other information provisions

For lamps and lamp systems in excess of the Exempt Risk Group the following information should be provided in the user information:

a) a clear statement that the lamp or lamp system is in excess of the Exempt Group and that the viewer-related risk is dependent upon how the users install and use the product;

b) the most restrictive optical radiation hazard and other optical radiation hazards in excess of Exempt Group (see Table 1);

c) exposure hazard values (EHVs) and the hazard distances with optional graphical presentation of distant-dependent EHV;

d) Hazard distances (HD) for all relevant viewer-related risk groups below the assigned one (for relevance see Tables 1 and 2);

e) adequate instructions for proper assembly, installation, maintenance and safe use, including clear warnings concerning precautions to avoid possible exposure to hazardous optical radiation;

f) advice on safe operating procedures and warnings concerning reasonably foreseeable malpractices, malfunctions and hazardous failure modes. Where maintenance procedures are detailed, they should, wherever possible, include explicit instructions on safe procedures to be followed;

g) reproduction of the labelling required in 5.4 and an explanation of its meaning shown in Table 2; and

h) information on what type of user controls may be considered.

NOTE The information required may be subject to national legislation.

Table 2 – Explanation of labelling information and guidance on control measures

Hazard	Exempt Risk Group	Risk Group 1	Risk Group 2	Risk Group 3
Ultraviolet hazard 200 nm to 400 nm	Not required	Minimise exposure to eyes or skin. Use appropriate shielding.	Eye or skin irritation may result from exposure. Use appropriate shielding.	Avoid eye and skin exposure to unshielded product.
Retinal blue light hazard 300 nm to 400 nm	Not required	Not required	Do not stare at operating lamp. May be harmful to the eyes.	Do not look at operating lamp. Eye injury may result.
Retinal blue light or thermal hazard 400 nm to 780 nm	Not required	Not required	Do not stare at operating lamp. May be harmful to the eyes.	Do not look at operating lamp. Eye injury may result.
Cornea/lens infrared hazard 780 nm to 3 000 nm	Not required	Use appropriate shielding or eye protection.	Avoid eye exposure. Use appropriate shielding or eye protection.	Avoid eye exposure. Use appropriate shielding or eye protection.
Retinal thermal hazard, weak visual stimulus 780 nm to 1400 nm	Not required	Do not stare at operating lamp.	Do not stare at operating lamp.	Do not look at operating lamp.

When a lamp or lamp system emits optical radiation in more than one hazard spectral region, the lamp or lamp system should be classified for the most restrictive case. If the optical radiation in any spectral region exceeds the limits for the Exempt Risk Group, appropriate warnings should be included on the product label. For example, for a lamp assigned to Risk Group 3 on the basis of a retinal IR hazard and emitting UV to the level of Risk Group 2, the legend of the label should indicate Risk Group 3, with the appropriate 'Warning' text; and show the 'Caution' text for Risk Group 2 for the UV, but should not mention Risk Group 2 explicitly, as illustrated in Figure 2.

RISK GROUP 3

WARNING IR emitted from this product. Do not look at operating lamp

CAUTION UV emitted from this product. Eye or skin irritation may result from exposure. Use appropriate shielding.

IEC 1579/09

Figure 2 – Example of warning label for a lamp with multiple hazard spectral regions

6 Allocation of safety measures

6.1 General

The manufacturer of the lamp or lamp system should perform a risk analysis to determine necessary safety measures and residual risks for the user, necessary warnings and proposed user safety precautions. The risk group classification assists the manufacturer in the design of engineering controls to achieve an acceptable level of safety of the lamps and lamp systems. The type of product and its intended use determines an acceptable level of emission, foreseeable exposure duration and foreseeable accessible distances.

Exposure to optical radiation should be reduced by controlling unwanted radiation at the source, e.g. by spectral filtering or by enclosures. Undesired hazardous UV and IR radiation should be avoided where possible, or attenuated by appropriate filters.

NOTE Selective control of unintentional spectral components in the visible spectral range could be more challenging because spectral filtering may cause change to essential colour or intensity of the lamp system.

The manufacturer should provide the user with safety information and should describe the types of user controls that can be considered. Depending on product application, the required control measures may include restricted and controlled access areas.

Examples of interior restricted access areas are:

- equipment cabinets in locked/dedicated rooms,
- locations occupied by service/maintenance personnel, and
- areas requiring equipment such as specialist access towers (e.g., street lighting, stadium lighting, etc.).

Allocation of restricted access areas is product-specific and should be addressed by product vertical standards.

Examples of controlled access areas include locked rooms with strictly-controlled access, fenced/secure areas, and interior areas of equipment requiring specialised tools or keys for access. Specification of controlled access areas is product-specific and should be addressed by product vertical standards.

In general, the requirements for training, restricting access to a hazard zone, and requiring personal protective equipment can only be considered for professional use products used under work place conditions and if other controls are inadequate or impractical. The safety of specific product types should be addressed in corresponding vertical standards.

6.2 Maximum acceptable viewer-related risk

Allocation of a lamp into a particular risk group is based on the assessment of lamp emission at a distance of 200 mm and the applicable risk group exposure duration. However, when a lamp is integrated into a product, depending on product design and its application, these assessment conditions may become non-representative. In this case, the product may be assessed at the minimum distance and maximum exposure duration representative for the application-specific conditions of foreseeable access (viewer-related risk).

The applications can be divided into three groups, according to the likelihood of intra-beam viewing of the source:

- Unintentional short term (automotive, spot, flash, projection);
- Intermittent, occasional (or possible) short-term (many toys, where the normal attention span of a child is short, laboratory equipment, home, signalling);
- Intentional (or likely) long-term (displays).

When a product is assessed under application-specific conditions, this viewer-related risk group classification may differ from the risk group of the lamp incorporated into the product. Table 3 provides guidance on the maximum permissible risk group of products accessible under application-specific conditions.

Thus, if a Risk Group 3 lamp is incorporated into a display (intentional long-term exposure), it is only acceptable if the viewer-related risk group of the display is Exempt.

If a Risk Group 3 lamp is incorporated into signalling equipment (intentional short-term exposure), it is only acceptable if the viewer-related Risk Group of the signalling equipment is maximum Risk Group 1 – foreseeable exposure is controlled by access distance and/or maximum exposure time.

If a Risk Group 3 lamp is incorporated into car headlights (unintentional short-term exposure), it is only acceptable if the viewer-related risk group of the headlights is a maximum of Risk Group 2 – foreseeable exposure is controlled by minimum access distance.

Table 3 – Maximum acceptable risk group of products assessed for viewer-related risk under application specific conditions

Risk group of the lamp system	**Risk group assessed under application specific conditions – viewer-related risk**		
	Unintentional short term	**Intentional short-term**	**Intentional (or likely) long-term**
Exempt Group	Exempt Risk Group	Exempt Risk Group	Exempt Risk Group
Risk Group 1	Risk Group 1	Risk Group 1	Exempt Risk Group – exposure limited by access distance or by controlled access
Risk Group 2	Risk Group 2	Risk Group 1 – exposure limited by access distance or/and exposure duration or product used in restricted location	Exempt Risk Group – exposure limited by access distance or by controlled access
Risk Group 3	Risk Group 2 – exposure limited by access distance or product used in restricted location	Risk Group 1 – exposure limited by access distance or/and exposure duration or product used in restricted location	Exempt Risk Group – exposure limited by access distance or by controlled access

Table 3 is for guidance. Application-related vertical standards may provide more details of the required assessment and specify safety control measures which may need to be considered.

Classification under application specific conditions is applicable only for the intended use of the product. The safety measures for servicing and maintenance personnel should be based on the risk group of the incorporated lamp and should not depend on the application of the lamp system.

Annex A
(informative)

Radiance and ocular hazards from extended sources

A.1 General

For extended sources which emit optical radiation in the retinal hazard region of the spectrum (400 nm to 1 400 nm), the concept of radiance is useful for describing sources and for managing the radiometric calculations involved in demonstrating the presence – or absence – of a retinal hazard.

Before discussing the usefulness of radiance, it is worth identifying source types and exposure situations for which radiance is unlikely to be helpful. Point sources have an undefined radiance, thus intrabeam viewing of lasers and any viewing of sources subtending a visual angle of 1,7 mrad or less is better served by the measurement and discussion of other radiometric quantities such as irradiance at a defined distance. If the source in question could be observed by magnifying optics, the possibility that the source subtense may increase above 1,7 mrad and, thus, become an extended source should be considered. However, in such cases a holistic treatment of the hazard from the source may still be better served by continuing with irradiance-type units to cover both point- and extended-source treatment of the same source.

Sources whose spectral output represents a hazard outside the retinal hazard region are poorly served by radiance characterization. Irradiance or radiant exposure is usually of more use with such sources. Conversion between measurement geometries is cumbersome and carries the potential for the introduction of errors. Thus, as a general rule, radiance is of use only in assessment of visible and near infrared sources. Luminance is the photometric analogue of radiance for visible light sources, and therefore IEC 62471 includes an upper luminance value as a guide to identifying lamp sources in the Exempt Risk Group.

A.2 Geometry of radiance

An assumed ‘geometry’ relating source to observer is used with radiance and its photometric analogue, luminance. This turns out to have very useful properties, both for hazard analysis and in photometry. Luminance is frequently used to describe the ‘brightness’ of emitting surfaces such as displays; for the same reasons, radiance can be used to define the hazard from emitting surfaces. Radiance is expressed in terms of power divided by area per solid angle ($W \cdot m^{-2} \cdot sr^{-1}$). One of the main consequences of radiance geometry, e.g. that of invariance with distance from an extended source, is shown in Figure A.1. As the observer or detector moves further away from the extended source, inverse square losses are compensated by an increase in the source area sampled.

