Eye Safety of IREDs used in Lamp Applications
Application Note

Introduction

As the radiated optical power of light emitting diodes (LEDs) has increased in recent years, the issue of eye safety has received an ever-increasing amount of attention. Within this context there has been much discussion about the right safety standard – either the **laser standard** IEC-60825 [2] or the **lamp safety standard** IEC-62471 [1] – to apply to the classification of LEDs. Before mid 2006 all LED applications were covered by the IEC-60825. Today most of the LED applications are covered by the **lamp standard**. Other than lasers, lamps are only generally defined in this standard as sources made to produce optical radiation. Lamp devices may also contain optical components like lenses or reflectors. Examples are lensed LEDs or reflector type lamps which may include lens covers as well. The status quo is, that for different applications of LEDs, like data transmission or irradiation of objects, different standards have to be used:

- data transmission → IEC-60825
- lamp applications → IEC-62471

Both safety standards do not cover general exposure scenarios and are not legally binding. However the presented methods and limit calculations are used as a basis in regional guidelines, e.g. in the European Directive 2006/25/EC [3], which describes “the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation)”.

This application note describes the possible hazards of infrared LEDs (IREDs) used for lamp applications with respect to the IEC-62471 standard and how to classify IREDs according to different risk groups.

The outline is as follows:
First, a general survey of the different hazards of IR-A radiation (780-1400 nm) and the basics of calculating the exposure limits are described. Next, the different risk groups for lamp classification are introduced, and finally three example calculations are presented to show how to do the calculations.

This note focuses on the IR-A range, so further photochemical hazards, e.g. by ultraviolet or blue radiation, are not considered. Only the main issues of the standard are explained and simplifications are made. The note gives guidance to classify applications that use IR emitting components regarding eye safety.
OSRAM gives assistance to the best of its knowledge, but does not guarantee that every hazard of any application is described by the information given in this text.
The eye safety classification of the final product, using IREDs, is the responsibility of the manufacturer.

Hazard Exposure Limits

When irradiating the human body with intense infrared light over a defined period of time, different tissues (such as skin or retina, see figure 1) are affected in different ways. That is why three distinct exposure limits are given in the IEC-62471 standard for IR-A radiation:

A) Infrared radiation hazard exposure limits for the eye (**cornea**)

B) Thermal hazard exposure limit for **skin** $(t < 10\ s)$

C) **Retinal** thermal hazard exposure limit

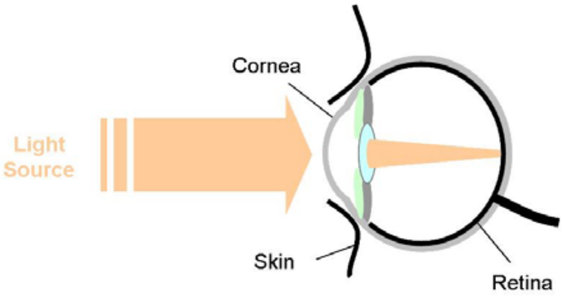

Fig. 1: Cross section of the human eye under irradiation.

Damage by IR-A radiation is caused primarily by the overheating of the irradiated tissue, resulting in the destruction of cells. This can cause, for example, a permanent vision handicap.

The irradiation limits of skin and cornea can be calculated in a quite simple way.

A) Exposure limits for the cornea

The maximum allowed irradiance E_{IR} ($E_{e,max}$) of the cornea for different time scales of exposure is defined as given below:

For exposure times t ≤ 1000 s the limit is depending on the exposure time itself

$$E_{IR} = \sum_{\lambda=780}^{3000} E_\lambda \cdot \Delta\lambda \le 18000 \cdot t^{-0.75} \quad [W \cdot m^{-2}] \qquad (1)$$

For exposure times t > 1000 s a fixed value is used:

$$E_{IR} = \sum_{\lambda=780}^{3000} E_\lambda \cdot \Delta\lambda \le 100 \qquad [W \cdot m^{-2}] \qquad (2)$$

where E_λ is the spectral irradiance in W/m²/nm, $\Delta\lambda$ given in nm and t in sec.*

For cold environments, the limit for t >1000 s is increased to 400 W/m² at 0°C and 300 W/m² at 10°C.

