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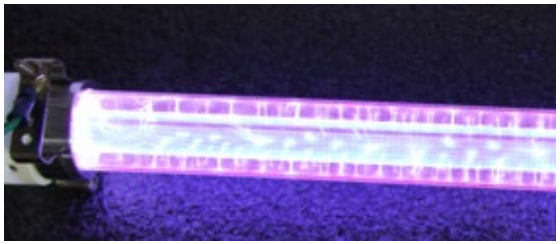
Boeing Research & Technology

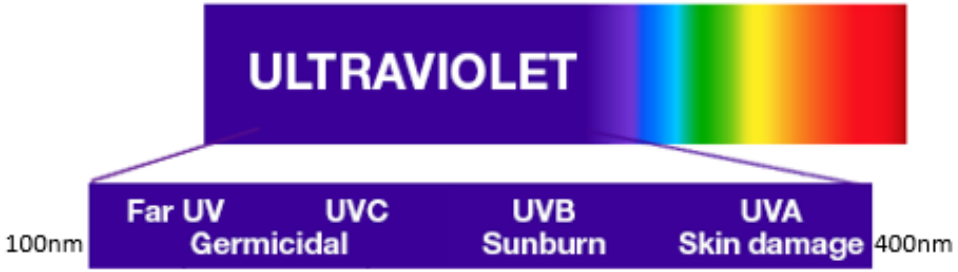
Using 222-nm Ultraviolet (UV) Light for Continuous Disinfection

DSIAC Webinar Briefing

Part 1 – 222 nm Technology



Source: Boeing nonproprietary



Source: Boeing nonproprietary

Q1-2021

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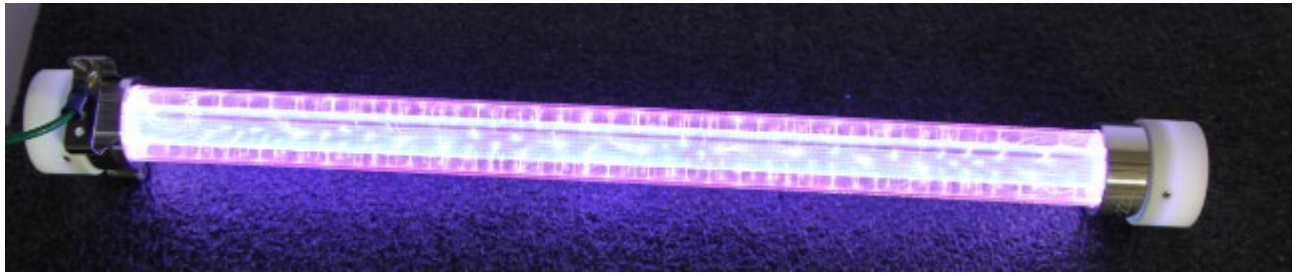
222-nm UV - Bottom Line, Up Front

- The 222-nm UV is **both safer and more effective** than longer wavelength mercury lamps and LEDs.
- This allows continuous disinfection in occupied areas.
  - Not possible with older UV systems.

Why?

- The 222-nm UV is safer and more effective because it is highly absorbed by **both protein and DNA.**

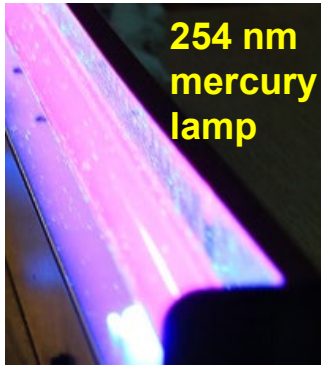
- Longer wavelength UV is not strongly absorbed by protein.