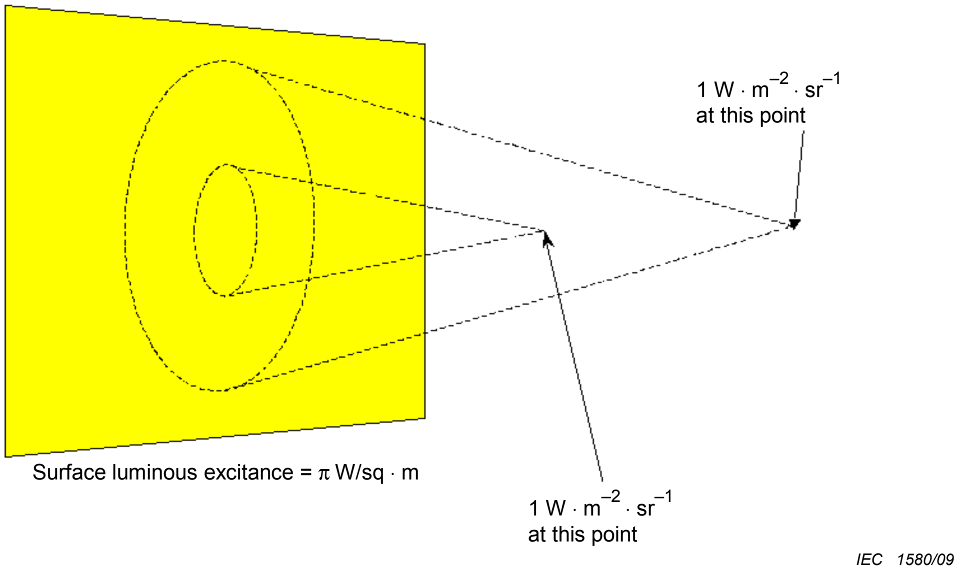


Figure A.1 – Invariance of radiance with distance from an extended source

Similar arguments can be used to show that radiance is conserved (subject to losses due to absorption), when refractive or reflective magnifying or minifying optics are interposed between an extended source and an observer. In other words, although the magnifying or minifying optics may change the apparent visual angle of the source, they also change the apparent light power per unit area to compensate, thus radiance is only affected by absorption in the optics and exit pupil coupling issues.

A.3 Relationship between retinal thresholds and source parameters

In experimental threshold determinations, retinal damage thresholds are usually measured in terms of irradiance at the retina, i.e. in $W \cdot m^{-2}$. Comparing the properties of sources to retinal damage thresholds would involve complicated irradiance transformations and, in the case of extended sources, lead to distance-dependent considerations. Re-expressing retinal thresholds in units of radiance means that treatment of the optics of the eye, plus any intervening optics, in hazard evaluation is greatly simplified.

A.4 Limitations to the use of radiance in hazard evaluation

Some limitations on the use of radiance to characterise light sources have already been mentioned in Clause A.1 above.

Additionally, and of relevance to the lamp and lighting industry, measurement of radiance in order to characterise a source can be difficult for certain encapsulated or enclosed sources. The problem usually arises in defining the area of the source; the "m^{-2}" component of the units of radiance $W \cdot m^{-2} \cdot sr^{-1}$. Whilst measurement of radiant flux is usually straightforward and definition of source solid angle presents only moderate challenges; measurement of source area, or the area sampled by measuring instruments, can be extremely difficult. One possible solution is to define both solid angle and area at a real or virtual image of the source in an optical system, if one exists. Provided both solid angle and area are measured in the same plane, the validity of this follows from the "conservation of radiance" principle. However, those making the measurements must avoid falling into the trap of defining source area in one plane and solid angle in another.

A.5 Non-uniform sources

Measurements of the radiance of sources where the local radiant emission varies (i.e. non-uniform sources) should be integrated over the solid angles specified in IEC 62471. This ensures that the measured radiance is compared correctly with experimental retinal damage thresholds, taking into account eye movements and ocular aberrations.

A.6 Relationship between source radiance and spatially averaged radiance

The exposure limit values provided in radiance or time-integrated radiance respectively may lead to the assumption that by the principle of conservation of radiance, if a lamp emits below the radiance level specified (for a given risk group), the final luminaire can also not exceed the accessible emission limits. Therefore, in order to avoid repeated measurements, lamp manufacturers are requested to characterize the safety features of their devices (single lamps) and to provide related risk group allocations.

Usually, the radiance L ($W \cdot m^{-2} \cdot sr^{-1}$) is determined (see, for example, Figure A.2) by measuring the radiant power P (W) passing through a defined measurement aperture stop at a defined measurement distance r. The diameter d of the aperture defines the solid collection angle Ω (sr) and the measurement area A_{FOV} (herein defined as the area under the "field of view", FOV (m^2)) corresponds to the acceptance angle γ predetermined by the circular field stop in front of the detector. Usually, the source extends beyond the FOV, as shown in Figure A.2 (i.e. $\alpha > \gamma$). The radiance of the source is calculated from the radiant power P passing through the measurement aperture, the measurement area FOV, and the solid angle Ω:

L ($W \cdot m^{-2} \cdot sr^{-1}$) = P [W] / (Ω (sr) × A_{FOV} (m^2))

The time integrated radiance is measured in the same way. However, the measurement of the optical power P is replaced by a measurement of the radiant energy Q.

NOTE 1 Radiance L is by definition a differentially defined term:

$$L_e = \frac{\mathrm{d}\Phi_e}{\mathrm{d}A \cdot cos\,\theta \cdot \mathrm{d}\Omega} .$$

Therefore, it should be noted that the term FOV used above and the solid angle are already integrated magnitudes and that the above given formula for the power is already an integrated value (see IEV 845-01-34).

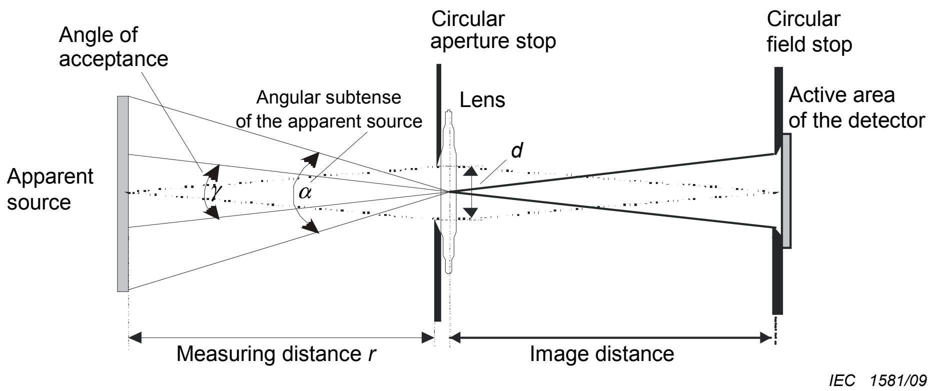
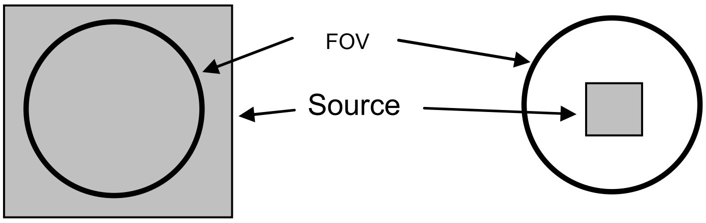


Figure A.2 – Usual measurement conditions for the determination of radiance and time integrated radiance

IEC 62471 requires the measurement of a spatially averaged radiance that takes into account physical movements and imaging properties of the eye. Measurements carried out in this way give a different result to conventional measurements of radiance, but the result is more representative of the ocular hazard from the source. Measurement of spatially averaged radiance requires a specified angle of acceptance γ which depends strongly on the exposure duration. Thus, the corresponding FOV of the measurement setup may be smaller than the source (overfilled, see Figure A.3a), or larger than the source (under-filled, Figure A.3b), depending on the individual source size and the applied exposure duration determined by the risk group. This is very different from conventional radiance measurements, where the source must always extend beyond the measurement area. Regardless of the real source size, the radiance limits are related to the FOV-defined area.



IEC 1582/09

IEC 1583/09

Figure A.3a – Source size larger than the FOV (overfilled)

Figure A.3b – Source size smaller than the FOV (under-filled)

Figure A.3 – Source sizes

Conservation of radiance can be applied if the extent of the single source with angular subtense α is larger than the applicable angle of acceptance (and the "true" source radiance, see Figure A.3a). If the source extent is smaller than the FOV, a safety statement based on the conservation of radiance is valid only as long as the relationship between the field of view and the source area remains unchanged. This relationship is likely to be changed by the integration of the single lamp or LED into luminaries (arrays) or with magnifying optics (see Annex D).

NOTE 2 Conservation of radiance for sources subtending an angle larger than the FOV assumes that the source is uniform, i.e. the source radiance is constant across the source. If the source is non-uniform then the FOV should be scanned around the source to determine the worst case.

Specifically, in the case of devices assigned to the Exempt Risk Group and for the most restrictive blue light hazards, the angle of acceptance is maximum at 100 mrad. From the worst case assessment distance of 200 mm, the corresponding diameter of the averaging FOV of 100 mrad amounts to 20 mm. The dimensions of LED-chips, single LEDs or common lamp-filaments are usually smaller. Complying with the Exempt Risk Group limit value using the spatially-averaged radiance, it means that the "true" radiance of the small component can theoretically be higher by the factor: $(\gamma/\alpha)^2$. Therefore, this Exempt Risk Group limit value can be exceeded, if a number of such components are combined in a lamp system, e.g. in high-density LED-arrays.

Another case is the attachment of beam-shaping optics to the component. In this case, a small apparent source is usually magnified or expanded (see Annex D) and may overfill the FOV; whereas, the "true" source radiance remains, to a first approximation, unchanged and high.

In general, an Exempt Risk Group source that is safe for 10 000 s exposure duration should also be safe at shorter exposures or viewing durations, i.e. it should satisfy the Risk Group 1 and Risk Group 2 criteria. Thus, at least for components, it is not appropriate to adhere rigidly to the classification requirements of the lamp safety standard.