The irradiance E_e can be calculated from the radiant intensity I_e and distance d (in the far field) using the inverse square law

$$E_e = I_e / d^2. \qquad (3)$$

Example calculation for SFH4232 using datasheet values, distance source to eye d=0.1 m, t >1000 s, I_F=1 A, $I_{e,typ}$=180 mW/sr, T_a=25°C:

The limit calculation for t >1000 s is done by equation (2):
Exposure limit (EL) is 100 W/m².
For actual exposure values the irradiance E_e according equation (3) is 0.18 W/sr/(0.1 m)² = 18 W/m², which is below the limit.

B) Exposure limits for skin

A similar equation can be used for the irradiance skin limit:

$$E_H = \sum_{\lambda=380}^{3000} E_\lambda \cdot \Delta\lambda \le 20000 \cdot t^{-0.75} \quad [W \cdot m^{-2}] \quad (t \le 10 s) \qquad (4)$$

Where E_λ is the spectral irradiance in W/m²/nm, $\Delta\lambda$ given in nm and t in seconds. For exposure times of more than ten seconds, acute pain occurs before the skin can be damaged.
In figure 2 the respective limit curves are shown. The shorter the light pulse, the higher the possible irradiance can be.
The diagram indicates that for skin the maximum irradiance limit is slightly higher than for the cornea. Therefore the cornea limit can be taken for worst case considerations.

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* Note that the term on the right side of equation (1) has the appropriate unit to satisfy E_{IR} in W/m². The same applies for the terms in the following equations. This is the same notation as used in IEC 62471.

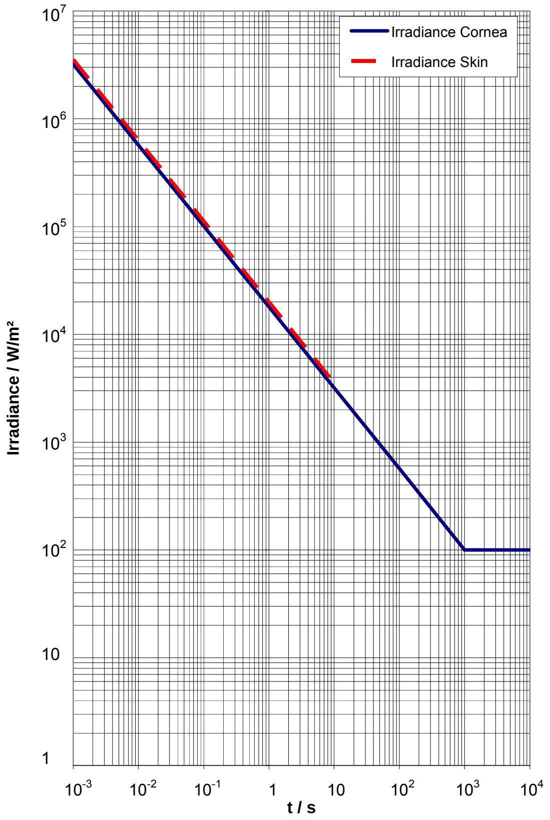

Fig. 2: Irradiance exposure limits as a function of time.

C) Exposure limits for the retina

When determining the limits of the retina, the pupil diameter, source size of the emitter and the emitted wavelength are important parameters.

For IR-A light the visual stimulus of the eye is very low. That means that the aversion response, which normally protects the eye from excessive continuous irradiation (for times greater than 0.25 s), does not work. As there is no trigger of the iris contraction, we have to calculate with the full 7 mm pupil diameter that collects the light.

The apparent light source is focused by the cornea and the lens onto the retina, and defines the irradiated area which is thermally stressed. Therefore the angular subtense α of the light source is correlated with the focus area. Due to physical limitations and movements of the eye, an effective $\alpha_{min,eff}$ is defined as a lower limit (as a function of exposure time). The upper limit α_{max} is always 0.1 radians (no spot-size variation on the retina considered for extended sources, see table 1). Calculation of angular subtense α at a viewing distance d for a mean source extension Z:

$$\alpha = Z/d \qquad (5)$$

$$\text{with } Z = (l+w)/2 \qquad (6)$$

where l is the length and w the width of the active area of the light source.
For radiance measurements (see appendix) the min/max limits of the acceptance angle γ_{FOV} have to be used as shown in table 1.

