DOMINANT™ Opto Technologies *Innovating Illumination*

Photobiological Safety for DOMINANT LEDs

Background

The potential photobiological hazard of LEDs was initially being assessed to be similar to laser in the laser safety standard by European Standard Organization. However, the assessment does not truly represent the LEDs because the radiances difference in both LED and lasers led to different applications as well as potential eye hazard levels. The EN 60825 (equivalent to IEC 60825) standard was then further revised to accommodate the issues. Finally, the LEDs were removed from the scope of IEC 60825-1:2007 and published as IEC 62471:2006 Photobiological Safety of Lamps. The scope of this standard applies to lamps and lamp systems safety including the safety of luminaires.

Hazard exposure limits (EL)

Optical radiation in general does not penetrate very deeply into biological tissues. The blue light and infrared irradiated from LED primarily affects the eye and skin. Thus the potential hazards for both blue light and infrared are governed by following distinct exposure limits.

a. Retinal blue light hazard exposure limit
b. Blue light (small source) hazard exposure limits for the eye (cornea)
c. Infrared radiation hazard exposure limit for the eye (cornea)
d. Retinal thermal hazard exposure limit
e. Thermal hazard exposure limit for the skin

a. Blue light hazard exposure limits

For exposure time $t \leq 10^4$ s, the maximum radiance from blue light shall not exceed the level defined by equations below.

$$L_B = \sum_{300}^{700} \sum_{t} L_\lambda(\lambda, t) \cdot B(\lambda) \cdot \Delta\lambda \quad \leq \frac{10^6}{t} \qquad [Wm^{-2}sr^{-1}] \qquad (1)$$

For exposure time $t > 10^4$ s, the radiance is limited to a constant value:

$$L_B = \sum_{300}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda \quad \leq 100 \qquad [Wm^{-2}sr^{-1}] \qquad (2)$$

where L_λ is the spectral radiance in $Wm^{-2}sr^{-1}nm^{-1}$, B_λ is the blue light hazard weighting function, $\Delta\lambda$ is the bandwidth in nm and t in seconds.

The maximum permissible exposure duration, t_{max} for weighted source radiance, L_B that exceeding 100 $Wm^{-2}sr^{-1}$ within $t \leq 10^4$ s is computed as follows:

$$t_{max} = \frac{10^6}{L_B} \qquad [s] \qquad (3)$$

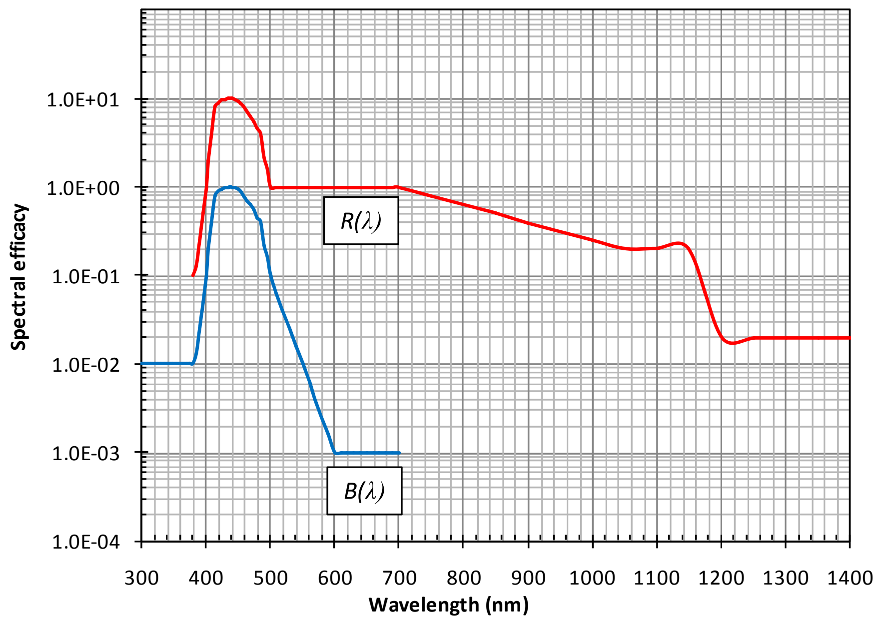


Figure 1: Blue light weighting hazard function B(λ) and thermal weighting hazard function R(λ)

b. Blue light (small source) hazard exposure limits for the eye

For blue light source with size less than 0.011 radians, the EL derivation for exposure time $t \leq 100$ s can be simplified using spectral irradiance:

$$E_B = \sum_{300}^{700} \sum_{t} E_\lambda(\lambda, t) \cdot B(\lambda) \cdot \Delta\lambda \quad \leq \frac{100}{t} \qquad [Wm^{-2}] \qquad (4)$$