Source: Boeing nonproprietary

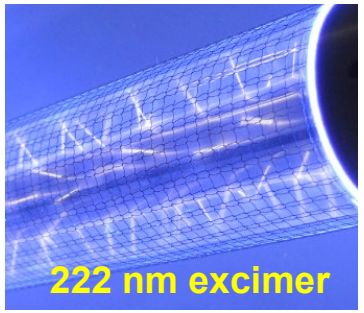
A Very Brief History of UV Disinfection

- The germicidal properties of UV light have been known since the 1930s.
- Early UV disinfection and the majority of UV disinfection today are done with mercury vapor lamps, which have strong emissions at 254 nm.
- In recent years, LEDs that emit at useful germicidal frequencies between 260 and 280 nm have gone into mass production.
- Recently, a new type of UV disinfection technology has emerged using excimer lamps that emit at 222 nm.
  - This 222 nm technology is game changing.



Source: Wikimedia commons

Source: Boeing nonproprietary

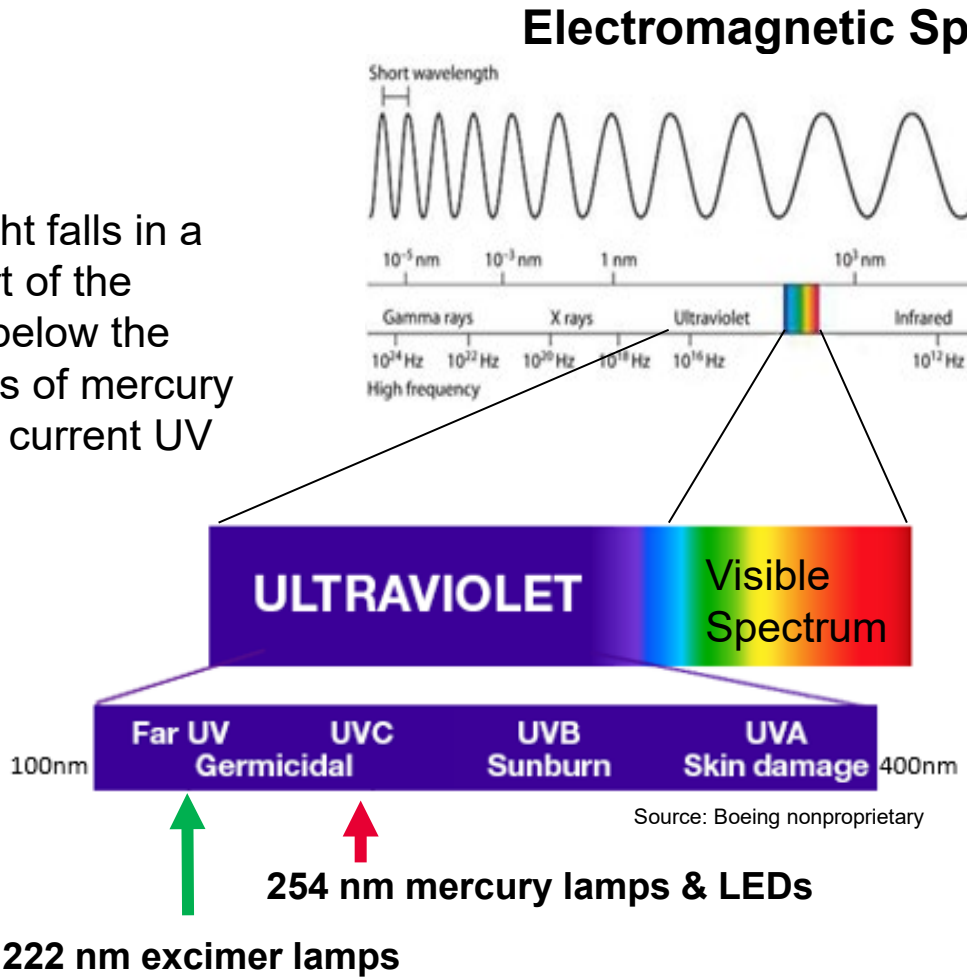


Source: Boeing nonproprietary

UV Light Spectrum

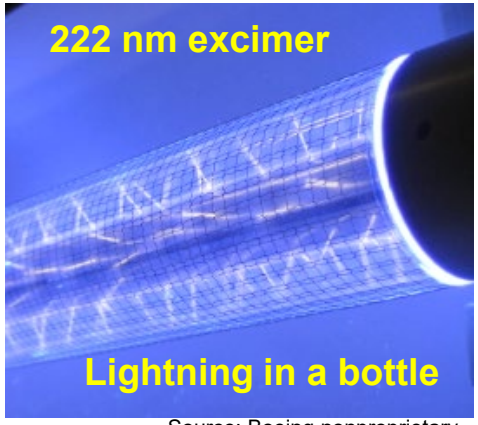
Source:
Boeing nonproprietary

- 222-nm light falls in a unique part of the spectrum below the frequencies of mercury lamps and current UV LEDs.



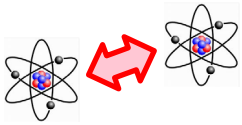
222 nm Excimer Lamps

