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Lamp and LED Safety – Classification vs. Realistic Exposure Analysis

Paper #801

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Abstract

The international lamp safety standard IEC 62471 "Photobiological safety of lamps and lamp systems" defines criteria to classify lamps into one of four risk groups (exempt, RG1, RG2, RG3). RG3 is referred to as "high risk" and is usually not considered as appropriate as a consumer product unless made safe by the housing (the luminaire or the lamp system). While the exempt group and RG1 is usually accepted as "safe", there are concerns – particularly for LEDs – if RG2 is appropriate for lighting of rooms or streets, or as consumer products without a warning label. To support a balanced view of the actual risk associated to the use of a product, this paper discusses the rules of how to determine the risk group. Strictly speaking IEC 62471:2006 requires risk group classification only for lamps and not for luminaires or lamp systems. Due to different reasons, the risk group might not reflect the actual risk: small assumed eye movements, wide ranges of permitted exposure durations per risk group as well as safety margins between limits and injury thresholds. For lighting and many other applications, for instance, RG2 when associated with visible light emission can probably be considered as sufficiently safe for consumer products even without warning labels. When UV emission is not an issue, it can be argued that for regular lamps and luminaires, risk group classification does not appear to be necessary. We also argue that it is not justified to consider LEDs differently than other, conventional light sources in a discussion about retinal hazards.

Introduction

The standard IEC 62471 "Photobiological safety of lamps and lamp systems", published by the IEC in 2006 [1], is an international standard that was originally developed by the CIE, published already in 2002 [2] as CIE S009 (IEC 62471:2006 is identical to CIE S009 from 2002). For the development of CIE S009, the CIE technical committee adopted the concept of assigning risk groups to lamps from the ANSI recommended practice document series RP 27 [3]. In Europe the standard was published in 2008 as EN 62471 and this standard is harmonized under the Low Voltage Directive. The only difference between EN 62471 and IEC 62471 is that in EN 62471, the exposure limits are given in an informative Annex. The limits that are used to classify lamps (referred to as emission limits) are in both versions the same (Table 6.1 in the documents).

In the discussion about IEC 62471 [4] it is necessary to distinguish between lamps and lamp systems; the latter is the term used in the standard to designate the complete product, while the lamp is the light source inside the lamp system. Examples of lamp systems are vehicle headlamps, flashlights ("torches" in UK), street lights, stage spot lights but also infrared surveillance illumination systems, or UV emitting devices. For general lighting purposes, what is referred to as a "lamp system" in IEC 62471 is usually referred to as a "luminaire". The lamp on the other hand is the actual light source, such as a light bulb or fluorescent tube, or a xenon lamp. Thus a lamp system contains one or more lamps and is made up of a housing, electric components such as a socket, and often reflectors and/or covers. Usually the lamp can be replaced, but in modern LED luminaires this is often no longer the case.

It is often overlooked that the testing criteria and application of a risk group specified in IEC 62471 applies to lamps only and not to lamp systems: Clause 6 of IEC 62471:2006 has the title "Lamp Classification" and states *"This clause is concerned with lamp classification. However a similar classification system could be applicable to luminaires or other systems containing operating lamps."* The background is that the classification system was developed by ANSI/ IESNA with the intent that the lamp manufacturer assigns a risk group to the lamp, as information for the luminaire (lamp system) manufacturer who then, for higher risk group lamps, knows that for instance a cover is needed to absorb UV (when the system was developed in the 1970s and 1980s [4], the main concern and motivation was UV emission from fluorescent lamps). However, in practice, IEC 62471 is often also applied to assign risk groups to luminaires, where it is noteworthy that the standard permits a certain flexibility (see quote above).

When it comes to product safety and public health, risk groups are often used to define which lamps and luminaires are of potential concern, and for instance, are not appropriate for consumer products. While this kind of usage of risk groups is understandable (but for luminaires this is actually not fully consistent with the standard, since the standard only requires classification of lamps and not of luminaires; see the original intent of the risk group as information by the lamp manufacturer for the luminaire manufacturer), it is important that the technical committees developing standards and the policy makers are aware of limitations of the risk groups and that often the actual risk for a given product and usage is less than reflected by the risk group. Otherwise needless restrictions are the result that can either induce additional cost of products or hinder the introduction of new technologies, such as when invitation to tenders for new LED luminaires require [5] "*The LEDs shall comply to Photo biological Safety norms as per IEC 62471 and should fall in the exempt group for indoor luminaires and in the exempt or low risk group for outdoor LED luminaires*"; or when street luminaires even have to be in the Exempt group only, for instance in [6] "*Light without blue and no photo biological risk; have been tested according to the IEC 62471 (first edition, 2006-07) and been classified as Exempt group*.". Also in terms of product safety, there are implications that RG2 is questionable for flash lights or bicycle luminaires, at least without warning labels [7].

With respect to warning labels we note that IEC 62471:2006 does not require warning labels or other manufacturer requirements such as warnings in manuals, since the concept is that these requirements are required, where appropriate, in vertical, product type-specific standards. IEC TR 62471-2 [8] contains *guidance* for possible warnings for lamp systems, but it is not a normative standard, it is a Technical Report (TR) only.

