ULTRAVIOLET GERMICIDAL IRRADIATION (UVGI) – THE GOOD, THE BAD AND BUYER BEWARE

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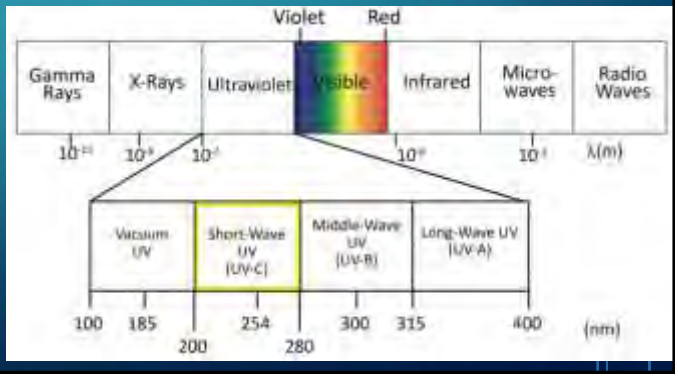
PDS-Webinar

WHAT IS "GERMICIDAL RADIATION" - OR "GERMICIDAL LIGHT?"

- UV-C, although longer-wavelengths of UV-B in sunlight are less effective, but have effectiveness, as summer sunlight is very intense.
- UV-C is the only effective means for disinfecting air!
- IES Draft UVGI Standard states that UV-A and violet light have only marginal effects inactivating most microbes



UVGI - REVISITING AN OLD TECHNOLOGY

- Appropriately designed and applied, UVGI technology has been an effective means of microbial disinfection.
- UVGI offers about the only method for air disinfection (other than gas, which cannot be used with unprotected persons present)
- The covid-19 (SARS CoV-2 virus) outbreak, however, has resulted in the marketing and sale of numerous UVGI products from handheld wands to large scale robotics.

SARS-CoV2:

PRIMARY MEANS OF TRANSMISSION

- as stated last spring by Dr. E. Nardell

- Airborne Transmission
  - Respiratory Droplets (e.g., coughs)
  - Aerosolized Droplet Nuclei
- 2nd - Contact Transmission (fomites)

The Breathing Zone as Shown by a Schlieren Mirror

From: Tang JW, Nicolle ADG, Pantelic J, Jiang M, Sekhr C, et al. (2011) Qualitative Real-Time Schlieren and Shadowgraph Imaging of Human Exhaled Airflows: An Aid to Aerosol Infection Control. PLOS ONE 6(6): e21392.

The Breathing Zone as Shown by a Schlieren Mirror

Normal Breathing

From: Tang JW, Nicolle ADG, Pantelic J, Jiang M, Sekhr C, et al. (2011) Qualitative Real-Time Schlieren and Shadowgraph Imaging of Human Exhaled Airflows: An Aid to Aerosol Infection Control. PLOS ONE 6(6): e21392.

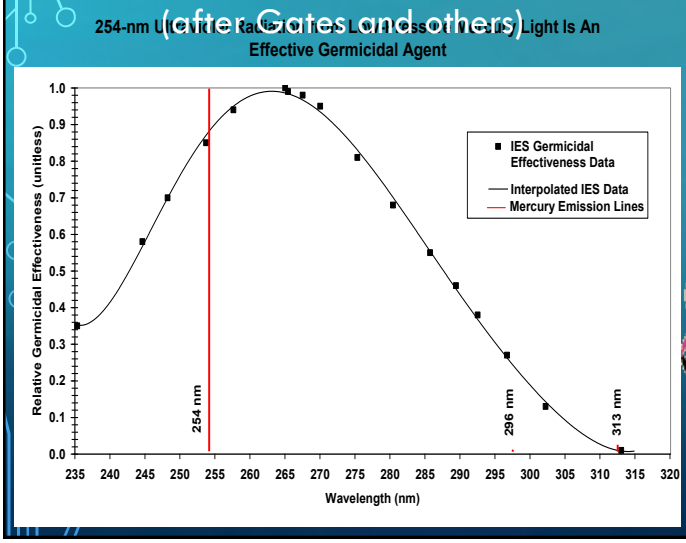
The Breathing Zone as Shown by a Schlieren Mirror

Speaking - Particularly large when shouting or singing!

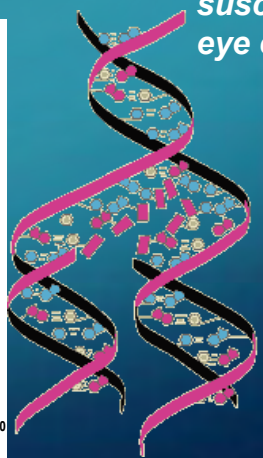
From: Tang JW, Nicolle ADG, Pantelic J, Jiang M, Sekhr C, et al. (2011) Qualitative Real-Time Schlieren and Shadowgraph Imaging of Human Exhaled Airflows: An Aid to Aerosol Infection Control. PLOS ONE 6(6): e21392.

