Part 3: Whole-Room and Other UVC Applications

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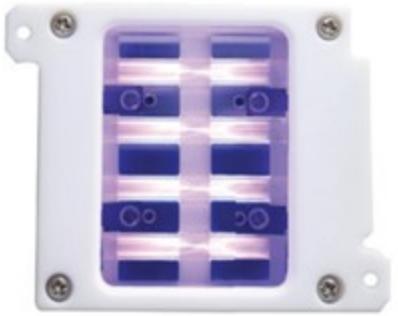
Whole-Room UVC

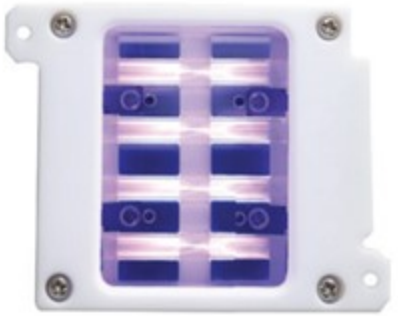
- Air
- Surfaces



Whole-Room UVC

- Air
- Surfaces

- Fixed
- Mobile



Whole-Room UVC

- **Design criteria for air disinfection:**

Whole-Room UVC

- **Design criteria for air disinfection:**
  - **Dose**

Whole-Room UVC

- **Design criteria for air disinfection:**
  - **Dose**
  - **Dose**

Whole-Room UVC

- **Design criteria for air disinfection:**
  - **Dose**
  - **Dose**
  - **Dose**

Whole-Room UVC

- **Design criteria for air disinfection:**
  - **Dose**
  - **Dose**
  - **Dose**
  - **Air mixing**

Whole-Room UVC

- Design criteria for air disinfection:
  - Dose
  - Dose
  - Dose
  - Air mixing
  - Only in unoccupied space w/ 254 nm

UV Dose

Wavelength?

UV Dose

Wavelength? 222 nm? 254 nm?

UV Dose

Wavelength? 222 nm? 254 nm?

$$\text{UV Dose}_{\text{CoV}} \neq \text{UV Dose}_{\text{MTB}} \neq \text{UV Dose}_{\text{Anthrax}}$$

UV Dose

Wavelength?

$\text{UV Dose}_{\text{CoV}} \neq \text{UV Dose}_{\text{MTB}} \neq \text{UV Dose}_{\text{Anthrax}}$

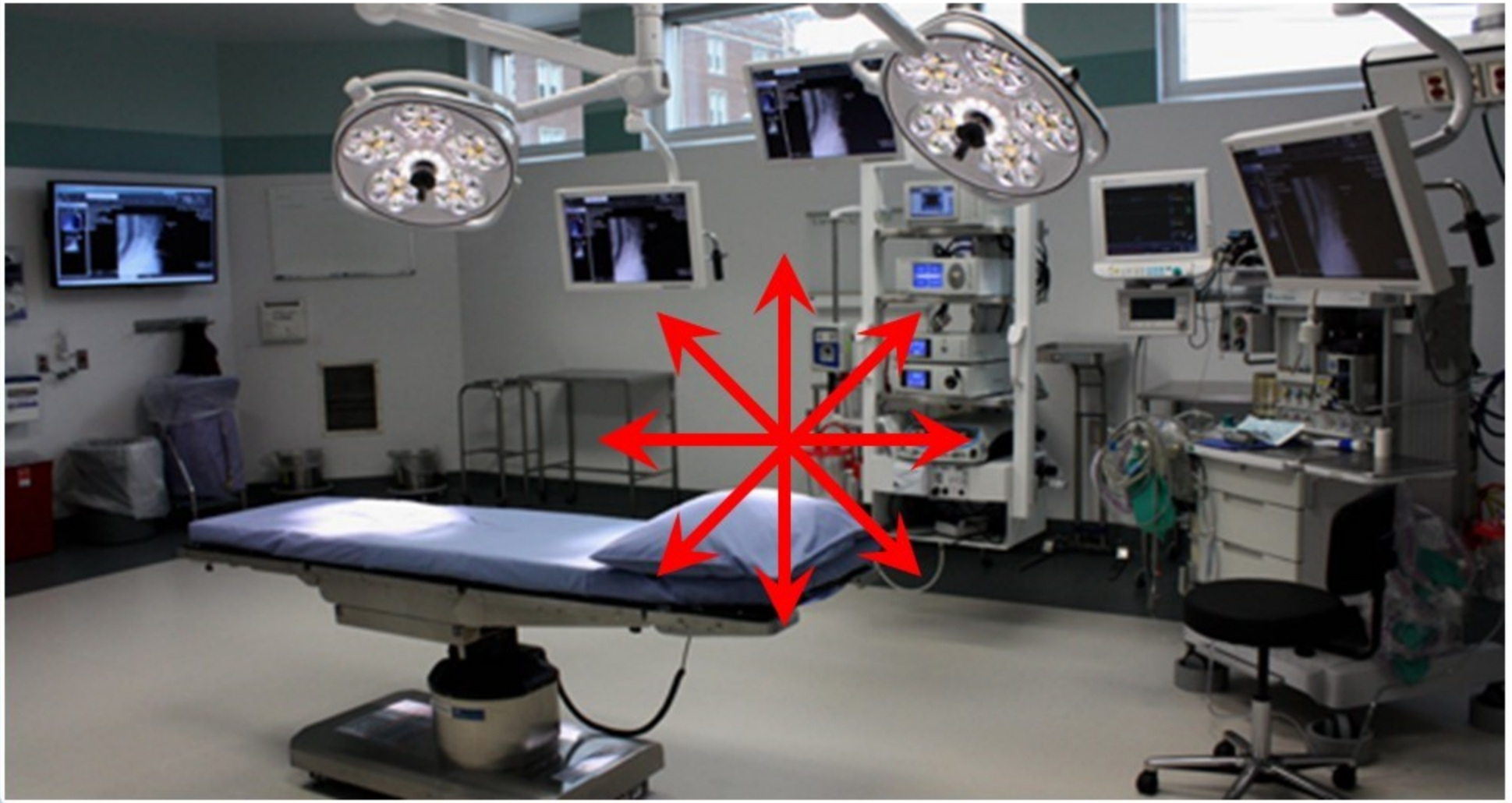
Inactivation Rate?

