

Eye Safety With LED Components

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INTRODUCTION

This application note explains the current standards and regulations related to LED components (both packaged LEDs and LED light engines or modules) and photobiological safety. It also provides guidance for expected maximum risk group classifications for Cree's visible light LED components in accordance with these standards. Visible light LED components, as that term is used in this document, include both white LEDs and LED modules and colored LEDs with the dominant wavelengths between 400 nm and 680 nm.

At a high enough intensity, all light sources have the potential to be harmful to both the skin and the eyes through ultraviolet (UV), blue light (400-480 nm) and/or infrared (IR) emissions. LEDs that emit blue light may be identified by multiple names, such as blue, royal blue or dental blue. (As of the date of this application note, Cree does not produce a dental blue LED). Additionally, most white packaged LEDs (including Cree's) are made using blue-emitting LED die and therefore emit a portion of their total output as blue light.

Cree has engaged an independent lab to conduct photobiological testing, also known as eye safety testing, on its blue, royal blue and select white LED components. The results of this testing (explained below in further detail) show significant health risks from some of Cree's visible light LED components when viewed without diffusers or secondary optical devices. These risks warrant an advisory notice to indicate the potential for eye injury caused by prolonged viewing of blue light from these devices.

To date, the testing shows that Cree's blue and royal blue LED components (450-485 nm dominant wavelengths) pose a higher potential eye safety hazard than its white LED components. Other colors of LED components, such as green and red LED components, do not pose as significant of an eye safety risk. Regardless of LED color, Cree advises users to not look directly at any operating LED component. Further, Cree recommends that any manufacturer that is incorporating Cree® LED components into its lighting products make an assessment of how these components could create a light exposure risk to its employees during the manufacturing process. Such risks can be minimized by using engineering controls (e.g., light-blocking screens or filters, or current-limiting resistors in a test apparatus) or personnel protection equipment (e.g., light-filtering or blocking eyewear).

During the eye safety testing of Cree's visible light LED components, the LED solder-point temperature or LED module case temperature was controlled to be at or below what is normally observed in most LED luminaire (lighting fixture) designs – this control ensures maximized, or worst case, light output. Depending on the final luminaire design, the eye safety risks associated with a particular use of Cree LED components could differ from data provided in this application note, or the third party test results, due to differences in operating conditions.

In addition to risk incident to blue light, very bright light can elevate the temperature of retinal tissue and pose a hazard. Retinal thermal hazards are defined by the intensity of visual light radiation focused by the cornea on the retina of the human eye. The image formed on the retina becomes the affected area of the eye subject to thermal damage. As shown in Figure 1¹, the retinal thermal hazard function includes a much broader range of wavelengths than the blue light hazard function.

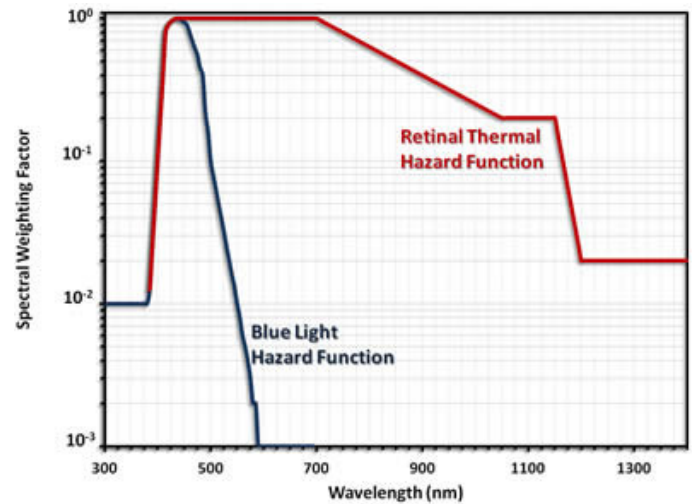


Figure 1: Retinal thermal and blue light hazard functions

PHOTOBIOLOGICAL STANDARDS AND REGULATIONS FOR LED COMPONENTS

Before the fall of 2008, most LEDs were tested and labeled in accordance with the IEC/EN 60825 laser safety (coherent light source) standard. The IEC/EN 60825 standard, however, was not considered appropriate for conventional packaged LEDs because most LEDs are not designed to be coherent light sources (except for laser diodes). Further, the IEC/EN 60825 standard does not define risk groups for LED luminaires, so it does not consider changes in the eye safety risks created by elements other than individual LED components, such as secondary optics, reflectors, or diffusers. As a result, in late 2008 a newer standard, referred to as IEC 62471-2006 (plus the supporting ANSI/IESNA RP-27 testing methodology), was adopted for conventional, or lighting class, LEDs. The detailed photobiological testing results provided below in this application note are based on the new standard and the ANSI/IESNA RP-27 testing methodology.

As of the date of publication of this application note, a few countries may still refer to IEC/EN 60825 as the prevailing standard. Since IEC/EN 60825 was the only safety standard for LED components available for many years, Cree previously tested several of its XLamp® white LEDs in accordance with the IEC/EN 60825 and found that many of them would be considered Class 2 devices under such standard. Products released in 2010 or later likely have not been tested or evaluated using IEC 60825.

The summary of results presented below were performed on standalone Cree LED components to aid in fixture design and to assess the general safety of personnel exposed to LED-based emissions in the manufacturing setting. No single test result is meant to be indicative of all XLamp LEDs and LED modules under all operation conditions, i.e., operation within a range of forward currents is possible with any LED. Further, the risk classification of a standalone LED component has little or no bearing on the risk classification of the final luminaire. Accordingly, once Cree LED components are incorporated into a luminaire or related LED lighting product, Cree recommends and EU consumer and commercial directives and the IEC 62471-2006 standard generally require that the assembly be tested under ANSI/IESNA RP-27 (or an equivalent measurement methodology) to assess the eye safety risk of the lighting system.

