

PHOTOBIOLOGICAL SAFETY ISSUES - UVGI INSTALLATIONS

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CHAIR, IES PHOTOBIOLOGY COMMITTEE

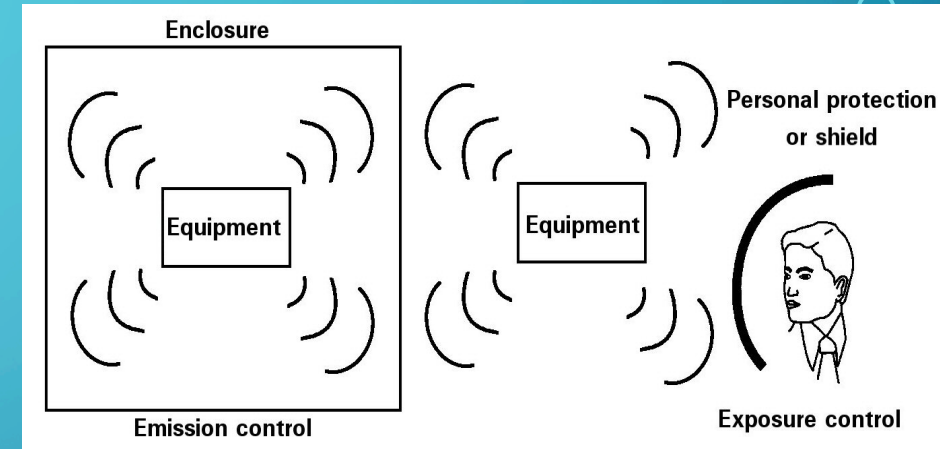
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Photobiological Exposure Limits for UV and safety standards for lamps and lamp systems

• Emission Limits

- Used in Product Safety Standards (IEC, UL, etc.)
- Often termed “accessible emission limits”
- Measurement conditions specified based upon pre-determined human exposure conditions



• Exposure Limits

- Used for occupational safety standards (TLVs)
- Measured at location of exposed person



IES PHOTOBIOLOGY COMMITTEE DRAFT STANDARD

BASIS – The EXISTING GENERAL STANDARD:

- ANSI/IES RP27-20 (Combined Version of RP27-1, -2, -3) *Recommended Practice for Photobiological Safety for Lamps and Lamp Systems*
 - General guidance since the first editions dating to 1993
 - Basis for CIE S009/IEC62471:2006
 - Provides Risk Groups, Exempt, RG-1, RG-2, RG-3 (UVGI – RG-3, high-risk)

CURRENT DRAFT STANDARD FOR UVGI

- RP27-xx *Recommended Practice: Ultraviolet Germicidal Irradiation (UVGI)*
 - Focus on safety of upper-room (or whole-room) UVGI
 - Completed first ballot on Dec 23, 2020; now addressing editorial comments

SARS-CoV2:

PRIMARY MEANS OF TRANSMISSION

- as stated last spring by Dr. E. Nardell

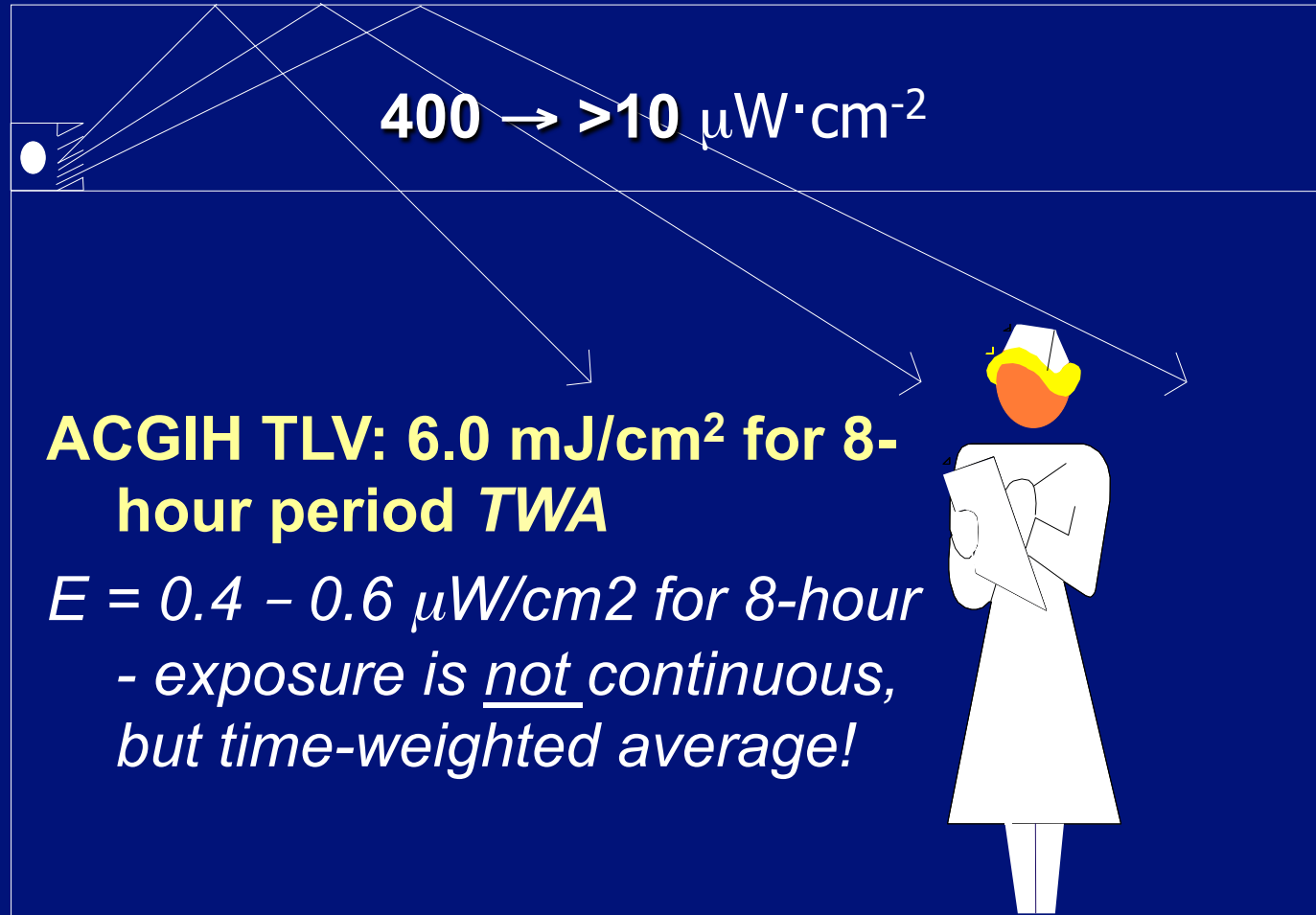
- Airborne Transmission
 - Respiratory Droplets (e.g., coughs)
 - Aerosolized Droplet Nuclei
- 2nd - Contact Transmission (fomites)



From Dr. Nardell:

“Upper Room 254 nm UV 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 UV Shelter Study (TIUSS) showed no eye or skin complaints compared to placebo lamps

Ref: Public Health Rep. 2008 Jan-Feb;123(1):52-60

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.

