Far-UVC in Healthcare

Team Name: Light Legends

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Abstract

Current methods of sterilizing environments are insufficient, as has been brought to public attention by the emergence of the coronavirus pandemic that began earlier this year. As of right now, there is not a safe way to consistently and thoroughly eliminate viruses from high traffic areas during the many hours that people (possible carriers) are passing through them. A far-UVC light disinfection device would address this issue by constantly deactivating viruses while people are present, significantly reducing the opportunity for their spread in a simple and time-effective manner. Ideal device characteristics include a large coverage area, 99.9% sterilization efficacy, cost and manufacturing efficiency, and proven safety for non-target organisms, specifically humans.

Problem Statement and Motivation

Germicidal ultraviolet light (254 nm), referred to as GUVC light, has been proven as an efficient source of killing pathogens with 99.9% effectiveness. Unfortunately, due to the nature of this longer wavelength, GUVC light can only be utilized in settings where no humans are present, as prolonged exposure to this light can cause temporary or permanent eye and skin damage . As an alternative, Far-UVC light (~220 nm) has been proposed to have little to no health risks due to less penetration into human skin from its shorter wavelength, while still maintaining the same effectiveness rate as GUVC light [1]. Our goal is to perform a meta-analysis to further investigate the effectiveness of Far UVC light in preventing coronavirus strains HCoV-229E, HCoV-OC43, and SARS-CoV-2 from existing on surfaces and in the air. By using published research, probability equations and models (Beer-Lambert Law), we will design a product and theoretically prove the product's 99.9% efficacy in a 3.72m^2 clinical patient bathroom.

Background Research

- UVC and far-UVC kill cells by damaging DNA which disrupts cell division[2]
- Far-UVC (222 nm) smaller wavelength is unable to penetrate living human cells but penetrate viruses and bacteria due to size[1]
- Far-UVC light has similar inactivation efficacy to GUVC against pathogens due to physical and genomic size[1]
- Most existing far-UVC devices are Kr-Cl excimer lamps

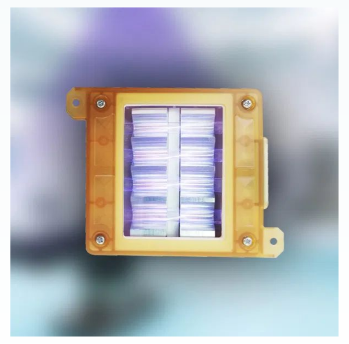


Figure 1: Care222 Filtered Far-UVC Excimer Lamp

Design Criteria

- Disinfect with 99.9% efficacy of airborne and surface adherent viral particles: HCoV-229E, HCoV-OC43, and SARS-CoV-2
- Product must fit in the context of a patient bathroom: ≈ 10.20 m^3 (3.72 m^2 floor)
- Adhere to current International Commission of Non-Ionizing Radiation Protection (ICNIRP) safety standards for exposure to 222 nm light by the public
  - ~ 3 mJ /cm^2 / hour with a maximum of 23 mJ / cm^2 per 8-hour exposure [3]
- Shelf-life of 50,000 hours
- No specific cost criteria given

Testing

- Min Dosage for 99.9% Effectiveness
  - HCoV-229E → 1.68 mJ/cm^2
  - HCoV-OC43 → 1.17 mJ/cm^2
  - SARS-CoV-2 → 1.17-1.68 mJ/cm^2
- Beer-Lambert's Law
  - Penetration depth through N, N2, O, and O2 = 110 km [4]
  - Absorbance is negligible
- ICNIRP Safety Standards
  - 0.05 mJ/cm^2/min for 1 hour max
  - 0.047 mJ/cm^2/min for 8 hours max
- Most effective Far-UVC Light
  - 0.2 W/cm2 Ushio Lamp
  - 135.4 - 194.8 minutes at 0.047 mJ/cm^2/min
  - 136.7 - 196.2 minutes at 0.05 mJ/cm^2/min
  - 10 lamps → durations from the two different standards on the two different strains were under an hour.
  - 20 lamps → disinfection time under 30 minutes for HCoV-OC43 at 0.05 mJ/cm^2/min

Element	Absorption Coefficient 1/M*m	Concentration (M)	Optical Path Length (m)	Absorbance
H_2O (g)	10^{-3}	.01904	3.04	3.32576e-5
CO_2 (g)	10^{-3}	.02272	3.04	6.90688e-5

Table 1: The absorption coefficients and concentrations for H2O and CO2 and their corresponding absorbance of Far-UVC light (222 nm).