DNA - A KEY TARGET MOLECULE FOR UV-C

IES Germicidal Action Spectrum (after Gates and others)



…for bacteria and some viruses, but also the susceptible molecule in eye or skin!



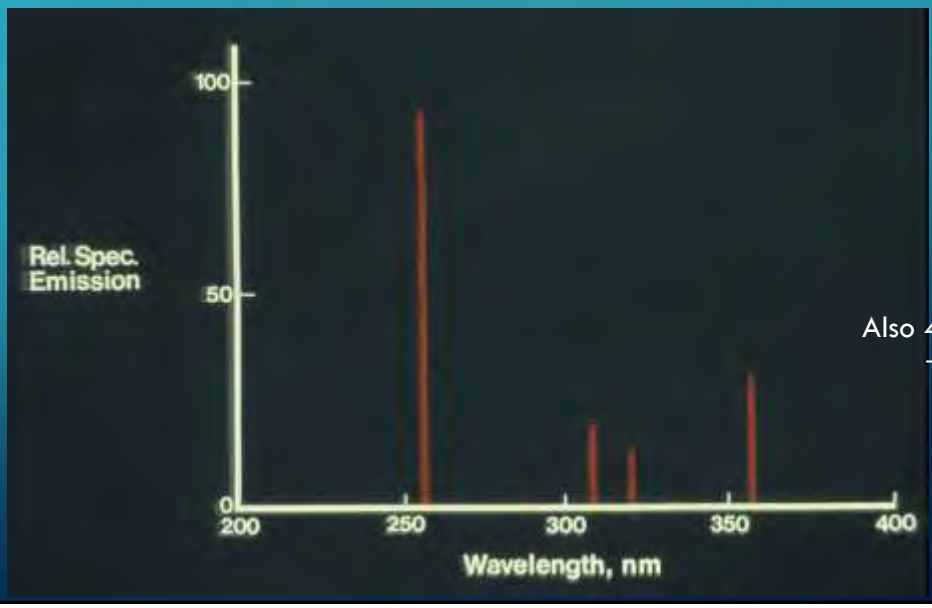
- Adenine
- Guanine
- Thymine
- Cytosine

But SARS-CoV-2 is a RNA virus!

REMEMBER: PHOTON ENERGY

- All light is composed of photons of energy: "The Quantum Theory"
- The energy of a single photon varies with wavelength: $Q = 7.8 \times 10^{-17}$ J @ 254 nm
- Photon energy increases with decreasing wavelength
- In photochemistry: One photon interacts with one absorbing molecule – the chromophore
- Millions of photons inactivate a micro-organism

LOW-PRESSURE MERCURY (GERMICIDAL) LAMP EMISSION— SEVERAL MONOCHROMATIC LINES – BUT 90% AT 254 NM

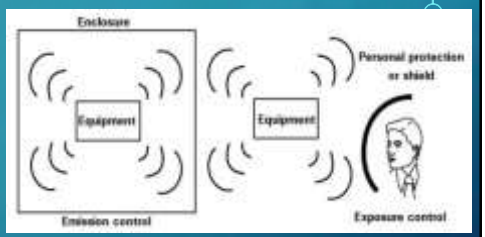


WHERE DO STANDARDS COME FROM?

- **Exposure limits**
  - American Conference of Governmental Industrial Hygienists (ACGIH) – 1972, 1985
  - International Commission on Non-Ionizing Radiation Protection (ICNIRP) – 2005
- **Product safety standards – lamps**
  - IES RP27-1, -2, -3 Photobiological safety of lamps – since 1993; latest – 2017
  - CIE S009:2002; then IEC62471:2006 – now in final phase of update
  - IES RP27-x – UVGI new draft now being voted
  - IEC 62471-6 – Ultraviolet lamps and lamp systems (UVGI included) – now in CD (draft)

Photobiological Exposure Limits for UV and safety standards for lamps and lamp systems

- Emission Limits
  - Used in Product Safety Standards
  - Often termed "accessible emission limits"
  - Measurement conditions specified based upon pre-determined human exposure conditions