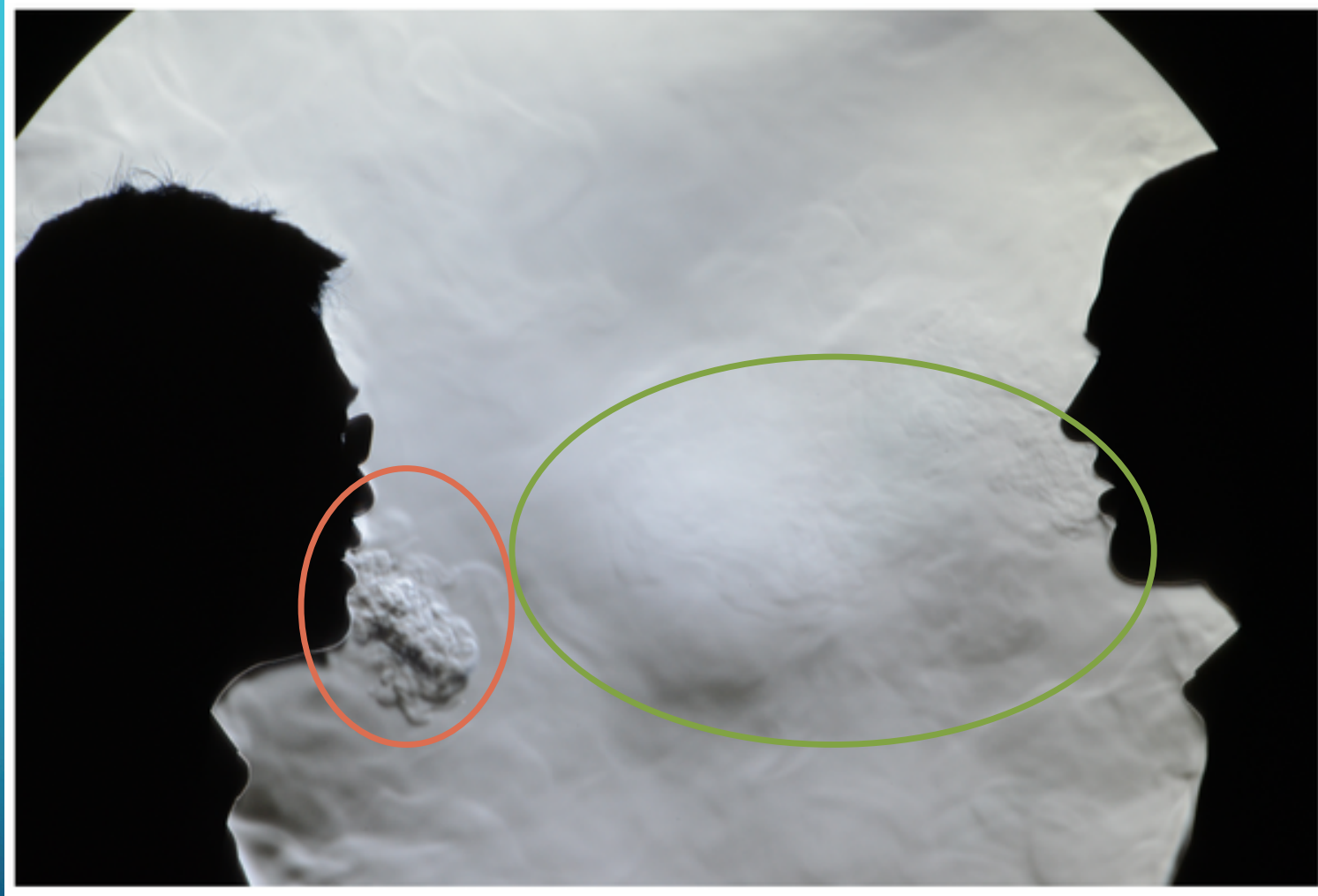
The Breathing Zone as Shown by a Schlieren Mirror

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.

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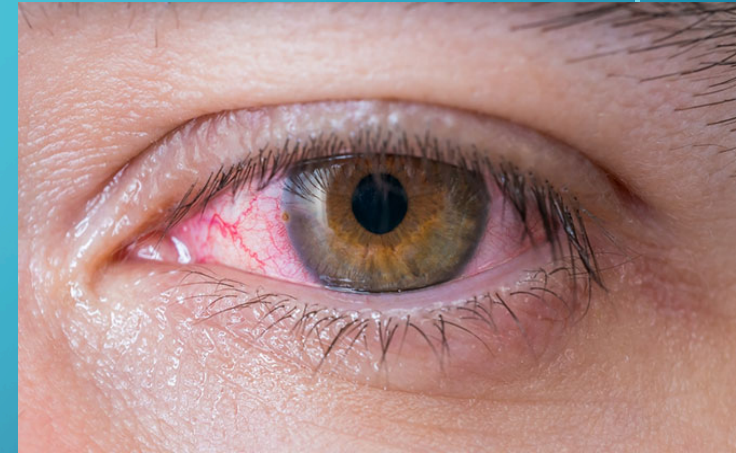


Speaking -
Particularly large
when shouting or
singing!

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.

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)

DOSIMETRY FOR HUMAN EXPOSURE LIMITS - THE CONCEPT OF PHOTOBIOLOGICAL DOSE

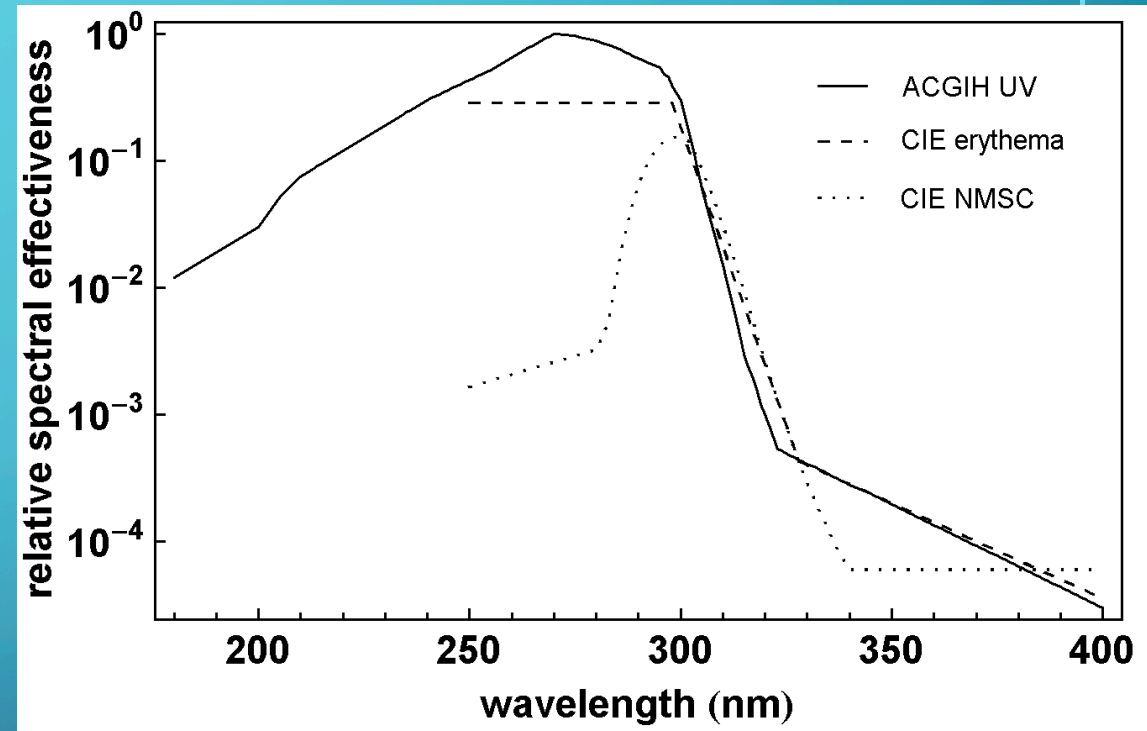
- Fundamental to photobiology - Bunsen-Roscoe Law (photochemistry)
 - reciprocity of dose-rate (irradiance) E and time t
 - $E \times t = H =$ “the exposure dose”
 - Loss of reciprocity over several hours typical
- Normally all optical radiation, including UV is absorbed on a surface
- Power divided 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