¹ Copyright © University of Ottawa, Office of Risk Management; "Photobiological Effects", www.uottawa.ca/services/ehss/IOREffects.html

The IEC 62471-2006 standard specifies four (4) classifications, called risk groups, for lamps and lamp systems (excluding lasers) emitting light in wavelengths from 200 to 3000 nm as set forth in Table 1 below.²

Table 1: Risk groups

Risk Group	Risk	Definition
Exempt	None	No photobiological hazard
RG-1	Low Risk	No photobiological hazard under normal behavioral limitation
RG-2	Moderate risk	Does not pose a hazard due to aversion response to bright light or thermal discomfort
RG-3	High risk	Hazardous even for momentary exposure

SUMMARY TEST RESULTS

Table 2 and Table 3 below summarize the eye safety test results for Cree LED components pursuant to the IEC 62471 classification system. The risks noted below are based on the measured blue light emissions. Upon testing, Cree LED components demonstrated no other hazardous properties defined by IEC 62471-2006 or ANSI/IESNA RP-27.

When electrical conditions are constant, risk rankings for each product tend to decrease in order from royal blue, blue, cool white, neutral white, to warm white. Figure 2 pictorially shows that decrease.

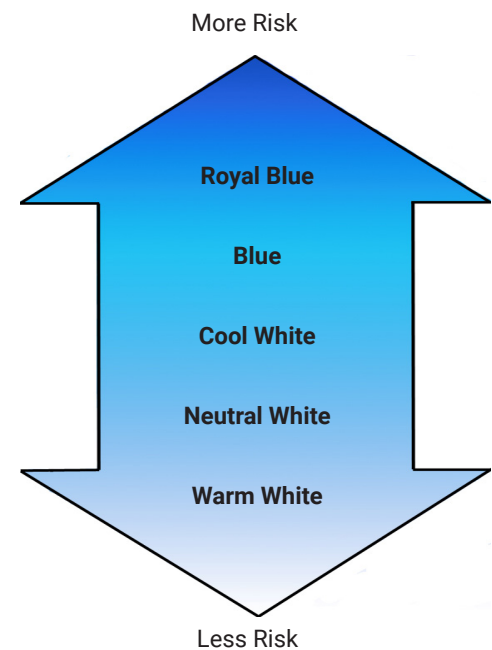


Figure 2: Risk decreases from royal blue to warm white at constant electrical conditions

Cree has begun eye safety testing of cool white, neutral white and warm white versions of XLamp LEDs. Included in the test results in Table 2, as applicable, are the drive conditions at which an LED exceeds the risk group 1 and risk group 2 thresholds. Also included are the illuminance threshold (E_{thr}), the illuminance at the risk group 1/risk group 2 threshold, and the minimum safe distance (d_{min}), the distance from the light source at which an LED exceeds the risk group 1 threshold. These results will be included in Table 2 as they become available. The E_{thr} and d_{min} test results values shown in Table 2 in lux and millimeters, respectively, have been converted to the foot-candles and feet values shown in parentheses.

² IEC 62471 Photobiological safety of lamps and lamp systems - First edition, 2006-2007

Contact a Cree sales representative for more information regarding the Cree XLamp LEDs referenced in Table 2 and the Cree LED modules referenced in Table 3.

Table 2: Summary table of XLamp LED eye safety test results

XLamp® LED	Color	Test Report Issue Date	Maximum Drive Condition	Risk Group Classification at Maximum Drive Condition	Exceeds RG-1 Threshold At	RG-1/RG-2 Threshold		Exceeds RG-2 Threshold At
						E _{thr}	d _{min}	
CMA1306 (36-V)	Cool White	January 25, 2019	1.600 A (9 V) 0.800 A (18 V) 0.400 A (36 V)	RG-2 Moderate risk	0.089 A	704 lux (65.4 fc)	873 mm (2.86 ft)	Not applicable
CMA1306 (9-V)	Neutral White	January 25, 2019		RG-2 Moderate risk	0.580 A	1197 lux (111.21 fc)	681 mm (2.23 ft)	Not applicable
CMA1306 (36-V)	Warm White	January 25, 2019		RG-2 Moderate risk	0.243 A	1941 lux (180.3 fc)	529 mm (1.74 ft)	Not applicable
CMA1516	Cool White	February 1, 2018	1.050 A	RG-2 Moderate risk	0.248 A	925 lux (85.9 fc)	1359 mm (4.46 ft)	Not applicable
	Neutral White	February 1, 2018	1.050 A	RG-2 Moderate risk	0.403 A	1473 lux (136.8 fc)	1013 mm (3.32 ft)	Not applicable
	Warm White	February 1, 2018	1.050 A	RG-2 Moderate risk	0.631 A	2290 lux (212.7 fc)	1824 mm (2.70 ft)	Not applicable
CMA1825	Cool White	February 1, 2018	1.600 A	RG-2 Moderate risk	0.442 A	860 lux (79.9 fc)	1634 mm (5.36 ft)	Not applicable
	Neutral White	February 1, 2018	1.600 A	RG-2 Moderate risk	0.828 A	1633 lux (151.7 fc)	1225 mm (4.02 ft)	Not applicable
	Warm White	February 1, 2018	1.600 A	RG-2 Moderate risk	1.363 A	2595 lux (241.1 fc)	959 mm (3.15 ft)	Not applicable
CMA1840	Cool White	February 1, 2018	2.300 A	RG-2 Moderate risk	0.589 A	854 lux (79.3 fc)	1990 mm (6.53 ft)	Not applicable
	Neutral White	February 1, 2018	2.300 A	RG-2 Moderate risk	1.075 A	1580 lux (146.8 fc)	1433 mm (4.70 ft)	Not applicable
	Warm White	February 1, 2018	2.300 A	RG-2 Moderate risk	1.570 A	2216 lux (205.9 fc)	1228 mm (4.03 ft)	Not applicable
CMA2550	Cool White	February 1, 2018	3.300 A	RG-2 Moderate risk	1.684 A	849 lux (78.9 fc)	2347 mm (7.70 ft)	Not applicable
	Neutral White	February 1, 2018	3.300 A	RG-2 Moderate risk	1.059 A	1430 lux (132.9 fc)	1803 mm (5.92 ft)	Not applicable
	Warm White	February 1, 2018	3.300 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CMA3090 (72 V)	Cool White	February 1, 2018	3.600 A (48 V) 2.400 A (72 V)	RG-2 Moderate risk	0.813 A	830 lux (77.1 fc)	2627 mm (8.62 ft)	Not applicable
	Neutral White	February 1, 2018		RG-2 Moderate risk	1.502 A	1489 lux (138.3 fc)	1990 mm (6.53 ft)	Not applicable
	Warm White	February 1, 2018		RG-1 Low risk	Not applicable	Not applicable		Not applicable
CMT1407	Cool White	April 4, 2018	0.500 A	RG-2 Moderate risk	0.322 A	982 lux (91.2 fc)	1009 mm (3.31 ft)	Not applicable
	Neutral White	April 4, 2018	0.500 A	RG-2 Moderate risk	0.495 A	1578 lux (146.6 fc)	745 mm (2.44 ft)	Not applicable
	Warm White	April 4, 2018	0.500 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CMT1412	Cool White	April 4, 2018	0.750 A	RG-2 Moderate risk	0.274 A	987 lux (91.7 fc)	1141 mm (3.74 ft)	Not applicable
	Neutral White	April 4, 2018	0.750 A	RG-2 Moderate risk	0.415 A	1631 lux (151.5 fc)	938 mm (3.08 ft)	Not applicable
	Warm White	April 4, 2018	0.750 A	RG-2 Moderate risk	0.703 A	2100 lux (195.1 fc)	730 mm (2.40 ft)	Not applicable