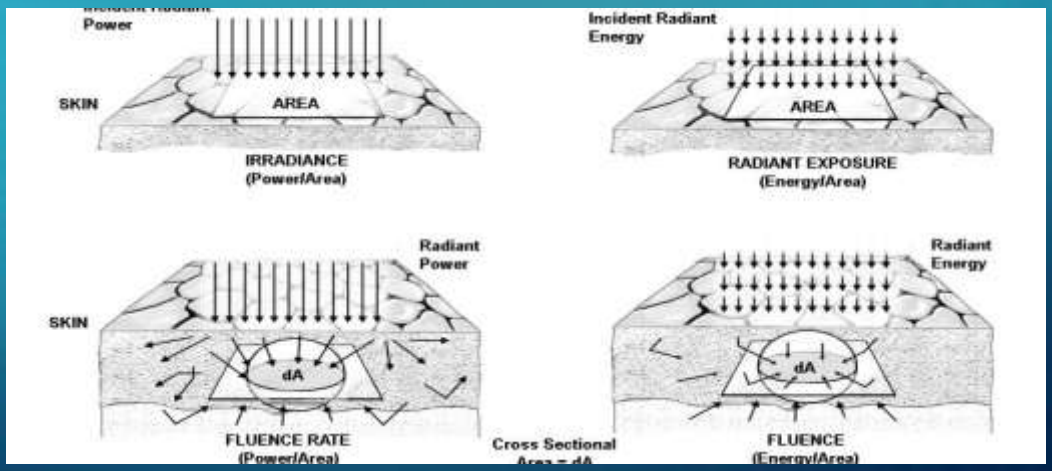


- Exposure Limits
  - Used for occupational safety standards
  - Measured at location of exposed person

DOSIMETRY FOR HUMAN EXPOSURE LIMITS - THE CONCEPT OF PHOTOBIOLOGICAL DOSE

- Fundamental to photobiology - Bunsen-Roscoe Law (photochemistry)
  - reciprocity of dose-rate (irradiance) E and time t
    - E x t = H = "the exposure dose"
    - Loss of reciprocity over several hours typical
- Normally all optical radiation, including UV is absorbed on a surface
- Power divided by exposed surface area is the irradiance, E, or "the dose-rate" –however:
- In tissue or in air, photobiological exposure rate is fluence rate in power-per-unit-area

DESCRIBING EXPOSURES (CIE)

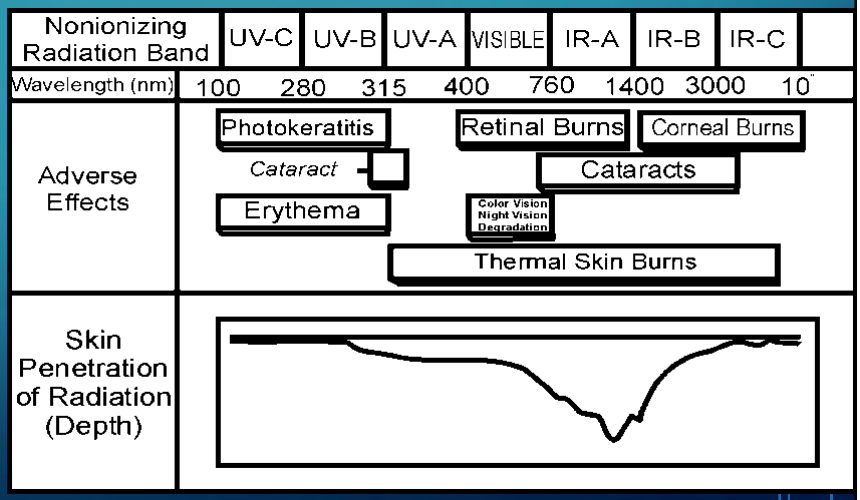


Current guidance – Fluence rate of ~5-15 μW/cm^2 in room air

UV PHOTOBIOLOGICAL EFFECTS
ON HUMANS

UV-C safety issues:

1. Eye irritation (photokeratitis)
2. Skin irritation (erythema)
3. …but what about *skin cancer?*



OCCUPATIONAL SAFETY ISSUES

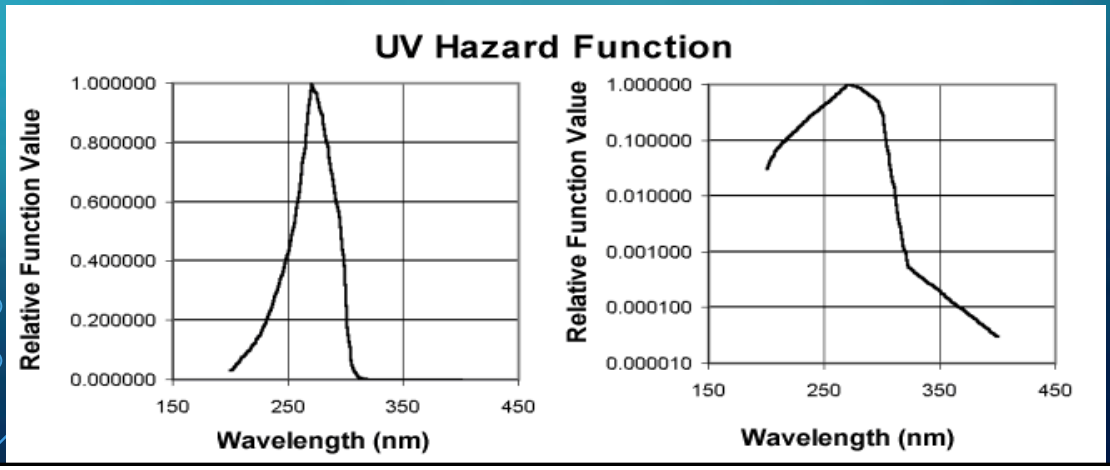
- **Ultraviolet Safety is a very important issue!**
- **Accidental exposure of skin & eyes:**
  - Photokeratitis ("welder's flash," or "snowblindness" – with symptom of *"sand in the eyes" - Cornea is most sensitive tissue*
  - Erythema – reddening of the skin
    - Can be severe if penetrating UV-B rays ("sunburn")
    - Mild if UV-C – very superficial absorption
- **Delayed Effects**
  - Skin Cancer?
    - UV-B in sunlight penetrates to basal (germinative) layer of epidermis and is the recognized cause of most skin cancers
    - UV-C heavily absorbed in superficial epidermis & stratum corneum

