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Next Generation PPE for Real-time Inactivation of Airborne Biological Threats, Part I: Experimental Measurements

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Background, Project Motivation

Need for Real-Time Inactivation of Airborne Biological Threats

➔ COVID-19 Pandemic, RSV, *M. Tuberculosis*

Image Source: US FDA

Existing technology uses physical separation (filtration)

- N95 Masks are the standard: ≥95% separation of particles with $d_p \geq 0.3\ \mu m$

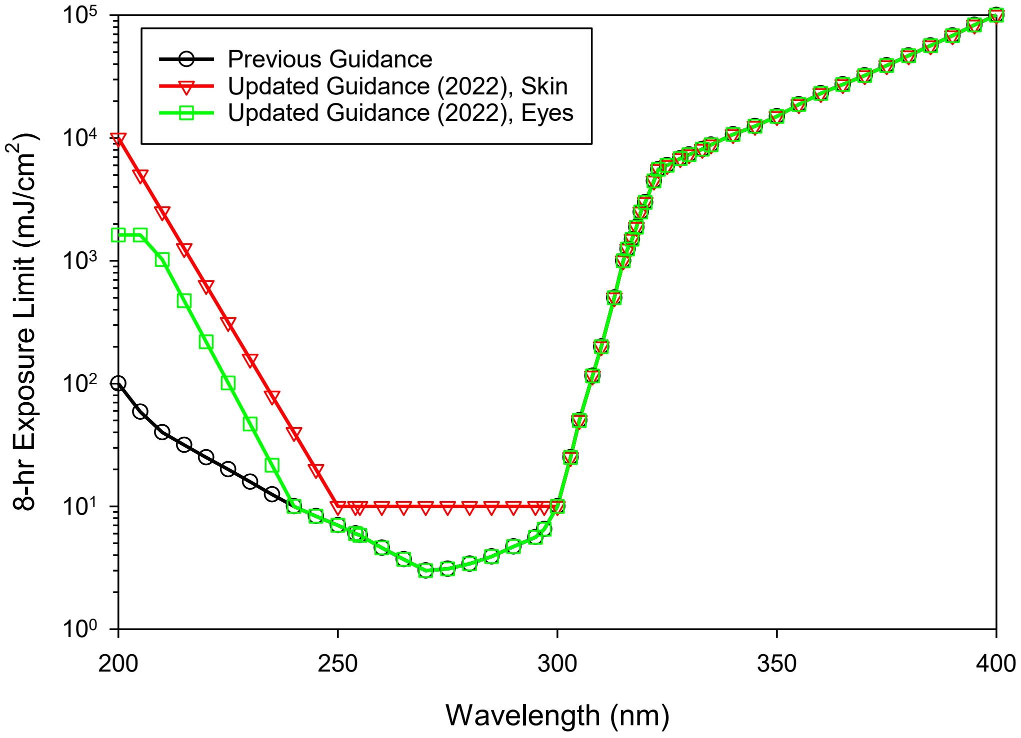
Lack of consistent testing methods for air disinfection systems

- Effectiveness of devices cannot be reliably or consistently compared or quantified

Project Goal: Develop and demonstrate 'mask' device that employs UVC-based inactivation of airborne pathogens

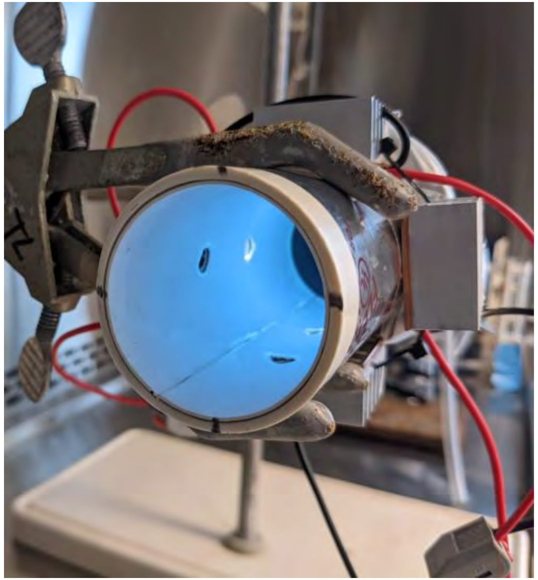
Use of UVC for Real Time Treatment of Air: Constraints

- Sufficient dose of UVC provides effective inactivation of airborne pathogens including SARS-CoV-2, influenza, and others
- The dose delivered to skin and eyes must be kept below Threshold Limit Values (TLVs)