For exposure time $t > 100$s, the radiance is limited to a constant value:

$$E_B = \sum_{300}^{700} \sum_{t} e_\lambda \cdot B(\lambda) \cdot \Delta\lambda \quad \leq 1 \qquad [Wm^{-2}] \qquad (5)$$

where E_λ is the spectral irradiance in $Wm^{-2}sr^{-1}nm^{-1}$, B_λ is the blue light hazard weighting function, $\Delta\lambda$ is the bandwidth in nm and t in seconds.

For blue light source weight irradiance, E_B greater than 0.01 Wm^{-2} within $t \leq 100$ s, the maximum allowable exposure duration is calculated as followed:

$$t_{\max} = \frac{100}{E_B} \qquad [s] \qquad (6)$$

c. Infrared radiation hazard exposure limits for the eye

The exposure of infrared radiation within $t \leq 1000$ s is restricted to:

$$E_{IR} = \sum_{780}^{3000} E_\lambda \cdot \Delta\lambda \quad \leq \frac{18000}{t^{0.75}} \qquad [Wm^{-2}] \qquad (7)$$

For time t > 1000 s, the irradiance becomes independent to duration of exposure:

$$E_{IR} = \sum_{780}^{3000} E_{\lambda} \cdot \Delta\lambda \leq 100 \qquad [Wm^{-2}] \qquad (8)$$

where E_{λ} is the spectral irradiance in $Wm^{-2}sr^{-1}nm^{-1}$, $\Delta\lambda$ given in nm and t in seconds. In cold environments, the EL for t > 1000 s is increased to 400 Wm^{-2} at 0°C and 300 Wm^{-2} at 10°C.

d. Retinal thermal hazard exposure limits

Apparent light entering the pupil is focused by the cornea and lens. Then it is projected at back of the eye where the retina lies and that defines the optical irradiation induced stressed region. The angular substense, α at a viewing distance, d can be determined by:

$$\alpha = \frac{1}{d}\left(\frac{l+w}{2}\right) \qquad [rad] \qquad (9)$$

with l and w are the length and width of the source respectively. Since the size of the pupil changes with the level of luminance, the effective angular substense, α_{eff} of blue light at a given exposure duration is listed in the table below.

Wavelength, λ (nm)	**Duration, *t*** (s)	$\alpha_{min,eff}$, γ_{FOV} (rad)	$\alpha_{max,eff}$, γ_{FOV} (rad)
380 - 1400	$t \leq 0.25$	0.0017	0.1
	$0.25 < t < 10$	$0.0017 \sqrt{\frac{t}{0.25}}$	0.1
	$t \geq 10$	0.011	0.1
Blue Light (Additional remarks)	$t \leq 100$	0.011	0.1
	$100 < t < 10000$	$0.011 \sqrt{\frac{t}{100}}$	0.1
	$t \geq 10000$	0.1	0.1

Table 1: Limits of the angular substense, α and measurements field of view, γ_{FOV} at different time range

For irradiance measurement, the angular substense, α is defined by field of view, γ_{FOV} given in equation below.

$$\alpha_{eff} = \gamma_{FOV} = \frac{F}{r} \qquad [rad] \qquad (11)$$

where F is the size of the field stop and r is the distance source to detector.

