HAZARD ASSESSMENT OF LAMPS FOLLOWING THE CIE LAMP SAFETY STANDARD

Marko Weber; Karl Schulmeister

ARC Seibersdorf research, Health Physics Division
A-2444 Seibersdorf

ABSTRACT

In 2001, the CIE published a safety standard for lamps [1], specifying exposure limits for the eye and the skin for broadband radiation from the UV to the IR, and defining a lamp classification scheme in terms of risk groups. For the CIE standard, the exposure limits were adopted from ICNIRP, the risk group classification from the northern American lamp safety standard IESNA RP 27.

This paper presents, the results of safety evaluations of a number of sources following the requirements of the CIE lamp safety standard. The evaluated lamps, in terms of spectrum, cover the whole spectrum, from UV to visible and far infrared sources. Potential hazards from exposure to optical radiation include sun burn of the skin, photokeratokonjunctivis of the cornea, cataract of the lens and retinal damage due to thermal or photochemical interaction. For retinal hazards, the measurement requirements and exposure limits are accounting for eye movements and for the retinal image size, using the concept of radiance being averaged over a specific field of view. This averaging FOV is unique to photobiological safety evaluations, resulting in measured values which can be several orders of magnitude below the actual physical radiance of the source. If the measurement requirements stated in the CIE lamp safety standard are not considered, over-restrictive safety assessments of lamps would result.

For the evaluated sources, the risk for eye and skin damage based on the ICNIRP exposure limits and the resulting risk groups will be discussed and practical issues regarding the measurement requirements pointed out.

In addition to this practical part, the measurement requirements and exposure limits of the CIE Lamp Safety Standard will be compared to other standards. Although these standards are partially equivalent and contain threshold limit values for the same potential hazards, there are some remarkable differences in their exposure limits and in their measurement parameters.

Keywords: Risk group, risk group classification, photobiological hazard, lamp safety standard

1. INTRODUCTION

The CIE-Standard “Photobiological Safety of Lamps and Lamp Systems” specifies a risk group classification for pulsed and unpulsed lamps and lamp systems in order to indicate the potential photobiological risk of the lamp. Two different distances of measurement are defined in the standard for the risk group classification depending on the intended use: the distance where the illuminance level equals 500 lux for general lighting service lamps and 20 cm for non-general lighting service lamp. This work discusses how we have applied the standard to a number of lamps. We classified various types of non general lighting service lamps for both the ‘500 lux’ and the 20 cm measurement distance. The results emphasise that the differentiation regarding the type of lamp and therefore the measurement distance has a great impact on the classification: The same lamp could be assigned to different risk groups whether it is evaluated as a general lighting service (GLS) lamp or as a non general lighting service lamp (NGLS).

As a reference to the measured lamps, we applied the CIE lamp safety standard to the most frequently used ‘lighting source’, the sun, although we are aware that this standard is not applicable for the evaluation of the sun. The background of this comparison is to aid the interpretation of the potential hazard of the evaluated lamps.

2. METHODS

For the spectral measurement of the lamps and the sun we used a doublemonochromator DM 150 with an averaging aperture of 25 mm in diameter for the input optic. The evaluated lamps were a Philips 160 W Blacklight Blue Lamp, a sunlamp (Osram Ultra Vitalux 300 W) and an infrared spotlight (Dennard 500) such as used for surveillance lighting (a quartz tungsten halogen lamp with an IR filter). All three lamps are non general lighting service lamps, and consequently they have to be evaluated in a distance of 20 cm according to the CIE lamp safety standard.

Spectral measurements of the sun in the spectral region of 200 nm to 500 nm were performed at Seibersdorf (~48,5°N) at noon on a cloudless mid-august day (10th august 2000, GMT 13:00, summertime). The received irradiance was taken to evaluate the sun according to the actinic and near UV hazard. For the other risk group classification criteria we took the standard total air mass 1.5 spectral irradiance of the sun published by the American Society for Testing and Materials [2].

For photobiological hazards which require the measurement of the radiance of the source, such as retinal thermal or blue light hazard we applied the alternative radiance measurement method as specified in the standard (a field stop was placed directly in front of the source in order to define a specific instrument field of view γ). This set-up implies that the field stop can be placed sufficiently close to the apparent source, otherwise the standard radiance measurement method has to be used.

With the spectroradiometer we measured the spectral irradiance of the source. The spectral irradiance was weighted with the spectral weighting function ($B(\lambda)$, $R(\lambda)$) and integrated over the wavelength. The result was then the effective irradiance, which could be compared with the emission limits for risk groups. The following table 1 shows the emission limits for risk groups according to the new CIE lamp safety standard.

Table 1. CIE emission limits and risk group time criteria of continuous wave lamps.

Risk Name	Action Spectrum	Symbol	Emission Limits/Risk Group Time Criteria			Units
			Exempt Group	Low Risk	Moderate Risk	
Actinic UV	$S_{UV}(\lambda)$	E_S	0,001	0,003	0,03	W m^{-2}
			30000	10000	1000	s
Near UV		E_{UVA}	10	33	100	W m^{-2}
			1000	300	100	s
Blue Light Retinal Hazard	$B(\lambda)$	L_B	100	10000	4000000	W m^{-2}sr^{-1}
			10000	100	0,25	s
Blue Light Small Source	$B(\lambda)$	E_B	1,0	1,0	400	W m^{-2}
						s
Retinal Thermal Hazard	$R(\lambda)$	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}
						s
IR eye		L_{IR}	100	570	3200	W m^{-2}
			1000	100	10	s

To derive the radiance value L from the measured irradiance value E we used the equation $L = E/\Omega$.

For retinal hazard exposure limits, the measurement requirements and exposure limits are accounting for eye movements and for the retinal image size, using the concept of radiance being averaged over a specific field of view. This averaging field of view changes with the exposure time. A short eye exposure will result in a small exposed area on the retina due to small eye movements. Consequently a small field of view is used for “short exposure time” measurements (min. 1,7 mrad). For long exposure durations the eye movements increase and spread the radiant energy over a larger area of the retina. This situation is considered in the CIE lamp safety standard by the use of a larger field of view up to a maximum of 0,1 rad [3].

3. RESULTS AN DISCUSSION

In figures 1, 2 and 3 the spectra of the three evaluated lamps and the sun are shown. Table 2 gives the results of the risk group classification and shows the assigned risk group for the lamp and the sun.