Time range	$\alpha_{min\ eff}$, $\gamma_{FOV\ min}$ in rad	α_{max}, $\gamma_{FOV\ max}$ in rad
t ≤ 0.25s	0.0017	0.1
0.25s <t< 10s	$0.0017 \cdot \sqrt{t/0.25}$	0.1
t ≥ 10s	0.011	0.1

Table 1: Limits of the angular subtense α and measurement field of view γ_{FOV} for the different time ranges.

The thermal stress is dependent on the wavelength as well. The so-called burn hazard weighting function is defined as:

$$R(\lambda) = 10^{[(700-\lambda)/500]} \qquad (7)$$

with the wavelength λ in nm from 700-1050 nm is shown in figure 3. The hazard decays with increasing wavelength.

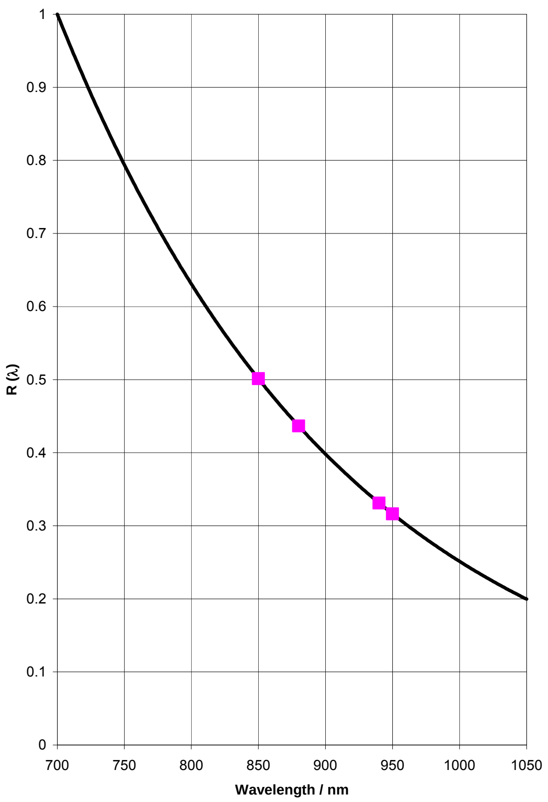

Fig. 3: Burn hazard weighting function R(λ).

Putting everything together the retinal thermal hazard exposure limit (EL) for the *burn hazard weighted radiance* L_R for exposure times below 10 sec, which is also valid for the visible spectral region, is defined as

λ = 380 – 1400 nm (t = 10 µs …10 s):

$$L_R = \sum_{\lambda=380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \le \frac{50000}{\alpha \cdot t^{0.25}} \quad [W \cdot m^{-2} \cdot sr^{-1}] \quad (8)$$

L_λ is the spectral radiance in W/m²/nm/sr, use numerical value of α in rad and t in sec.

For longer exposure times we have to distinguish between the visible range (strong visual stimulus of the human eye) and the near infrared range (weak visual stimulus).

The near infrared *burn hazard weighted radiance* L_{IR} (*for weak visual stimulus*) is limited to

λ = 780 – 1400 nm (t > 10 s):

$$L_{IR} = \sum_{\lambda=780}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \le \frac{6000}{\alpha} [W \cdot m^{-2} \cdot sr^{-1}] \quad (t > 10 s). \quad (9)$$

L_λ is the spectral radiance in W/m²/nm/sr, use numerical value of α in rad and t in sec.

In good approximation one can use

$$L_{IR} \approx Ie \cdot R(\lambda) / ((l+w)/2)^2 \qquad (10)$$

to calculate the radiance L_{IR} from data sheet values.

The calculated radiance exposure limits (for the possible extreme angular subtenses α as a function of the exposure time are shown in figure 4.

The description of a measurement method to obtain the radiance of the emitted radiation can be found in the appendix.