Risk Groups: Large Time Base Steps

IEC 62471 defines risk groups for lamps [4] that are based on a number of emission limits; for different potential hazards to the eye, corresponding limits are defined (see Table 1). These emission limits are directly adopted from the exposure limits promulgated by ICNIRP for the equivalent hazards [9, 10], but in the standard they are not used as exposure limits for the eye or skin of individuals, they are used as product safety emission limits to determine the risk group. Per hazard, the emission limits for the risk groups are derived with different time bases. For instance, the basic limit for actinic UV (protecting against photo-keratitis of the eye and UV induced skin damage) is $H_{UV\ limit} = 30\ J\ m^{-2}$. As an exposure limit, this limit applies to the total effective radiant exposure determined over a duration of 30 000 seconds (about 8 hours). The term "effective" implies here that the exposure level was spectrally weighted with the applicable biological weighting function, or "action spectrum" $S(\lambda)$.

The time base for the Exempt Group (in practice also often referred to as Risk Group 0, RG0) is 30 000 seconds, resulting in an emission limit, expressed as irradiance $E_{UV\_RG0} = 0.001\ W\ m^{-2}$ ($E_{UV\_RG0} = H_{UV\ limit}$ / time base RG0), which is then stated in Table 6.1 of the standard as emission limit for the Exempt Group, and also summarized here in Table 1.

Table 1. Overview of types of hazards distinguished for the photobiological hazard assessment of lamps, and emission limits for the risk groups.

Hazard	biolog. spectral weighting function	Symbol	Emission limit/ *Second row: time base* Exempt Group (RG0)	RG1	RG2	Unit
Actinic UV	$S_{UV}(\lambda)$	E_S	0.001	0.003	0.03	$W\ m^{-2}$
			30000	*10000*	*1000*	*s*
Near UV (UV-A)		E_{UVA}	10	33	100	$W\ m^{-2}$
			1000	*300*	*100*	*s*
Blue Light Hazard (basic limit)	$B(\lambda)$	L_B	100	10000	4000000	$W\ m^{-2}\ sr^{-1}$
			10000	*100*	*0.25*	*s*
Blue Light Hazard (small source)	$B(\lambda)$	E_B	1.0	1.0	400	$W\ m^{-2}$
			10000	*100*	*0.25*	*s*
Retinal thermal	$R(\lambda)$	L_R	28000/α	28000/α	71000/α	$W\ m^{-2}\ sr^{-1}$
			10	*10*	*0.25*	*s*
Retinal thermal, weak visual stimulus	$R(\lambda)$	L_{IR}	6000/α	6000/α	6000/α	$W\ m^{-2}\ sr^{-1}$
			10	*10*	*10*	*s*
IR radiation, eye		E_{IR}	100	570	3200	$W\ m^{-2}$
			1000	*100*	*10*	*s*

The time base for Risk Group 1 (RG1) for the actinic UV hazard equals 10 000 seconds, resulting in an emission limit for RG1 of $0.003\ W\ m^{-2}$. The time base for RG2 equals 1000 seconds, resulting in an emission limit for RG2 of $0.03\ W\ m^{-2}$. If a lamp, at the defined classification distance, is associated to an effective UV irradiance level (weighted with the applicable actinic action spectrum $S(\lambda)$) of more than $0.03\ W\ m^{-2}$, then it is RG3 based on the actinic UV emission limit (for other hazards, the emission level might be associated to less than RG3). This means that for RG3 lamps the underlying exposure limit of 30 J m^{-2} is exceeded in less than 1000 seconds (the time base of RG2) – all for the case of exposure at the classification distance. Similarly, when the effective irradiance at the classification distance is between 0.003 W m^{-2} and 0.03 W m^{-2} the lamp is RG2 and the exposure duration, at the classification distance, to reach and exceed the basic limit of 30 J m^{-2} is somewhere between the time base for RG2 (1000 seconds) and that of RG1 (10 000 seconds). Therefore, the range of "permitted exposure durations" (at the classification distance) for a given risk group is relatively wide: a lamp that leads to exceeding of the actinic UV limit after 17 minutes (1020 seconds) is RG2, but a lamp where the limit is only exceeded after 2 hours and 45 minutes (9900 seconds) is also in Risk Group 2. In practice, when the exposure lasts for instance for about one hour (added up over 8 hours), the latter is well below the exposure limit and "no risk" while the first example has exceeded the exposure limit by more than three times. Clearly RG2 based on the UV actinic hazard does not mean that every RG2 lamp represents a risk when the exposure duration (at the classification distance) is longer than 1000 seconds. On the contrary, 1000 seconds is the shortest associated exposure duration to reach the underlying exposure limit.

