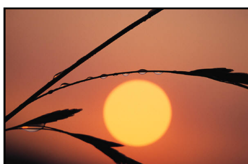
Can We Really Measure Optical Radiation Hazards?

CORM - May 2016

David H. Sliney, Ph.D.
Chairman, Illuminating Engineering Society (IESNA) Photobiology Committee
Consulting Medical Physicist
Fallston, MD, USA

Associate, Department of Environmental Health Sciences
Bloomberg School of Public Health
Johns Hopkins University, Baltimore, MD, USA

Formerly: Manager, Laser/Optical Radiation Program
US A Center for Health Promotion & Preventive Medicine
Aberdeen Proving Ground, MD, USA



The Sun is Good!

- Sunlight is wonderful!
  - ….but sunburns are ***bad***
  - …and skin-cancers are ***bad***
  - …and snowblindness is ***bad***

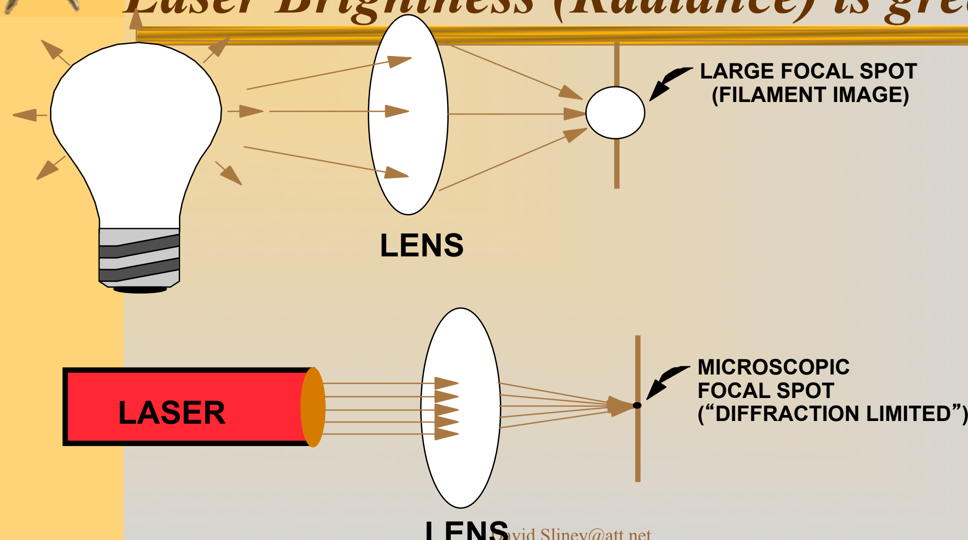
Lasers are Dangerous! Lamps are Safe!

- Lasers are recognized as potentially very hazardous, particularly for the human eye from ***acute, accidental exposures***.
- However, lamps (including LEDs) are almost always completely safe.
  - But there are some hazardous examples – generally UV-B/ C lamps!
  - Chronic, long-term exposures to UV may be of concern

D Sliney 2016

And most importantly, the difference is that lamps and LEDs are radiance limited, but..

Laser Brightness (Radiance) is great



From Sliney DH and Trokel, S, 1993

David.Sliney@att.net

4

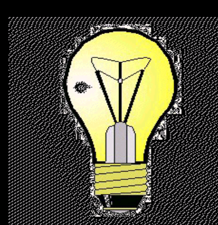
Then why are Lamp (even LED) Safety Issues being raised today?

- Lamps are generally safe. That conclusion comes from over a century of experience. Glare limits exposure durations.
- Acute eye and skin burns are rare except from intense UV lamps (e.g., sunlamps and germicidal UV-C lamps).
- New, energy-reduction lamp technologies, CFLs and LEDs.
- Laser safety standards experts tried to apply laser safety concepts to lamps - acute safety rationale to chronic exposure
- Greater interest of electrical safety test houses to test lamp photobiological safety and the growth of influence of test houses in IEC TC76

D Sliney 2016

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 incandescents
- Are there any new safety issues?
- French ANSES Report of 2010 on LED lighting raises concerns about blue light – Recommended the use of RG-1 or below!
- EU Expert Committee* 2012- a concern
- AMA - *Adverse Health Effects of Nighttime Lighting*
- US 2013 DoE statement and Global Lighting Association report say SSL is safe!

D Sliney 2013

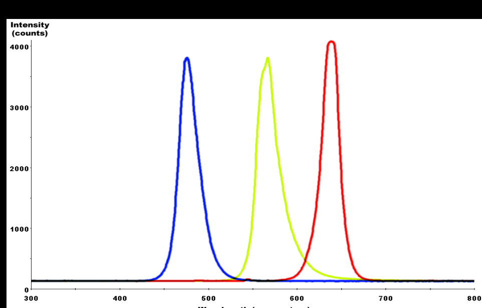
*SCENIHR

Technical Standards Committees
(ANSI, IEC, ISO, IEC)

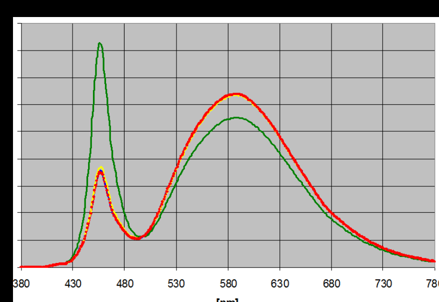
- Typically, committees are industry dominated
- In recent years the testing laboratories have increased their participation – searching for new business? Then, there are consultants!
- The great **leap forward** – Let us test LEDs for safety!!...but how do you know that there are no hazards? Give us something to measure!
- Confusion in the Committee – What hazards can we measure? What **direction(s)** should we move toward? There are many directions – give us directions!

Why in the world would anyone be concerned about…
Two types of "White" LEDs ?

RGB LED – Metamers



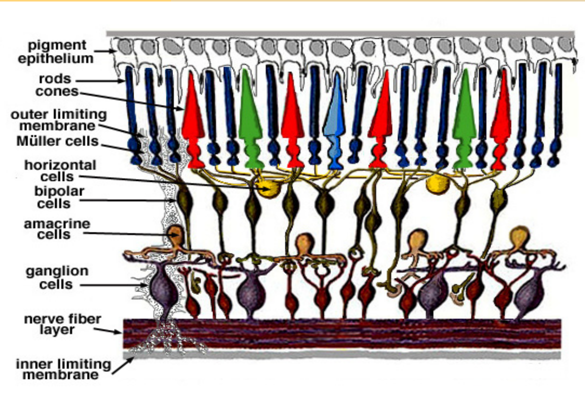
Blue-LED-pumped yellow phosphor, but - is low CCT is preferred?



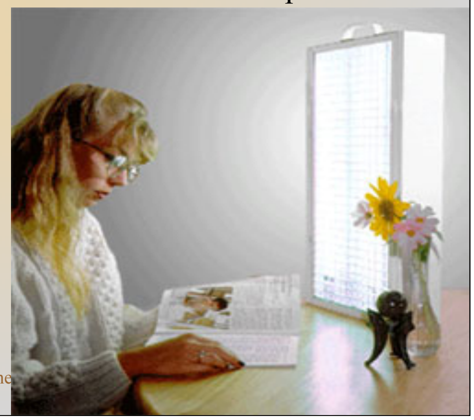
Both have significant spectral power in the blue 470-nm region

Phototherapy of Winter Depression: Photosensitive Retinal Ganglion Cells: How do we measure light at the retina?

Ganglion-cell photoreception—light input for circadian effects



What is the retinal exposure?



So what are the real hazards of excessive exposure to optical radiation? ANSI RP27

- ***Ultraviolet spectrum (180 – 400 nm)***
  - – Corneal (surface) and skin exposure – S(λ) weighting
  - – UV-A hazards – no action spectrum
- ***Visible spectrum (limits within 380-780 nm)***
  - – Retinal photochemical – “the blue-light-hazard”
  - – Retinal thermal – R(λ) weighting (only large arc sources)
- Infrared – (0.78 μm to 3.0 μm), i.e., IR-A & IR-B
  - – IR – Cornea and Lens (long-term, chronic concern)
  - – IR – Retinal thermal, but low visual stimulus (IR-A only)

Basic Measurement Requirements

- Since photobiological hazards are strongly wavelength dependent, we must have at least a spectral power distribution (SPD) or spectral irradiance/radiance
- Thermal effects are far less dependent on wavelength, but we at least need some degree of spectral band distribution
- Safety standards now identify at least 5-6 different biological effects with different wavelength dependence (i.e., different "action spectra") & geometry

Photobiological effectiveness depends on…

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

    EXPOSURE DURATION

    SOURCE RADIANCE

    and

    EXPOSURE GEOMETRY

    Studying sunlight exposure exemplifies these factors!
  - **Lamp safety standards must consider these and TWA!**

D Sliney 2016

How do we know what is a safe exposure?

- Laser limits were based upon laboratory and clinical medical studies of acute exposures – this was relatively straightforward.
- HOWEVER…
- Setting limits to protect about chronic effects is very difficult. There are even questions as to what causes some delayed ocular diseases! We had to analyze chronic sunlight exposures

Environmental Sunlight Exposure and Ocular Health

- Photokeratitis or "snowblindness" (acute)
- Pterygium--strong association
- Cataract—type and onset age are both strongly dependent upon latitude (Sasaki, et al.)
- Labrador keratitis (droplet keratopathy or "spheroidal degeneration of the cornea"): association
- Retinal Effects (?): possible, but only a weak association (if any) shown by epidemiology

D Sliney

Pterygium—Common in Sunny Open Climates

Common in Australia and the tropics…..

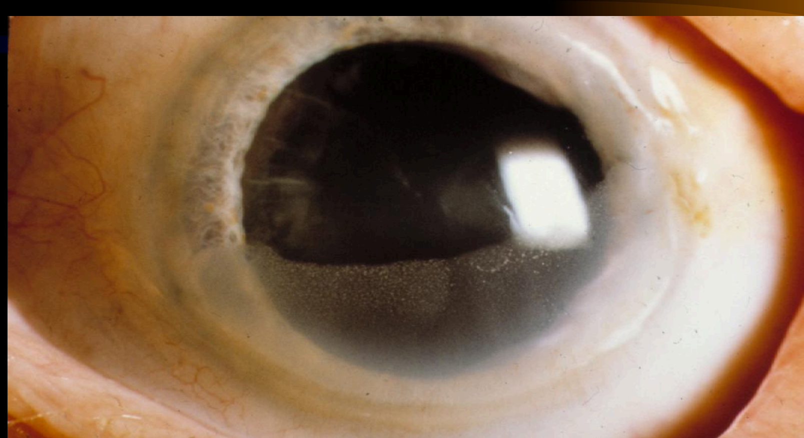
…but much less common in Germany or Eastern Europe.

Can a sunglass standard have the same requirements for all climates?