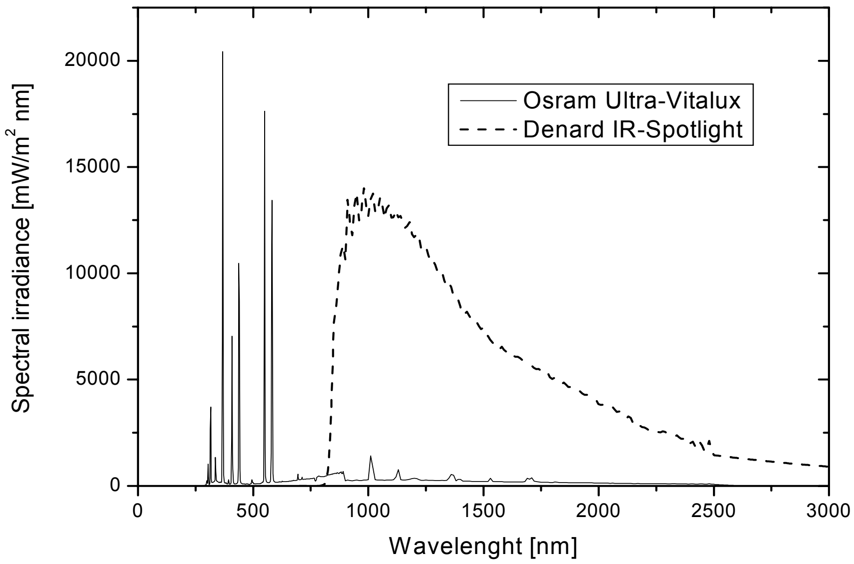

Figure 1. Spectra of the Osram Vita-Lux (sunlamp) 300 W and the Denard IR-Spotlight type 2020 500 W.

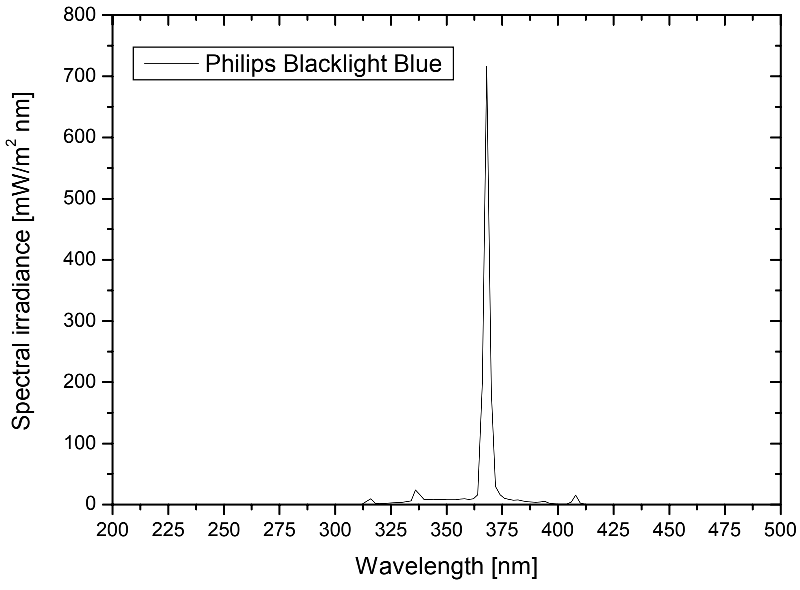

Figure 2. Spectra of the Philips Blacklight Blue 160 W.

The evaluations of the lamps lead to the following results:

The Osram sunlamp (Ultra-Vitalux) evaluated at a distance of 20 cm is a lamp of risk group 3 due to its high actinic UV content. If this lamp would be evaluated (although it should not be considered as a GLS lamp) under the 500 lux condition it would only be a lamp of risk group 2. This measurement distance of 500 lux would be more than two meters. When the distance from the user to the lamp would be less than two meters, the potential photobiological hazard would be underestimated by the 500 lux distance. The CIE lamp standard has set the measurement distance for non general lighting service lamps at a distance of 20 cm. For the measurement of the actinic hazard and the parameters eye-UVA and eye-IR a detector field of view γ of 1,4 rad (80°) was realized according to the CIE lamp standard.

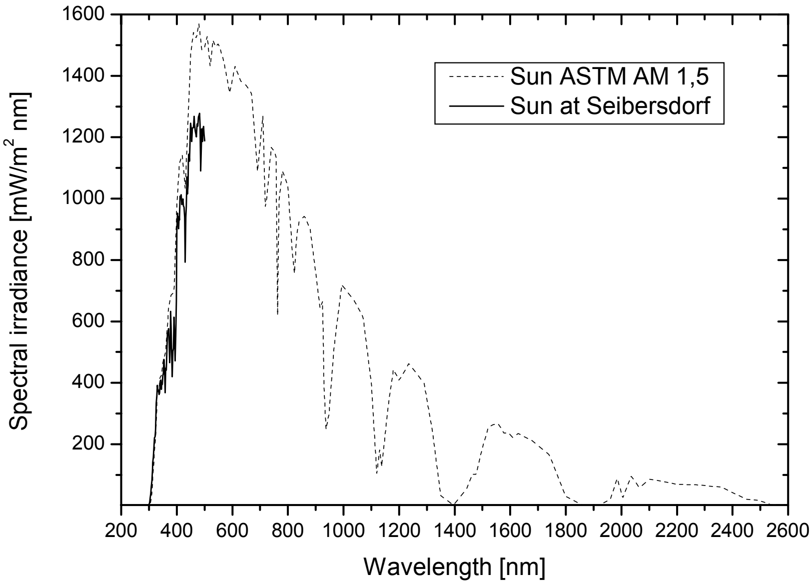

Figure 3. Spectra of the sun

Table 2. Results of the risk group classification. While the risk group as such only applies to the whole lamp (written in bold, italic numbers), we have indicated the 'per hazard' risk group (non-bold italic numbers) to see which one's of the hazards is the most critical one.