The maximum EL to protect retinal from thermal injury is calculated based on the integrated spectral radiance of the light source, L_{λ} and weighting function, $R(\lambda)$. The EL is a function of exposure time, t and angular substense, α from the source in radians when 10 μs ≤ t ≤ 10 s.

$$L_R = \sum_{380}^{1400} L_{\lambda} \cdot R(\lambda) \cdot \Delta\lambda \leq \frac{50000}{\alpha \cdot t^{0.25}} \qquad [Wm^{-2}sr^{-1}] \qquad (12)$$

For longer exposure time, *t* > 10 s, the EL is defined by the near infrared range (weak visual stimulus, 780 – 1400 nm) and limited to:

$$L_{IR} = \sum_{780}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \le \frac{6000}{\alpha} \qquad [Wm^{-2}sr^{-1}] \qquad (13)$$

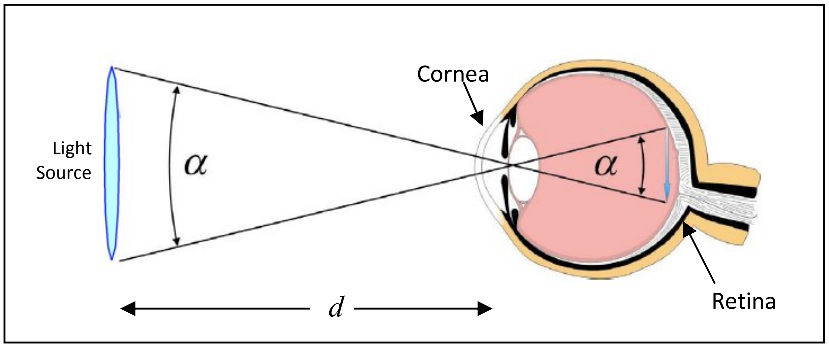


Figure 2: Angular substense, *α* at a viewing distance, *d*.

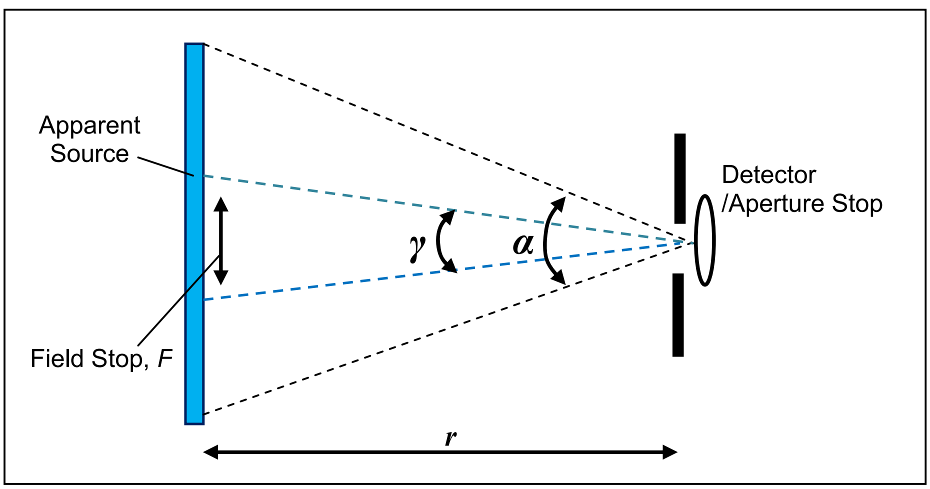


Figure 3: Alternative radiance measurement technique.

e. Thermal hazard exposure limit for skin

The highest EL of skin for *t* ≤ 10s shall be limited to:

$$E_H = \sum_{380}^{3000} \sum_{t} E_\lambda(\lambda, t) \cdot \Delta\lambda \le \frac{20000}{t^{0.75}} \qquad [Jm^{-2}] \qquad (12)$$

where E_λ is the spectral irradiance in $Wm^{-2}nm^{-1}$, $\Delta\lambda$ given in nm and *t* in seconds. For exposure longer than 10 s, EL is not provided because severe pain occurs before the skin can be damaged.

Lamp Classification

The following table, it summarizes the limits and potential risk group classification of lamps constructed using blue light and infrared irradiated LED.