- Photokeratoconjunctivitis

- Erythema (skin reddening)

THE BASIS OF UV EXPOSURE LIMITS—THE ACTION SPECTRUM: ICNIRP/ACGIH UV HAZARD FUNCTION

Action spectra are best plotted in a semi-logarithmic plot!



WHAT IS SPECTRAL "WEIGHTING"?

ICNIRP/ACGIH LIMIT

- Exposure dose limit H_{eff} is based on spectral weighting
- The spectral irradiance is weighted by the envelope UV-Hazard action spectrum S(λ) that is normalized to 270 nm

THE WEIGHTING FORMULA

$$E_{eff} = \sum_{180}^{400} E_{\lambda} \bullet S(\lambda) \bullet \Delta\lambda$$

- Then, the permissible exposure duration, t_{max} is:

  $t_{max} = (3\ mJ/cm^2)/E_{eff}$

Since the TLV is 3 mJ/cm^2

Limit for the eye but only a guideline for the skin

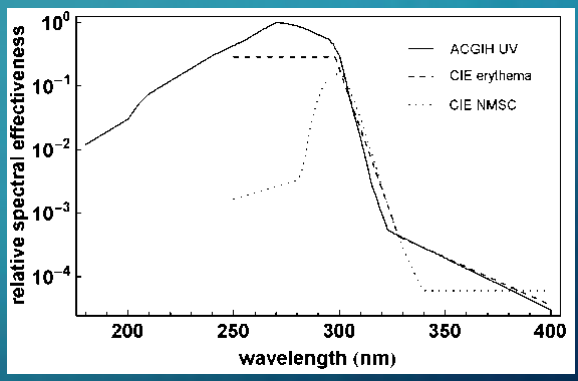
LPA 18

WHAT ARE THE SAFETY GUIDELINES FOR HUMAN EXPOSURE IN THE GUV UV – C BAND?

- **Action spectrum for safety is the ACGIH/ ICNIRP/CIE/ISO/IEC action spectrum S(λ)**

$$E_{eff} = \sum_{180}^{400} E_\lambda \bullet S(\lambda) \bullet \Delta\lambda$$

- S(λ)-spectral weighting leads to an *effective radiant exposure* of 3.0 mJ/cm^2 (30 J/m^2)
- Limit is **daily** – including multiple exposures
- Time-weighted average (TWA) over a day
- At 254 nm this is 6 mJ/cm^2 (60 J/m^2)
  - Or, time-averaged irradiance of 0.2 μW/cm^2
- Large safety margin for human skin in UV-C – Should there be two limits? – *For the Eye, For the Skin?*



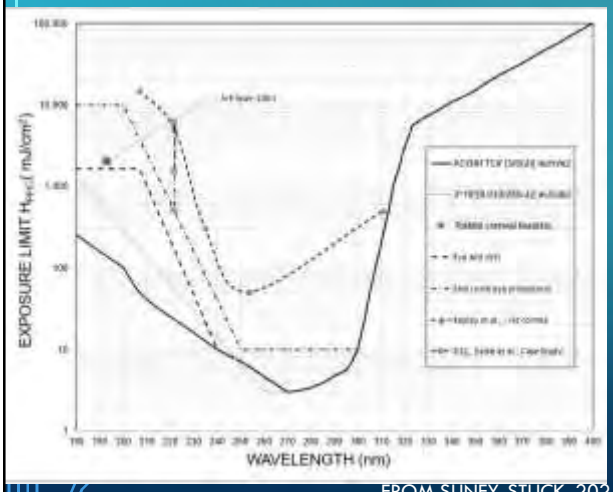
ACGIH UV S(λ) spectral weighting function (action spectrum) is the solid line.