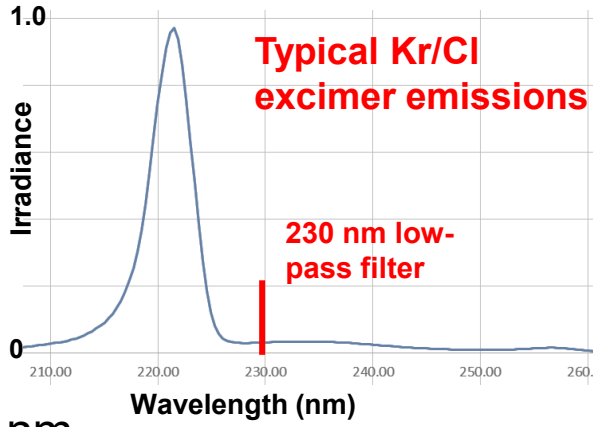
- An excimer lamp is a glass bottle filled with gas that has high-voltage electrodes along its length.



Source: Boeing nonproprietary

- A high-voltage discharge between inner and outer electrodes creates a “temporary” molecule that rapidly decays.
  - This “temporary” molecule decay creates the light.
  - The gas mixture determines the light frequency created by this molecular decay.





Source: Boeing nonproprietary

- Excimer lamps typically operate at thousands of volts and more than 10,000 Hz.
- Kr/Cl excimer (exciplex) lamps primarily emit light at 222 nm.
- 222-nm LEDs are in research, but none are in mass production.

222-nm UV Is Absorbed by DNA and Protein.

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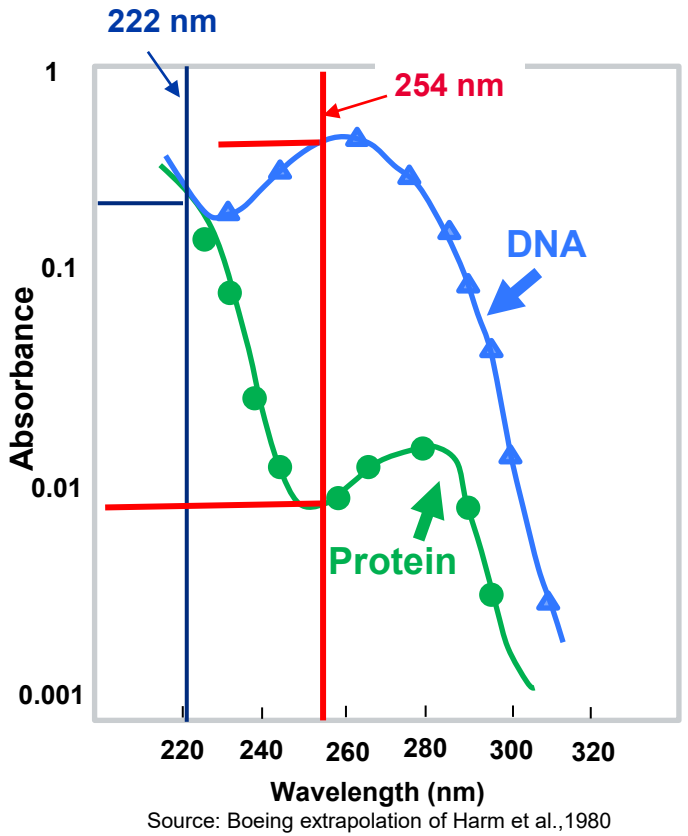
- **222-nm UV has unique properties** and is **NOT** the same as mercury lamps or UV LEDs.
- 222-nm UV is **highly absorbed by both protein bonds and DNA.**
- This protein absorption makes 222-nm UV **safe** for human exposure.

