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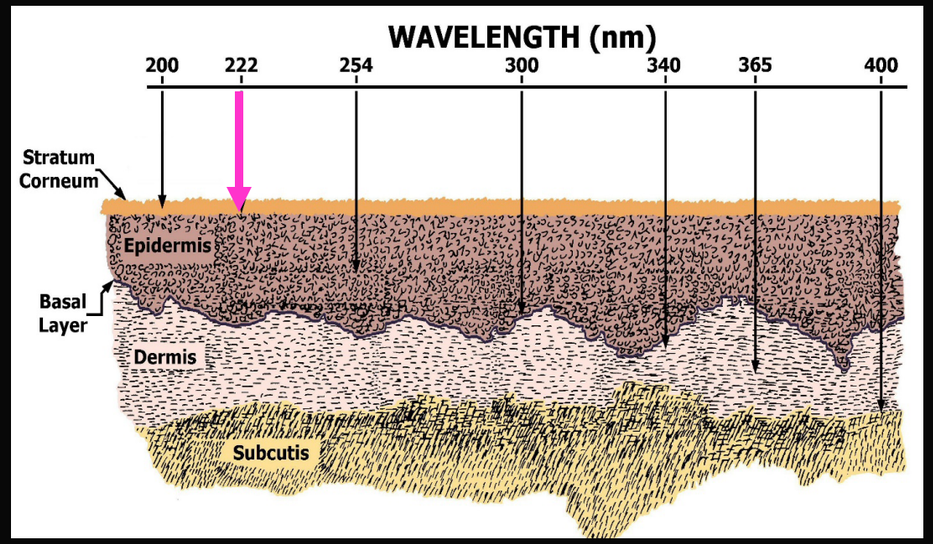
Far-UVC Light:

A practical and safe approach to markedly reduce airborne pathogens in occupied rooms



David Brenner , Columbia University

djb3@columbia.edu

Far UVC
A potential adjunct to current approaches for room air disinfection

- Natural Ventilation – inconsistent or impractical
- Mechanical ventilation – flow limited
- Room air cleaners / HEPA filters – flow limited

- Germicidal Ultraviolet Light

We have known for many years that UVC is very efficient at inactivating airborne pathogens

Philadelphia Day School 1941

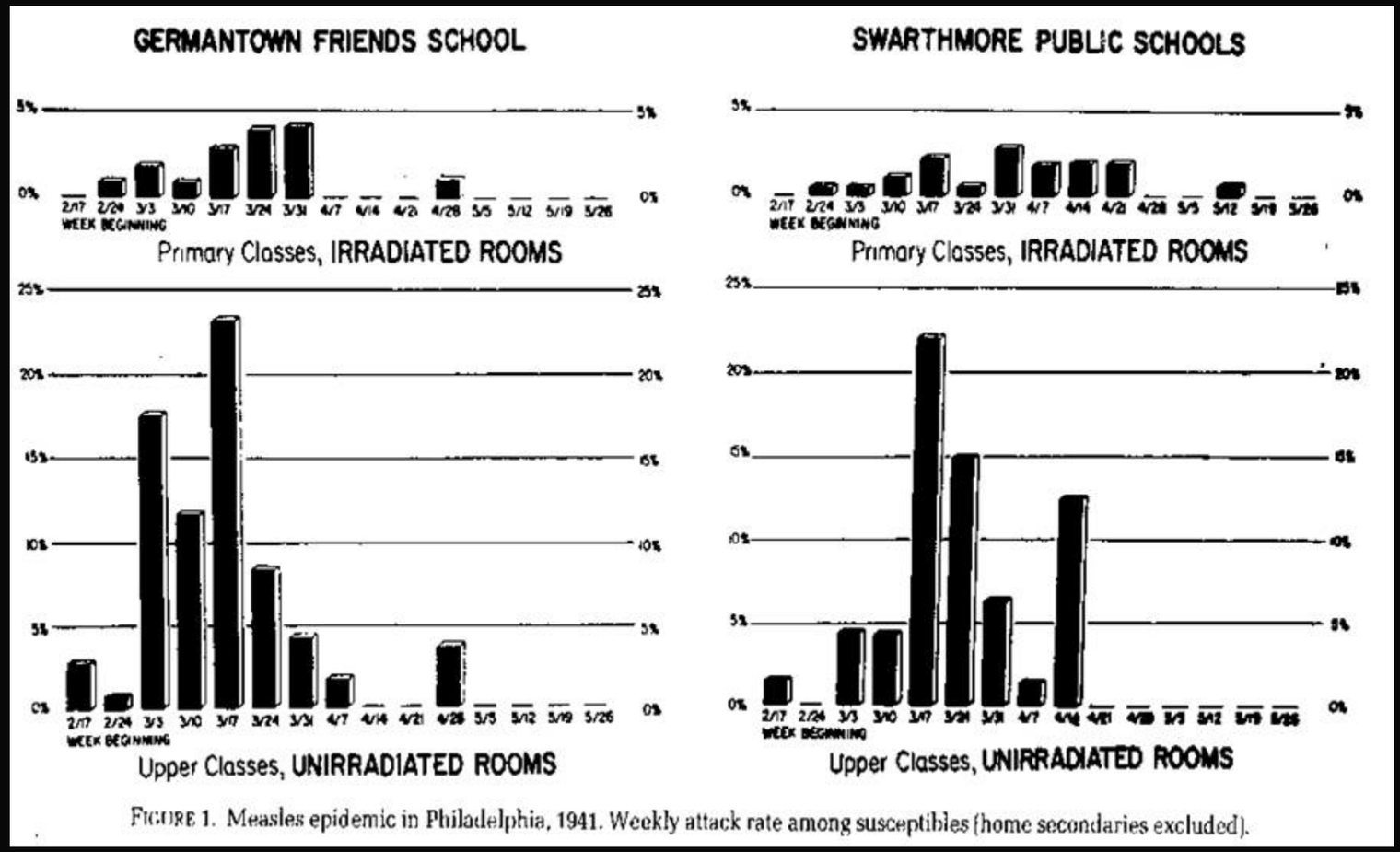
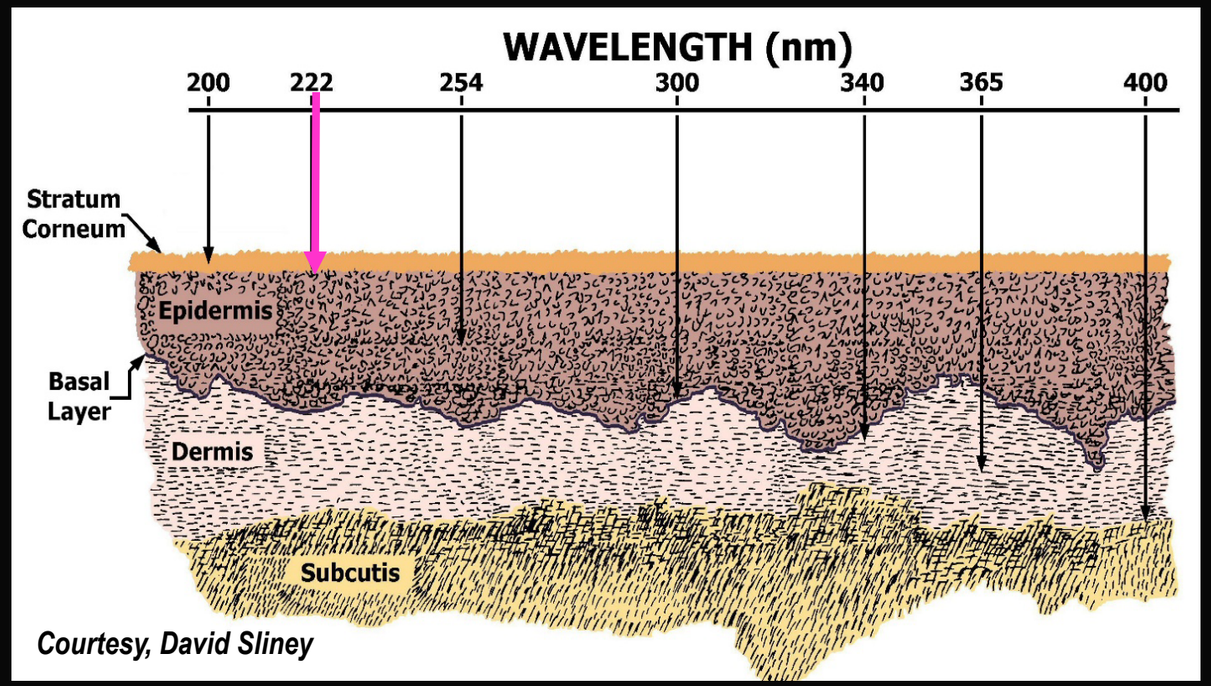


FIGURE 1. Measles epidemic in Philadelphia, 1941. Weekly attack rate among susceptibles (home secondaries excluded).