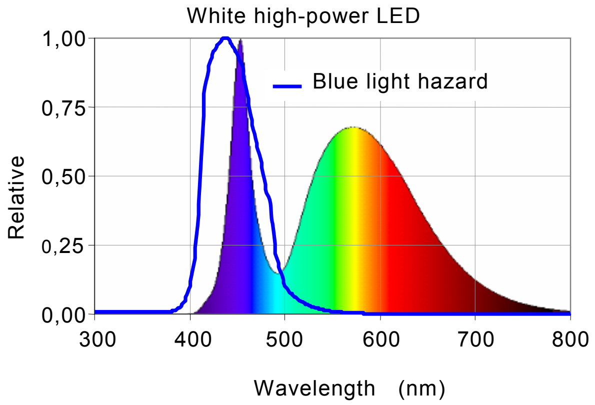
NOTE 3 The FOV is dependent on the risk group, which could mean that a component meets the requirements for the Exempt Risk Group, but not the requirements for Risk Groups 1 and 2. In these situations, allocation to the Exempt Risk Group may be justified.

The lamp or LED manufacturer should determine the “true” source radiance for comparison with the limit values and classification, where a minimum angle of acceptance of 1,7 mrad should be applied.

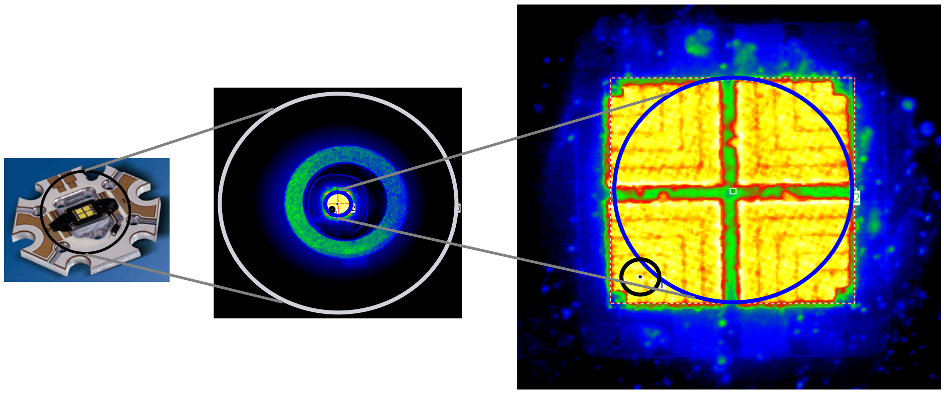
In cases of large sources, where the FOVs are always over-filled (Figure A.3a), the resulting radiance values should be independent of the FOV.

In the case of small sources (Figure A.3b), the worst case scenario for a component is transferable and useful for the classification of the final lamp system. However, this assessment might be over-restrictive for the final product/lamp system/luminaire and in such cases the manufacturer should consider assessing the product with different FOVs.

Figure A.4 shows an example of a “pc-white” LED component, where the B(λ)-weighted radiance was measured with an imaging radiance-meter.



γ_{FOV} [mrad]	Measured [$W \cdot m^{-2} \cdot sr^{-1}$]	Limit [$W \cdot m^{-2} \cdot sr^{-1}$]
100 (Exempt Risk Group)	250	100
11 (Risk Group 1)	$7,5 \times 10^3$	1×10^4
1,7 (Risk Group 2)	$1,1 \times 10^4$	4×10^6



γ_{FOV}: 100 and 11 mrad 1,7 and 11 mrad

IEC 1584/09

Measurement with three applicable FOVs from a distance of 200 mm (i.e. future application unknown).

Source: W. Halbritter e.a. Proc. CIE Expert Symposium 2008 on Advances in Photometry and Colorimetry

Figure A.4 – B(λ)-weighted radiance distribution of a state-of-the-art “pc-white” LED component

According to the risk group specifications, three angles of acceptance were applied to one and the same device. The table in Figure A.4 shows the measured radiance values for each γ_{FOV}, as well as the applicable limits.

As discussed above, if the device was assessed as a component for future integration into complex systems and the angle of acceptance of 1,7 mrad was applied, it should be allocated to Risk Group 2 since the limit for Risk Group 1 (1×10^4 W·m^{-2}·sr^{-1}) is exceeded under this condition. This presents a worst case classification on the very conservative side and the lamp system manufacturer cannot increase this class in any case.

However, if this device was considered as the final product and if the risk group allocation was too restrictive (since the final product possibly already incorporates some safety measures), a full analysis according to IEC 62471 should be performed. In this case, the final product would be allocated to Risk Group 1, since when measured with the appropriate FOVs, the B(λ)-weighted radiance exceeds the Exempt Risk Group limits only.

Annex B
(informative)

Determination of hazard distances

B.1 General

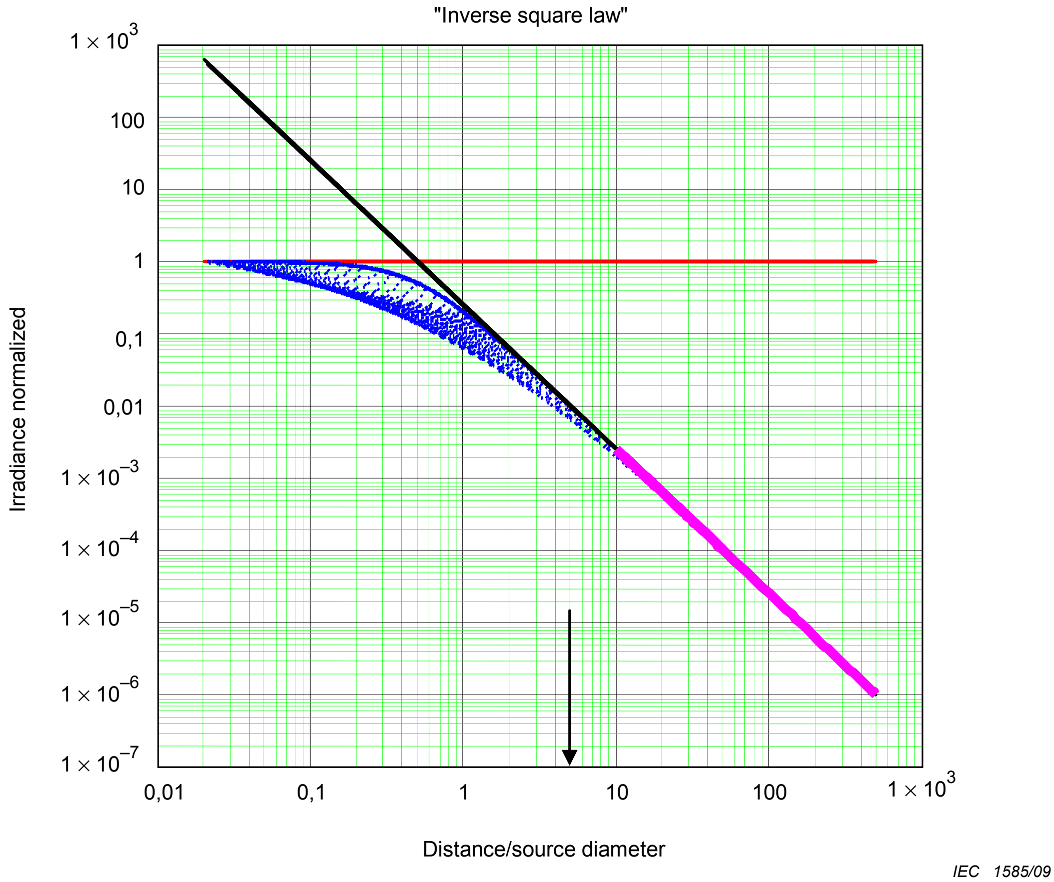
Generally, in order to be independent of the use condition, the classification of optical sources into risk groups is usually based on some worst case assumptions, e.g. for exposure duration, pupil size and viewing distance. Thus, the required measurement distance in the lamp safety standard is usually 200 mm, which corresponds to a reasonable minimum viewing distance for humans. However, the spatial emission of lamps is often divergent and the real hazard for the intended or accidental viewer at a reasonable distance might not be appropriately reflected by the worst case classification of the lamp. Therefore, the value of a minimum safe viewing distance (HD) of a lamp system becomes important. In this context, the HD is defined as the distance from the source at which the measured value of the source emission equals the appropriate accessible exposure limit value (ELV). As the ELVs are provided for different risk groups, the corresponding hazard distances can be determined for each risk group as well in order to determine the risk for intended/accidental viewers. The rough guidance for the development of vertical application-related standards in Clause 6 is essentially based on this concept. Thus, it depends on the application (e.g. the likelihood of direct source viewing), which viewer-related risk (respective HD) is acceptable in particular cases (see Table 3 of the technical report). The corresponding HD can be used for the allocation of appropriate safety measures, for example, by prevention of access to shorter distances to the source.

The limit values of IEC 62471 are provided in two different terms which require separate consideration. For the limits provided as irradiances (outside the retinal hazard region) an inverse square relationship between the measured value and the source distance can be assumed for first approximations. This is not generally applicable to the retina limits that are provided as time integrated source radiance because the resulting radiance values should not vary when measured from different distances.

B.2 Limits provided in irradiance

B.2.1 General relationships

Outside the retinal hazard wavelength range (400 nm to 1 400 nm) the ELV of the lamp safety standard are provided as irradiance (in $W \cdot m^{-2}$). For these irradiance limits, the fundamental inverse square law of radiometry may be used to determine a safe viewing distance. However, it can only be applied to divergent source in the far-field, where the size of the source is small compared to the assessment distance. As a "rule of thumb", the distance to the source should be greater than five times the dimension of the source. The general relationships between a given source radiance and the corresponding irradiance by the source at several distances and for different source dimensions are shown in Figure B.1



Key

x-axis: relation between distances and source diameter i.e. ~1/α.

Blue: general relationship between *L* and *E* (for a wide range of source sizes and distances – hence the large number of “blue lines”).

Red: “radiance conservation” (*E* is proportional to *L*).

Black: inverse square law (*E* is proportional to L/r^2).

Magenta: corresponding range of angular subtense under consideration.

Figure B.1 – Normalized correlation between radiance *L* and corresponding irradiance *E* for varying values of source diameter and distance

As indicated in Figure B.1 (arrow), the deviation between the rigorous relationship between *L* and *E* (blue line) and the (simple) inverse square relation (black) is less than 1% if the relationship between source distance and source diameter (x-axis) is greater than 5. The magenta line, which indicates the corresponding range of angular subtenses under consideration (between α_{min} and α_{max}) shows that for hazard assessments according to IEC 62471, far-field-conditions generally apply. Thus, the fundamental inverse square law of radiometry and photometry may be used to determine the hazard distance (HD).

