The Need for Fluence-Rate Measurement Instruments

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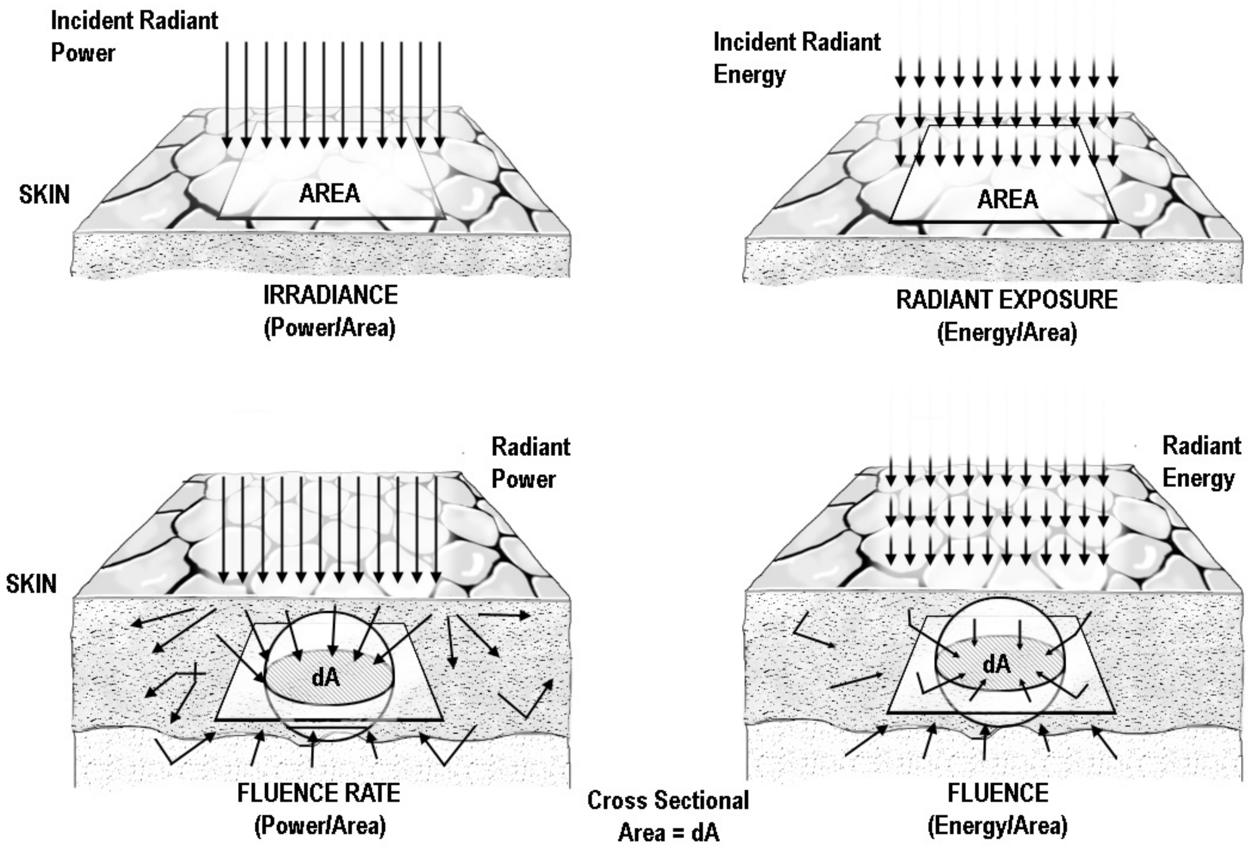
Why is Fluence Rate Important?

- Fluence rate is sometimes referred to as ***spherical irradiance***

- The reason that fluence and fluence rate are important in photobiology relates to the fact that backscatter, or photons arriving from different sources at a sensitive biological molecule – a chromophore – are equally effective regardless of direction; hence cosine-response irradiance detectors greatly underestimate the fluence-rate.