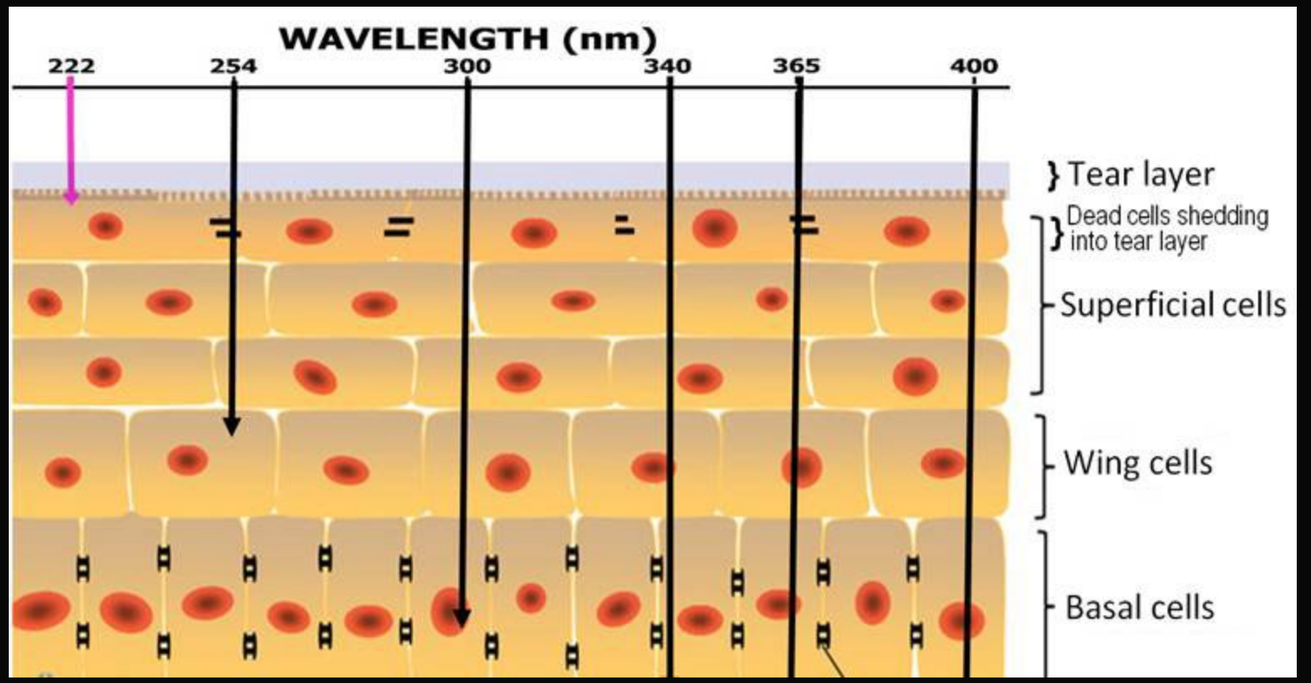
Wells et al 1941

But conventional 254-nm germicidal UVC is a potential health hazard…

Because of its very limited penetration to the key cells on the skin and eye Far-UVC has the potential to be safe for human exposure while efficiently killing airborne pathogens



Skin



Corneal epithelium

Far-UVC Light

- Is it safe?
- Does it work?

Far-UVC Light Efficacy

- Does it work?

Far-UVC to reduce airborne virus levels in a heavily occupied mouse cage-cleaning room

>99% airborne MNV viral reduction by far-UVC in an occupied room which contains high levels of aerosolized airborne virus

Scientific Reports | (2024) 14:6722 | https://doi.org/10.1038/s41598-024-57441-z nature portfolio
www.nature.com/scientificreports

scientific reports

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OPEN

222 nm far-UVC light markedly reduces the level of infectious airborne virus in an occupied room

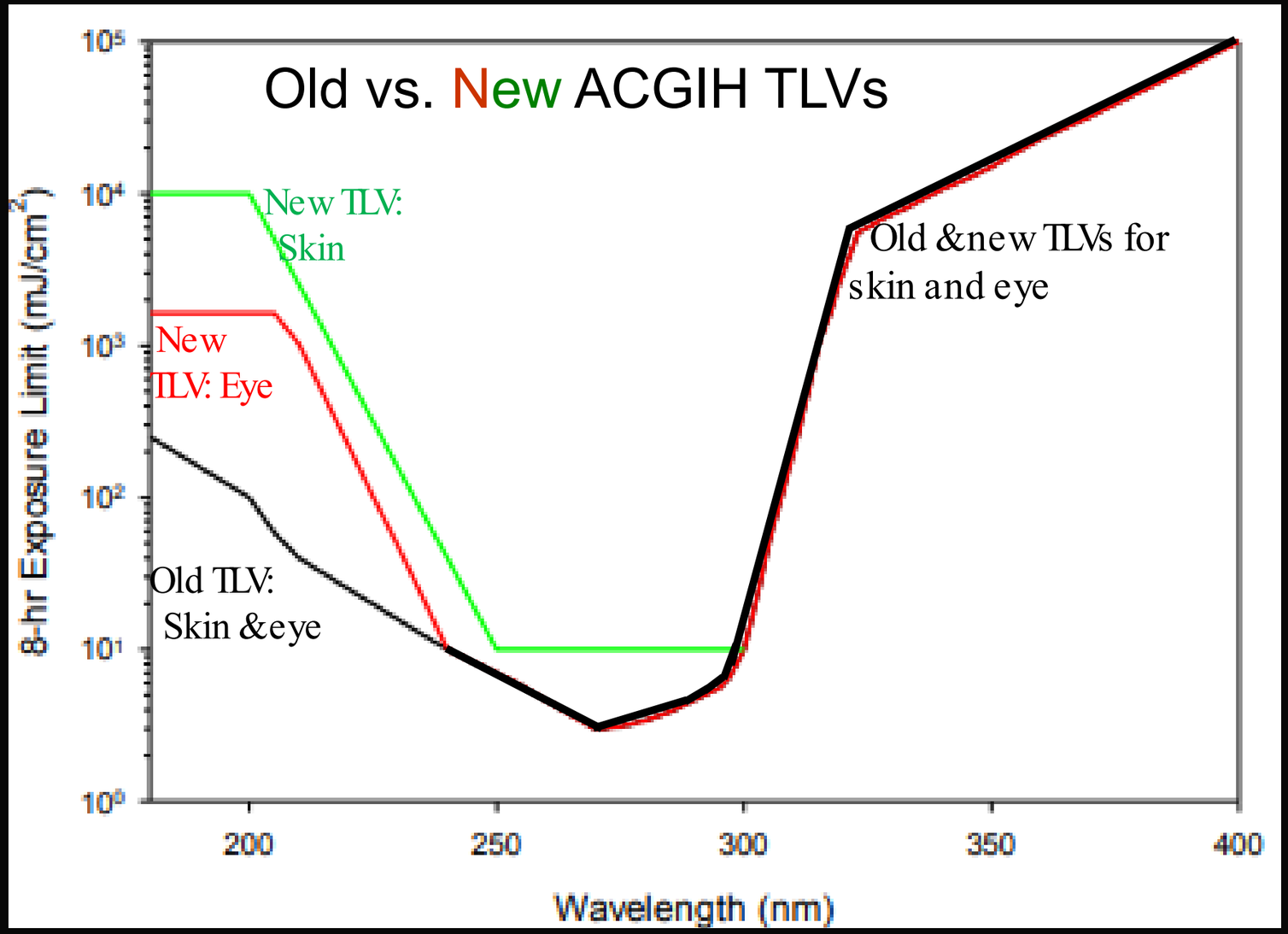
Manuela Buonanno[1,3]✉, Norman J. Kleiman[2,3], David Welch[1,3], Raabia Hashmi[1], Igor Shuryak[1] & David J. Brenner[1]✉

An emerging intervention for control of airborne-mediated pandemics and epidemics is whole-room far-UVC (200–235 nm). Laboratory studies have shown that 222-nm light inactivates airborne pathogens, potentially without harm to exposed occupants. While encouraging results have been reported in benchtop studies and in room-sized bioaerosol chambers, there is a need for quantitative studies of airborne pathogen reduction in occupied rooms. We quantified far-UVC mediated reduction of aerosolized murine norovirus (MNV) in an occupied mouse-cage cleaning room within an animal-care facility. Benchtop studies suggest that MNV is a conservative surrogate for airborne viruses such as influenza and coronavirus. Using four 222-nm fixtures installed in the ceiling, and staying well within current recommended regulatory limits, far-UVC reduced airborne infectious MNV by 99.8% (95% CI: 98.2–99.9%). Similar to previous room-sized bioaerosol chamber studies on far-UVC efficacy, these results suggest that aerosolized virus susceptibility is significantly higher in room-scale tests than in bench-scale laboratory studies. That said, as opposed to controlled laboratory studies, uncertainties in this study related to airflow patterns, virus residence time, and dose to the collected virus introduce uncertainty into the inactivation estimates. This study is the first to directly demonstrate far-UVC anti-microbial efficacy against airborne pathogens in an occupied indoor location.