- Mercury lamps and UV LEDs use UV-C between 250 and 280 nm.
- 250–280-nm UV has low absorption by protein.
- UV-C in the 250–280 nm range is **carcinogenic** and cannot be used on occupied areas.



Source: Boeing extrapolation of Harm et al.,1980

- Protein has **25 times** better absorption of 222 nm compared to 254 nm.
- DNA absorption is similar for both frequencies.

UV Transmittance of Mouse and Human Skin

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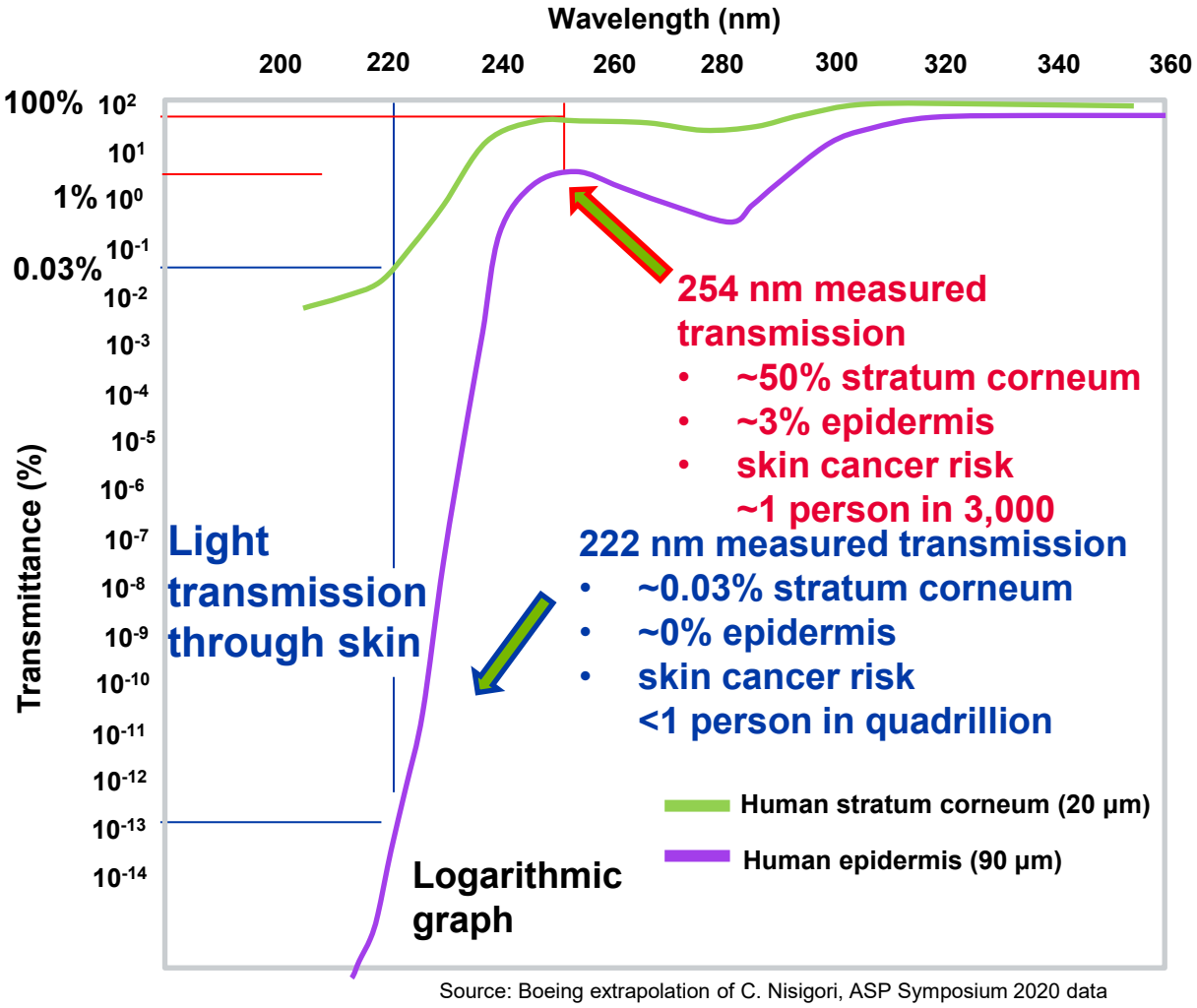


