Health Implications of New Lamp Technology

Progress with Lamp Safety Standards

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CIE-Davis, CA,
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Optical Radiation Safety Standards

- Several national and international standard groups
- In the US:
  - ACGIH Threshold Limit Values, UV, lasers, etc.
  - ANSI Z136.1 for lasers with MPEs 0.1 ps -30 ks
  - ANSI RP 27.1 to ANSI RP 27.3 Lamp Safety
- Internationally:
  - International Commission on Non-Ionizing Radiation Protection (www.ICNIRP.org)
  - CIE S009/IEC62471 for lamps but IEC 60825-Lasers

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Current Activities in IESNA Photobiology Committee

- IESNA Photobiology Committee is updating RP-27 series on photobiological safety of lamps and lamp systems
  - RP 27.3 – should it be general or include GLS lamps?
  - RP 27.4 – GLS and luminaires?
  - RP 27.5 – Projectors
  - RP 27.6 – Ultraviolet lamps
  - RP 27.7 – Infrared lamps
- RP 27-1, 2 and 3 should be "horizontal"

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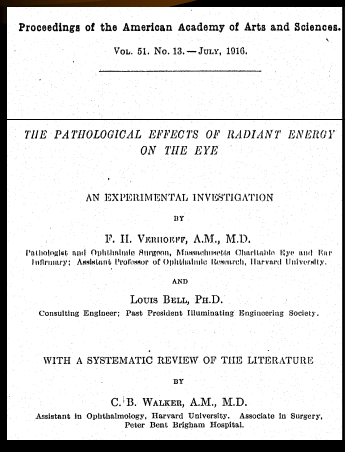
Optical Safety of Lamps– not New!

- 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

F. H. Verhoeff, A.M., M.D.

Pathologist and Ophthalmic Surgeon, Massachusetts Charitable Eye and Ear Infirmary; Assistant Professor of Ophthalmic Research, Harvard University.

AND

Louis Bell, Ph.D.

Consulting Engineer; Past President Illuminating Engineering Society.

WITH A SYSTEMATIC REVIEW OF THE LITERATURE

BY

C. B. Walker, A.M., M.D.

Assistant in Ophthalmology, Harvard University. Associate in Surgery, Peter Bent Brigham Hospital.

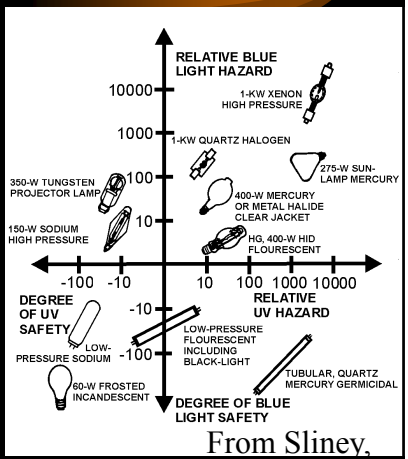
F. H. Verhoeff and Louis Bell, 1916

THE fundamental purpose of this investigation has been to discover what if any pathological effects can be produced upon the structure of the eye by exposure to artificial or natural sources of light. That such action may occur under sufficiently powerful exposure to radiant energy is certain, but the essential fact is the discovery of the quantitative relations between the amount of incident energy and the effects. These relations have generally been left quite out of the reckoning in discussing the subject, with the result of leading to vague and often quite unwarranted conclusions as irrelevant as if one should condemn steam heating as dangerous because one can burn his finger upon a radiator.

Quoted in: Sliney & Wolbarsht, *Safety with Lasers and Other Optical Sources—a Comprehensive Handbook*, New York, Plenum, 1980, 500 pages 2006