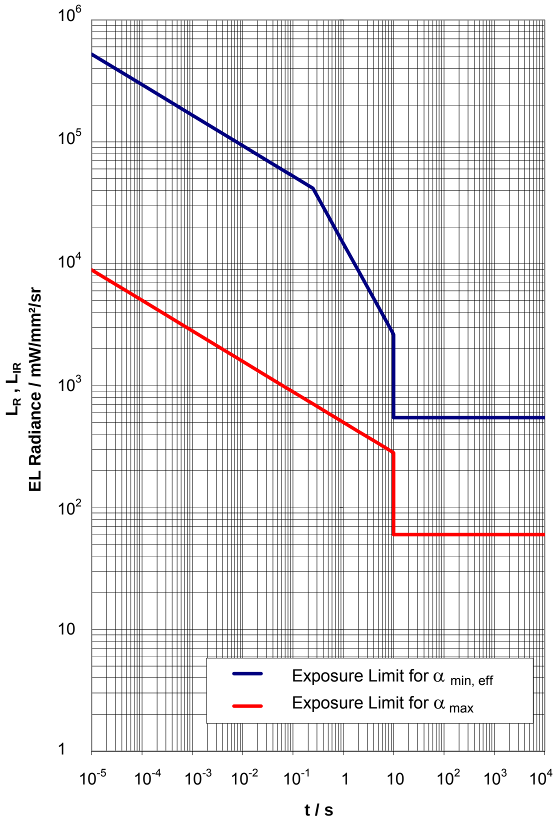

Fig 4: Exposure limits (EL) over irradiation time t.

Example values for Platinum Dragon SFH4232 (850 nm), I_F=1A, $I_{e,typ}$=180 mW/sr, die size 1x1 mm², distance d=200 mm, t=100 s, T_a=25°C using data sheet values:

	SFH4232	
Die size l x w [mm²]	1x1	data sheet
$\alpha < \alpha_{\text{min eff}}$ [rad]	0.005	acc. (5)
$\alpha_{\text{min eff}}$ (t ≥ 10s) [rad]	0.011	acc. Table 1
λ [nm]	850	data sheet
$R(\lambda)$	~0.5	acc. (7)
L_{IR}[†] [mW/mm²/sr]	**89.6**	acc. (9)
L_{IR}[‡] [mW/mm²/sr]	**90**	acc. (10)
Exposure Limit for L_{IR} [mW/mm²/sr]	**545.5**	acc. (9)

Pulsed Lamps

For repetitively pulsed lamps the weighted radiant exposure ($t_{avg,max}$ = 0.25s) shall be compared with the continuous wave exposure limits (EL) by using the time averaged values (see figure 5) of the pulsed emission as long as E_e of the single pulse does not exceed any limit on its own.

$$E_{e,\text{time avg}} = E_{e,\text{pulse}} \cdot D = E_{e,\text{pulse}} \cdot t_{\text{pulse}} / t_{\text{period}}, \quad (11)$$

D: Duty cycle.

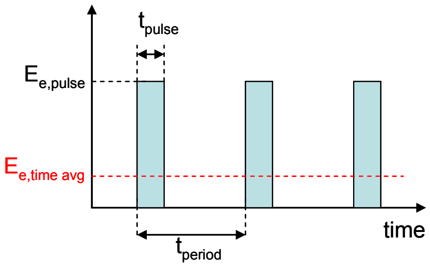

Fig. 5: Schematic of time averaged E_e.

Lamp Risk groups

According to IEC-62471-1 [1] the hazard values are reported at a fixed distance **d = 200 mm**.

The emission limits for the risk groups are defined as (α given in rad):

- Exempt group (no hazard)

$L_R \leq 28000/\alpha$ [W/m²/sr] within 10s, acc. (8)

L_{IR} (low vis stimulus) $\leq 6000/\alpha$ [W/m²/sr] within 1000s – for retina

$E_{IR} \leq 100$ [W/m²] within 1000s – for cornea

- Risk Group 1 (Low Risk)

$L_R \leq 28000/\alpha$ [W/m²/sr] within 10s

L_{IR} (low vis stimulus) $\leq 6000/\alpha$ [W/m²/sr] within 100s

$E_{IR} \leq 570$ [W/m²] within 100s

- Risk Group 2 (Moderate Risk)