XLamp® LED	Color	Test Report Issue Date	Maximum Drive Condition	Risk Group Classification at Maximum Drive Condition	Exceeds RG-1 Threshold At	RG-1/RG-2 Threshold		Exceeds RG-2 Threshold At
						E _{thr}	d _{min}	
CMT1420	Cool White	April 11, 2018	1.300 A	RG-2 Moderate risk	0.299 A	952 lux (88.4 fc)	1359 mm (4.46 ft)	Not applicable
	Neutral White	April 11, 2018	1.300 A	RG-2 Moderate risk	0.475 A	1511 lux (140.4 fc)	1109 mm (3.64 ft)	Not applicable
	Warm White	April 11, 2018	1.300 A	RG-2 Moderate risk	0.730 A	2192 lux (203.6 fc)	923 mm (3.03 ft)	Not applicable
CMT1922	Cool White	April 17, 2018	1.500 A	RG-2 Moderate risk	0.486 A	903 lux (83.9 fc)	1618 mm (2.03 ft)	Not applicable
	Neutral White	April 17, 2018	1.500 A	RG-2 Moderate risk	1.260 A	1629 lux (151.3 fc)	1179 mm (3.87 ft)	Not applicable
	Warm White	April 17, 2018	1.500 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CMT1925	Cool White	March 16, 2018	1.700 A	RG-2 Moderate risk	0.741 A	886 lux (82.3 fc)	1653 mm (5.42 ft)	Not applicable
	Neutral White	March 16, 2018	1.700 A	RG-2 Moderate risk	1.241 A	1376 lux (127.8 fc)	1293 mm (4.24 ft)	Not applicable
	Warm White	March 16, 2018	1.700 A	RG-2 Moderate risk	1.656 A	2117 lux (196.7 fc)	449 mm (1.47 ft)	Not applicable
CMT1930	Cool White	April 11, 2018	2.000 A	RG-2 Moderate risk	0.539 A	844 lux (78.4 fc)	1935 mm (6.35 ft)	Not applicable
	Neutral White	April 11, 2018	2.000 A	RG-2 Moderate risk	1.054 A	1639 lux (152.3 fc)	1313 mm (4.31 ft)	Not applicable
	Warm White	April 11, 2018	2.000 A	RG-2 Moderate risk	1.484 A	2144 lux (199.2 fc)	1171 mm (3.84 ft)	Not applicable
CMT1945	Cool White	April 11, 2018	2.500 A	RG-2 Moderate risk	0.586 A	867 lux (80.5 fc)	2011 mm (6.60 ft)	Not applicable
	Neutral White	April 11, 2018	2.500 A	RG-2 Moderate risk	1.065 A	1471 lux (136.7 fc)	1490 mm (4.89 ft)	Not applicable
	Warm White	April 11, 2018	2.500 A	RG-2 Moderate risk	1.522 A	2082 lux (193.4 fc)	1267 mm (4.16 ft)	Not applicable
CMT2850	Cool White	March 21, 2018	3.500 A	RG-2 Moderate risk	1.518 A	926 lux (86.0 fc)	2723 mm (8.93 ft)	Not applicable
	Neutral White	March 21, 2018	3.500 A	RG-2 Moderate risk	2.435 A	1318 lux (122.4 fc)	1986 mm (6.52 ft)	Not applicable
	Warm White	March 21, 2018	3.500 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CMT2870	Cool White	April 11, 2018	2.800 A	RG-2 Moderate risk	0.927 A	889 lux (82.6 fc)	2720 mm (8.92 ft)	Not applicable
	Neutral White	April 11, 2018	2.800 A	RG-2 Moderate risk	1.865 A	1701 lux (158.0 fc)	1929 mm (6.33 ft)	Not applicable
	Warm White	April 11, 2018	2.800 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CMT2890	Cool White	March 20, 2018	3.300 A	RG-2 Moderate risk	1.169 A	885 lux (82.2 fc)	2787 mm (9.14 ft)	Not applicable
	Neutral White	March 20, 2018	3.300 A	RG-2 Moderate risk	1.715 A	1395 lux (129.6 fc)	2161 mm (7.09 ft)	Not applicable
	Warm White	March 20, 2018	3.300 A	RG-2 Moderate risk	3.238 A	2186 lux (203.1 fc)	1811 mm (5.94 ft)	Not applicable
CXA1304 (36 V)	Cool White	September 25, 2015	1.000 A (9 V) 0.500 A (18 V) 0.250 A (36 V)	RG-2 Moderate risk	0.095 A	794 lux (73.8 fc)	569 mm (1.88 ft)	Not applicable
	Neutral White	September 25, 2015		RG-2 Moderate risk	0.188 A	1359 lux (126.3 fc)	459 mm (1.51 ft)	Not applicable
	Warm White	September 25, 2015		RG-1 Low risk	Not applicable	Not applicable		Not applicable