		Measured Radiance/Irradiance (**Risk Group**)					
Lamp	Measuring distance	Actinic UV	Eye-UVA	Eye-IR	Retinal blue	Retinal thermal	Skin thermal
Osram Ultra-VitaLux	20 cm	872 mW/m^2 (***3***)	87,6 W/m^2 (*2*)	401 W/m^2 (*1*)	325 [1)] W/m^2 sr 2473 [2)] W/m^2 sr (*1*)	47352 [2)] W/m^2 sr (*Exempt*)	758 W/m^2
	250 cm (~ 500 lux)	5 mW/m^2 (***2***)	0,5 W/m^2 (*Exempt*)	2,3 W/m^2 (*Exempt*)	1,5 [1)] W/m^2 sr (*Exempt*)	256 [2)] W/m^2 sr (*Exempt*)	4,3 W/m^2
Philips Blacklight Blue	20 cm	0,5 mW/m^2 (***Exempt***)	2 W/m^2 (*Exempt*)	1,5 W/m^2 (*Exempt*)	4,3 [1)] W/m^2 sr (*Exempt*)	673 [2)] W/m^2 sr (*Exempt*)	3,7 W/m^2
Dennard IR-Spotlight	20 cm			11901 W/m^2 (***3***)		4051 [2) 3)] W/m^2 sr (*Exempt*)	11901 W/m^2
Sun	$1{,}49 \times 10^8$ km	35 mW/m^2 (***3***)	37,7 W/m^2 (*2*)	411 W/m^2 (*1*)	89 W/m^2 (*2*) (small source)	1,364 $\times 10^7$ W/m^2 sr (*2*)	963 W/m^2

[1)] measured with an averaging FOV of 0,1 rad
[2)] measured with an averaging FOV of 0,011 rad
[3)] retinal thermal weak visual stimulus

The Ultra-Vitalux was also evaluated for the retinal blue light hazard parameter. For the exempt group criteria (exposure limit should not be exceed within 10000 s) it was first measured with a field of view of 0,1 rad. A radiance of 325 W/m^{2}sr was obtained for this condition, where eye movements, due to the long exposure time, play an important role. The emission limits of the exempt group of 100 W/m^{2}sr was exceeded, therefore the lamp had to be measured for the risk group 1 criteria. For the risk group 1 condition (exposure limit should not be exceeded within 100 s) the same source was measured with an averaging field of view of 11 mrad. With this smaller FOV, the lamp was sampled for hot-spots and a maximum radiance of 2473 W/m^{2}sr was obtained. This radiance is less than the emission limit of risk group 1 (10000 W/m^{2}sr), consequently the Ultra-Vitalux would be a low risk lamp according to the blue light hazard parameter.

The Philips Blacklight Blue is assigned to the exempt group because it does not exceed any exposure limit of the exempt group.

The Dennard IR-spotlight exceeds the exposure limit of risk group 2 for ocular infrared radiation. As a consequence it is a lamp of risk group 3. This lamp was also measured for the retinal thermal limit, but it does not exceed the exposure limit of the exempt group. The IR-spotlight had to be evaluated as a low luminance source (luminance < 10 cd/m^2). The natural response of a restricted pupil does not apply to such a source. This fact is considered in the standard by a lower exposure limit for a low luminance source. The spectrum of the IR-spotlight begins at the wavelength of 750 nm, having a maximum at 1050 nm. The emitted radiation of the spotlight in the red and IR region of the spectrum is not as effective for causing a retinal burn compared with wavelengths in the spectral region of the visible. This fact is taken into account with the burn hazard function $R(\lambda)$: For wavelengths above 700 nm the spectral weighting burn hazard function $R(\lambda)$ has values less than 1 and it's values are decreasing with increasing wavelengths. Both the Blacklight Blue and the infrared spotlight were only evaluated at a distance of 20 cm, as for these lamps it is clear that they are NGLS lamps. Their main spectrum is in the ultraviolet or in the infrared region and the lamp output does not reach 500 lux at any distance from the lamp.

The measured results for the thermal exposure of the skin are also given in table 2, although this parameter is not considered in the risk group classification. To draw the line between a safe and a potential hazardous source for this parameter, the thermal hazard exposure limit for the skin of the CIE-Standard should be used. For an exposure duration of ten seconds a maximum irradiance of 3556 W/m^2 is allowed. Except for the IR-spotlight, which exceeds this threshold limit by a factor of 3, the measured sources do not pose a potential thermal hazard for the skin.

If the CIE-standard was applied to the world's "standard light source", the sun, it would be assigned to the risk group 3 due to its high actinic UV content. The irradiance/radiance of the sun depends on many parameters (season, time of the day, sky cover, latitude, altitude, etc.) that the results given in table 2 are only valid for the conditions mentioned under point 2. Due to its diameter (1,391x10^6 km) and its distance to the earth the sun can be evaluated as a small source (angular subtense α ~ 9,3 mrad). For both parameters, retinal blue light small source and retinal thermal hazard, the sun would be at least a lamp of risk group 2 (we did not measure the sun with the risk group 2 criteria for these two parameters which requires a FOV γ of 1,7 mrad).

The hazards of the evaluated lamps can be compared to the sun as follows:

- The sunlamp Osram Ultra-Vitalux is stronger than the sun in the UV region of the spectrum, exceeding the results of the sun by a factor of more than 20 for the parameter actinic UV and more than 2 for the parameter eye-UVA. Therefore the user should not underestimate the potential hazard of this lamp and should take reasonable precautions when using this lamp.
- The Dennard IR-spotlight exceeds the value of the sun for the parameter eye-IR by a factor of more than 28 and the risk group 2 threshold limit value for this parameter by a factor of more than 3.
- The Philips Blacklight Blue does not pose a photobiological risk.

4. COMPARISON BETWEEN VARIOUS LAMP STANDARDS

Beside the CIE Lamp Safety Standard a number of other Safety Standards/Guidelines exist, having mainly the same goal as the CIE standard: To define exposure limits and to protect people from potential hazardous radiation of lamps and lamp systems. They all give exposure limits for the number of relevant optical radiation hazards, however the threshold limit values and some measurement parameters may vary from standard to standard. Also these standards use different synonyms for their exposure limits: exposure limit (EL), maximum permissible exposure (MPE) and threshold limit value (TLV). For all of the presented documents below, the limits are not intended as fine lines between safe and hazardous levels. Rather, they are intended to be used as guidelines in the control of exposures [11].