$L_R \leq 71000/\alpha$ [W/m²/sr] within 0.25s

L_{IR} (low vis stimulus) $\leq 6000/\alpha$ [W/m²/sr] within 10s

$E_{IR} \leq 3200$ [W/m²] within 10s

- Risk Group 3 (High Risk)
One of the limits of Risk group 2 is exceeded

The labelling of the classified IR products is described in the second part of the safety standard IEC-62471-2 [4] as follows:

Hazard	**Exempt Risk Group**	**Risk Group 1**	**Risk Group 2**	**Risk Group 3**
Cornea/lens infrared hazard 780 nm – 3000 nm	Not required	NOTICE IR emitted from this product	CAUTION IR emitted from this product	WARNING IR emitted from this product
Retinal thermal hazard, weak visual stimulus 780 nm – 1400 nm	Not required	WARNING IR emitted from this product	WARNING IR emitted from this product	WARNING IR emitted from this product

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[†] calculated from real spectral data.

[‡] calculated using $L_{IR} \approx Ie \cdot R(\lambda) / ((l+w)/2)^2 =$ 180 mW/sr · 0.50 / 1 mm² = 90 mW/mm²/sr.
For simplification and as a worst case scenario the total Ie of the part is assumed to be direct radiation from the die.

Example 1:
Array of 10x SFH4232 (Platinum Dragon® package), DC operation at I_F=1 A for irradiation purpose. Die size =1x1 mm², 850 nm, t >1000 s,
$I_{e,typ}$(T_a=25°C) =180 mW/sr, minimum distance to user r > 0.5 m in application.

Lamp classification (d = 0.2m)

- Cornea Hazard

Emission limit (EL) calculation:
Assuming ideal overlap of radiation characteristics of 10x SFH4232 (worst case).

⇨ total I_e = 1.8 W/sr

Based on (3):

E_e = I_e/d^2 = 1.8 W/sr /(0.2 m)²
= **45 W/m²**
< E_{IR} = 100 W/m² (EL).

Note:
E_e depends on the number of IREDs. Exposure limit would be reached when using more than 22 SFH4232 @ I_F=1 A with ideal overlap.

- Retinal Hazard

Calculation of the emission limit (EL):
The angular subtense α is calculated acc. (5) and (6):
α = Z/d = 1 mm/200 mm = 0.005 rad
with Z=(l+w)/2=(1 mm+1 mm)/2=1 mm

According to table 1 with t = 1000s

⇨ α_{eff} = 0.011rad.

Based on (9) the Emission limit (EL) for the radiance is
L_{IR} = 6000 / α_{eff} = **545.5 mW/mm²/sr**

Calculation of actual value **L_{IR}** based on example data:

R(λ=850 nm) = 0.50 (fig.3)
L_{IR} = $I_e \cdot R(\lambda) / ((l+w)/2)^2$ acc. (10)
= 180 mW/sr· 0.50 / (1 mm)²
= **90 mW/mm²/sr**
<< 545.5 mW/mm²/sr (EL)

Summary:
Limits of L_{IR} and E_{IR} are not exceeded within 1000s.

⇨ **Exempt group (no risk)**

Actual exposure scenario in example 1 with distance r > 0.5 m:
E_e = I_e/d^2 = 1.8 W/sr / (0.5 m)²
= **7.2 W/m²**

Example 2:
Arrangement of 2x SFH4740 (OSTAR Observation® package), DC operation at I_F=1 A for irradiation purpose.
Die size for one OSTAR (5x2) mm², 850 nm, t > 1000 s,
$I_{e,typ}$(T_a=25°C) =1400 mW/sr, minimum distance to user r > 1 m in application

Lamp classification (d = 0.2 m)

- Cornea Hazard

Emission limit (EL) calculation:
Assuming ideal overlap of radiation characteristics of 2x SFH4740 (worst case).

⇨ total I_e = 2.8 W/sr

Based on (3)
E_e = I_e/d^2 = 2.8 W/sr / (0.2 m)²
= **70 W/m²**
< E_{IR} = 100 W/m² (EL).

Note:
E_e depends on the number of IREDs, limit would be reached when using more than 2 SFH4740 @ I_F=1 A with ideal overlap.

