EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 62471

September 2008

English version

Photobiological safety of lamps and lamp systems
(IEC 62471:2006, modified)

Sécurité photobiologique des lampes
et des appareils utilisant des lampes
(CEI 62471:2006, modifiée)

Photobiologische Sicherheit
von Lampen und Lampensystemen
(IEC 62471:2006, modifiziert)

This European Standard was approved by CENELEC on 2008-09-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Ref. No. EN 62471:2008 E

Foreword

The text of the International Standard IEC 62471:2006, prepared by IEC TC 76 "Optical radiation safety and laser equipment", together with the common modifications prepared by the Technical Committee CENELEC TC 76, Optical radiation safety and laser equipment, was submitted to the formal vote and was approved by CENELEC as EN 62471 on 2008-09-01.

This European Standard partially supersedes EN 60825-1:1994 + corrigendum February 1995 + A1:2002 + A2:2001 + A2:2001/corrigendum April 2004.

The following dates were fixed:

– latest date by which the EN has to be implemented
  at national level by publication of an identical
  national standard or by endorsement   (dop)   2009-09-01

– latest date by which the national standards conflicting
  with the EN have to be withdrawn   (dow)   2011-09-01

Annex ZA has been added by CENELEC.

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Endorsement notice

The text of the International Standard IEC 62471:2006/CIE S 009:2002 was approved by CENELEC as a European Standard with agreed common modifications as given below.

The International Standard IEC 62471:2006 was prepared as CIE S 009:2002 by the International Commission on Illumination. It was submitted to the IEC National Committees for voting under the Fast Track Procedure. It is published as a double logo IEC and CIE standard.

COMMON MODIFICATIONS

4   Exposure limits

Move the contents of the whole Clause 4 into a new informative Annex ZB. Keep the numbering.

Replace the current Clause 4 with the following:

4   Exposure limits

The original Clause 4 of IEC 62471:2006 contains provisions governing limiting values for the exposure of persons falling within the area of the health and safety of workers. Within Europe those limiting values are already covered by the Artificial Optical Radiation Directive (2006/25/EC). Thus, the limits of the directive have to be applied instead of those fixed in IEC 62471:2006.

For information the original Clause 4 of IEC 62471:2006 was moved to the informative Annex ZB under retention of the respective numbering.

4.1   General

Delete the first paragraph.

Table 6.1 – Emission limits for risk groups of continuous wave lamps

Add the following note to the table:

NOTE   The action functions: see Table 4.1 and Table 4.2
        The applicable aperture diameters: see 4.2.1
        The limitations for the angular subtenses: see 4.2.2
        The related measurement condition 5.2.3 and the range of acceptance angles: see Table 5.5.

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Annex ZA
(normative)

**Normative references to international publications
with their corresponding European publications**

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.

NOTE   When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
CIE 17.4	1987	International Lighting Vocabulary (ILV)	-	-
CIE 53	1982	Methods of characterizing the performance of radiometers and photometers	-	-
CIE 63	1984	The spectroradiometric measurement of light sources	-	-
CIE 105	1993	Spectroradiometry of pulsed optical radiation sources	-	-
ISO/IEC Guide	1995	Guide to the expression of uncertainty in measurement (GUM)	-	-

NORME INTERNATIONALE

INTERNATIONAL STANDARD

CEI

IEC

62471

CIE S 009:2002

Première édition
First edition
2006-07

Sécurité photobiologique des lampes
et des appareils utilisant des lampes

Photobiological safety of lamps
and lamp systems

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PHOTOBIOLOGICAL SAFETY OF LAMPS AND LAMP SYSTEMS

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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The International Standard IEC 62471 has been submitted by the International Commission on Illumination (CIE) and has been processed through IEC technical committee 76: Optical radiation safety and laser equipment

This standard was prepared as Standard CIE S 009:2002 by the International Commission on Illumination. It was submitted to the IEC National Committees for voting under the Fast Track Procedure as the following documents:

FDIS	Report on voting
76/340/FDIS	76/343/RVD

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

This publication is published as a double logo standard.

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.

The International Commission on Illumination (abbreviated as CIE from its French title) is an organization devoted to international cooperation and exchange of information among its member countries on all matters relating to the science and art of lighting.

Foreword of the International Commission on Illumination (CIE)

Standards produced by the Commission Internationale de l'Eclairage (CIE) are a concise documentation of data defining aspects of light and lighting, for which international harmony requires such unique definition. CIE Standards are therefore a primary source of internationally accepted and agreed data, which can be taken, essentially unaltered, into universal standard systems.

The CIE undertook a major review of the official recommendations on photobiological effects, their dose relationships and measurement. Based on the guidelines given by the International Commission on Non-Ionising Radiation Protection (ICNIRP), the CIE undertook to apply these guidelines to lamps and lamp systems. The present standard describes present day knowledge of the subject but does not absolve those carrying out experiments with humans from their responsibility for the safety and well being of the subjects involved.

This Standard has been prepared by CIE Technical Committee 6-47, "Photobiological Lamp Safety Standard", and was approved by the National Committees of the CIE. During the preparation of the standard IEC TC34 co-operated with CIE TC 6-47 through the participation of a number of their members.

NOTE   CIE kindly acknowledges the consent of the Illuminating Engineering Society of North America who permitted to use extensive parts of the documents ANSI/IESNA RP-27.1. "Photobiological Safety for Lamps and Lamp Systems – General Requirements", ANSI/IESNA RP-27.2. "Photobiological Safety for Lamps and Lamp Systems – Measurement Systems - Measurement Techniques" and ANSI/IESNA RP-27.3. "Photobiological Safety for Lamps and Lamp Systems – Risk Group Classification and Labeling" as much of the basis for this standard. (Each publication may be purchased from Publications Department, IESNA, 120 Wall Street, 17th floor, New York, New York 10005-4001, by fax 212-248-5017 or through the web site: http://www.iesna.org).

INTRODUCTION

Lamps were developed and produced in large quantities and became commonplace in an era when industry-wide safety standards were not the norm. The evaluation and control of optical radiation hazards from lamps and lamp systems is a far more complicated subject than similar tasks for a single-wavelength laser system. The required radiometric measurements are quite involved, for they do not deal with the simple optics of a point source, but rather with an extended source that may or may not be altered by diffusers or projection optics. Also the wavelength distribution of the lamp may be altered by ancillary optical elements, diffusers, lenses, and the like, as well as variations in operating conditions.

To evaluate a broad-band optical source, such as an arc lamp, an incandescent lamp, a fluorescent lamp, an array of lamps or a lamp system, it is first necessary to determine the spectral distribution of optical radiation emitted from the source at the point or points of nearest human access. This accessible emission spectral distribution of interest for a lighting system may differ from that actually being emitted by the lamp alone due to the filtration by any optical elements (e.g., projection optics) in the light path. Secondly, the size, or projected size, of the source must be characterized in the retinal hazard spectral region. Thirdly, it may be necessary to determine the variation of irradiance and effective radiance with distance. The performance of the necessary measurements is normally not an easy task without sophisticated instruments. Thus it was decided to include reference measurement techniques for lamps and lamp systems in this standard. The measurement techniques along with the described risk group classification scheme will provide common ground for both lamp manufacturers and users to define the specific photobiological hazards of any given lamp and/or lamp system.

Finally, there are well known optical radiation hazards associated with some lamps and lamp systems. The purpose of this standard is to provide a standardized technique for evaluation of potential radiation hazards that may be associated with various lamps and lamp systems.

PHOTOBIOLOGICAL SAFETY OF LAMPS AND LAMP SYSTEMS

1. SCOPE

This International Standard gives guidance for evaluating the photobiological safety of lamps and lamp systems including luminaires. Specifically it specifies the exposure limits, reference measurement technique and classification scheme for the evaluation and control of photobiological hazards from all electrically powered incoherent broadband sources of optical radiation, including LEDs but excluding lasers, in the wavelength range from 200 nm through 3000 nm.

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.

CIE 17.4-1987   *International lighting vocabulary* (ILV) – Joint publication IEC/CIE

CIE 53-1982   *Methods of characterizing the performance of radiometers and photometers*

CIE 63-1984   *The spectroradiometric measurement of light sources*

CIE 105-1993   *Spectroradiometry of pulsed optical radiation sources*

ISO   *Guide to the expression of uncertainty in measurement,* ISO, Geneva, 1995.

3. DEFINITIONS, SYMBOLS AND ABBREVIATIONS

For the purposes of this standard, the following definitions, symbols and abbreviations apply.

3.1 actinic dose (see ILV 845-06-23)

Quantity obtained by weighting spectrally the dose according to the actinic action spectrum value at the corresponding wavelength.

> Unit: $J \cdot m^{-2}$

Note: This definition implies that an action spectrum is adopted for the actinic effect considered, and that its maximum value is generally normalized to 1. When giving a quantitative amount, it is essential to specify which quantity dose or actinic dose is meant, as the unit is the same.

3.2 angular subtense (α)

Visual angle subtended by the apparent source at the eye of an observer or at the point of measurement. In this standard subtended angles are denoted by the full included angle, not the half angle.

> Unit: radian

Note: The angular subtense α will generally be modified by incorporation of lenses and mirrors as projector optics, i.e. the angular subtense of the apparent source will differ from the angular subtense of the physical source.

3.3 aperture, aperture stop

Opening that defines the area over which average optical emission is measured. For spectral irradiance measurements this opening is usually the entrance of a small sphere placed in front of the radiometer/spectroradiometer entrance slit.

3.4 blue light hazard (BLH)

Potential for a photochemically induced retinal injury resulting from radiation exposure at wavelengths primarily between 400 nm and 500 nm. This damage mechanism dominates over the thermal damage mechanism for times exceeding 10 seconds.

3.5 continuous wave (CW) lamp

Lamp that is operated with a continuous output for a time greater than 0,25 s, i.e., a non-pulsed lamp.

Note: In this standard, General lighting service (GLS) lamps are defined to be Continuous wave lamps.

3.6 erythema (see ILV 845-06-15)

Reddening of the skin; as used in this standard the reddening of the skin resulting from inflammatory effects from solar radiation or artificial optical radiation.

Note: The degree of delayed erythema is used as a guide to dosages applied in ultraviolet therapy.

3.7 exposure distance

Nearest point of human exposure consistent with the application of the lamp or lamp system. For lamps radiating in all directions the distance is measured from the centre of the filament or arc source. For reflector-type lamps the distance is measured from the outside edge of the lens or the plane defining the end of the reflector in a lens free reflector.

Unit: m

3.8 exposure limit (EL)

Level of exposure to the eye or skin that is not expected to result in adverse biological effects.

3.9 eye movements

The normal eye, when focused on an object, moves slightly in a random motion with a frequency of a few hertz. This rapid eye movement causes the image from a point source to be spread over an area of the retina equivalent to an angular subtense of about 0,011 radians. Furthermore, for times greater than about 100 seconds the focused stare capability breaks down causing further spreading of the radiant power over the retina due to task determined eye movements, e.g. as in reading.

3.10 field of view

Solid angle as "seen" by the detector (acceptance angle), such as the radiometer/ spectroradiometer, out of which the detector receives radiation.

Unit: sr

Note 1: The field of view should not be confused with the angular subtense of the apparent source α.
Note 2: A plane angle is sometimes used to describe a circular symmetric solid angle field of view.

3.11 general lighting service (GLS) lamps

Term for lamps intended for lighting spaces that are typically occupied or viewed by people. Examples would be lamps for lighting offices, schools, homes, factories, roadways, or automobiles. It does not include lamps for such uses as film projection, reprographic processes, "suntanning", industrial processes, medical treatment and searchlight applications.

3.12 hazard distance

See skin hazard distance or ocular hazard distance.

3.13 illuminance (at a point of a surface) (*E_v*) (see ILV 845-01-38)

Quotient of the luminous flux dΦ_v incident on an element of the surface containing the point, by the area dA of that element.

$$E_v = \frac{d\Phi_v}{dA}$$

(3.1)

Unit: lx

3.14 infrared radiation (IR) (see ILV 845-01-04)

Optical radiation for which the wavelengths are longer than those for visible radiation.

Note: For infrared radiation, the range between 780 nm and 10^6 nm is commonly subdivided into: IR-A (780 nm to 1400 nm), IR-B (1400 nm to 3000 nm), and IR-C (3000 nm to 10^6 nm).

Infrared radiation is often evaluated in terms of the spectral total radiation per unit area (irradiance) incident upon a surface. Examples of applications of infrared radiation are industrial heating, drying, baking, and photo-reproduction. Some applications, such as infrared viewing systems, involve detectors sensitive to a restricted range of wavelengths. In these cases, the spectral characteristics of the source and detector are of importance.

3.15 intended use

Use of a product, process or service in accordance with specifications, instructions and information provided by the supplier.

3.16 irradiance (at a point of the surface) (see ILV 845-01-37)

Quotient of the radiant flux dΦ incident on an element of a surface containing the point, by the area dA of that element, i.e.,

$$E = \frac{d\Phi}{dA}$$

(3.2)

Unit: W·m^{-2}

3.17 lamp (see ILV 845-07-03)

Source made to produce optical radiation, usually visible.

Note: The term "lamp" is sometimes used for certain types of luminaires.

These types of luminaires consist of a lamp with shade, reflector, enclosing globe, housing, or other accessories.

As used in this standard, the term means an electrically powered source, other than a laser, that produces radiation in the visible region of the electromagnetic spectrum. Devices that generate light and have integral components for optical control, such as lenses or reflectors, also are considered lamps. Examples include a lensed LED, lens-end lamp, and reflector types, that consist of a source within a parabolic or elliptical reflector assembly, normally including a lens cover.