In such cases, between the irradiance E_1 at a source distance r_1 and the irradiance E_2 at source distance r_2, the following relationship holds:

$$E_1 r_1^2 = E_2 r_2^2$$

It means that if the spectrally weighted irradiance-ELV is exceeded by a value E_1 at the measurement distance r_1, the corresponding HD r_2 can be calculated as:

$$HD = \sqrt{\frac{E_1 \cdot r_1^2}{ELV}}$$

Therefore, if r_1 = 200 mm:

$$HD = \sqrt{\frac{E_1 \cdot 0{,}04}{ELV}} \text{, in m}$$

The irradiance-ELV in the above equation can be calculated for each risk group.

B.2.2 Impact of beam-shaping optics

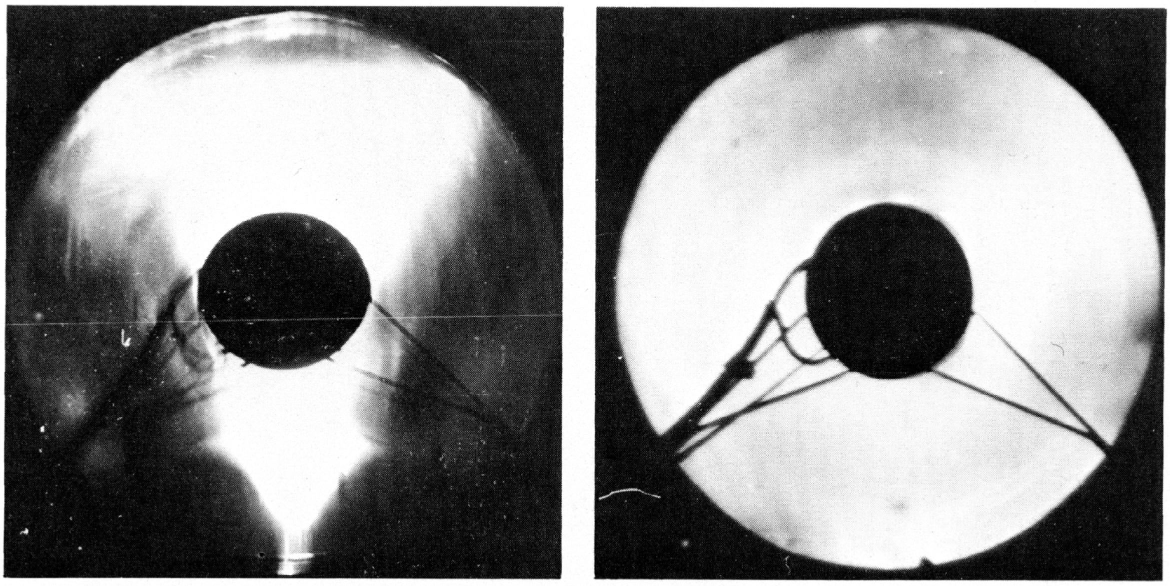
B.2.2.1 Lamps with projection systems

Generally, care should be taken when considering sources with beam-shaping optics, see Annex D. Although the general relationships in Figure B.1 remain valid, in such cases the source may be magnified, see Figure B.2 (whereas, the irradiance increases). That means that the linear relationship between radiance *L* and irradiance *E* (red line) extends to the greater source distances and 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:

$$r_f \approx a \times f / D$$

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



IEC 1586/09

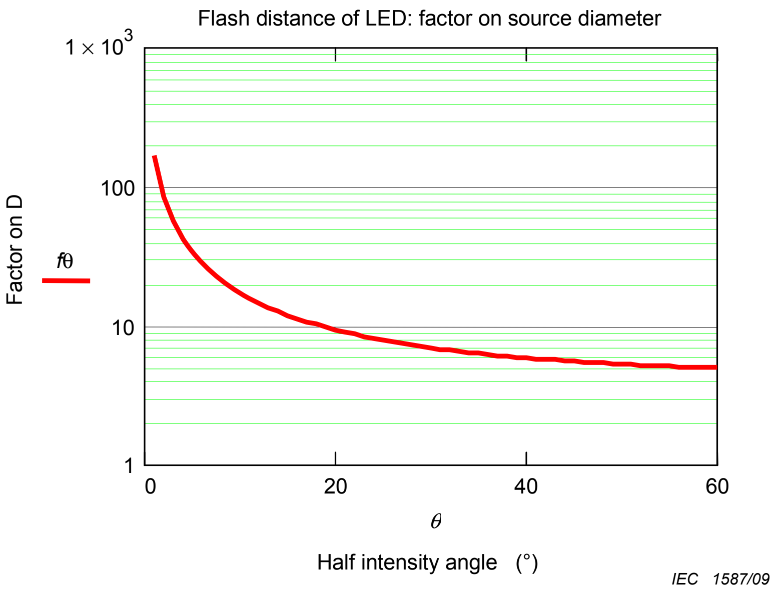
At relatively close viewing distances the triangular shape of the arc is visible, but at longer distances the reflector optic is fully "flashed" (filled) and the beam irradiance drops in proportion to the inverse square of the distance. (Source: Sliney and Wolbarsht, Safety with Lasers and Other Optical Sources, New York, Plenum, 1980).

Figure B.2 – Direct intra-beam viewing of an arc searchlight showing a magnification of the actual arc

B.2.2.2 Plastic encapsulated LEDs with integrated optics

For the more or less directional radiation of LEDs the flash distance may amount to up to 60 times the diameter of the source depending on the half intensity angle (θ) of the spatial emission distribution.

For ideal Lambertian cosine-distributed LED chips the "rule of thumb" also holds: the distance to the source should be greater than five times the dimension of the source. However, the factor f on the source dimension increases if the emission of the encapsulated LED is directed by means of reflectors or lenses depending on the half intensity angle (available from data sheets). This can be calculated and Figure B.3 shows the range of factors on source diameter, D, depending on the half intensity angle of LEDs.



y-axis: factors on the source diameter D.

Figure B.3 – Calculated flash distance of LEDs depending on the individual half intensity angle θ of the spatial emission

As shown in Figure B.3, for an ideal Lambertian source with θ = 60° the factor *f* amounts to 5, as for the above mentioned "rule of thumb".

Example: For $\theta = 5°$, $f \geq 34$; thus, for a source of diameter D = 10 mm the minimum distance r_f from where the inverse square law applies amounts to 340 mm, which is larger than the standard measurement distance of 200 mm.

If the flash distance is larger than the measurement distance, the hazard distance HD can be calculated using the above equation by replacing r_1 with r_f of the applicable "flash distance".

B.2.3 Example: Graphical representation of the maximum allowable exposure duration versus the minimum safety distance for the derivation of safety measures

Following IEC 62471, the exposure limit value (ELV) for the actinic UV hazard is 30 J·m^{-2} , or in irradiance, $ELV(t)$ = 30/t W·m^{-2}, where t is the exposure duration in seconds.

This leads to the risk group-related irradiance limits (ELV in W·m^{-2}):

Exempt Risk Group (t = 30 000 s):	ELV_{Ex} = 0,001 W·m^{-2}
Risk Group 1 (t = 10 000 s):	ELV_{RG1} = 0,003 W·m^{-2}
Risk Group 2 (t = 1 000 s):	ELV_{RG2} = 0,03 W·m^{-2}

For UV hazard, spectral weighting with the S(λ)- function is required. This weighting is usually applied after a spectrally-resolved measurement. Inversely, it is also possible to calculate related source spectra-specific limit values by weighting the spectra with the action functions. These values correspond to integrating, i.e. spectrally unresolved, measurements.

Consider an example source of a Planckian radiator with a colour-temperature of 5 800 K. After weighting with the action function S(λ), the source-specific applicable limit values for the actinic UV-hazard changes from 30 J·m^{-2} (effective) to 250 J·m^{-2} (unweighted). Therefore, for this example:

Exempt Risk Group (t = 30 000 s): ELV_{Ex} = 0,008 W·m^{-2}

Risk Group 1 (t = 10 000 s): ELV_{RG1} = 0,025 W·m^{-2}

Risk Group 2 (t = 1 000 s): ELV_{RG2} = 0,25 W·m^{-2}

For this example, the irradiance measurement within the corresponding wavelength range 200 nm to 400 nm at a distance r_1 = 200 mm resulted in E_S = 10 W·m^{-2} (Risk Group 3).

The minimum safe viewing distance (HD) for this irradiance can be calculated:

$$HD = \sqrt{\frac{E_1 \cdot 0{,}04}{ELV}}$$

which leads to the following distances for each Risk Group:

Exempt Risk Group: HD_{Ex} = 7 m

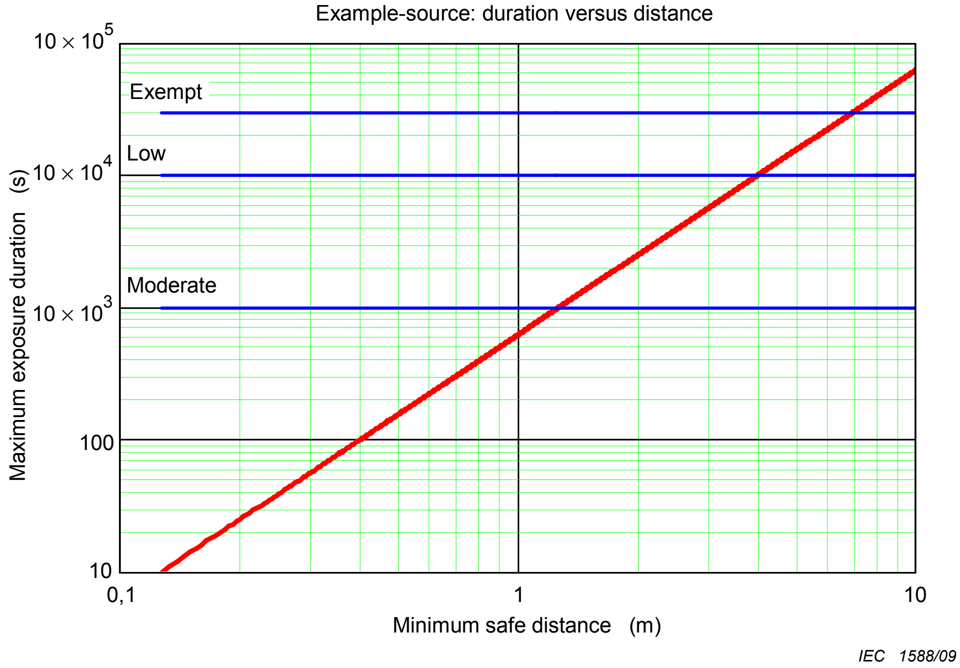
Risk Group 1: HD_{RG1} = 4 m

Risk Group 2: HD_{RG2} = 1,3 m

A similar calculation can be performed more generally with the time-dependent ELV:

$$HD(t) = \sqrt{\frac{E_1 \cdot 0{,}04}{ELV(t)}} \; .$$

With this calculation, a simple graphical presentation of the maximum allowable exposure duration versus the HD is possible (Figure B.4):



These represent safe use conditions as long as the parameter-combinations for the exposure duration and the HD are below the red line. As indicated in the figure, the appropriate safety parameter set might also be chosen risk group-specific.