XLamp® LED	Color	Test Report Issue Date	Maximum Drive Condition	Risk Group Classification at Maximum Drive Condition	Exceeds RG-1 Threshold At	RG-1/RG-2 Threshold		Exceeds RG-2 Threshold At
						E _{thr}	d _{min}	
CXA1310 (36 V)	Cool White	September 28, 2015	1.050 A (18 V) 0.525 A (36 V)	RG-2 Moderate risk	0.110 A	811 lux (75.3 fc)	884 mm (2.90 ft)	Not applicable
	Neutral White	September 28, 2015		RG-2 Moderate risk	0.244 A	1777 lux (165.1 fc)	585 mm (1.92 ft)	Not applicable
	Warm White	September 28, 2015		RG-2 Moderate risk	0.363 A	2168 lux (201.4 fc)	498 mm (1.63 ft)	Not applicable
CXA1507 (36 V)	Cool White	September 4, 2014	0.750 A (18 V) 0.375 A (36 V)	RG-2 Moderate risk	0.221 A			Not applicable
	Neutral White	September 4, 2014		RG-2 Moderate risk	0.327 A			Not applicable
	Warm White	September 4, 2014		RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA1512 (18 V)	Cool White	August 18, 2014	1.200 A (18 V) 0.600 A (36 V)	RG-2 Moderate risk	0.216 A			Not applicable
	Neutral White	August 18, 2014		RG-2 Moderate risk	0.399 A			Not applicable
	Warm White	August 18, 2014		RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA1816	Cool White	August 20, 2014	0.900 A	RG-2 Moderate risk	0.316 A			Not applicable
	Neutral White	August 20, 2014	0.900 A	RG-2 Moderate risk	0.405 A			Not applicable
	Warm White	August 20, 2014	0.900 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA1820	Cool White	September 10, 2014	1.050 A	RG-2 Moderate risk	0.359 A			Not applicable
	Neutral White	September 10, 2014	1.050 A	RG-2 Moderate risk	0.424 A			Not applicable
	Warm White	September 10, 2014	1.050 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA1830	Cool White	August 13, 2014	1.400 A	RG-2 Moderate risk	0.447 A			Not applicable
	Neutral White	August 13, 2014	1.400 A	RG-2 Moderate risk	0.587 A			Not applicable
	Warm White	August 13, 2014	1.400 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA2520	Cool White	September 3, 2014	1.250 A	RG-2 Moderate risk	0.980 A			Not applicable
	Neutral White	September 3, 2014	1.250 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Warm White	September 3, 2014	1.250 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA2530	Cool White	August 21, 2014	1.600 A	RG-2 Moderate risk	0.936 A			Not applicable
	Neutral White	August 21, 2014	1.600 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Warm White	August 21, 2014	1.600 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA2540	Cool White	August 5, 2014	2.100 A	RG-2 Moderate risk	1.266 A			Not applicable
	Neutral White	August 5, 2014	2.100 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Warm White	August 5, 2014	2.100 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA3050	Cool White	March 30, 2015	2.500 A	RG-2 Moderate risk	1.442 A	898 lux (83.4 fc)	1976 mm (6.48 ft)	Not applicable
	Neutral White	March 30, 2015	2.500 A	RG-2 Moderate risk	2.122 A	1156 lux (107.4 fc)	1768 mm (5.80 ft)	Not applicable
	Warm White	March 30, 2015	2.500 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA3070	Cool White	January 8, 2015	2.800 A	RG-2 Moderate risk	1.297 A			Not applicable
	Neutral White	January 8, 2015	2.800 A	RG-2 Moderate risk	1.745 A			Not applicable
	Warm White	January 8, 2015	2.800 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXA3590 (72 V)	Cool White	September 17, 2015	3.600 A (36 V) 1.800 A (72 V)	RG-2 Moderate risk	0.895 A	773 lux (71.8 fc)	2173 mm (7.13 ft)	Not applicable
	Neutral White	September 17, 2015		RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Warm White	September 17, 2015		RG-1 Low risk	Not applicable	Not applicable		Not applicable

