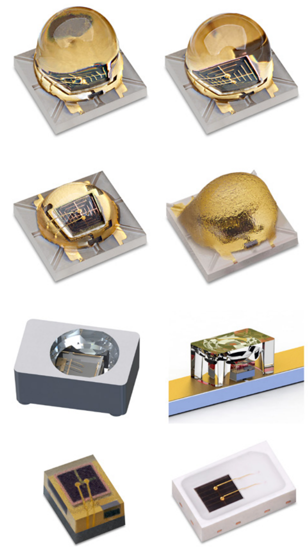
INFRARED

LUXEON IR Family Eye Safety

Assembly and Handling Guidelines



Introduction

Light Emitting Diodes (LEDs) are becoming the standard light source for illumination infrared (IR) applications. High power LEDs have a high optical radiating power and a small light emitting surface, resulting in brightness of the light emission surface that is significant with respect to the lamps safety standard.

The IEC-62471:2006 standard "Photobiological safety of lamps and lamp systems" is applicable when considering the eye and skin safety impact by LEDs. This application brief covers LEDs and lamps with IR wavelengths. The standard (IEC-62471:2006) defines exposure limits (EL) for eye and skin which depend on exposure duration and on whether a lamp emits in continuous or pulsed mode. Depending on the radiating power and brightness, lamps and LEDs are categorized into risk groups. Depending on the risk group classification, the manufacturer may need to put warning labels on products and\or packaging and include instructions for users.

In this application brief some examples are given on how to classify the risk group. It gives an overview of the IEC-62471 standard and does not necessarily cover all application conditions. For final product classification and eye safety certification, the manufacturer should check with accredited laboratories that can assist in the exact classification of the product with IR LEDs.

This application brief will focus on IR-A (700nm-1000nm) radiation and contains examples of exposure limit calculations. As the focus is on IR exposure, the photochemical hazards from UV, blue light and retinal blue hazard are assumed to be negligible.

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1. Exposure Limits for Near Infrared Lamps

When the human body is exposed to intense near infrared light, one needs to consider the following metrics for safety:

- Skin irradiance: thermal hazard exposure limit for skin
- Eye irradiance: exposure limits for cornea
- Focusing of light by eye lens on retina (retinal thermal exposure limits (weak stimulus))

1.1 Exposure Limits for Skin

High or intense infrared radiation exposure can increase the tissue temperature and can lead to injury; IEC-62471 defines an exposure limit (EL) for near UV, visible and infrared radiant exposure (380nm-3000nm) only for exposure durations, 't', less than 10 seconds. As for longer exposure durations, severe pain will be registered before any skin damage occurs.

Exposure limits for visible and infrared exposure of the skin must be less than:

Equation (1):

$$E_H = \sum_{\lambda=380}^{3000} \sum_{t} E_\lambda(\lambda, t) \,.\, \Delta t \,.\, \Delta\lambda \leq 20000 \,.\, t^{-0.75} \quad W.m^{-2} \quad (t \leq 10s)$$

Where:

$E\lambda$ (λ,t)	=	spectral irradiance in $W.m^{-2}.nm^{-1}$
$\Delta\lambda$	=	bandwidth in nm
t	=	exposure time in seconds

Figure 1 below shows maximum irradiance (W/m^2) limits for skin at different exposure times.

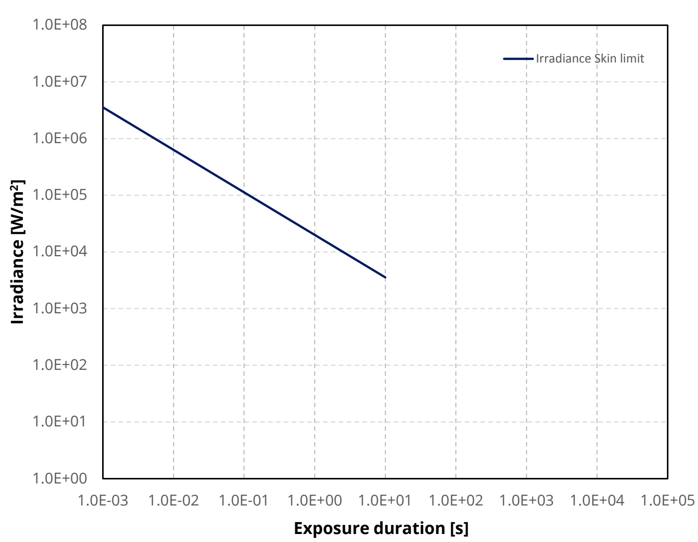

Figure 1. Maximum irradiance limit for skin with respect to different exposure times.