UV and Blue-Light Hazards

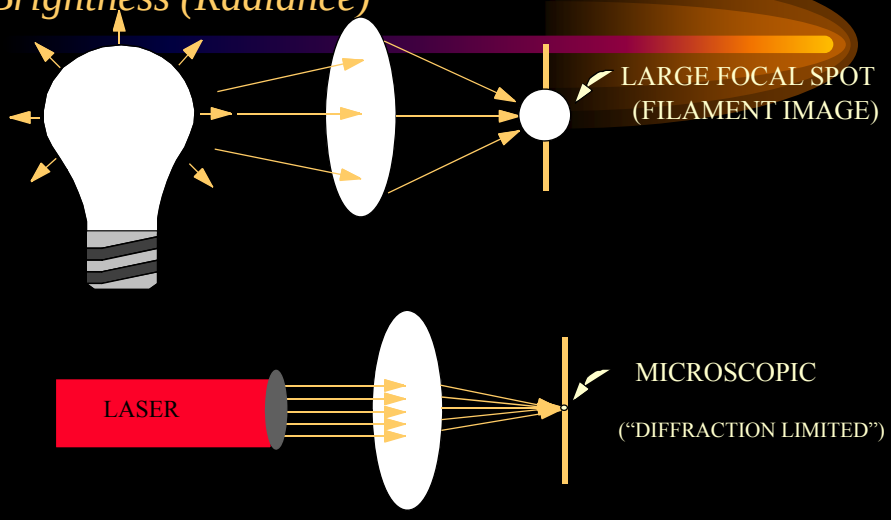
- UV and blue-light phototoxicity are the key potential hazards in lamp safety standards
  - Concerns of chronic exposure
  - Two infrared limits and retinal thermal limits are seldom and issue
- By contrast, laser safety standards are almost always focused on acute thermal effects on retina



From Sliney, Sliney, DH, (1982)

Conventional and solid-state lamps (LEDs) are radiance limited and incoherent MPEs in terms of radiance, but some laser-safety 'experts' want strong safety controls on LEDs!

Lasers are much more hazardous because of Brightness (Radiance)



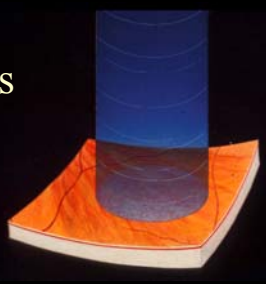
From Sliney DH and Trokel, S, 1993

David.Sliney@att.net

1992

Retinal Safety Standards—Thermal and the Blue-Light Hazard

- Most laser exposures are acute, accidental exposures and result from thermal or thermo-acoustic effects.
- Retinal hazards from lamps and LEDs are primarily from blue light
- Other light-damage mechanisms exist, but not relevant
- New findings point to the need for caution for ophthalmic-instrument exposures!



UVR and blue light are scattered out of the direct image making the yellow-to-red sun safe to view directly at sunset

D Sliney 2006

Emission Limits for Risk Groups of Continuous Wave Lamps

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 10

Why have questions been raised about the safety of SSL?

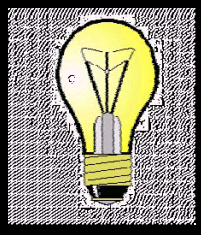

vs


- Do energy-efficient CFL & solid-state lamps have potentially significant health & safety implications?
  - Often shorter-wavelength, cooler spectra…
  - Humans evolved under diurnal (changing) sunlight
  - Artificial sources, fire, later oil lamps, then incandescent lamps, have spectra largely along the Planckian locus—rich in longer wavelengths. Current preference in domestic settings.
  - Use of fluorescent lighting, richer in shorter wavelengths in homes has traditionally been limited ("too harsh" perception in US).
- SSL (not CFLs) – eliminate UV hazard, but lose UV benefits
- Are any concerns about health and safety realistic?

D Sliney 2006

Can Lamp Spectra Be Important?

- *Good-bye incandescent lamp!*



- *Is there any reason why a warm-white spectrum is popular?*

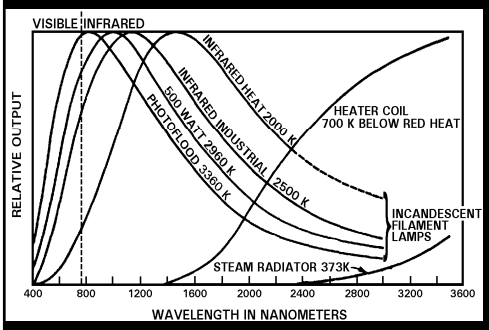
- We have traditionally read the evening newspaper under a tungsten-halogen reading light or dine under dimmed incandescent lamps.
- Are there any new safety issues?
- French ANSES Report of 2010 on LED lighting raises concerns about blue light – Use only RG-1 or below!
- EU Expert Committee* 2012-concern
- US 2013 DoE statement says SSL safe!