3.18 lamp system

Any manufactured product or assemblage of components that incorporates or is intended to incorporate a lamp.

3.19 large source

Size of the source image on the retina which is so large that radial heat flow in the radial direction from the center of the image to the surrounding biological tissue is negligibly small compared to heat flow in the axial direction.

3.20 laser

Source emitting coherent optical radiation produced by stimulated emission.

3.21 light

See visible radiation.

3.22 light emitting diode (LED) (see ILV 845-04-40)

Solid state device embodying a p-n junction emitting optical radiation without gain when excited by an electric current.

3.23 lumen (see ILV 845-01-51)

SI unit of luminous flux: Luminous flux emitted in a unit solid angle (steradian) by a uniform point source having a luminous intensity of 1 candela, or equivalently, the luminous flux of a beam of monochromatic radiation whose frequency is $540 \cdot 10^{12}$ hertz and whose radiant flux is 1/683 watt.

3.24 luminaire (see ILV 845-10-01)

Apparatus which distributes, filters or transforms the light emitted from one or more lamps and which includes, except the lamps themselves, all the parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting them to the electric supply.

The words "luminaire" and "lamp system" are often assumed to be synonymous. For the purposes of this standard, the word "luminaire" is restricted to apparatus used for distributing light in general lighting, while "lamp system" implies use of lamps in other than general lighting applications.

3.25 luminance (in a given direction, at a given point of a real or imaginary surface) **(L_v)** (see ILV 845-01-35)

Quantity defined by the formula

$$L_v = \frac{\mathrm{d}\Phi_v}{\mathrm{d}A \cdot \cos\theta \cdot \mathrm{d}\Omega} \tag{3.3}$$

where $\mathrm{d}\Phi_v$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $\mathrm{d}\Omega$ containing the given direction; $\mathrm{d}A$ is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam.

  Unit: $\mathrm{cd} \cdot \mathrm{m}^{-2}$

3.26 lux (see ILV 845-01-52)

SI unit of illuminance: Illuminance produced on a surface of area 1 square metre by a luminous flux of 1 lumen uniformly distributed over that surface.

3.27 ocular hazard distance

Distance from a source within which the radiance or irradiance for a given exposure duration exceeds the applicable exposure limit.

  Unit: m

3.28 optical radiation (see ILV 845-01-02)

Electromagnetic radiation at wavelengths between the region of transition to X-rays (wavelength approximately 1 nm) and the region of transition to radio waves (wavelength approximately 10^6 nm).

Ultraviolet radiation in the wavelength range below 180 nm (vacuum UV) is strongly absorbed by the oxygen in air. For the purpose of this standard the wavelength band of optical radiation is limited to wavelengths greater than 200 nm. Further, the eye transmits optical radiation to the retina between 380 and 1400 nm. Thus this wavelength range requires special consideration in determining the photobiological safety of the retina.

3.29 photokeratoconjunctivitis

Inflammatory response of the cornea and conjunctiva following exposure to ultraviolet (UV) radiation. Wavelengths shorter than 320 nm are most effective in causing this condition. The peak of the action spectrum is approximately at 270 nm.

Note: Different action spectra have been published for photokeratitis and photoconjuctivitis (CIE 106/2 and CIE 106/3–1993); however, the latest studies support the use of a single action spectrum for both ocular effects (CIE 106/1–1993).

3.30 pulsed lamp

Lamp that delivers its energy in the form of a single pulse or a train of pulses where each pulse is assumed to have a duration of less than 0,25 s. A lamp with a continuous train of pulses or modulated radiant energy where the peak radiated power is at least ten times the average radiated power.

Note 1: The **duration** of a lamp pulse is the time interval between the half-power points on the leading and the trailing edges of the pulse.

Note 2: In this standard, General lighting service lamps are defined to be Continuous wave lamps (see clause 3.5). Examples of pulsed lamps include photoflash lamps, flash lamps in photocopy machines, pulse-modulated LEDs, and strobe lights.

3.31 radiance (in a given direction at a given point of a real or imaginary surface) **(L)** (see ILV 845-01-34)

Quantity defined by the formula,

$$L = \frac{d\Phi}{dA \cdot \cos\theta \cdot d\Omega}$$ (3.4)

where $d\Phi$ is the radiant power (flux) transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam.

Unit: $W \cdot m^{-2} \cdot sr^{-1}$

The same definition holds for the time-integrated radiance L_i if, in the equation for L, the radiant power $d\Phi$ is replaced by the radiant energy dQ.

3.32 radiant energy (see ILV 845-01-27)

Time integral of the radiant power, Φ over a given duration, Δt.

$$Q = \int_0^t \Phi \cdot dt$$ (3.5)

Unit: J

3.33 radiant exposure (at a point of a surface, for a given duration) (see ILV 845-01-42)

Quotient of the radiant energy, dQ, incident on an element of the surface containing the point over the given duration, by the area dA of that element.

$$H = \frac{dQ}{dA}$$ (3.6a)

Unit: $J \cdot m^{-2}$

Equivalently the radiant exposure is defined as the integral of the irradiance, E, at a given point over a given duration, Δt.

$$H = \int_{\Delta t} E \cdot dt$$ (3.6b)

3.34 radiant power (*Φ*) (see ILV 845-01-24)

Power emitted, transmitted or received in the form of radiation. Radiant power is often called *radiant flux*.

   Unit: watt (W)

3.35 retina (see ILV 845-02-01)

Tissue situated inside the back of the eye that is sensitive to light stimuli; it contains photoreceptors, the cones and the rods, and nerve cells that transmit to the optic nerve the signals resulting from stimulation of the photoreceptors.

3.36 retinal burn

Photochemical or thermal retinal lesion.

3.37 retinal hazard region

Spectral region from 380 nm to 1400 nm (visible plus IR-A) within which the normal ocular media transmit optical radiation to the retina.

3.38 skin hazard distance

Distance at which the irradiance exceeds the applicable exposure limit for 8 hours exposure.

   Unit: m

3.39 spectral distribution (see ILV 845-01-17)

Quotient of the radiant, luminous or photon quantity $dX(\lambda)$ contained in an elementary range $d\lambda$ of wavelength at the wavelength λ, by that range.

$$X_\lambda = \frac{dX(\lambda)}{d\lambda} \tag{3.7}$$

   Unit: $[X] \cdot nm^{-1}$

Note: The term spectral distribution is to be preferred when dealing with the function $X_\lambda(\lambda)$ over a wide range of wavelengths, not at a particular wavelength.

3.40 spectral irradiance

Quotient of the radiant power $d\Phi(\lambda)$ in a wavelength interval $d\lambda$, incident on an element of a surface, by the area dA of that element and by the wavelength interval $d\lambda$.

$$E_\lambda = \frac{d\Phi(\lambda)}{dA \cdot d\lambda} \tag{3.8}$$

   Unit: $W \cdot m^{-2} \cdot nm^{-1}$

3.41 spectral radiance (for a wavelength interval $d\lambda$, in a given direction at a given point) **(L_λ)**

Ratio of the radiant power $d\Phi(\lambda)$ passing through that point and propagating within the solid angle $d\Omega$ in the given direction, to the product of the wavelength interval $d\lambda$ and the area of a section of that beam on a plane perpendicular to this direction (cos θ dA) containing the given point and to the solid angle $d\Omega$.

$$L_\lambda = \frac{d\Phi(\lambda)}{dA \cdot \cos\theta \cdot d\Omega \cdot d\lambda} \tag{3.9}$$

   Unit: $W \cdot m^{-2} \cdot nm^{-1} \cdot sr^{-1}$

3.42 steradian (see ILV 845-01-20)

SI unit of solid angle. A solid angle that, having its vertex at the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

3.43 ultraviolet radiation (UV) (see ILV 845-01-05)

Optical radiation for which the wavelengths are shorter than those for visible radiation.

Note: For ultraviolet (UV) radiation, the range between 100 nm and 400 nm is commonly subdivided into: UV-A, from 315 nm to 400 nm; UV-B, from 280 nm to 315 nm; and UV-C, from 100 nm to 280 nm.

These designations for the UV should not be taken as precise limits, particularly for photobiological effects.

In some fields of photobiology the wavelength bands are taken from 200 nm to 290 nm, from 290 nm to 320 nm, and from 320 nm to 400 nm. Sometimes these are (incorrectly) called by the names UV-A, UV-B and UV-C, respectively. Ultraviolet radiation at wavelengths less than 180 nm is considered vacuum ultraviolet radiation. Note that radiation between 380 nm and 400 nm is considered visible radiation although it is also within the formal definition of the ultraviolet band.

3.44 visible radiation (see ILV 845-01-03)

Any optical radiation capable of directly causing a visual sensation.

Note: There are no precise limits for the spectral range of visible radiation since they depend upon the amount of radiant power reaching the retina and the responsivity of the observer. The lower limit is generally taken between 360 nm and 400 nm and the upper limit between 760 nm and 830 nm.

3.45 visual angle

Angle subtended by an object or detail at the point of observation is considered to be the visual angle. The SI unit for the angle is the radian although it may also be measured in milliradians, degrees, or minutes of arc.

4. EXPOSURE LIMITS (EL'S)

4.1 General

Individuals in the vicinity of lamps and lamp systems shall not be exposed to levels exceeding the limits developed in the following sections. The exposure limit (EL) values are taken from various ICNIRP guidelines which, in turn, are based on the best available information from experimental studies (see Annex A for summary of publications).

The exposure limits represent conditions under which it is believed that nearly all individuals in the general population may be repeatedly exposed without adverse health effects. However, they do not apply to abnormally photosensitive individuals or to individuals concomitantly exposed to photosensitizing agents, which makes individuals much more susceptible to adverse health effects from optical radiation. Such individuals, in general, are more susceptible to adverse health effects from optical radiation than individuals who are not abnormally photosensitive or concomitantly exposed to photosensitizing agents. The susceptibility of photosensitive individuals varies greatly, and it is not possible to set exposure limits for this portion of the population.

The exposure limits in this standard apply to continuous sources where the exposure duration is not less than 0,01 ms and not more than any 8-hour period, and should be used as guides in the control of exposure. The values should not be regarded as precisely defined lines between safe and unsafe levels.

The limits for exposure to broad-band visible and IR-A radiation for the eye require knowledge of the spectral radiance of the source, L_λ, and total irradiance, E, as measured at the position(s) of the eye of the exposed person. Such detailed spectral data of a light source are generally required only if the luminance of the source exceeds 10^4 cd·m^{-2}. At a luminance less than this value, the exposure limits are expected to be not exceeded. The exposure limits are given in clause 4.3.

4.2 Specific factors involved in the determination and application of retinal exposure limits

4.2.1 Pupil diameter

The radiant flux that enters the eye and is absorbed by the retina (380 nm to 1400 nm range) is proportional to the pupil area. It is known that the pupil diameter decreases from around 7 mm diameter at very low luminance (< 0,01 cd·m^{-2}) to about 2 mm at luminance values on the order of 10000 cd·m^{-2}. A weak visual stimulus is defined herein as one whose maximum luminance (averaged over a circular field-of-view subtending 0,011 radian) is less than 10 cd·m^{-2}. For a given luminance the individual pupil diameter varies considerably. Therefore, in the establishment of these exposure limits only two different pupil diameters were assumed, as follows:

- When the luminance of the source is adequately high (> 10 cd·m^{-2}), and the exposure duration is greater than 0,25 s, e.g., as applicable for the blue light hazard or retinal thermal hazard, a 3 mm pupil diameter (7 mm^2 area) was used to derive the exposure limit.
- When the luminance of the source is low, i.e., infrared radiation is present with little or no visible stimulus, the EL is based on a 7 mm (38,5 mm^2 area) pupil diameter. The 7 mm diameter is also assumed when evaluating the photobiological hazard from pulsed sources and/or for exposure durations of less than 0,25 s.
- For situations where a near infrared source is used with high ambient light levels a pupil diameter of 3 mm may be assumed and the EL limits may be adjusted to higher values by the square of the ratio of the pupil diameter. Under such conditions the EL can be increased by a factor of $(7/3)^2$ = 5,5.

4.2.2 Angular subtense of source and measurement field-of-view

For radiation in the wavelength range 380 nm to 1400 nm the area of the retina irradiated is an important element in determining the EL's for both the blue light and retinal thermal hazards. Since the cornea and lens of the eye focuses the apparent source on the retina the best method to describe the irradiated area is to relate this area to the angular subtense of the apparent source, α. Due to physical limitations of the eye the smallest image that can be formed on the retina of a still eye is limited to a minimum value, α_{min}, even for a point source. In this standard the value for α_{min} is 0,0017 radian. Measurements of emitted radiation from apparent point sources, either pulsed or very high radiance continuous wave sources, that relate to the retinal thermal ELs at 0,25 second (blink reflex time), shall use the 0,0017 radian angular subtense as the measurement field of view.

For times greater than about 0,25 second, rapid eye movements begin to smear the image of the source over a larger angle, called α_{eff} in this standard. For exposure times of ten seconds the smeared image of a point source covers an area of the retina equivalent to an angle of about 0,011 radian. Thus the effective angular subtense α_{eff} to be used in measuring radiance to compare to the EL for the retinal thermal or blue light hazard at ten seconds exposure duration shall be 0,011 radian. For continuity the dependence of α_{eff} between 0,25 s and 10 s is assumed to increase from α_{min} to 0,011 radian as the square root of time, i.e., α_{eff} is proportional to $\alpha_{min} \cdot t^{0,5}$, i.e., $\alpha_{eff} = \alpha_{min} \cdot \sqrt{(t/0,25)}$. Little data is available to support this time dependence, so it should be used with caution. The time dependent relationship is normally not needed as the source radiance is usually evaluated at 0,25 s or at 10 s, as can be determined by reviewing the risk criteria described in clause 6.