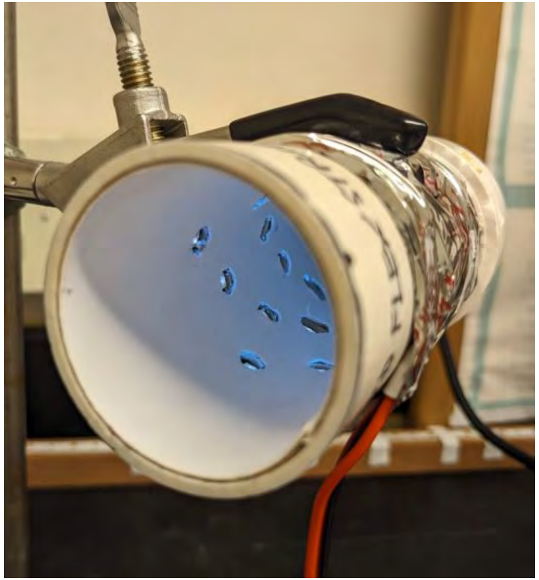
Source: Blatchley *et al.* (2022) “Far UV-C radiation: An emerging tool for pandemic control,” *Critical Reviews in Environmental Science & Technology*, https://doi.org/10.1080/10643389.2022.2084315.

UV-C Reactors Tested Using Methodology



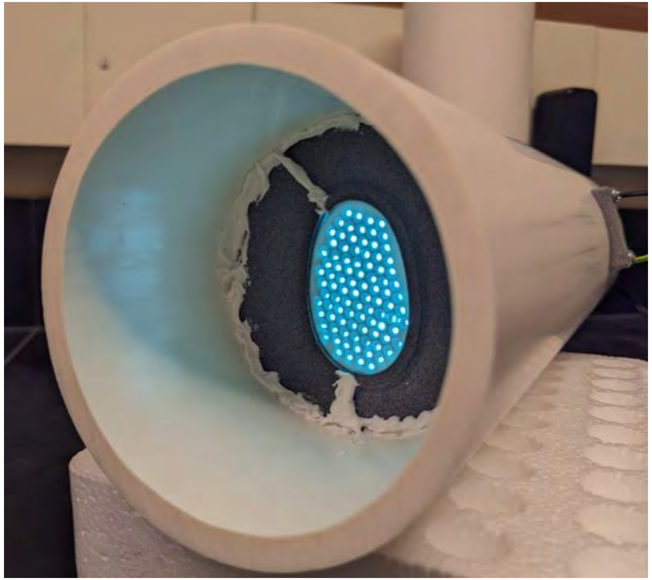
Nichia LED Reactor

Four LEDs, 282 nm (peak)



“Barber Pole” LED Reactor

27 LEDs, 277 nm (peak)

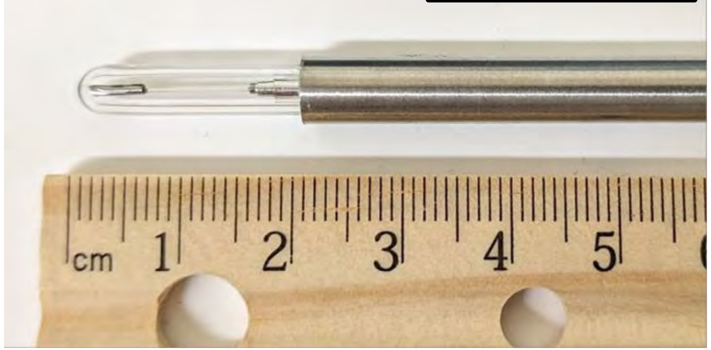


Pod Reactor

LP Hg, 254 nm

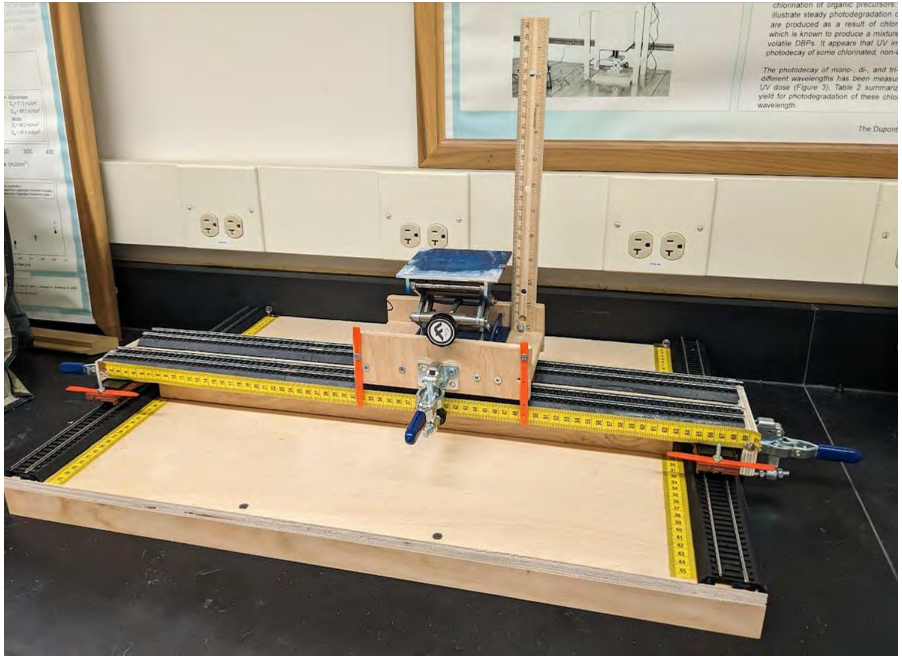
Measuring the Fluence Rate Field in Reactors