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 (**weighting**) $S(\lambda)$

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

- $S(\lambda)$ -spectral weighting leads to an **effective radiant exposure** of 3.0 mJ/cm² (30 J/m²)
- Limit is **daily** – including multiple exposures
- Time-weighted average (TWA) over a day
- At 254 nm this is 6 mJ/cm² (60 J/m²)
 - Or, time-averaged irradiance of 0.2 μW/cm²
- Large safety margin for human skin in UV-C – Should there be two limits? – *For the Eye, For the Skin?*



ACGIH UV $S(\lambda)$ spectral weighting function (action spectrum) is the solid line.

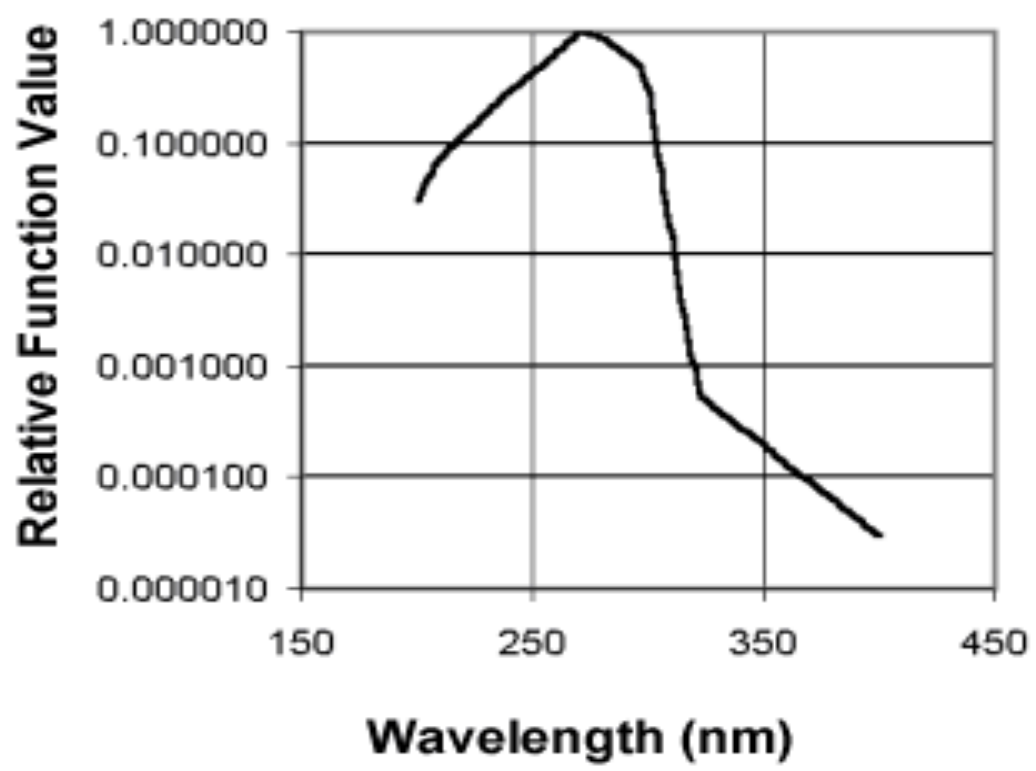
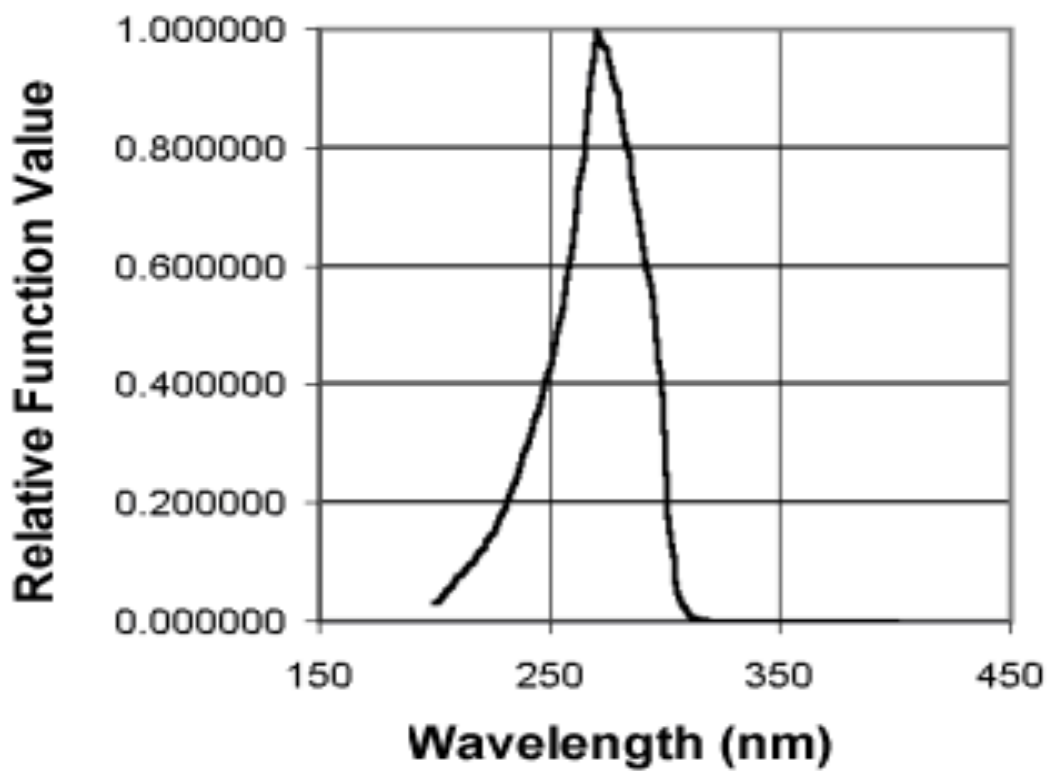
$$S(\lambda) = 1.0 \text{ at } 270 \text{ nm}$$