Generally, the earlier documents influenced the development of the latest standards, as exposure limits and measurement techniques were taken from the older standards and adopted for the new guidelines. For the CIE standard, the exposure limits were adopted from various ICNIRP guidelines [4, 5] which, in turn, are based on the best available information from experimental studies. The CIE risk group classification was adopted from a northern American lamp safety standard IESNA RP 27 [6]. The American National Standards Institute (ANSI)/Illuminating Engineering Society of North America (IESNA) based their exposure limits [7, 8] on the threshold limit values given by the American Conference of Governmental Industrial Hygienists (ACGIH) [9]. The International Electrotechnical Commission (IEC) based their standard for incoherent optical radiation [10] on the ICNIRP guidelines.

In the following the standards mentioned above will be compared, their differences will be pointed out and discussed. Table 3 below gives a general overview over the exposure limits which are set for the different optical radiation hazards in the various standards.

4.1 CIE S 009/E:2002

One point that makes the CIE lamp safety standard more user-friendly compared with other standards is that the CIE standard uses two different symbols for the angular subtense α of the apparent source and the field of view γ of the detector. In other standards, like IEC and ICNIRP the Greek letter α is used for both the angular subtense and the field of view although these are two different parameters.

For the photobiological parameter blue light hazard the CIE standard specifies the dependence of the field of view γ on the exposure duration most comprehensively. The field of view can vary from 1,7 mrad for a short time exposure of 0,25 s up to 100 mrad for exposure durations longer than 10000 s (figure 4).

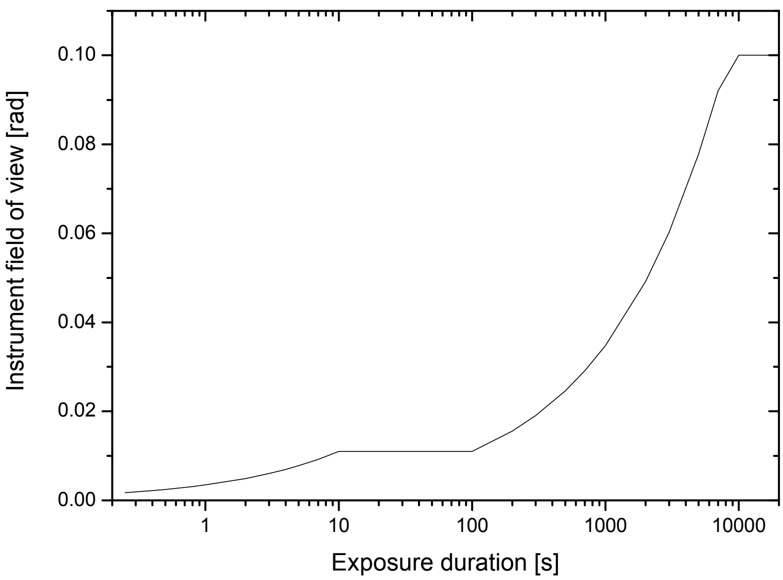

Figure 4. Dependence of the instrument field of view from the exposure duration as specified in the CIE lamp safety standard for blue light hazard.

Table 3. Photochemical exposure limits of different standards on incoherent optical radiation.