Hazard	Risk Group				
	Exempt (No Hazard)	Risk Group 1 (Low Risk)	Risk Group 2 (Moderate Risk)	Risk Group 3 (High Risk)	Unit
Retinal Blue Light	$L_B < 100$	$L_B < 10{,}000$	$L_B < 4{,}000{,}000$	Warning when exceeded limits of Risk Group 2	$Wm^{-2}sr^{-1}$
Retinal Blue light, small source (α < 0.011 rad)	$E_B < 1.0$	$E_B < 1.0$	$E_B < 400$		Wm^{-2}
Retinal thermal	$L_R < 28000/ \alpha$	$L_R < 28000/ \alpha$	$L_R < 71000/ \alpha$		$Wm^{-2}sr^{-1}$
Retinal thermal, weak visual stimulus (including non-GLS source)	$L_{IR} < 6000/ \alpha$	$L_{IR} < 6000/ \alpha$	$L_{IR} < 6000/ \alpha$		$Wm^{-2}sr^{-1}$
IR radiation	$E_{IR} < 100$	$E_{IR} < 570$	$E_{IR} < 3200$		Wm^{-2}

Table 3: Emission limits for risks group of continuous wave lamps.

The hazard value for lamps intended for general light service (GLS) is reported at distance which produces a luminance of 500 lux. Meanwhile, the measurement distance for other light sources is fixed at 200 mm.

The recommended control measure for each hazard risk groups is listed in the following table.

Hazard	Risk Group			
	Exempt (No Hazard)	Risk Group 1 (Low Risk)	Risk Group 2 (Moderate Risk)	Risk Group 3 (High Risk)
Retinal Blue Light (300 – 700 nm)	Not required	Not required	Do not stare at operating lamp. May be harmful to the eyes.	Do not look at operating lamp. May result in eye injury.
Retinal Blue light, small source				
Retinal thermal (380 – 1400 nm)				
Retinal thermal, weak visual stimulus (780 – 1400 nm)	Not required	Do not stare at operating lamp.	Do not stare at operating lamp.	Do not look at operating lamp.
IR radiation (780 – 3000 nm)		Use appropriate shielding for eyes	Avoid eye exposure. Use appropriate shielding or eye protection.	Avoid eye exposure. Use appropriate shielding or eye protection.

Table 4: Recommended control measure for each hazard risk groups.

Analysis

Majority of LED produce by Dominant is visible LED with wavelength spectrum fall into range from 400nm to 700nm. Thus by default there is no risk of UV or IR radiation exposure from these LED. The photobiological risk of visible LED is hence confined to blue light hazard and retinal thermal hazard. Table below summarized the maximum brightness part number from each platforms of LED produced in Dominant and their respective risk hazard classification.

Blue				White			
Platform	**Part No.**	**Maximum Luminous Flux [lm]**	**Risk Hazard**	**Platform**	**Part No.**	**Maximum Luminous Flux [lm]**	**Risk Hazard**
SPNova	NPB-JSG	27.0	RG1	SPNova	NPW-RSD	113.6	Exempt
PowerDomi	DWB-LJG	2.7	Exempt	Primax	NAW-BSG	39.8	Exempt
Domi	DDB-HJS	1.3	Exempt	PowerDomi	DWW-WJG	8.9	Exempt
MiniDomi	DNB-DZJS	1.3	Exempt	Domi	DDW-WJG	7.5	Exempt
MultiDomi	D6RTB-HJD	1.2	Exempt	MiniDomi	DNW-UJG	2.7	Exempt
Spice	SSB-HLD	0.4	Exempt	Spice	SSW-HLD	1.3	Exempt
Through-hole LED	L5B-N1500	1.0	RG 1	Through-hole LED	L5W-N1500	4.0	RG 1
Primax	NAB-FSG	10.7	Exempt	PrimaxPlus	MAW-YZHG	168	Exempt

Table 5: List of LED with the maximum brightness part number from each platform.

Summary

Based on the measurement result, it is proven that the worst case exposure scenario in Dominant visible LED product range is classified under Risk Group 1 (Low Risk). However, this assessment applies to the LED components alone. For custom application that involves module integration and secondary optics, power density would be one of the additional factor to be considered into the analysis.