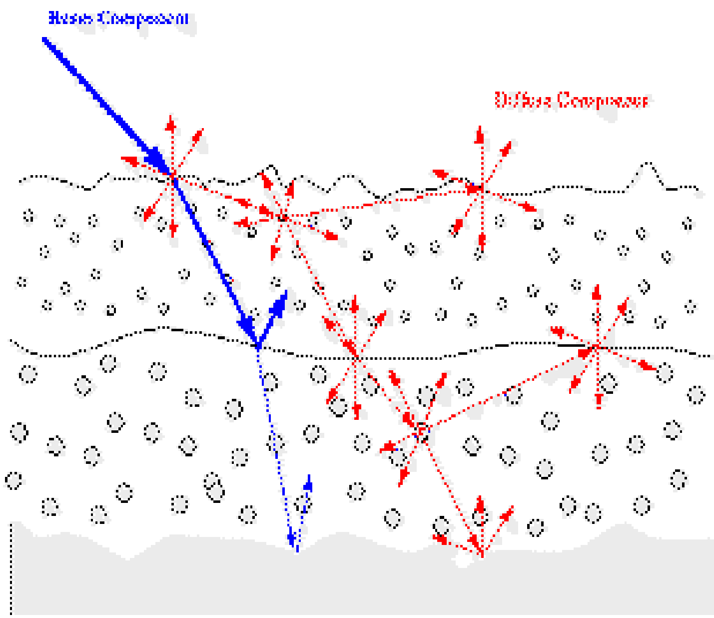
CIE Radiometric Quantities Important in Photobiology

- It is disappointing that so many engineers misuse the term “fluence” to mean either irradiance or radiant exposure!
- Fluence is the “dose” in photochemical interactions with molecules
- Because multiple scattering (and backscatter) in tissue, the highest fluence is often below the surface!
  - This is not a violation of Conservation of Energy!
  - It is a “summation of hits” at the molecule



Why is Fluence Rate Important?

- Fluence rate is particularly important to measure or calculate in photobiology.
- Fluence rate probes have been developed in past decades to measure internal body tissue exposure rates for photoactivation of drugs (as in photodynamic therapy, PDT).
- Today, with the increased interest in the application of indoor **germicidal ultraviolet (GUV)** inactivation of aerosolized viruses and bacteria, there is a true need to actually measure ultraviolet-C fluence-rate rather than to measure simple UV-C irradiance within the disinfection irradiation zone



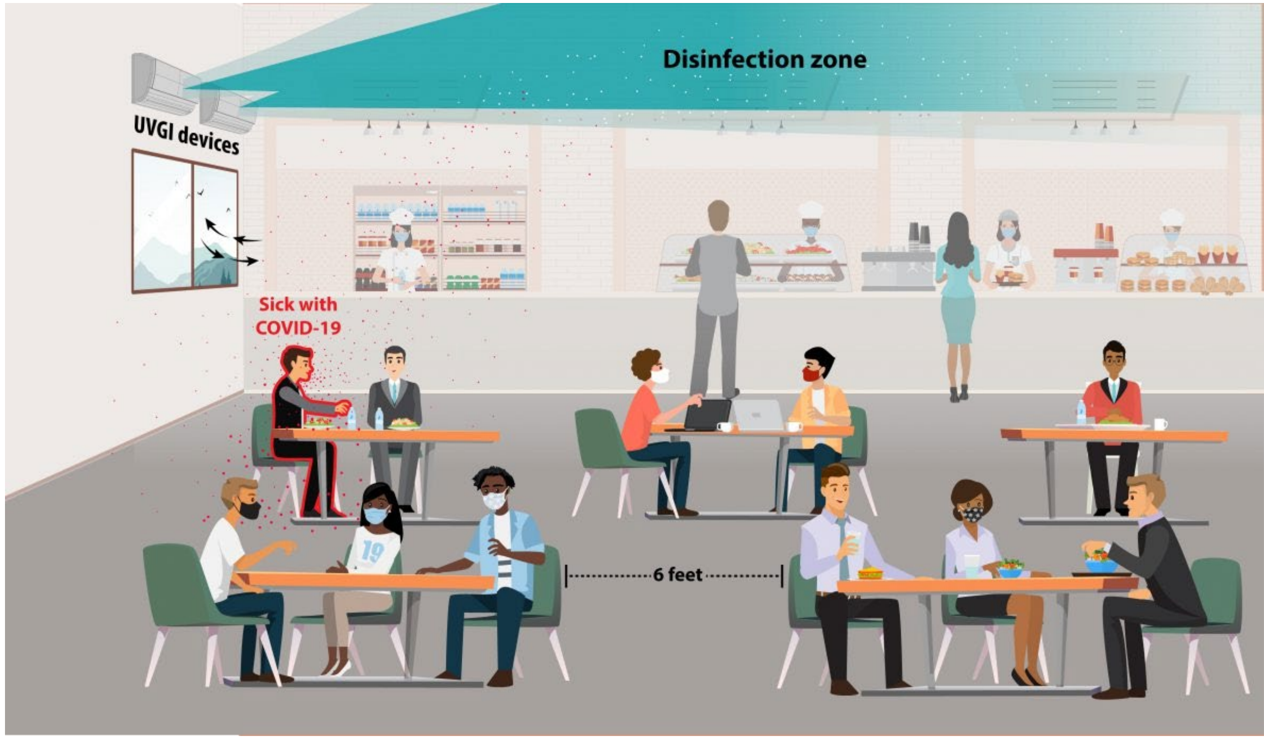
What is Germicidal Ultraviolet Radiation?