XLamp® LED	Color	Test Report Issue Date	Maximum Drive Condition	Risk Group Classification at Maximum Drive Condition	Exceeds RG-1 Threshold At	RG-1/RG-2 Threshold		Exceeds RG-2 Threshold At
						E _{thr}	d _{min}	
CXB1304 (9 V)	Cool White	March 4, 2016	1.000 A (9 V) 0.500 A (18 V) 0.250 A (36 V)	RG-2 Moderate risk	0.608 A	1003 lux (93.2 fc)	592 mm (1.94 ft)	Not applicable
	Neutral White	March 4, 2016		RG-2 Moderate risk	0.811 A	1625 lux (151.0 fc)	447 mm (1.47 ft)	Not applicable
	Warm White	March 4, 2016		RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXB1310 (18 V)	Cool White	July 11, 2016	1.400 A (18 V) 0.700 A (36 V)	RG-2 Moderate risk	0.180 A	730 lux (67.8 fc)	1191 mm (3.91 ft)	Not applicable
	Neutral White	July 11, 2016		RG-2 Moderate risk	0.410 A	1438 lux (133.6 fc)	849 mm (2.79 ft)	Not applicable
CXB1310 (36 V)	Warm White	July 11, 2016		RG-2 Moderate risk	0.346 A	2510 lux (233.2 fc)	599 mm (1.97 ft)	Not applicable
CXB1507 (36 V)	Cool White	October 29, 2015	0.750 A (18 V) 0.375 A (36 V)	RG-2 Moderate risk	0.277 A	1121 lux (104.1 fc)	725 mm (2.38 ft)	Not applicable
	Neutral White	October 29, 2015		RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Warm White	October 29, 2015		RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXB1512 (36 V)	Cool White	December 21, 2016	1.200 A (18 V) 0.600 A (36 V)	RG-2 Moderate risk	0.239 A	963 lux (89.5 fc)	976 mm (3.20 ft)	Not applicable
	Neutral White	December 21, 2016		RG-2 Moderate risk	0.446 A	1718 lux (159.6 fc)	769 mm (2.52 ft)	Not applicable
	Warm White	December 21, 2016		RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXB1520	Cool White	June 1, 2016	1.400 A	RG-2 Moderate risk	0.297 A	837 lux (77.8 fc)	1554 mm (5.10 ft)	Not applicable
	Neutral White	June 1, 2016	1.400 A	RG-2 Moderate risk	0.391 A	1597 lux (148.4 fc)	1036 mm (3.40 ft)	Not applicable
	Warm White	June 1, 2016	1.400 A	RG-2 Moderate risk	1.049 A	3252 lux (302.1 fc)	781 mm (2.56 ft)	Not applicable
CXB1816	Cool White	March 18, 2016	0.900 A	RG-2 Moderate risk	0.620 A	1196 lux (111.1 fc)	1046 mm (3.43 ft)	Not applicable
	Neutral White	March 18, 2016	0.900 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Warm White	March 18, 2016	0.900 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXB1820	Cool White	November 5, 2015	1.050 A	RG-2 Moderate risk	0.427 A	958 lux (88.0 fc)	1267 mm (4.16 ft)	Not applicable
	Neutral White	November 5, 2015	1.050 A	RG-2 Moderate risk	0.909 A	1898 lux (176.3 fc)	899 mm (2.95 ft)	Not applicable
	Warm White	November 5, 2015	1.050 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXB1830	Cool White	November 6, 2015	1.400 A	RG-2 Moderate risk	0.660 A	1024 lux (95.1 fc)	1224 mm (4.02 ft)	Not applicable
	Neutral White	November 6, 2015	1.400 A	RG-2 Moderate risk	1.101 A	1681 lux (156.2 fc)	1071 mm (3.51 ft)	Not applicable
	Warm White	November 6, 2015	1.400 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXB2530	Cool White	March 30, 2016	1.600 A	RG-2 Moderate risk	1.424 A	815 lux (75.7 fc)	1839 mm (6.03 ft)	Not applicable
	Neutral White	March 30, 2016	1.600 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Warm White	March 30, 2016	1.600 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXB2540	Cool White	February 5, 2016	2.100 A	RG-2 Moderate risk	1.359 A	2559 lux (237.7 fc)	1096 mm (3.60 ft)	Not applicable
	Neutral White	February 5, 2016	2.100 A	RG-2 Moderate risk	1.948 A	2622 lux (243.6 fc)	1123 mm (3.68 ft)	Not applicable
	Warm White	February 5, 2016	2.100 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable

XLamp® LED	Color	Test Report Issue Date	Maximum Drive Condition	Risk Group Classification at Maximum Drive Condition	Exceeds RG-1 Threshold At	RG-1/RG-2 Threshold		Exceeds RG-2 Threshold At
						E _{thr}	d _{min}	
CXB3050	Cool White	January 12, 2016	2.500 A	RG-2 Moderate risk	0.660 A	2285 lux (212.3 fc)	1330 mm (4.36 ft)	Not applicable
	Neutral White	January 12, 2016	2.500 A	RG-2 Moderate risk	1.221 A	2308 lux (2124.4 fc)	1353 mm (4.44 ft)	Not applicable
	Warm White	January 12, 2016	2.500 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXB3070	Cool White	February 2, 2016	2.800 A	RG-2 Moderate risk	1.506 A	2096 lux (194.7 fc)	1525 mm (5.00 ft)	Not applicable
	Neutral White	February 2, 2016	2.800 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Warm White	February 2, 2016	2.800 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
CXB3590 (72 V)	Cool White	March 17, 2016	3.600 A (36 V) 1.800 A (72 V)	RG-2 Moderate risk	1.510 A	871 lux (80.9 fc)	2554 mm (8.38 ft)	Not applicable
	Neutral White	March 17, 2016		RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Warm White	March 17, 2016		RG-1 Low risk	Not applicable	Not applicable		Not applicable
MC-E (4S)	Cool White	June 26, 2009	2.800 A	RG-2 Moderate risk				Not applicable
	Neutral White							
	Warm White							
MHB-A (36 V)	Cool White	March 26, 2015	0.700 A (9 V) 0.350 A (18 V) 0.175 A (36 V)	RG-2 Moderate risk	0.075 A	743 lux (69.0 fc)	560 mm (1.84 ft)	Not applicable
	Neutral White	March 26, 2015		RG-2 Moderate risk	0.109 A	1054 lux (97.9 fc)	460 mm (1.51 ft)	Not applicable
	Warm White	March 26, 2015		RG-1 Low risk	Not applicable	Not applicable		Not applicable
MHB-B (18 V)	Cool White	August 2, 2017	0.700 A (9 V) 0.350 A (18 V) 0.175 A (36 V)	RG-2 Moderate risk	0.148 A	987 lux (91.7 fc)	529 mm (1.74 ft)	Not applicable
	Neutral White	August 2, 2017		RG-2 Moderate risk	0.229 A	1461 lux (135.7 fc)	440 mm (1.44 ft)	Not applicable
	Warm White	August 2, 2017		RG-1 Low risk	Not applicable	Not applicable		Not applicable
MHD-E (36 V)	Cool White	July 7, 2015	1.400 A (9 V) 0.700 A (18 V) 0.350 A (36 V)	RG-2 Moderate risk	0.128 A	866 lux (80.5 fc)	710 mm (2.33 ft)	Not applicable
	Neutral White	July 7, 2015		RG-2 Moderate risk	0.142 A	985 lux (91.5 fc)	689 mm (2.27 ft)	Not applicable
	Warm White	July 7, 2015		RG-1 Low risk	Not applicable	Not applicable		Not applicable
MHD-G (36 V)	Cool White	July 13, 2015	1.000 A (18 V) 0.500 A (36 V)	RG-2 Moderate risk	0.175 A	903 lux (83.9 fc)	828 mm (2.72 ft)	Not applicable
	Neutral White	July 13, 2015		RG-2 Moderate risk	0.211 A	1270 lux (118.0 fc)	726 mm (2.38 ft)	Not applicable
	Warm White	July 13, 2015		RG-1 Low risk	Not applicable	Not applicable		Not applicable
MK-R (12 V)	Cool White		2.500 A (6 V) 1.250 A (12 V)					
	Neutral White							
	Warm White	October 25, 2013		RG-2 Moderate risk	1.200 A			Not applicable
ML-E	Cool White	April 27, 2012	0.150 A	Exempt	Not applicable	Not applicable		Not applicable
	Neutral White							
	Warm White							
	Blue	May 3, 2013	0.350 A	RG-2 Moderate risk				Not applicable
MX-6	Cool White	September 4, 2009	0.350 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Neutral White							
	Warm White							