1.2 Exposure Limit for Cornea

Intense light exposures can have thermal effects on the cornea. In IEC-62471, exposure limits of irradiance (W/m^2) on the cornea, 'E_{IR}', are defined in two scenarios:

For exposure time, 't', ≤1,000s:

Equation (2):

$$E_{IR} = \sum_{\lambda=780}^{3000} E_{\lambda}.\Delta\lambda \leq 18000\,.\,t^{-0.75} \quad W.m^{-2} \;\; (t \leq 1000s)$$

Equation (3):

$$E_{IR} = \sum_{\lambda=780}^{3000} E_{\lambda}.\Delta\lambda \leq 100 \quad W.m^{-2} \;\; (t > 1000s)$$

Where:

Eλ	=	spectral irradiance in W.m^{-2}.nm^{-1}
Δλ	=	bandwidth in nm
t	=	exposure time in seconds

Figure 2 below shows the maximum allowed irradiance levels as a function of exposure time for the cornea, as well as for skin. The graph shows that irradiance exposure limits for the cornea are slightly lower than for skin, so exposure levels based on the limit for cornea exposure can be considered to be more restrictive.

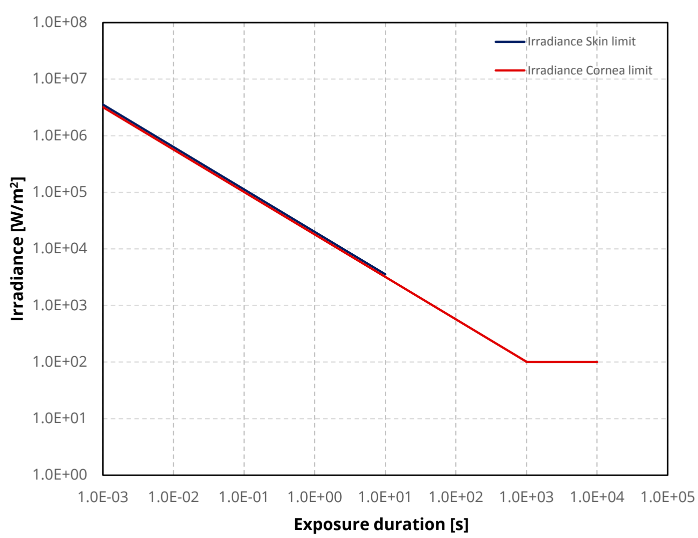

Figure 2. Maximum irradiance limit for cornea exposure with respect to exposure time.

For target distances much larger than source size, the irradiance on the target can be calculated by:

Equation (4):

$$E = \frac{I}{d^2} \quad W.m^{-2}$$

Where:

E	=	irradiance on the target in W.m^{-2}
I	=	radiant intensity of the source (in the target direction) in W/sr
d	=	target distance from source (d>>source size) in m

For lamp classification target distance, 'd' is fixed to 0.2m.

1.2.1 Example Calculation with LUXEON IR Compact

As an example, the irradiance on the cornea is calculated using an LUXEON IR Compact LED at nominal drive conditions (I_f=1A, T_j=25°C), where the LED is positioned at a distance of 20cm. The exposure duration is assumed to be larger than 1,000s.

Table 1. Cornea limit check for LUXEON IR Compact.

	PARAMETERS	VALUES	REMARKS
Inputs	Measurement distance (mm)	200	Given
	I (W/sr at 1A, nominal conditions)	0.25	Datasheet
	Exposure duration, t (seconds)	>1,000	Given
Calculations	E_{IR} limit (W/m^2)	100	From Equation (3)
	E (W/m^2)	6.25	From Equation (4)
	Result	E < E_{IR} limit	Eye safe

As E <E_{IR}, LUXEON IR Compact is safe for cornea as well as for skin exposure (according to Figure 2 and section 1.2) at nominal operating conditions (continuous drive current).