- **90%**
- **99%**
- **99.9%**
- **99.99%**

Droplets on Surfaces

Angle & Shading of UVC Rays

Angle & Shading of UVC Rays



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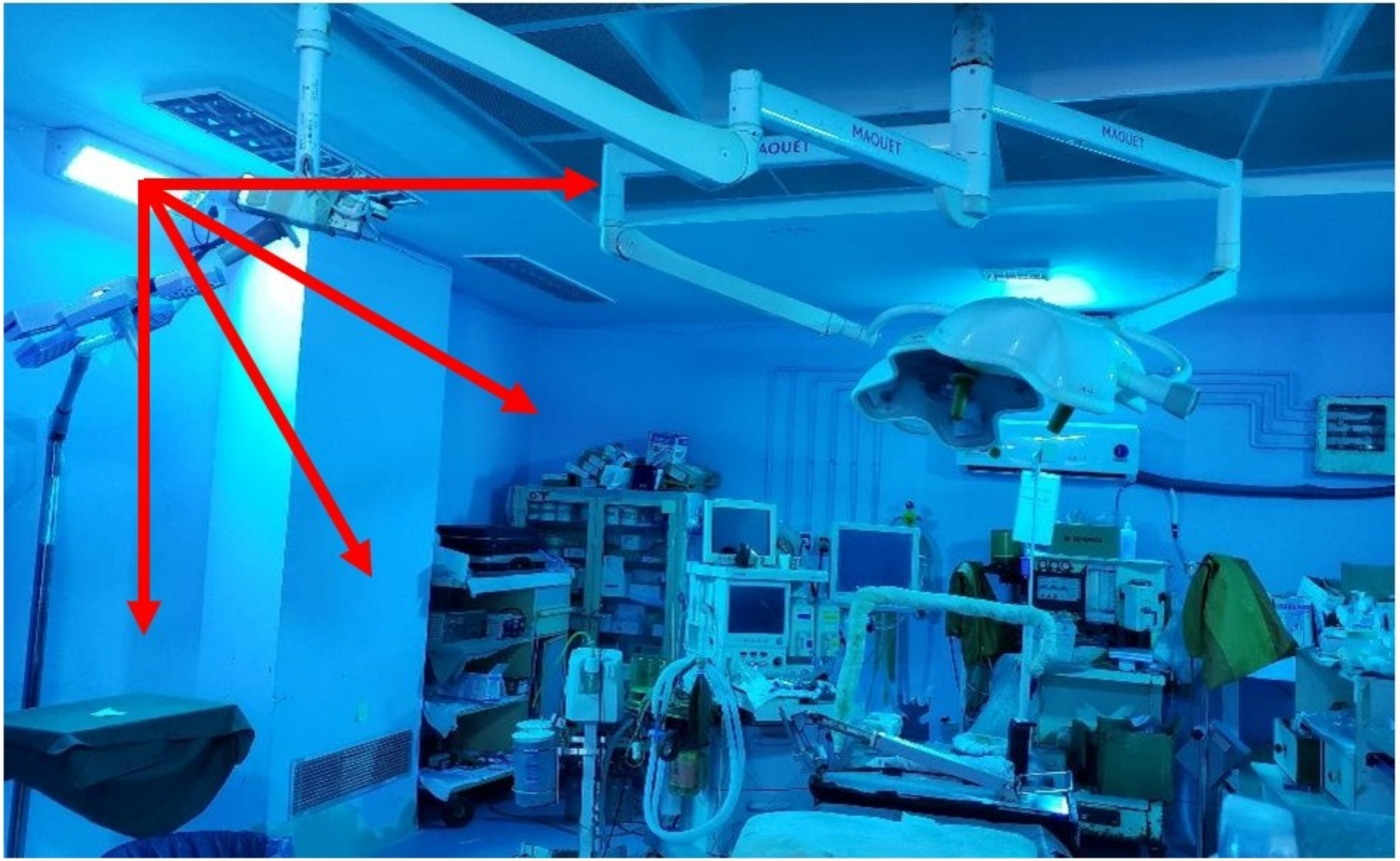
