Update on Revisions of Standards for Photobiological Safety of Lamps

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1

Standards Used for Assessing the Potential Optical Hazards of Lamps

- ANSI/IESNA RP-27.1-15 (general concepts)
  RP-27.2-00 (measurements)
  RP-27.3-16 (lamp risk groups)
- CIE S 009/E:2002 (extended-source lamps; based on three earlier IESNA RP-27 series)
- IEC 60825-1 (for lasers, but can be used for SLD "point-source" assessments)

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2

Potential Optical Radiation Hazards of Lamp Products

- Photobiological hazards from artificial sources (lamps, including LEDs) – if they exist at all, are from lengthy exposures.
  - Laser injuries from acute, momentary exposures
    - Thermal injuries
    - Skin burns from infrared, retinal burns (400-1400 nm)
  - Lamp injuries from lengthy exposures
    - Ultraviolet hazards from UV-B leakage (or UVGI)
    - Blue-light hazard – Photomaculopathy, which requires forceful staring at the source, overcoming aversion response

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Laser Safety and Lamp Safety Standards: A Problem of Philosophical Approach

- CIE now working alone without IEC TC76 JTC
- IEC TC76 worked first on lasers – not lamps.
  - Many engineers who first approach lamp safety standards have already worked with laser safety standards, and this can pose a problem
    - Underlying approach for lamp safety is that most lamps are safe (and intended for viewing)
    - Underlying approach for laser safety is that most lasers are hazardous unless enclosed.

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A Key Point about the Photobiological Safety of Lamps

- Most lasers pose a potential hazard!
  - Generally only a thermal hazard from a momentary exposure within hazard distance.
- Almost all lamps are safe!
  - Generally it is the short-wave ultraviolet (UV-B and UV-A) that poses a potential photochemical hazard from lengthy exposures
  - Time-Weighted-Average (TWA) Exposure can be controversial in standards committee.

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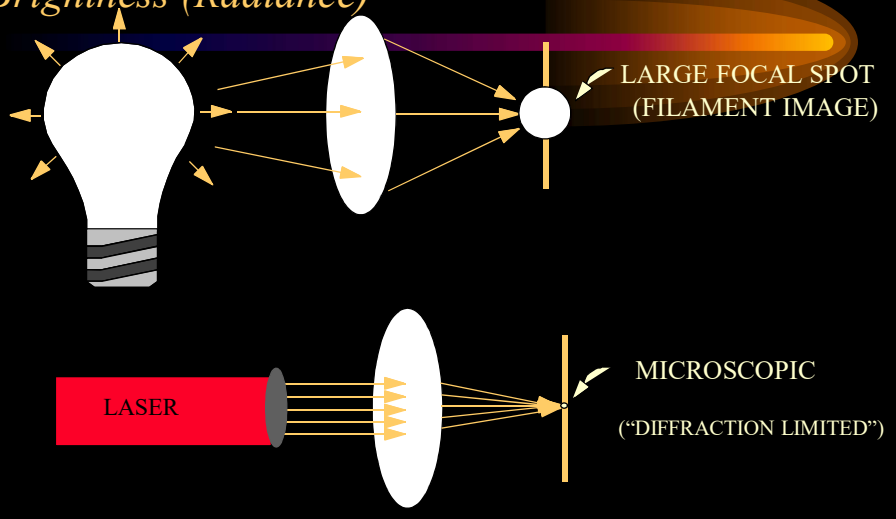
5

Conventional and solid-state lamps (LEDs) are radiance limited and incoherent MPEs are given in terms of **radiance**

Lasers are much more hazardous because of Brightness (Radiance)



From Sliney DH and Trokel, S, 1993

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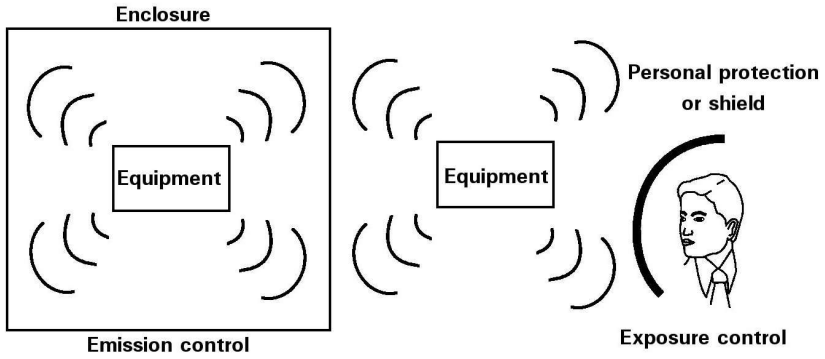
1992