$$S(\lambda) = 0.5 \text{ at } 254 \text{ nm}$$

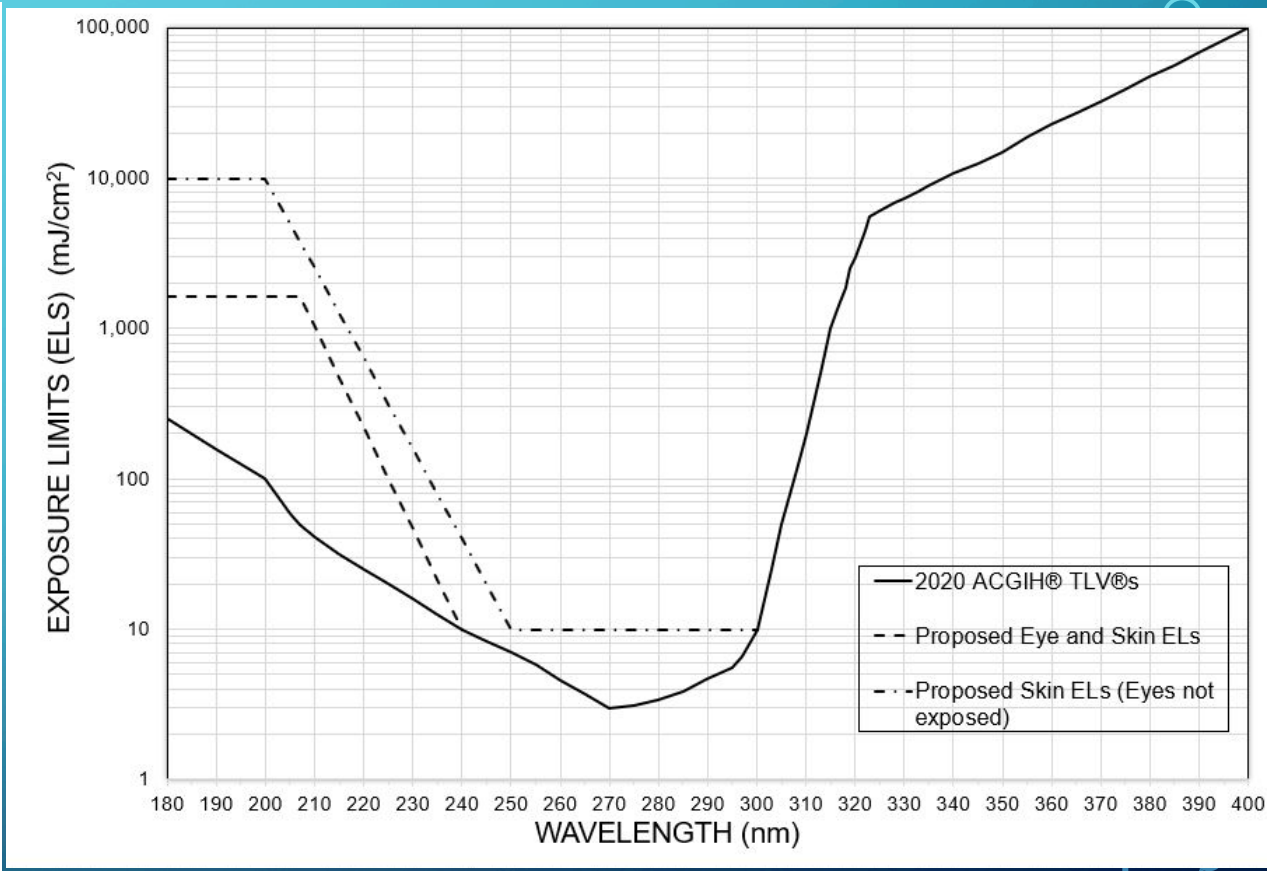
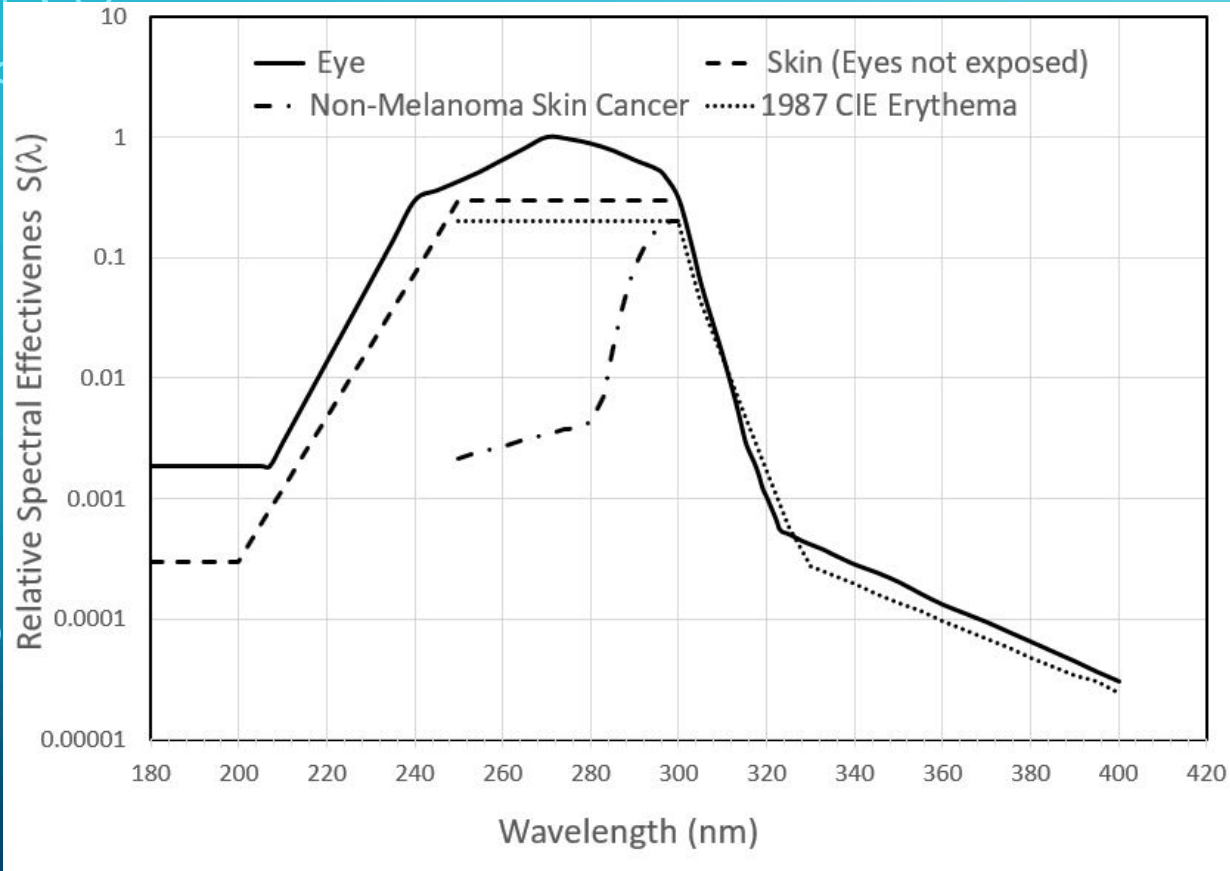
THE BASIS OF UV EXPOSURE LIMITS—THE ACTION SPECTRUM: ICNIRP/ACGIH UV HAZARD FUNCTION

