# Technical Information Sheets: SFRP

Société Française de Radioprotection

## LED lighting and retinal damage

CARD WRITTEN BY SÉBASTIEN POINT AND ANNICK BARLIER-SALSI

Most of incandescent bulbs have been withdrawn from sale because of their infrared-rich spectrum and poor conversion efficiency between electric and visible power. Currently, the only replacement technologies for domestic lighting are fluorescent bulbs or tubes, and light-emitting diodes (LEDs). LEDs, especially white and blue ones, worth attention. In some exposure conditions, their radiance, rich in blue, may lead to photoretinitis. It was also suggested that LEDs may take part in AMD (age-related macular degeneration) first appearance, and in possible circadian rhythms disruption.

## 1 - WHAT IS AN LED?

Most of white LEDs on sale are made of an Indium Gallium Nitride (InGaN) diode covered by phosphor material, which is in general Yttrium Aluminum garnet enhanced with Cerium (Ce:YAG). Figure 1 shows a schematic view of a white phosphor-coated LED structure.

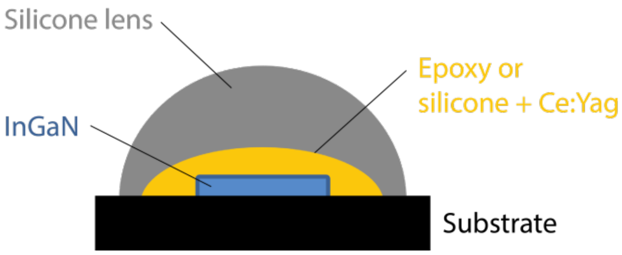


**Figure 1: Simplified structure of a white phosphor-coated LED. Source: adapted from [1].**

Through a radiative recombination process, the diode, when switched on, emits an incoherent blue radiation centered at 450/460 nm wavelength. A part of this blue radiation is converted by phosphor into a continuous radiation which covers the visible spectrum part in the wavelength range between 500 and 700 nm. Therefore the white-phosphor coated LED spectrum is created by the superposition of the non-converted blue radiation and the radiation generated by the phosphor de-excitation (see Figure 2).

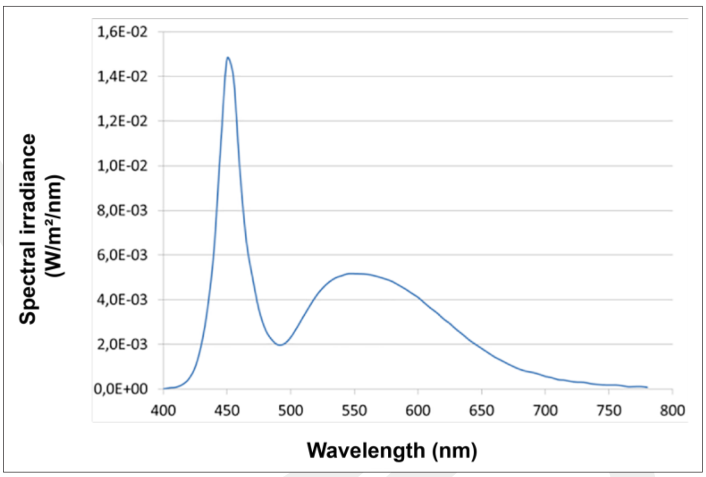


**Figure 2: Typical spectrum of a white phosphor-coated LED. Source: adapted from [1].**



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## 2- CAN LED LIGHTING BE HARMFUL?

The main features of white phosphor-coated LEDs are:

- A high luminance, which can make it glaring.
- A visible spectrum rich in short wavelengths (blue light), inherent in its operating principle.

A high luminance rich in short radiations can overexpose retina and lead to photoretinitis through photochemical mechanisms. Yet the action spectrum of blue light[1] defined by the ICNIRP [2] (written B(λ)) covers the peak emission of a white phosphor-coated LED (see Figure 3).