Source: Boeing extrapolation of C. Nisigori, ASP Symposium 2020 data

- **Measured transmittance of stratum corneum**
- Estimated transmittance of human epidermis

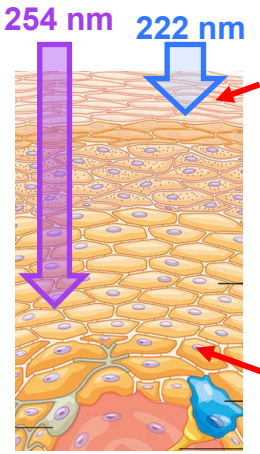


Image Source: Wikimedia commons

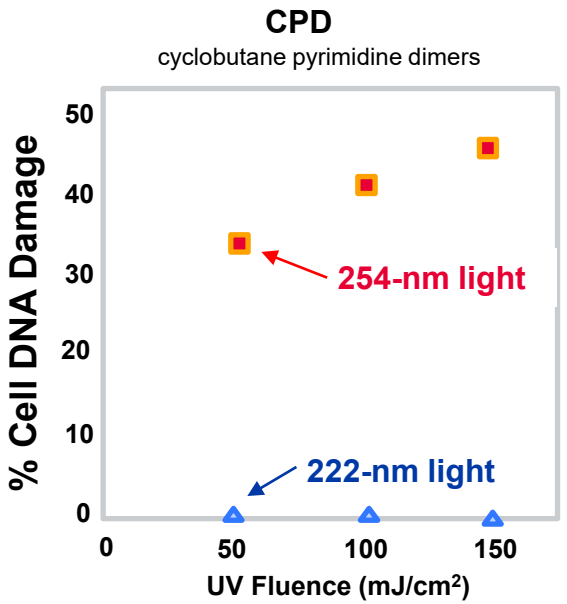
222-nm UV is safer than sunlight.

222 nm Safety Data

- Numerous 222 nm exposure studies conducted on both humans and animals support the raising of the human daily exposure limit (TLV) to over 500 mJ/cm^2.
  - Human and animal skin tests up to 1,000 mJ/cm^2, with no adverse effects.
  - Animal eye tests up to 600 mJ/cm^2, with no adverse effects.
  - Columbia/Brenner lifetime hairless mouse study
    - Study completed 60-week mouse lifetime
    - Exposed 8 hours/day, 5 days a week to 500 mJ/cm^2 222 nm: no adverse effects detected
    - Post-mortem autopsies and pathology in process
    - Boeing working with Columbia
  - Multiple studies of DNA damage to mammalian cells show that 254-nm light causes increasing DNA damage in mammalian cells with increasing dosage, but 222-nm light does not.