Appendix I

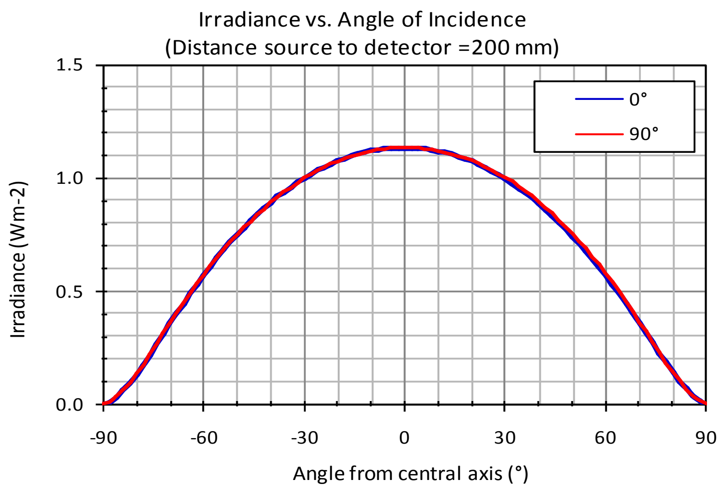
LED Type	SPNova BLUE
Luminous flux	27.0 lm at I_F = 350 mA, T = 25°C
Peak Wavelength	455 nm
Color	Blue
Small Source	Yes
Peak Irradiance measured, E_λ	1.134 Wm^{-2} at T = 25°C (Refer to chart below)

Risk Group Categories for Continuous Wave

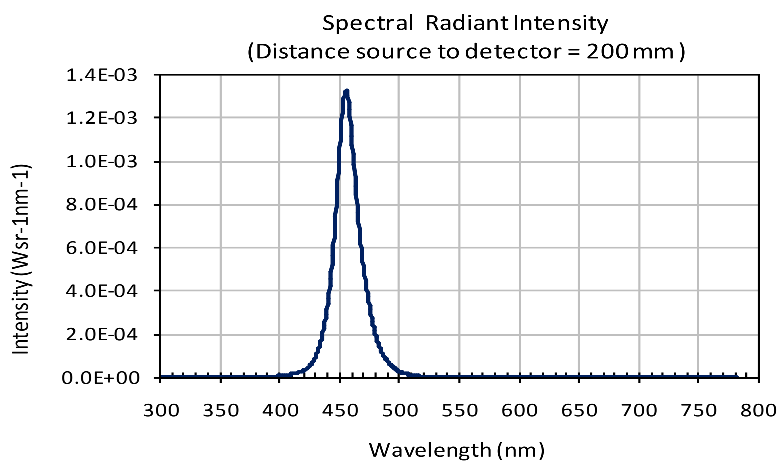
Risk Factor	Risk Group Result
Actinic UV, E_S (200 – 400 nm)	Exempt**
Near UV, E_{UVA} (315 – 400 nm)	Exempt**
Blue Light, L_B (300 – 700 nm)	Risk Group 1 (Low Risk)
Blue Light Small Source, E_B (300 – 700 nm)	Exempt
Retinal Thermal, L_R (380 – 1400 nm)	Exempt
Retinal Thermal Weak Stimulus, L_R (380 – 1400 nm)	Exempt**
Infrared Radiation for eye, L_{IR} (780 – 3000 nm)	Exempt**

**No emission in the wavelength range of the listed risk category.

Irradiance Profile at 200 mm



Spectrum



Appendix II

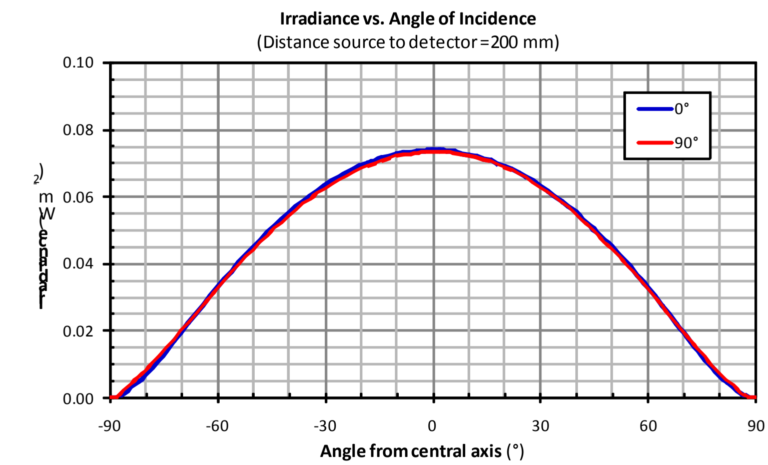
LED Type	DomiLED
Luminous flux	7.5 lm at I_F = 20 mA, T = 25°C
Peak Wavelength	445 nm
Wavelength measured	300 – 800 nm
Color	White
Small Source	No
Peak Irradiance measured, E_λ	0.074 Wm^{-2} at T = 25°C (Refer to chart below)