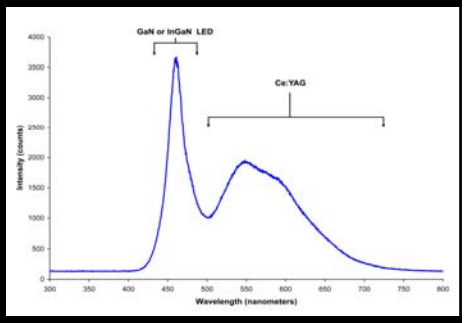
D Sliney 2013 *SCENIHR

Energy Efficiency — the Need to Switch from Planckian Radiators

- From much energy outside the visible…

…to almost all of the energy in the visible





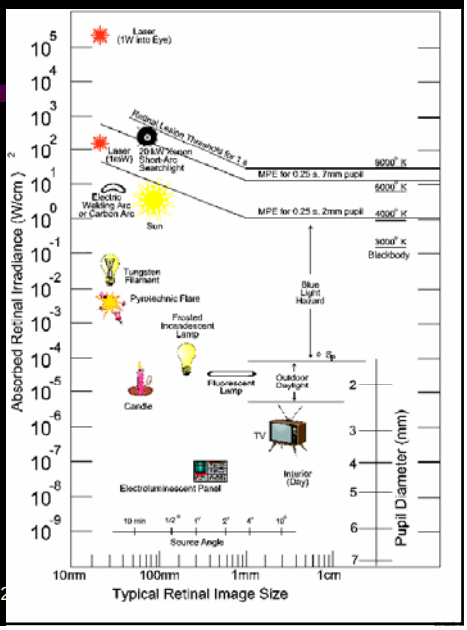
D Sliney 2006

But just how important photo-biologically is a change in spectrum?

- Both the current CFLs and LEDs tend to have cooler (and irregular) spectra.
- Can the effective color temperature tell us?
- Safety can be improved, but…?
- To answer these questions, we must identify the relevant photobiological action spectra.
  - UV and blue-light hazard functions - phototoxicity
  - Circadian effects, other neuro-endocrine effects
  - Recognizing different photoreceptor ganglion cells and neural pathways

Retinal Illumination

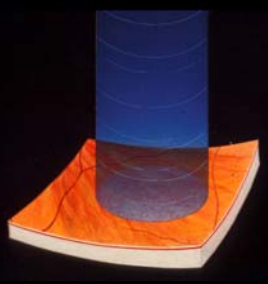
- The ambient outdoor illumination of the retina is of the order of 0.02-0.1 mW/cm^2 (< 1 cd/cm^2 and these levels are just comfortable to view
- Retinal illuminance outdoors is ~ 5x10^5 td
- The sun's image is a million times greater
- But, does sunlight contribute to age-related retinal degeneration?