Image Source: Wikimedia commons

600 mJ/cm^2 eye exposure

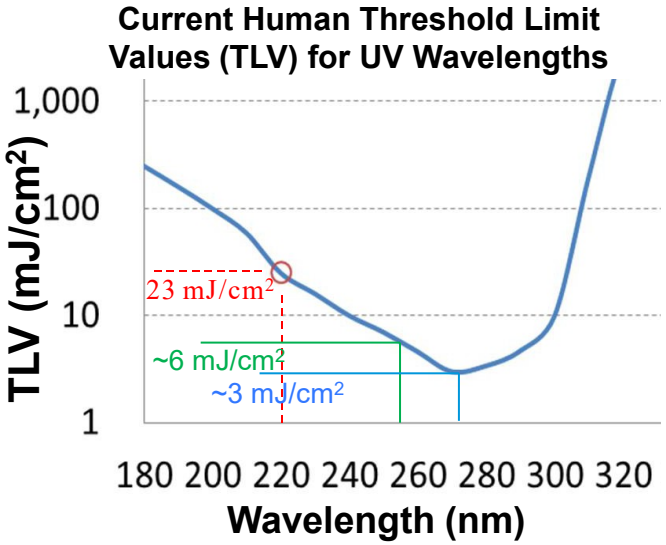


Source: Boeing extrapolation of Brenner ICUDAS data

Current Exposure Guidelines

- UV disinfection devices are regulated by the EPA as a pesticide device.
- No FDA-mandated UV exposure limit.
  - (unless used as part of medical device)
- Threshold Limit Value (TLV) is a guideline generally followed in industrial settings.
- The current 222 nm TLV value is based on old assumptions and does not include new safety data.
- **Work is ongoing with regulators to increase the 222 nm limit to over 500 mJ/cm² based upon the new human and animal safety data.**
- This will allow continuous disinfection in short time frames.

ACGIH (American Conference of Governmental Industrial Hygienists)

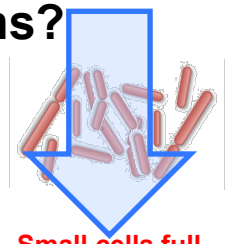


Source: Boeing extrapolation of ACGIH TLV data

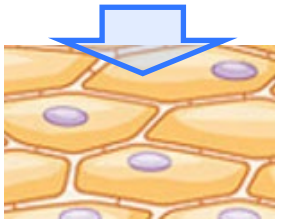
222-nm UV Is Deadly to All Pathogens.

If 222-nm UV is safer for humans, why does it kill pathogens?

- Because pathogen cells are tiny and human cells are large.
- 222-nm UV easily penetrates a few microns into protein.
- 222-nm UV fully penetrates small cells.
  - Human cells are about 40 µm in diameter.
    - Not fully penetrated by 222-nm UV
  - Bacteria & virus are less than 1 µm in diameter.
    - Full penetration of bacteria and virus
  - Destroys bacterial and virus cell walls and DNA.



Small cells full penetration

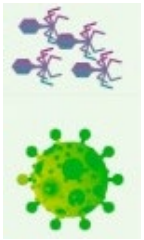


Large cells partial penetration

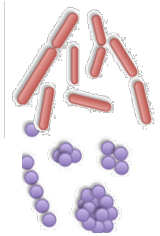
Image Sources: Wikimedia commons

Microbes are 10X smaller than human cells and are fully penetrated by far UV.