Far-UVC Biological Safety

1. It’s the biophysics!
2. There are existing national and international safety regulatory frameworks
3. Multiple peer-reviewed published safety studies: human skin models, human skin, mouse skin, mouse and rat eyes

Regulatory UV limits as a function of UV wavelength



ACGIH 222 nm TLVs

(Pre 2022)

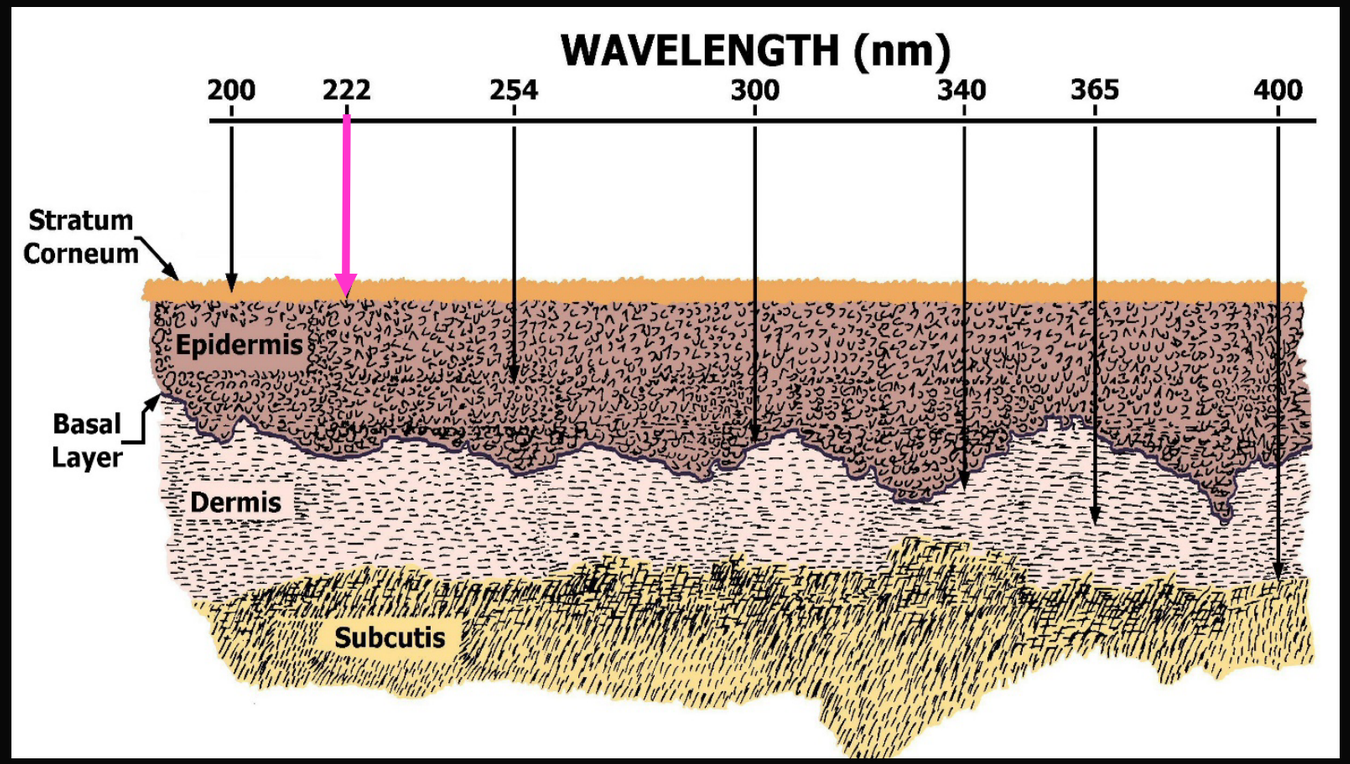
23 mJ/cm² / 8-h day for skin & eye

(Post 2022)