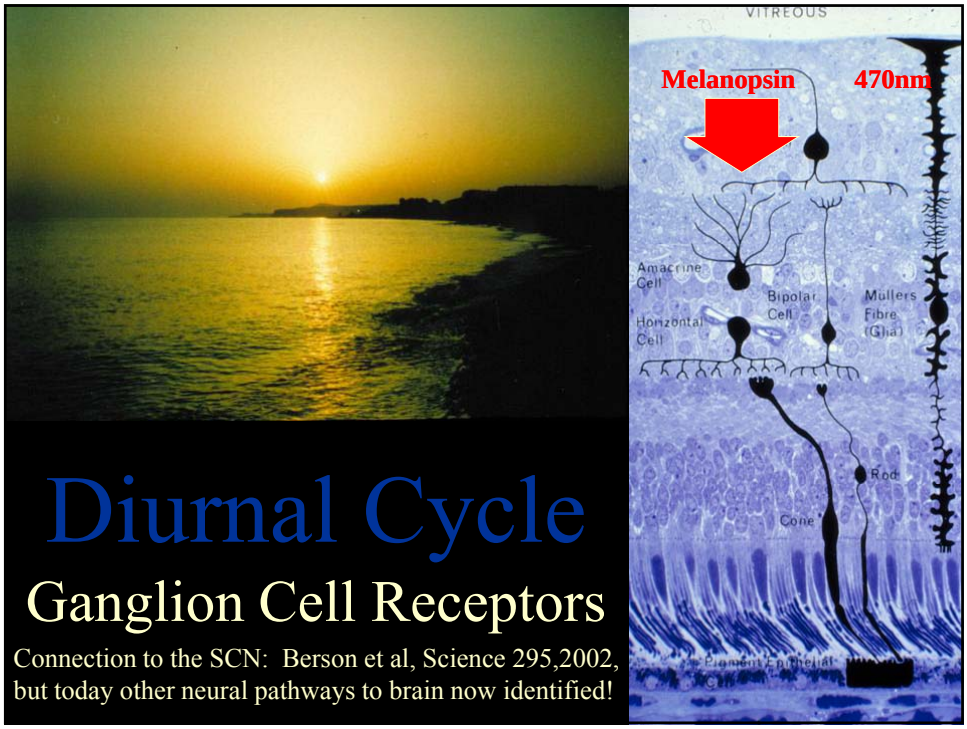


D Sliney 2

Another new concern:
Neuro-endocrine effects?

- Recent studies have confirmed the presence of a newly discovered array of retinal light receptors in the ganglion cell layer of the retina.
- Action-spectrum for the suppression of melatonin secreted by pineal body is in the blue spectrum.





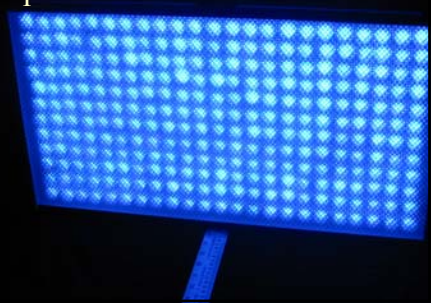
Diurnal Cycle

Ganglion Cell Receptors

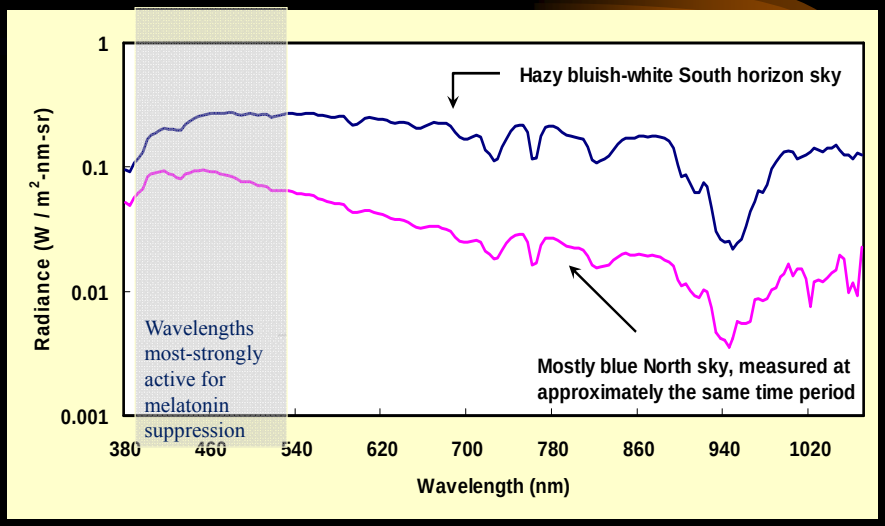
Connection to the SCN: Berson et al, Science 295,2002, but today other neural pathways to brain now identified!