- Only UV-C (100-280 nm) has been shown highly effective

- And GUV *efficacy* requires measures of fluence rate

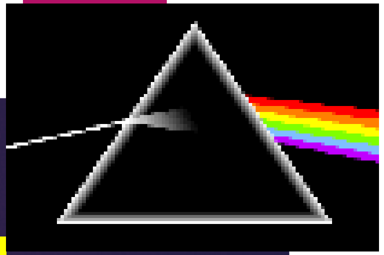
- **Germicidal UV – a History**
  - GUV for air disinfection was demonstrated in the 1920s and 1930s
  - Widely used through the 1950s when there were no vaccines for measles, mumps, polio, etc.
  - Largely went into obscurity except to control tuberculosis (TB) – in special locations and in some other countries.
  - Upper-Air UV-C is still used in TB hospitals

Upper-Room UV-C irradiates above 1.9 m if ceiling height is sufficient – traditional Hg-lamp 254-nm



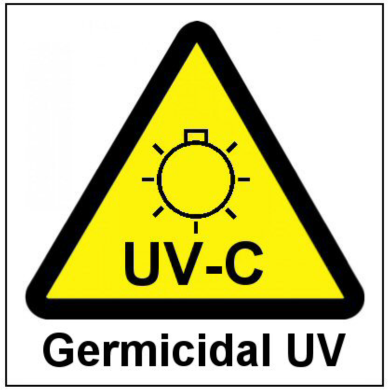
Remember:

The CIE Photobiological Spectral Bands



- In the early 1930's, the CIE Committee on Photobiology created the concept of the CIE photobiological spectral bands and named the bands. These remain as international standards for ***short-hand notations***:

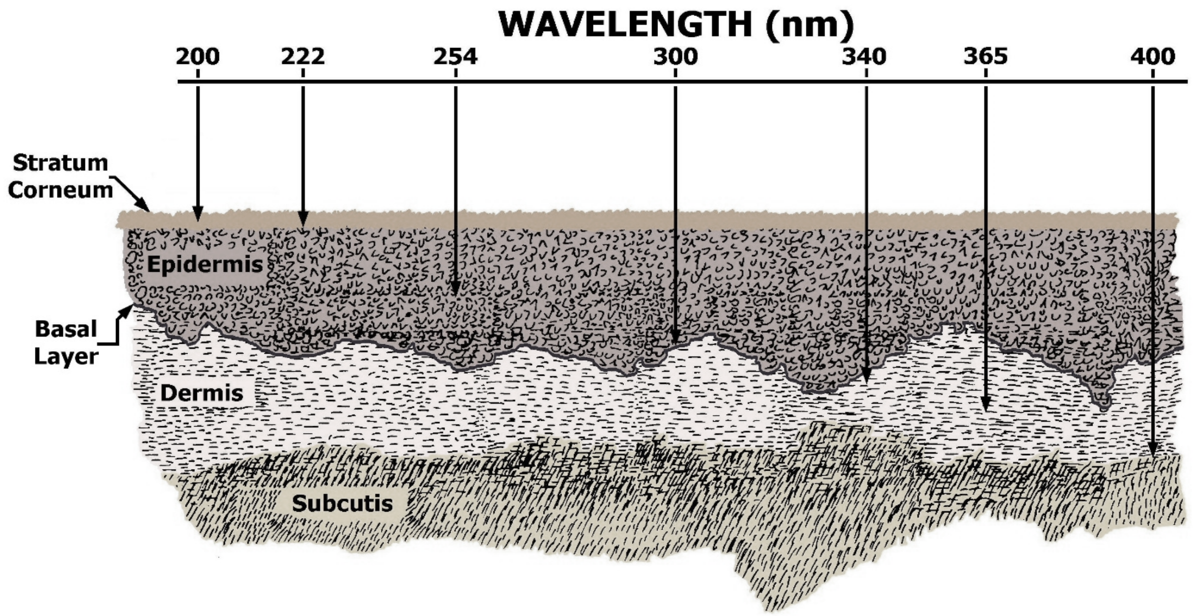
- UV-A 315 nm to 400 nm ("near UV radiation" or "black light")
- UV-B 280 nm to 315 nm ("actinic radiation")
- UV-C 100 nm to 280 nm ("germicidal")
- **Visible 360-380 nm to 780 nm (overlap intended)***
- IR-A 760-780 nm to 1400 nm (0.78 µm to 3.0 µm)
- IR-B 1400 nm to 3000 nm (1.4 µm to 3.0 µm)
- IR-C 3000 nm to 10^6 nm (3.0 µm to 1 mm)