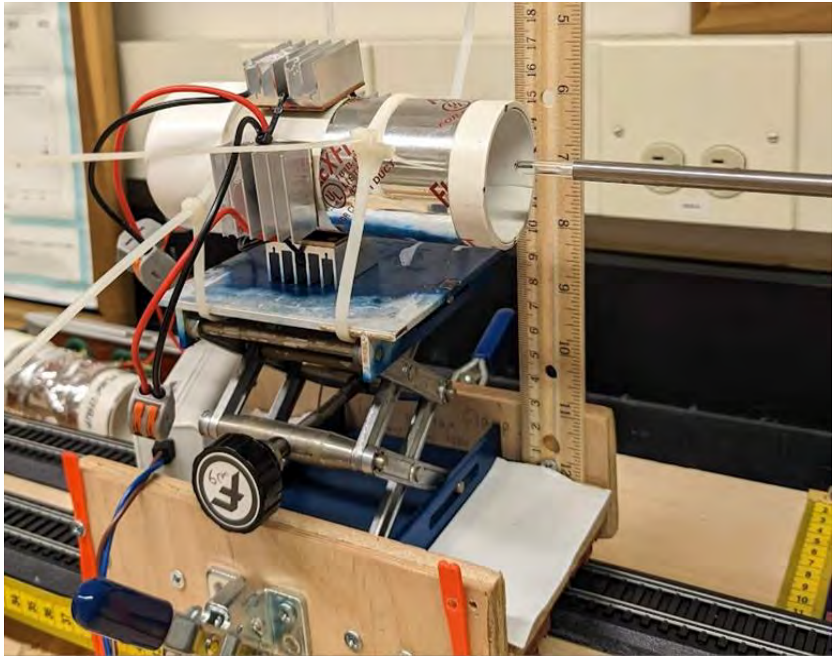
- Fluence Rate (FR) field depends on:
  - Reactor geometry
  - Lamp power
  - Lamp placement
  - Reflective media
- FR compared with results of numerical simulations (See Part 2)
- Measurements of FR conducted using MFSD
  - Accepts photons from ~all incident angles
  - Allows measurement of local fluence rate
  - Calibration against NIST-calibrated radiometer
  - Mengkai Li presentation Tuesday 4:20 PM



Positioning Device

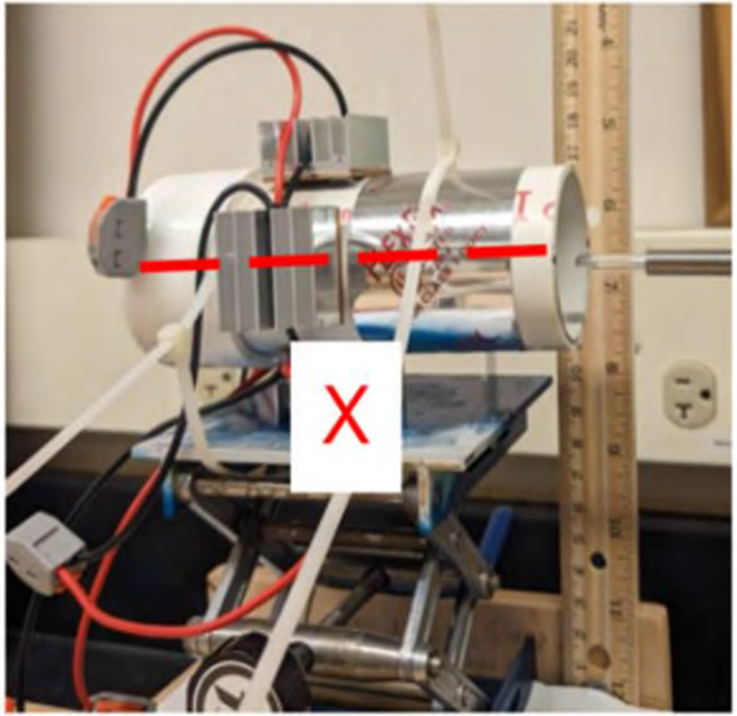
- Allowed precise positioning in all three directions (x,y,z)
- Position of MFSD was fixed, reactor was moved