White, or Blue LED Array for Treating Winter Depression

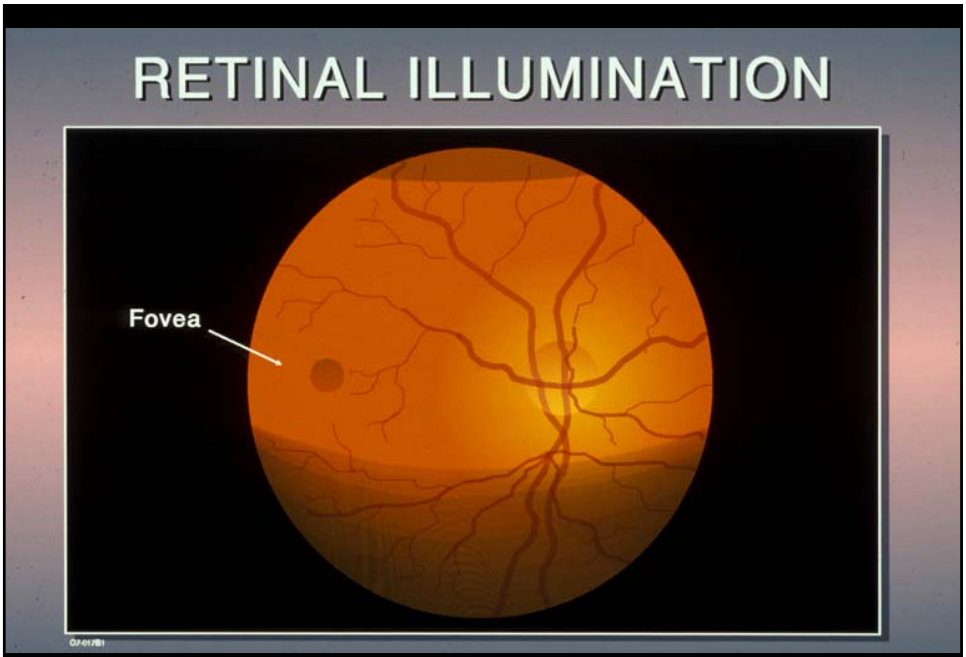
Melatonin-suppression was the first major biomedical research emphasis



At a Given Time, the Radiance of Sky Quadrants Can Vary Significantly



Retinal irradiances from the blue sky are orders of magnitude below light hazard levels



Regardless of ambient light levels, the macula is always exposed

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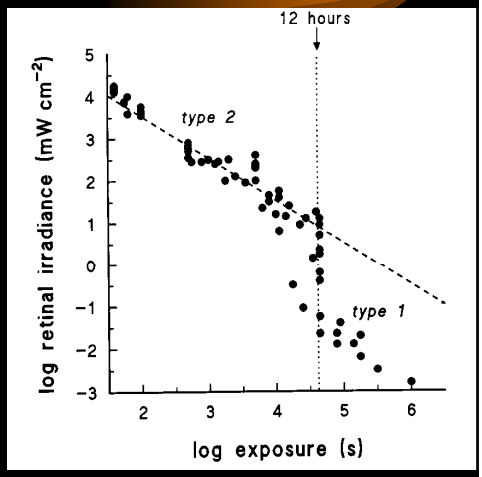
Why have there been concerns about photochemically induced retinal injury?

- At least 2 types of light damage:
- Type 1
  - Noell, 1966—12 h/day
  - rhodopsin, cone opsins
- Type 2
  - Ham, Mueller, Sliney, 1976
  - blue-light chromophore 446
  - Photomaculopathy
  - Only Type 2 considered in lamp safety standards!

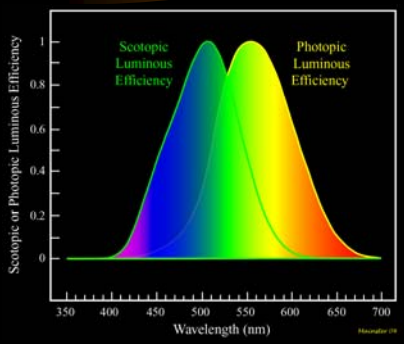


D Sliney 1991

Light Damage of the Retina Type 1

- Results from sustained (+12 h?) photobleaching of retinal photopigments
- Not considered for current lamp safety standards
- Important only for ophthalmic instruments – L_V limits in cd/cm^2

But are these limits also important in general lighting? GLS!?

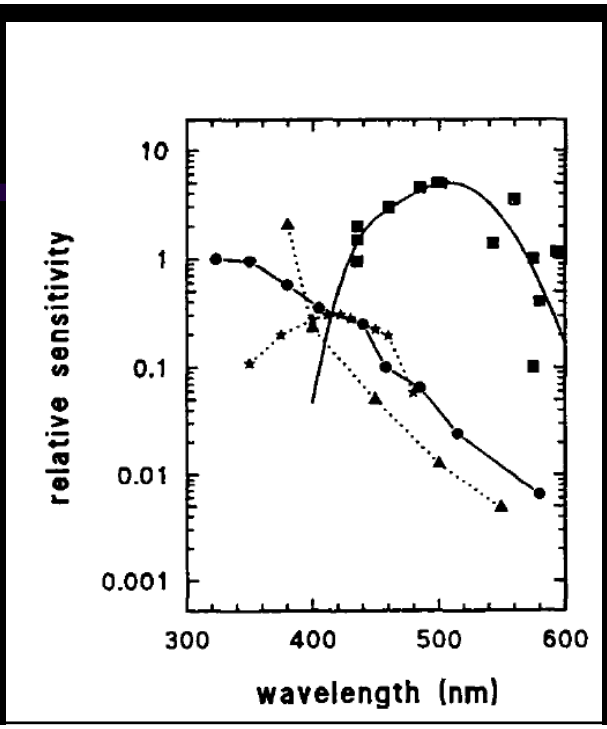


D Sliney 2006

Two Types of Light Damage for the Mammalian Retina:

Type 1 (Noel) resulting from a full-bleach of retinal pigments resulting in toxic build-up of retinal (?) in the Retinal Pigment Epithelium (RPE)

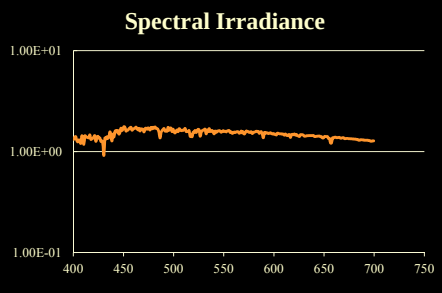
Type 2 (Ham) resulting from phototoxic reaction in RPE—the blue-light hazard



Question 1 (comment):

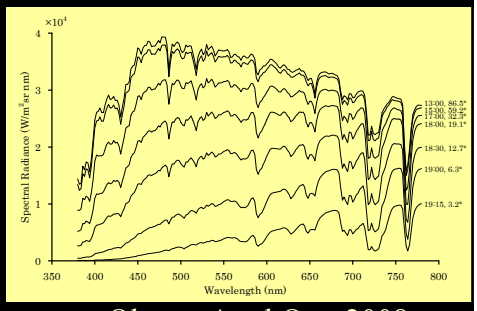
The sun really is not white overhead

- Answer: It is "white" from the standpoint of cone visual response as seen on a proper logarithmic scale for vision.



Wengraitis, 1998 -log

D Sliney 2010



Okuno, Appl Opt, 2008

Photobiological effectiveness depends on…

- **NOT JUST WAVELENGTH!**
  - *but also*

    EXPOSURE DURATION

    SOURCE RADIANCE

    and

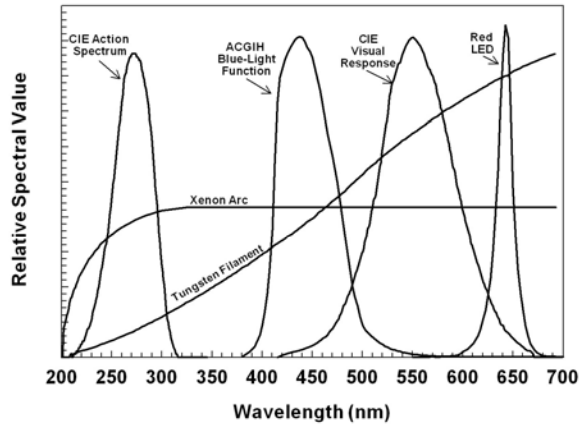
    EXPOSURE GEOMETRY
  - **Lamp safety standards must consider these!**

D Sliney 2006

Spectral Weighting

—the visible light (e.g., CIE lux) does not predict the relative photobiological effectiveness

- LEDs have a very limited spectral emission
- Other lamps have very specific spectral distributions
- Lamp envelope may block UV



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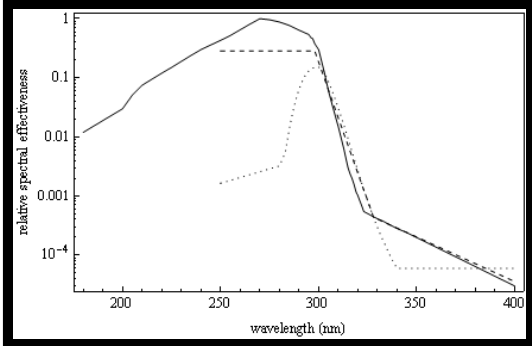
UV Action Spectra Applied in Risk Analyses