Hazard name	Standard/ Guideline	Relevant equation	Wavelenght range [nm]	Exposure duration [s]	Instrument field of view	Exposure limit	Pupil size (assumed) [mm]	Limiting aperture [mm diameter]
Actinic UV skin & eye	CIE	$E_S = \sum E_\lambda \cdot S(\lambda) \cdot \Delta\lambda$	200 - 400	< 30000 (8 h)	1,4 (80°)	30/t Wm^{-2}		≤ 50 (25), 7
	ANSI/IESNA			≤ 8 h	80°	30/t Wm^{-2}		≤ 25, 7
	ICNIRP		180 - 400	≤ 8 h		30/t Wm^{-2}		≤ 50, 7
	IEC			≤ 8 h		30/t Wm^{-2}		1 (t ≤ 3s), 7 (t > 3s)
	ACGIH			≤ 8 h	80°	30/t Wm^{-2}		
Eye UV-A	CIE	$E_{UVA} = \sum E_\lambda \cdot \Delta\lambda$	315 - 400	≤ 1000 > 1000	1,4 (80°)	10000/t Wm^{-2} 10 Wm^{-2}		≤ 50 (25), 7
	ANSI/IESNA		320 - 400	< 1000 ≥ 1000	80°	10000/t Wm^{-2} 10 Wm^{-2}		≤ 25, 7
	ICNIRP		315 - 400	≤ 8 h		10000 Jm^{-2}		≤ 50, 7
	IEC	$H_{UV} = \sum H_\lambda(\lambda) \cdot \Delta\lambda$		≤ 8 h		10000 Jm^{-2}		1 (t ≤ 3s), 7 (t > 3s)
	ACGIH	$E_{UVA} = \sum E_\lambda \cdot \Delta\lambda$	320 - 400	< 1000 > 1000	80°	10000/t Wm^{-2} 10 Wm^{-2}		
Retinal Blue Light Small Source	CIE	$E_B = \sum E_\lambda \cdot B(\lambda) \cdot \Delta\lambda$	300 - 700	≤ 100 > 100	< 0,011	100/t Wm^{-2} 1 Wm^{-2}		≤ 50 (25), 7
	ANSI/IESNA		400 - 700	≤ 10000 > 10000	0,011	100/t Wm^{-2} 0.01 Wm^{-2}		≤ 25, 7
	ICNIRP		300 - 700	≤ 10000 > 10000		100/t Wm^{-2} 0.01 Wm^{-2}		≤ 50, 7
	IEC			≤ 10000 > 10000		100/t Wm^{-2} 0.01 Wm^{-2}	7 (t < 0,5s), 3 (t > 0,5s)	7
	ACGIH		400 - 700	≤ 10000 > 10000		100/t Wm^{-2} 0.01 Wm^{-2}		
Eye IR	CIE	$E_{IR} = \sum E_\lambda \cdot \Delta\lambda$	780 - 3000	≤ 1000 > 1000	1,4 (80°)	18000/$t^{0,75}$ Wm^{-2} 100 Wm^{-2}		≤ 50 (25), 7
	ANSI/IESNA		770 - 3000	< 1000 > 1000		18000/$t^{0,75}$ Wm^{-2} 100 Wm^{-2}		≤ 25, 7
	ICNIRP		780 - 3000	< 1000 > 1000		18000/$t^{0,75}$ Wm^{-2} 100 Wm^{-2}		≤ 50, 7
	IEC			< 1000 ≥ 1000		18000/$t^{0,75}$ Wm^{-2} 100 Wm^{-2}	7 (t < 0,5s), 3 (t > 0,5s)	1 (t ≤ 3s), 3,5 (t > 3s)
	ACGIH			≤ 1000 > 1000		18000/$t^{0,75}$ Wm^{-2} 100 Wm^{-2}		
Skin Thermal Hazard	CIE	$E_H = \sum E_\lambda \cdot \Delta\lambda$	380 - 3000	< 10	2π sr.	20000/$t^{0,75}$ Wm^{-2}		≤ 50 (25), 7
	ANSI/IESNA	$H = \sum E_\lambda \cdot t \cdot \Delta\lambda$	400 - 3000	≤ 1 1 < t ≤ 10	2π sr.	20000 Jm^{-2} 20000 * $t^{0,35}$ Jm^{-2}		≤ 25, 7
	ICNIRP		380 - 3000	< 10		20000 * $t^{0,25}$ Jm^{-2}		≤ 50, 7
	IEC			< 10		20000 * $t^{0,25}$ Jm^{-2}		3,5
Retinal Blue Light	CIE	$L_B = \sum L_\lambda \cdot B(\lambda) \cdot \Delta\lambda$	300 - 700	0,25 - 10 10 - 100 100 - 10000 ≥ 10000	0,011 • √(t/10) 0,011 0,0011 • √t 0,1	10^6/t $Wm^{-2}sr^{-1}$ 10^6/t $Wm^{-2}sr^{-1}$ 10^6/t $Wm^{-2}sr^{-1}$ 100 $Wm^{-2}sr^{-1}$	3	
	ANSI/IESNA		400 - 700	≤ 10000 > 10000	0,011	10^6/t $Wm^{-2}sr^{-1}$ 100 $Wm^{-2}sr^{-1}$	3	
	ICNIRP		300 - 700	< 10000 > 10000	0,011 $0,2^{1)}$	10^6/t $Wm^{-2}sr^{-1}$ 100 $Wm^{-2}sr^{-1}$		
	IEC			≤ 10000 > 10000	0,011	10^6/t $Wm^{-2}sr^{-1}$ 100 $Wm^{-2}sr^{-1}$	7 (t < 0,5s), 3 (t > 0,5s)	7
	ACGIH		400 - 700	≤ 10000 > 10000		10^6/t $Wm^{-2}sr^{-1}$ 100 $Wm^{-2}sr^{-1}$	2 - 3	
Retinal Thermal	CIE	$L_R = \sum L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$	380 - 1400	$1*10^{-5}$< t < 0,25 0,25 - 10	0,0017 0,011 • √(t/10)	50000/(α•$t^{0,25}$) $Wm^{-2}sr^{-1}$ 50000/(α•$t^{0,25}$) $Wm^{-2}sr^{-1}$	3 (7 for t < 0,25 s)	
	ANSI/IESNA		400 - 1400	$1*10^{-6}$ < t < 10 s	0,011	50000/(α•$t^{0,25}$) $Wm^{-2}sr^{-1}$	7 (3 for t ≥ 10 s)	
	ICNIRP		380 - 1400	$1*10^{-5}$ ≤ t ≤ 10 s	0,0017 $0,011^{2)}$	50000/(α•$t^{0,25}$) $Wm^{-2}sr^{-1}$	3 (7 for t < 0,5 s)	
	IEC			< $1,8*10^{-5}$ $1,8*10^{-5}$ ≤ t ≤ 10 > 10	0,0015 ≤ α ≤ 0,1	41,2/(C_α•$t^{0,9}$) $Wm^{-2}sr^{-1}$ 50000/(C_α•$t^{0,25}$) $Wm^{-2}sr^{-1}$ 28000/C_α $Wm^{-2}sr^{-1}$	7 (t < 0,5s), 3 (t > 0,5s)	7
	ACGIH		400 - 1400	$1*10^{-6}$ < t < 10 s		50000/(α•$t^{0,25}$) $Wm^{-2}sr^{-1}$		
Retinal Thermal Weak Stimulus	CIE	$L_{IR} = \sum L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$	780 - 1400	> 10	0,011 ≤ γ ≤ 0,1	6000/α $Wm^{-2}sr^{-1}$	7	
	ANSI/IESNA	$L_{IR} = \sum L_\lambda \cdot \Delta\lambda$	770 - 1400	> 10	0,011	6000/α $Wm^{-2}sr^{-1}$	7	
	ICNIRP*	$L_{IR} = \sum L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$	780 - 1400	> 10	0,011 ≤ α ≤ 0,1	6000/α $Wm^{-2}sr^{-1}$	7	
	IEC*			≥ 10	0,011 ≤ α ≤ 0,1	6000/C_α $Wm^{-2}sr^{-1}$	3	7
	ACGIH		770 - 1400	< 8 h		6000/α $Wm^{-2}sr^{-1}$	7	

*: t < 10 s: ELs from L_R have to be taken

Other standards do not specify the instrument field of view in this continuous form. They only indicate the field of view for certain exposure durations (short time exposure: 1,7 mrad, 10 – 100 s: 11 mrad, t ≥ 10000 s: 100 mrad) and this will be sufficient for the evaluation of a lamp. In reality a lamp will not be evaluated if it is safe for a 6 s or a 500 s exposure, and even the risk group classification for the blue light hazard parameter is based on the three field of view values (according to the risk group time criteria, table 1) given above.

A remarkable difference in the CIE standard to the other standards can be found in the exposure limits for the retinal blue light parameter for small sources (angular subtense α of the source < 11 mrad). The CIE gives an irradiance exposure limit for t > 100 s of 1 W m^{-2} while all other standards indicate their exposure limit for t ≤ 10000 s of 100/t W m^{-2} and for t > 10000 s of 0,01 W m^{-2}. The consequence of this diverging threshold limit values is shown in figure 5. For a 10000 s exposure the CIE exposure limit is 100 times greater than the limits in the other standards. From the author's point of view the value as specified in CIE is correct when one considers the dependence of the field of view on exposure duration. This temporal dependence cancels with the temporal dependence of the exposure limit when it is specified as irradiance value. It seems that in the other documents, the small source exposure limit was derived with the field of view of 11 mrad that applies to 100 s.