  - Source: CIE Publication 134/1 – Standardization of the Terms UVA1, UVA2 & UVB

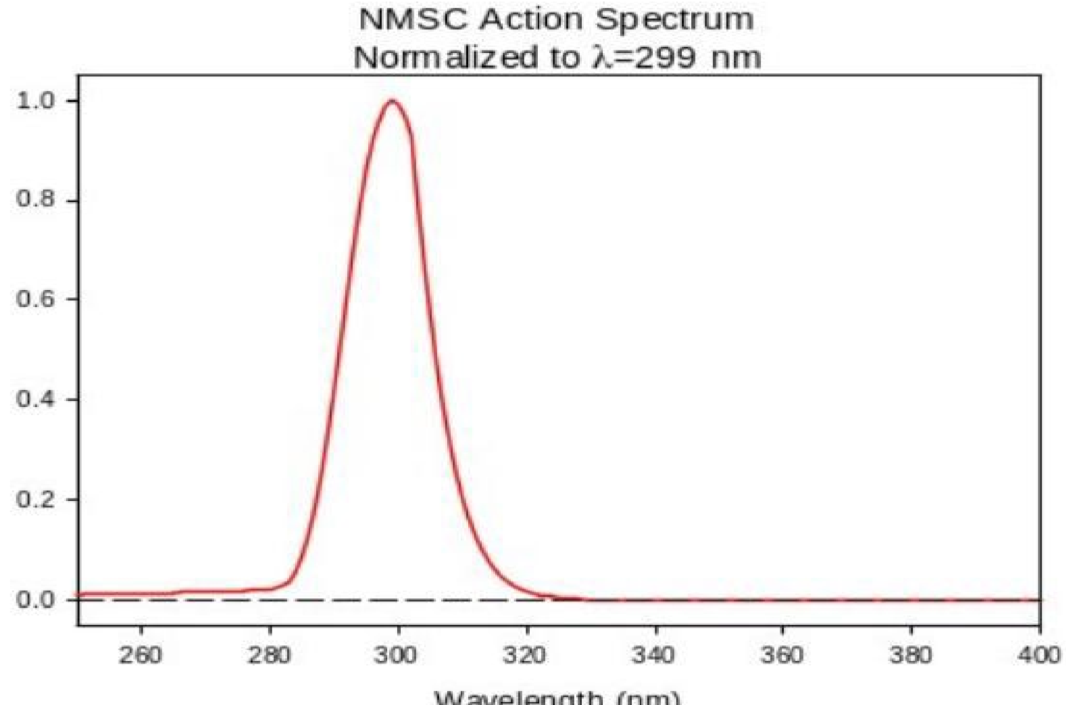
Delayed effects in the Skin Depend on Penetration depth which depends on wavelength *and UV-C is absorbed superficially*

A risk of skin cancer ("photocarcinogenesis") exists if significant rays reach the germininative ('basal') layer of the epidermis but less than 1% of UV-C does.



(figure adapted from Sliney & Wolbarsht, 1980)

- UV-C exposure poses very low carcinogenic risk compared to UV-B in sunlight.