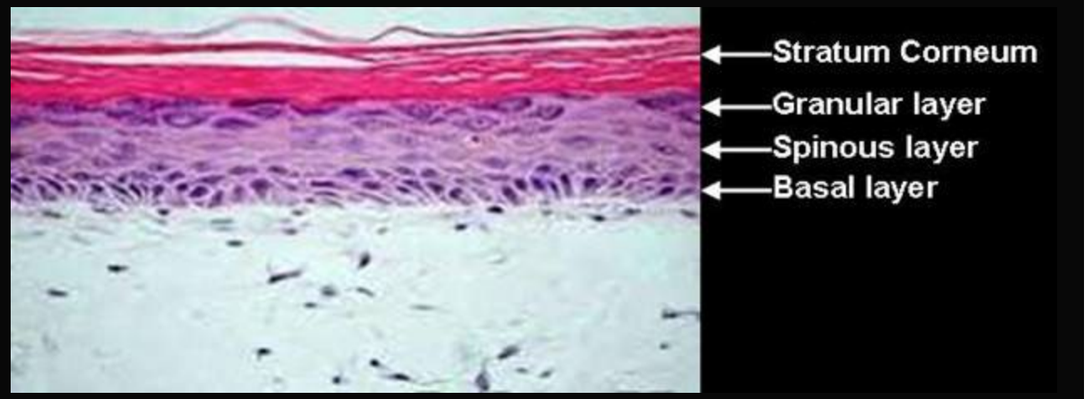
Skin: 480 mJ/cm² / 8-h day

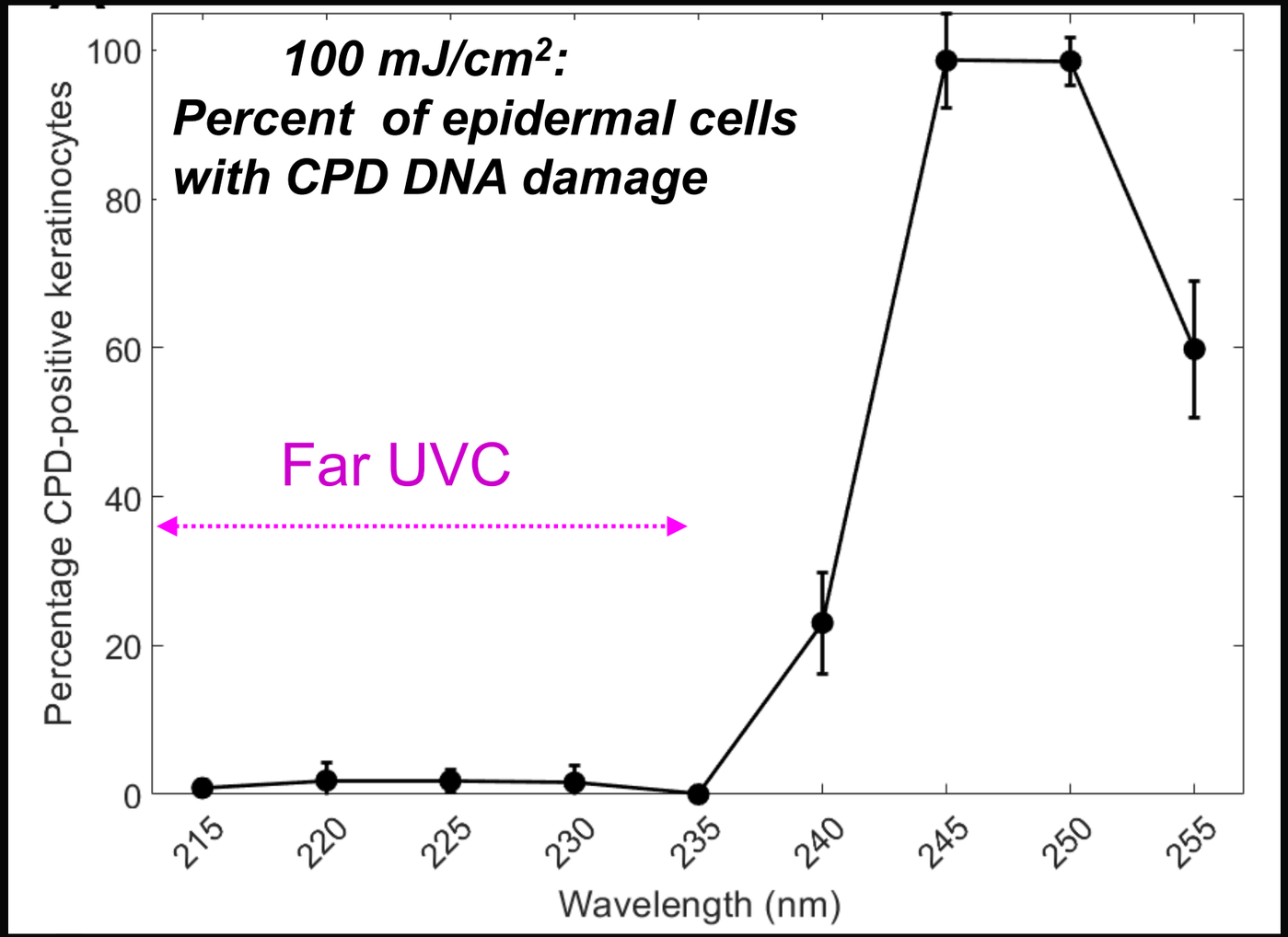
Eye: 160 mJ/cm² / 8-h day

SKIN SAFETY STUDIES



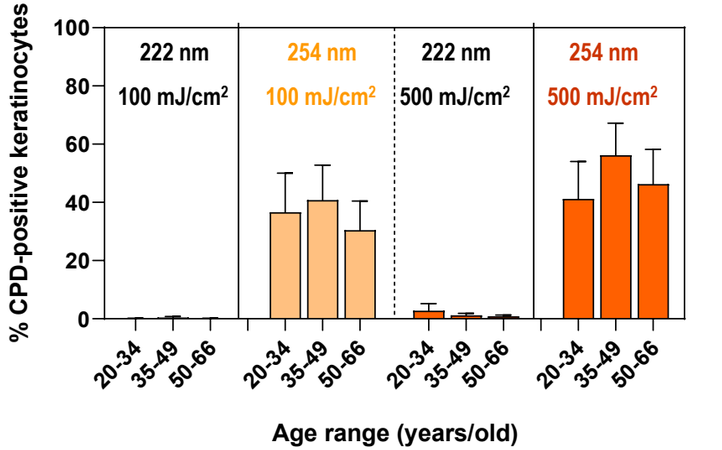
DNA damage to epidermal cells in human skin model as a function of UVC wavelength

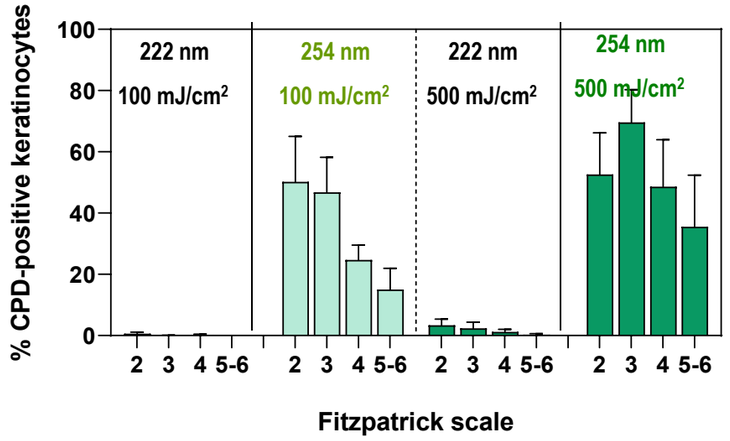




Welch et al 2022

Age, sex, melanin, ethnicity & Fitzpatrick scale do not have any effect on 222 nm skin response





Human skin exposed in vivo to very high far-UVC doses

Photochemistry and Photobiology, 2021, 97: 527–531

Special Issue Research Article

Extreme Exposure to Filtered Far-UVC: A Case Study†

Ewan Eadie[1]*, Isla M. R. Barnard[2], Sally H. Ibbotson[3] and Kenneth Wood[2]

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[2]SUPA, School of Physics & Astronomy, University of St Andrews, St Andrews, UK
[3]Scottish Photobiology Service, Photobiology Unit, University of Dundee, Ninewells Hospital and Medical School, Dundee, UK

Received 18 August 2020, accepted 17 January 2021, DOI: 10.1111/php.13385

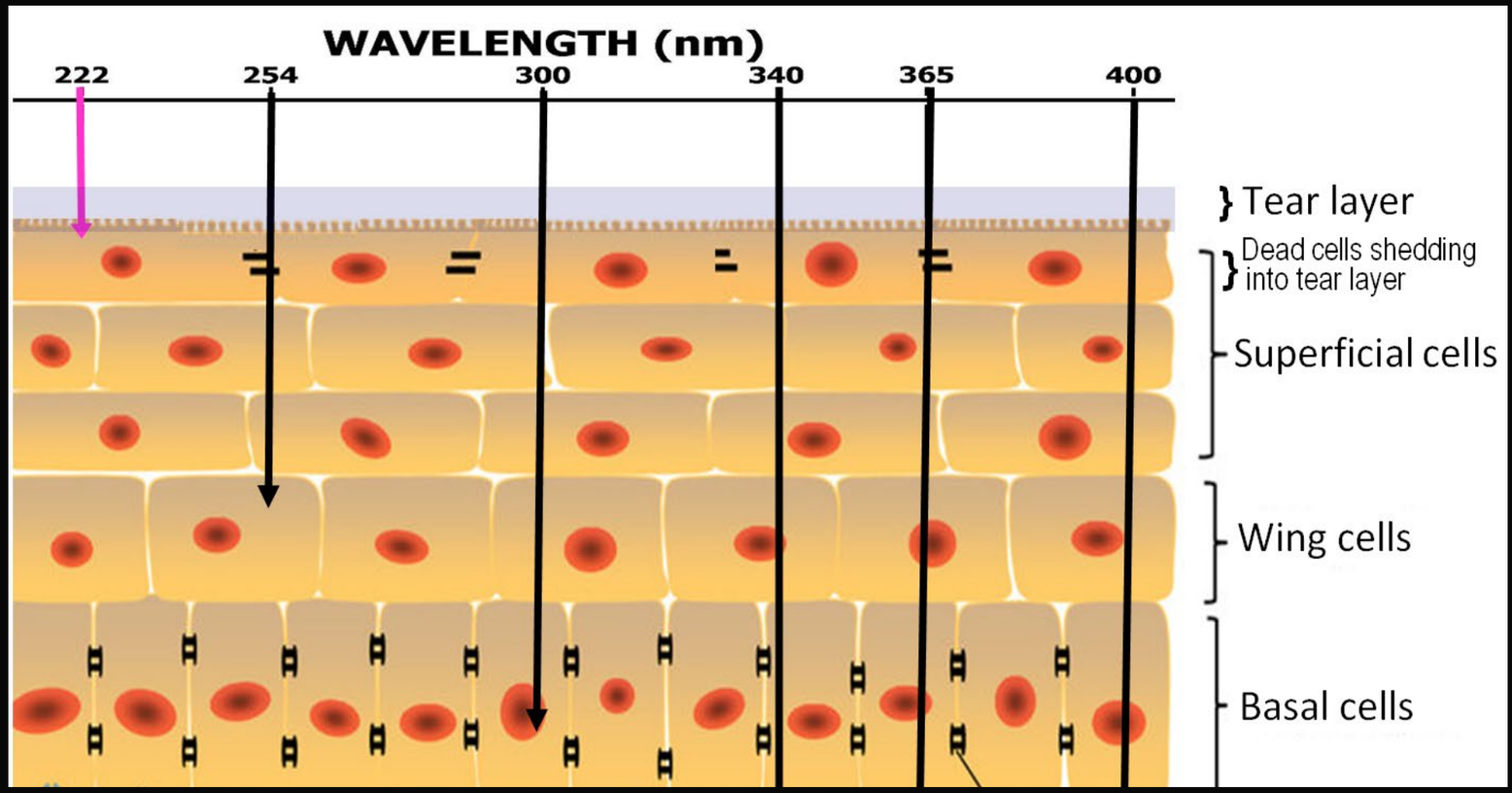
ABSTRACT

Far-UVC devices are being commercially sold as "safe for humans" for the inactivation of SARS-CoV-2, without supporting human safety data. We felt there was a need for rapid proof-of-concept human self-exposure, to inform future controlled research and promote informed discussion. A Fitzpatrick Skin Type II individual exposed their inner forearms to large radiant exposures from a filtered Krypton-Chloride (KrCl) far-UVC system (SafeZoneUVC, Ushio Inc., Tokyo, Japan) with peak emission at 222 nm. No visible skin changes were observed at 1500 mJ cm^{-2}; whereas, skin yellowing that appeared immediately and resolved within 24 h occurred with a 6000 mJ cm^{-2} exposure. No erythema was observed at any time point with exposures up to 18 000 mJ cm^{-2}. These results combined with Monte Carlo Radiative Transfer computer modeling suggest that filtering longer ultraviolet wavelengths is critical for the human skin safety of far-UVC devices. This work also contributes to growing arguments for the exploration of exposure limit expansion, which would subsequently enable faster inactivation of viruses.