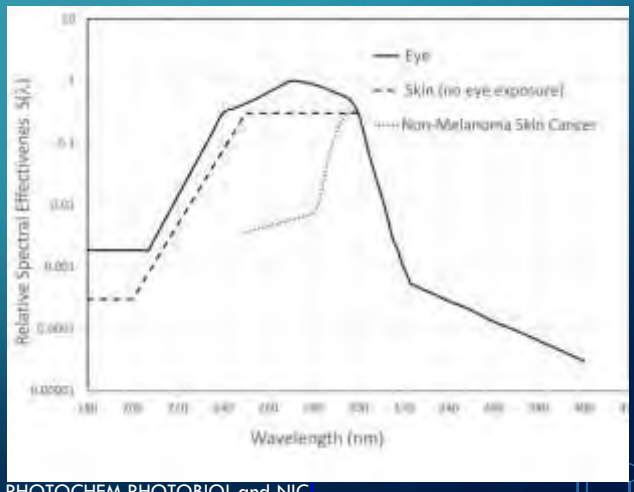
S(λ) = 1.0 at 270 nm

S(λ) = 0.5 at 254 nm

ACGIH NOTICE OF INTENT TO CHANGE – 2021 ULTRAVIOLET RADIATION (UV-C ADJUSTMENT)

NIC PROPOSAL HAS HIGHER LIMITS FOR SKIN THAN EYE AT λ < 300 NM AND INCREASE TLVS FOR EYE AT λ < 240 NM



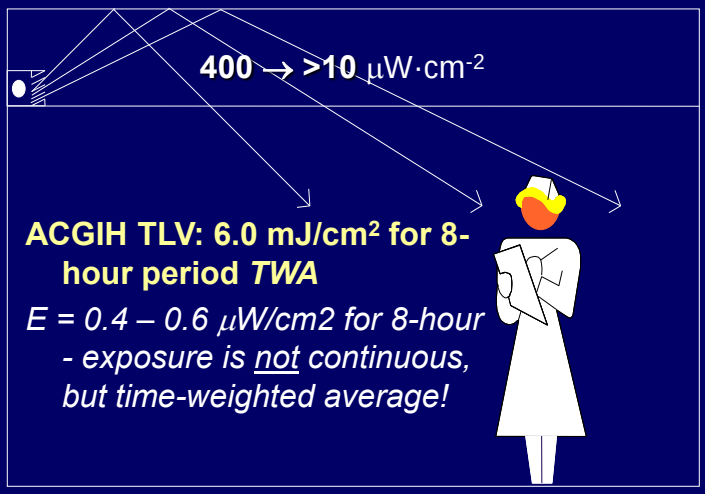


FROM SLINEY, STUCK, 2021, PHOTOCHEM PHOTOBIOL and NIC

From Dr. Nardell:

"Upper Room 254 nm GUV is Safe for Room Occupants"

The TLV is measured only within an 80-degree cone angle!



TLV is a limiting value for the eyes

Skin limit may be raised in the future

Tuberculosis **U**V **S**helter **S**tudy (TIUSS) showed no eye or skin complaints compared to placebo lamps
Ref: Public Health Rep. 2008 Jan-Feb;123(1):52-60

UVGI SAFETY REVIEWS

- UV Germicidal irradiation can be safely and effectively used for upper air disinfection with out a significant risk for long term delayed effects such as skin cancer. (CIE 187:2010)

Photochemistry and Photobiology,
Invited Review

Balancing the Risk of Eye Irritation from UV-C with Infection from Bioaerosols†

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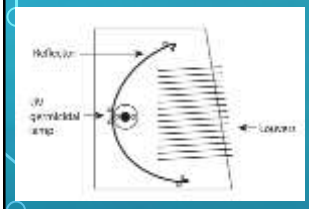
Received 13 November 2012, accepted 3 May 2013, DOI: 10.1111/php.12093