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MAQUET
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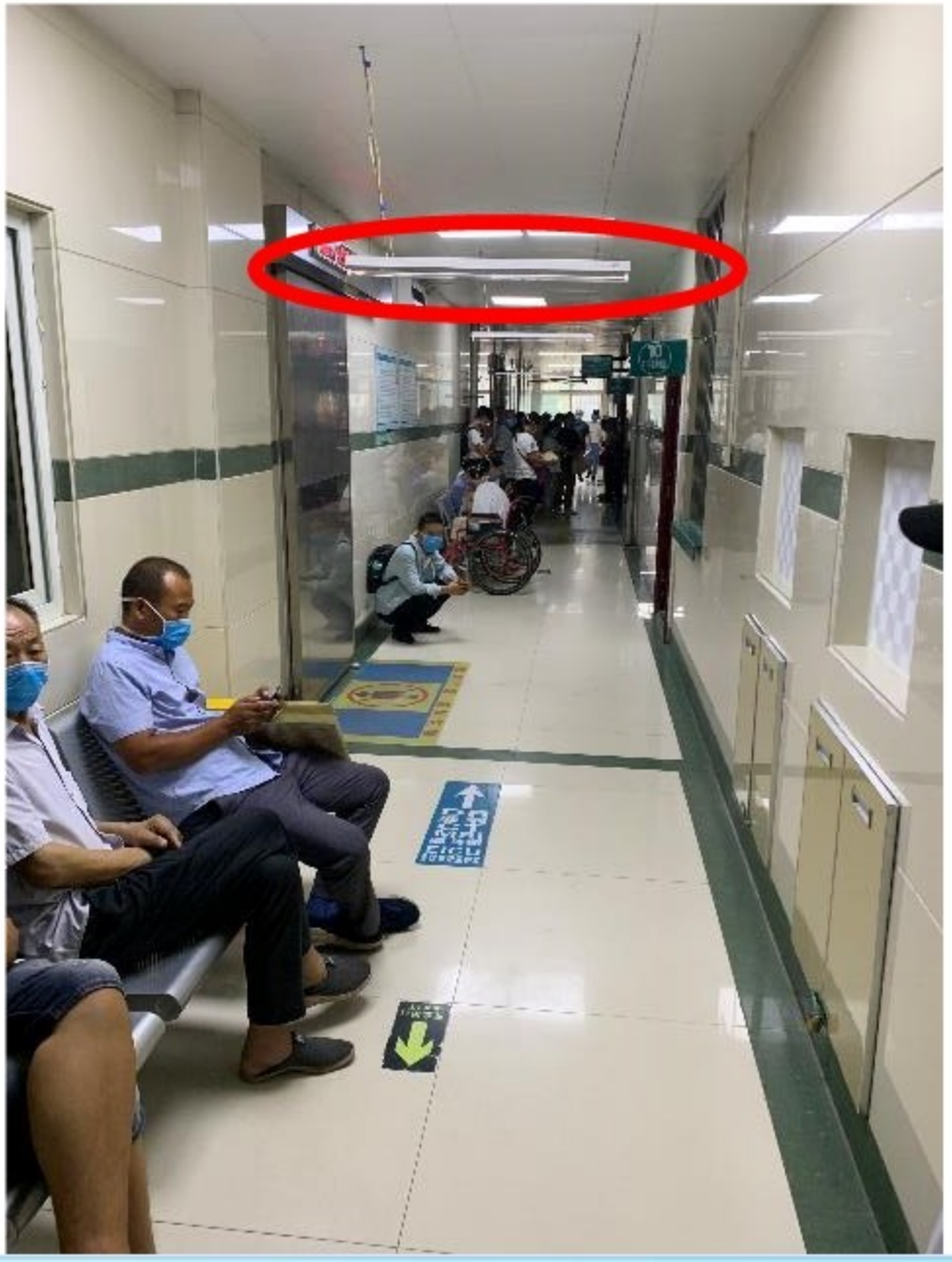
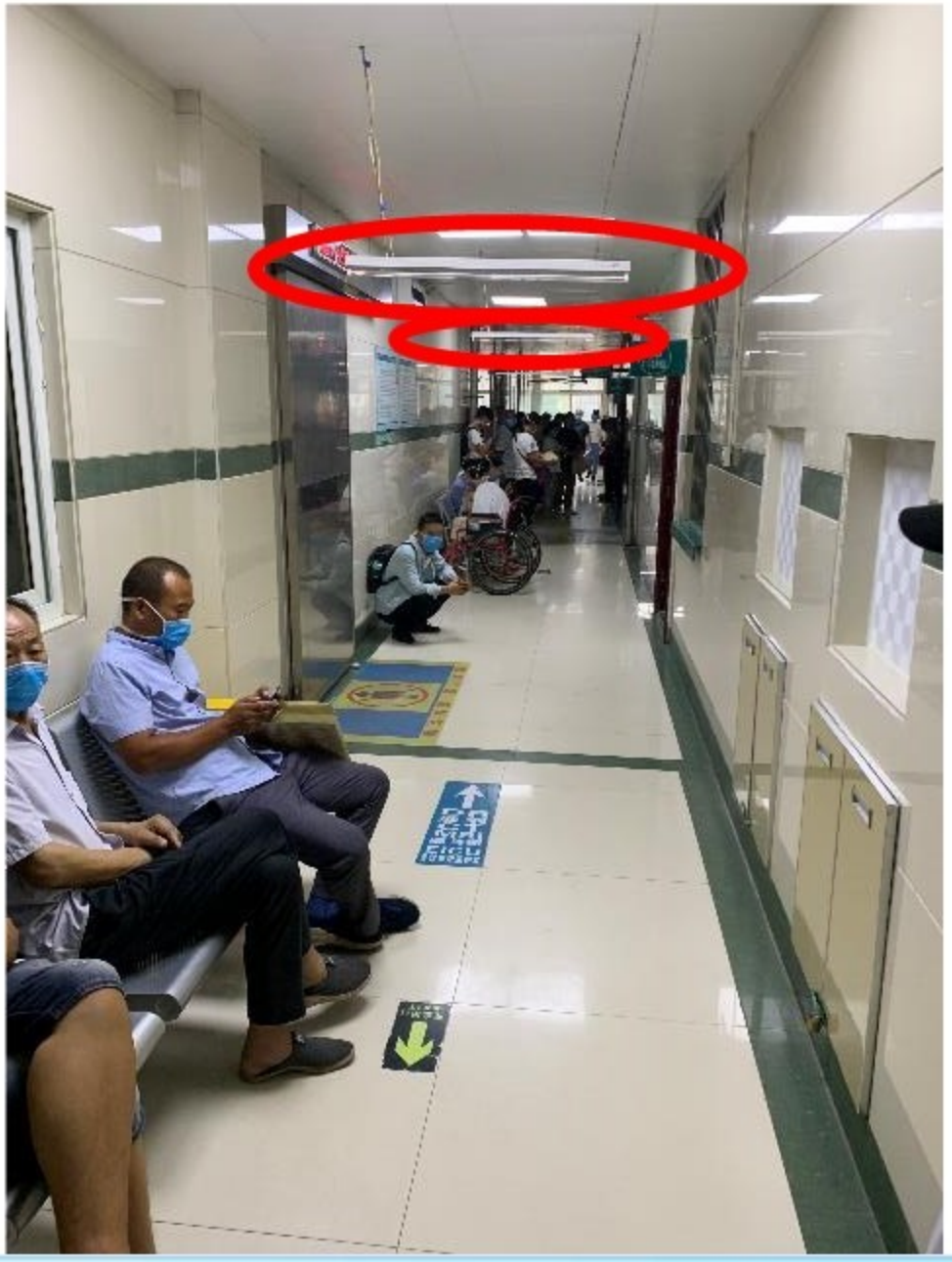