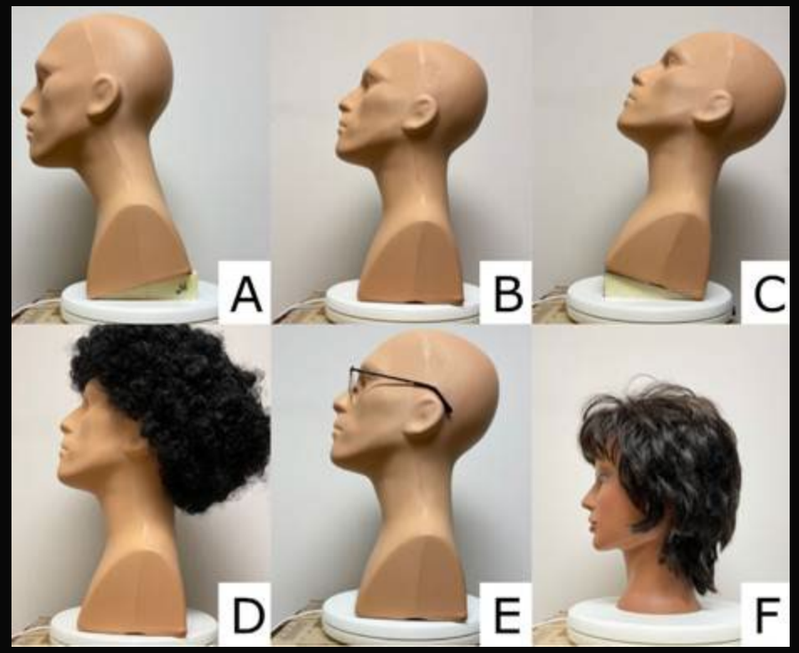
bacteria and viruses and employed in a range of industries (3–6). The established UVC wavelength routinely used for germicidal tasks is the mercury emission wavelength of 253.7 nm, which has been shown to inactivate SARS-CoV-2 but also results in acute adverse reactions in the skin and eyes (7, 8).

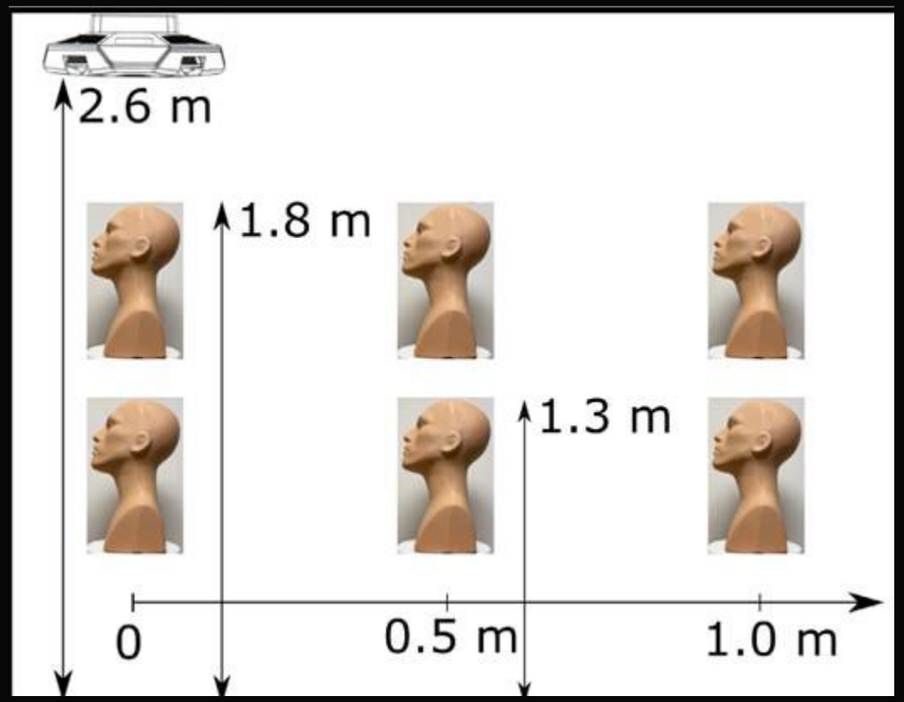
Far-UVC is a term, which loosely incorporates wavelengths between 200 and 230 nm. Current far-UVC published research is dominated by Krypton-Chloride (KrCl) excimer lamps, which emit predominantly at 222 nm but can include low-power long-wavelength emissions. It has been demonstrated that far-UVC, emitted by KrCl excimer lamps, inactivates SARS-CoV-2 on surfaces as well as human coronaviruses alpha HCoV-229E and beta HCoV-OC43 in air (9, 10). However, it does not induce premutagenic DNA lesions in mouse skin, even when chronically irradiating mice particularly susceptible to ultraviolet radiation (11–13). These laboratory data are being used commercially to intensively promote and sell far-UVC systems to the global public. At the beginning of the COVID-19 pandemic, the only published study investigating a far-UVC system in humans had contradicted the laboratory results, showing skin damage in the

OCCULAR SAFETY STUDIES



The human eye is partially shielded from overhead light by the brow/forehead

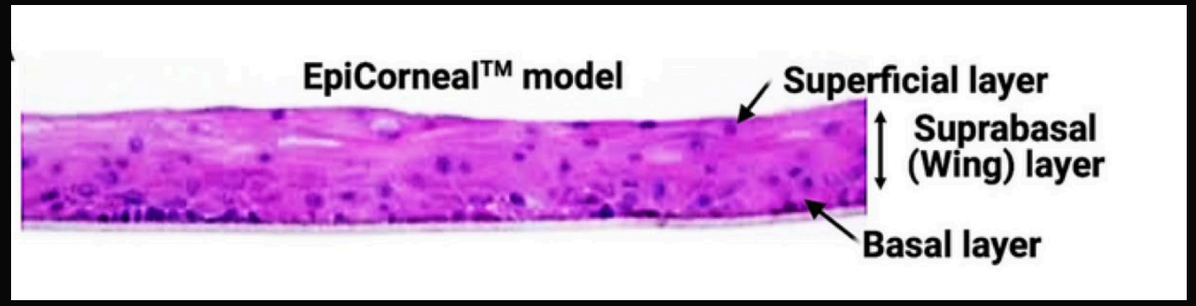


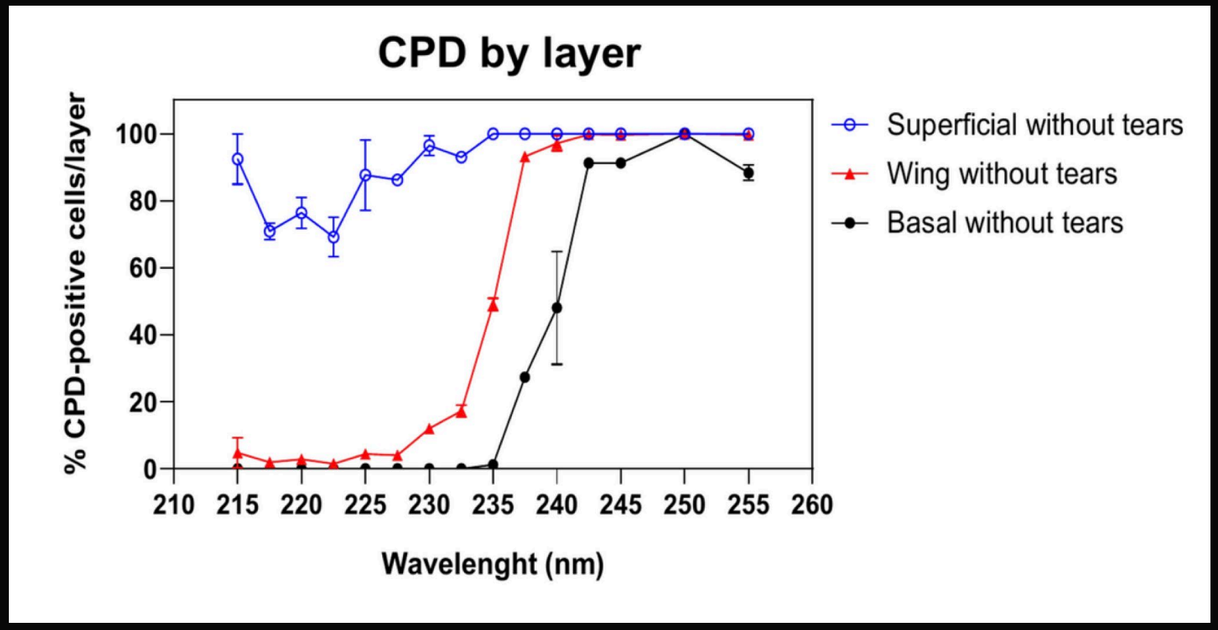


"At the manikin position with the highest dose to the eyes, the average eye dose was 5.8% of the maximum skin dose"