XLamp® LED	Color	Test Report Issue Date	Maximum Drive Condition	Risk Group Classification at Maximum Drive Condition	Exceeds RG-1 Threshold At	RG-1/RG-2 Threshold		Exceeds RG-2 Threshold At
						E _{thr}	d _{min}	
XB-D	Cool White	September 10, 2015	1.000 A	RG-2 Moderate risk	0.201 A	827 lux (76.8 fc)	331 mm (1.09 ft)	Not applicable
	Neutral White	September 10, 2015	1.000 A	RG-2 Moderate risk	0.284 A	1182 lux (109.8 fc)	277 mm (0.91 ft)	Not applicable
	Warm White	September 10, 2015	1.000 A	RG-2 Moderate risk	0.494 A	1771 lux (164.5 fc)	221 mm (0.73 ft)	Not applicable
	Royal Blue	September 8, 2015	1.000 A	RG-2 Moderate risk	0.055 A	60 lux (5.6 fc)	509 mm (1.67 ft)	Not applicable
	Green	October 5, 2012	1.000 A	Exempt	Not applicable	Not applicable		Not applicable
	PC Amber	June 5, 2018	1.000 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
XB-H	Cool White	September 17, 2014	1.500 A	RG-2 Moderate risk				Not applicable
	Neutral White							
	Warm White							
XD16	Cool White	February 1, 2018	2.000 A	RG-2 Moderate risk	0.282 A	995 lux (92.4 fc)	421 mm (1.38 ft)	Not applicable
	Neutral White	February 1, 2018	2.000 A	RG-2 Moderate risk	0.702 A	2266 lux (210.5 fc)	271 mm (0.89 ft)	Not applicable
	Warm White	February 1, 2018	2.000 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
XH-G	Cool White	November 11, 2013	0.350 A	Exempt	Not applicable	Not applicable		Not applicable
	Neutral White							
	Warm White							
XHP35 High Density	Cool White	February 26, 2016	1.050 A	RG-2 Moderate risk	0.068 A	783 lux (72.7 fc)	732 mm (2.40 ft)	Not applicable
	Neutral White	February 26, 2016	1.050 A	RG-2 Moderate risk	0.130 A	1285 lux (119.4 fc)	542 mm (1.78 ft)	Not applicable
	Warm White	February 26, 2016	1.050 A	RG-2 Moderate risk	0.196 A	1942 lux (180.4 fc)	455 mm (1.49 ft)	Not applicable
XHP35 High Intensity	Cool White	March 23, 2016	1.050 A	RG-2 Moderate risk	0.078 A	1034 lux (96.1 fc)	675 mm (2.21 ft)	Not applicable
	Neutral White	March 23, 2016	1.050 A	RG-2 Moderate risk	0.130 A	1506 lux (139.9 fc)	537 mm (1.76 ft)	Not applicable
	Warm White	March 23, 2016	1.050 A	RG-2 Moderate risk	0.123 A	2263 lux (207.7 fc)	448 mm (1.47 ft)	Not applicable
XHP35.2	Cool White	August 9, 2018	1.050 A	RG-2 Moderate risk	0.149 A	669 lux (62.2 fc)	821 mm (2.69 ft)	Not applicable
	Neutral White	August 9, 2018	1.050 A	RG-2 Moderate risk	0.212 A	1104 lux (102.6 fc)	647 mm (2.12 ft)	Not applicable
	Warm White	August 9, 2018	1.050 A	RG-2 Moderate risk	0.290 A	1379 (128.1 fc)	529 mm (1.74 ft)	Not applicable
XHP50 (6 V)	Cool White	June 9, 2015	3.000 A (6 V) 1.500 A (12 V)	RG-2 Moderate risk	0.381 A	853 lux (79.3 fc)	865 mm (2.84 ft)	Not applicable
	Neutral White	June 9, 2015		RG-2 Moderate risk	0.494 A	1010 lux (93.8 fc)	783 mm (2.57 ft)	Not applicable
	Warm White	June 9, 2015		RG-2 Moderate risk	1.295 A	2329 lux (216.4 fc)	485 mm (1.59 ft)	Not applicable
XHP50.2 (12 V)	Cool White	January 3, 2017	6.000 A (3 V) 3.000 A (6 V) 1.500 A (12 V)	RG-2 Moderate risk	0.162 A	601 lux (55.8 fc)	1007 mm (3.30 ft)	Not applicable
	Neutral White	January 3, 2017		RG-2 Moderate risk	0.284 A	1135 lux (105.4 fc)	756 mm (2.48 ft)	Not applicable
	Warm White	January 3, 2017		RG-2 Moderate risk	0.451 A	1778 lux (165.2 fc)	582 mm (1.91 ft)	Not applicable