Figure B.4 – Actinic UV-related safe use conditions for the example radiator

The applicable HD depends on the viewer-related risk group, which depends on the application of the lamp system (the likelihood for direct source viewing). If, for example, the lamp system is used for signalling (occasional viewing), then the maximum risk group for the intended viewer is Risk Group 1 (see Table 3). However, this classification depends upon how the users install and use the product. In any case, the conditions for the appropriate risk group have to be assured by control measures (e.g. appropriate installation location) to prevent the access for the intended viewers closer than the Risk Group 1 hazard of 4 m.

In some cases, as indicated in Figure B.4, there would be another possibility. In the example of actinic UV-hazard, the time base for Risk Group 1 is 10 000 s. If it is likely that the duration of exposure or direct viewing in practice is shorter (e.g. due to a limited switch-on time of an information board), the HD can be reduced accordingly. Generally, long-term direct viewing of a signal or information board is not realistic and the duration is limited to the time necessary for taking the information. For such an approach, graphical presentation of the HD versus the exposure duration is helpful. If, for instance, the likely maximum viewing duration in this example would be limited to 100 s, the corresponding HD would amount to 40 cm. However, possibilities depend on the dominating (most restrictive) hazard and the related time bases. Greater details may be provided in application-related vertical standards.

B.3 Limits provided in time integrated radiance

B.3.1 General relationships

Within the wavelength range 380 nm to 1 400 nm, the exposure limit values are provided in terms of radiance (in $W{\cdot}m^{-2}{\cdot}sr^{-1}$). Thus, the retinal exposure depends linearly on the source radiance.

As mentioned above, unlike the irradiance, the measured radiance values should, in first order, not vary when measured from different source distances.

However, the main and distinguishing feature of IEC 62471, compared with usual optical classification methods, is that IEC 62471 considers spatially averaged radiances instead of the “true” source radiance (see Annex A of this technical report). Independent from the actual angular subtense of a source, the measurement is averaged over a specific defined acceptance angle γ and the limit applies to the correspondingly determined area in the source-plane. Thus, while the assessment distance increases up to the location of the HD position, the acceptance angle has to remain constant (independent of the source distance), whereas the angular subtense α of the source decreases. In other words, whereas the source area itself remains unchanged the corresponding FOV in the plane of the source increases: i.e. the relationship between source dimension and the averaging FOV changes with the distance. This has no real consequences, as long as the source area remains larger than the applicable FOV.

However, especially for the blue light hazard of the Exempt Risk Group, the maximum applicable acceptance angle is 100 mrad: at 200 mm distance a FOV equivalent to 20 mm source diameter. This is larger than most filaments or single LEDs. From a certain distance, the angular subtense becomes smaller than the angle of acceptance with increasing source distance. At this source specific distance, r_{IS} an inverse square relationship between source and spatially averaged radiance starts. This issue is important for the determination of hazard distances in general, and in the case of GLS sources it is assumed that this may happen for the 500 lux distance (see Annex C). Under such arrangements, for an unchanged source radiance the measured value of the spatially averaged radiance decreases with increasing measurement distance following the relationship $(\gamma/\alpha)^2$. Since the spatially averaged radiance limit is related to the area of the under-filled (see Annex A) FOV which is averaged over an extended and increasing area; whereas the real source dimension remains unchanged.

From a certain distance, the angular subtense becomes smaller than the angle of acceptance with increasing source distance. HD values can also be determined in cases where the retinal hazard limits in terms of radiance are most restrictive. The smaller the source size, the shorter the HD. The measured spatially averaged radiance decreases with increasing distance and at the point where it equals the applicable risk group-specific limit values, the corresponding HD can be determined. It should be noted that each limit value is combined with a specific acceptance angle. The decrease of the measured spatially averaged radiance with increasing distance may be more significant, if the increasing γ with the applicable limit values are taken into account.

If required, the source-specific distance r_{IS}, where the linear relationship between source and spatially averaged radiance breaks down and inverse square relationship starts, can be calculated. Hence, similar to the equation for the irradiance limits, the HD for limiting radiance values can be calculated as:

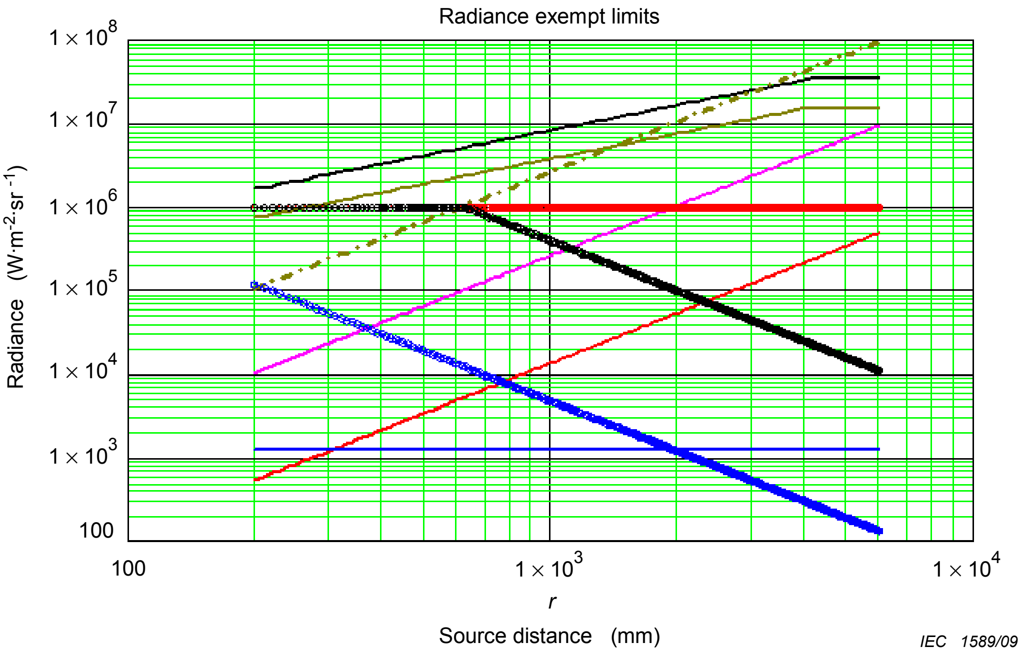
$$HD = \sqrt{\frac{L_{\mathrm{S}} \cdot r_{\mathrm{IS}}^2}{ELV}}$$

Where L_{S} is source radiance, ELV is applicable exposure limit value of the spatially averaged radiance for a given risk group and hazard.

The above relationship is valid as long as the calculated HD is larger than r_{IS}. Hazard distance can be calculated for each risk group. Since γ depends on the risk group, the corresponding value should be applied for the determination of r_{IS}.

B.3.2 Example

Example of blue light hazard radiances and limit values for a pc-white light-emitting LED is shown in Annex C. In cases of sources with more extended spectral emission, other hazards, as well as their possible overlapping or crossing with increasing distances, should be considered when determining hazard distance. It can be challenging, as indicated in a theoretical consideration in Figure B.5. This Figure shows all applicable Exempt Risk Group limit values for a halogen lamp of 7 mm source diameter. In order to make limits comparable in one figure, the irradiance limits (see Clause B.2) were transferred into corresponding radiance limits, which include a dependency on the source size and the distance (see Figure B.1). The radiance limits for retinal thermal hazards became distance dependant due to the decrease of angular subtense with increasing distance, until the angular subtense equals α_{min}, see Figure B.5: the kinks in the brown and black solid lines. For the sake of completeness, the theoretical modelling of the different spatially averaged radiances with the distance as they would be measured according to the Exempt Risk Group requirements are also shown, assuming a source luminance of 3×10^7 cd·m^{-2}.



Key

Blue: blue light hazard

Red: actinic UV hazard

Magenta: UV eye hazard

Brown: retinal thermal hazard at low visual stimulus

Black: retinal thermal hazard

Brown dash-dotted: cornea/lens hazard

Based on a “true” source radiance of 1×10^6 W·m^{-2}·sr^{-1}, the values of the physiological radiance as they would be measured at increasing distances are also shown:

- blue circles: blue light hazard (measured with γ = 100 mrad);
- black circles: retinal thermal hazard (measured with γ = 11 mrad);
- red circles: (unchanged) corresponding radiance for comparison with the limit values that are originally provided in irradiance.

Figure B.5 – Distance-dependant (spectrally weighted) Exempt Risk Group limits for the spatially averaged radiance of a halogen lamp of 7 mm source size

The figure is more complex if the other risk group limits and the different distances (due to the different or not applicable acceptance angles) of the spatially averaged radiances are considered.