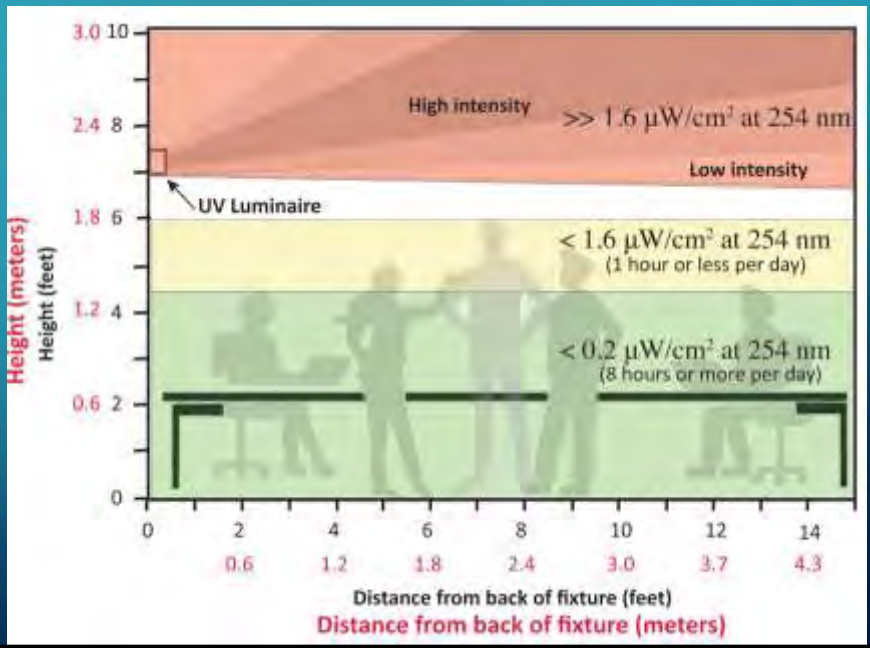
ABSTRACT

The very aspect (phototoxicity) that makes short-wavelength ultraviolet (UV) radiation an effective germicidal agent also is responsible for the unwanted side effects of erythema (reddening of

ASSESSING EXPOSURES FOR UPPER-ROOM UV-C UVGI

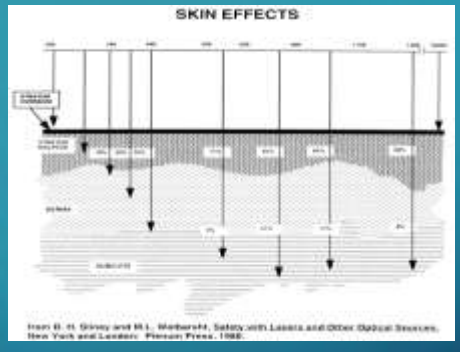


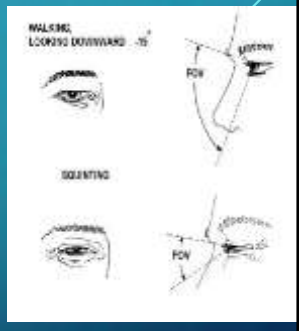
A good example of how time-weighted averaging (TWA) is employed to assess risk from scattered UV-C – *an example!*



WHY ARE UV SAFETY MEASUREMENTS MADE WITH AN INSTRUMENT WITH AN 80° CONE FIELD-OF-VIEW?