Why is Germicidal UV-C Important?

- *And why is Far UV-C (200-235 nm) a new interest?*

- **Why is germicidal UV-C important**?
- Only relatively safe means to inactivate microbes in indoor air
- And worldwide, airborne transmitted diseases have great health impact
  - Covid-19: 6.9 million deaths (1.1 M in US)
  - Influenza: ~500,000 deaths/year
  - TB: 1.6 million deaths/year
  - … the next pandemic
  - …potential bioterrorism
- Upper-room UV-C 254-nm used widely in the past for infectious diseases

- **KrCl Excimer lamps that emit filtered 222-nm** far UV-C are now being used for aerosol inactivation in occupied spaces
- 222-nm barely penetrates the stratum corneum and produces CPDs only in top layer of epidermal (non-mitotic) cells – **very high MED**

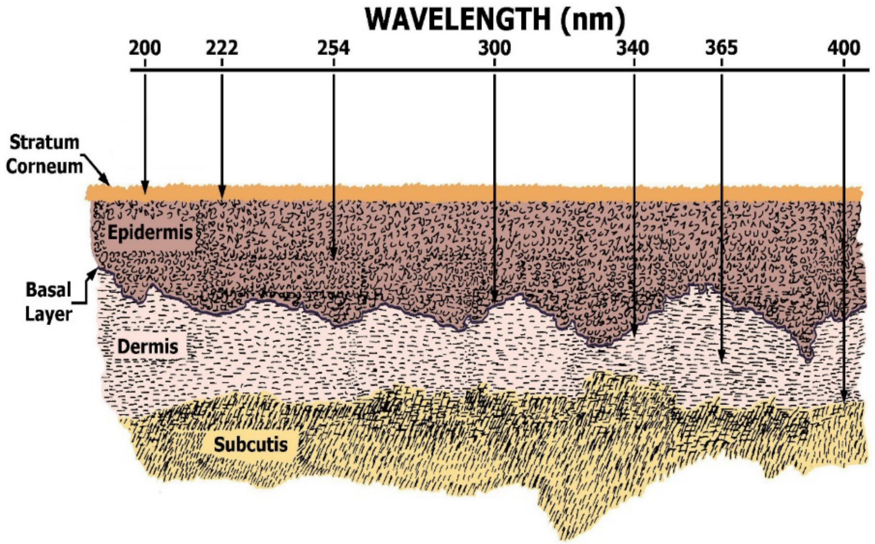


Image adapted from Sliney & Wolbarsht, 1980

Have fluence-rate probes been developed?

- Fluence-rate probes developed for use in biomedical laser applications made use of a spherical integrator tip at the end of an optical fiber which transmitted light to a detector.
- In medical applications, the photobiological effect could be measured, but in indoor atmospheres it is very difficult to measure inactivation of microbes.
- Alternatively, in past GUV installations, fluence detectors have measured the photochemical change within a quartz vial suspended in air.

What have engineers done in the past to estimate photobiological dose rate?

- A surface detector that is "cosine corrected" has an effective field-of-view of only π steradians (sr) and not the full 2-π sr of a hemisphere.
- In medical photobiology fluence is defined at a single point (e.g., a single molecule) deep beneath the skin where there is an infinitesimal circular area element dA that can be altered by photons arriving from any direction (i.e., from 4-π s (sr).
- In medical treatments for cancer using photodynamic therapy, engineers built the fluence-rate dosimeter probes by using a fiber-optic tip that can be inserted into tissue to measure fluence rate to include the huge added scatter component that occurs within tissue in the near infrared and red end of the visible
- Engineers at U Colo. (Shelly Miller et al.) employed four cosine detectors together aimed in four directions to measure fluence rate in an upper-room germicidal installation!

The Big Problem: Calibration

- Fluence-rate probes have been made
- But this leads to a big challenge on how to calibrate these types of detectors. Radiometric standards are needed!
- Perhaps, center them inside an integrating sphere – where a small lamp would have been placed to measure the lamp's total radiant power?
- Can we reverse calculate?

CONCLUSIONS

- There is a public-health need for further development of effective germicidal UV (GUV) depends on reliable instruments to measure fluence rate in the UV-C band.

- CORM and CIE should encourage national laboratories to develop a means to calibrate fluence and fluence-rate detectors.