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

UV Hazard Function



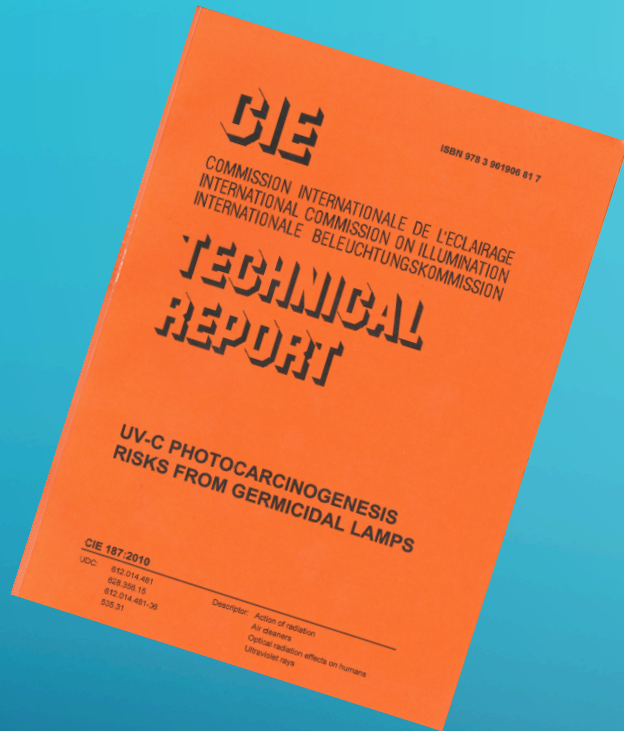
ACGIH NOTICE OF INTENT TO CHANGE – 2021 ULTRAVIOLET RADIATION (UV-C ADJUSTMENT)



NIC Action spectra $S(\lambda)$ & CIE NMSC

ACGIH NIC UV-C Exposure LIMITS (TLVs)

UVGI SAFETY REVIEWS



Photochemistry and Photobiology,
Invited Review

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

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¹Consulting Medical Physicist, Fallston, Maryland

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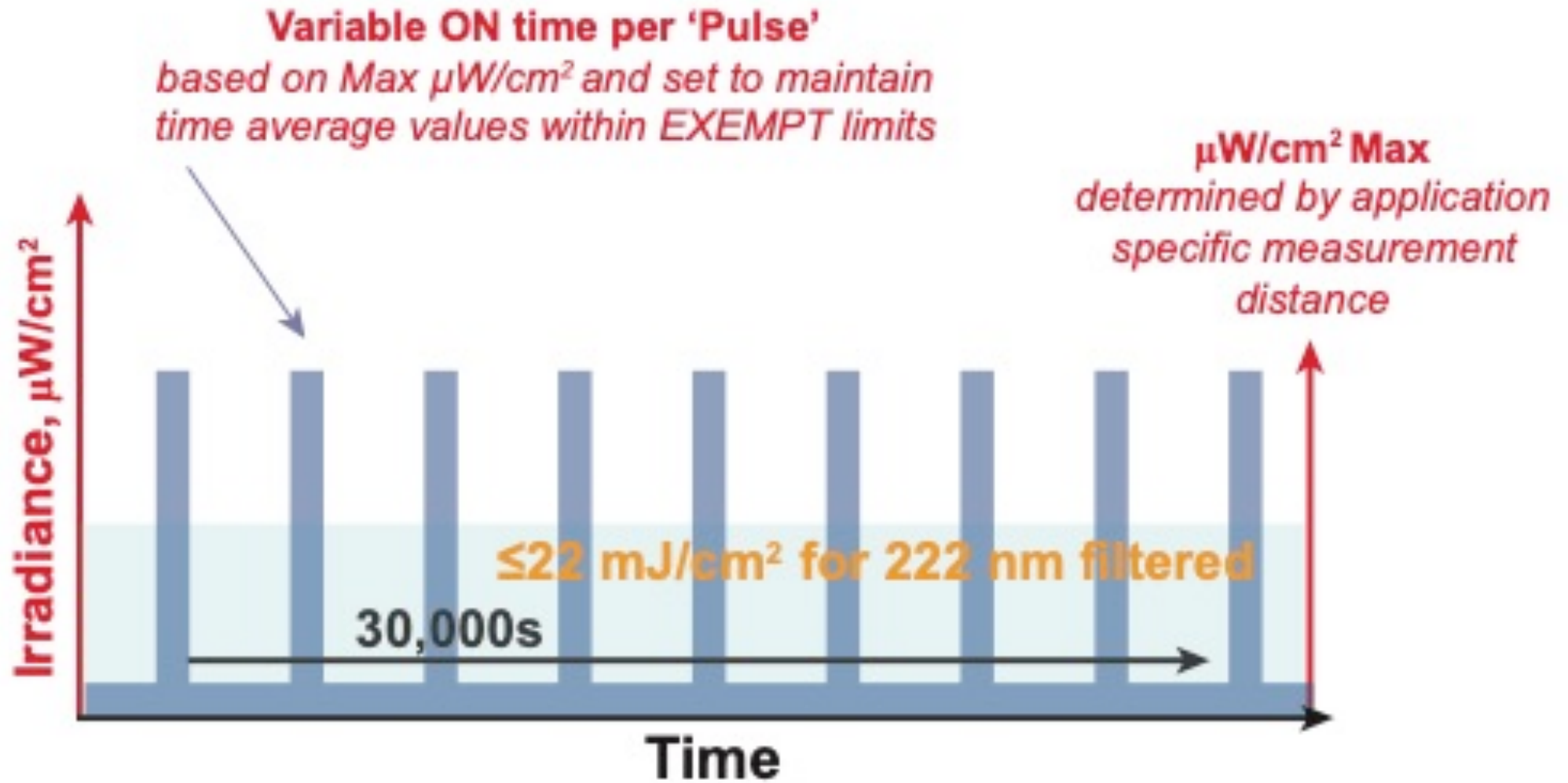
Received 13 November 2012, accepted 3 May 2013, DOI: 10.1111/php.12093

ABSTRACT

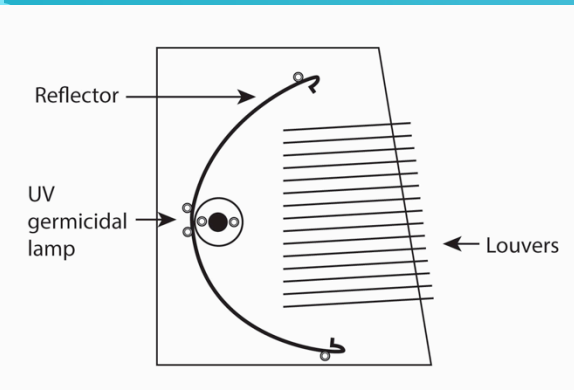
The very aspect (phototoxicity) that makes short-wavelength ultraviolet (UV) radiation an effective germicidal agent also is responsible for the unwanted side effects of erythema (reddening of

- 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)