D Sliney

Labrador Keratitis

(droplet keratopathy, spheroidal degeneration)

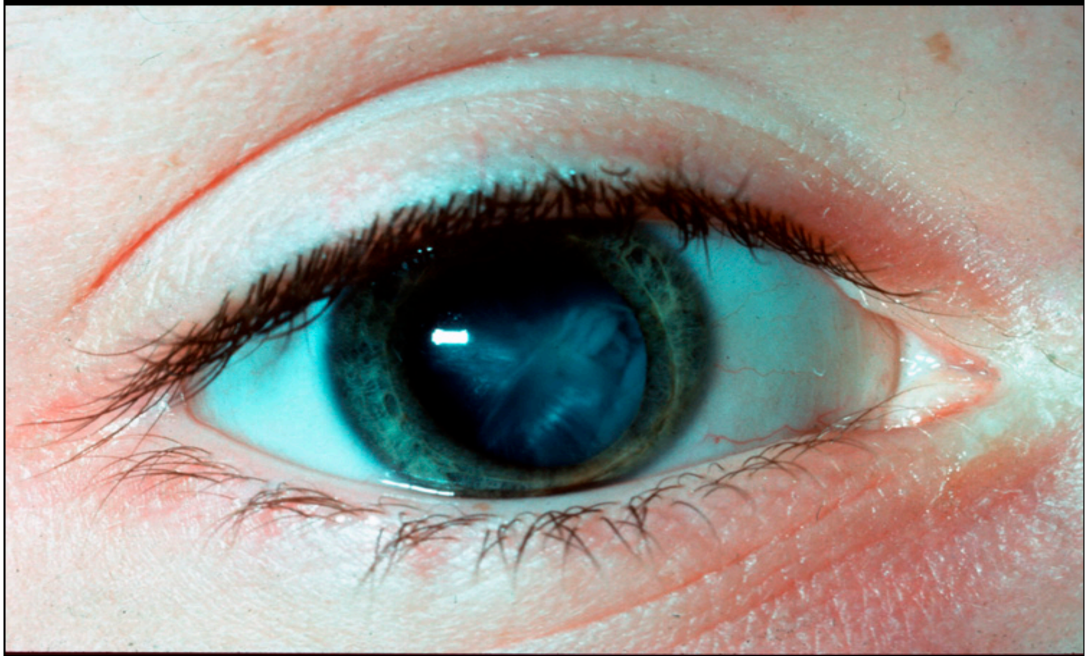


Corneal degeneration found in areas of high ambient reflected UV

ICOH-2006 -Milan

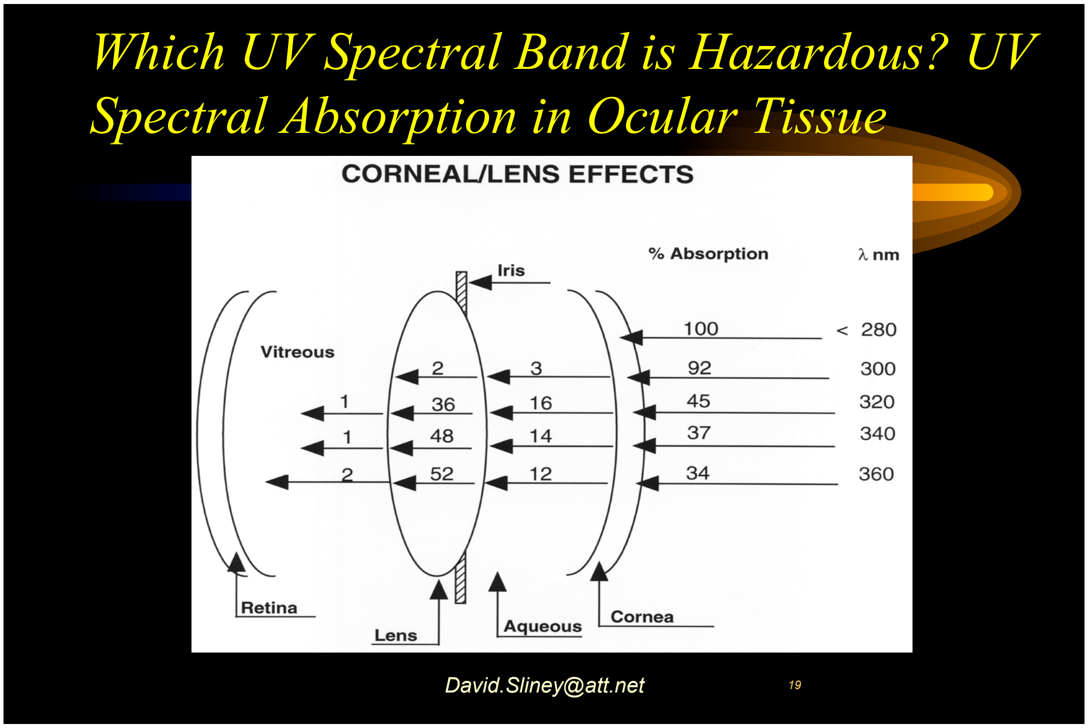
16

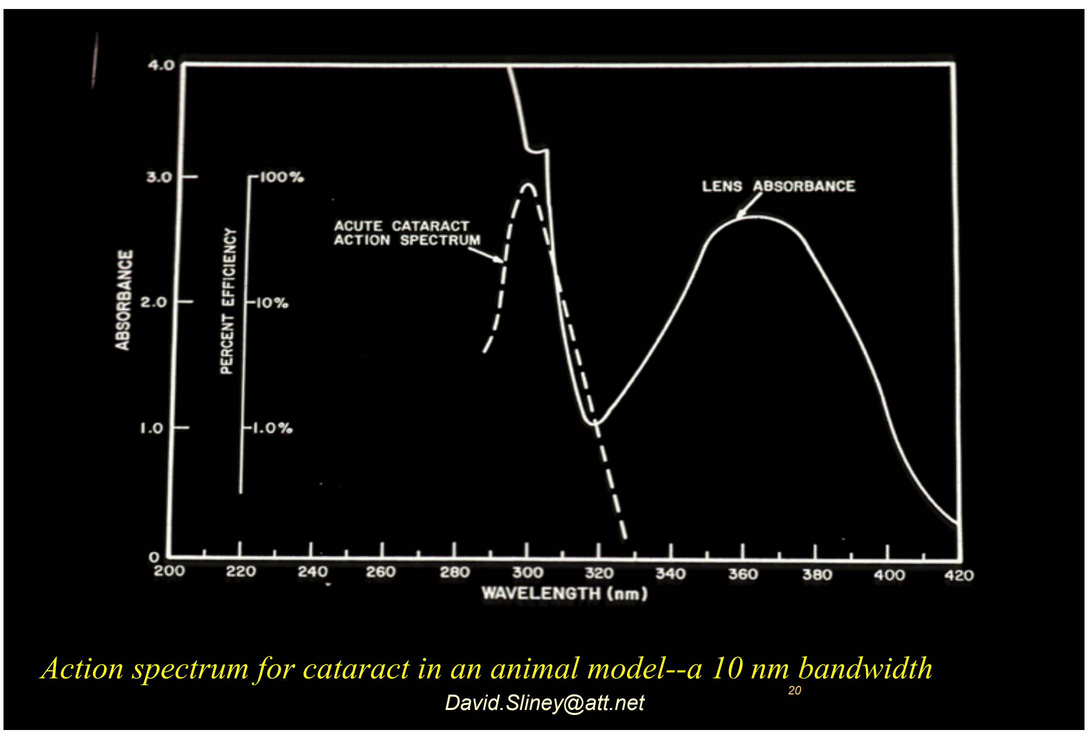
Cataract (lenticular opacity) - normally a delayed effect

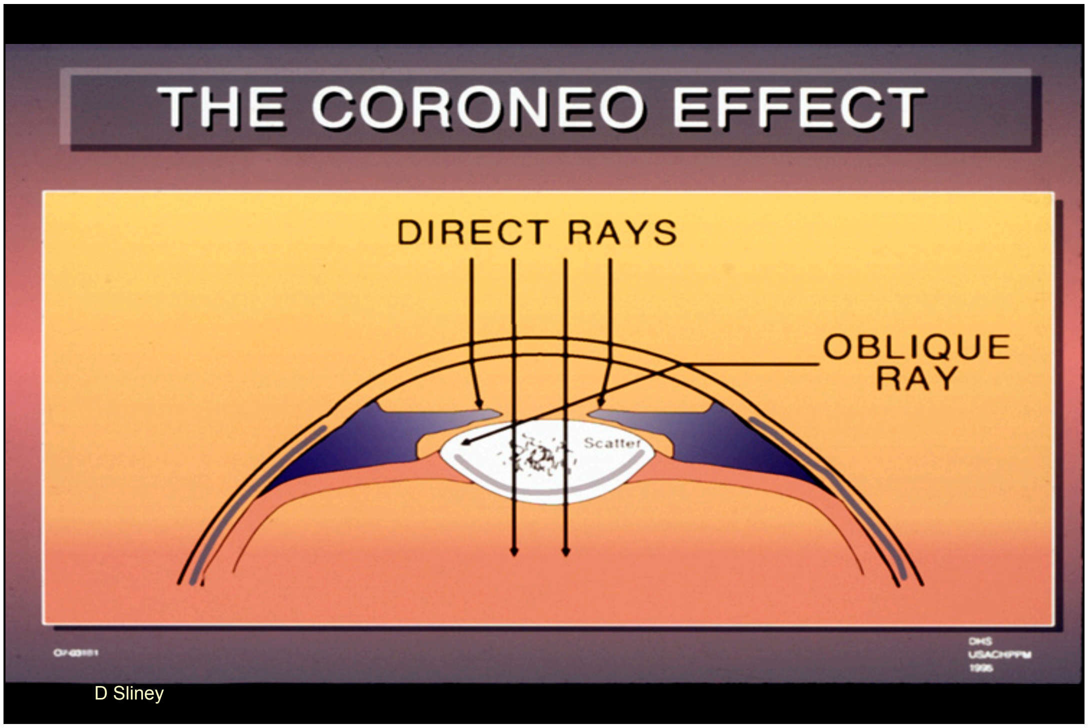


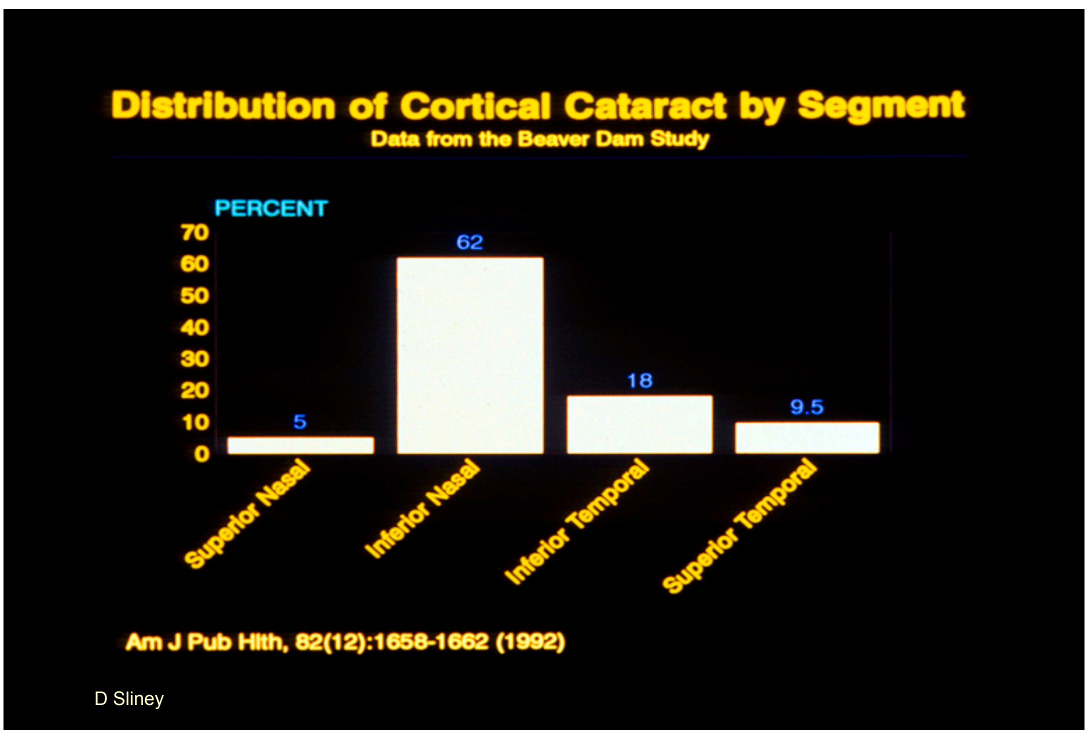
UV and Cataract

- Determination of chronic exposure effects is difficult because of confounding factors
- Epidemiological studies appear to conflict on the role of UVR
- Major problems of studies relate to poor ocular dosimetry (effect of sunglasses)
- Coroneo Effect may be significant