The time base of a given risk group and type of hazard is thus the border for the shortest exposure duration to reach the underlying exposure limit and therefore, for a given lamp, the exposure duration to reach the underlying exposure limit will be *longer* than the time base, often considerably longer. Therefore there is a wide range associated to a given RG in terms of actually exceeding the actinic UV exposure limit (similar ranges apply for the blue light hazard exposure limit given as radiance): for the case that the actual accumulated exposure duration during one day is less than the critical duration (exposure is assumed at the classification distance), then the exposure limit of 30 J m^{-2} is not reached and there is in reality, for a given application that is associated with an exposure duration shorter than the critical one, "zero risk" even though the lamp is a RG2 lamp. Even an RG3 lamp can be "safe" when the exposure duration per day, assumed to be at the classification distance, is correspondingly short (when the exposure is further away, the exposure duration can be longer, see below). It should be noted that for small lamps, where the inverse-square law would apply, a ten-fold difference in emission limit may actually be little more than a 3-fold change in exposure distance.

It is also important that the irradiance value that is defined as emission limit for the actinic UV hazard needs to be understood as a limit for the *average* irradiance [4] or "time-weighted average" (TWA). The underlying basic limit for the emission limits is, after all, the 30 J m^{-2} "dose" limit and it is the *average* irradiance multiplied by the exposure duration (the averaging duration) which results in the dose (the radiant exposure) that is compared against the limit. Thus it is permitted that the *peak* irradiance is significantly higher than the emission limit specified as irradiance, when there are episodes with lower irradiance levels that "compensate" for the episodes with higher irradiance so that overall the average irradiance remains below the respective limit.

Classification Distance Usually not Equal to Exposure Distance

The large range of "exposure duration to reach the exposure limit" within a given risk group is further amplified by the difference between the actual exposure distance (relevant for the risk) and the classification distance, which is the distance prescribed in IEC 62471 to be used for the classification of *lamps* (the classification distance for *lamp systems* is not prescribed in IEC 62471:2006 and is a parameter that might be chosen based on the type of the product as long as no product-type specific standard exists). The classification distance is 20 cm for non-General Lighting Service (non-GLS) lamps and it is equal to the distance where the illuminance equals 500 lx for GLS lamps. When the actual exposure occurs at a distance that is farther than the classification distance, the irradiance is reduced. For exposures at distances farther than the classification distance, the exposure duration to reach the underlying exposure limit will be correspondingly longer than determined at the classification distance. Again, at the exposure distance of a given use-case and for limited exposure durations (which can be longer, the further away the exposure occurs) even RG3 lamps (or luminaires) can be "safe".

Photochemical Retinal Hazard: RG2 is in Practice often as "Safe" as RG1 or RG0

The discussion of the UV hazard above was intended to demonstrate the concept of time base and risk groups. For the case of white LEDs, when based on blue LEDs and phosphor converters, UV emission is not an issue. The retinal thermal RG2 limit can also only be exceeded by very special luminaries such as high performance stage lights with large projection optics, and not by normal LEDs or LED luminaires such as used for general lighting. Therefore, with the noted exceptions, the only relevant emission limit for white and blue LEDs is the "blue light hazard" (BLH) limit. For the blue light hazard, the underlying exposure limit defined by ICNIRP is a radiance dose and equals 10^6 J m^{-2} sr^{-1}; the associated exposure level is added over 10 000 seconds (in an equivalent way as the actinic UV limit of 30 J m^{-2} applies to the exposure level added over 30 000 s). The emission limits for the risk groups (Table 1), expressed as radiance, are derived again by dividing the underlying dose limit by the time base.