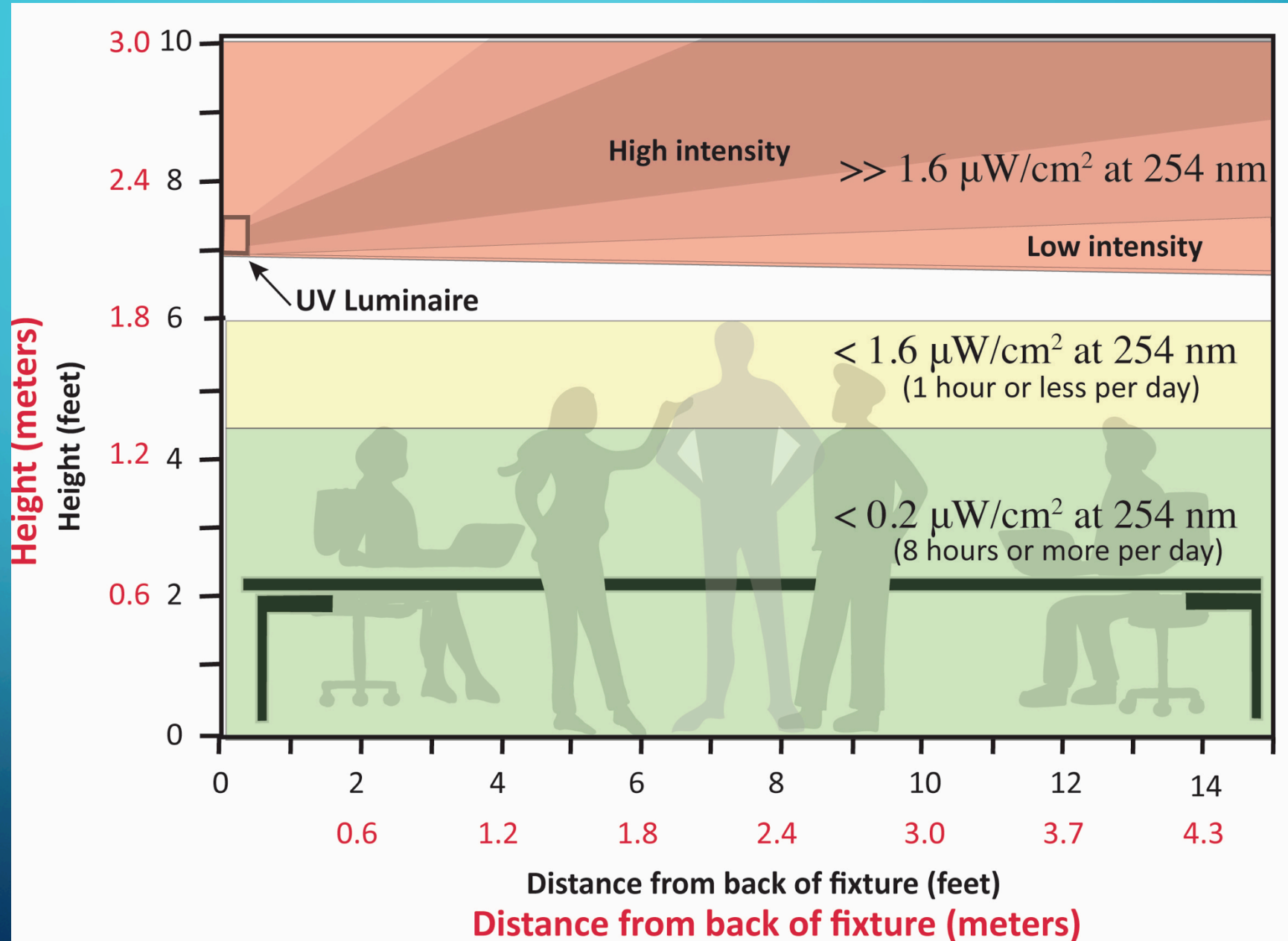
TIME-WEIGHTED AVERAGING OF LIMITS - ACCOUNTING FOR EXPOSURE DOSE LIMITS



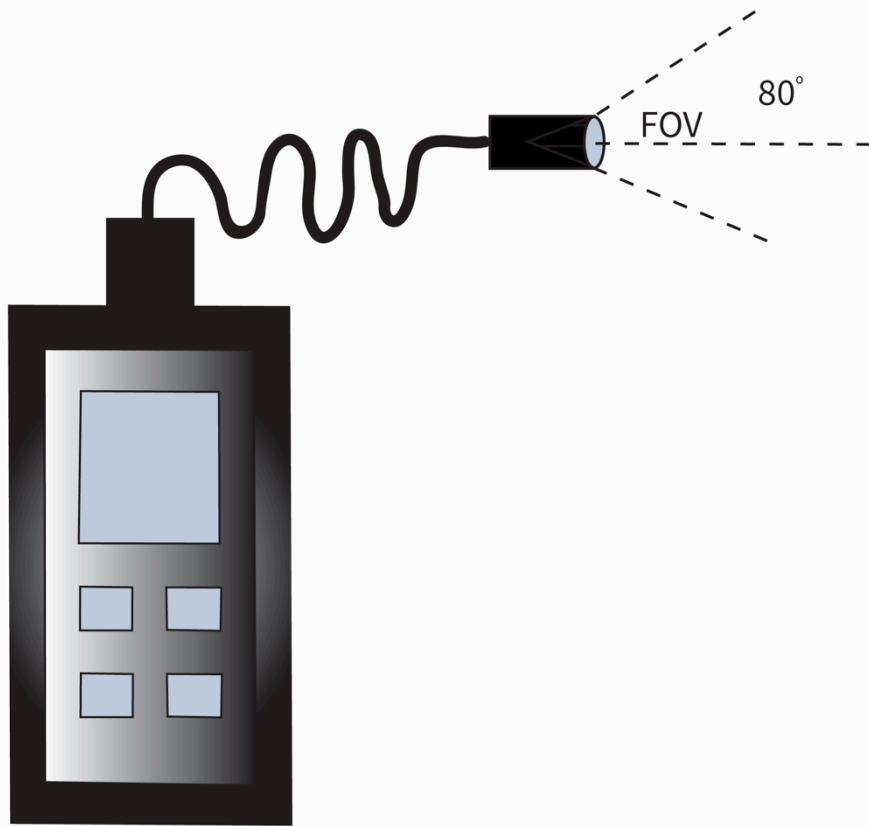
ASSESSING EXPOSURES FOR UPPER-ROOM UV-C UVGI