In addition, for the blue light hazard, for exposure times greater than 100 seconds, the irradiated area of the retina from a small source will be further spread over a larger area due to task determined eye movements, except for situations where the eye is fixed medically, e.g., during ophthalmological operations. For measurements of radiance from sources to be compared to the blue light hazard exposure limit, the effective angular subtense α_{eff} is set equal to 0,011 radian for times less than 100 s. For times greater than 10000 s, α_{eff} is set to 0,1 radian. Again, for convenience, it is assumed that α_{eff}

grows roughly as the square root of time with time between 100 s and 10000 s, i.e., α_{eff} = 0,011·√(t/100), (note that the formula is not exact). The maximum value of the angular subtense, α_{max}, is 0,1 radian for all retinal hazards in this standard. Thus note that above 10000 seconds α_{eff} is equal to α_{max}.

For apparent sources subtending an angle above the maximum angular subtense, α_{max}, the EL for retinal hazards are independent of the source size.

The angular subtense of an oblong source shall be determined by the arithmetic mean of the maximum and minimum angular dimensions of the source. For example, α for a 20 mm long by 3 mm diameter tubular source at a viewing distance of r = 200 mm in a direction normal to the lamp axis would be determined from the mean dimension, Z.

Z = (20+3)/2 = 11,5 mm.

Thus

$\alpha = Z$ /r = 11,5/200 = 0,058 radian.

Any angular dimension larger than α_{max} shall be limited to α_{max} and any angular dimension smaller than α_{min} shall be limited to α_{min}, prior to the determination of the arithmetic mean. Thus in the above example if the linear distance was larger than 20 mm, only the 20 mm value would be used in the calculation of the effective source size.

4.3 Hazard exposure limits

4.3.1 Actinic UV hazard exposure limit for the skin and eye

The limits for exposure to ultraviolet radiation incident upon the unprotected skin or eye apply to exposure within any 8-hour period. Continuous exposure for times greater than 8 hours in any day need not be considered. The exposure limit for effective radiant exposure is 30 J·m^{-2}.

To protect against injury of the eye or skin from ultraviolet radiation exposure produced by a broadband source, the effective integrated spectral irradiance, E_s, of the light source shall not exceed the levels defined by:

$$E_s \cdot t = \sum_{200}^{400} \sum_t E_\lambda(\lambda,t) \cdot S_{UV}(\lambda) \cdot \Delta t \cdot \Delta\lambda \le 30 \qquad \text{J·m}^{-2} \qquad (4.1)$$

where:

$E_\lambda(\lambda,t)$ is the spectral irradiance in W·m^{-2}·nm^{-1},
$S_{UV}(\lambda)$ is the actinic ultraviolet hazard weighting function,
$\Delta\lambda$ is the bandwidth in nm,
t is the exposure duration in seconds.

The actinic weighting function, $S_{UV}(\lambda)$, is shown in graphical form in Figure 4.1. Since the function ranges over many orders of magnitude $S_{UV}(\lambda)$ is shown logarithmically. In addition the spectral values of $S_{UV}(\lambda)$ are listed in Table 4.1.

The permissible time for exposure to ultraviolet radiation incident upon the unprotected eye or skin shall be computed by:

$$t_{max} = \frac{30}{E_s} \qquad \text{s} \qquad (4.2)$$

where:

t_{max} is the permissible exposure time in seconds,
E_s, is the effective ultraviolet irradiance in W·m^{-2}.

Table 4.1 Spectral weighting function for assessing ultraviolet hazards for skin and eye.

Wavelength[1] λ, nm	UV hazard function $S_{UV}(\lambda)$	Wavelength λ, nm	UV hazard function $S_{UV}(\lambda)$
200	0,030	313*	0,006
205	0,051	315	0,003
210	0,075	316	0,0024
215	0,095	317	0,0020
220	0,120	318	0,0016
225	0,150	319	0,0012
230	0,190	320	0,0010
235	0,240	322	0,00067
240	0,300	323	0,00054
245	0,360	325	0,00050
250	0,430	328	0,00044
254*	0,500	330	0,00041
255	0,520	333*	0,00037
260	0,650	335	0,00034
265	0,810	340	0,00028
270	1,000	345	0,00024
275	0,960	350	0,00020
280*	0,880	355	0,00016
285	0,770	360	0,00013
290	0,640	365*	0,00011
295	0,540	370	0,000093
297*	0,460	375	0,000077
300	0,300	380	0,000064
303*	0,120	385	0,000053
305	0,060	390	0,000044
308	0,026	395	0,000036
310	0,015	400	0,000030

[1] Wavelengths chosen are representative: other values should be obtained by logarithmic interpolation at intermediate wavelengths.

* Emission lines of a mercury discharge spectrum.

4.3.2 Near-UV hazard exposure limit for the eye

For the spectral region 315 nm to 400 nm (UV-A) the total radiant exposure to the eye shall not exceed 10000 J·m^{-2} for exposure times less than 1000 s. For exposure times greater than 1000 s (approximately 16 minutes) the UV-A irradiance for the unprotected eye, E_{UVA}, shall not exceed 10 W·m^{-2}.

These specifications can be expressed as follows:

$$E_{UVA} \cdot t = \sum_{315}^{400} \sum_{t} E_\lambda(\lambda, t) \cdot \Delta t \cdot \Delta\lambda \le 10000 \quad \text{J·m}^{-2} \qquad (t < 1000 \text{ s}) \qquad (4.3a)$$

$$E_{UVA} \le 10 \qquad\qquad \text{W·m}^{-2} \qquad (t \ge 1000 \text{ s}) \qquad (4.3b)$$

where:

$E_\lambda(\lambda, t)$ is the spectral irradiance in W·m^{-2}·nm^{-1},
$\Delta\lambda$ is the bandwidth in nm,
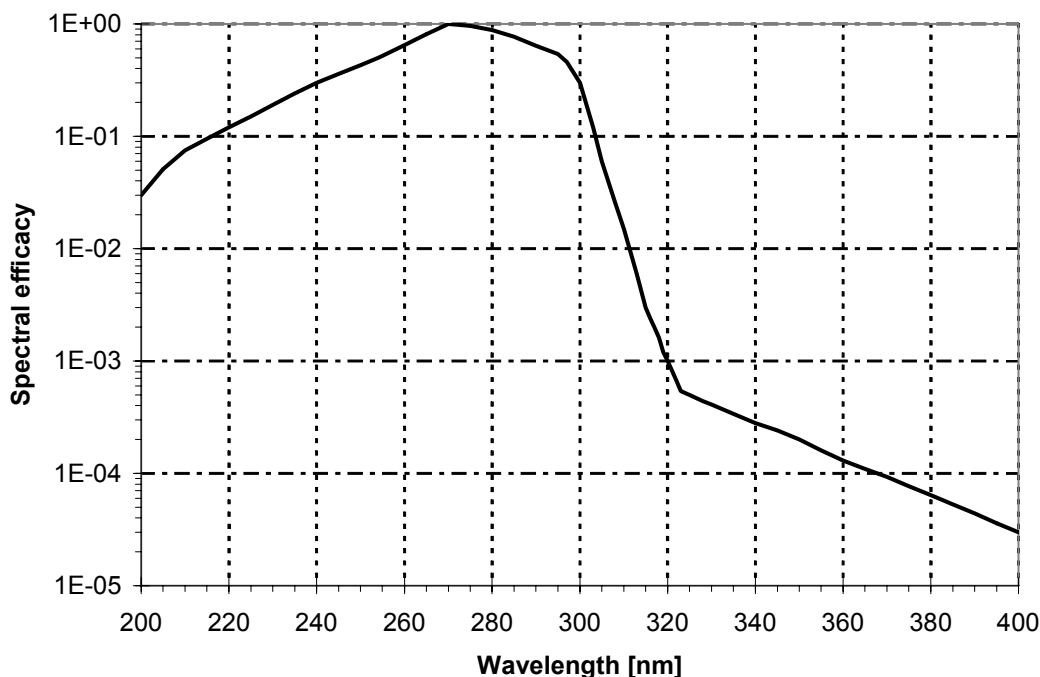t is the exposure duration in seconds.

Figure 4.1 Spectral weighting function, $S_{UV}(\lambda)$, for actinic UV hazard
for skin and eye.

The permissible time for exposure to ultraviolet radiation incident upon the unprotected eye for times less than 1000 s, shall be computed by:

$$t_{max} \leq \frac{10000}{E_{UVA}} \qquad \text{s} \qquad (4.4)$$

Note: For eye exposure in the UV-A region ICNIRP, in 1989, changed the above EL to extend the radiant exposure of 10000 J·m^{-2} from 1000 s to 10000 s (2,6 h) and to 1 W/m^2 for 10000 s ≤ t ≤ 30000 s (8 h).

4.3.3 Retinal blue light hazard exposure limit

To protect against retinal photochemical injury from chronic blue-light exposure, the integrated spectral radiance of the light source weighted against the blue-light hazard function, $B(\lambda)$, i.e., the blue light weighted radiance, L_B, shall not exceed the levels defined by:

$$L_B \cdot t = \sum_{300}^{700} \sum_{t} L_\lambda(\lambda,t) \cdot B(\lambda) \cdot \Delta t \cdot \Delta\lambda \leq 10^6 \quad \text{J·m}^{-2}\text{·sr}^{-1} \qquad \text{(for } t \leq 10^4 \text{ s)} \qquad (4.5a)$$

$$L_B = \sum_{300}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda \leq 100 \qquad \text{W·m}^{-2}\text{·sr}^{-1} \qquad \text{(for } t > 10^4 \text{ s)} \qquad (4.5b)$$

where:

$L_\lambda(\lambda,t)$ is the spectral radiance in W·m^{-2}·sr^{-1}·nm^{-1},
$B(\lambda)$ is the blue-light hazard weighting function,
$\Delta\lambda$ is the bandwidth in nm,
t is the exposure duration in seconds.

The blue-light spectral weighting function, $B(\lambda)$, is shown in graphical form in Figure 4.2 along with the retinal thermal weighting function, $R(\lambda)$. Again, as in Figure 4.1, since the functions range over many orders of magnitude the ordinate values are plotted logarithmically. In addition the spectral values of $B(\lambda)$ and $R(\lambda)$ are listed in Table 4.2.

Table 4.2 Spectral weighting functions for assessing retinal hazards from broadband optical sources.

Wavelength nm	Blue-light hazard function $B(\lambda)$	Burn hazard function $R(\lambda)$
300	0,01	
305	0,01	
310	0,01	
315	0,01	
320	0,01	
325	0,01	
330	0,01	
335	0,01	
340	0,01	
345	0,01	
350	0,01	
355	0,01	
360	0,01	
365	0,01	
370	0,01	
375	0,01	
380	0,01	0,1
385	0,013	0,13
390	0,025	0,25
395	0,05	0,5
400	0,10	1,0
405	0,20	2,0
410	0,40	4,0
415	0,80	8,0
420	0,90	9,0
425	0,95	9,5
430	0,98	9,8
435	1,00	10,0
440	1,00	10,0
445	0,97	9,7
450	0,94	9,4
455	0,90	9,0
460	0,80	8,0
465	0,70	7,0
470	0,62	6,2
475	0,55	5,5
480	0,45	4,5
485	0,40	4,0
490	0,22	2,2
495	0,16	1,6
500-600	$10^{[(450-\lambda)/50]}$	1,0
600-700	0,001	1,0
700-1050		$10^{[(700-\lambda)/500]}$
1050-1150		0,2
1150-1200		$0,2 \cdot 10^{0,02(1150-\lambda)}$
1200-1400		0,02

For a weighted source radiance, L_B, exceeding 100 W·m^{-2}·sr^{-1}, the maximum permissible exposure duration, t_{max}, shall be computed:

$$t_{max} = \frac{10^6}{L_B} \qquad \text{s} \qquad \text{(for } t \leq 10^4 \text{ s)} \qquad (4.6)$$

where:

t_{max} is the maximum permissible exposure duration in seconds,
L_B is the blue-light hazard weighted radiance.

Note 1: The spectral radiance L_λ shall be averaged over a right circular cone field-of-view of α_{eff}, as described in clause 4.2.2.
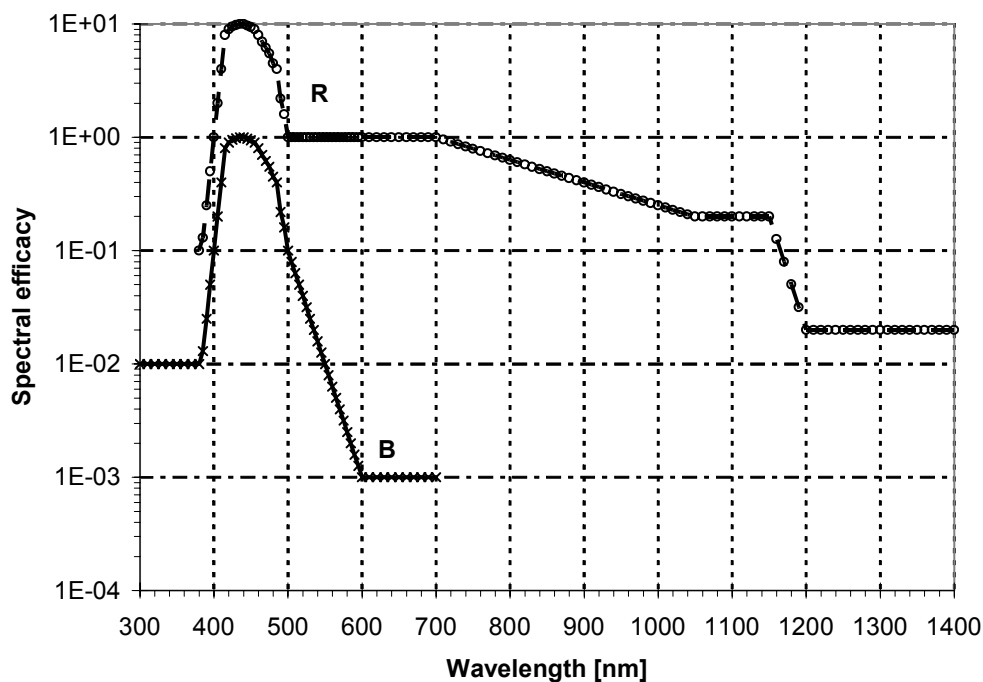
Figure 4.2 Spectral weighting functions for retinal hazards:
$B(\lambda)$ and $R(\lambda)$.