6

Remember:
Product Safety Standards Control *Emissions* (AELs),
but
Occupational Safety Standards Control *Exposures* (MPEs)



NOTE that laser Class 1 and 2 AELs are based upon the MPEs

And Lamp RG AELs are based on MPEs for different durations at realistic exposure/viewing distances and differing skin & eye distance

DHS 7

7

Different Measurements – Laser ouput power/energy – Lamp spectroradiometry

- **For a laser, only the hazards at one wavelength of interest are reflected in the MPE, and competing hazard mechanisms lead to, at most, *two limits, known as"dual limits."***
- **With broad-band lamp sources, at least *five* different potential hazards must be assessed (in UV, VIS, IR)**
- **Except for Retinal Thermal, all are for lengthy exposures (minutes to hours) – causing almost endless debates as to TWA for application**

DHS 8

8

Tabulating the Limits – Radiance (400 nm – 1400 nm)

- Laser limits are expressed as corneal *irradiance* ($W \cdot cm^{-2}$) and *radiant exposure* ($J \cdot cm^{-2}$), and broad-band limits as *radiance* ($W \cdot cm^{-2} \cdot sr^{-1}$) limits to protect the retina.
- Some laser limits may be easier to apply to a non-laser, monochromatic point-source, such as super-luminescent diodes and OFCS fiber tips, and incoherent source limits to some large-source laser displays.

DHS 9

9

Progress? Updates of the IES & CIE standards for photobiological safety of lamps and lamp systems

- Both the IESNA (ANSI) and international (CIE) standards have been undergoing a tortuous revision process in the past few years.
- IESNA/ANSI RP-27-3 standard for risk group classification of lamps was published in 2017 with new guidance on risk-assessment distances
- CIE Standard S009 (also IEC 62471) has been revised to a nearly final draft with significant changes from the 1st Edn., 2002.
  - Extensive delays due to disagreements on what spectroradiometric measurement distances should be set and what guidance on measurements should be in this basic international standard.
  - In reality few people are ever positioned (exposed) over an average day at distances less than a meter; however, for good UV signal-to-noise ratios, the earlier editions recommended a 20-cm reference measurement distance.
- Added problems relate to a widespread misunderstanding of the actual, very low risks of most of the photobiological risk groups.
  - Some groups want "zero risk," for day-long exposure at "point-blank" range!
  - Some European groups want only RG-0 as if "ionizing radiation!"

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10

Why the big problems in CIE JTC?

- Confusing laser safety experience as relevant to lamps – IEC TR 62471-2 drafted in IECTC76.
  - Introduces erroneous concept of "hazard distance"
  - Suggested unprecedented labels for non-hazardous lamps in RG-1 and RG-2!
  - Inadequate presentation of time-weighted average
  - Led to over-reaction of lamp hazards – particularly in the European Community
- CIE D2 wanted detailed measurement guidance and uncertainty discussions in S009/IEC62471-1

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11

Required Measurement Data

- Initially: broad-band measurements to assure that rigorous, spectroradiometric measurements are not required, or…
- Spectroradiometric Information
  - Spectral Radiant Power Distribution
  - Spectral Irradiance
  - Spectral Radiance over FOV (γ) of 11 or 100 mrad
- Source Size
- Reference Measurement Distance (20 cm default)

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12

Emission Limits for Risk Groups of Continuous Wave Lamps-2002

Risk	Action Spectrum	Symbol	Emission Limits			Units
			Exempt	Low Risk	Mod Risk	
Actinic UV	$S(\lambda)$	E_s	0.001	0.003	0.03	W/m^2
Near UV		E_{UVA}	10	33	100	W/m^2
Blue Light	$B(\lambda)$	L_B	100	10000	4000000	$W/(m^2 \cdot sr)$
Blue Light, small source	$B(\lambda)$	E_B	1.0*	1.0	400	W/m^2
Retinal Thermal	$R(\lambda)$	L_R	28000/α	28000/α	71000/α	$W/(m^2 \cdot sr)$
Retinal Thermal, weak visual stimulus**	$R(\lambda)$	L_{IR}	6000/α	6000/α	6000/α	$W/(m^2 \cdot sr)$
IR Radiation, Eye		E_{IR}	100	570	3200	W/m^2