Viruses and Bacteria Smaller Than Human Cells



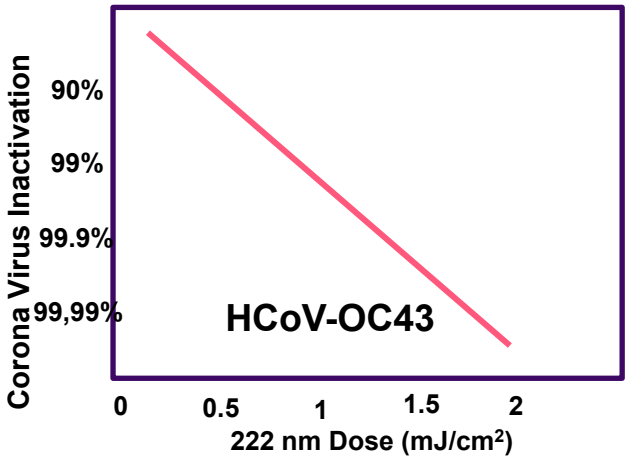
Virus
100 nm



Bacteria
1 µm

Plant & Animal Cells
15–80 µm

Image Sources: Wikimedia commons



Source: Boeing extrapolation of Brenner ICUDAS data

222-nm UV Is Very Effective for Coronavirus.

- Coronaviruses are mostly protein.
- Coronaviruses are very small, ~0.1 µm.
- Fully penetrated and rapidly destroyed by 222-nm UV.

SARS-CoV-2 coronavirus

- Required UV dose for 99.9% **surface** disinfection
  - 254 nm: ~6.5 mJ/cm^2
  - 222 nm: ~3 mJ/cm^2 **(222 is twice as effective)**
- Required UV dose for 90% **surface** disinfection
  - 222 nm: ~1 mJ/cm^2

HCoV-229E coronavirus

- Required UV dose for 99% **airborne** disinfection
  - 222 nm: 1.1 mJ/cm^2
- Required UV dose for 90% **airborne** disinfection
  - 222 nm: 0.56 mJ/cm^2

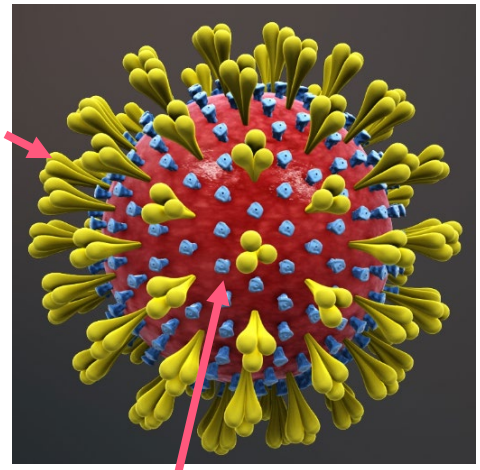


Image Source: Wikimedia commons

222-nm UV Is NOT Subject to Photoreactivation.

- Both 222-nm UV and 250–300-nm UV damage the DNA of the targeted pathogen, which **inactivates** the pathogen's ability to replicate.
- **Photoreactivation is a repair mechanism** pathogens can use to repair themselves after their DNA is damaged by UV light.
- Many bacteria and some viruses have the photolyase gene that allows them to repair DNA using ordinary blue light.
- For some pathogens, 250–300-nm UV damaged DNA can be repaired in as little as a few hours' exposure to blue light (**reactivating** them).
- **222-nm UV is not subject to photoreactivation** since both DNA and the cell wall are destroyed.
  - No reported photoreactivation of 222 nm inactivated microbes.

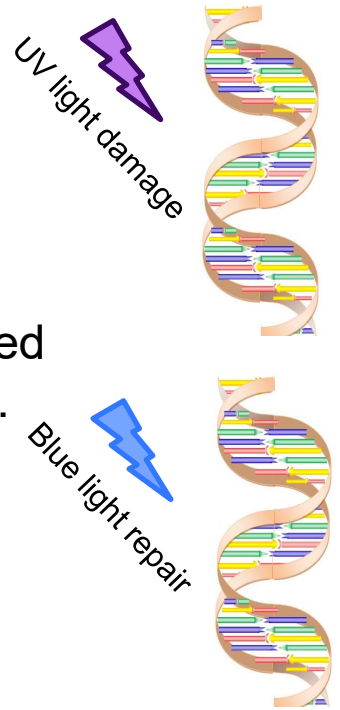


Image Source:
Wikimedia commons

Applications of 222 nm Technology

- 222 nm technology is the preferred system when disinfecting occupied areas.
  - Allows continuous disinfection in occupied areas
  - Highly effective
  - Optical power can be dialed up or down as needed