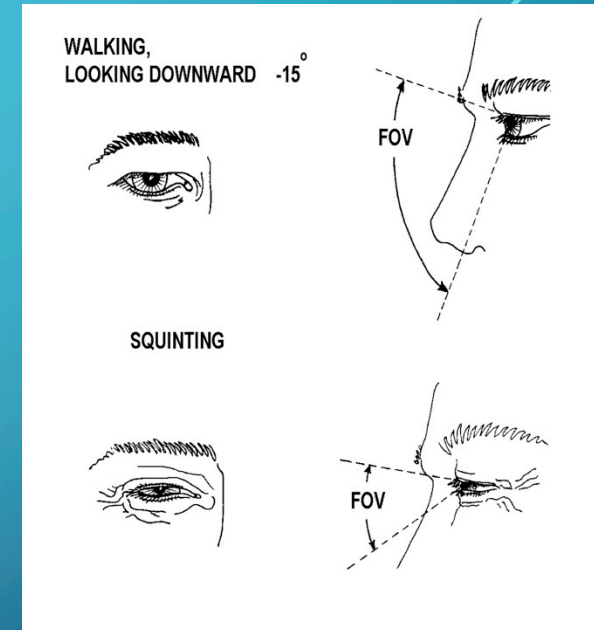
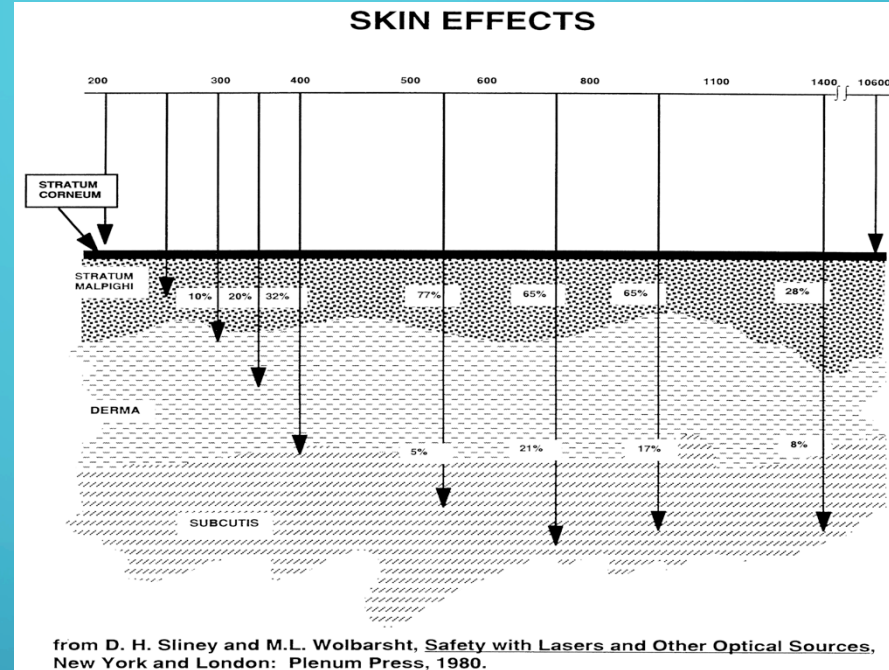
A good example of how time-weighted averaging (TWA) is employed to assess risk from scattered UV-C an example!