Risk Group Categories for Continuous Wave

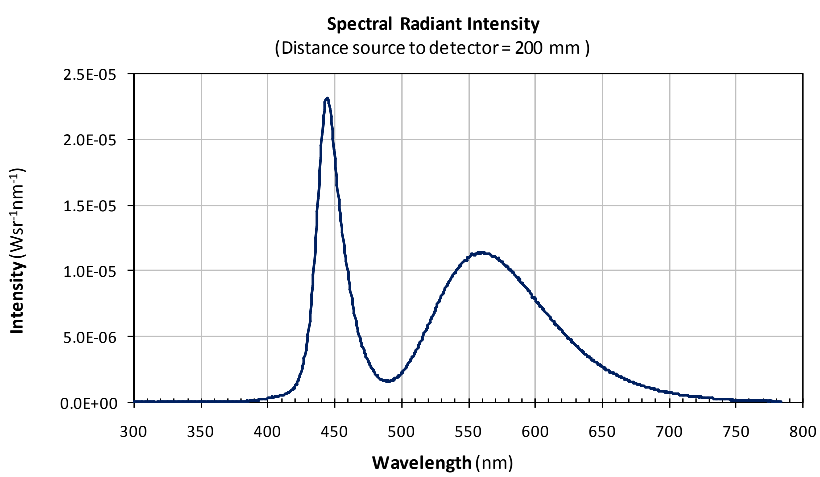
Risk Factor	Risk Group Result
Actinic UV, E_S (200 – 400 nm)	Exempt**
Near UV, E_{UVA} (315 – 400 nm)	Exempt**
Blue Light, L_B (300 – 700 nm)	Exempt
Blue Light Small Source, E_B (300 – 700 nm)	Exempt
Retinal Thermal, L_R (380 – 1400 nm)	Exempt
Retinal Thermal Weak Stimulus, L_R (380 – 1400 nm)	Exempt**
Infrared Radiation for eye, L_{IR} (780 – 3000 nm)	Exempt**

**No emission in the wavelength range of the listed risk category.

Irradiance Profile at 200 mm



Spectrum



Appendix III

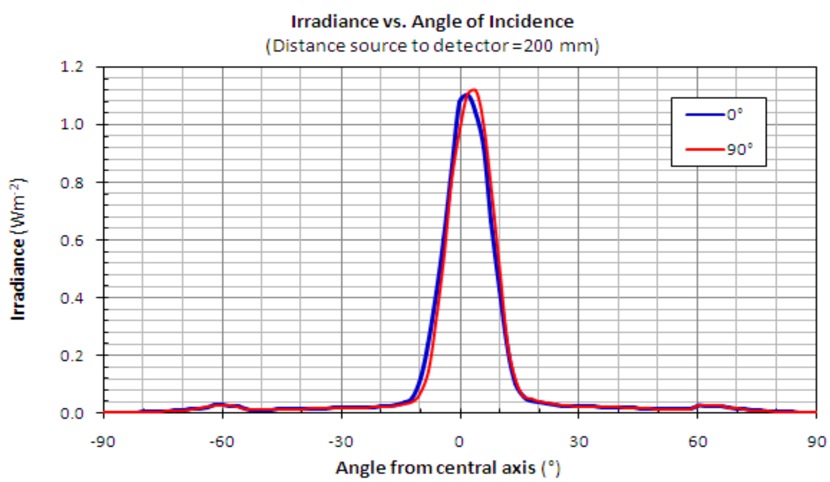
LED Type	Through-hole LED
Luminous flux	1.0 lm at I_F = 20 mA, T = 25°C
Peak Wavelength	465 nm
Color	Blue
Small Source	Yes
Peak Irradiance measured, E_λ	1.109 Wm^{-2} at T = 25°C (Refer to chart below)