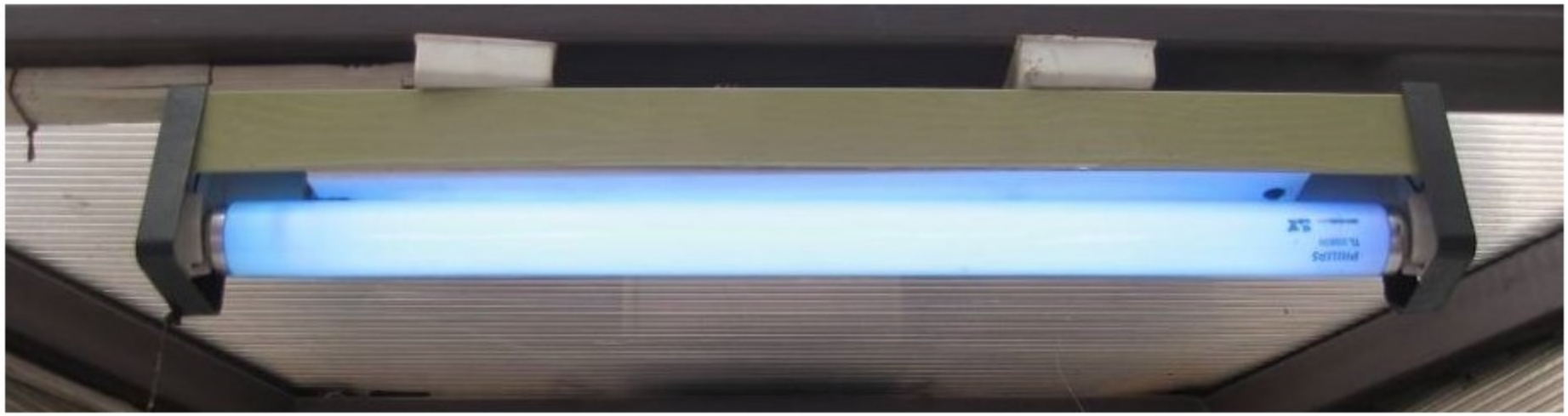


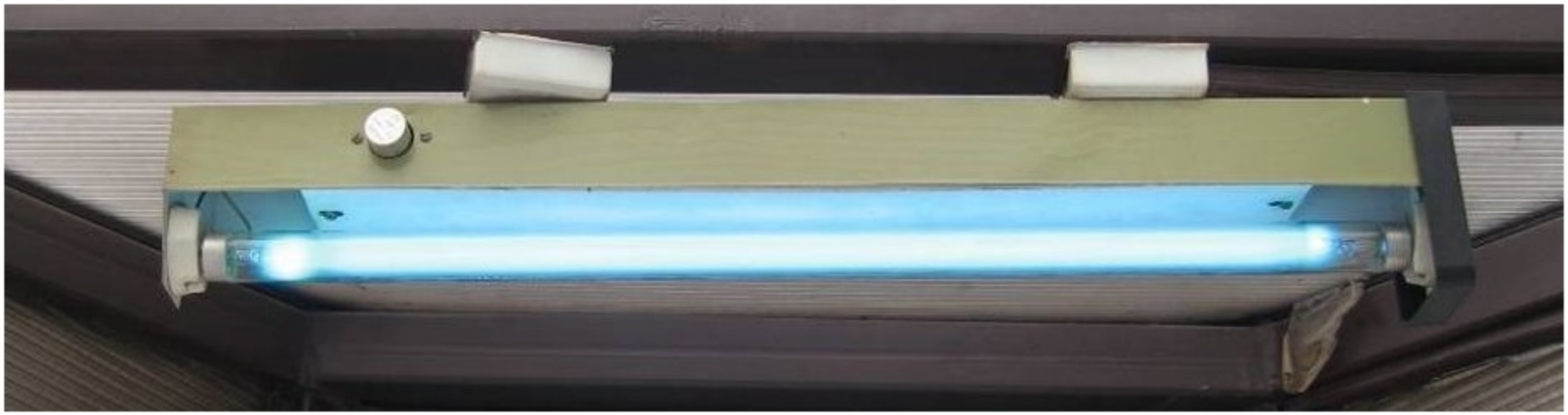
How much UVC_{254} goes through plastic?

How much UVC_{254} goes through plastic?

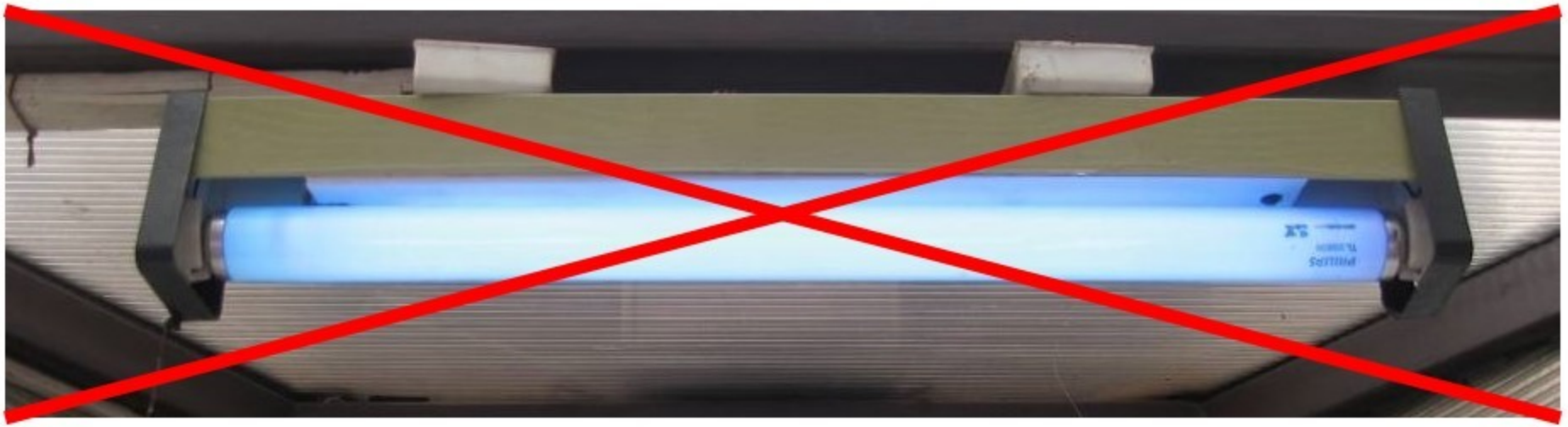
None!!!

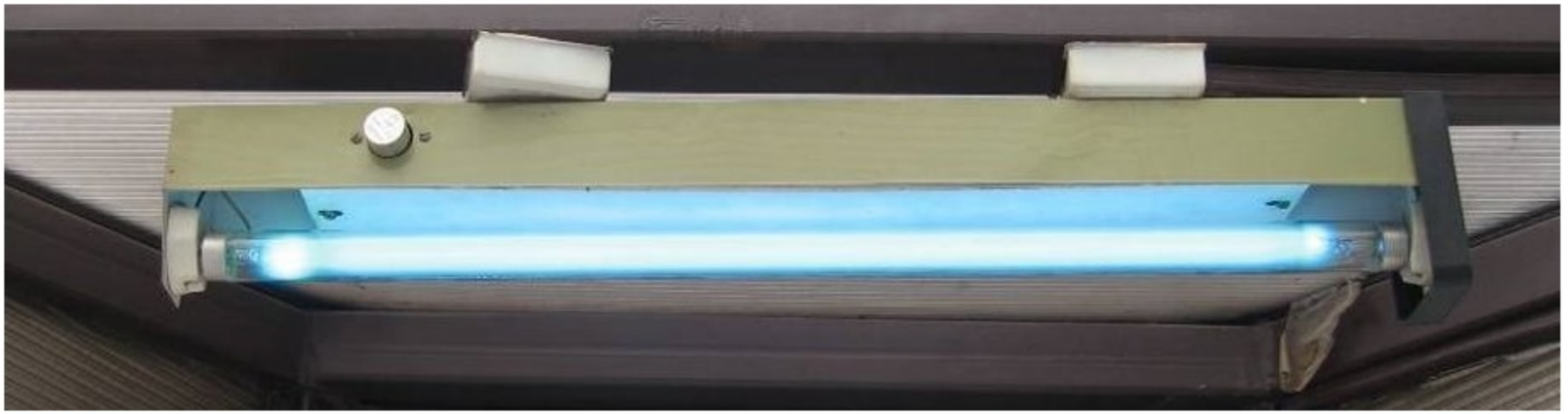
Which one is a UVC254 lamp?





Which one is a UVC254 lamp?





