UV Safety Measurements – Rationale and Problems

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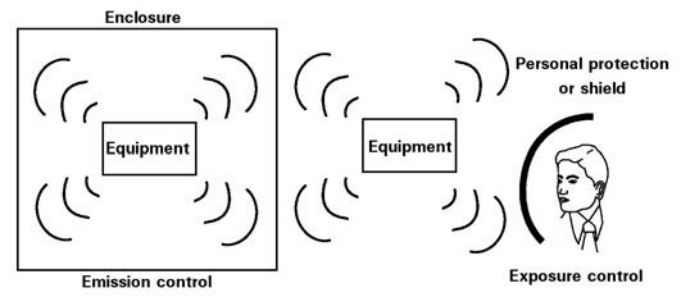
Introduction and Background

- UV radiometry, spectroradiometry is used in optical radiation safety.
  - Field measurements in workplaces
  - Lamp safety standards
    - Risk assessments – Determining Risk Groups
    - Assessment distances vs. measurement distances
- Challenges
  - Measure trace UV-B/C emitted by a lamp
  - Measure small UV-B (280-315 nm) in outdoor sunlight in the presence of intense visible & UV-A (315-400 nm).

How are Risk-Group Emission Limits Based upon Exposure Limits

- The accessible emission limits (AELs) for Product Safety Standards have to be derived from exposure limits
  - Based upon reasonably foreseeable worst-case exposures
  - Example: Lamp Safety Risk Groups (RGs)
  - The challenges are: at what distances, for how long an exposure?

AELs developed by product experts, and tested by technicians



Occupational and Environmental Health Specialists apply ELs

Occupational Exposure to Ultraviolet Radiation (UVR) – Measuring On-Site

- Occupational exposure to UVR is a significant risk for outdoor workers
- Indoor workers are normally fully protected to avoid acute effects
- Arc welding operations are most intense sources.
  - *Electromagnetic interference!*
  - *Note the potential exposure to scattered UVR in this case!*

My important lessons in the development and application of ELs

- In my nearly 50-years of experience in developing and applying exposure limits for optical radiation (and other physical agents), I have found that:
- ***Risk assessments too often grossly over-estimate real exposure conditions*** by taking a worst-case exposure distance and assume 8 –h exposures!
  - Ultraviolet (UV) cornea/skin – S(λ)-spectral weighting
  - Ultraviolet – lens/retina – UVA – un-weighted
- **Continuous UV ocular exposure (i.e., direct viewing) rather than just a realistic TWA skin exposure**

Ultraviolet Radiation Exposure Limits – Basis of Lamp Product Safety Standards

- Several national and international advisory groups
- For example, in the USA:
  - ACGIH Threshold Limit Values (TLVs) used by hygienists.
  - 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 -laser & incoherent
  - CIE S009/IEC62471 for lamps but IEC 60825-1 (2014) Lasers

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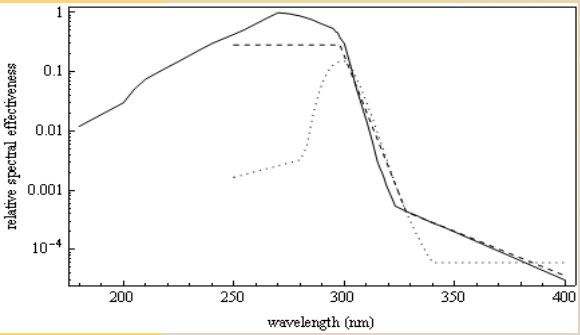
UV Action Spectra Applied in Risk Analyses for Eye and Skin



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)