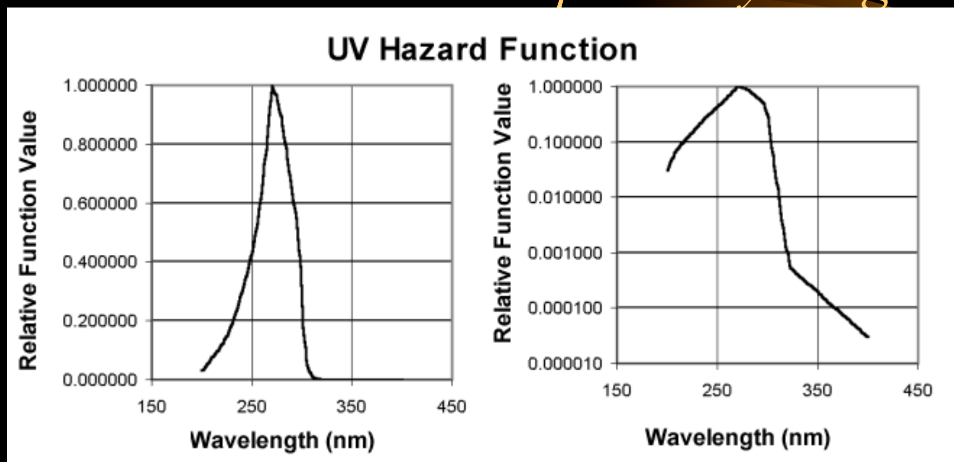

Which UV Spectral Band is Hazardous? UV Spectral Absorption in Ocular Tissue
CORNEAL/LENS EFFECTS
% Absorption
λ nm
Iris
Vitreous
100
< 280
2
3
92
300
1
36
16
45
320
1
48
14
37
340
2
52
12
34
360
Retina
Lens
Aqueous
Cornea
David.Sliney@att.net
19


4.0
3.0
2.0
1.0
0
ABSORBANCE
PERCENT EFFICIENCY
100%
10%
1.0%
ACUTE CATARACT ACTION SPECTRUM
LENS ABSORBANCE
200
220
240
260
280
300
320
340
360
380
400
420
WAVELENGTH (nm)
Action spectrum for cataract in an animal model--a 10 nm bandwidth
David.Sliney@att.net
20


THE CORONEO EFFECT
DIRECT RAYS
OBLIQUE
RAY
Scatter
D Sliney


Distribution of Cortical Cataract by Segment
Data from the Beaver Dam Study
PERCENT
70
60
50
40
30
20
10
0
5
62
18
9.5
Superior Nasal
Inferior Nasal
Inferior Temporal
Superior Temporal
Am J Pub Hlth, 82(12):1658-1662 (1992)
D Sliney

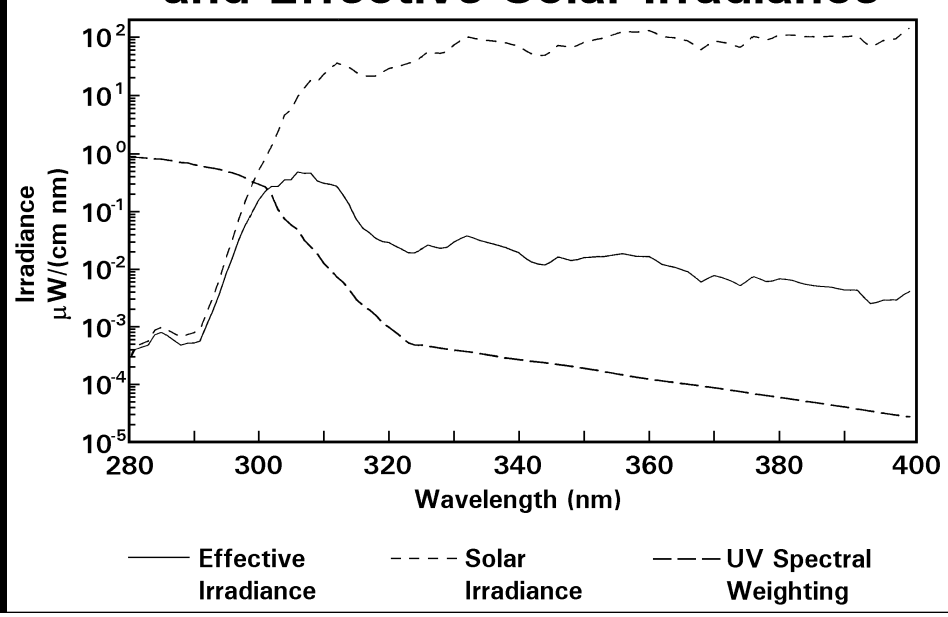
ICNIRP UV Exposure Guideline Limit is 30 J·m^{-2} spectrally weighted



DNA is apparently the most important target molecule for both the eye and skin —only the pre-filtering to DNA changes action spectra

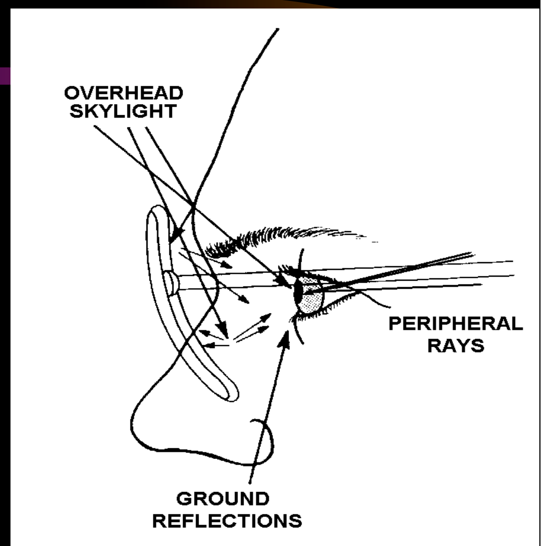
D Sliney

Weighted Solar Irradiance and Effective Solar Irradiance



UV Ocular Exposure with Sunglasses

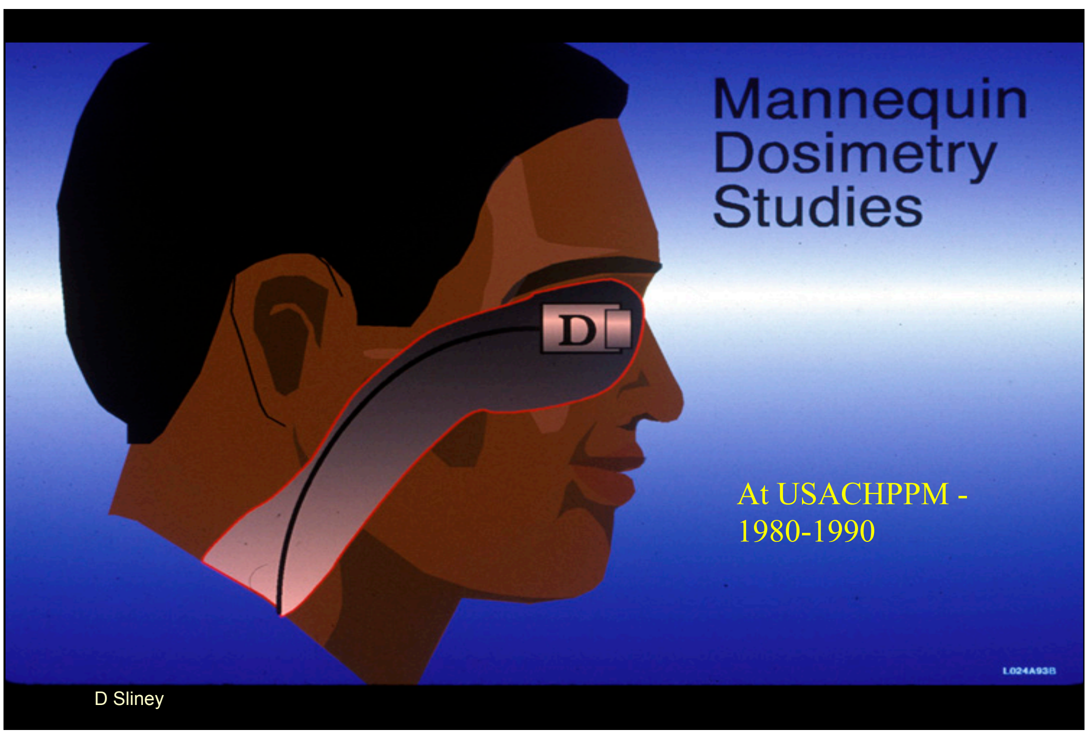
- Solar ultraviolet exposure of the eye cannot be addressed without considering overhead and peripheral exposure
- Rosenthal et al., Sasaki et al, and Sliney, all outfitted mannequins with sunglasses and measured ocular exposure
- At least 20% of ambient reaches the eyes
- Coroneo Effect is also important



D Sliney

D Sliney


D Sliney


Mannequin
Dosimetry
Studies
D
At USACHPPM -
1980-1990
L024A93B
D Sliney

Our Studies of UV Ocular Exposure

- Studies at the US Army Center for Health Promotion and Preventive Medicine (USACHPPM) show substantial exposure of the eyes behind most commercial sunglasses.
- Mannequins with UV detectors as eyes were used to study the exposure from normal and snow-covered terrain with and without different eye protectors
- The best protectors were Inuit (Eskimo) slit goggles from a museum—tenfold better protection that typical commercial sunglasses with "UV blocking" lenses!

Wrap-Around Sunglasses are Best –Smaller Lenses, Limited Protection

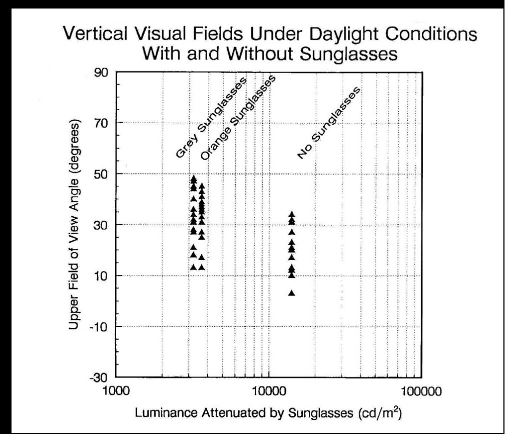
Wrap-around design protects against the Coroneo Effect

What not previously appreciated—the dark lenses allow the lids to open and *increase* the exposure of the critically important DNA in nasal lens cell nuclei!