Higher power LED products with projection optics that enlarge the apparent source (so that the averaging of radiance over 11 mrad has a reduced effect) can reach up to RG2 levels, based on the blue light hazard (i.e. the RG1 limit defined for the blue light hazard is exceeded). Examples are high power torches ("flashlights" in the USA) or vehicle headlamps. We see that also for this hazard, for RG2, the associated "permitted exposure duration" is very wide: it ranges from 0.25 seconds to 100 seconds, resulting in a permitted radiance (at the classification distance) that varies by up to a factor 400. This also needs to be taken into account when discussing the "risk" for injury for higher brightness products that are in the RG2 range (again noting that the risk group classification is required in IEC 62471:2006 only for lamps and not for lamp systems - flashlights and vehicle head lamps constitute lamp systems and not lamps), particularly of white LEDs which, as relatively new technology, are under heightened scrutiny even though the radiance of many metal halide or xenon lamps is significantly higher than can be reached by LEDs. It makes a significant difference if the exposure duration to reach the underlying blue light hazard limit of 10^6 J m^{-2} sr^{-1} is reached after a relatively short exposure duration of, for instance, 1 second or after a relatively long "staring duration" of 20 seconds or even 90 seconds. RG2 is often associated to the meaning of lower risk (compared to RG3) because of aversion responses (implying that this aversion response protects from injury when being exposed to RG2 lamps). Clearly for a scenario where the exposure duration needed to reach the exposure limit equals 10 seconds or longer, it is not really aversion responses that are relevant, it is more the general behavioral response of simply not staring into a very bright light (discomfort glare), which limits the exposure. But even if somebody would stare into a very bright light for 10 seconds or longer, it can be assumed that the pupil is going to be smaller than ~3.5 mm which is the one assumed in the derivation of the exposure limit, resulting in a lower effective retinal irradiance. Further, and most prominently, the averaging angle of acceptance defined to determine the exposure level that is compared against the blue light hazard emission limit is defined to be 11 mrad when determining RG2. The averaging angle of acceptance intends to account for involuntary eye movements that lead to a reduction of the retinal average irradiance when the image of the source is smaller than the averaging angle [11, 12]. An angle of 11 mrad is equivalent to the approximate angular subtense of the thumb nail on an extended arm. Thus the risk group classification assumes that a person stares into the source, for the respective duration (for RG2 up to 100 seconds), with eye movements that extend only over 11 mrad, i.e. equivalent to only looking at the thumb-nail of the extended arm for up to 100 seconds; this is difficult to imagine as achievable even if there is no bright light associated to the viewing scenario. Thus the specification of 11 mrad is a very conservative assumption with respect to eye-movements, if not unrealistic especially for the case of exposure durations longer than a few seconds. When eye movements are for a practical scenario larger than assumed for the classification of the lamp, then the image of a relatively small lamp will be moved across the retina and the effective retinal radiant exposure of a given point on the retina is reduced. This is equivalent to an averaging angle of acceptance of larger than 11 mrad. Consequently, the exposure duration to reach the underlying exposure limit of 10^6 J m^{-2} sr^{-1} is prolonged. For instance, if the angular subtense of the behavioral eye movements were 110 mrad (which is still small for normal vision and for a bright source) instead of 11 mrad, then for a source that at the viewing distance is smaller than 11 mrad, the effective (averaged) radiance would be smaller by a factor of 100, and the exposure duration to reach the underlying exposure limit is extended by that factor, effectively making an RG2 lamp into a RG1 or RG0-"effective exposure".

Additionally to the above discussed issues of pupil diameter and eye movements, there is an inherent margin between the "blue light hazard" exposure limit as defined by ICNIRP and the injury threshold that leads to photochemically induced retinal injury. For humans that safety margin is not known, but compared to ophthalmoscopically visible lesions in rhesus monkeys [13, 14] it is of the order of 20 for the exposure durations covered by the studies of up to 100 seconds. Thus, when the exposure level (determined with assumed eye movements of only 11 mrad) is for instance reaching the exposure limit after 5 seconds (with assumed pupil diameters of not less than 3 mm) and the margin to injury is assumed - for the sake of argument - of being a factor 10, then the staring time needed to cause an injury is 50 seconds. Again, even if staring into a very bright lamp for 50 seconds occurs it is very unlikely to be possible with only limited eye movements. Eye movements that are larger than the retinal image will additionally lead to prolonged "permitted" exposure durations in terms of risk for retinal injury. This explains why there is not a single case, to our knowledge, of retinal injury from an RG2 lamp or luminaire, leading to a scotoma, other than from ophthalmic instruments such as operating microscopes used for eye surgery when the operation and illumination takes longer as stated in the manual (where the dose limit used for that information is a factor of almost 5 higher than the base exposure limit used in IEC 62471).

The apparent lack of retinal injury caused by RG2 lamps and lamp systems is also consistent with those sources of optical radiation that *are* documented to have caused retinal photochemical injury, namely the sun as well as welding arcs. Staring into the sun, particularly when there is a solar eclipse, lead to a number of scotomas [15, 16]. Some cases of permanent retinal injury are also documented for welders staring into the welding arc without eye protection [17-20]. In all cases a “sufficiently long” staring duration is needed to induce the injury. The sun at intermediate and higher elevations would, by the way, be an RG3 light source based on the retinal thermal limit which is exceeded in significantly less than 0.25 s. That the sun, for unaided eye exposure, apparently does not result in retinal thermal injury which would be associated to exposure durations less than seconds, even though it is a RG3 source, is due to the assumption of a 7 mm pupil for the retinal thermal limit as well as the inherent safety margin for the retinal thermal limit.

The interpretation of RG2, when it comes to retinal hazards, as “moderate risk” or “safe due to aversion responses and only for very short exposure durations” is therefore, for most types of products, misleading and over-restrictive. The designation of “moderate risk” was also used in IEC 62471:2006 but the responsible IEC Technical Committee, TC 76 jointly with CIE for the next edition of the standard (to be re-published as IEC 62471-1 Edition 1) plans to avoid designations for the risk groups, due to widely varying risk per risk group and also widely varying types of products. Historically, the designation “moderate risk” can be explained and is appropriate with respect to UV emission where, at the classification distance, the underlying exposure limit of 30 J m^{-2} is exceeded for exposure durations between 1000 s (about 15 minutes) to 10 000 s (2.8 hours).