XLamp® LED	Color	Test Report Issue Date	Maximum Drive Condition	Risk Group Classification at Maximum Drive Condition	Exceeds RG-1 Threshold At	RG-1/RG-2 Threshold		Exceeds RG-2 Threshold At
						E _{thr}	d _{min}	
XHP70 (6 V)	Cool White	June 12, 2015	4.800 A (6 V) 2.400 A (12 V)	RG-2 Moderate risk*	0.548 A	673 lux (62.5 fc)	1223 mm (4.01 ft)	Not applicable
	Neutral White	June 12, 2015		RG-2 Moderate risk	0.879 A	1034 lux (96.1 fc)	913 mm (3.00 ft)	Not applicable
	Warm White	June 12, 2015		RG-2 Moderate risk	1.782 A	2037 lux (189.2 fc)	676 mm (2.22 ft)	Not applicable
XHP70.2 (12 V)	Cool White	February 1, 2018	4.800 A (6 V) 2.400 A (12 V)	RG-2 Moderate risk	0.331 A	685 lux (63.6 fc)	1242 mm (4.07 ft)	Not applicable
	Neutral White	February 1, 2018		RG-2 Moderate risk	0.560 A	1305 lux (121.2 fc)	954 mm (3.13 ft)	Not applicable
	Warm White	February 1, 2018		RG-2 Moderate risk	0.899 A	1791 lux (166.4 fc)	727 mm (2.39 ft)	Not applicable
XM-L®	Cool White	June 5, 2011	0.700 A	RG-2 Moderate risk				Not applicable
	Neutral White							
	Warm White							
XM-L Color	Cool White	December 5, 2017	1.000 A	RG-2 Moderate risk	0.164 A	655 lux (60.9 fc)	345 mm (1.13 ft)	Not applicable
	Neutral White	December 5, 2017	1.000 A	RG-2 Moderate risk	0.288 A	1202 lux (111.7 fc)	267 mm (0.88 ft)	Not applicable
	Warm White	December 5, 2017	1.000 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Blue	December 5, 2017	1.000 A	RG-2 Moderate risk	0.060 A	35 lux (3.3 fc)	531 mm (1.74 ft)	Not applicable
	Green	December 5, 2017	1.000 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Red	December 5, 2017	1.000 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
XM-L EasyWhite® (12 V)	Cool White	June 4, 2012	2.000 A (6 V) 1.000 A (12 V)	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Neutral White							
	Warm White							
XM-L2	Cool White	August 7, 2014	3.000 A	RG-2 Moderate risk	0.320 A			Not applicable
	Neutral White	August 7, 2014	3.000 A	RG-2 Moderate risk	0.499 A			Not applicable
	Warm White	August 7, 2014	3.000 A	RG-2 Moderate risk	0.798 A			Not applicable
XP-C	Cool White	September 5, 2013	0.500 A	RG-2 Moderate risk	0.100 A			Not applicable
	Neutral White							
	Warm White							
XP-E	Cool White	June 26, 2009	1.000 A	RG-2 Moderate risk				Not applicable
	Neutral White							
	Warm White							
	Royal Blue	June 26, 2009	1.000 A	RG-2 Moderate risk				Not applicable
	Blue	June 26, 2009	1.000 A	RG-2 Moderate risk				Not applicable
XP-E High-Efficiency White	Cool White	June 5, 2011	1.000 A	Exempt	Not applicable	Not applicable		Not applicable
	Neutral White							
	Warm White							

* LED is also classified as Risk Group 2 for retinal thermal hazard.