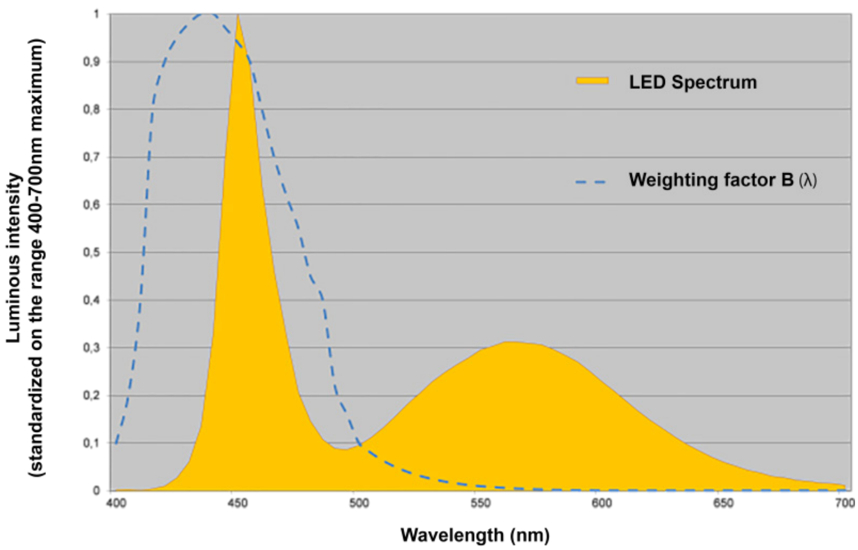


**Figure 3: Action spectrum of blue light on human retina. Source: adapted from [3].**

Overexposure is characterized by a blind spot (scotoma) in the fovea central area (see figure 4), where the light energy has been focused. Sensitivity loss can be permanent. Clinically, bleaching appears in the lesion area within 48 hours after the overexposure. Action mechanisms, still misunderstood, would involve reactive oxygen species.

1-In this note, blue light refers to the light whose wavelengths are covered by the action spectrum of ICNIRP.



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The maximal acceptable radiant dose of blue light ($D_{bmax}$) below which no biological effect is expected is $10^6$ J/(m².sr).

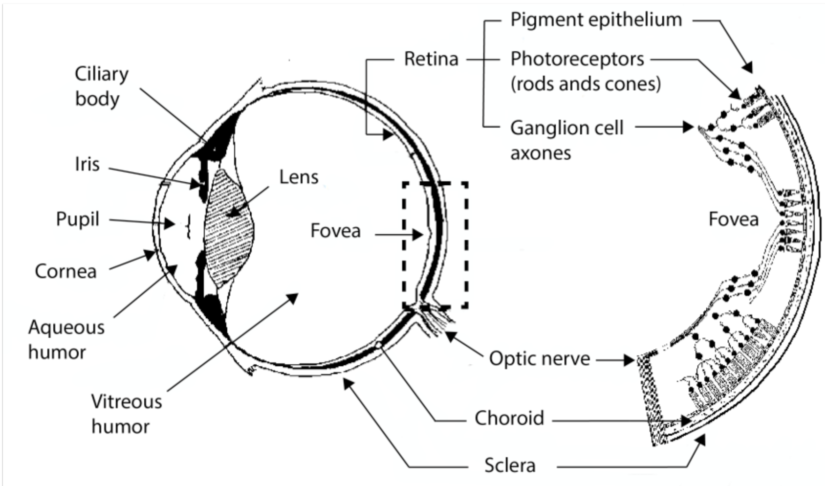


**Figure 4: Eye model. Source: adapted from [15].**

## 3- What are the requirements of lamps design standards?

Design standards of lamps and luminaires include requirements of photobiological safety based on the standard IEC 62471 [5] or its technical report IEC-TR 62778 [6].