Standards Activities – Photobiology

International - USA

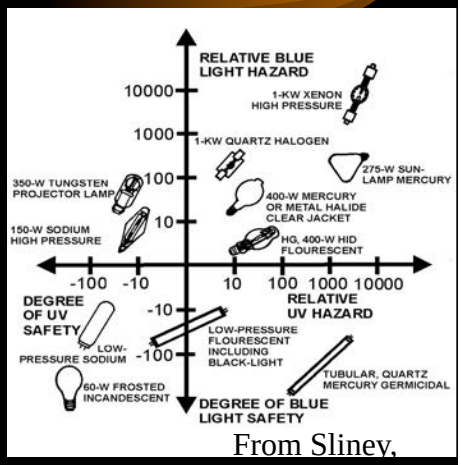
- IEC TC 76 – Lasers, optical safety
  - IEC 60825-1 – Lasers – horizontal
  - IEC 62471/CIES009 – Lamps – horizontal standard from CIE
  - IEC 62471-2 TR on applying -1
  - IEC 62571-3 – IPL - medical
  - IEC 62471-4 – Measurements
  - IEC 62471-5 – Image Projectors
  - IEC 62471-6 – UV lamps
  - IEC 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 – (future?) Photographic and Reprographic
- FDA/CDRH – 21CFR1040 series

The traditional optical safety concern with lamps:

UV and Blue-Light Hazards

- UV and blue-light phototoxicity are the key potential hazards in lamp safety standards – (8-h dose additive)
  - 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 and no TWA needed



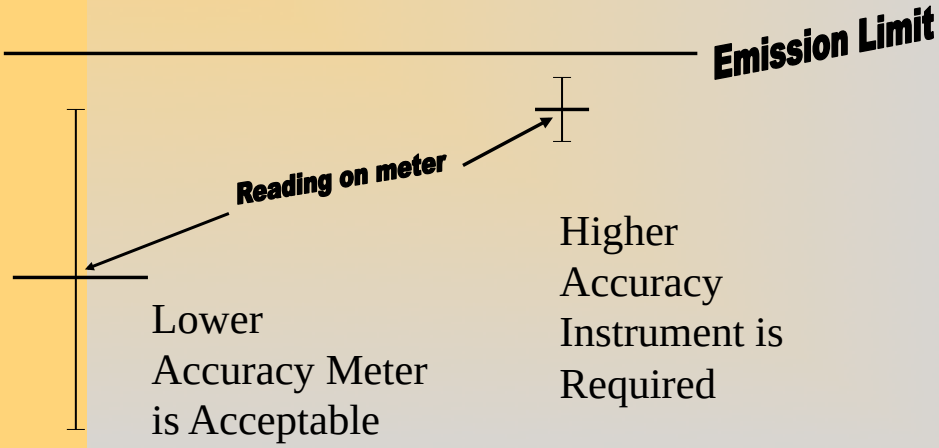
From Sliney, Sliney, DH, (1982)

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

Simple Instruments may suffice – The "Uncertainty Budget:"

An issue in Standards - Meeting a Limit:

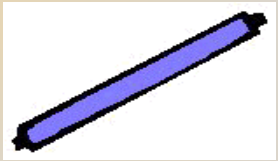


Lower Accuracy Meter is Acceptable

Higher Accuracy Instrument is Required

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). This must be understood to assess TWA
- Effect from a single, acute exposure: UV photokeratitis ("snow blindness")
- Effects from chronic exposure:
  - Cataract
  - Pterygium and pinguecula



- ***UV was driving issue for RP-27 series developed in the US in 1970s and 1980s – primarily for fluorescent lamps***

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

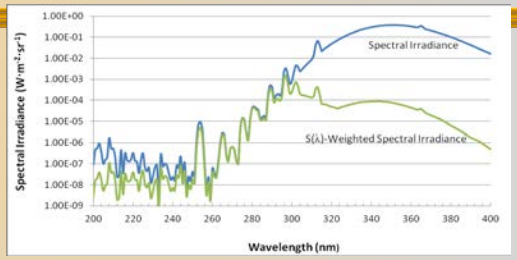
Lamp Exposure Conditions

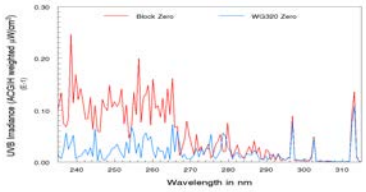
CONCEPTS EMPLOYED IN LAMP APPLICATION STANDARDS

- 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 as a TWA illuminance.