1.3 Exposure Limits for Retina

When eyes are exposed to the radiation, light rays are focused on the retina and form an apparent image of the source. If this light energy focused on the retina is very high, then it can heat up retinal surface; IEC-62471 defines an exposure limit of the radiation to the eyes.

1.3.1 Parameters Influencing Exposure Limits for Retina

This section explains important parameters and defines retina eye safety.

1.3.1.1 Pupil Diameter

Pupil diameter represents the area of the aperture of the eye through which light can pass and can be focused on retina. Normal maximum pupil diameter is around 7mm (area = 38.5mm^2), which decreases further as per visual stimulus of the eye, depending on ambient light levels. For near infrared (NIR), visual stimulus is quite low, so, as worst-case scenario, a pupil diameter of 7mm should be used for exposure limit calculations for retina safety.

1.3.1.2 Angular Subtense of the Source

The cornea and the eye lens focus image of apparent source on the retina. The irradiated area of the retina is related to the angular subtense of the apparent source α. Due to physical limitations of the eye, the smallest possible image formed on the retina defines a minimum value of angle of subtense, α_{min}, even for a point source, which is α_{min} = 0.0017rad (for exposure duration t ≤0.25s, which is blink reflex time).

1.3.1.3 Exposure Duration

Exposure duration influences the image of the source on the retina. For short exposure, t ≤0.25s, the eye can focus well, which defines α_{min} = 0.0017rad. However, for t >0.25s, rapid eye movement smears the image of the apparent source over a larger area, which defines a larger value of α known as α_{eff}. Table 2 below summarizes the angular subtense α for different time ranges. Maximum value of α is always 0.1rad. This means for extended sources which has angular subtense more than α_{max}, the exposure limit for retinal hazard will be independent of source size.

Table 2. Influence of exposure time on α.

EXPOSURE TIME (t)	α_{min}	α_{eff}	α_{max}
t ≤0.25s	0.0017rad		0.1rad
0.25s < t < 10s		0.0017 . √(t/0.25) rad	0.1rad
t ≥10s		0.011rad	0.1rad

The angular subtense α of a source is calculated by dividing size of the source (arithmetic mean of the length and breadth of the source) by viewing distance as shown in Equation 5 below.

Equation (5):

$$\alpha = \frac{(l + b)/2}{d} \quad sr$$

Where:

l = length of source in meters
b = breadth of source in meters
d = viewing distance in meters

1.3.1.4 Wavelength and Spectra of the Radiation

Thermal impact of light is dependent on the wavelength (λ) of light. A spectral weighting function called "burn hazard weighting function," R(λ), is defined as near infrared spectral region:

Equation (6):

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

Figure 3 below shows the R(λ) curve for near infrared wavelengths (700nm-1050nm).

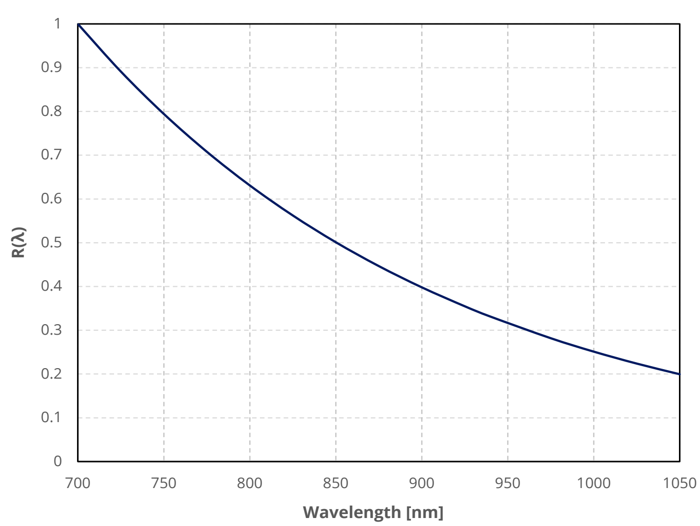

Figure 3. Burn hazard weighting function, R(λ), with respect to wavelength.

As the wavelength increases, R(λ) decreases, which indicates less thermal stress on the eye. As an example, R(λ) for 850nm and 940nm is shown in Table 3 below.