In the CIE document it is noted that the exposure limits apply for exposure durations up to 8 hours. However, in table 5.4 of the CIE standard it is indicated that the maximum exposure duration for the parameter actinic UV (eye and skin) with 30000 s, which is not exactly equal 8 hours. To express the maximum exposure duration in seconds 28800 s would be the correct term. In practice, it is not likely that this difference of 1200 s will lead to big differences in the evaluation of a lamp. The difference in the threshold limit for the varying exposure times will only be 4 percent.

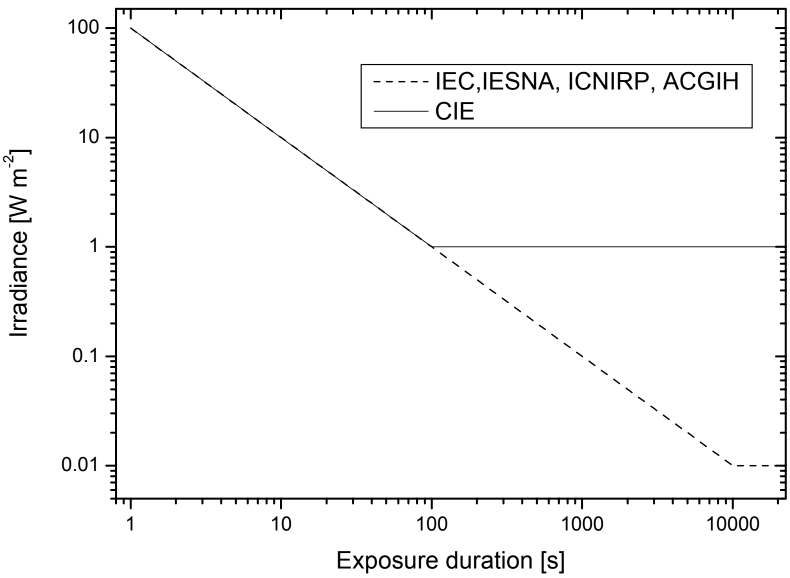

Figure 5. Comparison of the exposure limit for the parameter retinal blue light small source expressed in terms of irradiance.

4.2 ANSI/IESNA RP-27 Series

ANSI/IESNA was the first who introduced a risk group classification for lamps. Although it served as a model for the CIE classification scheme, there are some differences between these two standards. The ANSI/IESNA standard includes labelling of the lamps or lamp manufacturer requirements, while the CIE standard does not cover this field and refers to other standardisation committees such as IEC TC-34 (Lamps and Related Equipment).

For 7 out of 8 photobiological hazard parameters ANSI/IESNA uses other wavelength ranges than the CIE Standard. The differences in the wavelength ranges vary from 5 nm for the parameter Eye UV-A up to 100 nm for the two retinal blue light hazard parameters. Although ANSI/IESNA regards a 100 nm narrower wavelength range (400 nm – 700 nm) for the blue light hazard parameter, they have set the same exposure limits than the CIE (300 nm – 700 nm). In the evaluation of a GLS-lamp this relatively big difference will not necessarily lead to two completely different results, because the spectral blue-light hazard weighting function $B(\lambda)$ has relatively low values in the region of 300 nm – 400 nm, as they range from 0,01 for 300 nm to 0,1 for 400 nm. However, differences in the evaluation results may arise for a lamp, which has a strong spectrum in the UVA region close to the visible part of the spectrum. Xenon lamps and especially UVA-LEDs are examples. The same applies for the parameter retinal thermal hazard, where the CIE standard regards a 20 nm wider wavelength range then the ANSI/IESNA standard.

One of the most apparent differences between the IESNA and the other standards can be found in the retinal thermal weak visual stimulus parameter. The IESNA standard does not take the burn hazard spectral weighting function $R(\lambda)$ into account for this photobiological parameter. It seems that this is a misprint in the IESNA standard. According to IESNA the evaluated IR-spotlight would be assigned to the risk group 3 while it is a lamp of the exempt group according to the CIE standard for the retinal thermal weak visual stimulus parameter. This absence of the spectral weighting function makes the ANSI/IESNA standard more (and unnecessarily) conservative for sources where a strong visual stimulus is absent compared with other standards, because for wavelengths from 770 nm to 1400 nm (the wavelength range which is considered for this parameter) the spectral weighting burn hazard function $R(\lambda)$ has values less than 1.

The ANSI/IESNA Standard allows a higher radiant exposure for the thermal hazard of the skin compared to other standards. Figure 6 below shows the differences between the standards for the skin thermal hazard parameter. All standards give the same threshold limit value for an exposure duration of 1 s, but the ANSI/IESNA standard diverges from the others the shorter or the higher the exposure duration becomes. For an exposure duration of 0,1 s the limit of ANSI/IESNA is 77 % higher and for the maximum exposure of 10 s 25 % higher than the radiant exposure limits of other standards.

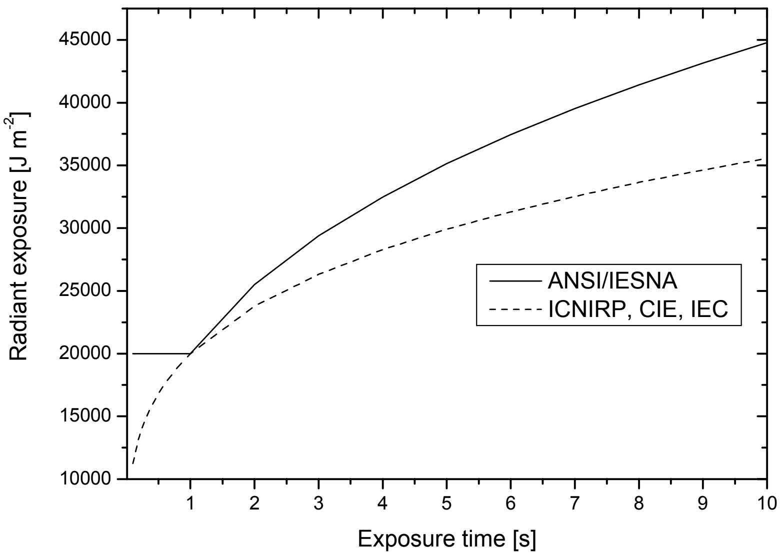

Figure 6. Maximum radiant exposure for the thermal hazard of the skin given by different standards.