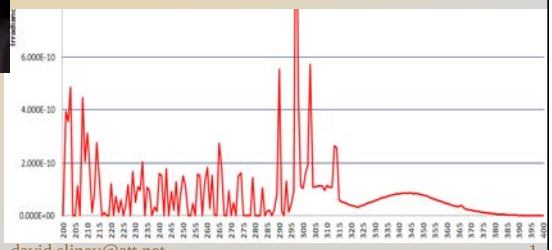
Origin of the 20-cm Reference Measurement Distance (UV issue)

- The most challenging AEL spectroradiometric measurement was: $E_{UV\text{-}effective}$ where stray light and noise produced a large uncertainty
- Also, the closest reasonable facial distance to observe a lamp momentarily for RG-3.- not RG-1!





Noise issue!



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History of UV Limits for Artificial Sources

- 1912-1916 – No precautions except for UV emissions – general caution
- 1948 – Amer. 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*: Risk Groups (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)

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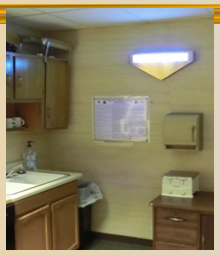
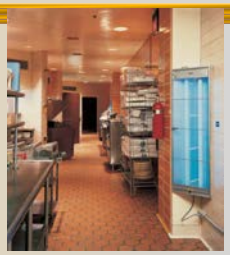
UV-A Insect Light Trap (ILT) Lamps

Entry-Way to Food-Processing Plants

Industrial & Restaurant Kitchens





Other sites in Pharmaceutical Laboratories and Food-Processing Plants – RG assessment distance > 1 m

Photos Courtesy of Gilbert Industries

UV-C Germicidal Lamp Applications

- Increased concerns about multi-drug-resistant (MDR) viral & bacterial agents in health care; TB issues
- Return to use of UV-C germicidal lamps in location of highly infectious agents (common in 1940s-1950s
- May require a benefits vs. risks acceptance
- Recent publication of EC SCHEER report on UV-C as an "emerging issue" of new technology rather than a rediscovery to old technology.
  - Many classical studies of UV effects were not cited
  - Problem: old literature not readily accessible on internet?
  - Hausser-Vahle & SCUP action spectra were ignored

Photobiological effectiveness depends on…

- **NOT JUST WAVELENGTH!**
  - *but also*
    EXPOSURE DURATION
    SOURCE RADIANCE (for retinal exposures)
    and
    EXPOSURE GEOMETRY
  - **Lamp safety standards must consider these and TWA!**

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An Important Take-Home Message

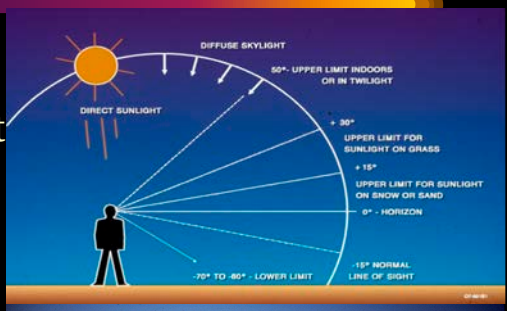
- The measurement distance is *NOT* the assessment distance or distance-time factor used for the TWA exposure applied for risk assessment & RG determination!!!
- Assessment distances are now emphasized in IEC 62471-1 *draft* standard and IEC 62471-6 UV lamps *draft*

- ***Examples***
  - Insect traps – 1 m and 2 m depending on size
  - Infrared heat lamps
  - UV emissions from GLS are at 500 lx (TWA), i.e., equivalent to 2 µW/lm -eff
  - Searchlights – 1 m
  - Cinema projectors – 1 m
  - UV-A exposure over a day

Is a ratio to total irradiance and skin vs. eyes' exposure

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



Humans, and all living organisms evolved under sunlight, and the sun's daily spectral variation signals plant life, animals and humans to regulate circadian functions!
UV and Blue Light safety are also affected!

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

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ANNEX – for further discussions

Comparing Measurements for Thermal vs. Photochemical Els/AELs

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)