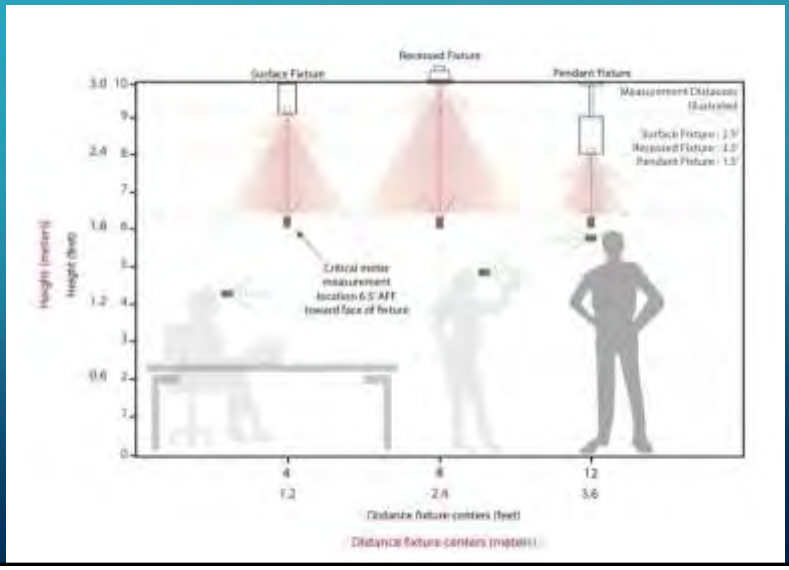
Safety meter with 80° cone FOV





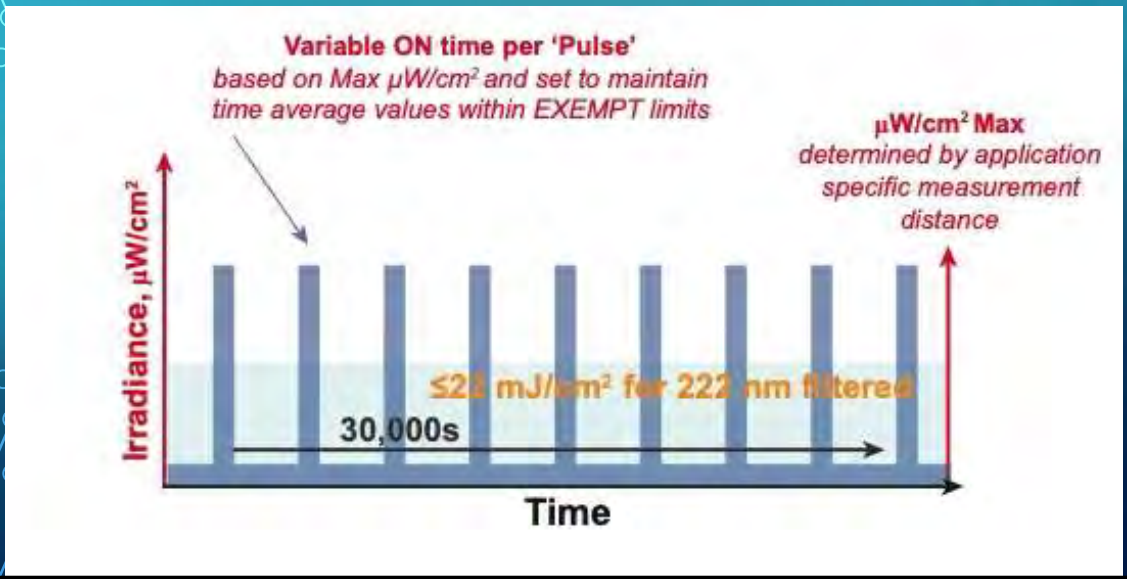
The eyes' upper FOV is limited to ~ 45°-50°; overhead down-lighting fixtures are above the eyes' FOV. The epidermal skin tissue receives little from obliquely incident rays because of exponential absorption in the stratum corneum and the outermost epidermis and the oblique rays are also much more reflected (Fresnel reflection).

HOW DO WE APPLY THE HUMAN EXPOSURE LIMITS OF ACGIH AND ICNIRP? AND THE PHOTOBIOLOGICAL LAMP SAFETY STANDARDS IEC62471:2006 AND IES RP27-3-17?

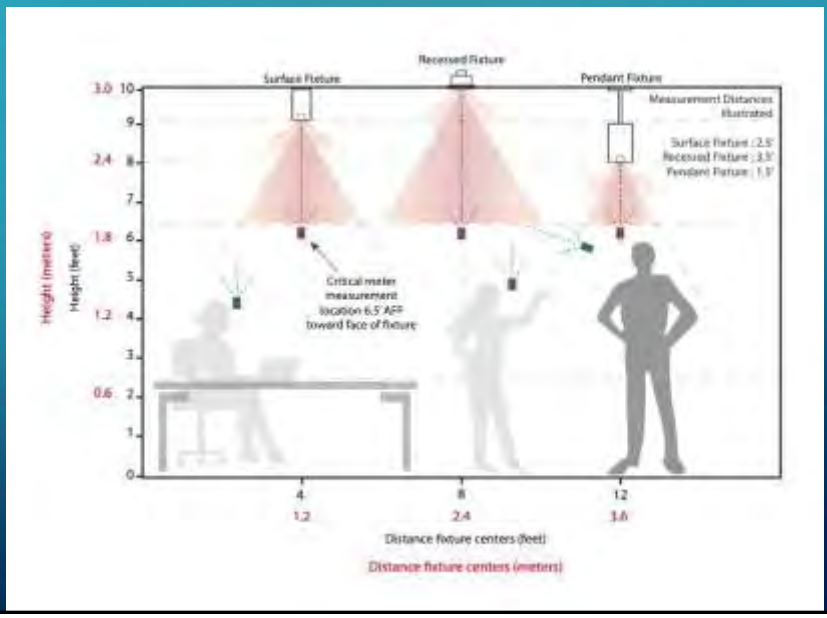


The correct assessment of ***ocular*** exposure is to aim the 80° FOV meter horizontally and at the typical viewing directions

REMEMBER: TIME-WEIGHTED AVERAGING OF LIMITS - *ACCOUNTING FOR EXPOSURE DOSE LIMITS*



REALISTIC ASSESSMENT OF OVERHEAD SKIN EXPOSURE

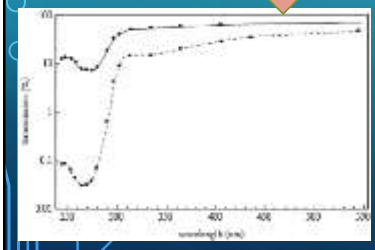


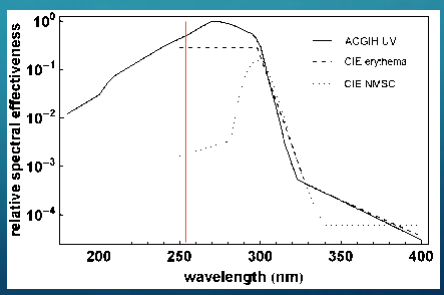
Aim detector upward and toward fixtures

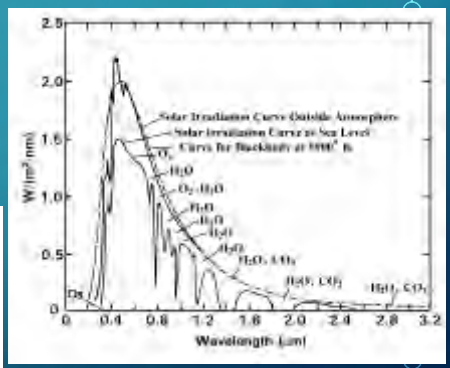
IS THERE A REALISTIC SKIN CANCER RISK?