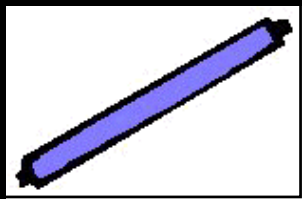


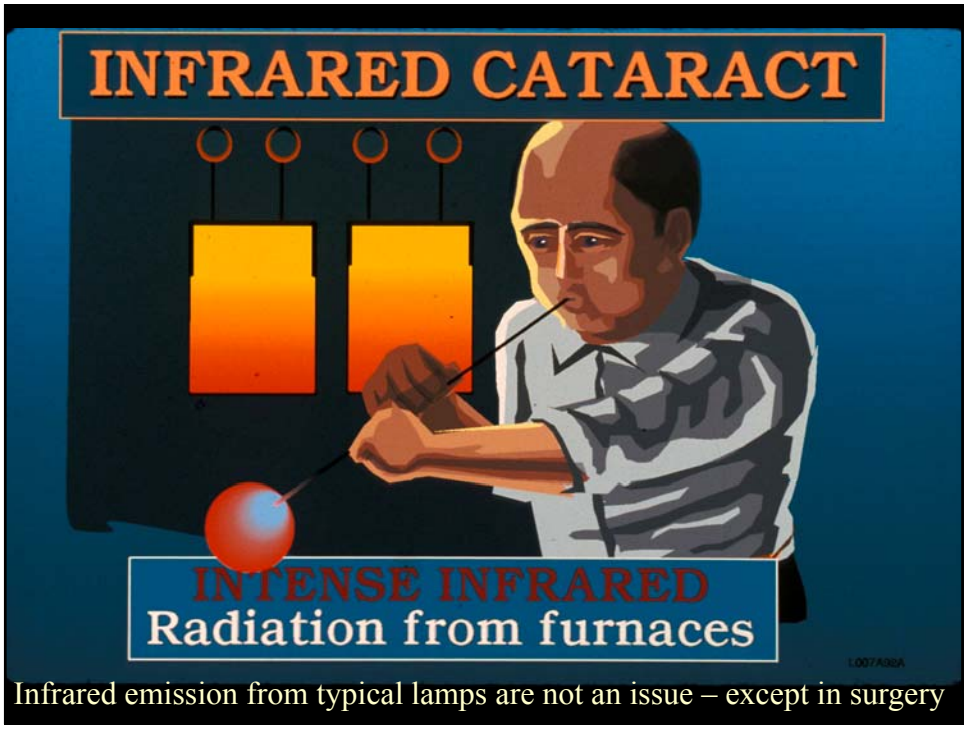
The importance of recognizing that all biologically relate at λ ~300 nm

- 3 UV Action spectra—different at λ < 300 nm:
  - ACGIH/ICNIRP UV S(λ) hazard function, applied in CIE lamp safety stnd. S009
  - CIE standardized erythemal A.S. applied in UV index
  - CIE standardized A.S. for photocarcinogenesis—note low value at 254 nm (UVGI)

Ultraviolet hazards to the eye

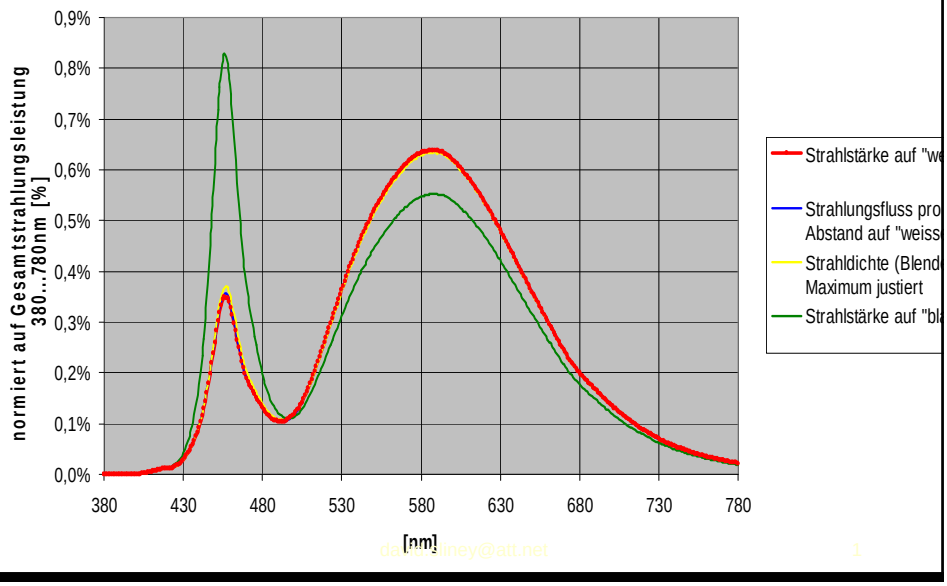
- The eye has evolved under a constant bath of ultraviolet rays from the sun—but the eye is well adapted because of geometry and the avoidance of bright light
- Effect from a single, acute exposure: UV photokeratitis ("snow blindness")
- Effects from chronic exposure:
  - Cataract
  - Pterygium and pinguecula