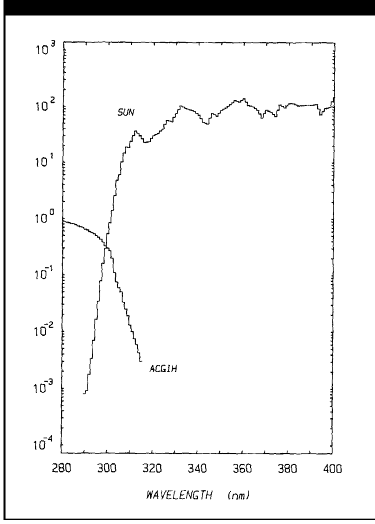
Deaver-Sliney Sunglass Study

- When the upper limit of the field of view (determined by the upper lid position) was measured with and without sunglasses, the lid opened indirectly with the increased luminance of the scene.
- The result: intra-ocular UV dose to the nasal cell nuclei of the crystalline lens doubled when wearing general-purpose lenses!

D Sliney

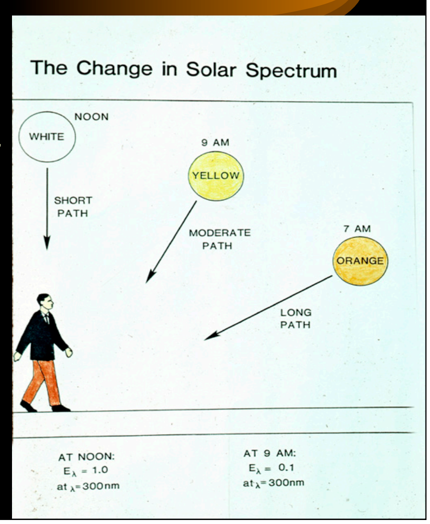


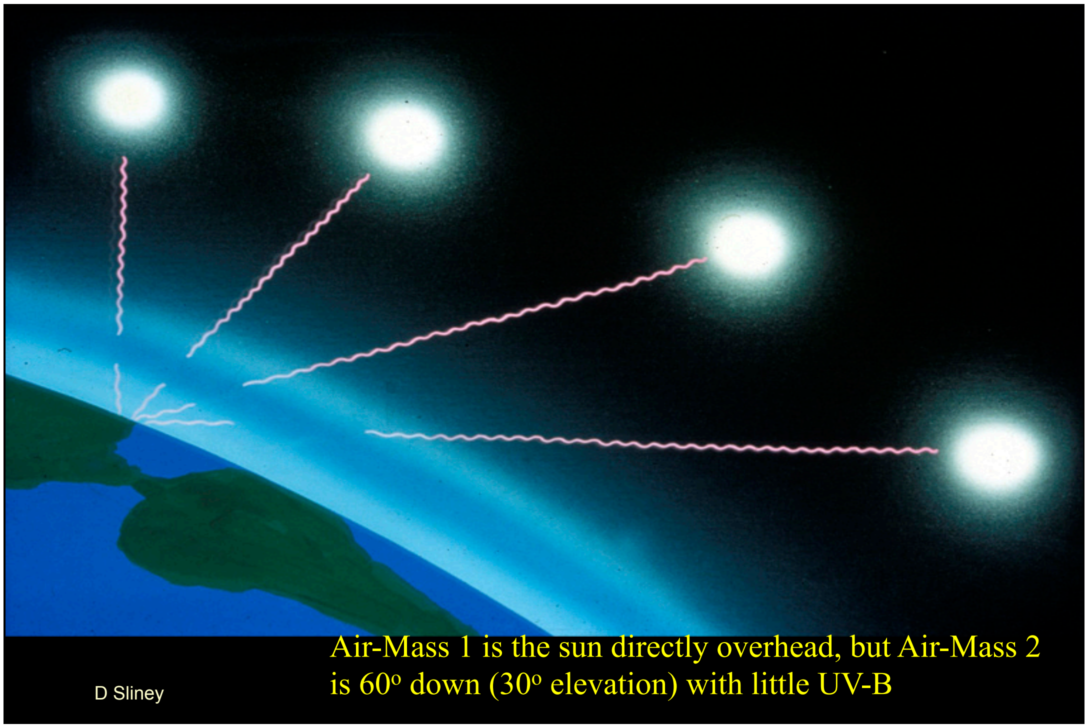
The Spectrum of Sunlight

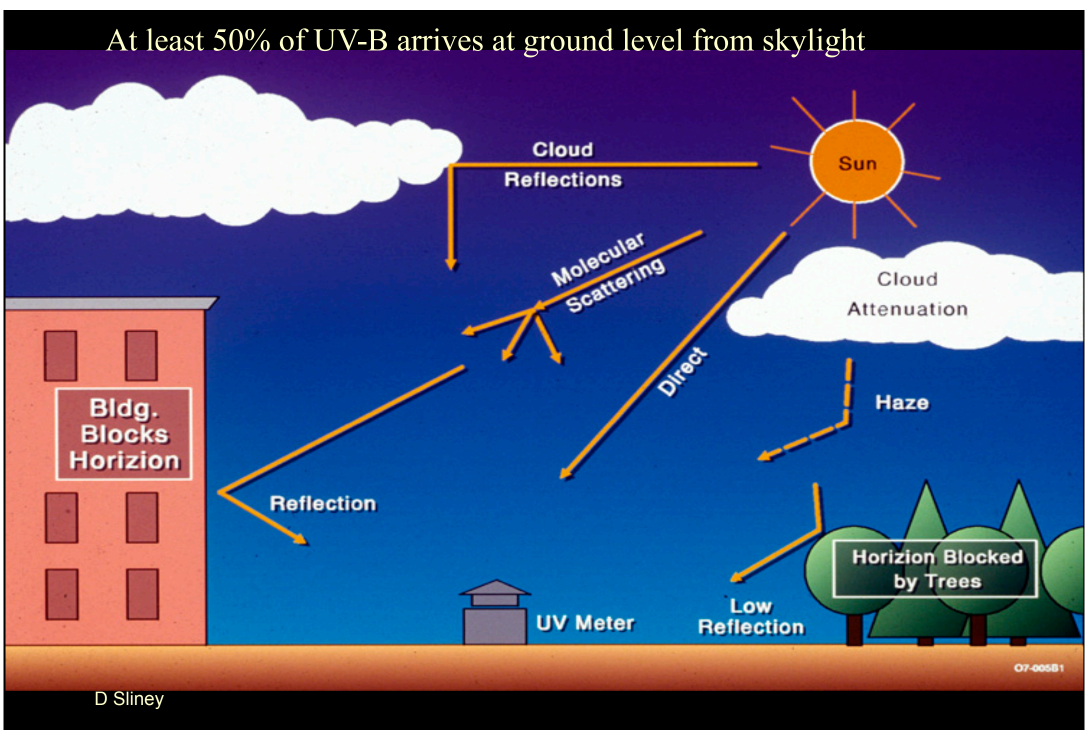


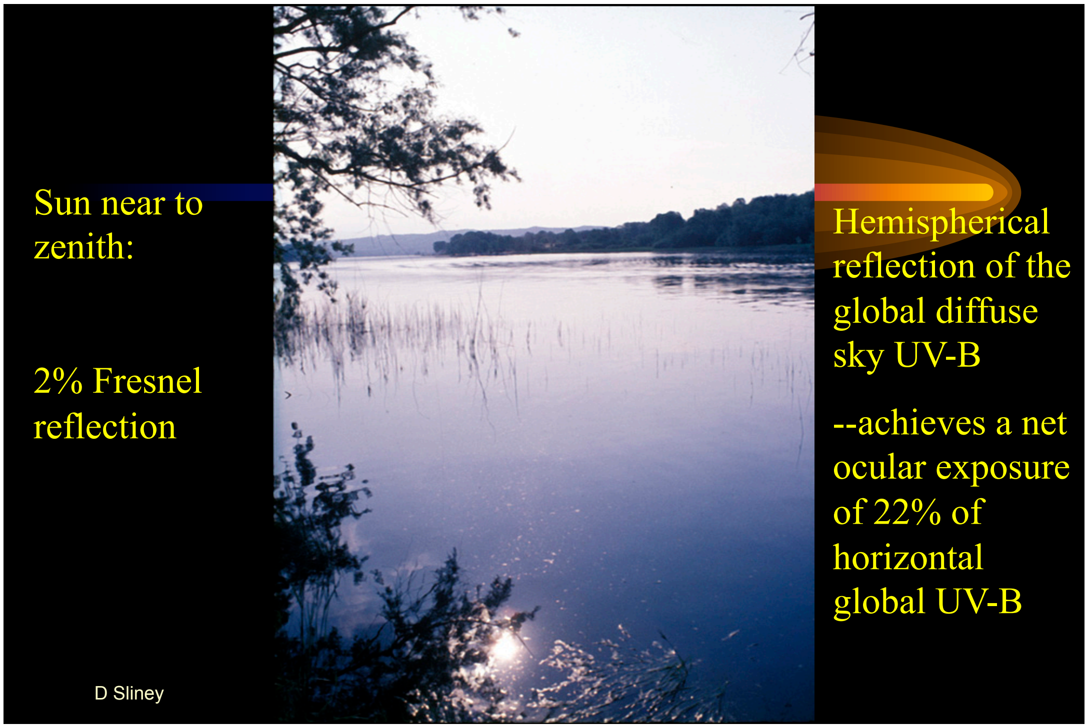
A sunburn is quite possible within 20 minutes in the mid-day summer sun

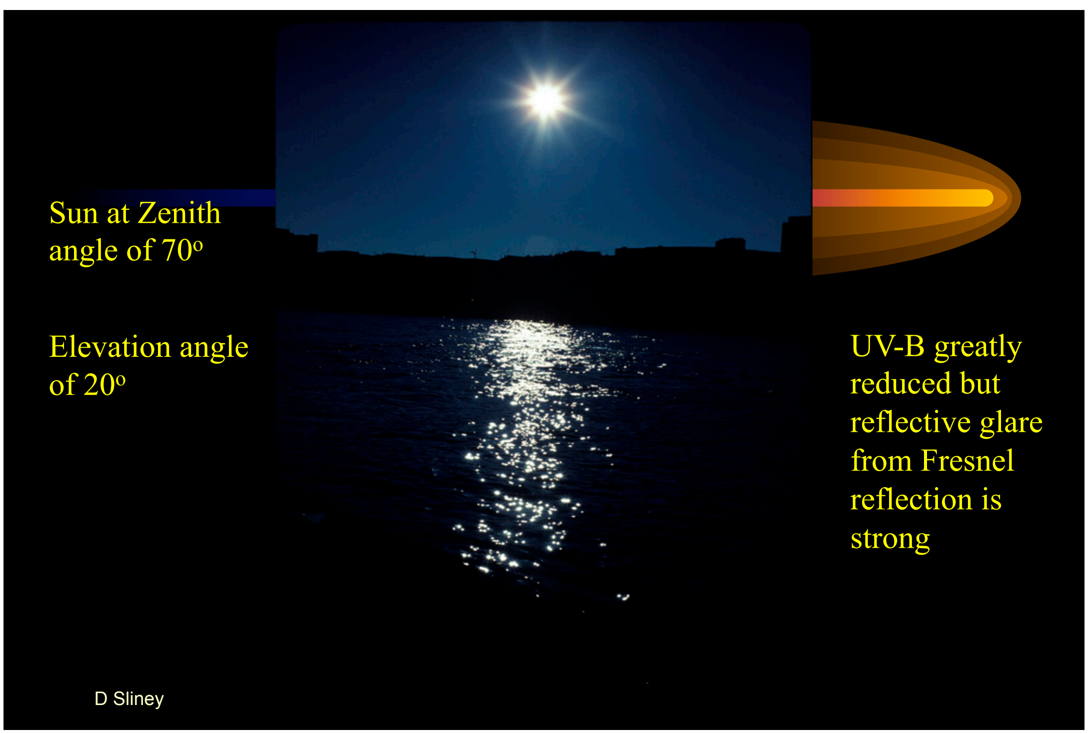
However, one can play golf from 07:00 to 10:00 for 3 hours