Excimer Lamp	Duration Required for 99.9% Efficacy on HCoV-OC43 (min)	Duration Required for 99.9% Efficacy on HCoV-229E (min)
Ushio Lamp (5μW/cm² at 2m)	4,439,409	6,386,199
Sailon Lamp (35μW/cm² at 100 cm)	634,305	912,319
Larson Lamp (80 μW/cm² at 3.9878 cm)	277,477	399,157
Ushio Lamp (.2W/cm² from the source)	135.4	194.8

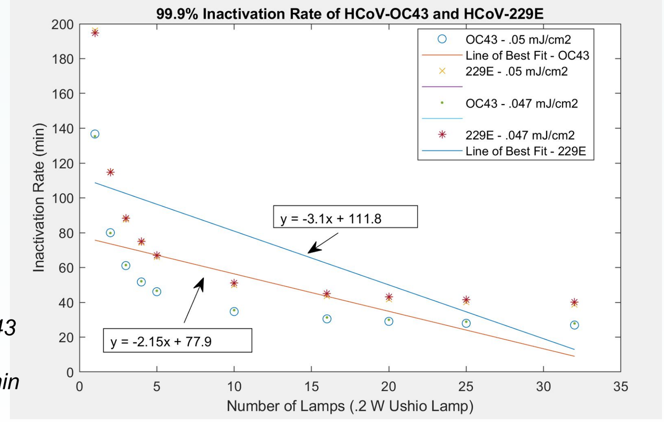
Table 2: The durations for each lamp to reach 99.9% efficacy adhering to the 0.047 mJ/cm^2/min limit

Excimer Lamp	Duration Required for 99.9% Efficacy on HCoV-OC43 (min)	Duration Required for 99.9% Efficacy on HCoV-229E (min)
Ushio Lamp (5μW/cm² at 2m)	4,529,210	6,503,482
Sailon Lamp (35μW/cm² at 100 cm)	647,033	929,074
Larson Lamp (80 μW/cm² at 3.9878 cm)	283,093	406,493
Ushio Lamp (.2W/cm² from the source)	136.7	196.2

Table 3: The durations for each lamp to reach 99.9% efficacy adhering to the 0.05 mJ/cm^2/min limit

Number of Lamps - Ushio Lamp (.2W/cm² Intensity)	Duration Required for HCoV-OC43 at a rate of 0.05 mJ/cm²/min (min)	Duration Required for HCoV-229E at a rate of 0.05 mJ/cm²/min (min)	Duration Required for HCoV-OC43 at a rate of 0.047 mJ/cm²/min (min)	Duration Required for HCoV-229E at a rate of 0.0047 mJ/cm²/min (min)
1	**136.7**	**196.2**	**135.4**	**194.8**
2	**80**	**114.9**	**79.8**	**114.8**
3	**61.1**	**87.7**	**61.4**	**88.3**
10	**34.7**	**49.9**	**35.5**	**51.1**
20	**29.06**	**41.7**	**29.95**	**43.1**

Table 4: Durations required to reach 99.9% efficacy adhering to the two ICNIRP limits



Graph 1: Inactivation Rate vs Number of Lamps for HCoV-OC43 and HCoV-229E at 0.05 mJ/cm^2/min and 0.047 mJ/cm^2/min