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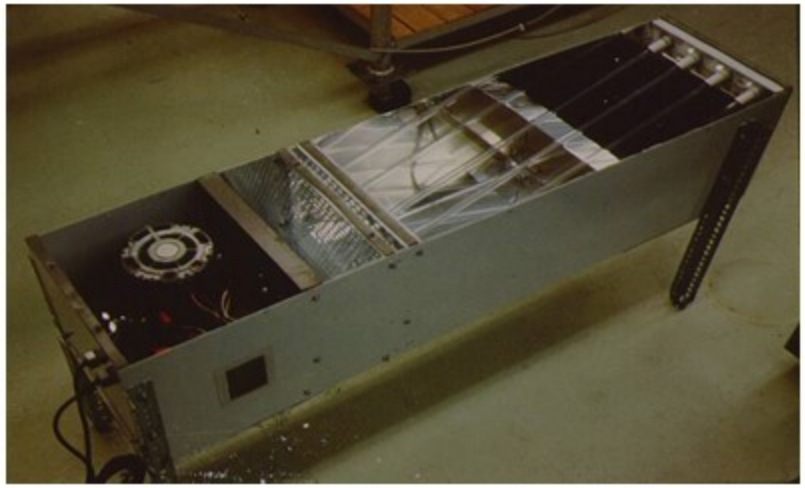
Whole-Room UVC_{254}

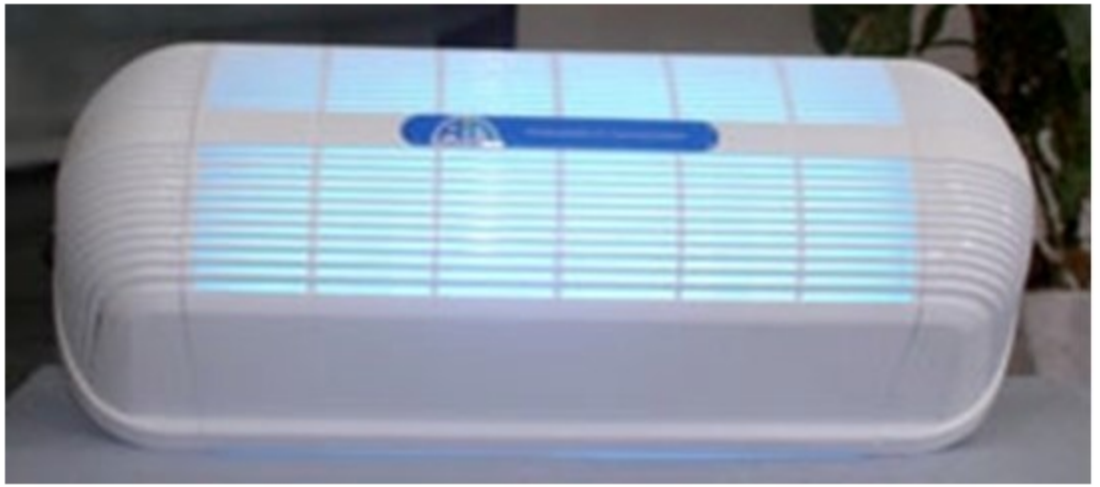
Air & Surface Disinfection (mobile)

Whole-Room UVC_{254}

Air & Surface Disinfection (mobile)

Room Air Cleaners





RACs are Supplemental to Mechanical Ventilation

- **Room**

RACs are Supplemental to Mechanical Ventilation

- Room
  - 5m x 3m x 2.7m
    - $40m^3$

RACs are Supplemental to Mechanical Ventilation

- Room
  - 5m x 3m x 2.7m
    - $40m^3$
  - Required ACH
    - 12

RACs are Supplemental to Mechanical Ventilation

- Room
  - 5m x 3m x 2.7m
    - $40m^3$
  - Required ACH
    - 12
  - Mechanical Ventilation with K = 1
    - $240\ m^3/h$

RACs are Supplemental to Mechanical Ventilation

- Room
  - 5m x 3m x 2.7m
    - $40m^3$
  - Required ACH
    - 12
  - Mechanical Ventilation with K = 1
    - 240 m^3/h
  - Required Additional Ventilation
    - 240 m^3/h

Method for Measuring Performance of Portable Household Electric Room Air Cleaners

ANSI/AHAM AC-1-2019

AHAM
ASSOCIATION OF HOME APPLIANCE MANUFACTURERS

1111 19th Street NW ▸ Suite 402 ▸ Washington, DC 20036
t 202.872.5955 f 202.872.9354 www.aham.org

Clean Air Delivery Rate (CADR)

- **Effective airflow rate**
  - **Actual airflow rate corrected for particle removal efficiency**

Clean Air Delivery Rate (CADR)

- Effective airflow rate
  - Actual airflow rate corrected for particle removal efficiency
- Particles
  - Smoke
  - Dust
  - Pollen

Clean Air Delivery Rate (CADR)

- Technologies
  - HEPA Filters
  - ULPA Filters
  - Electrostatic Filters
  - Electrostatic Precipitators
  - Ionization

Clean Air Delivery Rate (CADR)

- Technologies
  - HEPA Filters
  - ULPA Filters
  - Electrostatic Filters
  - Electrostatic Precipitators
  - Ionization
- **NONE of the above technologies inactivate bacteria or viruses**

Clean Air Delivery Rate (CADR) and Air Changes per Hour (ACH)

Clean Air Delivery Rate (CADR)

- UVC does NOT remove viral, fungal, or bacterial particles; rather, it inactivates them
- CADR for bioaerosols is a function of UVC dose and susceptibility of microorganism to UVC.
- UVC dose (mJ/cm^2 or $mW\text{-}s/cm^2$):
  - UVC irradiance
  - Exposure time

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https://doi.org/10.1080/02786826.2018.1431386

Inactivation of airborne viruses using vacuum ultraviolet photocatalysis for a flow-through indoor air purifier with short irradiation time

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ABSTRACT

Many ultraviolet (UV)-based disinfection methods have been developed; however, these methods usually use the recirculating mode or need long irradiation periods due to its low photon energy. Vacuum UV (VUV) was recently found to be a promising light source, despite its ozone generation. In this study, we investigated photocatalysis reactions by VUV with short irradiation times (0.004–0.125 s) for simultaneously inactivating airborne MS2 viruses and degrading the generated ozone toward a flow-through air disinfection system with high flow-rates. We developed three effective shapes for the catalyst frame: 2 mm and 5 mm pleated, and spiral-type Pd-TiO_2 catalysts. The 2 mm pleated Pd-TiO_2/VUV photocatalyst exhibited the highest activity for simultaneous MS2 inactivation and ozone degradation, and the catalytic activity was effective regardless of relative humidity. Considering the gas phase and catalyst surface effects, and the natural inactivation of VUV-irradiated but live MS2 viruses, the 2 mm pleated Pd-TiO_2/VUV and succeeding UV photocatalysis showed more than 90% in the overall inactivation efficiency with residual ozone of 35 ppb at an irradiation time of 0.009 s (flow-rate: 33 l/min). In contrast, most UV-based purifiers take longer times for disinfection. This system has the potential for an alternative to conventional UV-based air purifiers.