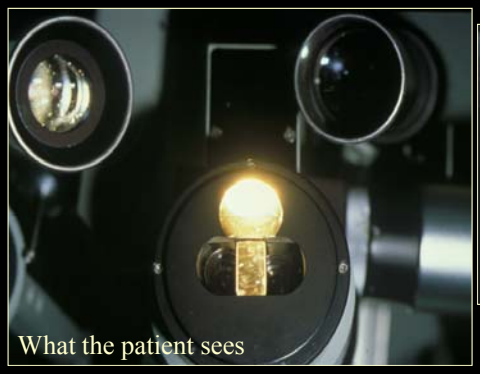


Infrared emission from typical lamps are not an issue – except in surgery

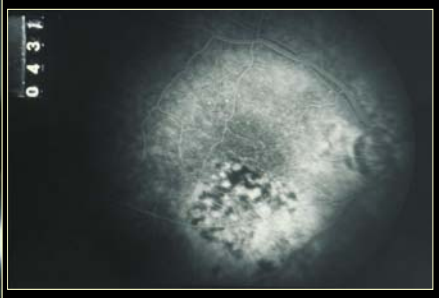
"White" LEDs -- Blue Peak



OPHTHALMIC INSTRUMENT HAZARDS



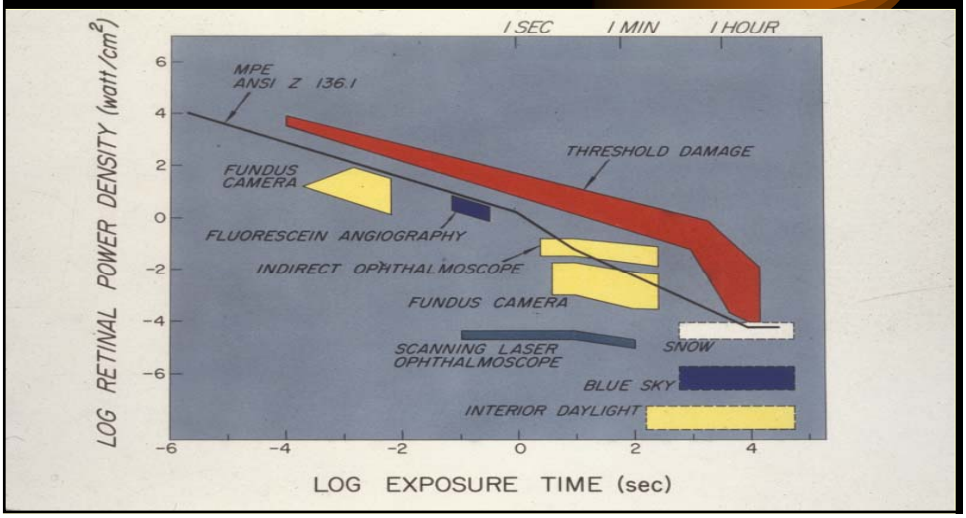
What the patient sees



What the ophthalmologist sees a few days later

D Sliney 1997

An earlier summary of ophthalmic instrument safety—Delori



Diode Projection System

- Lens concentrates (projects) the emission from the LED source into a beam
- Attempt is usually to produce the greatest collimation as possible (within reason)

- Diode projector optics cannot increase the final radiance ("brightness"), only change α

Our Conclusion:

- Mammals (and essentially all plants and animals) evolved under sunlight.
- Sunlight changes with time of day and season (i.e., with the solar zenith angle)
- This spectral shift provides temporal clues to our brain—much of which we are unaware
- We are largely unaware of the change in spectrum because of selective chromatic adaptation of our visual system (i.e., the different cone sensitivities adjust to perceive "white").

D Sliney 2006