Note 2: In the case of multiple source elements that are not contiguous, this criterion applies to a single source element. Also, it applies to the source as a whole when the average radiance over the full source is used.

4.3.4 Retinal blue light hazard exposure limit - small source

For a light source subtending an angle less than 0,011 radian the limits of clause 4.3.3 lead to a simpler equation based on the spectral irradiance rather than the spectral radiance. By application of Equation (5.4) it can be shown that the relationship between L and E, for a subtended angle of 0,011 radian is a factor of approximately 10^4. Thus the spectral irradiance at the eye E_λ, weighted against the blue-light hazard function $B(\lambda)$ (see Table 4.2) shall not exceed the levels defined by:

$$E_B \cdot t = \sum_{300}^{700} \sum_t E_\lambda(\lambda,t) \cdot B(\lambda) \cdot \Delta t \cdot \Delta\lambda \leq 100 \text{ J·m}^{-2} \qquad \text{(for } t \leq 100 \text{ s)} \qquad (4.7a)$$

$$E_B = \sum_{300}^{700} E_\lambda \cdot B(\lambda) \cdot \Delta\lambda \leq 1 \qquad \text{W·m}^{-2} \qquad \text{(for } t > 100 \text{ s)} \qquad (4.7b)$$

where:

$E_\lambda(\lambda,t)$ is the spectral irradiance in W·m^{-2}·nm^{-1},
$B(\lambda)$ is the blue light hazard weighting function,
$\Delta\lambda$ is the bandwidth in nm,
t is the exposure duration in seconds.

For a source where the blue light weighted irradiance, E_B, exceeds 0,01 W·m^{-2}, the maximum permissible exposure duration shall be computed:

$$t_{max} = \frac{100}{E_B} \qquad \qquad \text{s} \qquad \text{(for } t \leq 100 \text{ s)} \qquad (4.8)$$

where:

t_{max} is the maximum permissible exposure duration in seconds,
E_B is the blue light hazard weighted irradiance.

Note 1: Note that the exposure time at which E_B becomes independent of time is 100 s rather than the 10000 s given for L_B in Equation (4.6). The reason for this change is that for exposure times greater than 100 s it was assumed that the diameter of the irradiated area of the retina increases as the square root of time. Hence the effective irradiance of the retina decreases and the retinal radiant exposure deposited becomes independent of time for exposure durations between 100 s and 10 000 s due to the assumption of task-oriented eye movements. This behaviour is shown in the graphical representation of E_B in Figure 5.4.

Note 2: For ophthalmic instruments or for a stabilized eye during surgery where eye movements are minimal the exposure time is extended to 10 000 s. This implies that in such cases the blue light weighted irradiance should be $\leq 10^{-2}$ W·m^{-2}, i.e.,100 times smaller than that given in Equation (4.7b).

4.3.5 Retinal thermal hazard exposure limit

To protect against retinal thermal injury, the integrated spectral radiance of the light source, L_λ, weighted by the burn hazard weighting function $R(\lambda)$ (from Figure 4.2 and Table 4.2), i.e., the burn hazard weighted radiance, shall not exceed the levels defined by:

$$L_R = \sum_{380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \leq \frac{50000}{\alpha \cdot t^{0,25}} \qquad \text{W·m}^{-2}\text{·sr}^{-1} \qquad (10\ \mu s \leq t \leq 10s) \qquad (4.9)$$

where:

L_λ is the spectral radiance in W·m^{-2}·sr^{-1} nm^{-1},
$R(\lambda)$ is the burn hazard weighting function,
t is the viewing duration (or pulse duration if the lamp is pulsed), in seconds,
$\Delta\lambda$ is the bandwidth in nm,
α is the angular subtense of the source in radians.

Note 1: L_λ shall be averaged over a right circular cone field-of-view of not less than 0,0017 radian, and not more than 0,1 radian, included angle.

Note 2: In the case of multiple source elements that are not contiguous, this criterion applies to a single source element. Also it applies to the source as a whole when the average radiance over the full source is used.

4.3.6 Retinal thermal hazard exposure limit – weak visual stimulus

For an infrared heat lamp or any near-infrared source where a weak visual stimulus is inadequate to activate the aversion response, the near infrared (780 nm to 1400 nm) radiance, L_{IR}, as viewed by the eye for exposure times greater than 10 s shall be limited to:

$$L_{IR} = \sum_{780}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \leq \frac{6000}{\alpha} \qquad \text{W·m}^{-2}\text{·sr}^{-1} \qquad (t > 10\ s) \qquad (4.10)$$

where:

L_λ is the spectral radiance in W·m^{-2}·sr^{-1}·nm^{-1},
$R(\lambda)$ is the burn hazard weighting function,
$\Delta\lambda$ is the bandwidth in nm,
t is the exposure time in seconds,
α is the angular subtense in radians.

A weak visual stimulus is defined herein as one whose maximum luminance (averaged over a circular field-of-view subtending 0,011 radian) is less than 10 cd·m^{-2}.

Note 1: L_λ shall be averaged over a right circular cone field-of-view of not less than 0,011 radian nor more than 0,1 radian included angle.

Note 2: The limit expressed in Equations 4.11a and b is based upon a 7 mm diameter ocular pupil because it is assumed that the source luminance is weak. For situations where the ambient light can only be high, a pupil diameter of 3 mm may be assumed which implies that the EL can be adjusted to higher values by the square of the ratio of the pupil diameters (a factor of 5,5), i.e., the EL can be increased to $33000/\alpha$ W·m^{-2}·sr^{-1} (see clause 4.2.1).

4.3.7 Infrared radiation hazard exposure limits for the eye

To avoid thermal injury of the cornea and possible delayed effects upon the lens of the eye (cataractogenesis), ocular exposure to infrared radiation, E_{IR}, over the wavelength range 780 nm to 3000 nm, for times less than 1000 s, shall not exceed:

$$E_{IR} = \sum_{780}^{3000} E_{\lambda} \cdot \Delta\lambda \leq 18000 \cdot t^{-0,75} \qquad \text{W·m}^{-2} \qquad (t \leq 1000 \text{ s}) \qquad (4.11a)$$

For times greater than 1000 s the limit becomes:

$$E_{IR} = \sum_{780}^{3000} E_{\lambda} \cdot \Delta\lambda \leq 100 \qquad \text{W·m}^{-2} \qquad (t > 1000 \text{ s}) \qquad (4.11b)$$

where:

E_{λ} is the spectral irradiance in W·m^{-2}·nm^{-1},
$\Delta\lambda$ is the bandwidth in nm,
t is the exposure duration in seconds.

Note 1: In cold environments, the limits for long time exposure may be increased to 400 W·m^{-2} at 0°C and 300 W·m^{-2} at 10°C for applications where infrared sources are used for radiant heating.

Note 2: The contribution from IR-C is already incorporated in these limits for all incandescent sources.

4.3.8 Thermal hazard exposure limit for the skin

Visible and infrared radiant exposure (380 nm to 3000 nm) of the skin shall be limited to:

$$E_{H} \cdot t = \sum_{380}^{3000} \sum_{t} E_{\lambda}(\lambda, t) \cdot \Delta t \cdot \Delta\lambda \leq 20000 \cdot t^{0,25} \qquad \text{J·m}^{-2} \qquad (t \leq 10 \text{ s}) \qquad (4.12)$$

where:

$E_{\lambda}(\lambda, t)$ is the spectral irradiance in W·m^{-2}·nm^{-1},
$\Delta\lambda$ is the bandwidth in nm,
t is the exposure time in seconds.

Note: This exposure limit is based on skin injury due to a rise in tissue temperature and applies only to small area irradiation. Exposure limits for periods greater than 10 s are not provided. Severe pain occurs below the skin temperature required for skin injury, and an individual's exposure normally will be limited for comfort. Large area irradiation and heat stress are not evaluated since this involves consideration of heat exchange between the individual and the environment, physical activity, and various other factors, which cannot be applied in a product safety standard, but must be evaluated by environmental heat-stress criteria.

5. MEASUREMENT OF LAMPS AND LAMP SYSTEMS

The measurement of optical radiation for the purpose of computing photobiological radiation values poses significant challenges for the radiometrist. Typical photobiological action spectra such as $S_{UV}(\lambda)$ have rapidly changing values with slight change in wavelength. Furthermore, transmission of radiation from lamp sources with glass envelopes have rapidly increasing output with increasing wavelength in the region where $S_{UV}(\lambda)$ is rapidly decreasing. Hence issues of accuracy of the weighted results must be thoroughly considered.

While irradiance measurements are routinely performed, radiance measurements are not routine and often difficult to make, especially for the photobiological hazards, as they involve a field of view that changes depending on the hazard evaluation.

For these reasons it was thought necessary to include a rather lengthy discussion on the conditions and procedures needed to make emission measurements that will be used to assign risk group classification of various lamps and lamp systems.

It should be noted that the measurement procedures described in this standard are designed to account for biophysical phenomena. Specifically, they can involve averaging over apertures or field-of-views which would be considered inappropriate for general radiometric measurements. However, hazards might be overestimated if non-averaged measurement values were to be compared with the respective exposure limits.

To better provide a comparison of the various exposure limits, developed in clause 4.3, including the effects of the field-of-view, both a tabular and graphical summary are shown at the end of this clause. Thus Figure 5.4 and Table 5.4 summarizes the maximum values for each of the irradiance based hazard exposure quantities as a function of exposure time, while Figure 5.5 and Table 5.5 summarizes the maximum radiance based (retinal) hazard exposure quantities, also as a function of exposure time.

Note: The upper wavelength range for evaluation of any hazard is given as 3000 nm in clause 1. Spectral irradiance or radiance measurements using a monochromator are often difficult to make in the IR, particularly between 2500 and 3000 nm due to a lack of signal response and difficulty in obtaining calibrated sources. However, no weighting function is defined at wavelengths greater than 1400 nm. Thus broadband measurements for wavelengths between 1400 and 3000 nm are suitable in evaluating IR hazard conditions for the eye and skin in this region.

5.1 Measurement conditions

Measurement conditions shall be reported as part of the evaluation against the exposure limits and the assignment of risk classification.

5.1.1 Lamp ageing (seasoning)

To maintain stable output during the measurement process and provide reproducible results, lamps shall be seasoned for an appropriate period of time. During the initial period of operation a lamp output characteristic will change as its components come to near equilibrium. If measurements are taken of an unseasoned lamp, the variations within the measurement period and between measurements could be significant. As the output of a lamp generally decreases over life, the seasoning time should be short to result in conservative hazard evaluations.

Seasoning of lamps shall be done as stated in the appropriate IEC lamp standard.

Note: The seasoning time for discharge lamps, e.g., fluorescent or High Intensity Discharge (HID) types, is typically 100 h, for tungsten lamps it is on the order of one percent of rated lamp life. However, these seasoning criteria may differ for special applications, e.g. for solaria lamps.

5.1.2 Test environment

The accurate measurement of light sources requires a controlled environment. The operation of sources and measurement equipment is impacted by environmental factors. Additionally the formation of ozone in the measurement path may compromise accuracy and may present a safety hazard. For specific test conditions, see the appropriate IEC lamp standard or in the absence of such standards, the appropriate national standards or manufacturer's recommendations.

The ambient temperature will significantly influence the output of certain light sources; e.g., fluorescent lamps. The ambient temperature in which measurements are taken shall be maintained in accordance with the appropriate IEC lamp standard.

The characteristics of some light sources are also significantly affected by draughts. Air movement over the surface of test lamps, other than that caused by natural convection due to the lamp itself, should be reduced as much as possible consistent with safety considerations (ozone production). When the system under test provides interlocks that maintain circulation, measurements shall be performed with circulation.

5.1.3 Extraneous radiation

Careful checks should be made to ensure that extraneous sources of radiation and reflections do not add significantly to the measurement results. Often baffles are used to reduce extraneous radiation. Note that visually black surfaces can be reflective to UV and IR radiation. In addition radiation from hot baffles must be considered in infrared measurements due to the large input angle subtended by baffles.

5.1.4 Lamp operation

Operation of the test lamp shall be provided in accordance with the appropriate IEC lamp standard. If no standard for the lamp type exists, the lamp manufacturer's recommendation for operation should be used.

5.1.5 Lamp system operation

The power source for operation of the test lamp shall be provided in accordance with the appropriate IEC standard. If no standard for the control gear exists, the lamp manufacturer's recommendation for operation should be used.