ARTICLE HISTORY
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EDITOR
Tiina Reponen

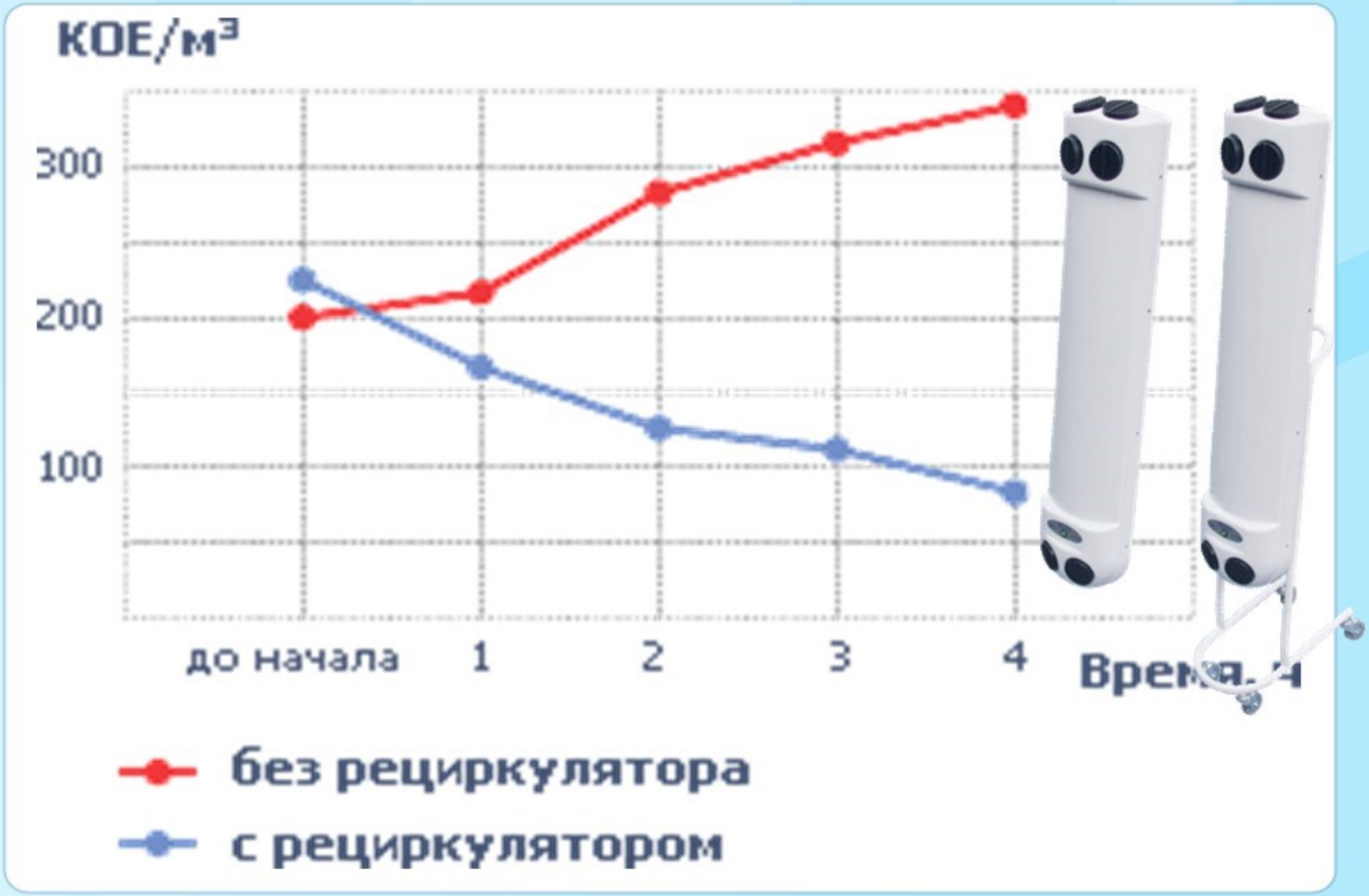
Table 1. Summary of studies on UV photocatalytic oxidation systems for disinfecting bioaerosols.

Light source	Target bioaerosols	Photoreactors	Irradiation time (flow rate)	Disinfection efficiency	Reference
UVA[a]	*Escherichia coli*	TiO_2-coated Pyrex tubular reactor	9–35 s (1.5–6l/min)	99.1–99.8%	(Keller et al. 2005)
UVA[a]	*Escherichia coli*	Continuous annual reactor with TiO_2-coated glass fiber filter	1.1 min (1l/min)	100%	(Pal et al. 2008)
UVA[a]	*Legionella pneumophila*	Three-dimensional solid foam structured reactor	1.5 s (21.6l/min)	94%	(Josset et al. 2010)
UVA[a]	Influenza virus H1N1	TiO_2-coated porous ceramic substrate	5 min (6–24l/min)	100%	(Daikoku et al. 2015)
UVA[a]	*Pseudomonas aeruginosa, Staphylococcus aureus,* Methicillin-resistant *Staphylococcus aureus, Aspergillus fumigatus*	Honeycomb structure made of P25 dip-coated cellulose acetate monoliths	15 min	74–98%	(Rodrigues-Silva et al. 2017)
UVA[a], UVC[b]	*Escherichia coli*	TiO_2-coated glass fiber substrates	~0.5 s (20l/min)	95%	(Lin et al. 2010)
UVA[a], UVC[b]	*Escherichia coli*	TiO_2-coated filter	2–6 h	100%	(Pigeot-Remy et al. 2014)
VUV[c]	MS2 phage	Spiral and pleated Pd-deposited TiO_2 flow-through reactor	0.004–0.125 s (33l/min)	47.8–100%	Present study