Air-Mass 1 is the sun directly overhead, but Air-Mass 2 is 60° down (30° elevation) with little UV-B
D Sliney

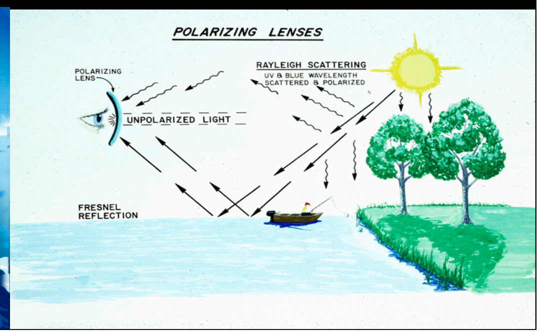

At least 50% of UV-B arrives at ground level from skylight
Cloud Reflections
Sun
Molecular Scattering
Cloud Attenuation
Direct
Haze
Bldg. Blocks Horizion
Reflection
Horizion Blocked by Trees
UV Meter
Low Reflection
O7-005B1
D Sliney


Sun near to zenith:
2% Fresnel reflection
Hemispherical reflection of the global diffuse sky UV-B
--achieves a net ocular exposure of 22% of horizontal global UV-B
D Sliney


Sun at Zenith angle of 70º
Elevation angle of 20º
UV-B greatly reduced but reflective glare from Fresnel reflection is strong
D Sliney

UV Exposures over Water – and Combating Reflective Glare

The UV exposure reflected from water is imaging the entire UV-rich sky. More than 50% of UV-B exposure is from diffuse skylight and not from direct sunlight.



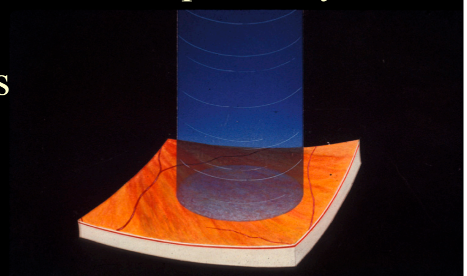
Retinal Safety

At sunrise or sunset the sun is safe to fixate (at least for a couple of minutes)—the atmosphere blocks direct UV and blue light. The atmosphere becomes effectively a safety filter for direct solar observation. Sunglasses are now required only for comfort. Indeed, let us consider retinal exposure…

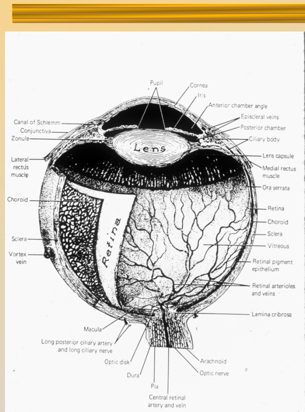
D Sliney

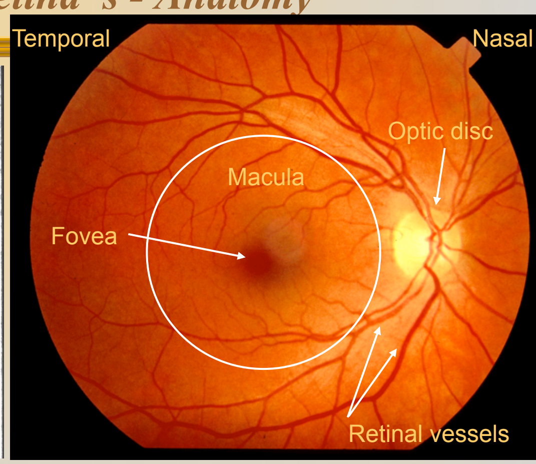
Retinal Safety Standards—Thermal and the Blue-Light Hazard

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



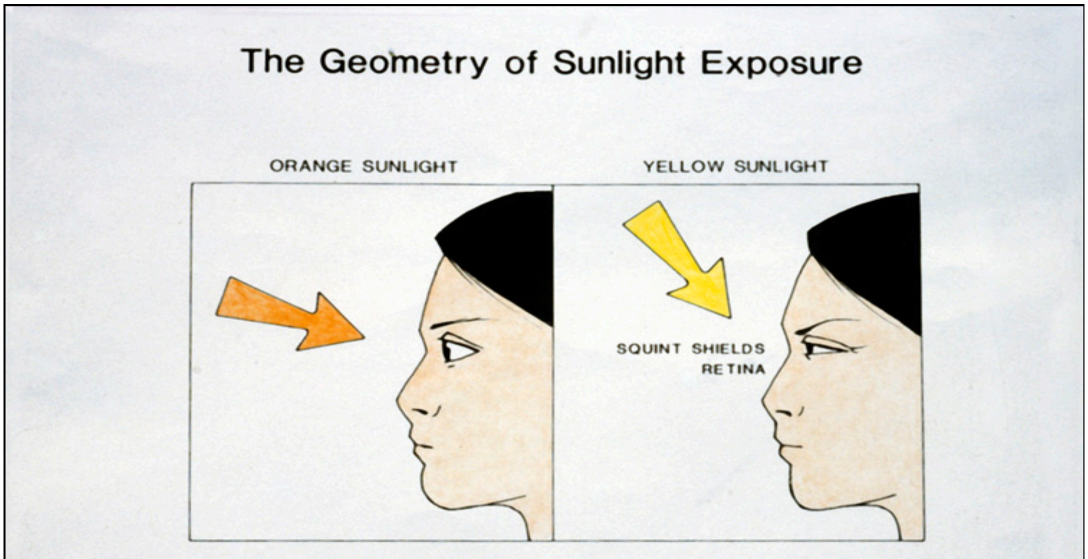
Blue-Light Retinal Phototoxicity is known as photomaculopathy by ophthalmologists. Why the macula? The Retina's - Anatomy





Eye Schematic - Courtesy Dr. Aiello, Massachussetts Eye and Ear, Boston

David.Sliney@att.net



Our natural eye protection

Lid-opening Studies

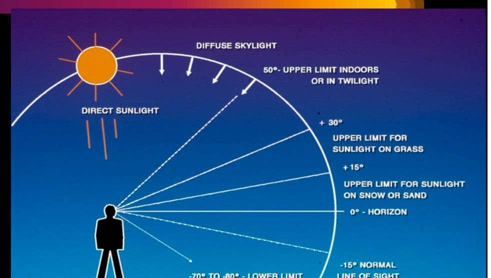
- Deaver and Sliney studied the position of the upper lid as a variation of field luminance during various levels of outdoor daylight

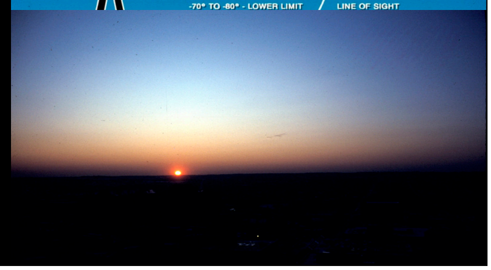
- Lid opening varied with great precision inversely as the luminance in the FOV
- Mathematical expression was developed

D Sliney

Exposure Geometry is important too!

- Central retinal (macular) exposure to blue light varies not only with time of day but also by geometry
- The upper lid lowers with brighter sky (Deaver et al., 1991)
- Direct viewing of the sun at sunset is safe because blue light and UV removed by scatter

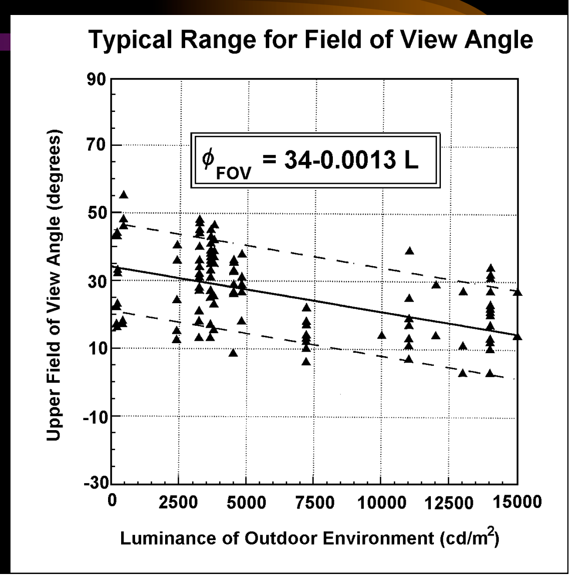




Lid Shading Experiments

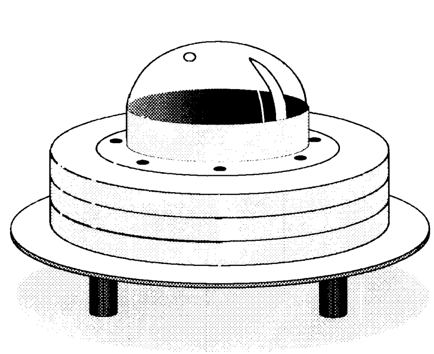
- Deaver and Sliney showed that for each individual the upper lid closed down linearly with increasing luminance
- There was considerable variation between subjects, but each subject’s lid opening corresponded to a line on the graph to the right that was parallel to the mean

D Sliney



Horizon Sky Measurements

– to capture the human-eye's UV exposure



a. Model 501 UV Biometer

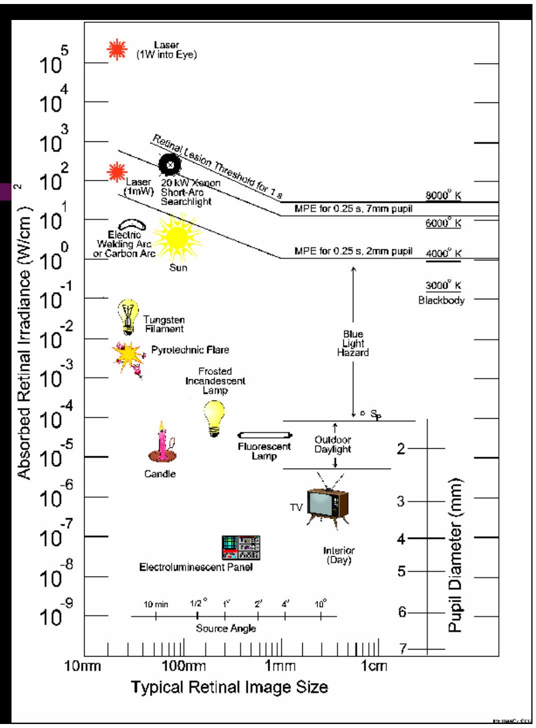
b. UV Biometer with 20 degree acceptance angle