Duncan et al 2022

Far-UVC DNA damage in a human cornea model





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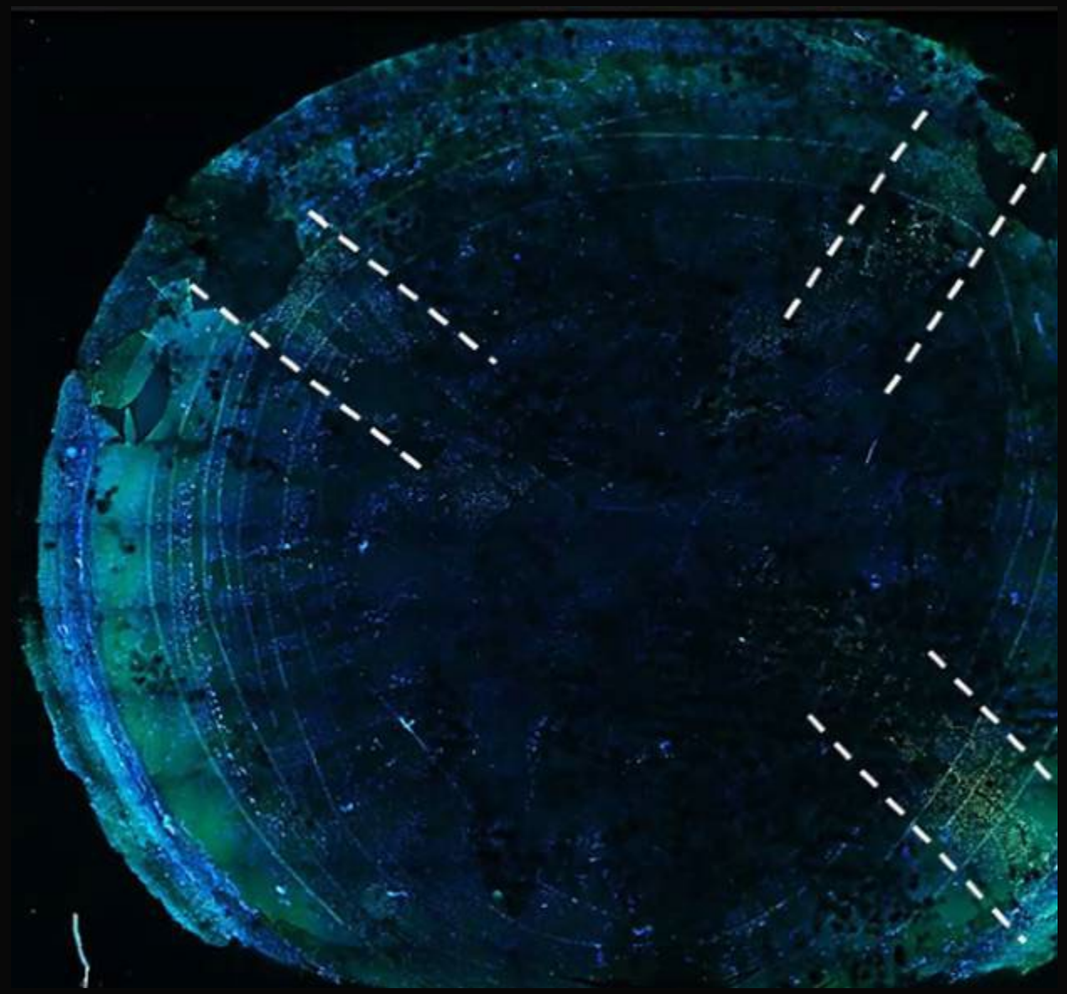
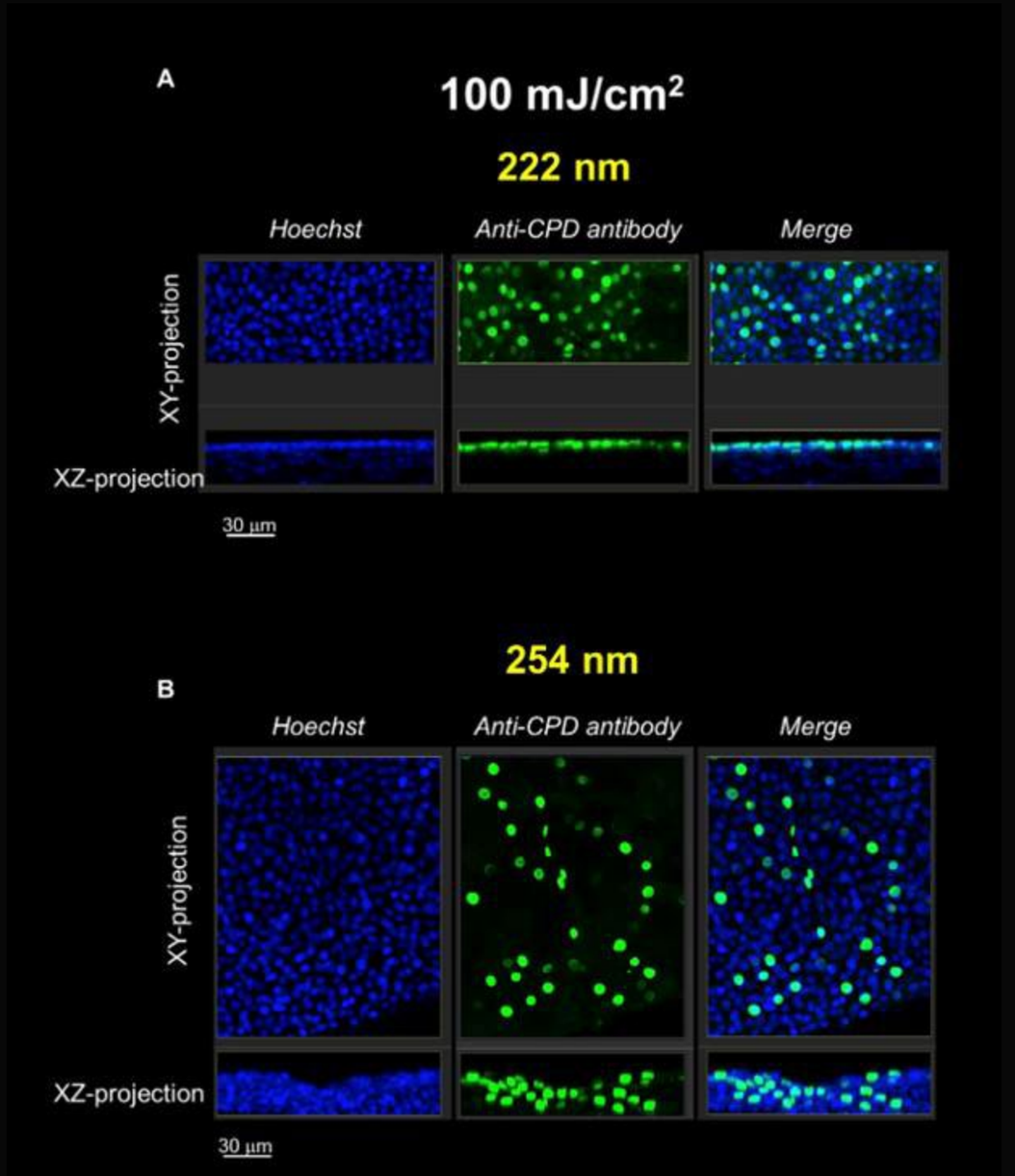
Wavelength-dependent DNA damage induced by single wavelengths of UV-C radiation (215 to 255 nm) in a human cornea model

Manuela Buonanno✉, Raabia Hashmi, Camryn E. Petersen, Zheng Tang, David Welch, Igor Shuryak & David J. Brenner

Using human corneas from the New York Eye Bank



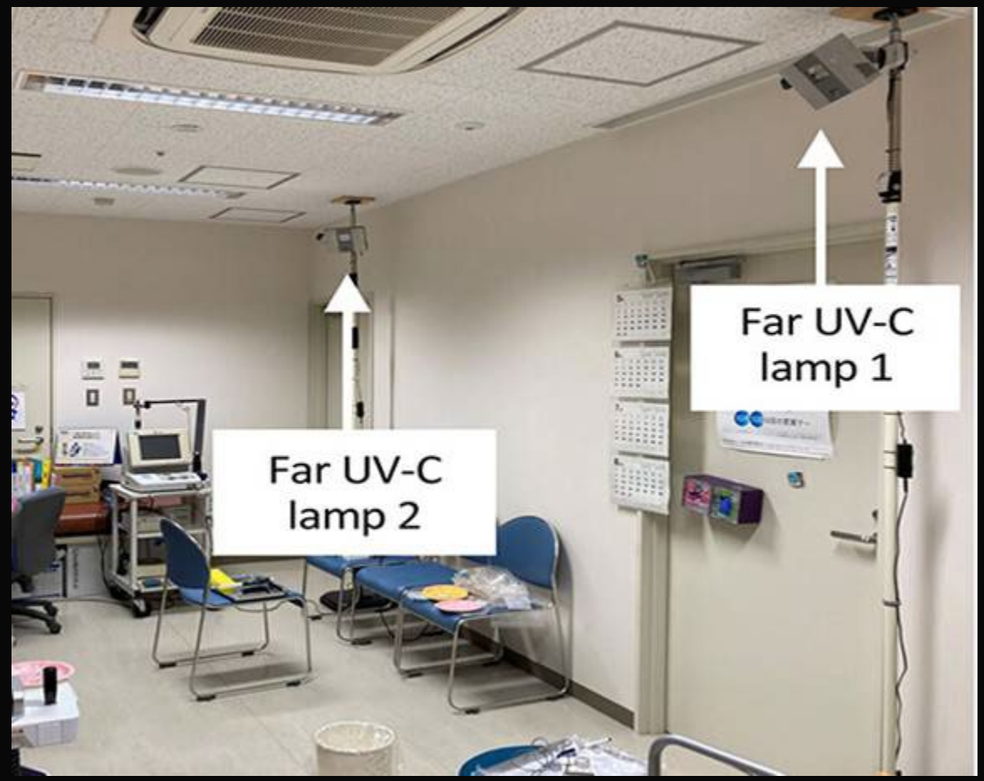


Far-UVC Ocular Safety:
Room-based studies

Simulated office (Scotland)