Relevant for Lighting: Diffuse Reflection or Transmission, not the Radiance of the Lamp

In the following, we discuss lamps and luminaires used for lighting of spaces such as homes, factories and offices. For lamps the term used in IEC 62471:2006 is “General lighting service” (GLS) lamps and that term can be extended also to luminaires (as intended for the next edition of IEC 62471, where, however, it is not planned to require a risk group classification for GLS luminaires, only for non-GLS lamp systems). The term GLS-lamps and GLS-luminaires is used somewhat wider in IEC 62471 as is common in the lighting industry and includes also desk-lamps, downlights, lights for the interior of a car, train or airplane, and shelf lights. In contrast to non-GLS lamps and non-GLS lamp systems such as flash-lamps or stage lighting, there are ergonomic and architectural principles for GLS lamp systems (i.e. GLS luminaires) that amongst others have the goal to avoid glare to result in comfortable lighting. In terms of potential photobiological hazards, when glare is avoided, the radiance is limited to low values and it is obvious that there is no hazard to the retina (as also reflected by the 10^4 cd m^{-2} exemption criterion in IEC 62471). The way to avoid glare is to either distribute the light over a larger area, such as by covering a lamp by a diffusor, or by avoiding that the light enters the eyes of occupants for the usual viewing directions, which can be affected by shielding the light and pointing the light only downwards or by indirect lighting. Consequently, in normal viewing scenarios relevant for long term exposure, a lamp with an intermediate or high radiance is either covered by a diffusor or it is shielded towards the sides or mounted outside the normal viewing direction; in all cases one does not look directly into the lamp for viewing directions associated to long-time exposure durations.

According to the classification specifications of IEC 62471 to determine the risk group of a lamp, the radiance of the lamp, such as an LED, is compared against the blue light hazard emission limit by orienting the measurement radiometer directly at the lamp (this also applies to the small-source blue light hazard limit expressed as irradiance, which is equivalent and derived from the radiance limit, see for instance references [11, 12]). We note again that the original intent of the risk group classification of lamps was to provide guidance for engineers using lamps, such as manufacturers of luminaires and of other products that use lamps (generally referred as lamp systems). Based on this background, direct radiance measurement appears appropriate for the classification of lamps (i.e. for the characterization of emission). A bare-lamp designation of RG-2 tells the luminaire manufacturer that diffusion or baffling is needed. However, when the classification geometry is translated to an *exposure* scenario, it is often unrealistic, as it assumes that the person looks directly into the source (Fig. 1). In reality, any lamp bright enough to be RG-2 because of blue light will be very uncomfortable to view for any length of time.

While the orientation of the detector - directly towards the lamp - is appropriate for an exposure and hazard analysis related to the skin (i.e. the actinic UV hazard which applies to both the skin and the eye), it is appropriate for an exposure analysis for the eye only for short, i.e. momentary exposures, not for normal long term viewing situations associated with GLS.

Lamps and luminaires that are designed to be both in the field of view for normal viewing directions and emitting light towards the eye are limited to low radiance levels by good general lighting practices, because higher brightness levels would be uncomfortable, resulting in discomfort or disability glare. These kind of luminaires are therefore diffuse with relatively low radiance, so that they would be usually RG1 or in the Exempt Group (Fig. 2) – for the case that the risk group classification is applied to GLS luminaires, which is not required in IEC 62471 and in our point of view does not appear to be justified. Due to the diffuse cover, the radiance of the lamp inside is not relevant.

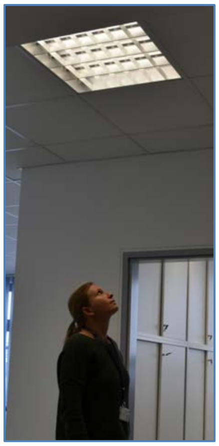

Figure 1. Classification of a lamp is based on direct radiance measurements and valid as characterization of the emission of the lamp. When the classification information of IEC 62471 is used for an exposure analysis, then this is often unrealistic since it implies that a person looks directly into the lamp. Lamp classification is intended originally as information for the luminaire manufacturer, not as information for exposure analysis of people.

Figure 2. Luminaires that are within the normal field of view feature diffusors, resulting in low radiance (left photo: wiki public domain).

Alternative to covering lamps with diffusors, reflectors and shields are used to avoid directing light emission towards the eye when a person looks straight ahead, as the example shown in Fig. 3. For these types of luminaires, the light that reaches the eye for a normal situation (i.e. for long-term exposure scenarios) is reflected from objects, such as from walls or from desks, the floor, etc. Thus, for this type of indirect lighting, for the exposure of people or for the potential hazard associated to the luminaire, it is also not the radiance of the lamp that is relevant for the normal (long term) exposure of the eye, but the radiance that is produced by diffuse reflection from the illuminated surfaces (walls, floor, etc.). This "reflected" radiance is not associated with the radiance of the lamp but to the irradiance at the walls and floor. The radiance of the wall and floor will be much smaller than the radiance of the lamp (even for white walls) and for the same lighting level (in terms of illuminance) produced at the wall, floor, etc. is independent of the radiance of the lamp: a small lamp with high radiance can produce the same illuminance at a given distance as a larger emitter with a lower radiance, or multiple lower radiance emitters.