A reasonable luminance of a halogen lamp is 3×10^7 $cd \cdot m^{-2}$. Under consideration of the applicable photometric-radiometric conversion factor, this value has been used for the calculation of the corresponding spatially averaged radiance in Figure B.5. The following hazard distances can be calculated, in m:

Table B.1 – Spatially averaged radiance

	Actinic UV	UV eye	Blue light	Retinal thermal	Retinal thermal low visual	Cornea lens
Risk Group 2	0,69	0,27	0,20	0,20	0,20	0,20
Risk Group 1	2,2	0,47	0,78	0,20	0,20	0,20
Exempt Risk Group (see Figure B.5)	3,8	0,85	0,86	0,20	0,20	0,27

In this example the actinic UV-hazard provides the most restrictive criterion, since for each risk group the hazard distance is greater than 200 mm. It should be noted, however, that the hazard that provides the most restrictive classification criterion does not necessarily also provide the greatest hazard distance.

The classification of this halogen lamp would result in Risk Group 3 with the actinic UV as the most restrictive hazard. If the UV emission is filtered out, the remaining most limiting criterion would be the blue light hazard. Based on the hazard distances, the classification in this case results in Risk Group 2. As discussed in Clause 6.2, such halogen lamps are mainly used under conditions of unintentional short term exposure (automotive, spot, flash, projection). As indicated in Table 3, in such cases the maximum acceptable viewer-related risk group should be Risk Group 2 where protection is based on aversion responses. Thus, the example lamp can be used in this application without any additional safety requirements, provided that the UV emission is filtered out. However, as also indicated in Clause 6.2, if the example lamp is used in applications that may require intentional short term exposure (laboratory, home, signalling), the maximum acceptable viewer-related risk group is Risk Group 1. Thus, a minimum accessible viewing distance of 0,78 m should be assured by appropriate control measures. No further restrictions are necessary, if the accessible viewing distance is greater than 0,86 m.

The “Blue light”-based Risk Group allocation will even change to RG 0 (exempt) if this halogen lamp is used exclusively for general lighting purposes (GLS) and the evaluation is performed at a distance that corresponds to an illumination level of 500 lux, see Annex C.

Annex C
(informative)

Sources for general lighting service (GLS)

Although IEC 62471 is primarily a horizontal standard, it provides application-related requirements. Specifically, sources that are exclusively used for general lighting service (GLS) should not be assessed by application of the worst case measurement distance of 200 mm, as is to be applied to all other sources. In these cases, "*…the hazard values shall be reported as either irradiance or radiance values at a distance which produces an illuminance of 500 lux…For all other light sources or lamp systems, including pulsed lamp sources, the hazard values shall be reported at a distance of 200 mm…*" (500 lux is a typical minimum visual task lighting level in offices or at workshop benches).

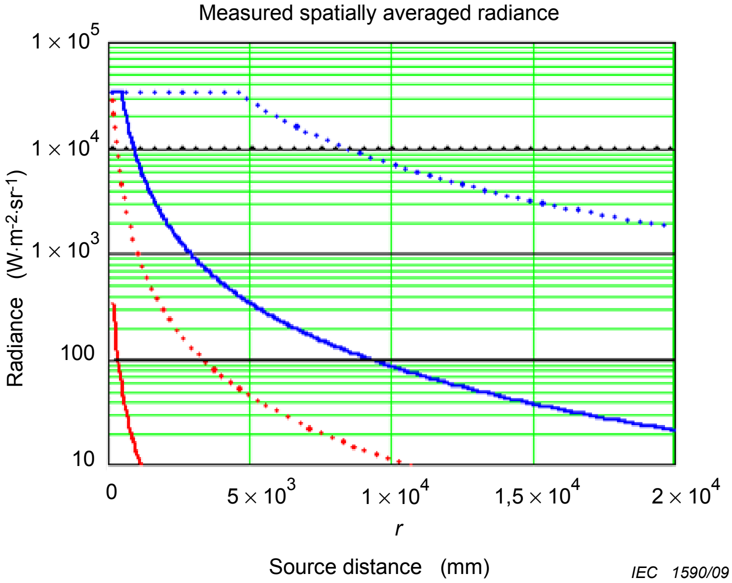
However, in many cases a lamp manufacturer may not know whether a specific lamp will be used for general lighting purposes and the categorisation of single lamps or LEDs should be performed at a distance of 200 mm. The 500 lux requirement is mainly related to the final luminaire. Additionally, the application of this requirement to single lamp is usually not meaningful, since lamps will be combined with other lamps (e.g. in an array) or attached to beam-shaping optics, etc. Thus, the required illuminance measurement of the final GLS-source takes into account contributions of the whole luminaire. Unlike the measurements for risk group classification, the acceptance angle for the illuminance measurement of GLS-sources should not be limited.

Compared with an assessment distance of 200 mm, the most important implication of the extended 500 lux distance is on the irradiance by the source, i.e. there appears to be an advantage in cases where the categorisation is based on irradiance limits. Following the ANSI/IESNA RP-27 Recommended Practice for Photobiological Safety for Lamps & Lamp Systems, the background for the introduction of this criterion was related to the irradiance-expressed UV limits. The irradiance usually decreases with increasing distance, following the inverse square law, whereas the radiance virtually remains unchanged. Therefore, there is no or little advantage of the increased assessment distance if the classification of the incorporated lamp is based on the most restrictive radiance limitations.

IEC 62471 considers spatially averaged radiance instead of the physical radiance (see Annex A). Independent of the angular subtense of a source, for comparison with the exposure limit values, the exposure level is averaged over a specific defined acceptance angle γ and the limit applies to the correspondingly determined field of view (FOV). Thus, while the assessment distance increases until the 500 lux position, this acceptance angle has to remain constant (independent of the source distance), whereas the angular subtense α of the source decreases. From a certain distance, the angular subtense becomes smaller than the angle of acceptance with increasing source distance. At this source-specific distance r_{IS} the inverse square relationship between the source and the spatially averaged radiance starts. This issue is important for the determination of hazard distances (see Annex B) and in case of GLS sources may also happen for the 500 lux distance.

The 500 lux criterion may provide relaxation also in cases where the retinal hazards with radiance limits are most restrictive: the smaller the source size, the greater the relaxation. Another example is shown in Figure C.1: a white-light-emitting LED with two different source sizes, for a single element and for an array. Due to the absence of UV emission, the blue light hazard dominates. The spectrally B(λ)-weighted source radiance at a distance of 200 mm amounts to $3{,}4 \times 10^{4}$ W·m^{-2}·sr^{-1}.

Figure C.1 shows the spatially averaged radiances at greater distances from the source. Two different source sizes are considered in this example: 2 mm (single LED: red lines) and 50 mm (LED-array: blue lines), in order to highlight the dependency of the measured radiance on the source size. The exposure limit values of IEC 62471 are indicated by the black lines: solid for the Exempt Risk Group and dotted for Risk Group 1.



For a given “true” radiance (with classification into Risk Group 2): development of the expected measured averaged (over acceptance angles of 11 mrad: dotted, and 100 mrad: solid lines) values of the spatially averaged radiance with increasing distance from the source of size: 2 mm (red line) and 50 mm (blue).

Figure C.1 – Measured spatially averaged radiance

It should be noted that in this figure two fixed acceptance angles were used applicable to the risk groups and in order to determine the risk group-specific hazard distances (see Annex B). Risk group-related hazard distances are in each case the distances where the dotted or the solid lines cross each other. Since the applicable blue light hazard limits are 100 $W{\cdot}m^{-2}{\cdot}sr^{-1}$ for the Exempt Risk Group and 1×10^4 $W{\cdot}m^{-2}{\cdot}sr^{-1}$ for Risk Group 1, white LED sources are allocated into Risk Group 2 if assessed from the standard measurement distance of 200 mm. The hazard distance calculation leads to the following distances, also shown in Figure C.1:

Table C.1 – Risk group-related inverse square law and hazard distances

Source diameter	**2 mm**		**50 mm**	
	r_{IS}	**HD**	r_{IS}	**HD**
Risk Group 1	0,02	0,34	4,5	8,4
Exempt Risk Group	0,18	0,37	0,5	9,2
The table shows Risk Group-related inverse square law and hazard distances (in m) for the two white LEDs (of equal radiance but different source size) in Figure C.1.				

The hazard distances of the extended LED (array) are large due to the relationship between source area and the FOV-defined area. In this case, the risk classification does not change from Risk Group 1 to the Exempt Risk Group until a distance of more than 8 m from the source. However, the next hazard distance for the Exempt Risk Group is shorter due to the increased FOV (see also Figure C.1). In order to check the implications of the GLS-requirement, the 500-lux distances of these sources can also be calculated. Limited to one single source the general relationship between the illuminance E at a certain source distance r and luminance L (of a circular source) is:

$$E = \pi \cdot L \frac{D^2}{\left(D^2 + 4r^2\right)}$$

where D is source dimension and r is distance between source of integral luminance L and the plane of irradiance E.

After rearrangement, and for E equals to 500 lux, the corresponding 500 lux distances can be calculated with the source size D and the luminance L, as shown in Figure C.2.

For a single source of size D, the distance of 500 lux solely depends on the luminance of the source:

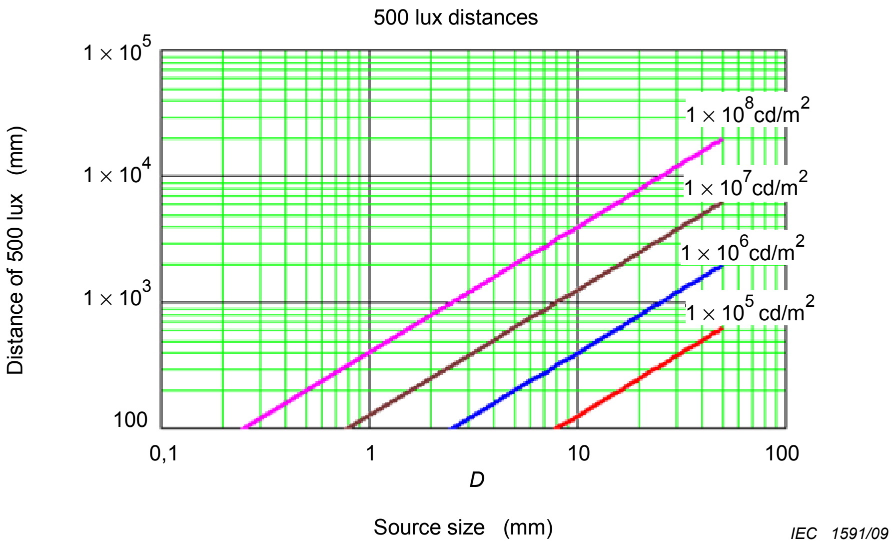


Figure C.2 – Relationships between illuminance of 500 lux and source luminance [cd/m²] (indicated) for several source sizes and distances of some typical luminances

The above general relationships are independent of the source type. Also, the radiance limit values in IEC 62471 are independent of the source type, but are provided in radiometric units. If the radiance limits are applied to the calculation of the 500 lux distances, the source-specific radiometric/photometric conversion factors would have to be applied. The different impact of the GLS criterion on several source types is mainly due to the different radiometric/photometric conversion factors (in $\mathrm{lm \cdot W^{-1}}$) and the spectral effectiveness of the B(λ)-weighting.