Source: Boeing nonproprietary

Examples:

- Rapid disinfection
  - High power mobile 222 nm wand
- Automated periodic UV disinfection
  - Boeing clean lavatory
- Persistent UV disinfection
  - Continuous disinfection of occupied areas

Source: Boeing nonproprietary

FAR UV TECHNOLOGIES

Part 2 – 222-nm Disinfection Lighting

DSIAC Briefing
DoD Applications and Installations of Continuous 222-nm Disinfection Lighting

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March 2021

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Current Applications of the 222-nm Disinfection Lighting

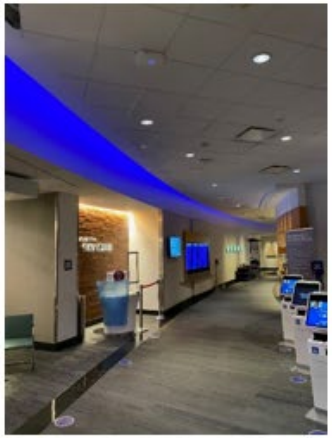
222nm disinfection lighting is best utilized in higher traffic – higher risk areas. Respiratory diseases are spread through the air and/or on surfaces as viruses and/or bacteria are introduced to an environment when an infected person breathes, talks, coughs, sneezes or sings. Higher risk DOD facilities and vehicles include but are not limited to:

Facilities

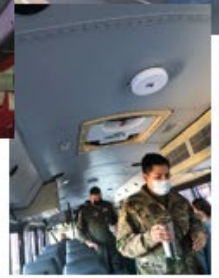
Dining Facilities
Athletic Facilities
Logistics - Support
Commissaries
Secure Rooms
Common Sleeping Areas

Airplanes

Airports

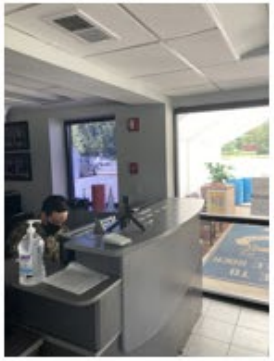


Buses

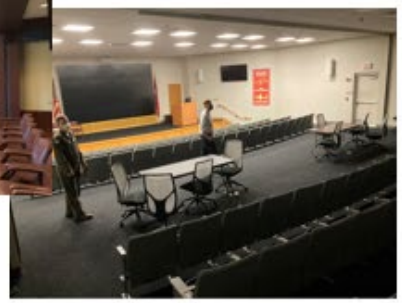


Current Applications of the 222-nm Disinfection Lighting

Visitor Centers



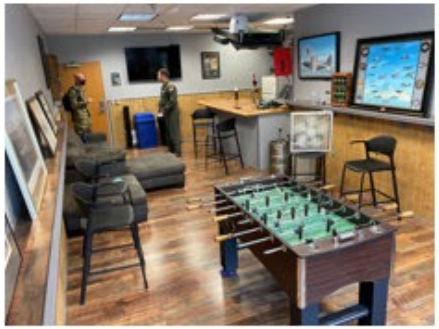
Conference Rooms - Auditoriums



Offices - Elevators

Bathrooms

Recreational Areas



Healthcare

Schools

Other Civilian Applications

Elderly Care
Day Care
Restaurants/Retail

Ferries/Cruise Ships
Trains
City Halls

Museums
Theaters
Hotels - Casinos