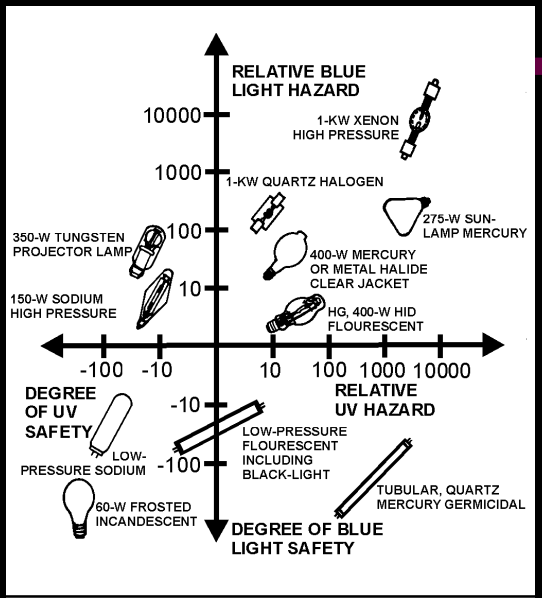
* Small source defined as one with a < 0.011 radian. Averaging field of view at 10000 s is 0.1 radian.

** Involves evaluation of non-GLS source

21-Feb-06 CIE S009:2002 13

13

Which UV and Blue-Light Hazards?



- Retinal thermal injuries common with lasers, but almost unknown from lamps.
- Only a magnified image of an arc lamp can possibly have the radiance sufficient to produe a retinal burn!
- Retinal thermal hazard evaluation is difficult (Sliney, DH, , 1982)

14

General Lighting Service (GLS) – An Example of Assessment Distance

- In CIE S009 all lamps are measured at one distance, but the RG determination is based upon converting to a 500 lux illumination (as time-averaged daily exposure)
- Use µW/lm for each of the seven hazards, etc.
- Controversial in Europe!

Lamp frosting and tube diameter traditionally was chosen to reduce luminance to < 1 cd/cm²

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15

Another Issue: The Aversion Response – the reactive pupil

- A rapidly closing pupil is dealt with differently in the two different sets of limits, leading to what appear to be "discontinuities" between pulsed and CW for broad-band retinal hazard limits
  - Laser safety standards emphasize "smooth" functions and employ Class 2 at 0.25 second
  - Lamp safety standards – Risk Group 2.
- Take-home message, RG-0, RG-2, RG-3 are "safe" for BLH in all reasonably foreseeable general use!!

DHS 16

16

Assessment Distance – Normally is *not* the Measurement Distance!

- Big issue for Non-GLS lamps
- Assessment distance for **products** is normally much greater than the 20-cm measurement distance (e.g., 1-2 m for products)
- Based on **Time-Weighted Average** Exposure in 24 h
- Measurement distance – on good Signal-to-Noise Ratio

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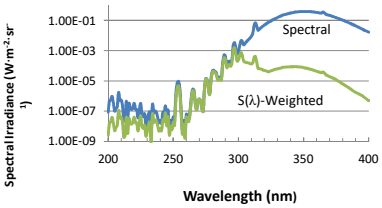
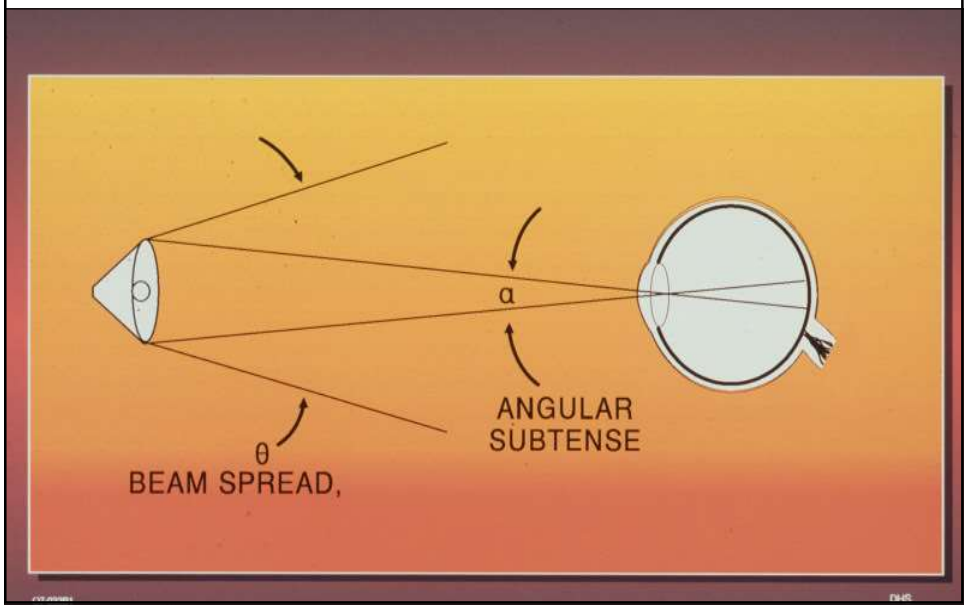
People do not view a lamp at 20 cm for long periods