THE FIRST LAW OF PHOTOBIOLOGY – PHOTONS HAVE TO BE ABSORBED TO PRODUCE AN EFFECT – AND THEY HAVE TO REACH THE TARGET MOLECULES

- TYPICAL CONCERN – If UV-C has highest photon energy why is it not more phototoxic and a more severe skin cancer risk!??
  - UV-B photons are less energetic but they penetrate deeper
- Bruls transmission measurements



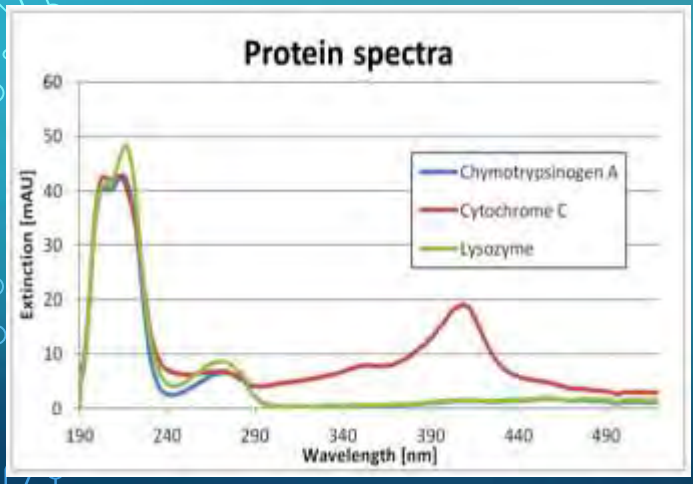


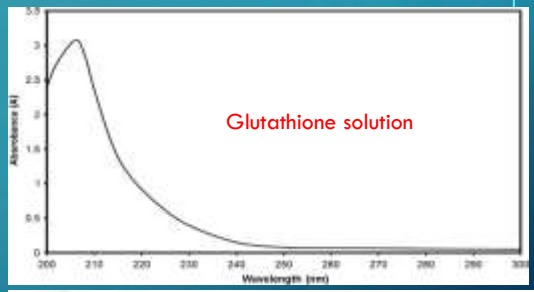


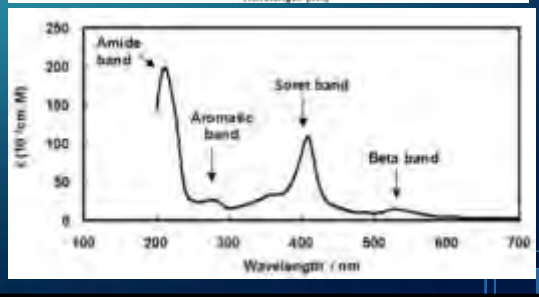
Sunlight spectrum – only trace amounts of UV-B reach ground level and no UV-C at all (Sliney & Wolbarsht, 1980); Sliney DH, Balancing the Risk of Eye Irritation from UV-C with Infection from Bioaerosols†2013

See: CIE 187:2010 – UV-C Photocarcinogenic Risks from Germicidal Lamps

WHY THE INTEREST IN SHORT-WAVELENGTH UV-C? IMPLICATIONS OF KEY BIOLOGICAL MOLECULES



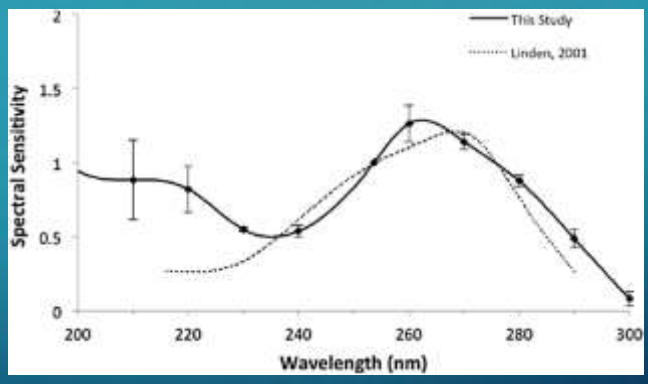




KrCl Excimer Lamps at 222 nm offer promise of a safer in-room (whole-room) application

BECK ET AL, 2015

Action spectra for validation of pathogen disinfection in medium-pressure ultraviolet (UV) Systems, *Water Research* (2015)



- This research from the University of Colorado led to the hope for applying 222/207-nm KrCl lamp for GUV! Later Presentation!
- Efficacy? Safety? Lamp technology?