Table 3. Influence of exposure time on α.

WAVELENGTH	R(λ)
850nm	0.501
940nm	0.331

1.3.2 Exposure Limits

The "retinal thermal hazards" exposure limit is defined in two scenarios as listed below.

1. For exposure time 10μs ≤ t ≤ 10s and wavelength = 380nm - 1400nm:

Equation (7):

$$L_R = \sum_{\lambda=380}^{1400} L_\lambda . R(\lambda) . \Delta\lambda \leq \frac{50000}{\alpha \, . \, t^{0.25}} \quad W.m^{-2} . sr^{-1} \;\; (10\mu s \leq t \leq 10s)$$

Where:

L_λ	=	spectral radiance in $W.m^{-2}.sr^{-1}.nm^{-1}$
R(λ)	=	burn hazard weighting function
t	=	viewing duration or pulse duration (for pulsed lamp) in seconds
Δλ	=	bandwidth in nm
α	=	angular subtense of the source in radians

2. For exposure time t >10s and wavelengths 780nm to 1400nm:

For IR sources, the visual stimulus is very low and cannot activate the aversion response. For near IR radiation and exposure times t >10s, the radiance limit LIR is defined as follows.

Equation (8):

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

Where:

L_λ	=	spectral radiance in $W.m^{-2}.sr^{-1}.nm^{-1}$
R(λ)	=	burn hazard weighting function
t	=	viewing duration or pulse duration (for pulsed lamp) in seconds
Δλ	=	bandwidth in nm
α	=	angular subtense of the source in radians

Figure 4 below shows radiance exposure limits over exposure times for α_{min} and α_{max}.

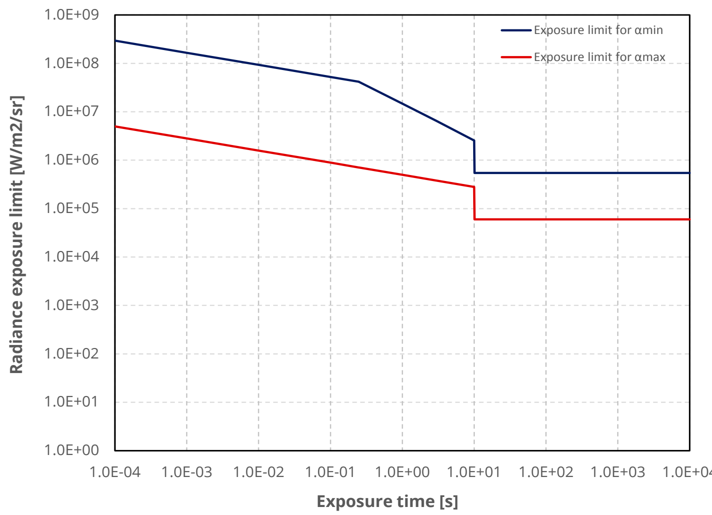

Figure 4. Radiance exposure limits for α_{min} and α_{max} with respect to exposure times.

As an approximation, the radiance value of an LED can be calculated with datasheet values as shown in Equation (9) below.

Equation (9):

$$L = \frac{I}{\left(\frac{l+b}{2}\right)^2} \, . \, R(\lambda) \quad W.m^{-2}.sr^{-1}$$

Where:

L	=	radiance of the source $W.m^{-2}.sr^{-1}.nm^{-1}$
I	=	radiant intensity of source (in the viewing direction) in W/sr
l	=	length of the source in meters
b	=	breadth of the source in meters
R(λ)	=	burn hazard weighting function

1.3.3 Example Calculation with LUXEON IR Compact

Example calculation for retina thermal exposure with LUXEON IR Compact at nominal drive conditions (I_f=1A, T_j=25°C), wavelength 850nm, viewing distance 20cm and exposure time t=1,000s.

From datasheet, die size = 1mmx1mm and I = 0.25 $W.m^{-2}$.

Table 4. Retinal limit check for LUXEON IR Compact.