20-cm Measurement distance reduces stray-light problems

17

One problem of clarification: Measurement angles - Angular subtense of the source is important for retinal hazard evaluations. (Beam spread is different)



18

Principal changes in CIE S009 stimulated by revolution in lighting

- We all known that the introduction of LEDs for general lighting service (GLS) has led to a revolution in lighting; and no UV and IR of note!
- Solid-State Lighting (SSL) offers changes in spectrum for many purposes.
- Circadian disturbances as a side-effect has been widely discussed but will not be introduced, since the "hazard/safety" aspect not relavant (?)

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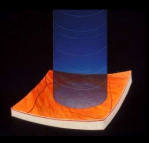
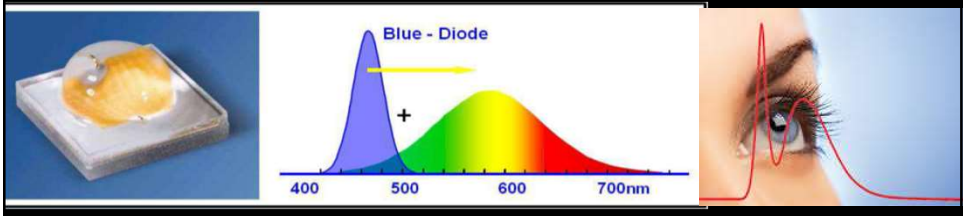
19

The "Blue-Light Hazard Issue from Typical "White-Light" LEDs

A blue-(indigo-) LED Chip pumps a phosphor, with the result that the "white" illumination is a combination of the fundamental chip spectrum superimposed on the yellow fluorescence. No UV or IR to speak of is emitted.





Courtesy Osram

20

LED Chip Arrays – More Light Output, but of no real thermal hazard

21

The Impact of the Sudden Change to LED Solid-State Lighting

- Circadian rhythm disruption, sinceLEDs for general lighting were initially at a very high "color temperature" with a strong blue peak ~ 460 nm.
- No UV emission – good! Or….???
- No IR-A and deep red emission. Implications unknown
- Potential for flicker since current regulated.

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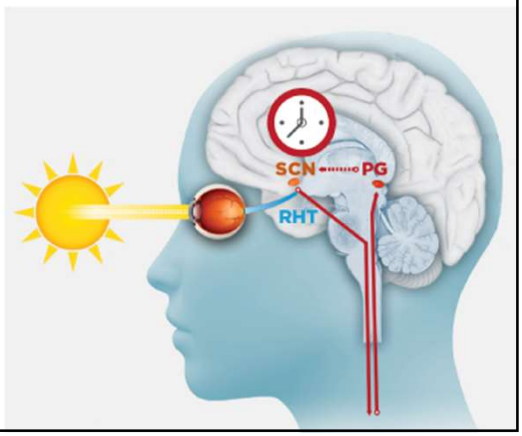
22

ipRGCs – Serve Important roles in Retinal Exposure to Light

- Although ipRGCs have been labeled "non-visual photoreceptors," they play important roles in pupil constriction (improving vision) and lid elevation (reducing sky glare)!
- The relationship of retinal irradiance to radiance:

  $E_r = 0.27\ L \bullet \tau \bullet d_e^2$

...even if non-imaging



23

Once there was only natural sunlight – or fire (including candles and oil lamps

- But today – and over the last century – electrically powered lamps have dominated our nights in developed countries.
- Since the 1880s – incandescent (red-rich) lamps

- Since the 1950s – fluorescent (green-rich) la
  - - at least in office and commercial settings

- Since the 2010s – Solid-state lighting (SSL) – - --- primarily (blue-rich) LEDs

- NOTE: The ever-increasing color temperature of light sources!

24

•Questions?