5.2 Measurement procedure

5.2.1 Irradiance measurements

The description given applies both to broadband and spectral irradiance measurements. An ideal instrument to measure irradiance involves a plane circular area detector of diameter D, sufficient to achieve the desired signal-to-noise ratio and, that:

- accepts radiation within a right circular cone whose centerline is normal to the plane of the detector area,
- has an angular spatial response varying as the cosine of the angle from the normal to the detector area,
- has a spectral response that is constant with position within a specified wavelength band from λ_1 to λ_2.

In this standard the minimum input aperture diameter shall be 7 mm with a maximum input aperture diameter of 50 mm. A plane circular aperture of 25 mm diameter is common on small integrating spheres, recommended above as the input for monochromators. The 25 mm diameter aperture is recommended for sources with spatially uniform optical radiation patterns. For sources that do not produce a spatially uniform irradiance, e.g., narrow beam reflector lamps, the peak irradiance (intensity) may be significantly higher than that obtained by measurement using the under-filled 25 mm diameter aperture. In such cases the detector aperture should be limited to a 7 mm diameter aperture.

Figure 5.1 schematically shows the main concepts involved in making irradiance or spectral irradiance measurements, including, if needed, the aperture to limit the field of view, of half angle, A, at some distance from the receptor that is large with respect to the detector diameter.

The measurement shall be made in that position of the beam giving the maximum reading. The instrument shall be calibrated to read in absolute incident radiant power per unit receiving area.

Note 1: From a practical point changing the input aperture requires significant extra work in re-calibration of the radiometer or spectroradiometer. If the change of irradiance with distance is known, one method of achieving the lower aperture requirement is to move the detector aperture (assume 25 mm diameter is used) away from the source to a measurement distance where the 7 mm aperture cone at a distance of 200 mm now fills the 25 mm aperture, i.e., a distance about 3,5 times the standard evaluation distance.

Note 2: The measured irradiance should not be averaged over a smaller aperture than specified, as this might result in an overestimation of the hazard. The minimum size of the averaging aperture is related to physiological and behavioural factors that result in the averaging of the incident radiation over a certain surface area.

Note 3: For a number of reasons, including the physiology of the eye, all the exposure levels for ultraviolet radiation discussed in clause 4.3.1 and 4.3.2 apply to sources that subtend an angle less than 80 degrees (1,4 radian), i.e., sources within 40 degrees of the normal to the irradiance area. Thus emission from sources that subtend a greater angle need to be measured only over a full angle of 80 degrees.

Irradiance measurements apply to the following hazards described in clause 4.3 of this standard.

* 315 nm – 400 nm ocular exposure limit, E_{UVA}
* IR hazard exposure limit, E_{IR}
* Skin – thermal hazard exposure limit, E_H

Spectral irradiance measurements apply to the following hazards also described in clause 4.3 of this standard.

* 200 – 400 nm skin and ocular exposure limit, E_S
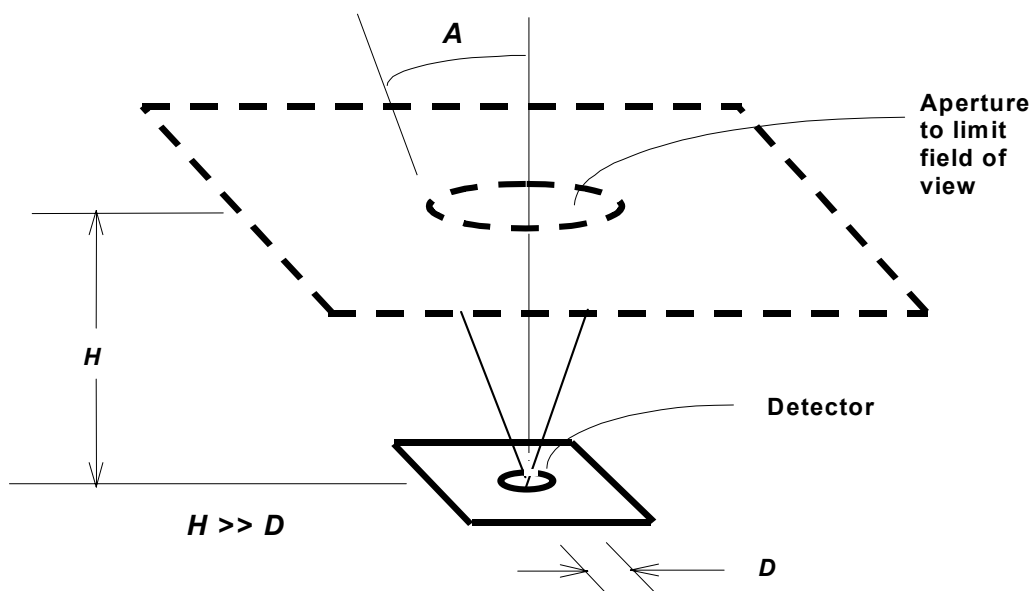* Retinal blue light hazard exposure limit – small source, E_B

Figure 5.1 Schematic - Irradiance measurements.

5.2.2 Radiance measurements

5.2.2.1 Standard method

The description given applies both to broadband and spectral radiance measurements. Radiance measurements are performed with an optical system that (see Figure 5.2):

- images the radiant source onto a detector,
- has a circular field stop to establish the specified angular extent of the averaging field of view α_{eff},
- has a circular entrance pupil (aperture stop) which acts as an averaging aperture in the sense of irradiance measurements and fulfils the same requirements as stated in clause 5.2.1. For small angles the relationship between the detector diameter and the focal distance of the imaging device is seen to be $d = \alpha_{eff} \cdot H$.

As with irradiance measurements, the minimum aperture stop diameter D, as shown in Figure 5.2, corresponds to a 7 mm pupil diameter for pulsed sources and is a biophysically recognised averaging aperture for cw sources where the pupil could be smaller but eye and head movements allow for this aperture averaging. As with irradiance measurements, the aperture stop can exceed 7 mm if the incident irradiance profile is sufficiently uniform.
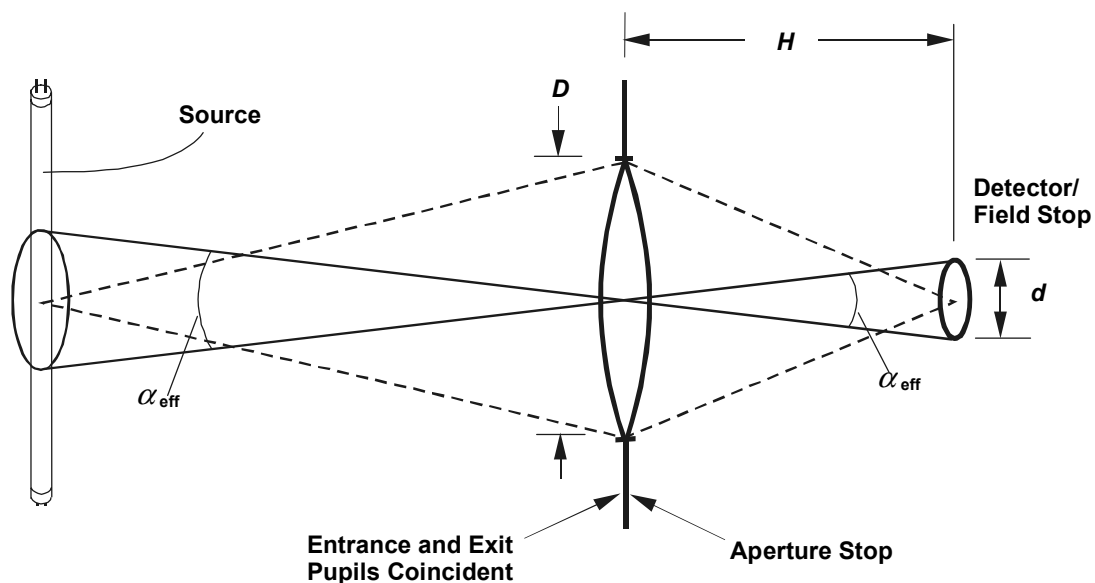

Figure 5.2 Example of an imaging device for radiance measurements.

The instrument shall be calibrated to read in absolute incident radiant power per unit receiving area and per unit solid angle of acceptance averaged over the field of view (FOV) of the instrument.

Note: The measured radiance should not be averaged over a smaller field of view than specified, as this might result in an overestimation of the hazard. The size of the averaging field of view is related to the extent of eye movements that distribute the radiant power of the source image over a larger area on the retina. The size of the averaging field of view α_{eff} is independent of the source size α. For sources that subtend an angle α smaller than the specified field of view α_{eff}, the averaged radiance value will be smaller than the actual physical radiance of the source; however this biologically effective value is the appropriate value to be compared to the exposure limit.

Spectral radiance measurements apply to the following hazards also described in clause 4.3 of this standard.

- Retinal blue light hazard exposure limit, L_B
- Retinal thermal exposure limit, L_R
- Retinal thermal exposure limit – weak visual stimulus, L_{IR}.

5.2.2.2 Alternative method

Radiance measurements can be conceptualised as an irradiance measurement performed with a well-defined field of view where the measured irradiance value is divided by the measurement field of view to obtain the radiance value. Alternatively to an imaging radiance set-up (above), an irradiance measurement set-up with a circular field stop placed at the source can be used to perform radiance measurements (Figure 5.3). The size of the field stop, F, and the distance of the field stop to the aperture stop, r, define the field of view, i.e.:

$$\gamma = F/r \tag{5.1}$$

This set-up implies that the field stop can be placed sufficiently close to the apparent source to produce the required field of view.

The relationship between the measured irradiance, E, and the source radiance, L, for detection normal to the source area, ($\theta = 0$ in definition 3.31), for small angles, is given as:

$$E = L \cdot \Omega , \tag{5.2}$$

where Ω, angle in sr, is the measurement field of view, i.e., the solid angle subtended by the planar angle, γ, angle in radian, shown in Figure 5.3. Furthermore, for small angles the relationship between the plane angle γ and the solid angle Ω is:

$$\Omega = \frac{\pi \cdot \gamma^2}{4} \tag{5.3}$$

Thus using the dimensions shown in Figure 5.3, the irradiance in terms of the source radiance is given by:

$$E = L \cdot \frac{\pi \cdot \gamma^2}{4} = L \cdot \frac{\pi \cdot F^2}{4 \cdot r^2} \tag{5.4}$$
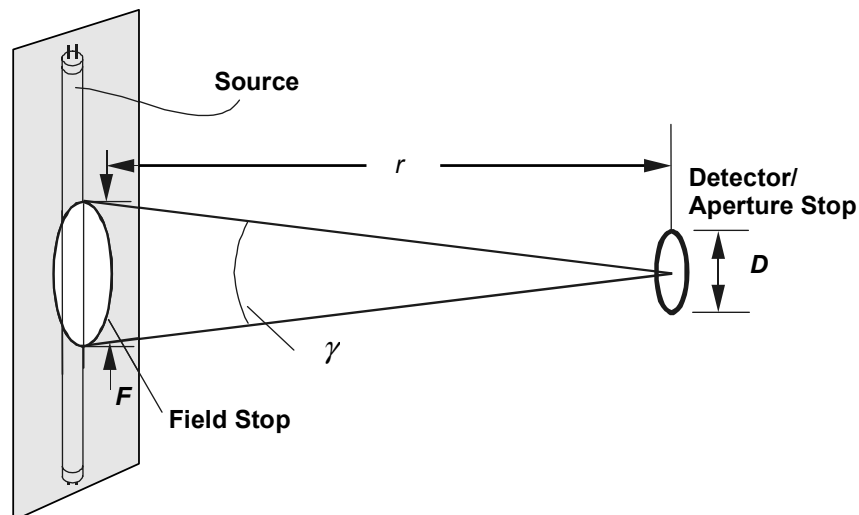

Figure 5.3 Alternative radiance technique.

When using the irradiance measurements to obtain radiance values to compare against a given hazard, the field stop diameter, F, must be set such that

$$\gamma = \alpha_{eff} \tag{5.5}$$

Note: The blue light hazard small-source-irradiance limit is equivalent to the radiance limit for the specified measurement averaging field of view. The irradiance limit is derived by multiplying the radiance limit with the averaging measurement field of view using Equation (5.4).

5.2.3 Measurement of source size

The determination of α, the angle subtended by a source, requires the determination of the 50% emission points of the source. Common methods using photography or solid state cameras should be used only after verifying that the spectral uniformity is sufficient to warrant the use of visible radiation as an analog for the IR radiation. Changes in spectra across a source can lead to different sizes in different regions of the spectra. (See *Sliney and Wolbarsht*, 1980, clause 12.6.6.)

5.2.4 Pulse width measurement for pulsed sources

The determination of Δt, the nominal pulse duration of a source, requires the determination of the time during which the emission is > 50% of its peak value. Common methods, e.g., using a photocell with an oscilloscope, should be applied only after verifying that the spectral uniformity is sufficient to warrant the use of visible radiation as an analog for the UV or IR radiation. Changes in spectra during a pulse can lead to different pulse widths in different regions of the spectra.

5.3 Analysis methods

5.3.1 Weighting curve interpolations

The weighting curves defined in Table 4.1 are normally not sufficiently resolved to perform the weighted source emission calculations. The functions are reasonably linear in any local region on semi-log coordinates. Therefore to standardize interpolated values, use linear interpolation on the log of given values to obtain intermediate points at the wavelength intervals desired, e.g., one nanometer interval recommended. Anti-logarithm of the interpolated numbers result in the values needed for the interpolated weighting factors.

5.3.2 Calculations

The calculation of source hazard values shall be performed by weighting the spectral scan by the appropriate function and calculating the total weighted energy. To provide a repeatable method this standard suggests interpolation or summing to one nanometer (1 nm) for the spectra below 400 nm. Weighting and summations are then performed at this 1 nm resolution. Above 400 nm, a step size of 5 nm is recommended.