Figure 3. In this example, the lamps are not covered but are shielded by reflectors so that they are only in the field of view when one looks up (photo by Hsiaopeitoo, CC BY-SA 3.0)

When a lamp is used for indirect lighting, down-lights or lighting of objects it is not in the normal field of view and it can therefore (based on good lighting principles) have a higher radiance as compared to lamps that are in the normal field of view. The radiance of lamps and luminaries used in such a way is only relevant for momentary exposures and potential retinal thermal hazards; however, technological limitations for radiance, at least for non-laser sources, result in the retinal thermal hazard not being a realistic concern. For the blue light hazard, long-term accumulated exposures are the relevant ones, but for long term accumulated exposures it is not the radiance of the lamp (that is not in the normal field of view) that is to be considered but the radiance of the illuminated surfaces that are in the normal field of view. This demonstrates that the risk group classification of lamps, which is based on the *radiance of the lamp*, for the blue light hazard is not directly "relevant" for exposure analysis for the case of indirect lighting or lighting of objects. For the case that a higher brightness lamp used for indirect or down-lights happens to be looked into (by looking up for instance), which is of course possible, due to glare and visual disturbance, the exposure duration is usually limited. Such a limited exposure duration is not only associated to very high brightness sources (which induce aversion responses such as squinting) but also to intermediate brightness levels where normal viewing behavior results in not looking into the lamp for longer; general experience shows us that the higher the radiance is (the brightness), the more intense is the aversion response and the shorter is the usual exposure duration. Comfortable prolonged exposure is associated only with very low radiance levels that are well below the BLH guidelines. Thus, good lighting principles dictate that light is reflected or shielded (Fig. 3.) or, when light emission is in the field of view for normal viewing directions, the luminaire has to be of low radiance, i.e. diffuse (Fig. 2).

While RG classification of *lamps* has value as information for manufacturers of luminaires (of the lamp system), subjection of GLS-*luminaires* to risk group classification (which is not intended in IEC 62471) often leads to over - restrictive interpretations of the hazard for the eye or skin that do not reflect the exposure and actual risk. A more realistic analysis needs to be based on the actual exposure.

In case the classification scheme is applied to luminaires (which is not a requirement in the current edition of IEC 62471), for general lighting, the classification rules of IEC 62471 reflect realistic exposure scenarios only for very low radiance diffuse luminaires (where the lamp or lamps in the luminaire is covered by a diffusor). For higher radiance luminaires that are used for down-lights or indirect lighting, radiance is also not the relevant quantity to characterize the blue light photochemical hazard for risk group classification of the luminaire which assumes continuous staring into the lamp. However, radiance is relevant for an exposure assessment of summed, repeated, momentary direct viewing of the lamp itself. For short time exposure, the retinal thermal limit is the relevant one to distinguish between RG2 and RG3, and for that limit, to assess direct radiance would be appropriate. However, the retinal thermal limit of RG2 can basically not be exceeded by GLS luminaires due to technological limitations of radiance (power density in the source). Only very high radiance sources (such as xenon lamps or metal halide lamps) with large apparent sources, resulting from projection optics that collimate the beam and enlarge the source, are candidates for RG3 lamp systems. Thus for GLS luminaires it does not appear necessary to apply retinal hazard limits and risk groups, or warning labels, and we again note that risk group classification is required in IEC 62471:2006 for lamps only and not for lamp systems. Thus, the hazard that remains to consider is the UV actinic hazard. This is known by the lighting industry and IEC standardization technical committee TC 34, where the limit of 2 mW/klm is defined for instance in IEC 60432-1 for quartz-halogen lamps in open luminaires, but also in other lamp specific standards. See [21] for a derivation of the 2 mW/klm limit from the UV limit of 10^{-3} W m^{-2} that is also defined for the exempt group in IEC 62471.

LED Spectra and some Notes on AMD

When white LEDs (blue LEDs with a phosphor cover) were developed at the end of the 1990s, the blue component was relatively strong and consequently the correlated color temperature (CCT) was very high. These types of “blue-ish”–white LEDs (Fig. 4) are still used in specialty lighting such as for searchlights, car head lamps or torches (flash lamps), where the CCT can reach 10 000 Kelvin or higher. For home-use lamps, i.e. for domestic lighting, at least in Europe and the USA, warm white LEDs of 2700 K to 3000 K are preferred. In offices, often lighting with intermediate color temperature is preferred (4100 K is popular in the USA and Europe).