A risk group classification according to the ANSI/IESNA Standard for the parameter blue light hazard can lead to different results compared to the risk group classification in the CIE Standard. Both have the same risk group 2 emission limits, but the averaging instrument field of view γ is not the same: According to ANSI/IESNA a field of view of 11 mrad applies for the risk group 2 criteria measurement (risk group 2 time criteria: 0,25 s), while the CIE indicates a field of view of 1,7 mrad. With the smaller field of view hot spots are more likely to be detected than with the larger instrument field of view, and with the CIE measurement conditions higher radiances can result for the same source compared with the ANSI/IESNA setup. A lamp that complies with risk group 2 criteria for blue light hazard according to ANSI/IESNA could be assigned to risk group 3 according to the CIE standard.

The ANSI/IESNA standard indicates an other exempt group emission limit for the blue light small source parameter than the CIE standard. The ANSI/IESNA exempt group emission limit is 0,8 W m^{-2} while the CIE gives an emission limit of 1 W m^{-2} for both the exempt and risk group 1.

A debatable difference between the ANSI/IESNA standard and the CIE Standard can be found in the assumed pupil diameter on which the exposure limit for the retinal thermal hazard parameter is based. ANSI/IESNA has based their exposure limit on a pupil diameter of 7 mm (only for a 10 s exposure a 3 mm pupil is assumed), while the CIE states to have used a 3 mm pupil diameter to derive the exposure limit. It is important to say that both standards give the same retinal thermal exposure limit, which is strange based on the statement about the pupil diameters. There is however a difference in the specified averaging field of view: measurements according to ANSI/IESNA have to be made with a field of view of 11 mrad independent of the exposure duration. The CIE standard uses a 1,7 mrad field of view for times shorter than 0,25 s and for times up to 10 s the field of view has the same time dependent course than given in figure 3. For practice only the 1,7 mrad and 11 mrad field of views are necessary for the risk group classification. For a short exposure the CIE standard is more conservative, as higher radiances can be measured due to the smaller field of view (detection of hot spots).

4.3 ICNIRP Guidelines on Limits of Exposure to Broad-Band Incoherent Optical Radiation

The CIE standard is based on the emission limits given in the ICNIRP guidelines for broad-band incoherent optical radiation, although there are some differences in their features.

For the photobiological hazard parameter ‘eye UV-A’, ICNIRP gives an emission limit expressed as radiant exposure of 10000 J m^{-2} (so does the IEC standard). CIE, ANSI/IESNA and ACGIH specify an exposure limit of 10000 J m^{-2} for times less or equal than 1000 s, and 10 W m^{-2} for times greater than 1000 s. Thus, for example, the CIE emission limit is nearly 29 times greater than the ICNIRP limit for an 8 hour exposure period. The differences in the threshold limit are shown in figure 7 below.

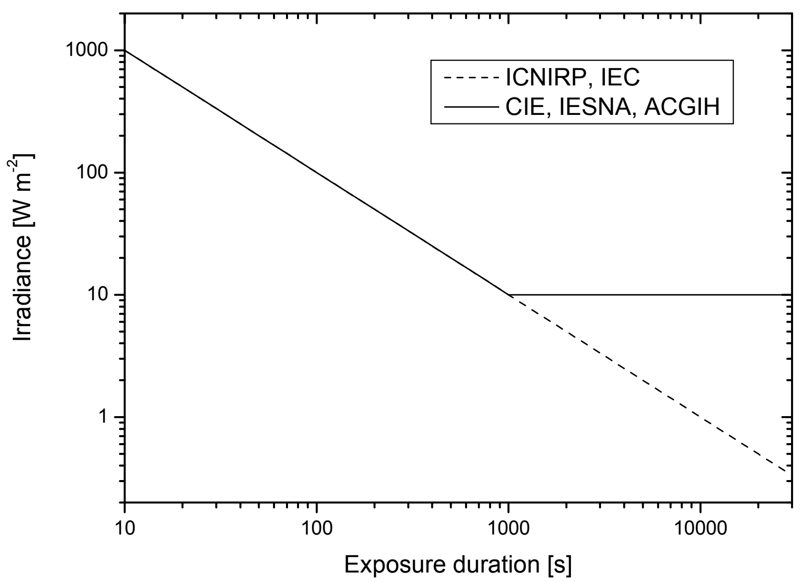

Figure 7. Exposure limits in different standards for the parameter eye UV-A expressed as irradiance.

This long-term limit is not based on experimental data for corneal inflammation but is intended to protect the lens from long-term exposure effects to include both photochemical and a thermal component. The levelling off of the limits given in CIE, IESNA and ACGIH is a committee decision based on risk analysis and make them less conservative (higher) than the higher time base for the additivity and therefore also higher limits for very long exposure durations as specified in the ICNIRP and IEC guidelines.

One other difference of the ICNIRP guideline to the CIE and ANSI/IESNA standard lies in the nature of the documents: while CIE and ANSI/IESNA is a specific standard intended for lamp safety classification, ICNIRP is a broader guideline that, as a consequence, does not give strict specifications for the measurement distance. The ICNIRP standard only offers a framework: The closest measurement distance for worst case situations is given with 10 – 20 cm. However for most lamps a distance of 1 meter would be appropriate up to ICNIRP. It is even possible to base the measurement distance upon considerations of the source luminance and ambient illumination.

The ICNIRP standard is the only standard which indicates a field of view up to 200 mrad for exposure durations of 1000 s and more. Other standards give a maximum field of view of only 100 mrad for long time exposures.

4.4 IEC TR 60825-9

The scope of the technical report IEC TR 60825-9 as developed by the IEC committee TC76 was to collate the ICNIRP exposure limits and to clarify measurement related issues. The IEC technical report on compilation of maximum permissible exposure to incoherent optical radiation differs from the other standards (such as the ICNIRP guideline) concerning the exposure limit for the UV-A exposition of the eye lens. The differences are shown in figure 6 above.

A noticeable difference of the IEC technical report is the time dependence of the angular subtense α of the source for times between 0,7 and 10 s. This seems to be inconsistent with all other standards, as they only indicate a time dependence of the instrument field of view γ. This seems to be a misprint and the instrument field of view γ is meant instead the angular subtense of the source α.