XLamp® LED	Color	Test Report Issue Date	Maximum Drive Condition	Risk Group Classification at Maximum Drive Condition	Exceeds RG-1 Threshold At	RG-1/RG-2 Threshold		Exceeds RG-2 Threshold At
						E _{thr}	d _{min}	
XP-E2	Cool White	November 6, 2014	1.000 A	RG-2 Moderate risk	0.172 A	1004 lux (93.3 fc)	366 mm (1.20 ft)	Not applicable
	Neutral White	November 6, 2014	1.000 A	RG-2 Moderate risk	0.219 A	1103 lux (102.5 fc)	298 mm (0.98 ft)	Not applicable
	Warm White	November 6, 2014	1.000 A	RG-2 Moderate risk	0.586 A	2454 lux (228.0 fc)	211 mm (0.70 ft)	Not applicable
	Royal Blue	June 6, 2018	1.000 A	RG-2 Moderate risk	0.047 A	36 lux (3.3 fc)	567 mm (1.86 ft)	Not applicable
	Blue	August 8, 2018	1.000 A	RG-2 Moderate risk	0.119 A	156 lux (14.5 fc)	439 mm (1.44 ft)	Not applicable
XP-G	Cool White	July 31, 2012	1.500 A	RG-2 Moderate risk				Not applicable
	Neutral White							
	Warm White							
XP-G2	Cool White	August 1, 2014	1.500 A	RG-2 Moderate risk	0.221 A			Not applicable
	Neutral White	August 1, 2014	1.500 A	RG-2 Moderate risk	0.260 A			Not applicable
	Warm White	August 1, 2014	1.500 A	RG-2 Moderate risk	0.728 A			Not applicable
XP-G2 High Efficacy	Cool White	August 20, 2018	2.000 A	RG-2 Moderate risk	0.085 A	534 lux (49.6 fc)	676 mm (2.22 ft)	Not applicable
	Neutral White	August 20, 2018	2.000 A	RG-2 Moderate risk	0.267 A	819 lux (76.1 fc)	611 mm (2.00 ft)	Not applicable
	Warm White	August 20, 2018	2.000 A	RG-2 Moderate risk	0.480 A	1528 (142.0 fc)	427 mm (1.40 ft)	Not applicable
XP-G3	Cool White	July 8, 2016	2.000 A	RG-2 Moderate risk	0.195 A	511 lux (47.5 fc)	651 mm (2.14 ft)	Not applicable
	Neutral White	July 8, 2016	2.000 A	RG-2 Moderate risk	0.426 A	884 lux (82.1 fc)	497 mm (1.63 ft)	Not applicable
	Warm White	July 8, 2016	2.000 A	RG-2 Moderate risk	0.598 A	1726 lux (160.4 fc)	349 mm (1.15 ft)	Not applicable
	Royal Blue	March 15, 2018	2.000 A	RG-2 Moderate risk	0.070 A	26 lux (2.4 fc)	853 mm (2.80 ft)	Not applicable
XP-L High Density	Cool White	April 30, 2015	3.000 A	RG-2 Moderate risk	0.252 A	591 lux (54.9 fc)	748 mm (2.45 ft)	Not applicable
	Neutral White	April 30, 2015	3.000 A	RG-2 Moderate risk	0.390 A	878 lux (81.6 fc)	587 mm (1.93 ft)	Not applicable
	Warm White	April 30, 2015	3.000 A	RG-2 Moderate risk	0.780 A	1797 lux (167.0 fc)	408 mm (1.34 ft)	Not applicable
XP-L High Intensity	Cool White	January 20, 2016	3.000 A	RG-2 Moderate risk	0.278 A	886 lux (82.3 fc)	602 mm (1.98 ft)	Not applicable
	Neutral White	January 20, 2016	3.000 A	RG-2 Moderate risk	0.420 A	1305 lux (121.2 fc)	499 mm (1.64 ft)	Not applicable
	Warm White	January 20, 2016	3.000 A	RG-2 Moderate risk	0.837 A	2303 lux (214.0 fc)	350 mm (1.15 ft)	Not applicable
XP-L2	Cool White	January 3, 2017	3.000 A	RG-2 Moderate risk	0.319 A	578 lux (53.7 fc)	784 mm (2.57 ft)	Not applicable
	Neutral White	January 3, 2017	3.000 A	RG-2 Moderate risk	0.609 A	1190 lux (110.6 fc)	553 mm (1.81 ft)	Not applicable
	Warm White	January 3, 2017	3.000 A	RG-2 Moderate risk	0.854 A	1444 lux (134.2 fc)	461 mm (1.51 ft)	Not applicable

XLamp® LED	Color	Test Report Issue Date	Maximum Drive Condition	Risk Group Classification at Maximum Drive Condition	Exceeds RG-1 Threshold At	RG-1/RG-2 Threshold		Exceeds RG-2 Threshold At
						E _{thr}	d _{min}	
XQ-E High Density	Cool White	November 18, 2014	1.000 A	RG-2 Moderate risk	0.239 A	722 lux (67.1 fc)	393 mm (1.29 ft)	Not applicable
	Neutral White	November 18, 2014	1.000 A	RG-2 Moderate risk	0.638 A	1595 lux (148.2 fc)	243 mm (0.80 ft)	Not applicable
	Warm White	November 18, 2014	1.000 A	RG-2 Moderate risk	0.846 A	2021 lux (187.8 fc)	201 mm (0.66 ft)	Not applicable
	Blue	September 17, 2014	1.000 A	RG-2 Moderate risk				Not applicable
XQ-E High Intensity	Cool White	August 8, 2016	1.000 A	RG-2 Moderate risk	0.304 A	911 lux (84.6 fc)	335 mm (1.10 ft)	Not applicable
	Neutral White	August 8, 2016	1.000 A	RG-2 Moderate risk	0.582 A	1323 lux (122.9 fc)	249 mm (0.82 ft)	Not applicable
	Warm White	August 8, 2016	1.000 A	RG-1 Low risk	Not applicable	Not applicable		Not applicable
	Royal Blue	August 8, 2016	1.000 A	RG-2 Moderate risk	0.130 A	25 lux (2.3 fc)	493 mm (1.62 ft)	Not applicable
XR-E	Cool White	June 26, 2009	1.000 A	RG-2 Moderate risk				Not applicable
	Neutral White							
	Warm White							
	Royal Blue	June 30, 2009	1.000 A	RG-3 High risk				
	Blue	June 26, 2009	1.000 A	RG-2 Moderate risk				Not applicable
XT-E	Cool White	August 6, 2014	1.500 A	RG-2 Moderate risk	0.275 A			Not applicable
	Neutral White	August 6, 2014	1.500 A	RG-2 Moderate risk	0.329 A			Not applicable
	Warm White	August 6, 2014	1.500 A	RG-2 Moderate risk	1.053 A			Not applicable
	Royal Blue	October 5, 2012	1.500 A	RG-2 Moderate risk				Not applicable
XT-E High Efficacy	Cool White	March 7, 2018	1.500 A	RG-2 Moderate risk	0.194 A	628 lux (58.3 fc)	519 mm (1.70 ft)	Not applicable
	Neutral White	March 7, 2018	1.500 A	RG-2 Moderate risk	0.310 A	1011 lux (93.9 fc)	396 mm (1.30 ft)	Not applicable
	Warm White	March 7, 2018	1.500 A	RG-2 Moderate risk	0.996 A	2765 lux (256.9 fc)	231 mm (0.76 ft)	Not applicable

Table 3: Summary table of LED module eye safety test results

LED Module	Lumens	Test Report Issue Date	Drive Condition	Risk Group Classification
LMH2	850	November 18, 2011	0.440 A	Exempt
	1250	November 18, 2011	0.440 A	Exempt
	2000	March 23, 2012	0.900 A	Exempt
	3000	March 23, 2012	0.900 A	Exempt
LMR4		August 22, 2011	0.070 A	Exempt