This standard defines the limited values of a measurable quantity, called blue light effective radiance (written Lb), on which the maximum permissible exposure time t depends, following the equation (1).

$$t = \frac{D_{bmax}}{L_b} \qquad (1)$$

Therefore, the dangerousness of a LED lamp is classified according to the rapidity of overexposure appearance, which depends on its blue light effective radiance (see Table 1). For instance, when exposed to a LED source with $L_b$ lower or equal to 100 W/m²/sr, an observer will receive a dose superior to $D_{bmax}$ ($10^6$ J/(m².sr)) at the earliest after a minimal exposure[2] time of 10 000 s, or approximately 2h45. For that exposure time, the LED in question is classified in risk group 0.

2-The exposure is defined in that case by the direct observation of the source at a distance of 20 cm.



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**Table 1: Correlation between blue light radiance, maximal exposure duration, and risk group.**

| RISK GROUP (RG) | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| t lim(s) | 10 000 | 100 | 0.25 | 0.25 |
| Lb lim(w.m$^{-2}$/sr) | <100 | <10 000 | <4000 000 | >4000 000 |
| Db (J/(m$^2$.sr) | $10^6$ | $10^6$ | $10^6$ | $10^6$ |

**w = watt, sr = steradian, J = Joule, m = meter, s = second**

Three scenarios stand out:

**First scenario:** the lamp is assigned to a safe group (RG0) or a low risk group (RG1). No marking is required and no restriction linked to blue light retinal risk is applicable.

**Second scenario:** the lamp is assigned to a moderate risk group (RG2):

- For fixed systems, a hazard distance, beyond which the risk goes down to RG1, must be calculated and the mounting instructions of the lamp or the luminaire must indicate that the product should be positioned so that prolonged staring at a distance closer than the hazard distance is not expected.
- For the portable lamps or luminaires, on the product housing must be indicated to not stare at the source.

**Third scenario:** the lamp is assigned to the high risk group (RG3). Currently the luminaire standard does not include this risk class, judging that this type of product is not available for sale.

There are some scientific debates regarding the Exposure Limit Values (ELV) which were initially defined by the ICNIRP for preventing possible retinal damages linked to high dose exposures. The current state of knowledge does not allow to prove the existence of a health risk linked to a chronic exposure to values inferior to ELV, but voices were heard for highlighting the lack of scientific data. Experts of Anses[3] in particular worried about this lack of data that does not allow to rule out the possibility that repeated and prolonged exposure could potentially induce a cumulative risk higher than that assessed by the current ELV [7]. Thus, researches should be carried out for expanding knowledge of blue light action mechanisms on humans, especially for answering the following questions:

- Are there mechanisms of appearance of lesions on retina exposed to low but permanent level of blue light? Is there a cumulative effect?
- Does exposure to blue light increase the appearance of age-related macular degeneration?
- Can generalization of lamps with spectrum rich in blue disrupt the biological clock of human being?

Studies on rodents are ongoing (for example [8] and [9]) in order to improve the understanding of mechanisms and better identify risks linked to chronic exposure. However, it must be noticed that the validity for humans of these animal models experiments can be discussed [17].

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## 4- HOW TO IDENTIFY THE RISK GROUP?

Evaluation of $L_b$ is formalized in the standard IEC 62471 by the equation (2). It has to be carried out on a lamp or a single luminaire, and does not take into account multiple exposure cases.

$$L_b = \int_{300\ nm}^{700\ nm} L\lambda(\lambda).B\lambda(\lambda).d\lambda \quad [W/m^2/sr] \qquad (2)$$

Action spectrum of blue light B(λ) is formalized in IEC 62471 which provides spectral efficiency values every 5 nm. Lλ is the spectral radiance measured on the field of view (that can be higher than the apparent size of the source). The measurement of the radiance on the field of view permits to take into account eye movements, which tend to decrease irradiance values on the retina. This step reduces the risk of overestimation of exposure, in particular for situations of long observation during which the eye is moving. This field of view increases proportionally to exposure time, according to the empirical relations of Table 2.