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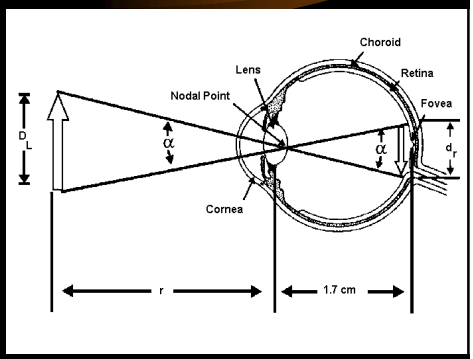
25

Calculating Retinal Irradiance —for extended sources: Radiance L

- The retinal irradiance E_r is:
- $E_r = 0.27\ L \cdot \tau \cdot d_e^{\,2}$
  - where L is the radiance of the source viewed
    - in units of $W \cdot cm^{-2} \cdot sr^{-1}$
  - τ is the transmittance of the ocular media
  - d_e is the pupillary diameter in cm
- Retinal Irradiance depends upon Source RADIANCE



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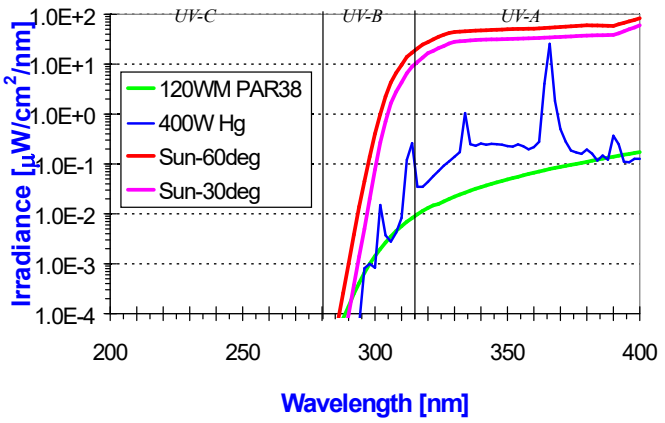
26

UV Spectral Irradiance of Sun compared with Incandescent and HID lamps at 1000 lux



From R. Bergman

27

Standards Activities and LEDs
Optical Radiation Safety Standards

- Several national and international standard groups, but internationally
  - International Commission on Non-Ionizing Radiation Protection (www.ICNIRP.org)
  - CIE S009/IEC62471 for lamps but IEC 60825-Lasers
- In the USA
  - American Conference of Governmental Industrial Hygienists (ACGIH) – Threshold Limit Values (TLVs)
  - Illuminating Engineering Society of North America

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28

Quick Measurement of Radiance:

my preferred method

- Materials and equipment
  - Irradiance meter
  - 2.2-mm aperture and mm ruler > 300 mm
  - Digital camera with manual focus and adjustable f/#, plus neutral-density D4-5 filter
    (Note: It is important to find a digital camera that sees IR-A)
- Method: Darken the room, photograph the source size with light on and with rule
- Measure irradiance at 200 mm with 2.2-mm aperture in front of the source

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29

Annex – A special Photobiolgical Hazard

Ophthalmic Instruments

- So what is the impact of:
  - Standards Activities
  - Changing Exposure Guidelines
  - New light sources such as LEDs

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30

ISO 172/SC7/WG6

- ISO 15004-2006 now up for revision
- New efforts to amend the Operating Microscope Standard and remove requirement for measurement, but the manufacturer must provide a worst-case safe exposure duration
- ISO 15752 Endoilluminators issued

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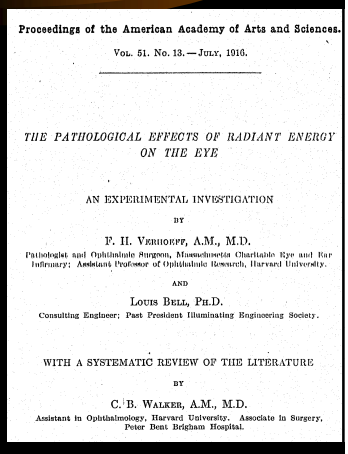
31

Optical Safety of Lamps– not New!

- Optical safety an issue in 1900:
- Widmark, 1889; Birch-Hirschfeld, 1912; Verhoef & Bell, 1916
- Lamp envelope size
- Minimize thermal-burn hazard
- UV photokeratitis risks (arcs)
- Verhoeff and Bell, 1916 (185pages)
  - "…no more dangerous than steam radiators"

D Sliney 2006



Proceedings of the American Academy of Arts and Sciences.

Vol. 51. No. 13. — July, 1916.

THE PATHOLOGICAL EFFECTS OF RADIANT ENERGY ON THE EYE

AN EXPERIMENTAL INVESTIGATION

BY

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WITH A SYSTEMATIC REVIEW OF THE LITERATURE

BY

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32