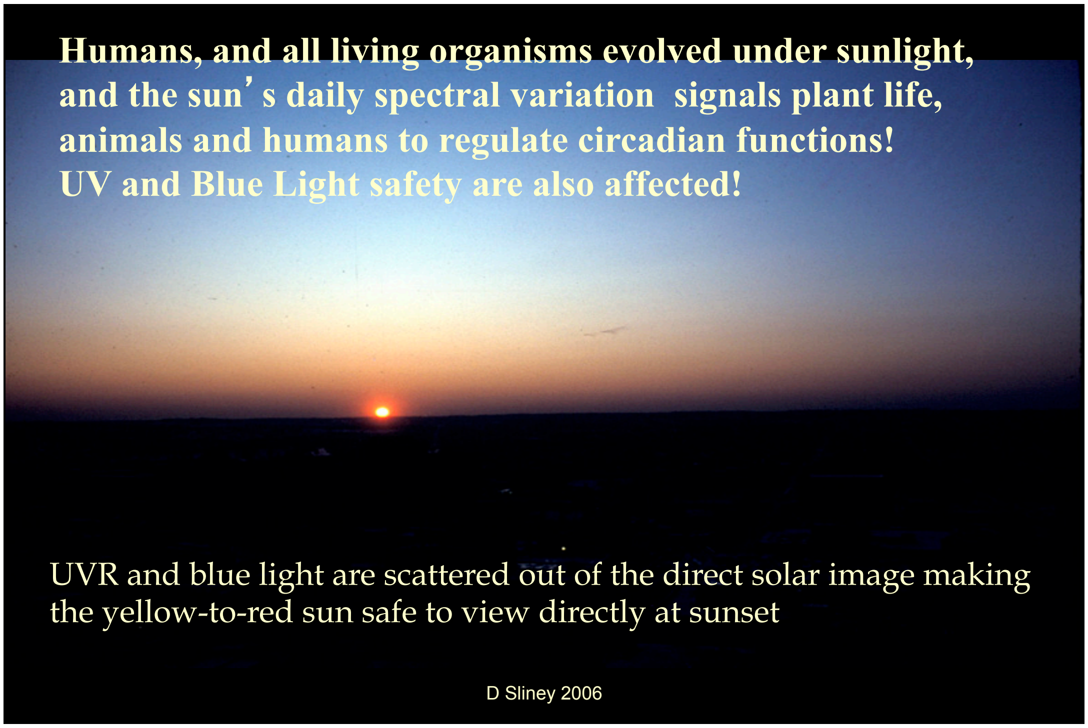
D Sliney

Retinal Illumination

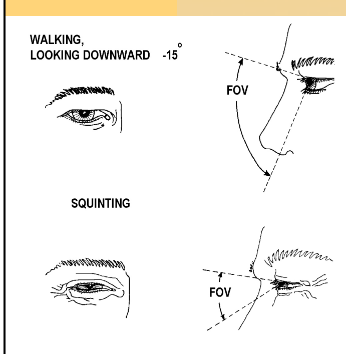
- The ambient outdoor illumination of the retina is of the order of 0.02-0.1 mW/cm^2 (< 1 cd/cm^2 and these levels are just comfortable to view – constricted pupil
- Retinal illuminance outdoors is ~ $5x10^5$ td (trolands – special unit)
- The sun's image is a million times greater.
- The skin irradiance is 1000 x greater than 0.1 mW/cm^2 at retina
- But, does sunlight contribute to age-related retinal degeneration?

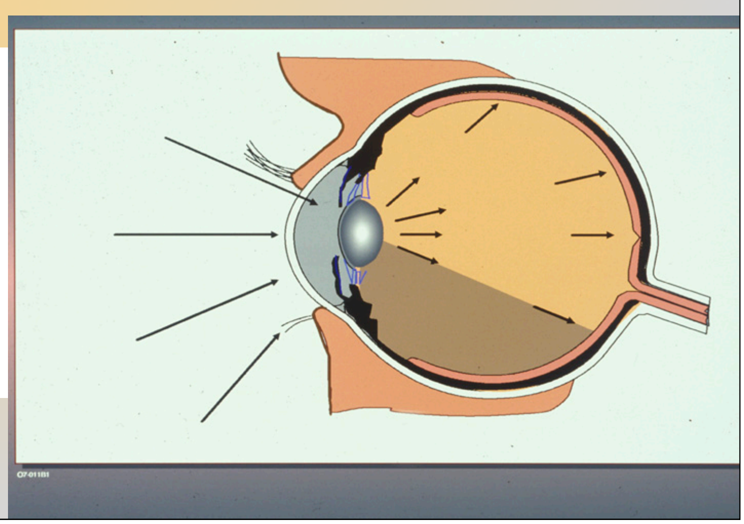
D Sliney 1996

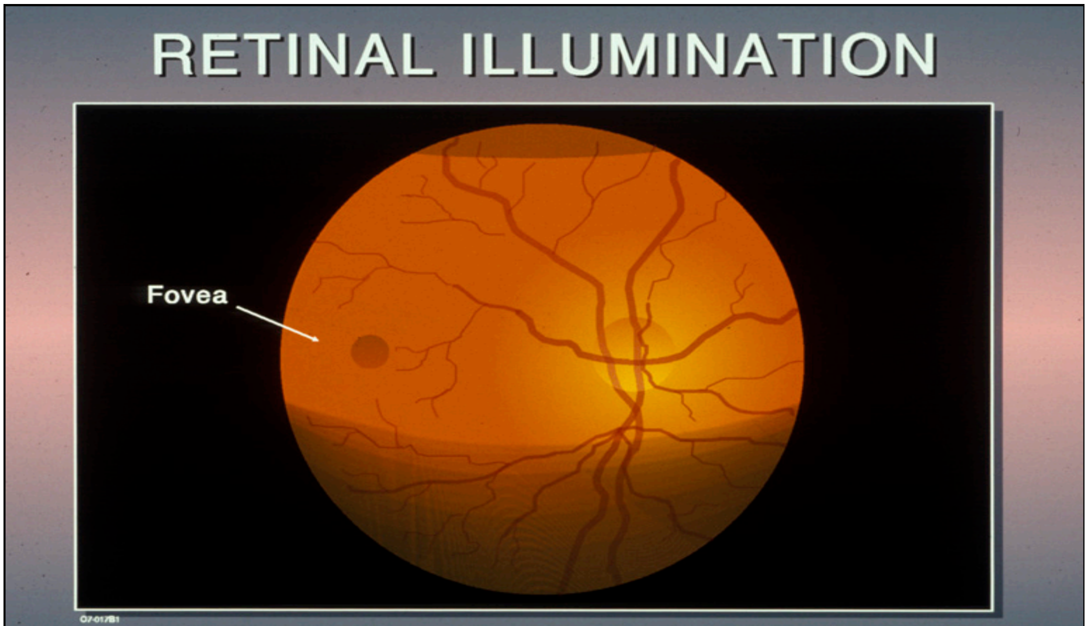




The Macula is always exposed – in order to see detail! Inferior retina often in darkness







Regardless of ambient light levels, the macula is always exposed; signs of ageing, such as lipofuscin clumps appear in superior retina (Beaver Dam study)

Epidemiological Studies – Light and AMD

- Most epidemiological studies (>20) fail to show an association of AMD with lifetime sunlight exposure.
- Taylor et al. (1992) did show correlation with blue light exposure.
- Why no association despite all the laboratory studies of light damage to the retina?

- Darzins et al. (1997) did not find macular degeneration to be associated with cumulative sunlight exposure . The control group even had higher cumulative sunlight exposure
- But, patients with macular degeneration did have a higher rate of poor tanning ability and glare sensitivity and they concluded that sun avoidance behavior could be a confounding factor which makes the association difficult to assess.
- But differing pupil size!?

BUT The Laboratory Studies…

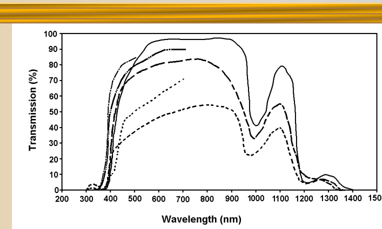
Suggest that blue light from sunlight should be dangerous

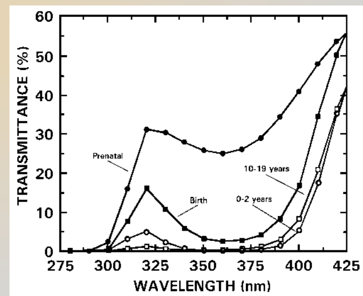
The Blue-Light Hazard and Retinal Toxicity —
the Available 'Knowledge Base'

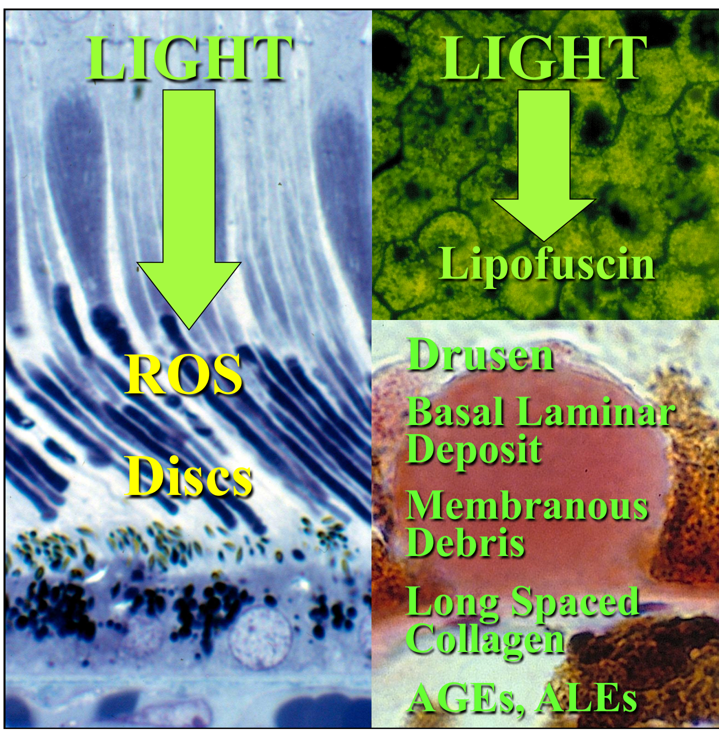
- Laboratory experimental data
  - Animal studies: primates, rabbits, rodents
  - *In vitro* studies (only for thermal injury)
- Biochemistry, molecular biology
- Theoretical arguments
- Clinical accidental injuries during eye surgery
- Sun-gazing and arc-gazing accidental exposures
- Are all data consistent?

Spectral Transmission to the Retina

- The spectral transmittance of the UV/ violet region diminishes in the ageing eye due to the buildup of absorbing proteins
- For very small children, small amounts of 295-325 nm UV reach the retina
- Spectral Transmittance of the Human Lens (Data of Barker et al.) is shown at right.
- Is this just a fascination of biochemists, or can childhood acute exposures lead to effects decades later?