Final Design

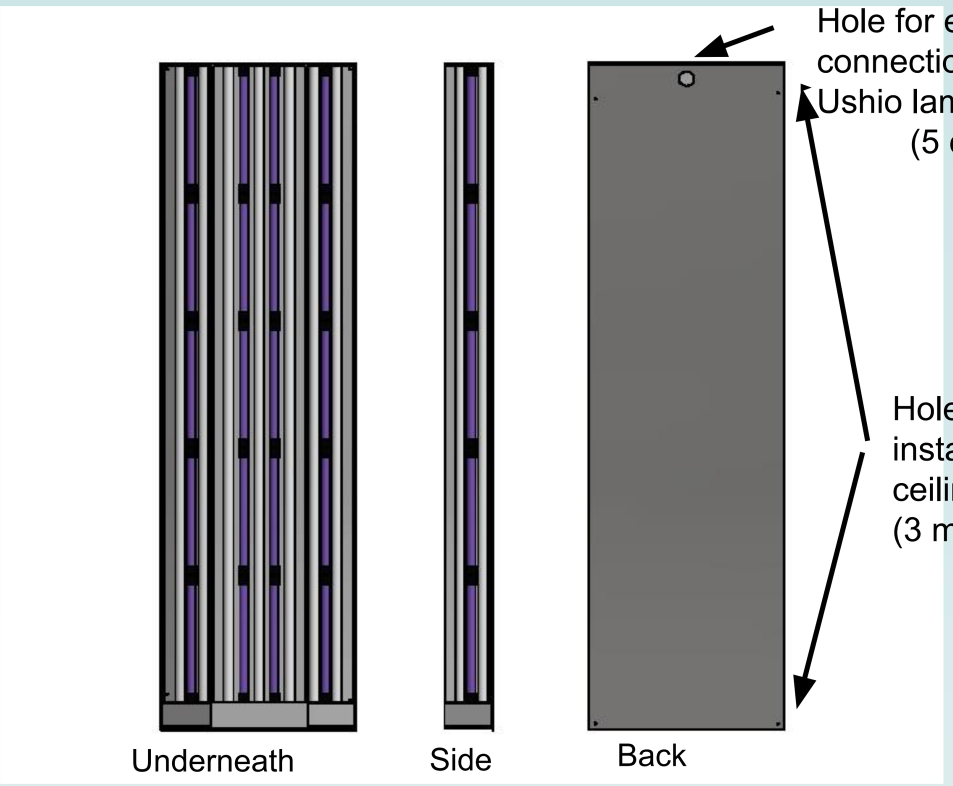


Figure 2: Underneath, side, and back views of FULED light fixture. In the underneath view you can see 4 rows of 5 ushio lamps and 7 bars of LED lights