With Figure C.2 and the respective formula, and by using an appropriate radiometric/photometric conversion factor for the white LED, the 500 lux distance can be determined for the two sources under consideration:

– 2 mm-source: 0,42 m ;
– 50 mm-source: 10,05 m.

A comparison of both values for each source with the data in Table C.1 shows that the 500 lux distances in both cases are larger than the inverse square law distances and, more importantly, the hazard distances for both lower risk groups. Therefore, the original risk group allocation changes from Risk Group 1 to the Exempt Risk Group by the application of the GLS requirement.

Calculated 500 lux distances are valid if the irradiance solely originates from the single source in each case; usually, irradiance also comprises contributions from other source elements or sources, since for this measurement the FOV is not limited. These distances represent the worst case of the closest 500 lux distances. Since, the larger these distances are, the more favourable is the relationship between the measured spatially averaged and the “true” radiance: see Figure C.1.

It should be noted that the above considerations are limited to the photochemical hazard, and care should be taken in cases where also thermal retinal hazards need to be considered. Especially for the Exempt Risk Group, the applicable acceptance angle for the measurement of the spatially averaged radiance according to IEC 62471 is different from the angle which should be applied for photochemical hazards.

It is possible that at the 500 lux distance the corresponding source radiance for thermal hazards should be additionally measured, whereas in relation to the blue light hazard the above $(\gamma/\alpha)^2$-relaxation applies. Additionally, although the measured radiance in relation to retinal thermal hazards would be constant under these conditions, the applicable exposure limit value in this case increases because it depends inversely on the angular subtense. This may compensate for some of the disadvantage compared with the blue light criterion and may lead to a crossover of the most restrictive hazards with the distance in the case of the 500 lux criterion for GLS and for the determination of safe viewing distances. This issue is even more complex if additionally exposure limit values in irradiance (as for UV-hazards) should be considered. These issues were discussed in conjunction with general distance-depending parameters in Annex B. Table C.2 repeats the results of the hazard distance calculations in Annex B for an example halogen lamp of 7 mm source diameter and with a reasonable measured luminance of 3×10^7 cd·m^{-2}.

Table C.2 – Risk group-related hazard distances for halogen lamp of 7 mm source diameter and with luminance of 3×10^7 cd·m^{-2}

Dimensions in metres

	Act. UV	UV eye	Blue light	Retinal thermal	Retinal thermal low visual	Cornea lens
Risk Group 2	0,69	0,27	0,20	0,20	0,20	0,20
Risk Group 1	2,2	0,47	0,78	0,20	0,20	0,20
Exempt Risk Group	3,8	0,85	0,86	0,20	0,20	0,27

Due to the broad spectral distribution, more optical radiation hazards have to be considered compared with the LED example (Table C.1). The classification for this halogen lamp results in Risk Group 3 with the actinic UV as the most restrictive hazard. If the UV emission is filtered out, the most limiting criterion is the blue light hazard. Based on the hazard distances in Table C.2, the classification in this case will be Risk Group 2. However, this allocation is based on the standard assessment distance of 200 mm. This source should be exclusively used for GLS and the risk group assessment should be performed at the greater distance where the illuminance equals 500 lux.

If this illuminance is achieved by this single source only, the corresponding closest 500 lux distance for this halogen lamp in the worst case is 1,5 m (Figure C.2). For the actinic UV hazards in Table C.2, this distance is shorter than the hazard distances for RG 1 and 0. Thus, the risk grouping would change from RG 3 to RG 2. In this respect, there is little advantage of the GLS assessment requirement. The situation improves for the remaining blue light hazard if the UV emission is filtered out.

The 500 lux distance is greater than all hazard distances which leads to allocation to the Exempt Risk Group.

This is a calculation-based worst case analysis. In practice, the 500 lux measurement also includes contributions from other source elements or from the environment and the 500 lux is likely be measured at even greater distances.

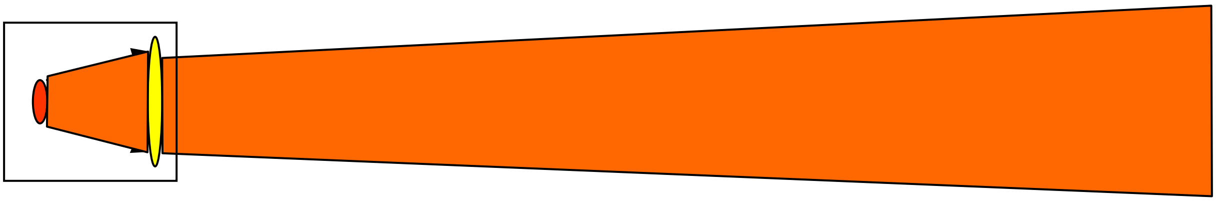
To summarise, there are cases with radiance-based dominating hazards where the GLS-criterion may provide a strong relaxation but there are other cases where it does not. This seems to depend on the source-specific radiometric/photometric conversion as well as on the effectiveness of the B(λ)-weighting. The 500 lux criterion does not assure in any case Exempt Risk Group conditions, as sometimes claimed. However, it should be noted that pc-white LEDs for GLS consistently have to be considered as Exempt Risk Group products.

Annex D
(informative)

Lamps and lamp systems with integrated, attached beam-shaping or projection optics

D.1 Background

The default condition for the ICNIRP guideline for incoherent broadband sources[1] and for the derived lamp safety standard is the "bare lamp". However, many lamps are employed in projection systems, e.g. for audio-visual applications, in searchlights, surgical and theatre lighting. The ultraviolet and infrared radiation may be typically filtered by the projection optics (Figure D.1) for some applications but should be reassessed by the lamp system manufacturer. In addition, many LEDs have built-in projection (beam-shaping) optics that increase the radiant or luminous intensity over that of a diffuse Lambertian surface-emitting LED chip.



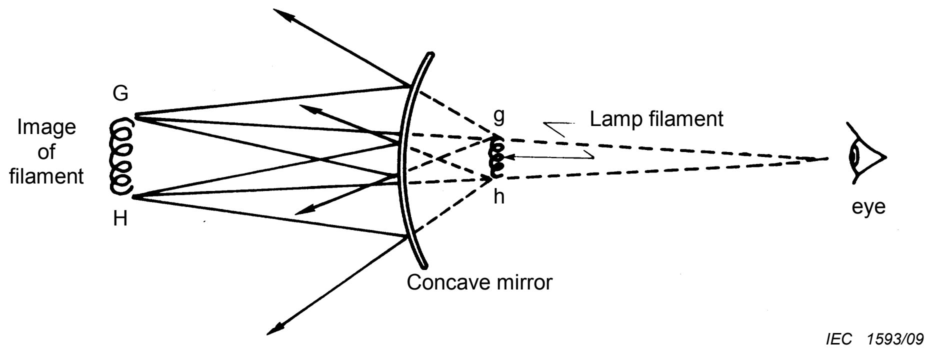
The radiance is conserved but the retinal image size increased with most projection optics.

Figure D.1 – Ultraviolet and infrared filtering by projection optics

The common problem in these cases is that such optics may distort the size and position of the source and form a virtual source image for a direct viewer. Size and location of this apparent source should be assessed in terms of possible retinal hazards. At least in the case of dominating thermal hazards, the angular subtense *α* of the apparent source itself should be known for the determination of the applicable limits. And the applicable measurement distance (200 mm or the 500 lux distance) in case of retinal hazards refers also to the position of the apparent source.

NOTE This is not applicable for the assessment of hazards for the lens/cornea in the infrared. For the example of a concave mirror, as in Figure D.2, the apparent source may be at a distance of 200 mm but the filament is in direct contact with the cornea!

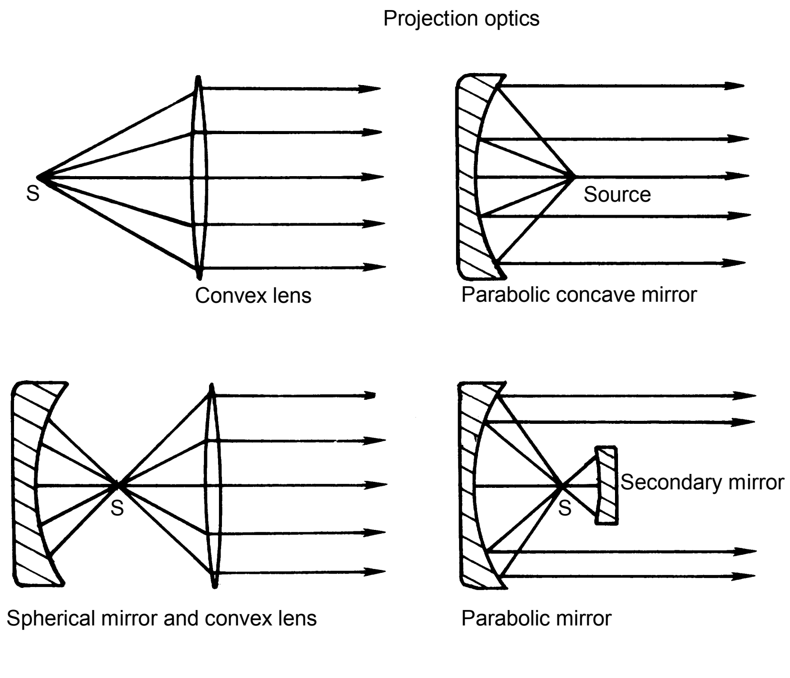
[1] Guidelines on Limits of Exposure to Broad-Band Incoherent Optical Radiation (0.38 to 3μm). *Health Physics*, 73 (3): 539-554; 1997.