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

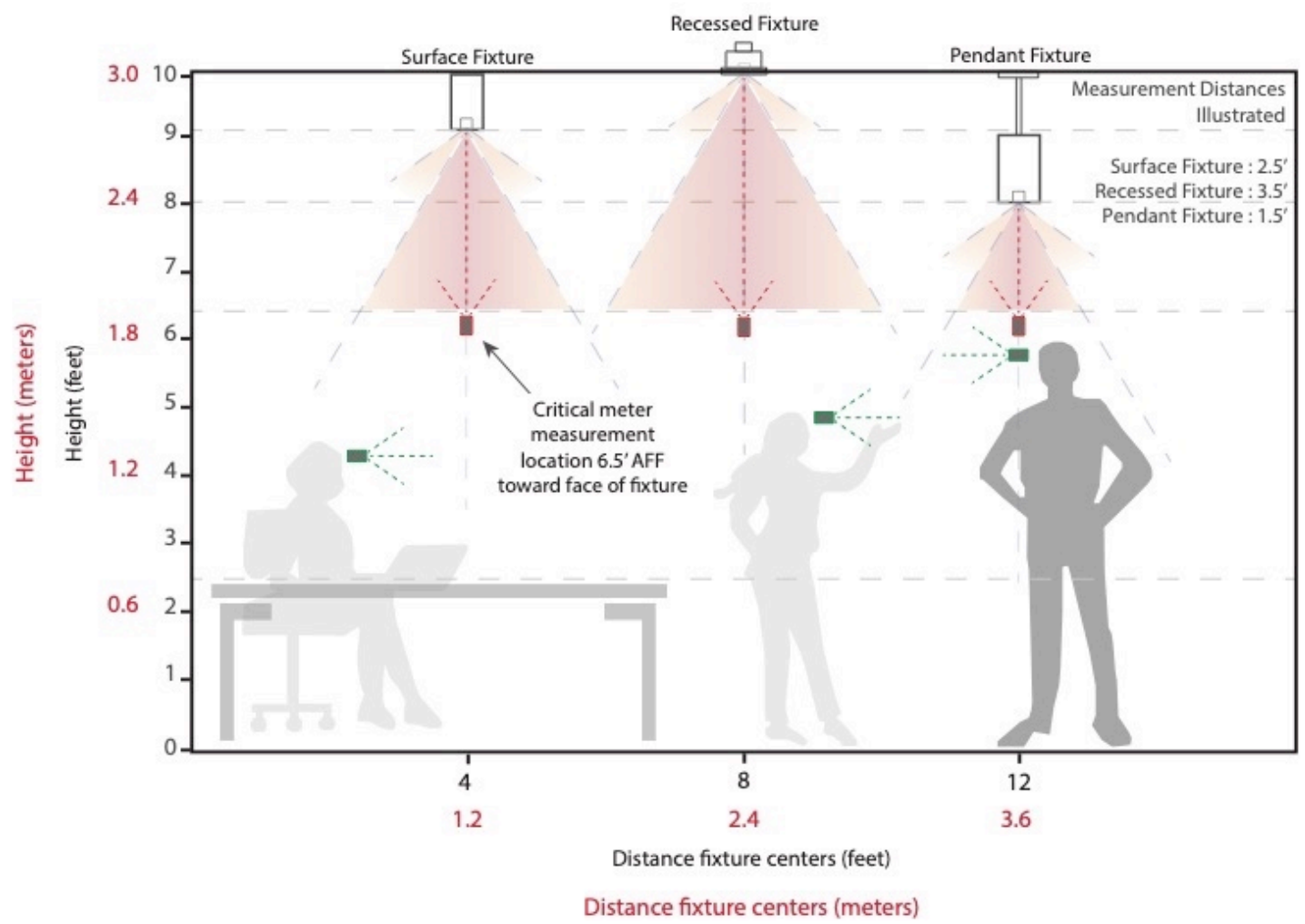


Safety meter with 80° cone FOV



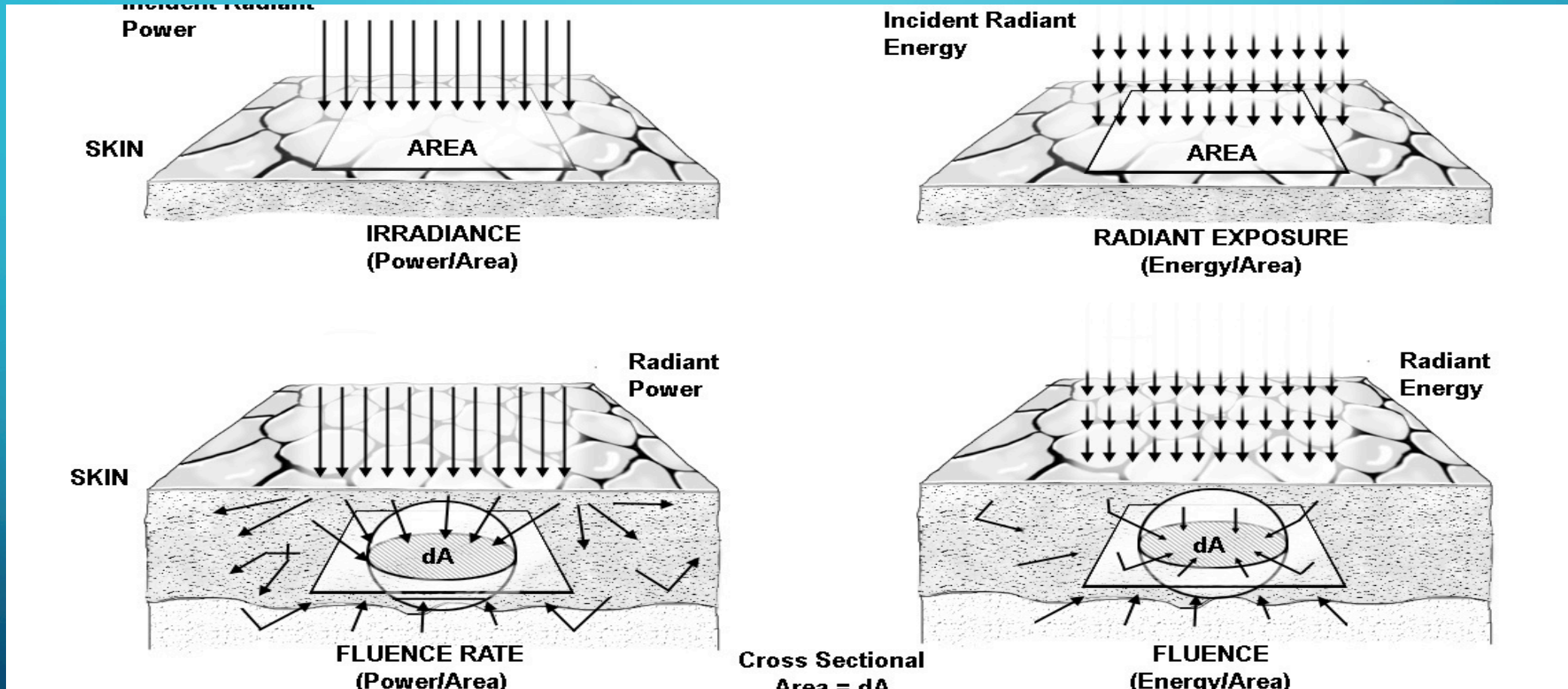
The eyes' upper FOV is limited to $\sim 45^\circ$ - 50° ; overhead down-lighting fixtures are above the eyes' FOV. The epidermal skin tissue receives little from obliquely incident rays because of exponential absorption in the stratum corneum and the outermost epidermis and the oblique rays are also 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

DESCRIBING EXPOSURES (CIE)

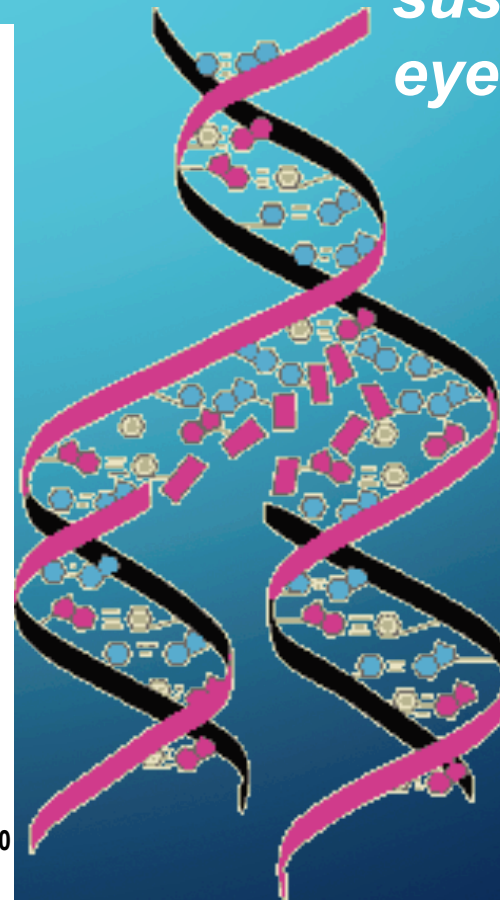
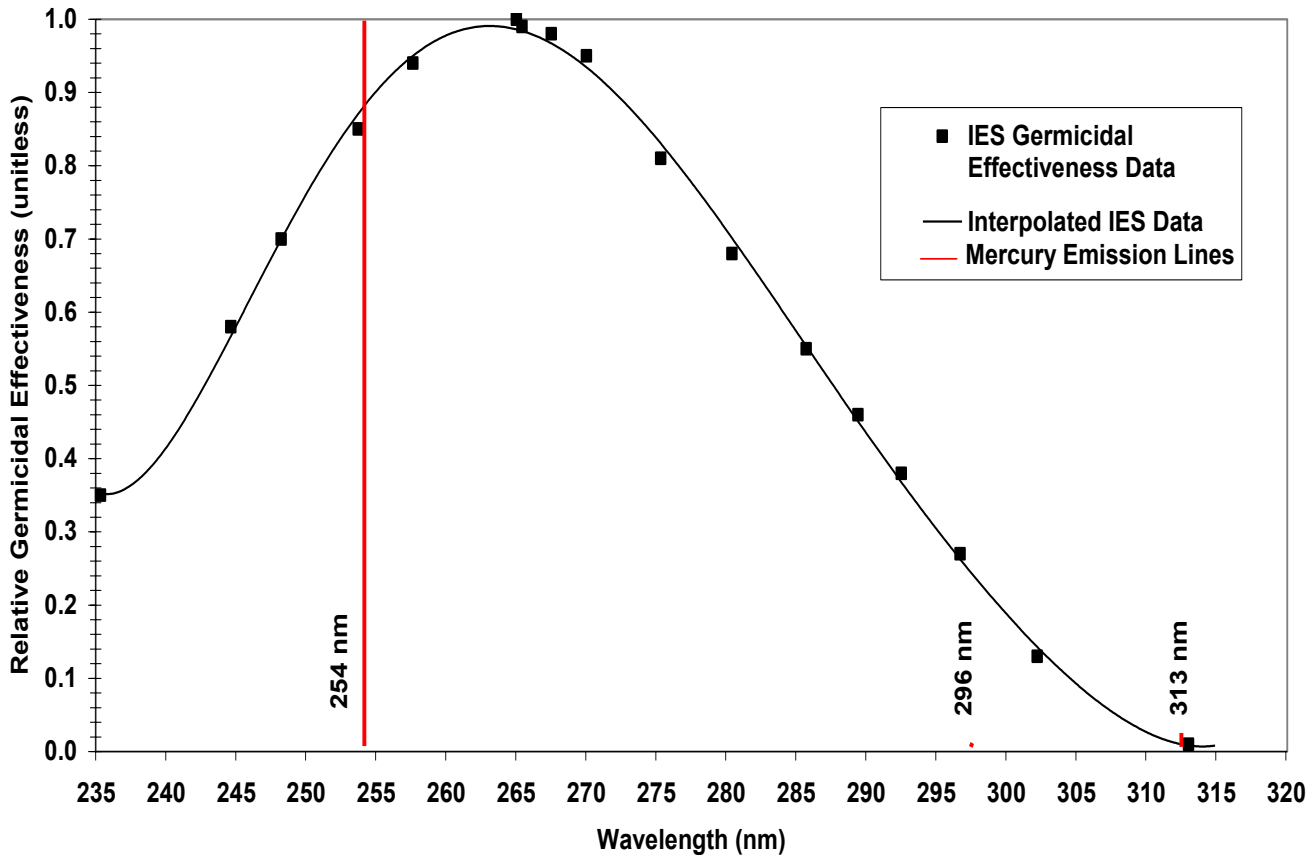


Current guidance – Fluence rate of $\sim 5-15 \mu\text{W}/\text{cm}^2$ in room air

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!