	PARAMETERS	VALUES	REMARKS
Inputs	Die size (l x w mm^2)	1.0 x 1.0	Datasheet
	Measurement distance (mm)	200	(Lamp Classification) Standard
	λ (nm)	850	Given
	I (W/sr @ 1A, nominal conditions)	0.25	Datasheet
Calculations	α (rad)	0.005	From Equation (5)
	α_{min} (t ≥10s) (rad)	0.011	From Table 2, α_{min}=0.011 if α <0.011
	R (λ)	0.501	From Equation (6)
	L_{IR} limit (W/m^2/Sr)	545,455	From Equation (8)
	L (W/m^2/Sr)	125,297	From Equation (9)
	Result	$L < L_{IR}$ limit	Eye safe

As $L < L_{IR}$ limit, LUXEON IR Compact is safe for retinal exposure at nominal DC operating conditions.

2. Lamp Classification and Risk Groups

For the classification and risk group definition of the lamps, the hazard values shall be checked at distance 'd'=0.2m. There are four risk groups defined:

- Exempt Group (no hazard)
- Risk Group 1 (low risk)
- Risk Group 2 (moderate risk)
- Risk Group 3 (high risk)

Summarizes of the emission limits for different risk groups are shown below in Table 5.

Table 5. Emission limits of risk groups for continuous wave lamps with IR radiation.

SYMBOL	EXPOSURE TIME (t)	EMISSION LIMITS				UNITS
		EXEMPT	LOW RISK	MODERATE RISK	HIGH RISK	
LR	10µs≤t≤10s	28000/α	28000/α	71000/α	>71000/α	$W.m^{-2}.sr^{-1}$
LIR	<1000s	6000/α	6000/α	6000/α	>6000/α	$W.m^{-2}.sr^{-1}$
EIR	<1000s	100	570	3200	>3200	$W.m^{-2}$

Based on the risk group classification above, IEC-62471-2 describes the labeling requirement of the IR products in Table 1.

Table 6. IEC-62471-2 labeling requirements by risk group.

HAZARD	EXEMPT GROUP	RISK GROUP 1	RISK GROUP 2	RISK GROUP 3
Cornea/lens IR hazard	Not required	**NOTICE** IR emitted from this product	**CAUTION** IR emitted from this product	**WARNING** IR emitted from this product
Retinal thermal hazard (weak stimulus) 780nm to 1400nm	Not required	**WARNING** IR emitted from this product	**WARNING** IR emitted from this product	**WARNING** IR emitted from this product

3. Example Calculations

3.1 LUXEON IR Compact + Optics

Calculate the exposure limits and indicate the risk group for LUXEON IR Compact with the 4429RPA19 reflector, which has a aperture diameter of 2.6mm and maximum intensity of 0.495 W/sr (@ 1A and junction temperature T_j=25°C) with peak wavelength of 940nm. Illuminator is at distance 20cm from eyes and exposure duration is more than 1,000s.

Per the LUXEON IR Compact datasheet, the die size is 1mm x 1mm. Although, aperture diameter of the optics is given 2.6mm, but worst case we choose the source size of 1mm x 1mm for eye safety assessment.

Table 7. Cornea exposure limit calculation for LUXEON IR Compact with 4429RPA19 reflector.

	PARAMETERS	VALUES	REMARKS
Inputs	Measurement distance (mm)	200	Given
	I (W/sr @ 1A, nominal conditions)	0.495	Datasheet
	Exposure duration, t (seconds)	>1,000	Given
Calculations	E_{IR} limit (W/m^2)	100	From Equation (3)
	E (W/m^2)	12.4	From Equation (4)
	Result	E < E_{IR} limit	Eye safe

The E < E_{IR} limit in Table 7 above shows that LUXEON IR Compact with the 4429RPA19 reflector is safe for cornea and skin exposures at the given operating and exposure conditions.

Table 8. Retina exposure limit calculation for LUXEON IR Compact with 4429RPA19 reflector.

	PARAMETERS	VALUES	REMARKS
Inputs	Source size (l x w mm^2)	1.0 x 1.0	For worst case
	Measurement distance (mm)	200	(Lamp Classification) Standard
	λ (nm)	940	Given
	I (W/sr @ 1A, nominal conditions)	0.495	Datasheet
Calculations	α (rad)	0.005	From Equation (5)
	α_{min} (t ≥10s) (rad)	0.011	From Table 2, α_{min}=0.011 if α <0.011
	R (λ)	0.331	From Equation (6)
	L_{IR} limit ($W/m^2/Sr$)	545,455	From Equation (8)
	L ($W/m^2/Sr$)	163,910	From Equation (9)
	Result	$L < L_{IR}$ limit	Eye safe

The $L < L_{IR}$ limit in Table 8 above shows that this illuminator is safe for retina exposure at the given operating and exposure conditions.