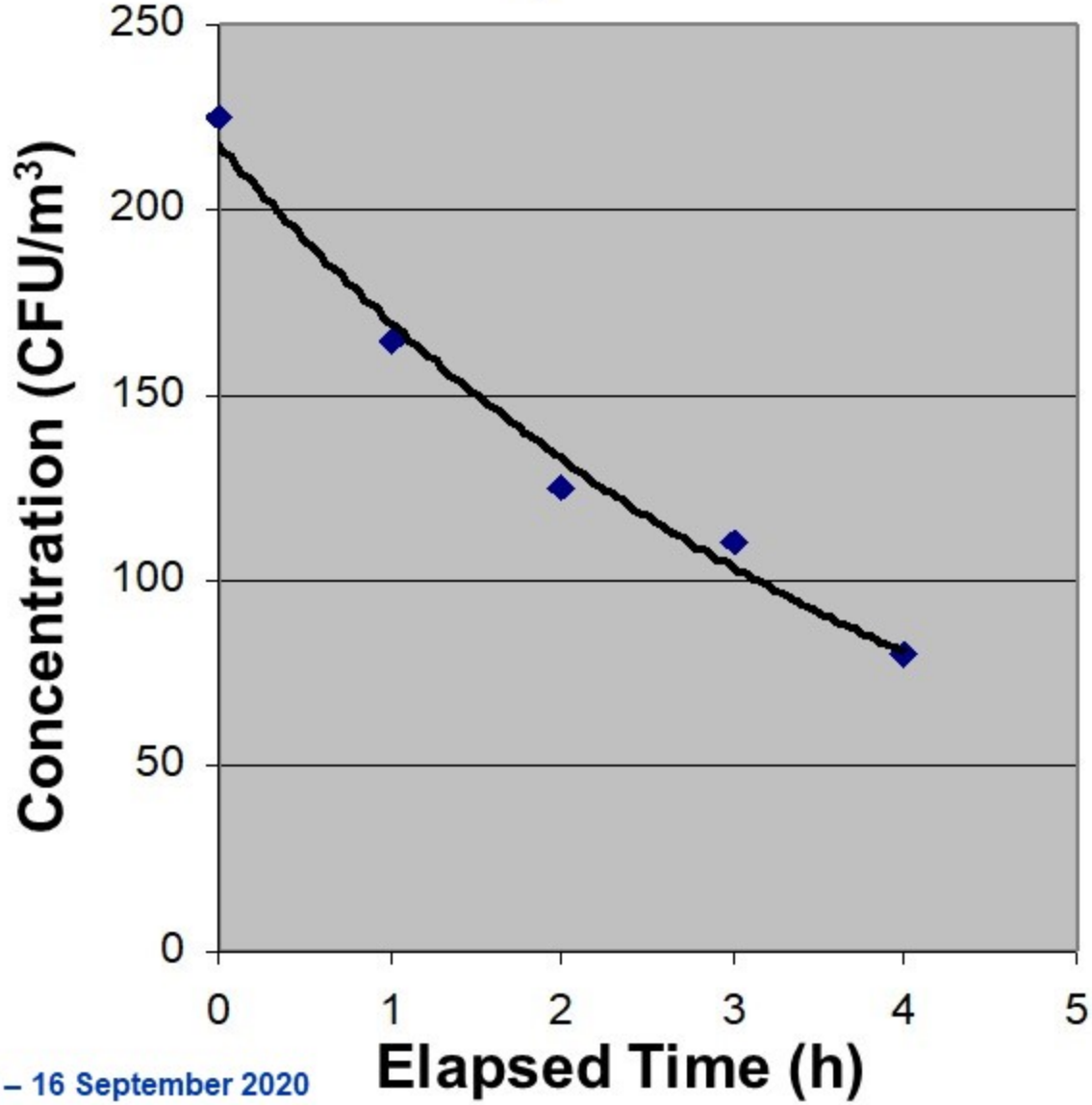
[a]UVA: 365 nm wavelength ultraviolet light.
[b]UVC: 254 nm wavelength ultraviolet light.
[c]VUV: 185 nm wavelength ultraviolet light.

1-33 L/min
0.035-1.17 cfm

Jeonghyun Kim & Jaesung Jang (2018) Inactivation of airborne viruses using vacuum ultraviolet photocatalysis for a flow-through indoor air purifier with short irradiation time, Aerosol Science and Technology, 52:5, 557-566, DOI: 10.1080/02786826.2018.1431386