The radiance is conserved but the retinal image size is increased. (Source: Sliney and Wolbarsht, *Safety with Lasers and Other Optical Sources*, New York, Plenum, 1980).

Figure D.2 – Magnified apparent source size of the filament in an incandescent projection lamp

Examples of projection optics are shown in Figure D.3.

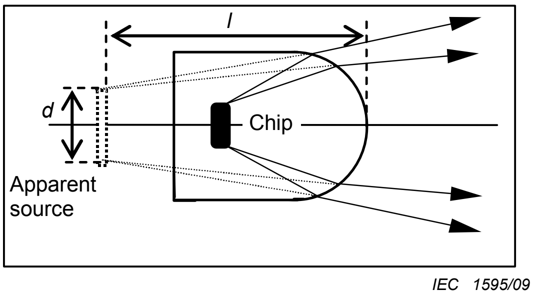


Different projection optics increase the apparent source size for the eye, but in each case, the radiance is limited to the radiance of the lamp source emitting element.

Figure D.3 – Examples of projection optics

D.2 LEDs

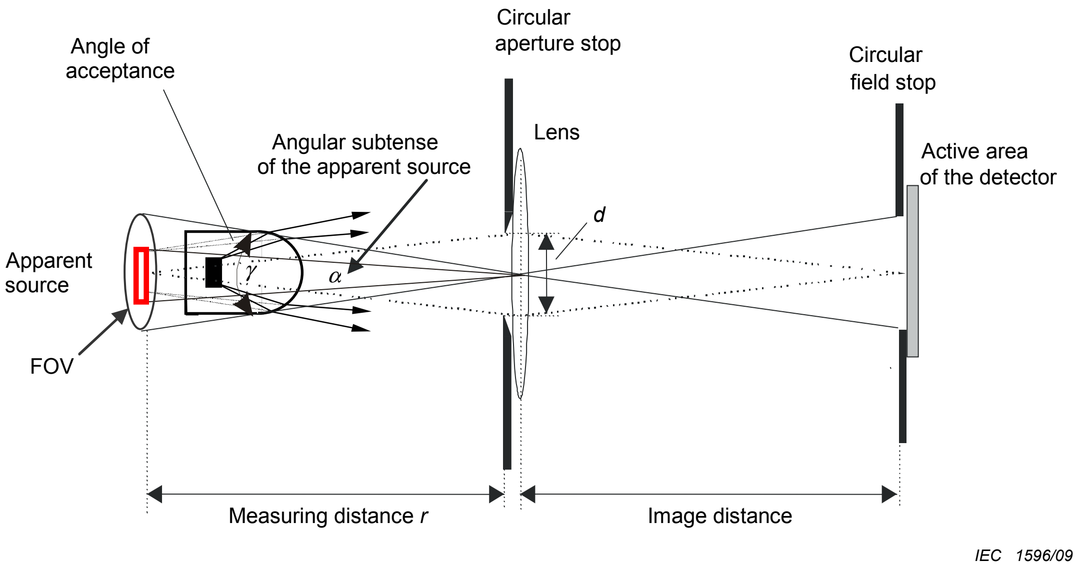
A common example for a lamp with built-in projection optics is the plastic encapsulated LED. For such LEDs, the virtual emitting area is determined not only by the chip size but also by the housing due to built-in lenses, reflectors and scattering materials. Plastic encapsulated LEDs form an apparent source which should be assessed in terms of possible retinal hazards. The measurement or assessment distance as required by IEC 62471 is related to the apparent source position, i.e. as well as the size *d*, also their relative location *l*, (see Figure D.4) should be known. As the beam concentration of such an LED may be modified by the distance from the chip to the lens and the radius of the hemisphere, the size and location of the apparent source is changing accordingly. With narrower beams the location of the apparent source shifted to longer distances (Figure D.4). In some cases, of dominating thermal retinal hazard, the angle α subtended by the apparent source has to be determined based on the dimension *d* in Figure D.4 of the 50% emission points and the applicable assessment distance. This commonly requires some kind of imaging and intensity profiling. The relative location (*l*) should be determined in any case. An example measurement arrangement is shown in the Figure D.5:



Area of chip: A_{Chip}

Area of apparent source: A_{LED}

Figure D.4 – Formation of a virtual LED chip image by the integrated lens



In this example, the applicable FOV (which depends on the risk group) for the measurement of the spatially averaged radiance is under-filled.

Figure D.5 – Imaging of the apparent source and measurement condition for the assessment of sources with built-in or attached projection optics

D.3 Consequences

D.3.1 Risk Group allocation

In most cases, the beam-shaping optics concentrates the Lambertian emission pattern of a filament or LED-chip into a beam in order to produce more directional emission. The true radiance is a property of the source and cannot be increased (made brighter) by the use of optical elements. Besides a modified luminous or radiant intensity in a selected direction, these optical systems also form a magnified projected source size in a viewer's eye (Figure D.4). Taking the LED in Figure D.4 as an example, it follows from the Law of the Conservation of the Radiance that the relationship between the real chip area A_{Chip} and the projected area A_{LED} source areas and the related luminous intensities of the original I_{Chip} and the modified I_{LED}, can be used as a first approximation for corrections or the determination of the apparent source size, respectively:

$$\frac{A_{\mathrm{LED}}}{A_{\mathrm{Chip}}} = \frac{I_{\mathrm{LED}}}{I_{\mathrm{Chip}}}$$

NOTE In many cases, the optics of the projection system limits part of the angular distribution of the source in an imaging system, reducing the radiance by these losses.

More concentrated/collimated radiation means that the power density within the beam is increased, and therefore increasing the corresponding resulting irradiance. Compared with the characteristics of a bare source or lamp, this may have consequences for hazard assessments of lamps and lamp systems with integrated, attached beam-shaping or projecting optics according to IEC 62471:

In cases of dominating non-retinal hazards (especially outside the wavelength range 380 nm to 780 nm and for skin hazards in general) where the limits are provided in irradiances, these limits should be compared with increased irradiances due to the additional optics. Additionally, the apparent or projected source may be recessed (up to infinity) by the optics and the measurement distance should be adapted accordingly, i.e. the measurement aperture varies in most cases to a closer distance in relation to the “physical” source. It should be recognised that it can go to zero-distance or even be negative.

Provided that the lamps are assessed using the guidance in this technical report (determination of the source radiance rather than the spatially averaged one), in the case of dominating blue light hazard, the hazard classification is, in first order, not affected by additional optics because the source radiance remains unchanged. The risk group remains the same, or may be reduced by filtering, etc.

In the case of dominating retinal thermal hazard, the limits are expressed in radiance. In this case they depend on the angular subtense of the source, i.e. they decrease with increasing source size due to the magnification, whereas the source radiance remains unchanged. In this case the classification might be affected by additional optics.

Additional optics may modify the irradiance of a source and have a significant impact where the classification is based on irradiance or radiant exposure-criteria, whereas, the radiance is unchanged and has less impact where the classification is based on radiance-criteria. However, in the latter case it should be verified if the most restrictive classification criterion for the lamp system has not been changed (from radiance to irradiance criterion) due to the increased irradiance.

D.3.2 Determination of hazard distances

The above is valid if the risk group classification of sources before and after attachment of additional optics is considered, that is, the transferability of the data for the bare lamp to the lamp system. In most practical cases, the next step would be the determination of the hazard distances. The principal impact of beam-shaping optics on the radiance-related hazard distances is shown in Figure C.1. Two example LED sources of equal radiance could be considered as the original (2 mm diameter) and the magnified one (50 mm diameter). Due to the modified relationship between the angular subtense and the acceptance angle in the case of source magnification, the hazard distance shifts to much longer distances.

Similarly, in the case of dominating irradiance limits, due to the increased power density, the hazard distance shifts to longer distances. Before using an inverse square relationship for HD determination, a possible “flash distance” should be considered (see Annex B, Clause B.1.2).

Bibliography

IEC 60432-1, *Incandescent lamps – Safety specifications – Part 1: Tungsten filament lamps for domestic and similar general lighting purposes*

IEC 60432-2, *Incandescent lamps – Safety specifications – Part 2: Tungsten-halogen lamps for domestic and similar general lighting purposes*

IEC 60432-3, *Incandescent lamps – Safety specifications – Part 3: Tungsten-halogen lamps (non-vehicle)*

IEC 61199, *Single-capped fluorescent lamps – Safety specifications*

IEC 61195, *Double-capped fluorescent lamps – Safety specifications*

IEC 62031:2008, *LED modules for general lighting – Safety specifications*

IEC 62035:1999, *Discharge lamps (excluding fluorescent lamps) – Safety specifications*
Amendment 1 (2003)[2]

ISO 15004-2:2007, *Ophthalmic instruments – Fundamental requirements and test methods – Part 2: Light hazard protection*

ANSI/IESNA RP-27.1-05, *Photobiological Safety for Lamps and Lamp Systems-General Requirements*

ANSI/IESNA RP-27.2-00, *Photobiological Safety for Lamps and Lamp Systems – Measurement Systems*

ANSI/IESNA RP-27.3-07, *Recommended Practice for Photobiological Safety for Lamps – Risk Group Classification and Labeling*

ICNIRP, Guidelines on Limits of Exposure to Ultraviolet Radiation of Wavelengths Between 180 nm and 400 nm (Incoherent Optical Radiation). *Health Physics,* 87 (2): 171-186; 2004.

ICNIRP, Guidelines on Limits of Exposure to Broad-Band Incoherent Optical Radiation (0,38 to 3 µm). *Health Physics,* 73 (3): 539-554; 1997.

[2] A consolidated edition 2.1 (2003) exists, including IEC 62035:1999 and its Amendment 1.

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