Table 5 shows that this product will be in the “Exempt Group” (no risk), and according to Table 6, no label will be required on the final product containing this illuminator.

3.2 Array of LUXEON IR Compact

Calculate the exposure limits and indicate the risk group for an array of 9 (3x3 arrangement) closely packed LUXEON IR Compact (940nm) LEDs with a gap of 0.2mm between the LEDs and driving at I_f =1.5A DC (T_j=85°C). Illuminator is at a distance of 1m from eyes and exposure duration is a maximum of 100s.

The datasheet shows the radiant intensity of the LUXEON IR Compact (λ=940nm) is 0.3 W/sr (@ 1A and T_j=25°C) and correction factor for I_f =1.5A and T_j=85°C (from datasheet) is 1.23. For an array of 9 LEDs, the worst-case scenario is the radiant intensity can overlap, ideally, to total radiant intensity = 9 * radiant intensity of single LED.

Table 9. Cornea exposure limit calculation for array of 9 LUXEON IR Compact.

	PARAMETERS	VALUES	REMARKS
Inputs	Distance (mm)	200	(Lamp Classification) Standard
	I (W/sr @ 1.5A, T_j=85°C)	0.3 x 1.23 = 0.369	Datasheet (single LED)
	Number of LEDs	9	
	Exposure duration, t (seconds)	>1,000	
Calculations	Total intensity (W/sr)	3.32	I x number of LEDs, ideal overlap
	E_{IR} limit (W/m^2)	569.2	t <1,000s, from Equation (2)
	E (W/m^2)	83	From Equation (4)
	Result	$E < E_{IR}$ limit	Eye safe

As $E < E_{IR}$ limit, so array of 9 LUXEON IR Compact at given operating condition and exposure time of 100s. From Equation (4), if viewing distance in application condition is 1m, then E = 3.3 W/m^2 << E_{IR}.

Table 10. Retina exposure limit calculation for array of 9 LUXEON IR Compact.

	PARAMETERS	VALUES	REMARKS
Inputs	Source size (l x w mm^2)	1.0 x 1.0	Single LED
	Measurement distance (mm)	200	(Lamp Classification) Standard
	λ (nm)	940	Given
	I (W/sr @ 1.5A, T_j=85°C)	0.3 x 1.23 = 0.369	Datasheet (single LED)
Calculations	α (rad)	0.005	From Equation (5)
	α_{min} (t ≥ 10s) (rad)	0.011	From Table 2, α_{min}=0.011 if α<0.011
	R (λ)	0.331	From Equation (6)
	L_{IR} limit (W/m^2/Sr)	545,455	From Equation (8)
	L (W/m^2/Sr)	122,187	From Equation (9)
	Result	L < L_{IR} limit	Eye safe

As L < L_{IR} limit, this illuminator is safe for retina exposure at the given operating and exposure conditions.

Table 5 shows that this product will be in the "Exempt Group" (no risk) for the application conditions.

4. References

1. EN 62471, Photobiological safety of lamps and lamp systems (IEC 62471:2006, modified), September 2008
2. IEC/TR 62471-2, Photobiological safety of lamps and lamp systems – Part 2: Guidance on Manufacturing requirements relating to non-laser optical radiation safety, 2009-08

About Lumileds

Companies developing automotive, mobile, IoT and illumination lighting applications need a partner who can collaborate with them to push the boundaries of light. With over 100 years of inventions and industry firsts, Lumileds is a global lighting solutions company that helps customers around the world deliver differentiated solutions to gain and maintain a competitive edge. As the inventor of Xenon technology, a pioneer in halogen lighting and the leader in high performance LEDs, Lumileds builds innovation, quality and reliability into its technology, products and every customer engagement. Together with its customers, Lumileds is making the world better, safer, more beautiful—with light.

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