**Table 2: empirical relations between the exposure time and the field of view of the human eye.**

| Exposure time range (in second) | Flat angle γ of the field of vision (in radians) |
|---|---|
| From 0,25 to 10 s | 0.011.√(t/10) |
| From 10 to 100 s | 0.011 |
| From 100 to 10 000 s | 0.0011.√t |
| Beyong 10 000 s | 0.1 |

The standard IEC 62471 recommends, for general lighting systems (GLS), that the measurement plan is placed at a distance where the source provides 500 Lux, with a minimum of 200 mm. Only pulsed lamps or specific use lamps (medical, industrial (e.g. lithography) or esthetic (e.g. tanning booths)) must be measured at 200 mm. However, the IEC-TR 62778 recommends a same distance of 200 mm for all lighting devices, considering that the value of 500 Lux is arbitrary and does not represent the diversity of all lighting situations. Design standards of luminaires (for example the EN 60598-1) use these recommendations, that anyway creates some practical difficulties: for a distance of 200 mm between the object and the detector, a 11 mrad field has to be materialized by a 2.2 mm diaphragm. Imaging methods are under development in laboratories, for improving the accuracy and precision of measurements [1] [10] [11].

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The thorough application of IEC 62471 requires skills and equipment that lamps and luminaires manufacturers who want to design products with white or blue LEDs have not necessarily. When the thorough measurement of spectral radiance is not possible, the technical report IEC-TR 62778 suggests an alternative risk assessment based on the measurement of white light luminance on the field of view and of light source chromaticity.

Whatever the method used, the choice of the lamp manufacturing step, during which the evaluation is performed, is important. As mentioned in the technical report IEC-TR 62778, 4 subgroups of LED luminaires are accepted:

- **Subgroup 0:** the diode.
- **Subgroup 1:** the diode in a package with or without an optical collimator, and covered with phosphor (for white phosphor-coated LEDs).
- **Subgroup 2:** the LED unit made of a printed circuit board with one or more LEDs.
- **Subgroup 3:** the LED unit with extended features (LEDs control electronics, mechanical fixing system).
- **Subgroup 4:** the LED luminaire ready to be sold.

Blue light risk assessment should be done as soon as possible. Ideally, the measurement has to be performed on the manufacturer site of subgroups 1 or 2, in order to supply usable technical data to lamps or luminaires manufacturer, who can this way design a product knowing the risk group of the LEDs ; it allows to foresee risk reduction systems if necessary, like optical diffusors. It should be kept in mind that the risk group measured on a single LED, taking into account the invariance of radiance, could never be increased by passive optical systems that the luminaire manufacturer would add (reflectors or lenses). As a result, by indicating the risk group reported by the LED manufacturer, the luminaire manufacturer takes the risk of overestimating the group, but not underestimating it.

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### 5- WHICH ARE THE POPULATIONS EXPOSED?

LED lamps are everywhere, both in indoor and outside lighting. It could be found in local housing, working places, commercial spaces, public lighting, etc. These days, everyone can be exposed to light emitted by LEDs. However, not all exposure situations can be defined as "risky". It depends on exposure conditions: type of LED, risk group [5], direct or diffuse view of the lamp, exposure time... However, some populations have a sharp sensitivity to visible light or are particularly exposed [7] [12]. Three specifically sensitive groups of population can be identified:

- Children whose skin and eyes, not mature enough, do not have all their filtering capacities.
- Aphakic (without lens) or pseudophakic (with artificial lens) persons whose ocular system filters no or a few short wavelengths radiations.
- People for whom blue light can worsen their pathology, because of some ocular or skin diseases, and people who have absorbed photosensitive substances.