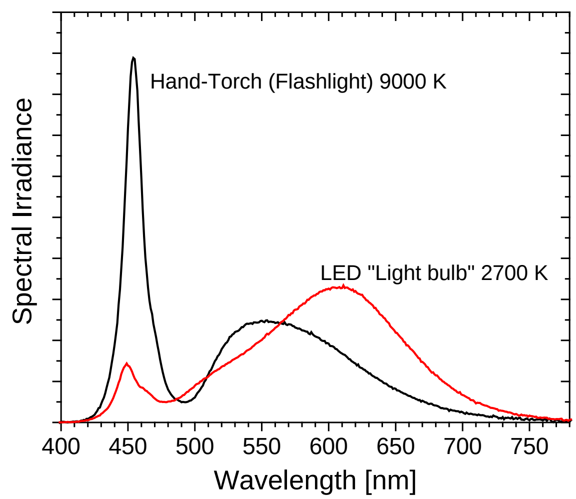

Fig. 4 Spectra of white LED flashlight and LED light bulb replacement; with correlated color temperatures; spectra normalized to equal unweighted irradiance.

Due to the pronounced emission in the blue part of the spectrum for high CCT LEDs, concerns about a “blue light hazard” was voiced by some research groups, medical doctors and other parties, particularly when white LEDs started to be used for lighting. This concern was also raised with respect to backlighting of computer screens, smart phones and TV screens. The blue emission was associated with the potential to induce age related macular degeneration, AMD [22] (acute retinal injuries was less of a concern, and we know from experience that acute injuries apparently do not occur).

In these discussions it was often overlooked that the "blue light hazard" exposure limit defined by ICNIRP and adopted by IEC 62471 does not relate to the potential role of light for the development AMD, but relates to an acute effect of "killing" retinal cells within hours after staring into extremely bright light sources such as the sun or welding arcs without eye protection. When such an exposure leads to retinal injury, a localized scotoma (a blind spot) is formed at the location of the image on the retina of typically less than 1 mm in size. This is associated to a completely different pathology as compared to AMD which has a significant prevalence only for ages above about 55 years. A detailed discussion of the potential role of light exposure and the development of AMD is not in the scope of this proceedings paper, but we would like to point out that besides the main factor of age, the risk for AMD is well established to be associated to a number of factors, such as smoking, nutrition and also genetic factors [23]. The role of exposure to sunlight in the development of AMD can be said to be controversial. Some epidemiological studies found a certain association between sunlight exposure over years [24-26] and risk to develop AMD, while others did not [27]. It is important to point out that these studies, correlated the exposure to *sunlight* to the incidence of AMD, not exposure to *artificial light*. In order to discuss potential effects of artificial lighting, differences in the respective lighting and retinal exposure levels need to be considered, and they can be assumed to be significantly different (illuminance levels of surfaces indoors are rarely exceeding 1000 lx while illuminance levels at the earth surface on sunny days are roughly 100 000 lx). What is well established is the correlation of blue light exposure and the suppression of melatonin production at night [28]. Thus when it comes to exposure to light in the evening from domestic lighting, smart phones, tablets and other screens, a reduction of the blue components might be prudent to avoid an effect on the circadian rhythm. But this is an issue not related to a retinal hazard.

Blue Light Hazard Depends on CCT not on Technology

There is some concern that the due to the "blue peak" of white LEDs there might be hazards associated to LEDs that are not found for other white light sources (see for instance [29]). With respect to this discussion we would like to note that only LEDs with very high color temperatures have a high blue peak; lower color temperatures have a significantly smaller blue component (see Fig. 4). Further, we know from experience that there is no actual "blue light hazard" in the sense of the acute effect that is related to the "blue light hazard" action spectrum and exposure limit that is associated to LED lighting, since no cases of scotoma are reported to our knowledge (scotoma that would be localized and established not longer than two days after staring into the bright light). As discussed above, the concerns about the "blue light" from white LEDs is not about acute effects but about AMD – however, for AMD, no action spectrum is known. It cannot be excluded, for instance, that outdoor UV radiation that reaches the retina, plays a role as a risk factor for AMD.

But even for the case that the action spectrum for light playing a role in AMD is similar to the action spectrum for acute retinal photochemical injury it should be considered the blue light hazard action spectrum B(λ) is relatively wide and there is high correlation of the CCT with the ratio of the blue light hazard effective irradiance to the non-weighted irradiance [21, 31]. Therefore, for a lighting scenario that produces, for instance, an illuminance of 500 lx at a white wall, the blue-light hazard effective radiance when looking at the wall depends basically on the CCT of the light source (i.e. if the 500 lx are produced by a more blueish light or by a more reddish light). Thus cold-white LED lighting with a given CCT has the same "blue light hazard" spectral fraction as fluorescent lighting with the same CCT. For those concerned that lower-level blue luminances could still pose a risk from chronic viewing (including as sometimes speculated for the development of AMD), then it stands to reason that the equivalent issue would be a concern for *any* type of lamp with the same color temperature. This means that warm LED light with color temperatures in the range of 2700 K is as "non-hazardous" as incandescent lamps with 2700 K. On the other hand, LED light with CCT of 4100 K used for office lighting is "as hazardous" (or "as non-hazardous") as 4100 K fluorescent lighting which has been in use in offices, schools, factories and warehouses since the 1950s.

Summarizing with respect to the speculation of artificial lighting playing a role in AMD we would like to point out that the action spectrum is not known and *if* visible light or UV from indoor lighting is a relevant risk factor (emphasizing that epidemiological studies only show an association for exposure to *sunlight*, if an association is found), it is not limited to LEDs. For the case that UV radiation plays a relevant role, we note that LED is the lamp type which emits the least amount of UV-A at a given illuminance level [21].