Risk Group Categories for Continuous Wave

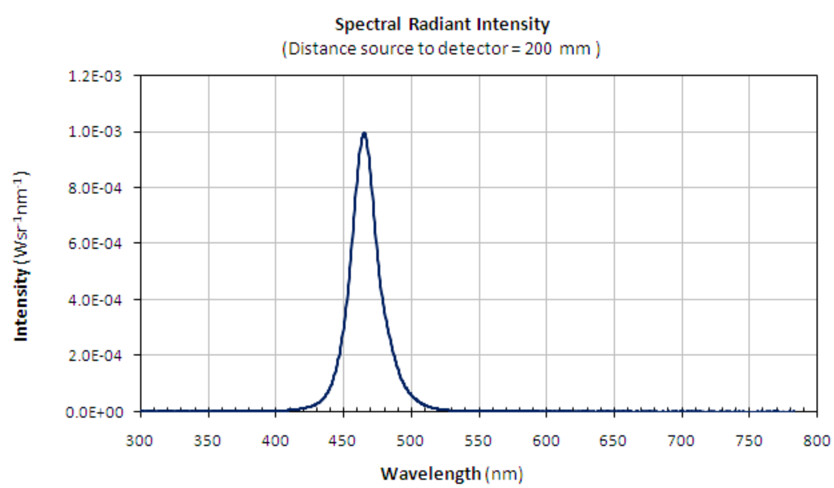
Risk Factor	Risk Group Result
Actinic UV, E_S (200 – 400 nm)	Exempt**
Near UV, E_{UVA} (315 – 400 nm)	Exempt**
Blue Light, L_B (300 – 700 nm)	Risk Group 1 (Low Risk)
Blue Light Small Source, E_B (300 – 700 nm)	Exempt
Retinal Thermal, L_R (380 – 1400 nm)	Exempt
Retinal Thermal Weak Stimulus, L_R (380 – 1400 nm)	Exempt**
Infrared Radiation for eye, L_{IR} (780 – 3000 nm)	Exempt**

**No emission in the wavelength range of the listed risk category.

Irradiance Profile at 200 mm



Spectrum



Appendix IV

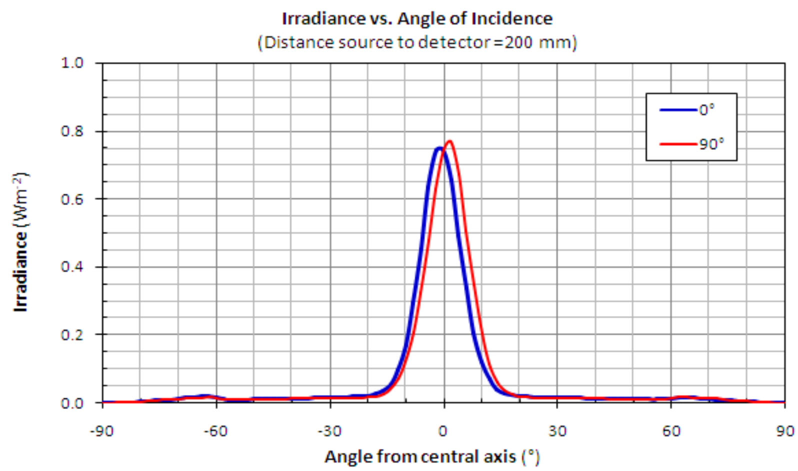
LED Type	Through-hole LED
Luminous flux	4.0 lm at I_F = 20 mA, T = 25°C
Peak Wavelength	460 nm
Wavelength measured	300 – 800 nm
Color	White
Small Source	Yes
Peak Irradiance measured, E_λ	0.756 Wm^{-2} at T = 25°C (Refer to chart below)

Risk Group Categories for Continuous Wave

Risk Factor	Risk Group Result
Actinic UV, E_S (200 – 400 nm)	Exempt**
Near UV, E_{UVA} (315 – 400 nm)	Exempt**
Blue Light, L_B (300 – 700 nm)	Risk Group 1 (Low Risk)
Blue Light Small Source, E_B (300 – 700 nm)	Exempt
Retinal Thermal, L_R (380 – 1400 nm)	Exempt
Retinal Thermal Weak Stimulus, L_R (380 – 1400 nm)	Exempt**
Infrared Radiation for eye, L_{IR} (780 – 3000 nm)	Exempt**

**No emission in the wavelength range of the listed risk category.

Irradiance Profile at 200 mm



Spectrum