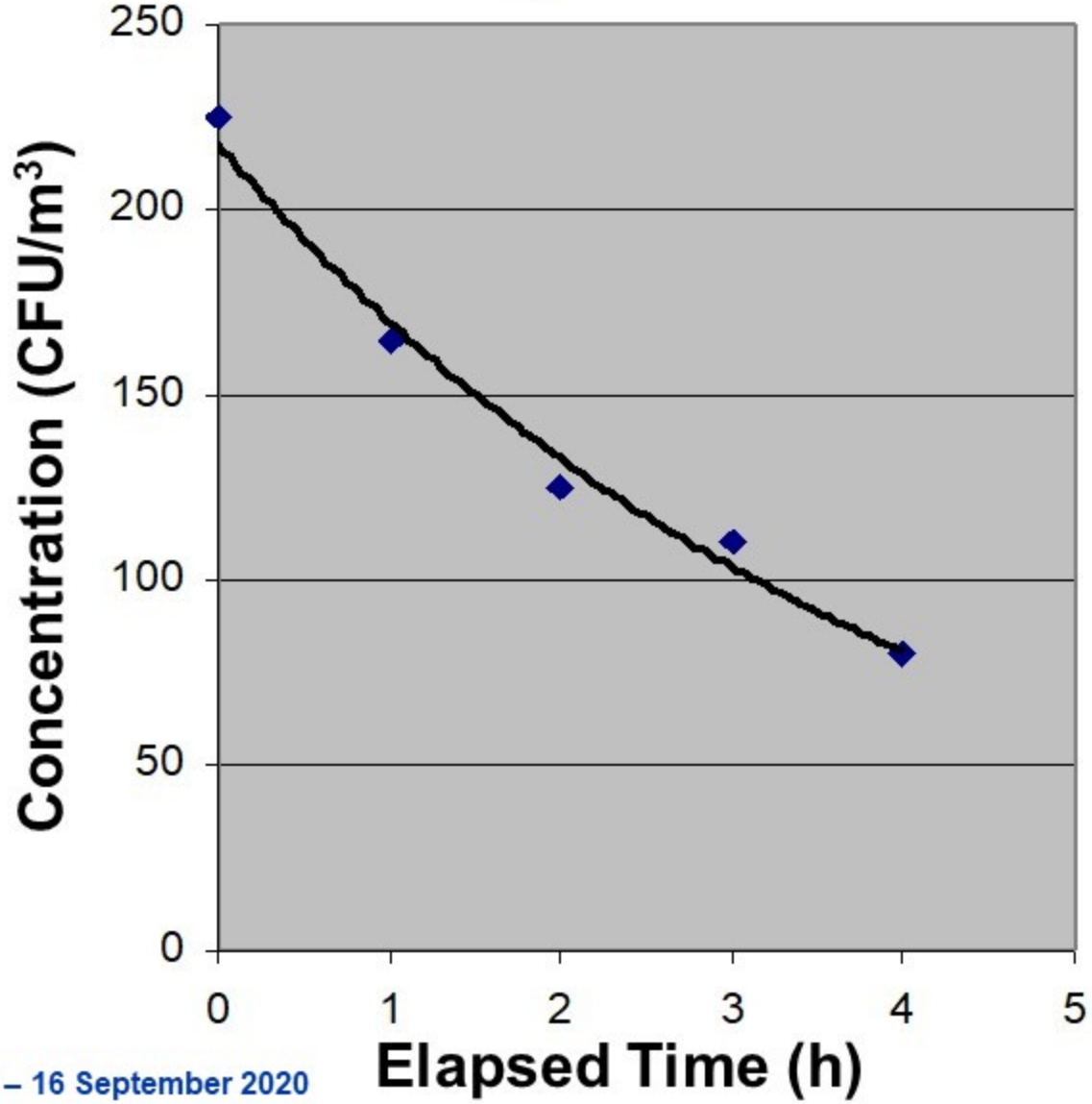

КОЕ/м³
300
200
100
до начала
1
2
3
4
Время, ч
без рециркулятора
с рециркулятором

How many ACH?
How many RACs are needed?



$$y = 217{,}3e^{-0{,}2474x}$$

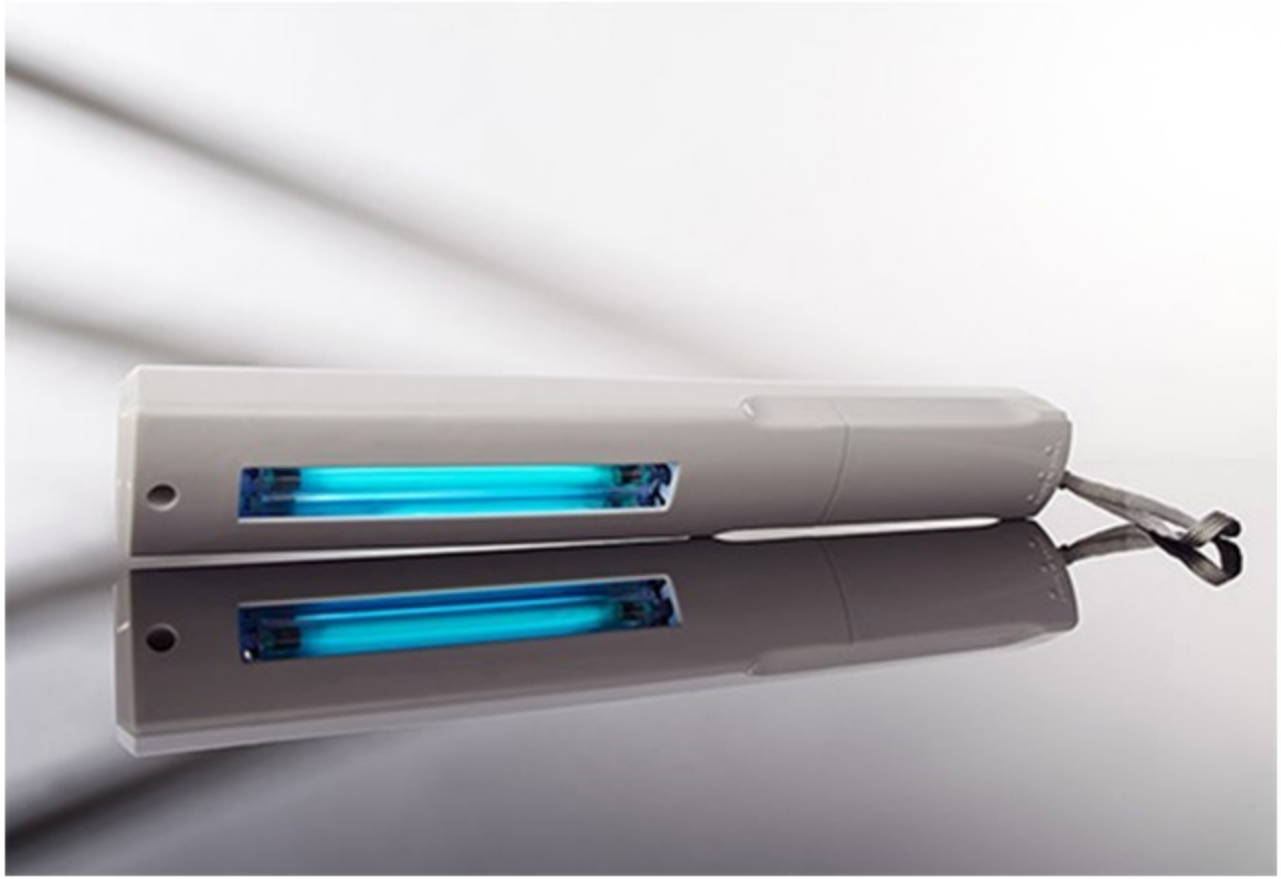
How many ACH?
How many RACs are needed?



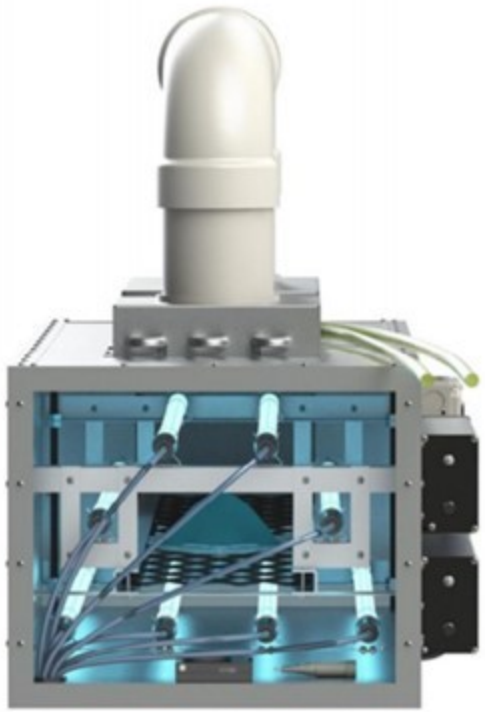
$y = 217{,}3e^{-0{,}2474x}$

ACH = 0,25

Disinfection of “Stuff”



Disinfection of PPE with UVGI



UV irradiation device fabricated and employed by Mills et al. (2018).

Nebraska Medicine

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Disinfection of Linens with UVGI

Summary of Applications (1)

- Ventilation Systems
  - Coil and duct surfaces
  - Air (sole method)
  - Air (supplemental filtration)

Summary of Applications (2)

- Room Systems
  - Upper-Room
    - Air
  - Whole-Room
    - Air
    - Surfaces
  - Room Air Cleaners
    - Air

Summary of Applications (3)

- Other Systems
  - PPE (including respirators)
  - Linens
  - Surfaces

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