Photoreceptor Cell Death

Compromised Transport

Why the problems of confirming delayed effects? Is it poor dosimetry?

- The weak link—what was each individual's sunlight exposure?
- What is the individual variation?
- What is a good surrogate for lack of an ocular dosimeter to measure lifelong exposure?

Past Metrics

- Questionnaires
  - Recall bias
- Sunglass wear
- Geography
- Ambient UV
- Ambient light
- Personal dosimeters
- Skin aging

Individual Variability

- Generally ignored factors in Epidemiological Studies
  - Individual's pupil size
  - Individual's sun-avoidance behavior
  - Individual Lid opening – really!?
  - Individual's lens/corneal spectral transmission
  - Potential photophobia
- How large a factor can each of these represent?
  - Two-to-five-fold ?
  - Lifetime light exposure increases with age anyway

…more on lamp safety standards!

There is really insufficient time to go into more detail…

✶ ANNEX

Optical Safety of Lamps– not a New Issue!

- 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"

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.

D Sliney 2006

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

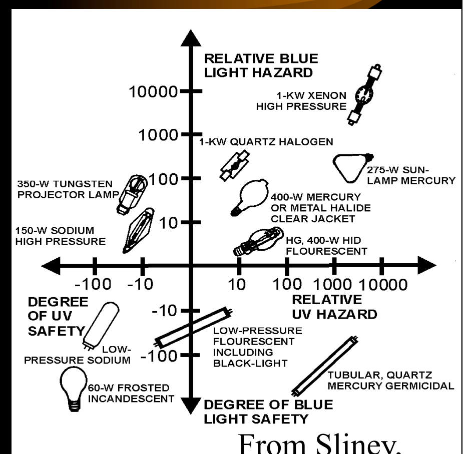
History of Lamp Safety Standards

- 1912-1916 – No precautions except for UV emissions
- 1948 – Am. Medical Assn–publishes UV-C limit (0.5 µW/cm² @254 nm)
- 1972 – Sliney/ACGIH/NIOSH – UV EL proposed – S(λ) basis
- 1973-1976 – Industrial hygienists, health physicists measure levels of UV from fluorescent lamps and voice concerns
- 1975-1995 – IESNA/ANSI develops RP-27 standards
  - Joint effort of health/medical/lamp industry (GE, Philips, Sylvania, Durotest)
  - *Photobiological Safety of Lamps and Lighting Systems*: RGs
- 1996-1999 – CIE TC 6-38 recommends CIE RG standard to be developed based upon IESNA RP27-1, RP27-3 (CIE Publ 134/3)
- 1999-2002 – CIE S009:2002 from CIE TC 6-47 (Chair: Bergman)
- 2006 – S-009 Becomes joint-logo standard with IEC (IEC 62471)

david.sliney@att.net

Before LEDs and Laser-pumped lamps:
UV and Blue-Light Hazards

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

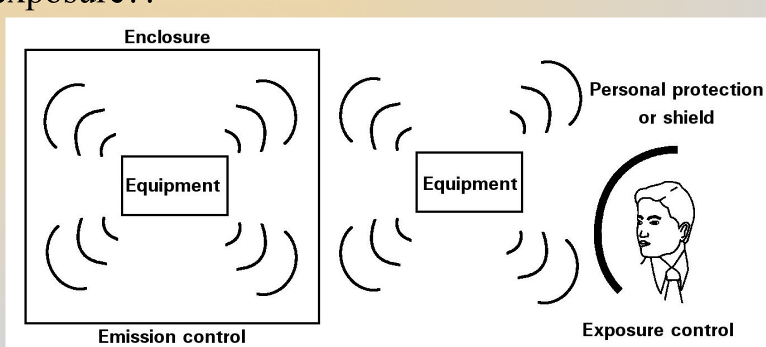


From Sliney,

Sliney, DH, (1982)

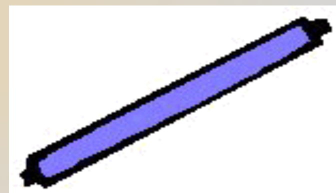
What are Risk-Group Emission Limits Based upon Exposure Limits

- The emission limits for Risk Groups (RGs) had to be derived from exposure limits
- The challenge is at what distance for how long is the exposure??



Concern-Ultraviolet hazards to the eye and skin — Exempt and RG-1

- The eye has evolved under a constant bath of ultraviolet rays from the sun—but the eye is well adapted because of limited exposure geometry and the avoidance of bright light (glare)
- Effect from a single, acute exposure: UV photokeratitis ("snow blindness")
- Effects from chronic exposure:
  - Cataract
  - Pterygium and pinguecula
- ***UV was driving force for RP-27 series developed in the US in 1970s and 1980s- fluorescent***



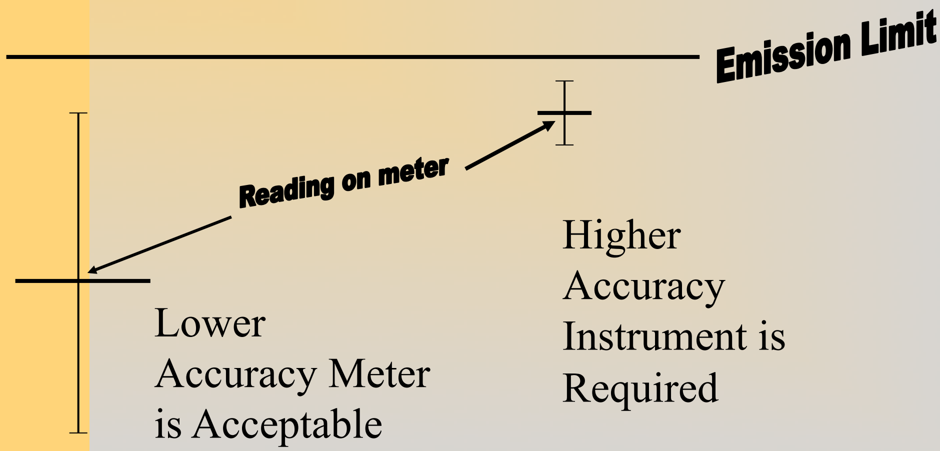
Optical Radiation Exposure Limits – The basis of Lamp Product Safety Standards

- Several national and international advisory groups
- For example, in the USA:
  - ACGIH Threshold Limit Values (TLVs), UV, lasers, etc.
  - ANSI Z136.1 (2014) for lasers with MPEs 0.1 ps -30 ks
  - ANSI RP 27.1 to ANSI RP 27.3 Lamp Photobiological Safety
- Internationally:
  - International Commission on Non-Ionizing Radiation Protection (www.ICNIRP.org) 2013
  - CIE S009/IEC62471 for lamps but IEC 60825-1 (2014) Lasers

D Sliney 2014

Measurements – The "Uncertainty Budget:"

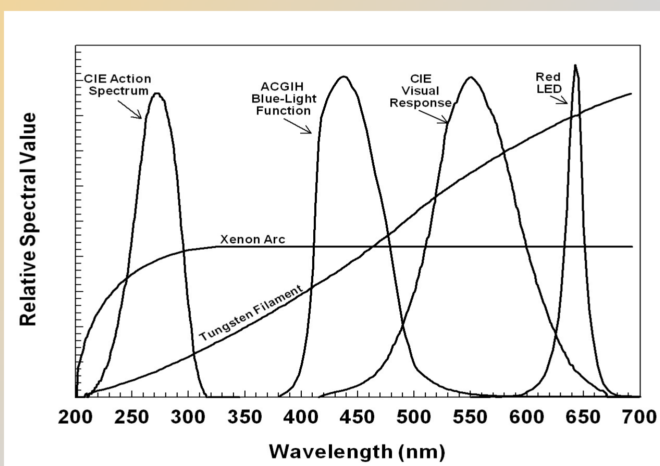
Meeting a Limit:



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, broad spectral distributions
- Lamp envelope may block UV
- Visible LEDs emit no significant UV



david.sliney@att.net 1

Contrasting Lasers and Lamps -

Lamp standards committees have had great difficulties with laser-safety experts, who try to apply laser-safety concepts to lamps!

Potential Hazard	Lasers	Lamps (including LEDs)
Exposure Durations	Acute, traumatic exposure	**Chronic, long-term**
Type of Exposure	Accidental, unintentional	Intentional or unavoidable
Primary Injury Mechanism	Thermal, cornea, retina, skin	Photochemical, eye and skin
Organ(s) of Most Concern	Primarily the eye (except Class 4) – Retinal or Corneal thermal injury	Both skin and eye
Probability of Exposure	Generally low, Probabilistic risk analysis employed in standards	Generally high, but not close by for lengthy exposures. Apply time-weighted-average (TWA)
Concern of source proximity	In the beam, localized	TWA at 500 lx typical worst-case
Spectral (wavelength) aspects	Fixed, normally one hazard	Broad-band, several hazards, Use of action spectra, e.g., S(λ), B(λ)
Safety: Hazard evaluation and risk assessments	Worst-case viewing (10 cm) – eye --very conservative pupil sizes	TWA exposures –considering skin as well as the eye (> 20 cm)

Time-Weighted Averaging (TWA)

- **TWA** is a critically important concept in occupational health – ACGIH, NIOSH and MAK set worker-exposure limits (ELs) as either ***ceiling*** values or as ***TWA*** values for chemical-agent (and physical-agent) exposures.
- This means that it is a time-integrated and spatially/ distance-integrated exposure. Hence 500 lux AEL
- For lamps, RG Emission Limits may be over 1,000 s to 8 hours - in J/m^2 or J/cm^2 for UV & BLH

What exposure duration(s) should apply? Distances?

- The greatest challenge in lamp standards relates to determining the worst-case time-averaged exposure duration (and closest time-averaged distance) for setting Accessible Emission Limits (AELs)
- IESNA Photobiology Committee members performed use studies, etc. (1980s) that led to 500 lx GLS criterion
- Limits adjusted to effective durations based on studies
  - Examples: 100 s, 300 s, 1000 s and 10,000 s

david.sliney@att.net

Lamp Exposure Conditions

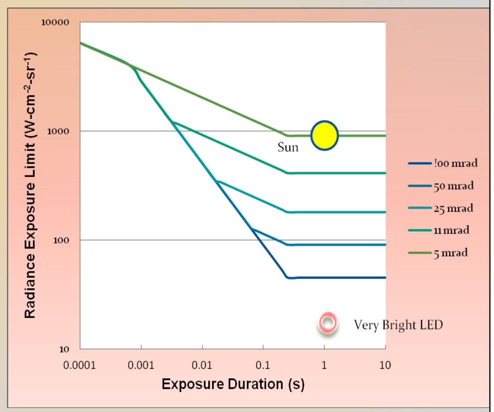
CONCEPTS EMPLOYED IN LAMP APPLICATION STANDARDS

- Left: Momentary direct viewing of a lamp at 20 cm viewing distance—glare
  - "LAMP-IN-THE-FACE" Maximum time-weighted average of 300 or 1000 s?
- Center: Task lighting must be indirect (~30 cm from back of hands)
- Right: Direct lighting is positioned to minimize glare under normal use.
- 500-lux criterion based upon many studies of use conditions and lighting design

david.sliney@att.net

Should We Drop Retinal Thermal Limits in Risk Group Determination?