Generally, the diameter of the measurement aperture is smaller in the IEC standard. According to CIE, ANSI/IESNA and ICNIRP where the diameter of the measurement aperture should be *at least* 7 mm (up to 50 mm allowed according to CIE), this is the *maximum* diameter which is allowed by the IEC. The IEC measurement aperture diameter varies between 1 mm and 7 mm and depends on the exposure duration and if the eye or the skin is exposed to the radiation, which are values which were adopted from the laser safety standard IEC 60825-1 [12]. The dependence of the measurement aperture on the exposure duration and on the exposed medium is unique for broad-band standards and can be found in table 2 of the IEC standard.

Further influence of the laser standard on this broad-band standard can not be dismissed: Beside the diameter of the measurement aperture the correction factor C_5 which is used in this technical report for pulsed sources, is quite the same than in the laser safety standard.

This technical report indicates a standard pupil diameter d_s (7 mm for t < 0,5 s and 3 mm for t > 0,5 s). Depending on the luminance of the visual field the diameter of the eye pupil varies. The IEC document contains a formula for the calculation of the real pupil diameter d_p in dependence of the luminance and finally to adjust the maximum permissible exposure in relation to the standard pupil diameter d_s.

Concerning the measurement distance the IEC is not as restrictive as CIE or ANSI/IESNA although it should be noted that, just as the original ICNIRP guidelines, the IEC technical report is not intended to be a product safety standard. The minimum distance for the exposure of the eye in the wavelength range of 380 nm to 1400 nm, of the measurement aperture to the apparent source should correspond to the minimum distance of intended use. However, it should not be less than 100 mm. Generally measurements should be made at points where human access is expected under reasonably foreseeable exposure conditions as determined by a risk assessment.

The determination of the source size α varies between CIE and IEC. In the CIE standard the determination of α requires the determination of the 50 % emission points of the source. Using the IEC method for sources with circular symmetry the diameter of the aperture is reduced until the power passing through the aperture is equal to 63 % of the total power. The same source therefore would be characterised to have a different source size, whether α is determined by the CIE or IEC method. This difference leads to two slightly different threshold limit values for the retinal thermal hazard parameter as α is indicated as denominator of the emission limit. In figure 8 the differences in the retinal thermal hazard exposure limit between IEC and CIE are shown.

The IEC standard indicates the MPE-values for the eye for exposures between 10^{-9} and 30000 s. The short exposure duration down to 1 ns is derived again from the laser standard. The minimum instrument field of view differs to other standards too, as it is given in the IEC report with 1,5 mrad (1,7 mrad in other standards).

4.5 ACGIH Threshold Limit Values

The American Conference of Governmental Industrial Hygienists was the first international organization to propose human exposure limits to incoherent optical radiation based upon reference action spectra [13]. The ACGIH, being a guideline for exposure limits in the workplace and not product emission standard, do not give precisely defined measurement distances. Unfortunately, they do not specify the instrument field of view γ. Also the guidelines do not contain a threshold limit value for the thermal exposure of the skin. The other threshold limit values are in good accordance with the emission limits of the ANSI/IESNA standard.

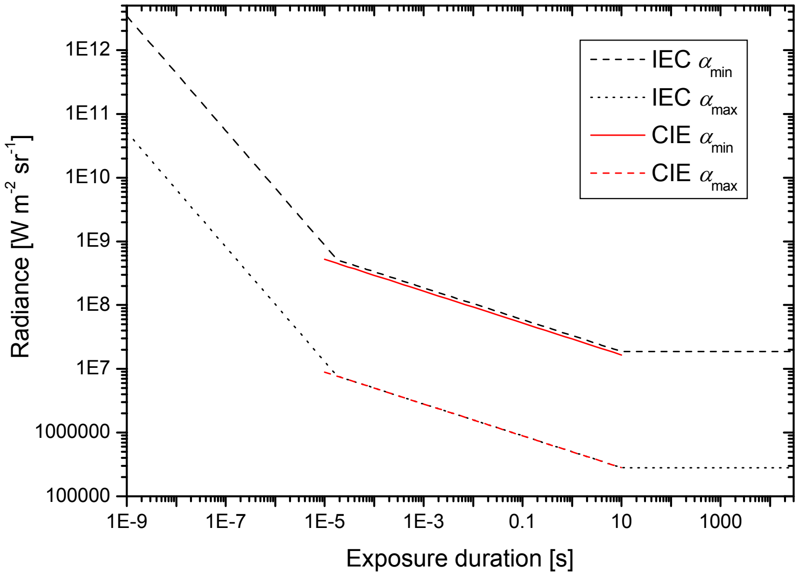

Figure 8. Retinal thermal hazard emission limits according to IEC and CIE given for the minimum (IEC: 1,5 mrad; CIE: 1,7 mrad) and maximum (100 mrad for both standards) angular subtense α of a source.

5. CONCLUSION

The CIE lamp safety standard was applied to evaluate the potential photobiological hazards of a number of specialised lamps. The standard distinguishes between lamps for daily use, low illuminance sources and special lamps, defining different measurement distances for these groups. The dependence of the irradiated area of the retina on the exposure duration is considered in the standard by an increasing averaging FOV with increasing exposure duration. With the application of the standard on three types of special lamps it was shown that the risk group classification is a good basis to characterise the photobiological hazard presented by those lamps.

The theoretical comparison of five documents that were identified to contain broad-band radiation exposure limits points out some differences in the standards concerning the measurement setup, the emission limits and some other additional parameters (e.g. pupil size). In practise, some of these differences are only minor while in special cases the differences can lead to controversial evaluation results when evaluating a lamp according to different standards. This was shown by the evaluation of the infrared spotlight according to CIE and ANSI/IESNA for the retinal thermal low luminance parameter. While some differences seem to be due to typographical errors or oversights, others reflect a different approach to risk analysis or are due to the varying dates of publication where some biophysical parameters such as eye movements were studied to a greater detail only recently and the recent publications could take account of that.

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Authors: Marko Weber, Karl Schulmeister

Affiliation
ARC Seibersdorf research, Health Physics Division
A-2444 Seibersdorf
Phone +43 50550 2535
Fax +43 50550 2502
e-mail: marko.weber@arcs.ac.at