- Retinal Hazard

Calculation of the emission limit (EL):
The angular subtense α is calculated acc. (5) and (6) for the chip arrangement in the SFH4740 package:
α = Z/d = 3.5 mm/200 mm = 0.0175 rad
with Z=(l+w)/2=(5 mm+2 mm)/2=3.5 mm

⇨ α_{eff} = 0.0175 rad (t=1000 s) (acc.to table1)

Based on (9) the Emission limit (EL) for the radiance is:
L_{IR} = 6000 / α_{eff} = **342.9 mW/mm²/sr**

Calculation of actual value **L_{IR}** based on example data:

R(λ=850 nm) = 0.50 (fig.3)
L_{IR} = $I_e \cdot R(\lambda) / ((l+w)/2)^2$ acc. (10)
= 1400 mW/sr · 0.50/(3.5 mm)²
= **57.1 mW/mm²/sr**
« 342.9 mW/mm²/sr (EL)

Summary:

Limits of L_{IR} and E_{IR} are not exceeded within 1000s.

⇨ **Exempt group (no risk)**

Actual exposure scenario in example 1 with distance r > 1 m:
E_e = I_e/d^2 = 2.8 W/sr / (1 m)²
= **2.8 W/m²**

Example 3:
Array of 20x SFH4240 (PowerTOPLED®
package), pulsed operation at $I_{F\ pulse}$=0.6 A, t_p=100 µs, dutycycle D=0.1 for irradiation purpose, minimum distance to user r > 0.5 m in application.
Die size: (0.3x0.3) mm², 940 nm, t >1000 s

From data sheet:
$I_{e,max}(T_a=25°C, I_F=0.6\ A)$ = 32 mW/sr · 5 [§] = 160 mW/sr

Lamp classification (d = 0.2 m)

- *Cornea Hazard*

Assuming an ideal overlap of radiation characteristics of the twenty SFH4240 (worst case).

⇨ I_e total = 20x 160 mW/sr = 3.2 W/sr

Based on (3)

E_e = $I_e/d^2 \cdot D$ = 3.2 W/sr/(0.2 m)² ·0.1
= **8 W/m²**
<< E_{IR} = 100 W/m² (EL).

Note:
E_e depends on the number of IREDs, limit would be reached when using 250 SFH4240 under the given conditions.

- *Retinal Hazard*

The angular subtense α is calculated acc. (5) and (6) for the chip in the TOPLED® package:

α (d=200 mm) = 0.3 mm/200 mm = 0.0015 rad

⇨ α_{eff} (tp=100 µs) = 0.0017 rad (acc. table1)

⇨ α_{eff} (tp=1000 s) = 0.011 rad (acc. table1)

Emission limit calculation for the burn hazard weighted radiance L_R according to (8):
EL for L_R = 50000/ $[\alpha_{eff} \cdot (100 \cdot 10^{-6})^{0.25}]$
(*Single Pulse)* = **$2.94 \cdot 10^5$** mW/mm²/sr

Emission limit calculation for the burn hazard weighted radiance L_{IR} (low visible stimulus) according to (9):
EL for L_{IR} = 6000/ α_{eff}
= **545.5** mW/mm²/sr

Calculation of actual value **L_R** and **L_{IR}** based on example data:
R(λ=940 nm) = 0.33
L_R (t=100 µs) = $I_e \cdot R(\lambda)/Z^2$ acc. (10)
(*Single Pulse)* = 160 mW/sr·0.33/(0.3 mm)²
= **586.7** mW/mm²/sr
« $2.94 \cdot 10^5$ mW/mm²/sr (EL)

L_{IR} (t=1000 s) = $I_e \cdot R(\lambda)/Z^2 \cdot D$
=160 mW/sr · 0.33 /
(0.3 mm)² · 0.1
= **58.7** mW/mm²/sr
« 545.5 mW/mm²/sr (EL)

Summary:

Limits of L_{IR} and E_{IR} are not exceeded within 1000s.

[§] Factor 5 from datasheet diagram Ie/Ie(100mA).