- Some have argued that the assessment of retinal thermal hazards should be dropped from CIE S009/IEC62471
- Certainly all but arc lamps should be excluded from testing against this hazard.



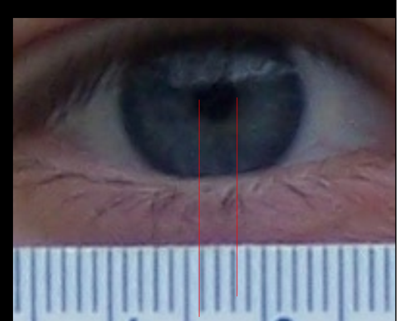
Retinal thermal exposure limits depend on source size (heat flow).

Pupil Size – Measurements Outdoors

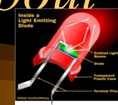
Overcast or Shady Conditions - Overall Results

N	Mean (mm)	Std Dev	Min (mm)	Max (mm)	95% CI for Mean LB	95% CI for Mean UB
86	2.39	0.29	1.44	3.03	2.33	2.45

- Values across all luminance measurements in outdoor settings where the sun was behind clouds.
- A conservative, 3-mm pupil was applied to BLH viewing limits



Why have questions been raised about the safety of solid-state lamps?



vs

- Do energy-efficient CFL & solid-state lamps have potentially significant health & safety implications?
  - Often shorter-wavelength, cooler spectra than incandescent lamps…
  - 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 (US perception that light was "too harsh" in home)
- SSL (not CFLs) – eliminate UV hazard, but lose 'benefits' of trace UV
- Are any concerns about health and safety of LEDs realistic?

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 but is this a safety issue?

Sliney, 2002

Ceiling Values for AELs

- For traumatic, accidental exposures where a thermal burn of the skin or eye is possible, a ceiling value applies (e.g., as are used for laser AELs)
- Thermal limits have been of interest for:
  - Most laser products – the primary cause for concern
  - Laser-illuminated and arc-lamp-discharge projectors
  - Infrared LEDs (lens, but not generally a realistic concern)
  - High-power arc lamps (rarely without protective housing)
  - Ophthalmic instruments (when avoidance response is absent)

New Optical Sources & Applications

- ***Higher-Power LEDs and LED Arrays***
- ***Medical Applications***
  - Internal-tissue exposures - endoscopes
  - Phototherapy (depression, etc.)
- ***Laser-pumped phosphor Lamps*** for high brightness
- ***Projector Systems***
  - Laser-illuminated projectors
  - Searchlights
  - Automotive headlights and infrared avoidance systems
- ***Ultraviolet Lamps/LEDs***

Standards Activities – Photobiology

International - USA

- IEC TC 76 – Lasers, optical safety
  - IEC 60825-1 – Lasers – horizontal
  - IEC 62471/CIES009 – Lamps – horizontal standard from CIE
  - IEC 62471-2 TR on applying -1
  - IEC 62571-3 – IPL - medical
  - IEC 62471-4 – Measurements
  - IEC 62471-5 – Image Projectors
  - IEC 62471-6(?) – UV lamps
  - IEC 62471-7(?) – IR lamps
  - IEC 60601- series – med. laser/IPL
- TC61 – Home Use laser/IPL
- TC62 – Medical – some joint TC76
- ANSI Z136 series – laser safety
- IESNA – Photobiology Committee (USA) – ANSI Recommended Practices (RPs)
  - RP27-1 – Exposure Limits- horiz.
  - RP27-2 – Lamp measurements
  - RP27-3 – Risk Group Classify
  - RP 27-4 – Ultraviolet Lamps
  - RP 27-5 – Projectors (all)
  - RP 27-6 – Infrared Lamps
  - RP 27-7 – (?) Photographic and Reprographic
- FDA/CDRH – 21CFR1040 series

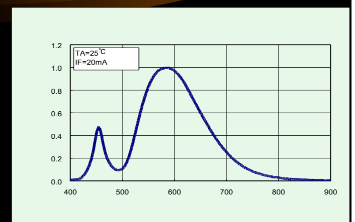
Emission Limits for Risk Groups of Continuous Wave Lamps - Changes

Risk	Action Spectrum	Symbol	Emission Limits			Units
			Exempt	Low Risk	Mod Risk	
Actinic UV	S(λ)	E_s	0.001	0.003	0.03	W/m^2
Near UV		E_{UVA}	10	33	100	W/m^2
Blue Light	B(λ)	L_B	100	10000	4000000	$W/(m^2 \cdot sr)$
Blue Light, small source	B(λ)	E_B	1.0*	1.0	400	W/m^2
Retinal Thermal	R(λ)	L_R	28000/α	28000/α	71000/α	$W/(m^2 \cdot sr)$
Retinal Thermal, weak visual stimulus**	R(λ)	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 . ⟺ = Changes planned because of ICNIRP ELs

Are there other LED 'phtobiological hazards' that might be of concern?

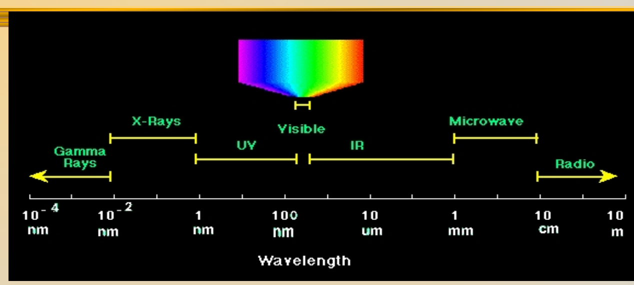
- Two other LED "safety" issues have been advanced, but these pose indirect safety issues.
  - Circadian disruption
  - Flicker effects – not really a new issue



- Circadian disruption – depends on CCT, thus not realistic if low CCT as shown above.
- Flicker – 8-13 Hz peak effect, but 3 – 100 Hz noted
  - IEEE 1789 - Slow in arriving at a consensus on recommendations

D Sliney 2014

Remember: Photon Energy and the Electromagnetic Spectrum

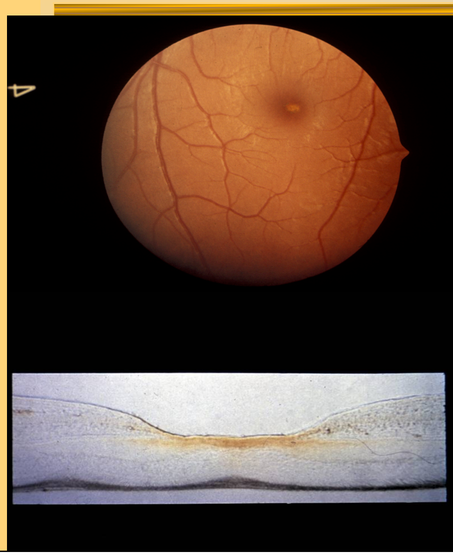


- The shorter the wavelength, the higher the photon energy! Hence greater potential hazard. Ionizing radiation (X rays and gamma rays) are more hazardous than optical radiation (e.g., ultraviolet radiation and visible radiation)
- The Photon energy in the visible and UV are sufficient to produce *photochemical* photobiological effects. Infrared photon energies generally unlikely to do so
- Young argued that more chromophores absorb and can be altered as the wavelength decrease, thus potential adverse effects increase with shorter wave-lengths - Young RW. The family of sunlight-related eye diseases. *Optom Vis Sci.* **71**(2):125-44 (1994).

Retinal Phototoxicity — key Questions regarding mechanisms..

- The long-standing public health question—what are the risks from intense light exposure—from sunlight and artificial sources?
  - Noell (1966) first showed light-induced retinal damage in rats – met by skeptics
  - During the following three decades, many investigators studied retinal damage—(Type 1) primarily in rodents (Organisciak, 2010).
  - Ham and colleagues (1976) demonstrated a second type of retinal injury in primates from blue light (termed 'Type 2 mechanism'), the 'blue-light' hazard.
  - Sperling showed selective blue cone damage (1980) at lower levels – still uncomfortable.
  - Today, there remain many questions!
  - Diurnal dependence on light damage (would ipRGCs play a role?)
  - Blue light hazard is Type 2 and in cone animals. Noell type damage (Type 1)
  - Can there be only one, or even four or five light damage mechanisms? Chromophores?
  - LED exposures should be used to resolve questions for free-running animal cages.
  - Better epidemiological studies that consider individual vaariation.

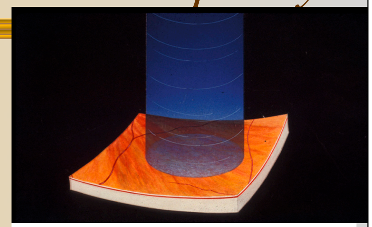
Retinal Hazards: "the blue-light hazard" (or photic maculopathy)

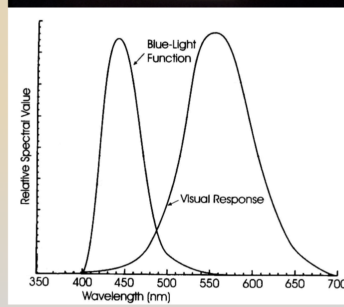


- Action spectrum described by Ham, Mueller and Sliney, ***Nature***, 1976
- Requires steady viewing for many seconds, as in retinal injuries from viewing a solar eclipse
  - Viewer has to overcome the natural aversion response to bright light

The Blue-Light Hazard – known as: Photoretinitis or Photomaculopathy

- Photochemical effect (peak ~ 445 nm)
- Threshold retinal radiant exposure is approximately 22 J·cm^{-2} and human exposure limits set at ~ 2.2 J·cm^{-2} in standards
- Most light sources are not rich in blue-violet wavelengths
- A "blue-blocking" filter can have 90% visual transmission and block > 90% of the "effective" blue-light radiance of sunlight or a "white-light" source
- An issue with blue-white LEDs?





The Aphakic Retinal Hazard

-limited data for case of the absense of crystalline lens

- The only careful study of UV retinal photochemical injury was from Ham et al., AJO,1982, in *rhesus*
- Are there two action spectra? …or more?
- i.e., is there more than one chromophore?
- Retinal radiant exposure threshold of 5.4 J/cm^2 at 350 nm
- This is important in eye surgery

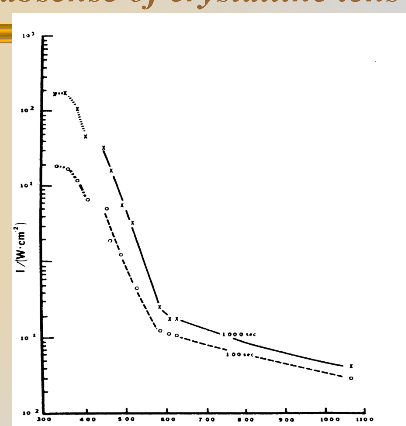


Fig. 2 (Ham and associates). The near-ultraviolet action spectra for minimal damage to the rhesus retina determined on fundus photographs immediately after 100- and 1,000-second exposures at the wavelengths 405, 380, 350, and 325 nm. The reciprocal of retinal irradiance in W·cm^{-2} is plotted logarithmically on the ordinate and the wavelength in nanometers on the abscissa. These data are compared with previous data on eight laser lines.[2]