5.3.3 Measurement uncertainty

The quality of all measurement results must be quantified by an analysis of the uncertainty. All calculated results must be paired with uncertainty values that conform to the guidance in the normative references. The uncertainty of each result will be reported as the expanded uncertainty, which is calculated from the combined standard uncertainty, u_c, by use of a coverage factor, k=2, as defined in the ISO guide listed in Clause 2. The values of uncertainty should be propagated from the calibration uncertainties, through the calculations and include all sources as described in Annex C.

Table 5.4 Summary of the ELs for the surface of the skin or cornea (irradiance based values)

Hazard Name	Relevant equation	Wavelength range nm	Exposure duration sec	Limiting aperture rad (deg)	EL in terms of constant irradiance W·m^{-2}
Actinic UV skin & eye	$E_s = \sum E_\lambda \cdot S(\lambda) \cdot \Delta\lambda$	200 – 400	< 30000	1,4 (80)	30/t
Eye UV-A	$E_{UVA} = \sum E_\lambda \cdot \Delta\lambda$	315 – 400	≤1000 >1000	1,4 (80)	10000/t 10
Blue-light small source	$E_B = \sum E_\lambda \cdot B(\lambda) \cdot \Delta\lambda$	300 – 700	≤100 >100	< 0,011	100/t 1,0
Eye IR	$E_{IR} = \sum E_\lambda \cdot \Delta\lambda$	780 –3000	≤1000 >1000	1,4 (80)	18000/$t^{0,75}$ 100
Skin thermal	$E_H = \sum E_\lambda \cdot \Delta\lambda$	380 – 3000	< 10	2π sr	20000/$t^{0,75}$

Table 5.5 Summary of the ELs for the retina (radiance based values)

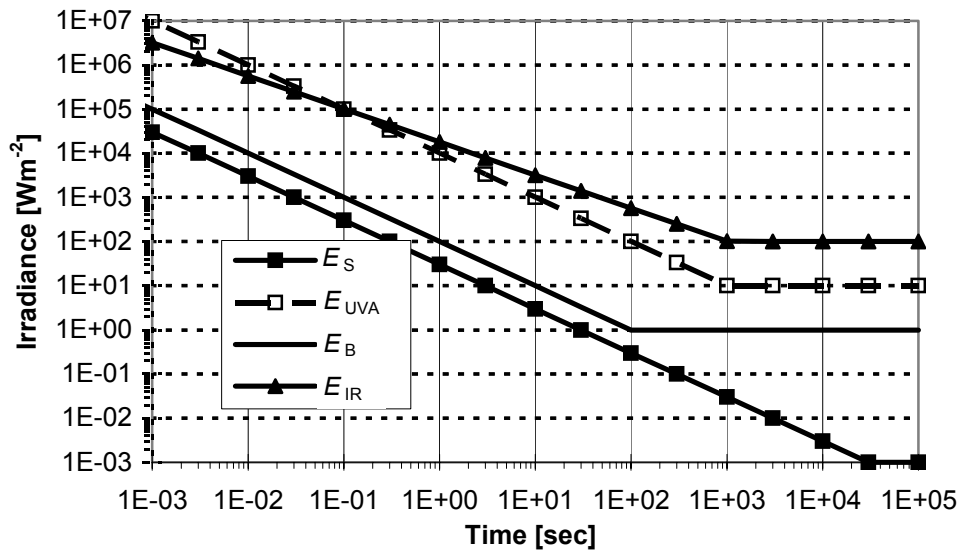| Hazard Name	Relevant equation	Wavelength range nm	Exposure duration sec	Field of view radians	EL in terms of constant radiance W·m^{-2}·sr^{-1})
Blue light	$L_B = \sum L_\lambda \cdot B(\lambda) \cdot \Delta\lambda$	300 – 700	0,25 – 10 10-100 100-10000 ≥ 10000	0,011·√(t/10) 0,011 0,0011·√t 0,1	10^6/t 10^6/t 10^6/t 100
Retinal thermal	$L_R = \sum L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$	380 – 1400	< 0,25 0,25 – 10	0,0017 0,011·√(t/10)	50000/(α·$t^{0,25}$) 50000/(α·$t^{0,25}$)
Retinal thermal (weak visual stimulus)	$L_{IR} = \sum L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$	780 – 1400	> 10	0,011	6000/α

Figure 5.4 Weighted irradiance exposure limits vs. time
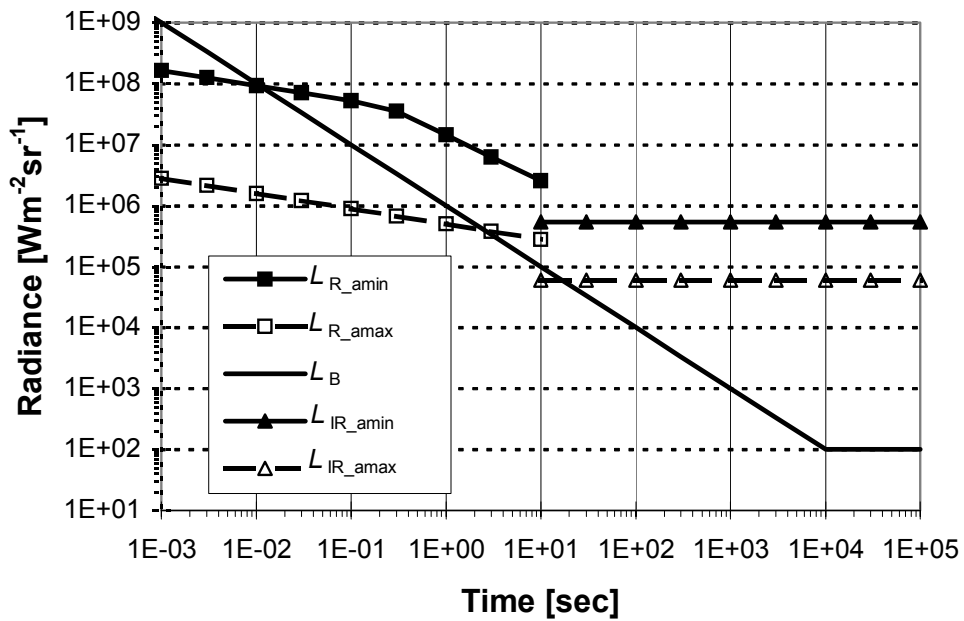for constant exposure.

Figure 5.5 Weighted radiance exposure limits vs. time
for constant exposure.

6. LAMP CLASSIFICATION

This standard was developed by CIE TC 6-47 with representation of IEC SC34A. This joint effort was deemed important so that issues concerning risk group classification and distance at which the photobiological hazard values due to lamp radiation are reported could be agreed upon. Since lamps may be hazardous from several aspects, a classification scheme is helpful. For the purposes of this standard it was decided that the values shall be reported as follows:

- for lamps intended for general lighting service (GLS), see definition 3.11, the hazard values shall be reported as either irradiance or radiance values at a distance which produces an illuminance of 500 lux, but not at a distance less than 200 mm;
- for all other light sources, including pulsed lamp sources, the hazard values shall be reported at a distance of 200 mm.

This clause is concerned with lamp classification. However a similar classification system could be applicable to luminaires or other systems containing operating lamps. For lamps intended for general lighting, the distance at which the irradiance measurements are made is left to the discretion of the measurement facility.

The classification scheme indicates only the potential risk. Depending upon use factors, time of exposure, and luminaire effects, these potential hazards may or may not actually become real hazards. Table 6.1 summarizes the various irradiance and radiance emission limits for each of the hazards discussed in clause 4.3 for each risk group classification.

Note: In some cases the same lamp may be used in both GLS and special applications and in such cases should be evaluated and rated for the intended applications.

6.1 Continuous wave lamps

6.1.1 Exempt group

The philosophical basis for the exempt group classification is that the lamp does not pose any photobiological hazard for the end points in this standard. This requirement is met by any lamp that does not pose

- an actinic ultraviolet hazard (E_s) within 8-hours exposure (30000 s), nor
- a near-UV hazard (E_{UVA}) within 1000 s, (about 16 min) nor
- a retinal blue-light hazard (L_B) within 10000 s (about 2,8 h), nor
- a retinal thermal hazard (L_R) within 10 s, nor
- an infrared radiation hazard for the eye (E_{IR}) within 1000 s.

These lamps are in the Exempt Group.

Also, lamps that emit infrared radiation without a strong visual stimulus (i.e., less than 10 cd·m^{-2}) and do not pose a near-infrared retinal hazard (L_{IR}) within 1000 s are in the Exempt Group.

6.1.2 Risk Group 1 (Low-Risk)

The philosophical basis for this classification is that the lamp does not pose a hazard due to normal behavioral limitations on exposure. This requirement is met by any lamp that exceeds the limits for the Exempt Group but that does not pose

- an actinic ultraviolet hazard (E_s) within 10000 s, nor
- a near ultraviolet hazard (E_{UVA}) within 300 s, nor
- a retinal blue-light hazard (L_B) within 100 s, nor
- a retinal thermal hazard (L_R) within 10 s, nor
- an infrared radiation hazard for the eye (E_{IR}) within 100 s.

These lamps are in Risk Group 1 (Low-Risk).

Also, lamps that emit infrared radiation without a strong visual stimulus (i.e., less than 10 cd·m^{-2}) and do not pose a near-infrared retinal hazard (L_{IR}), within 100 s are in Risk Group 1 (Low-Risk).

6.1.3 Risk Group 2 (Moderate-Risk)

The philosophical basis for the Risk Group 2 (Moderate-Risk) classification is that the lamp does not pose a hazard due to the aversion response to very bright light sources or due to thermal discomfort. This requirement is met by any lamp that exceeds the limits for Risk Group 1 (Low-Risk), but that does not pose

- an actinic ultraviolet hazard (E_s) within 1000 s exposure, nor
- a near ultraviolet hazard (E_{UVA}) within 100 s, nor
- a retinal blue-light hazard (L_B) within 0,25 s (aversion response), nor
- a retinal thermal hazard (L_R) within 0,25 s (aversion response), nor
- an infrared radiation hazard for the eye (E_{IR}) within 10 s.

Such lamps are in Risk Group 2 (Moderate-Risk).

Also, lamps that emit infrared radiation without a strong visual stimulus (i.e., less than 10 cd$\cdot$m^{-2}) and do not pose a near infrared retinal hazard (L_{IR}) within 10 s are in Risk Group 2 (Moderate-Risk).

6.1.4 Risk Group 3 (High-Risk)

The philosophical basis for this classification is that the lamp may pose a hazard even for momentary or brief exposure. Lamps which exceed the limits for Risk Group 2 (Moderate-Risk) are in Risk Group 3 (High-Risk).

6.2 Pulsed lamps

Pulsed lamp criteria shall apply to a single pulse and to any group of pulses within 0,25 second.

A pulsed lamp shall be evaluated at the highest nominal energy loading as specified by the manufacturer.

The relevant weighted radiant exposure, (H or $E\cdot t$), or time-integrated weighted radiance dose, ($L\cdot t$), for each pulse shall be obtained by integration of the weighted irradiance or radiance emitted from the source over the full pulse width, with the integration time limited to a maximum of 0,25 s. The weighted radiant exposure or weighted radiance dose calculated shall be compared to the exposure limits (ELs) given in clause 4.3 for each of the photobiological hazards evaluated.

Note: The weighted radiance values obtained shall be averaged over a right circular cone field of view of 0,0017 radian included angle as discussed in clause 4.2.2.

The risk group determination of the lamp being tested shall be made as follows:

- A lamp that exceeds the exposure limit shall be classified as belonging to Risk Group 3 (High-Risk).
- For single pulsed lamps, a lamp whose weighted radiant exposure or weighted radiance dose is below the EL shall be classified as belonging to the Exempt Group.
- For repetitively pulsed lamps, a lamp whose weighted radiant exposure or weighted radiance dose is below the EL, shall be evaluated using the Continuous wave risk criteria discussed in clause 6.1, using time averaged values of the pulsed emission.

Table 6.1 Emission limits for risk groups of continuous wave lamps.

Risk	Action spectrum	Symbol	Emission limits			Units
			Exempt	Low risk	Mod risk	
Actinic UV	$S_{UV}(\lambda)$	E_s	0,001	0,003	0,03	$W \cdot m^{-2}$
Near UV		E_{UVA}	10	33	100	$W \cdot m^{-2}$
Blue light	$B(\lambda)$	L_B	100	10000	4000000	$W \cdot m^{-2} \cdot sr^{-1}$
Blue light, small source	$B(\lambda)$	E_B	1,0*	1,0	400	$W \cdot m^{-2}$
Retinal thermal	$R(\lambda)$	L_R	$28000/\alpha$	$28000/\alpha$	$71000/\alpha$	$W \cdot m^{-2} \cdot sr^{-1}$
Retinal thermal, weak visual stimulus**	$R(\lambda)$	L_{IR}	$6000/\alpha$	$6000/\alpha$	$6000/\alpha$	$W \cdot m^{-2} \cdot sr^{-1}$
IR radiation, eye		E_{IR}	100	570	3200	$W \cdot m^{-2}$
* Small source defined as one with $\alpha < 0,011$ radian. Averaging field of view at 10000 s is 0,1 radian. ** Involves evaluation of non-GLS source						

ANNEX A
(informative)

SUMMARY OF BIOLOGICAL EFFECTS

Bioeffect datasheet #1: Infrared cataract

A.1   Bioeffect: INFRARED CATARACT also known as "industrial heat cataract", "furnaceman's cataract", or "glassblower's cataract".

A.1.1   Organ/Site: Eye/Crystalline Lens.