No short-term ocular discomfort

Kousha et al 2024

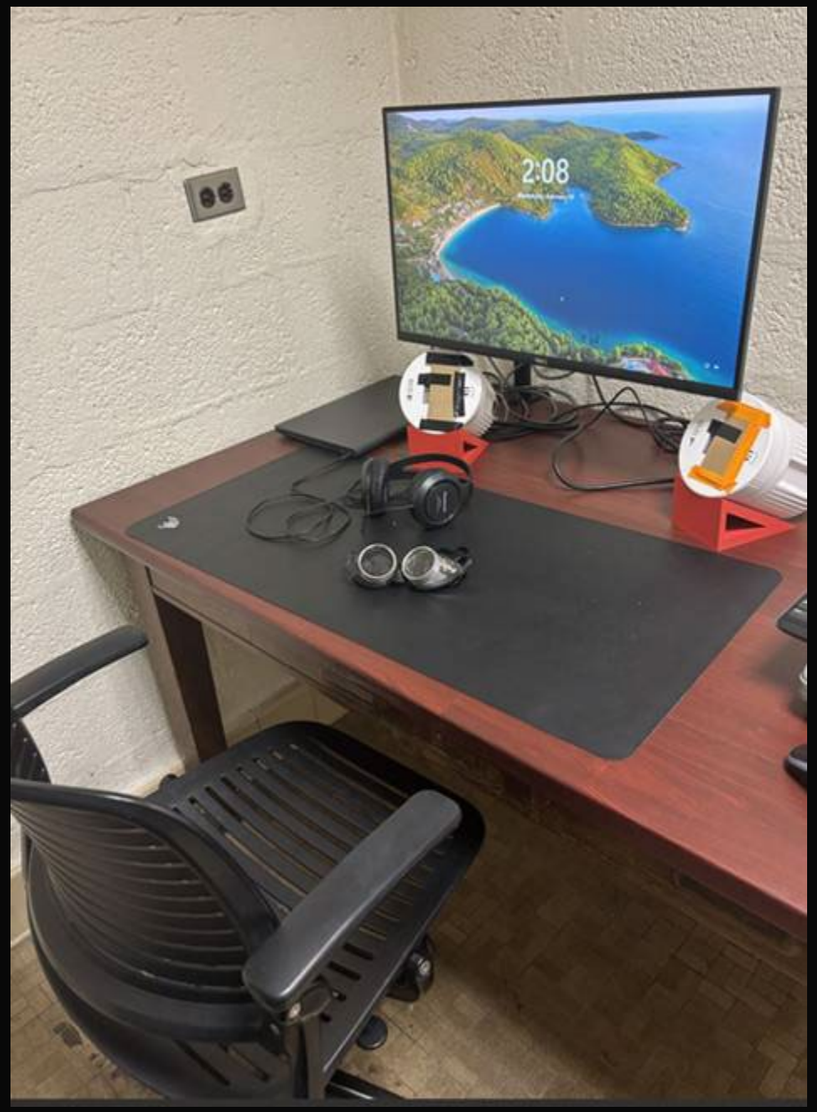


Medical exam room (Japan)

No long-term adverse ocular events

Sugihara et al 2023

Far-UVC while watching a 90-minute movie



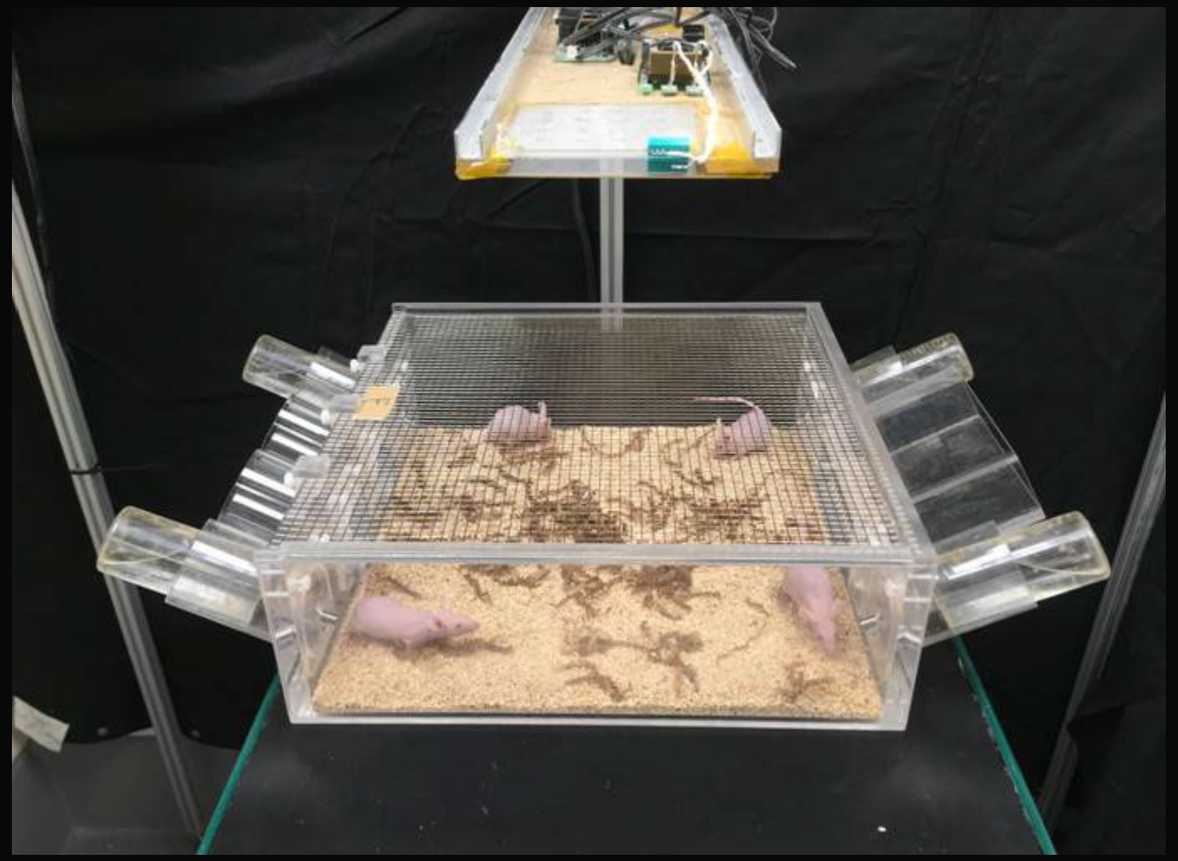
Subjects asked to quantitatively assess pain / discomfort at post exposure times from 15 min to 24 h, and undergo comprehensive longitudinal ocular anterior segment exams:

- One eye exposed, the other not exposed
- Imaging of corneal nerves
- Slit-lamp biomicroscopy
- Visual acuity & contrast sensitivity testing
- Corneal esthesiometry
- Analyses of tear quality

Long-Term Far-UVC Exposure

Safety studies in hairless mice

- Commercial 222 nm filtered excimer lamps
- 96 hairless SKH-1 mice given continuous daily exposures: (0, 50, 125, 400 mJ/cm^2 / day)
- 8 hours / day, 5 days / week
- 66 weeks total



Welch et al 2023

Photochemistry and Photobiology, 2023, 99: 168–175

Research Article

No Evidence of Induced Skin Cancer or Other Skin Abnormalities after Long-Term (66 week) Chronic Exposure to 222-nm Far-UVC Radiation

David Welch[1,†]*, Norman J. Kleiman[2,†], Peter C. Arden[2], Christine L. Kuryla[2], Manuela Buonanno[1], Brian Ponnaiya[1], Xuefeng Wu[1] and David J. Brenner[1]

[1]Center for Radiological Research, Columbia University Irving Medical Center, New York, New York
[2]Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University Irving Medical Center, New York, New York

Received 16 March 2022, accepted 23 May 2022, DOI: 10.1111/php.13656

ABSTRACT

Far-UVC radiation, typically defined as 200–235 nm, has similar or greater anti-microbial efficacy compared with conventional 254-nm germicidal radiation. In addition, biophysical considerations of the interaction of far-UVC with tissue, as well as multiple short-term safety studies in animal models and humans, suggest that far-UVC exposure may be safe for skin and eye tissue. Nevertheless, the potential for skin cancer after chronic long-term exposure to far-UVC has not been studied. Here, we assessed far-UVC induced carcinogenic skin changes and other pathological dermal abnormalities in 96 SKH-1 hairless mice of both sexes that were exposed to average daily dorsal skin doses of 400, 130 or 55 mJ cm^{-2} of 222 nm far-UVC radiation for 66 weeks, 5 days per week, 8 h per day, as well as similarly-treated unexposed controls. No evidence for increased skin cancer, abnormal skin growths or incidental skin pathology findings was observed in the far-UVC-exposed mice. In addition, there were no significant changes in morbidity or mortality,

acute damage to the skin and eye (2,3). By contrast, there is now compelling evidence that far-UVC radiation, commonly defined as wavelengths between 200 nm and 235 nm, is likely to be safer for direct human exposure (4–8), and also exhibits similarly or greater anti-microbial activity against both surface and airborne microbes (9–19). The combination of efficacy and safety suggests far-UVC may have broad applicability to provide continuous air disinfection even while humans are present (11,18).