Otherwise, some occupational categories are particularly exposed to blue light, among which:

- Careers in the performing arts: the LEDs spotlights have begun to replace some traditional spotlights. In many cases, the need for high lighting levels leads lighting engineers to install a lot of spotlights in the direct field of view of artists and technical staffs [10].
- People working on lighting installations: when a new installation is established or during maintenance works of lighting equipment, people are generally forced to look directly at the luminaire for ensuring its proper functioning. This checking process is often performed without diffuser or grid, at distances lower than normal use distances.
- Research and Development teams in charge of designing LEDs products: these people can be exposed during the development of printed circuit boards with LEDs or during photometric or colorimetric measurements.
- Teams in charge of quality control of LEDs: lamps for general and specific use (like surgical lights for operating theaters) are made of an assembly of LED chips. One of the steps in the manufacturing process consists in visually detecting defective LEDs. According to the manufacturing type, this control step can last more than one hour a day, during which the operator stares at the LEDs.
- Operators in charge of the quality control in general: electronic field, leather goods, etc. Nowadays, blue LEDs are often used as replacement for black light UV lamps. During this control, operators expose pieces to blue LEDs, for detecting failures through the light reflection.

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Users of "alternative" therapies based on the observation at low distance or the application on skin of colored artificial light, like chromotherapy, can also be considered as a population at risk. Users do not necessarily control the power of lamps used, the distance to their eyes, nor the exposure time, what lead to the risk of going over the maximal acceptable exposure [16][18].

## 6- IS PREVENTION POSSIBLE?

**General case:** an inside lighting installation has some ergonomics requirements, and LEDs are not the exception to the rule. The standard NF X35-103 [13], for example, defines the visual ergonomics principles applicable to lighting in working spaces. The implementation of these principles, especially regarding the glare and contrast limit, and the lighting homogeneity, is part of the first preventive measures concerning general room lighting. The limit of excessive luminance in the field of view leads necessarily to the reduction of the LEDs blue light exposure. For instance, the use of diffusers or luminaires specifically designed for LED lamps allows to meet many of these requirements. Then, for same illuminance, using several LEDs classified in the "safe" group is better than using one LED, more powerful, but classified in a higher group.

**Specific cases:** people who are particularly sensitive, and for whom it is recommended to limit the blue light exposure, can for example choose LED lamps with low color temperature (warm color) [12]. Occupational situations where people are particularly exposed to light emitted by LEDs often require protection against radiations. These protections are chosen so that their filtering characteristics allow to decrease the blue light radiant dose ($D_b$) below the maximal acceptable dose ($D_{bmax}$). The type of the protection chosen has to take into account the constraints required by the work type. However, whenever possible, solutions based on collective protection must be preferred. The case of the personnel in charge of the quality control of LEDs in production can be taken as an example. Some of rigid or flexible translucent screens (as welding curtains) placed between lamps to control and the operator effectively protect from blue light [14]. The use of protectors that filtrate specifically blue light changes the source apparent color, what can present drawbacks in some applications. The use of grey filters (neutral) can be beneficial. It diminishes the radiation received from LED equally on all wavelengths. In other occupational situations, as the maintenance of lighting installations, it is recommended to wear individual protection equipment which filters blue light. Similarly, in careers in the performing arts, wearing protection glasses adapted during the rehearsals for artists and during setting steps for the technical staff, allows to limit the levels of exposure to radiations.

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During the quality control performed under blue LEDs (aiming to replace black light UV lamps usually used), the need of collective and individual protectors depends on the intensity of reflected radiations and on the type of reflection: specular or diffuse.

When these operations are performed under a box lighted by blue LEDs, these LEDs must not be directly visible. Indeed, in these applications, only the reflected radiations are of interest, so it is not necessary to expose the operators.

In general, each time a process does not require a direct vision of the radiation source, it must be hidden from the workers' eyes.

For R&D activities, wearing glasses with neutral tinted lenses is appropriate. Generally, this protection can reduce the radiance or filter between 400 and 600 nm in order to remove the blue component of LED sources. Hiding the source is a priority for the personnel working for a long time next to LED panels performing long-term test.

Cases of misappropriation of LED technology in the context of "alternative" therapies performed without any medical supervision must encourage to improve the sharing of public information on the risk-benefit ratio of this type of practice.

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**ACKNOWLEDGEMENTS**

Authors want to thank Maïlys Beroud for her much appreciated help for English editing.

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