Conclusions and Summary

Historically the risk group classification scheme of ANSI/IESNA RP27 and IEC 62471 was developed to be applied to lamps, as information for the luminaire manufacturer whether additional filters or shielding is necessary to reduce the emission – at the time mostly related to UV radiation. It is therefore not surprising that the classification scheme is not reflecting the actual risk accurately in many cases when the risk group scheme is applied to luminaires (which is not a requirement in IEC 62471:2006) and where the dominating hazard is the blue light hazard.

The usage of risk groups as the basis for a risk analysis for the exposure of the eye or the skin to optical radiation is often over-simplified and over-restrictive. Risk group classification is based on some worst-case scenarios, such as that it implies intra-lamp exposure ("staring into the lamp") even for long time exposure durations and that eye movements extents reflected by averaging angles are, for exposure durations longer than a few seconds, unrealistically small. Also the range of associated emission durations to reach the underlying exposure limit is relatively crude (for RG2 for the blue light hazard for instance between 0.25 s and 100 s).

It is a challenge to develop a safety standard that assures a "safe product" on the one hand and is not over-restrictive on the other. The current edition of IEC 62471 does not require that luminaires are classified; some aspects of the classification of lamps are not ideally suited for luminaires. When it is considered for future editions of IEC 62471 to include lamps-systems and labeling into the scope, it should be considered that for regular lighting ("general lighting service" GLS) - for the case that UV emission is not an issue - it does not appear necessary to subject the product to risk group classification and potential labeling, at least not for non-laser illuminated light sources: momentary exposure does not present a hazard due to technological limitations and long term exposure is limited in radiance due to lighting principles to avoid glare as well as due to naturally limited exposure duration to bright light.

For several types of non-GLS lamps and lamp systems, risk group classification appears prudent and manufacturer's requirements for safe construction, labeling and user information should be covered by product safety standards. However, also these standards need to have a balanced level of requirements. For instance, non-GLS RG3 lamp systems should not be regarded as generally unfit for consumers, since the actual risk depends on exposure duration and distance, particularly for infrared and UV radiation but also to a degree for retinal hazards. Non-GLS RG2 lamp systems emitting white light can be, with some rare examples of intentional direct ocular long-term exposure at close distance, considered as "usually safe" when it comes to retinal hazards. Besides the general practical experience with high radiance light sources, this argument is supported by eye movements which can be assumed to be larger than assumed for the measurement criteria of IEC 62471 as well as the margin between the exposure limit and injury thresholds. Experience shows that even relatively bright sources that are RG2, such as metal halide spotlights or high power cinema projectors in practice do not result in retinal injuries even without warning labels – to the knowledge of the authors no case of retinal injury has been reported for RG2 lamp systems (which even for instance applies to RG3 cinema projectors with only one documented retinal injury [31]). A relevant issue for the discussion about warning labels is that for lamps which are radiance limited (contrary to lasers) it takes at least several seconds if not minutes of intentional staring into a bright light to induce injury, and mankind has evolved with a very bright source on the sky to learn that this is not prudent behavior. Product safety policy is usually that when a hazard is known, it is not necessary for the manufacturer to place a warning label on the product. It might be prudent to require warning labels for some RG2 lamp systems that are close to the emission limit, i.e. with associated exposure durations to reach the exposure limit of the order of less than 10 seconds. Also higher power blue LEDs should be avoided for toys and child-appealing products [32].

In the discussion of potential hazards associated to visible radiation from artificial lighting, we do not see the necessity to distinguish LEDs from other light sources (when it comes to UV emission, LEDs are associated to the lowest emission for a given illuminance level of all common lamp types). The main concern in these discussions is not *acute* retinal effects which would be recognized as a permanent blind spot shortly after staring into an extremely bright light, but the potential role of light exposure to increase the risk for age-related macular degeneration (AMD) – which takes at least 50 years to develop. It could well be that retinal exposure to outdoor light and UV levels over many years increases the risk for AMD to a certain degree, but indoor illuminance levels are a factor of the order of 100 lower (a detailed discussion of retinal exposure levels resulting from direct or indirect exposure outdoors vs. indoors is not in the scope of this paper). When the risk increase for AMD and year-long exposure to sunlight is not consistent amongst available epidemiological studies, then a risk increase from indoor lighting can be seen as highly speculative.

For the discussion about retinal hazards and lamps used for general lighting it is also important to recognize that the radiance of a lamp (as determined for risk group classification) is only relevant when a person looks directly into the lamp. However, directly looking into a bright light is only relevant for momentary exposures and potential retinal *thermal* hazards. For a potential retinal *photochemical* hazard (blue light hazard), long time exposure is relevant where for most applications, particularly for lighting, exposure is from reflections of surfaces that are lit. For this type of exposure, the radiance of a lamp or lamp system is not the appropriate quantity.

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