A.1.2   Spectral range: 700 nm to 1400 nm and possibly to 3000 nm.

A.1.3   Peak of action spectrum: Not known; probably between 900-1000 nm.

A.1.4   State of knowledge: Limited threshold data available for acute cataract for rabbit at 1064 nm (Wolbarsht, 1992) and IR-A region (Pitts and Cullen, 1981); no data for man. Degree of additivity and action spectrum unknown. Good epidemiological evidence (Lydahl, 1984).

A.1.5   Time course: Noticeable clouding of the lens generally following years of chronic high-level exposure, the elapsed time depending upon how much difference between exposure and threshold, heavy exposures producing reaction in shortest time.

A.1.6   Mechanism: Generally presumed to be thermal, although recent evidence suggests possible photochemical reaction - details not understood. The lens may be heated either from direct irradiation (Vogt, 1919) or by conductive heating from the heated iris (Goldmann, 1983).

A.1.7   Symptoms: Clouding of vision.

A.1.8   Needed information: Action spectrum, if existent, for acute and for effects of concomitant ultraviolet radiation exposure; additivity of multiple exposures, and the possibility of delayed effects from recurrent exposures.

A.1.9   Experience with lamps: Accidental injury is not known, even from exposure to heat lamps. Limited population exposed.

A.1.10   Key references:

GOLDMANN, H. Experimentelle Untersuchungen über die Genese des Feuerstars. 111 Mitteilung. Die Physik des Feuerstars I. Teil. *Arch. für Ophthalmol*., **130,** 93-130 (1983).

LYDAHL, E. Infrared Radiation and Cataract. *Acta Ophtalmologica*, Suppl. **166**, 1-63 (1984).

PITTS, D.G. and CULLEN, A.P. Determination of Infrared Radiation Levels for Acute Ocular Cataractogenesis. *von Graefes Arch. Ophthal*., **217**, 285-297 (1981).

SLINEY, D.H. and WOLBARSHT, M.L. *Safety with Lasers and Other Optical Sources.* New York, Plenum, (1980).

VOGT, A. Experimentelle Erzeugung von Katarakt durch isoliertes kurzwelliges Ultrarot, dem Rot beigemischt ist. *Klin. Mb/ Augenheilk.*, **63,** 230-231 (1919).

WOLBARSHT, M.L. Cataract from Infrared Lasers: Evidence for Photochemical Mechanisms. *Lasers and Light Ophthalmology*, **4**, 91-96 (1992).

Bioeffect datasheet #2: Photokeratitis

A.2   Bioeffect: PHOTOKERATITIS

A.2.1   Organ/Site: Eye/Cornea.

A.2.2   Spectral range: (180-200) nm to (400-420) nm; principally 200-320 nm.

A.2.3   Peak of action spectrum: approximately 270 nm (Pitts, 1971); approximately 288 nm (Cogan and Kinsey, 1946).

A.2.4 **State of knowledge**: Good acute threshold data available for rabbit (200 nm to 400 nm); for monkey (200 nm to 320 nm); for man (200 nm to 300 nm). Data from different laboratories are generally in good agreement.

A.2.5 **Time course**: Noticeable reaction generally delayed by 4 to 12 hours following the exposure, the elapsed time depending upon how much difference in exposure and threshold, heavy exposures producing reaction in shortest time; clearing in 24 to 48 hours, except for extremely severe exposures.

A.2.6 **Mechanism**: Photochemical reaction initiates chain of biological reactions; details not understood.

A.2.7 **Symptoms**: "Sand in the eye", blepharospasm (sudden, violent, involuntary contraction of the muscles of the eyelid), some clouding of vision; reaction in the palpebral fissure (opening between the upper and lower eyelids).

A.2.8 **Needed information**: Higher resolution of thresholds in 305 nm to 320 nm range; possibility of delayed effects due to recurrent exposures.

A.2.9 **Experience with lamps**: Not uncommon accidental exposure from germicidal lamps and mercury and xenon-arc lamps, but only in special applications. Limited population exposed.

A.2.10 **Key references**:

COGAN, D.G. and KINSEY, V.E. Action Spectrum of Keratitis Produced by Ultraviolet Radiation. *Arch. Ophthalmol*., **35**, 670-617 (1946).

HEDBLOM, E.E. Snowscape Eye Protection. *Arch. Environ. Health*, **2**, 685-704 (1961).

LEACH. W. M. *Biological Aspects of Ultraviolet Radiation, A Review of Hazards.* BRH/DBE **70-3**, U.S. Public Health Service, Bureau of Radiological Health, Rockville, Maryland (Sept. 1970).

MACKEEN, D., FINE, S., AARON, A., and FINE, B.S. Preventable Hazards at UV Wavelengths. *Laser Focus*, **7(4)**, 29 (1971).

PITTS, D.G. and TREDICI, T.J. The Effects of Ultraviolet on the Eye. *Ameri. Ind. Hyg. Ass. J.* **32(4)**, 235-246 (1971).

Bioeffect datasheet #3: Photoretinitis

A.3 **Bioeffect**: PHOTORETINITIS or "blue-light retinal injury"

A.3.1 **Organ/Site**: Eye/Retina.

A.3.2 **Spectral range:** 400 nm to 700 nm (principally 400-500 nm) in phakic eye (crystalline lens intact); 310 nm to 700 nm in aphakic (crystalline lens removed) eye (principally 310 nm to 500 nm).

A.3.3 **Peak of action spectrum:** Approximately 445 nm (Ham, 1976); approximately 310 nm in aphakic (Ham, 1980) in rhesus monkey.

A.3.4 **State of knowledge:** Good acute threshold data available for monkey and some corroborative data for man at medically used laser wavelengths and from accidental viewing of the sun or welding arcs.

A.3.5 **Time course**: This mechanism of injury is dominant over thermal injury only for lengthy (greater than 10 seconds) exposures. Noticeable reaction generally delayed by more than 12 hours following the exposure, the elapsed time depending upon how much difference in exposure and threshold, heavy exposures producing reaction in shortest time; greatest reaction generally noted at 48 hours. Some recovery is noted in human accidental exposures to arcs and sun-gazing.

A.3.6 **Mechanism**: Photochemical reaction initiates chain of biological reactions, apparently centered in retinal pigment epithelium; details not understood.

A.3.7 **Symptoms**: "Blind spot", or scotoma where the bright arc was imaged on the retina. A retinal visible lesion (normally depigmented from blue light or hyperpigmented from some ultraviolet wavelengths) is seen under ophthalmic examination within 48 hours post-exposure. Loss of vision may be permanent, although recovery is noted in mild cases.

A.3.8 **Needed information**: More knowledge of injury mechanism; data at 400 nm to 450 nm for exposure durations less than 10 seconds; data on additivity of multiple exposures and the possibility of delayed effects from to recurrent exposures at levels below the acute threshold.

A.3.9 **Experience with lamps**: Extremely rare or largely unreported injuries due to excessive exposure from staring at lamps. The natural aversion response normally limits exposure to preclude photoretinitis. Limited population potentially exposed.

A.3.10 Key references:

HAM, W.T. Jr, MUELLER, H.A., and SLINEY, D.H. Retinal Sensitivity to Damage by Short-Wavelength Light. *Nature*, **260(5547)**, 153-155 (1976).

HAM, W.T. Jr, RUFFOLO, J.J. Jr, MUELLER, H.A., and GUERRY, D. The Nature of Retinal Radiation Damage: Dependence on Wavelength, Power Level and Exposure Time. *Vision Res.*, **20(12)**, 1105-1111 (1980).

MAINSTER, M.A. Spectral Transmission of Intraocular Lenses and Retinal Damage from Intense Light Sources. *Am. J. Ophthalmol.*, **85**, 167-170 (1978).

MARSHALL, J. Light Damage and the Practice of Ophthalmology. In: *Intraocular Lens Implantation*, Rosen E., Arnott, E., and Haining, W. (eds). London, Moseby-Yearbook, Ltd. (1983).

PITTS, D.G. The Human Ultraviolet Action Spectrum. *American Journal Optom. Physiol. Opt.*, **51**, 946-960 (1974).

SLINEY, D.H. Eye Protective Techniques for Bright Light. *Ophthalmology*, **90(8)**, 937-944 (1983).

SLINEY, D.H. and WOLBARSHT, M.L. *Safety with Lasers and Other Optical Sources.* New York, Plenum (1980).

SPERLING, H.G. (ed). Intense Light Hazards in Ophthalmic Diagnosis and Treatment. Proceedings of a Symposium, *Vision Res.*, **20(12)**, 1033-1203 (1980).

VARMA, S.D. and LERMAN, S. (eds). *Proceedings of the First International Symposium on Light and Oxygen Effects on the Eye*. Oxford: IRL Press (1984) [also published as *Current Eye Res.,* **3(1)** (1984).]

WAXIER, M. and HITCHENS, V. (eds). *Optical Radiation and Visual Health.* Boca Raton, CRC Press (1986).

WILLIAMS, T.B. and BAKER, B.N. (eds). *The Effects of Constant Light on the Visual System.* New York, Plenum Press (1980).

YOUNG, R.W. A Theory of Central Retinal Disease. In: *New Directions in Ophthalmic Research*, Sears, M.L. (ed). New Haven, Yale University Press, 237-270 (1981).

Bioeffect datasheet #4: Retinal thermal injury

A.4 **Bioeffect**: RETINAL THERMAL INJURY

A.4.1 **Organ/Site**: Eye/Retina and Choroid.

A.4.2 **Spectral range**: 400 nm to 1400 nm (principally 400 nm to 1100 nm).

A.4.3 **Peak of action spectrum**: Approximately 500 nm (Ham, 1966).

A.4.4 **State of knowledge**: Good acute threshold data available for rabbit and monkey, and limited data for man. Data from different laboratories generally in good agreement.

A.4.5 **Time course**: This mechanism of injury is dominant over photochemical retinal injury for short (less than 10 seconds) exposures or at wavelengths greater than 700 nm. Noticeable reaction is normally immediate (or within 5 minutes) following the exposure. Recovery is limited or nonexistent.

A.4.6 **Mechanism**: Thermochemical reaction denatures proteins and other key biological components of cells with destruction of biological tissue. Light absorption and initial injury centered in retinal pigment epithelium and choroid.

A.4.7 **Symptoms**: "Blind spot" or scotoma where the bright source was imaged on the retina. A retinal lesion visible (normally depigmented) is seen under ophthalmic examination normally within 5 minutes, and certainly within 24 hours post-exposure. Loss of vision will be greatest just after the exposure and some limited recovery may occur within 14 days.

A.4.8 **Needed information**: More data on large image size (> 1 mm) exposures.

A.4.9 **Experience with lamps**: Virtually no lamp is capable of causing this type of injury. A xenon arc focussed into the eye can cause the effect as shown clinically. Hence the incidence must be extremely rare or largely unreported injuries from staring at magnified xenon arc. Natural aversion response normally limits exposure to preclude injury.

A.4.10 **Key references:**

ALLEN, R.A. Retinal Thermal Injury. *Proc ACGIH Topical Symposium*, 26-28 November 1979, ACGIH, Cincinnati, Ohio (1980).

HAM, W.T. Jr, RUFFOLO, J.J. Jr, MUELLER, H.A., and GUERRY, D. The Nature of Retinal Radiation Damage: Dependence on Wavelength, Power Level and Exposure Time. *Vision Res.*, **20(12)**, 1105-1111 (1980).

HAM, W.T. Jr, WILLIAMS, R.C., GEERAETS, W.J., MUELLER, H.A., GUERRY, D., CLARKE, A.M., and GEERAETS, W.J. Effects of Laser Radiation on the Mammalian Eye. *Trans. NY Acad. Sci.*, **28**, 517-526 (1966).

SLINEY, D.H. and WOLBARSHT, M.L. *Safety with Lasers and Other Optical Sources.* Plenum, New York (1980).

Bioeffect datasheet #5: Ultraviolet cataract

A.5 **Bioeftect**:　　　ULTRAVIOLET CATARACT

A.5.1 **Organ/Site**:　　Eye/Crystalline Lens

A.5.2 **Spectral range**: 290 nm to 325 nm; possibly to 400 nm.

A.5.3 **Peak of action spectrum**: Approximately 305 nm (Pitts, 1977) for acute cataract; no action spectrum available for effect at wavelengths > 325 nm (Lerman, 1980, Zigman, 1979).

A.5.4 **State of knowledge**: Good acute threshold data available for rabbit and monkey (295 nm to 325 nm); no data for man for acute cataract, but epidemiological evidence exists for chronic exposure to UV-B radiation (Taylor, 1988).

A.5.5 **Time course**:　　Noticeable clouding of the lens generally delayed by 4 or more hours following the exposure, the elapsed time depending upon how much difference in exposure and threshold, heavy exposures producing reaction in shortest time; some clearing within days only near threshold; otherwise permanent opacification of the lens.

A.5.6 **Mechanism**: Photochemical reaction; details not understood.

A.5.7 **Symptoms**: Clouding of vision.

A.5.8 Needed information: Action spectrum, if existent, for acute and effects for UV-A exposure; additivity of multiple exposures and the possibility of delayed effects from recurrent exposures.

A.5.9 Experience with lamps: Accidental injury is known, even from exposure to xenon-arc lamps. Limited population exposed.

A.5.10 Key references:

BRACHEM, A. Ophtalmic ultraviolet action spectra. *Am. J. Ophtalm., 41*, 969-976 (1956).

LERMAN, S. *Radiant Energy and the Eye*. Mac Millian, Inc., New York, (1980).