The biophysical rationale for far-UVC safety is related to the very short penetration depth of far-UVC wavelengths in biological materials (20,21). Thus, in skin, far-UVC wavelengths are absorbed primarily in the superficial, stratum corneum, which is composed of dead epithelial cells (7,21,22) with minimal penetration to the adjacent stratum granulosum, which consists of dead or dying epithelial cells. Biophysical measurements and theoretical calculations imply that far-UVC cannot penetrate to the stratum basale at the base of the epidermis (4,21), which contains live squamous and basal cells and melanocytes. Damage to cells in the stratum basale is associated with long-term, adverse der-

daily dorsal skin doses of 396 mJ/cm^2, 126 mJ/cm^2 or 56 mJ/cm^2 of 222 nm far-UVC radiation for 66 weeks, 5 days per week, 8 hours per day, as well as similarly-treated unexposed controls. No evidence for increased skin cancer, abnormal skin growths, or incidental skin pathology findings was observed in the far-UVC exposed mice.

Current Eye Research >
Volume 50, 2025 - Issue 10

Retina and Choroid

Chronic Far-UVC (222nm) Light Exposure of SKH-1 Hairless Mice Does Not Cause Detectable Eye Pathology or Visual Deficits

Peter C. Arden, Maria J. Talayero Schettino, Matthew D. Ramey, David Welch, Nabil A. Mahmoud, Imke T. Folkerts, ...show all

Pages 1064-1071 | Received 12 Nov 2024, Accepted 19 Jun 2025, Published online: 03 Aug 2025

Cite this article | https://doi.org/10.1080/02713683.2025.2524564 | Check for updates

Abstract

Purpose

Far-UVC light (200–235 nm) is a new antimicrobial technology proposed for use in occupied spaces. In contrast to conventional germicidal UV light (254 nm), theoretical considerations and emerging safety data suggest that the decreased penetration depth of shorter wavelength far-UVC light causes less damage to vulnerable eye and skin tissue. This study examined the ocular effects of chronic far-UVC exposure in hairless, immune-competent SKH-1 mice after long-term exposure.

Methods

Over 66 weeks, five days/week, eight hours/day, 48 each male and female mice were exposed to high (400 mJ/cm^2), medium (130 mJ/cm^2), low (55 mJ/cm^2), or no (0 mJ/cm^2) far-UVC (222 nm) light. Visual acuity and contrast sensitivity was determined using optokinetic methods, slit lamp examinations were made of the anterior segment, and intraocular pressure was determined. Analysis of corneal images quantified the extent

Far-UVC related changes in air quality: Ozone and Ultrafine Particulates

Test chambers

Real-life rooms

Far-UVC related changes in air quality:
Ozone and Ultrafine Particulates

Baltimore Hotel Room Study

Room Size: L×W×H; (Volume)	4.4×5.3×2.4 m (50 m^3)
Average air-exchange rate	1.4 (1.2–1.7) h^{-1}
Number of far-UVC lamps	3
Average far-UVC fluence rate	1.7–1.8 µW/cm^2
Measured background indoor ozone concentration	12 ppb
Measured change in indoor ozone concentration for far-UVC lamps "on"	↑ 5.7 ppb
Measured change in ultrafine particle concentration for far-UVC lamps "on"	↓ 158/cm^3/ppb

Kalliomäki et al 2023

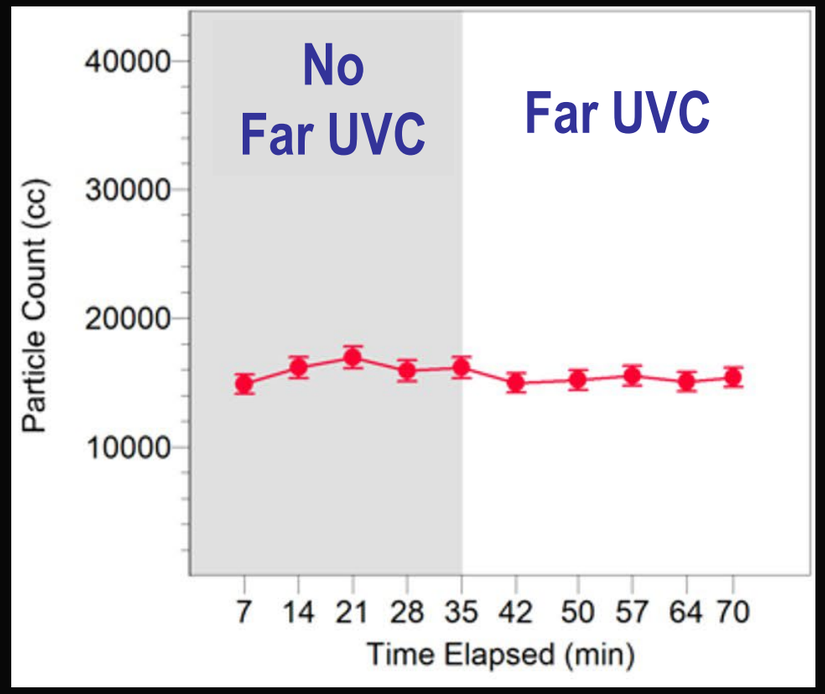
Far-UVC related change in air quality:

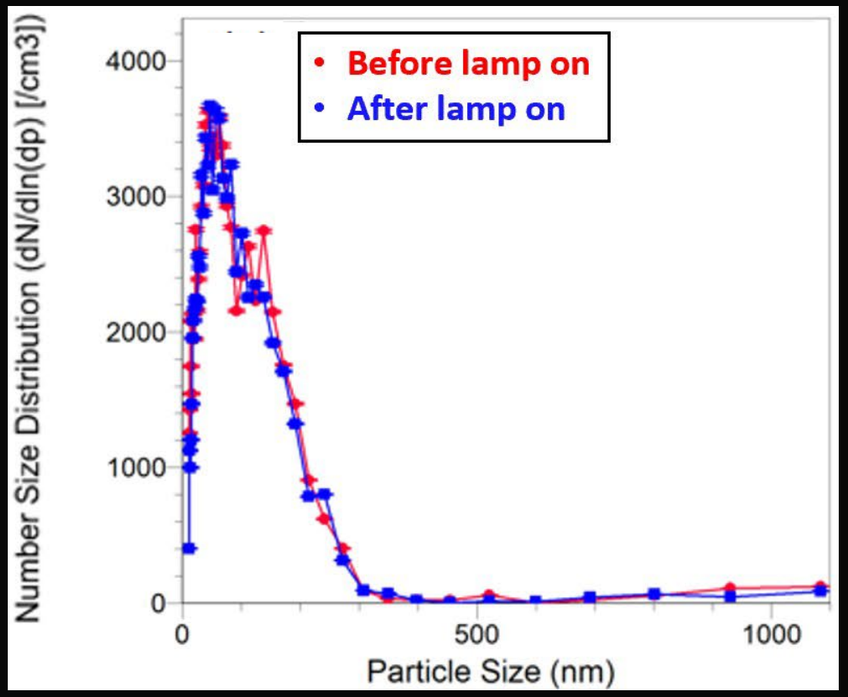
Ozone, Ultrafine Particulates

New York City conference room: ACH = 1.3/h

Maximum irradiance at 1.8 m: ~1 mW/cm²

Grimm SMPS particle counter / sizer:
Measurement range ~10 nm-1100 nm





Narouei et al 2025

Columbia Far-UVC real-world test room

- Real world - Carpets, sofas, bookshelves, etc
- Range of Far-UVC exposures
- Controlled ACH (0.2 - 10)
- Controlled humidity
- Sartorius Airport Md8 airborne pathogen sampler
- Anderson multi-stage airborne pathogen sampler
- Ozone measurements
- Grimm SMPS particle counter / sizer: 10 - 1100 nm

Far-UVC related changes in air quality:

Ozone and Ultrafine Particulates

Overall, far-UVC related changes in indoor air quality are only significant for far-UVC lamps operating above current regulatory dose limits, and which are situated in very airtight rooms

In Conclusion - Far UVC

- **Far-UVC is a promising practical option to markedly and safely reduce airborne viral loads in indoor locations**

- ***Extensive evidence for skin and ocular safety when used within current TLVs***
- ***No significant air- quality effects in real-world rooms when used within current TLVs***