⇨ **Exempt group (no risk)**

Actual exposure scenario in example 3 with distance r > 0.5 m:

$\mathbf{E_e}$ $= I_e/d^2 \cdot D = 3.2\ \text{W/sr}/(0.5\ \text{m})^2 \cdot 0.1$
$= \mathbf{1.28\ W/m^2}$

Glossary:

- α: Angular subtense [rad]
- EL: Exposure limit (for exposure time t > 0.01ms – 8h)
  Exposure level which is expected to cause no damage to eye or skin.
- $E_e = d\phi / dA$: Irradiance [W/m²]
  (weak visual stimulus for Lv < 10 cd/m²)
- L_λ: Spectral radiance [W/m²/nm/sr]
- L_R: Burn hazard weighted radiance [W/m²/sr]
- L_{IR}: Near infrared radiance [W/m²/sr]
- L_V: Luminance [cd/m²]
- $H = \int_{\Delta t} E \cdot dt$: Radiant Exposure [J/m²]
- ϕ: Optical Power [W]

Literature:

[1] IEC 62471:2006 / CIE S 009 / E:2002 Photobiological safety of lamps and lamp systems

[2] IEC 60825-1:2007 Safety of laser products – Part1: Equipment classification and requirement

[3] Directive 2006/25/EC, Official Journal of the European Union, 27.04.2006

[4] IEC/TR 62471-2 Ed. 1.0, Photobiological safety of lamps and lamp systems - Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety, 08/2009

Further information:

[5] “LED-Strahlung: Mögliche fotobiologische Gefährdungen und Sicherheitsvorschriften, Teil1“, Werner Horak, Strahlenschutzpraxis 03/2008, pp. 56-63

[6] “LED-Strahlung: Mögliche fotobiologische Gefährdungen und Sicherheitsvorschriften, Teil2“, Werner Horak, Strahlenschutzpraxis 04/2008, pp. 40-46

Appendix:

A possible setup to measure the radiance L is shown in figure A1.

The radiant power ϕ, that passes through a defined aperture stop at a defined distance r is measured with a detector at the image distance (the field stop aperture in front of the detector defines the acceptance angle γ_{FOV}).

The diameter d of the aperture (with a minimum size of 7 mm) defines the solid collection angle Ω (sr) and the measurement area A_{FOV}.
The radiance can be calculated as follows:

$$L = \phi / (\Omega \cdot A_{FOV}) \text{ [W/m²/sr]}.$$

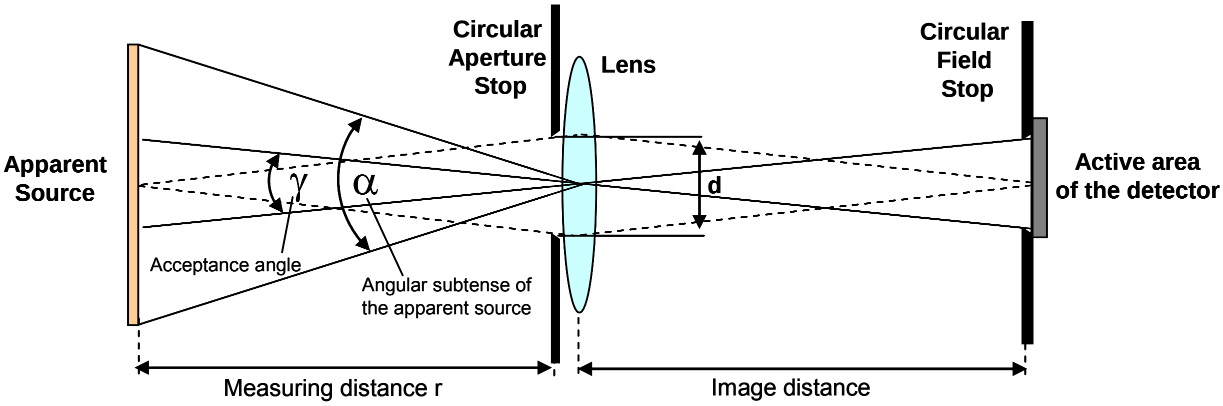

Fig. A1: Typical setup to measure the radiance of a light source [4].

Author: Dr. Claus Jäger

About Osram Opto Semiconductors
Osram Opto Semiconductors GmbH, Regensburg, is a wholly owned subsidiary of Osram GmbH, one of the world's three largest lamp manufacturers, and offers its customers a range of solutions based on semiconductor technology for lighting, sensor and visualisation applications. The company operates facilities in Regensburg (Germany), Sunnyvale (USA) and Penang (Malaysia). Further information is available at www.osram-os.com.