PARRISH, J.A., ANDERSON, R.R., URBACH, F., and PITTS, D. *UV-A: Biological Effects of Ultraviolet Radiation with Emphasis on Human Responses to Longwave Ultraviolet.* Plenum Press, New York (1978).

PITTS, D.G. The Ocular Ultraviolet Action Spectrum and Protection Criteria. *Health Physics*, **25**, 559-566 (1973).

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SLINEY, D.H. Estimating the Solar Ultraviolet Radiation Exposure to an Intraocular Lens Implant. *J. Cataract Refract. Surg*., **13**, 296-301, May 1987.

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Bioeffect datasheet #6: Ultraviolet erythema

A.6 Bioeftect: ULTRAVIOLET ERYTHEMA

A.6.1 Organ/Site: Skin

A.6.2 Spectral range: 180-200 to 400-420 nm; principally 200-320 nm.

A.6.3 Peak of action spectrum: Approximately 295 nm (Urbach, 1968, Anders, 1995); approximately 254 nm (Hausser, 1928, Coblentz, 1932, Freeman, 1966).

A.6.4 State of knowledge: Good acute threshold data available for man (254 to 400 nm). Data from different laboratories generally in good agreement if one takes into account two action spectra one for 4 to 8 hours and another for 24 to 48 hours.

A.6.5 Time course: Noticeable reaction generally delayed by 4 to 12 hours following the exposure, the elapsed time depending upon how much difference in exposure and threshold, heavy exposures producing reaction in shortest time; clearing in 24 to 48 hours, except for extremely severe exposures.

A.6.6 Mechanism: Photochemical reaction initiates chain of biological reactions; details not well understood (van der Leun, 1965).

A.6.7 Symptoms: "Sunburn", reddening of the skin at sites of ultraviolet radiation exposure.

A.6.8 Needed information: Higher resolution of thresholds in 305-320 nm range; possibility of delayed effects due to recurrent exposures.

A.6.9 Experience with lamps: Not uncommon accidental exposure from germicidal lamps and mercury and xenon-arc lamps, but only in special applications. Intentional exposure from sunlamp products.

A.6.10 Key references:

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ANNEX B
(informative)

MEASUREMENT METHOD

B.1 Instrumentation

B.1.1 Double monochromator: Recommended instrument

The measurement of a source for the purpose of hazard classification requires accuracy during calibration and testing. The detector's broad spectral response and high spectral resolution required to provide accurate weighting leads to stringent requirements for out-of-band stray light rejection. Calibration sources provide wide spectral output that must be rejected out of the pass-band. The ratio of out-of-band energy to pass-band energy at 270 nm for tungsten or tungsten-halogen calibration lamps should be smaller than 10^{-4}. The double monochromator is the only instrument that provides the needed selectivity, and it is recommended for hazard measurements involving UV and visible radiation. It is recognized that monochromator systems introduce limitations in convenience and speed. Use of a single monochromator in the UV or visible spectrum should be used only if comparable results to that from a double monochromator can be obtained. For example, a single monochromator may be sufficient for lamps such as LEDs known to have a very limited spectral emission band.

B.1.2 Broadband detectors

Modern broadband detectors, when calibrated against the appropriate action spectrum, and with appropriate precaution, may be used. When faced with short duration pulsed or low intensity sources, they are convenient to use. Broadband hazard sensors normally attempt to match the weighting spectra by the use of filters. The matching is never exact and leads to some amount of error. Spectral error contributes to uncertainty only to the extent that the source's spectrum or the detector's spectral response is unknown.

If the source spectrum is unknown, then the point of largest percentage deviation between the detector and the action spectrum must be assumed as the uncertainty. This uncertainty determination shall include consideration of the spectral region where the action spectrum is zero.

When both the detector's response and source's spectrum are known, straightforward calculations can generate a correction factor. Used with an appropriate correction factor, the broadband detector provides a valid method for measurements under this standard. It is incumbent upon the radiometrist to show that the correction factor is valid in each specific case. Variations that lead, or may lead, to changes in spectra require re-determination of the correction factor.

Note: The combination of weighted broadband radiometers and a double monochromator can improve the measurement process in many instances. A survey of spatial, temporal, or item-to-item variations of a source type can be rapidly accomplished using the filtered detector.

B.2 Instrument limitations

B.2.1 Noise equivalent irradiance

All instruments have a limit below which measurements are not possible. For hazard analysis, it is improper to report zero signal when the only known fact is that the measurement is below the instrument's limit. The instrument used for hazard testing must be characterized to determine the measurement limit level or levels. When the instrument reading is zero, or below the measurement limit, the corresponding measurement limit will be reported. If the value for the instrument limit is of significant level to affect the classification of sources then it is clear that a higher quality instrument is required.

Note: The measurement limit of a spectroradiometer is usually dominated by the noise limit of the detector. The noise limit of the detector can be taken as the RMS variation in the detector dark signal. The detector's noise limit is multiplied by the calibration spectrum for the system to give a spectrum with the same dimensions as the measurements, called the "noise equivalent input", NEI. The reported spectral measurement is the higher value at each wavelength of the measured spectrum and the NEI.

B.2.2 Instrument spectral response

The shape of the spectral response (slit function) and the ratio of the measurement interval to the bandwidth will determine whether the system is able to accurately measure signals with narrow spectral extent, for example atomic emission lines. (See Kostkowski, 1997, chapter 5.)

A monochromator with perfect triangular spectral response (slit function) used in a system that has a reporting interval that evenly divides into the bandwidth will accurately measure all signals regardless of their spectral shape. (See CIE 63 - 1984, clause 1.8.4.2.1, or Kostkowski, 1997, clause 5.9.) Deviations from this may lead to errors in measured energy. The spectral response of the system must be determined by high spectral resolution measurement of a narrow wavelength source. The measured spectrum must be symmetrical about the source wavelength to represent the system's response when set to the single wavelength. The system's ability to accurately measure the energy from a narrow band signal is the accuracy of obtaining the sum of the spectral responses at each reported wavelength. The variation across the summed spectrum is the potential error in total measured signal and must be included in the uncertainty analysis.

The result of hazard evaluations will be influenced by the instrument's characteristics. The bandwidth of the monochromator will change the weighted results of any spectrum with varying levels. All finite bandwidth instruments report signal at the wrong wavelength, leading to errors in the weighted sum.

Table B.1, below, lists the recommended bandwidth for 2% upper bound of uncertainty in weighted sums.

Table B.1 Recommended bandwidths

Range (nm)	Bandwidth (FWHM)
$200 \leq \lambda \leq 400$	≤ 4 nm
$400 \leq \lambda \leq 600$	≤ 8 nm
$600 \leq \lambda \leq 1400$	≤ 20 nm
$1400 \leq \lambda$	no bandwidth limitation

A more complete analysis that takes the source spectrum into account may be used to relax the suggested bandwidth accuracy. The results of the analysis must be included in the stated uncertainty of the measurement.

Note: Systems that constantly integrate the signal during the spectral scan will not experience errors in total measured power from spectral response shape or from the ratio of bandwidth to reporting interval. Large bandwidths will still lead to errors in weighted results with this type of instrument.

B.2.3 Wavelength accuracy

The wavelength accuracy of the instrument used to determine the spectral shape of a source has a great impact on the weighted values. For example, the UV hazard weighting function, $S_{UV}(\lambda)$, changes at an extreme rate, i.e. 250% over 3 nm at 300 nm. If a reasonable limit of error is desired then the measured energy must be assigned to its proper wavelength, so that it is appropriately weighted.

Table B.2 is an example showing the change in weighted results from a measurement reporting interval when the interval is moved by 0,1 nm. The measured values are calculated by assuming a spectroradiometer with a triangular response, 2 nm bandwidth, and 1 nm reporting interval. The sum of the measured values is equal as the line is shifted because of the principles described in clause B.2.2. The weighted measurement changes by 2 ½ % for a wavelength change of 0,1 nm. Errors of this magnitude may occur if the wavelength of the instrument is in error by 0,1 nm.

Table B.2 Example of error in weighted value for wavelength error

nm	$S_{UV}(\lambda)$	305 nm		305,1 nm		
		Measured	Weighted	Measured	Weighted	Ratio of sums
304	0,08485	0,25000	0,02121	0,22500	0,01909	
305	0,06000	0,50000	0,03000	0,47500	0,02850	
306	0,04540	0,25000	0,01135	0,27500	0,01249	
307	0,03436	0,00000	0,00000	0,02500	0,00086	
Sums		1,0000		1,0000		≥ 100%
Sums			0,06256		0,06094	≥ 97,4%

$S_{UV}(\lambda)$ is the UV hazard weighting function.

The wavelength accuracy of the monochromator used for hazard testing should be sufficient to provide weighted results with an error arising from wavelength inaccuracy less than three percent (3%). The needed accuracy therefore depends on the region of the spectrum and the weighting function used. Table B.3 summarizes the suggested accuracy which will bound the error to ~ 3 %.

Table B.3 Recommended wavelength accuracy

Range (nm)	Wavelength accuracy
$200 \le \lambda \le 300$	0,2 nm
$300 \le \lambda \le 325$	0,1 nm
$325 \le \lambda \le 600$	0,2 nm
$600 \le \lambda \le 1400$	2 nm

A more complete analysis that takes the source spectrum into account may be used to relax the suggested wavelength accuracy. The results of analysis must be included in the stated uncertainty of the measurement.

B.2.4 Stray radiant power

The absolute calibration of spectroradiometers requires the use of sources with broad spectral output and high energy. If the spectral rejection is insufficient, additional energy from other parts of the spectrum will be included in the calibration. The result of this type of error is to under-calibrate the spectroradiometer and leads to lower readings of the potential hazard. Typical ratios between the total energy and the signal passed by the monochromator are on the order of 10^4. To obtain 1% accuracy, rejection of out-of-band radiation needs to be on the order of 10^6. (See CIE 63 - 1984.)

B.2.5 Input optics for spectral irradiance measurements: Recommendation

A number of issues occur with monochromators using normal input optics. The calibration source and measurement source may not have the same polarization nor will they have the same source size leading to input angle variations. Furthermore the sources measured will subtend both small and large angles. These differences can lead to erroneous measurements. Using an integrating sphere as the input device to the monochromator is the recommended method for irradiance measurements because the random reflectance of the coating depolarizes the incoming light and proper design should match as closely as possible a cosine response and, further, multiple reflections within the integrating sphere consistently fill the radiometer's input. More difficulties may occur with the cosine response of UV-detectors.

A properly designed diffuser may also suffice as the input device to the monochromator or radiometer.

B.2.6 Linearity

The individual lamp or device under test must be assumed to have a different radiometric magnitude than the source used to calibrate the testing system. For the calibration to be useful, the linearity of the system must be known, and the test measurements must be performed within the range that is linear. Non-linearity within the system may be corrected using a calibration function to bring the system to linearity. Note that this adjustment must be applied to the calibration and the measurements.

B.3 Calibration sources

The recommended sources for calibration are the deuterium discharge lamp, for the UV region, and the calibration-grade tungsten or tungsten-halogen lamp for the higher wavelength UV, visible and near infrared region of the spectrum. The deuterium lamp may vary in output level while maintaining its spectral shape. Therefore the calibration of the system in the 200 nm to 350 nm region using the deuterium lamp shall be adjusted by comparison to the calibration level from the tungsten (or tungsten-halogen) lamp between 250 nm and 350 nm. The wavelength below which the deuterium shape is used shall be at as short a wavelength as practical considering the noise in the tungsten (or tungsten-halogen) lamp calibration.

ANNEX C
(informative)

UNCERTAINTY ANALYSIS

The analysis of uncertainty requires that all sources of uncertainty be quantitatively evaluated. The first step in uncertainty analysis is identifying the various uncertainty sources. Below is a list that can be the start of the evaluation of uncertainty for measurements used in classifying lamps and lamp systems. See further details in CIE 53 – 1982 Methods of characterizing the performance of radiometers and photometers.

Instrument
        Wavelength
        Bandwidth
        Response to varying spectra
        Linearity
        Stability
        Stray light
                Out-of-path
                Out-of-band
Calibration
        Standards (assigned uncertainty)
        Distance
        Alignment
        Electrical operation
Measurement
        Alignment
        Distance
        Source under test
                Stability
                Temperature
                Size
                Electrical operation

The individual uncertainty factors must be found or estimated. Each factor must then be propagated through the measurement to find the impact on the weighted values used in hazard classification. As seen in clause 5.3.3 above, the percent impact on the weighted values may be different from the percent uncertainty of the individual factor. This is seen in the change in output from an incandescent lamp as a function of the input current. The change in current changes the energy dissipated in the lamp and therefore changes the lamp's resistance and temperature. A change in current will not be followed linearly by a change in lamp's total output. Because of the change in temperature, the output at a single wavelength may not follow the change in total output. Though the changes are not linear, for small changes they can be considered linear. The normal way to propagate the uncertainty is to find the amount of the final value's change to the initial factors change. This ratio of the impact to the input change is called sensitivity. For the incandescent lamp example, a change in the lamp's current by a small percent leads to a change in the output at the wavelength of interest as shown.

Table C.1 Example of uncertainty propagation.

	Lamp Current	**Signal at 300 nm**
Setting 1	8,2000	8451
Setting 2	8,2011	8461
Change	0,0134%	0,118%

Sensitivity is 0,118% / 0,0134% = 9.

An uncertainty of 0,1% in current will be an uncertainty of 0,9% in output at 300 nm.

Each of the uncertainties must be carried through to the final value and expressed as a percentage. The full sets of uncertainties are combined in quadrature and this combined uncertainty expressed as a percentage is then reported with the measured value.

ANNEX D
(informative)

GENERAL REFERENCES

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