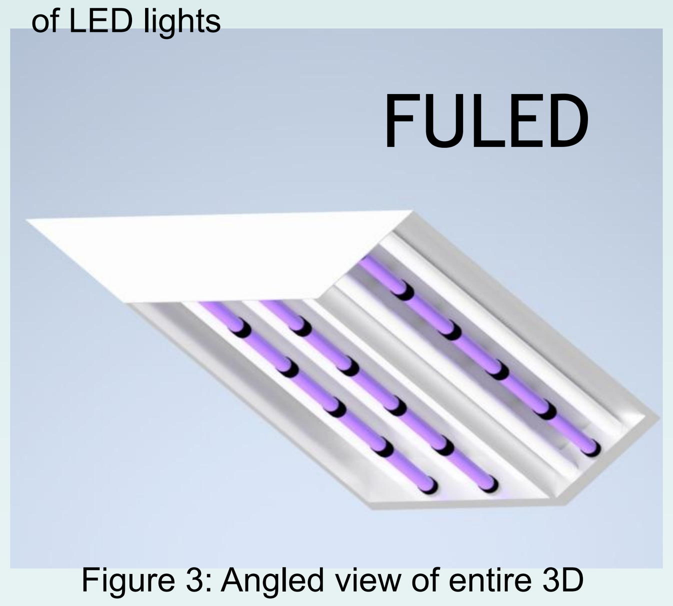


Figure 3: Angled view of entire 3D FULED fixture

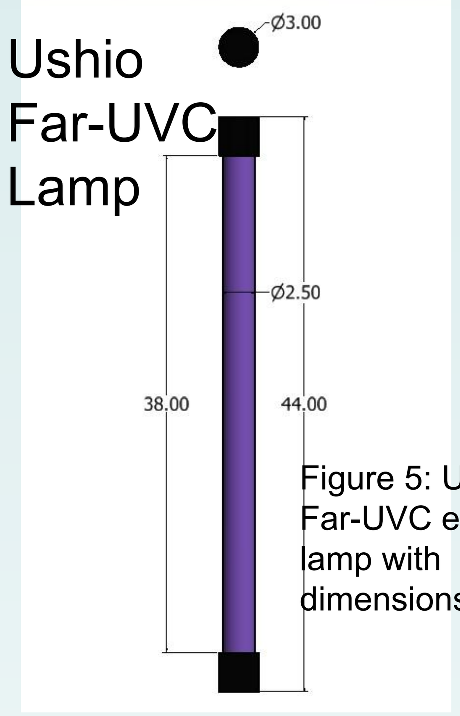


Figure 5: Ushio Far-UVC excimer lamp with dimensions in cm

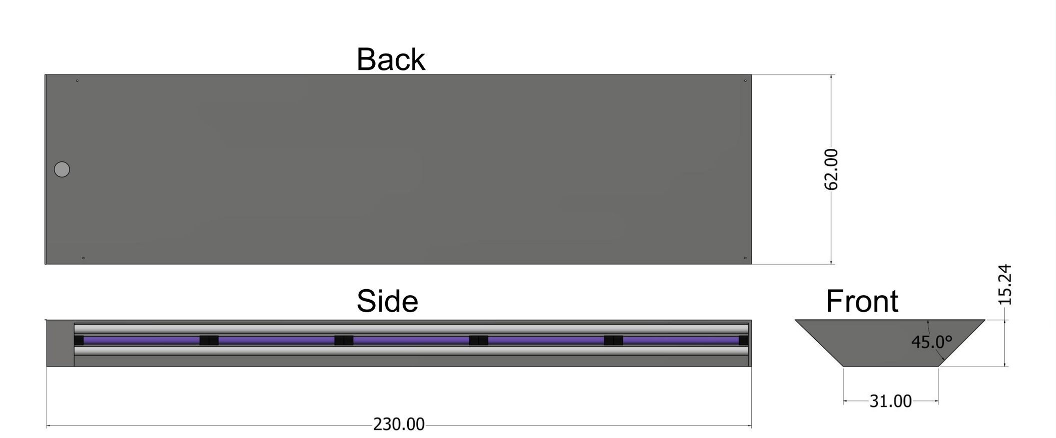


Figure 4: Back, side, and front views with dimensions in cm and angles in degrees

Our final design essentially is a prototype of what we would put together if we had the resources and time.

- Final Design:
  - 20 - 0.2 W/cm^2 Ushio Lamp
  - 99.9% disinfection of SARS-CoV-2
    - 29.06-41.7 minutes at 0.05mJ/cm^2/min
    - 29.95-43.1 minutes at 0.047mJ/cm^2/min
- Trapezoidal geometry allows for more coverage through the sides
- Holes allow for easy installment with regards to external power connection and attachment to the ceiling
- 7 LED bars of visible light (white tubes labeled in the diagram)

Conclusion and Discussion

- Used deactivation dosages for 2 strains of coronavirus to make connections with SARS-CoV-2 and determined the following using hypothetical prototypes:
  - Most effective type of lamp (.2 W Ushio Lamp)
  - Optimal amount of lamps to use (20 bulbs)
    - Graph 1 shows 99.9% inactivation rate for # lamps
  - Required exposure time to reach 99.9% inactivation (27-40 min for our design)
- Final design also has visible lighting, is in an optimal shape, can be easily fixed to the ceilings and has high efficacy
- Met the ICNIRP safety standards
- The absorbance was found to be negligible

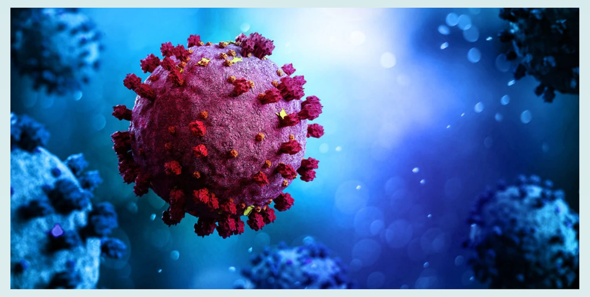


Figure 6: Depiction of SARS-CoV-2 under UV lighting. [5]

Future Work

- Experimental testing to prove efficacy and ensure safety (work on virus samples to determine efficacy and skin cells to determine safety)
- Finding optimal ratio of Intensity : Effectiveness : Cost (currently cost is about a couple thousand dollars per small lamp which does not provide much coverage)
  - Make Far UVC light marketable and available to install in public spaces
- Incorporate reflective materials to better hit target areas
- Far-UVC LED implementation to improve intensity and be more energy efficient
- Long term effects of far-UVC light on humans

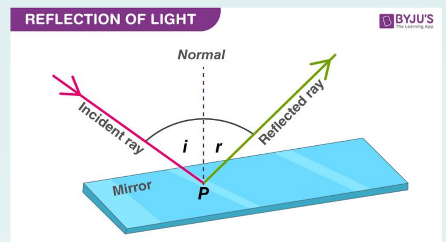


Figure 7: Image of the reflection of a light ray on a surface [6]

Figure 8: Image of an LED light [7]

References

[1] Buonanno, M., Welch, D., Shuryak, I. et al. Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses. Sci Rep 10, 10285 (2020).

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[4] - Sveta. "(7) Absorption." *SlideServe*, 10 Sept. 2014, www.slideserve.com/sveta/7-absorption.

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[6] Admin. "What Is Reflection of Light? - Definition, Laws, Types & Video." BYJUS, BYJU'S, 20 Aug. 2020, byjus.com/physics/reflection-of-light/.

[7] "Home." Super Bright LEDs, www.superbrightleds.com/moreinfo/rigid-light-bars/led-t5-integrated-light-fixtures-linkable-linear-led-task-lights-12v-4000k3000k/3654/.

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