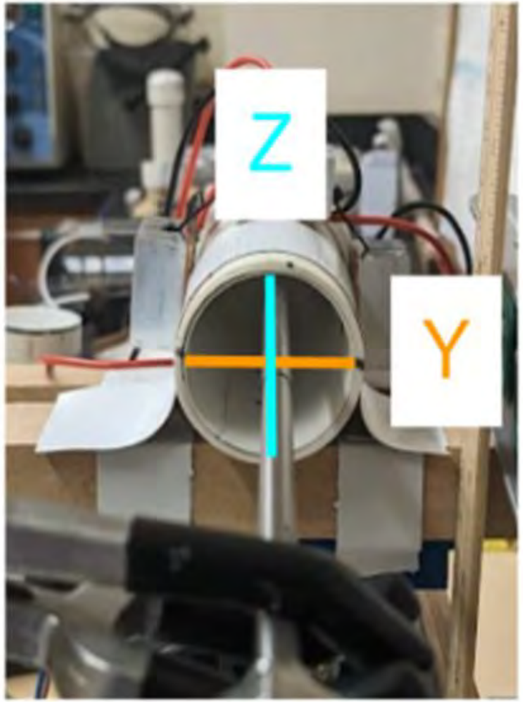




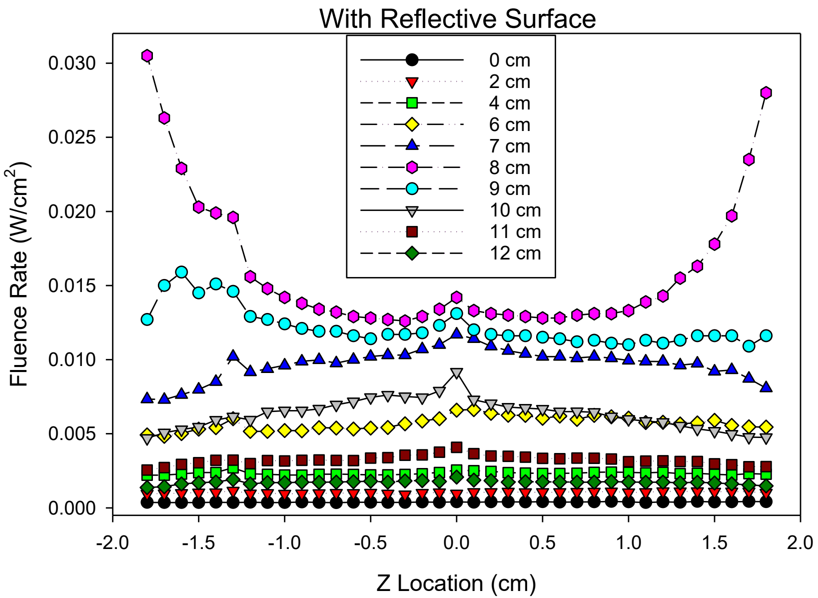
Locations of Measurements inside Reactors

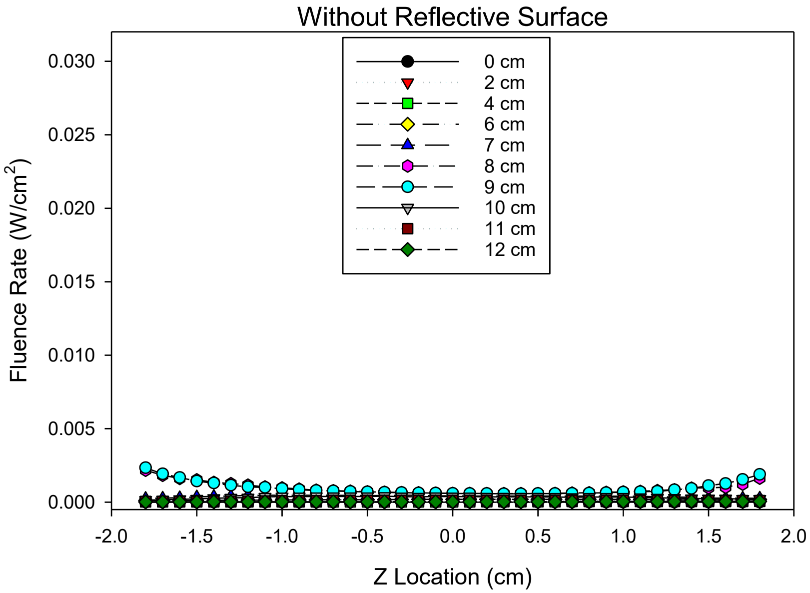
Measurements were taken at ten cross-sections (X) and at 1 mm increments along the Y and Z axes





MFSD Measurements Inside Nichia Reactor



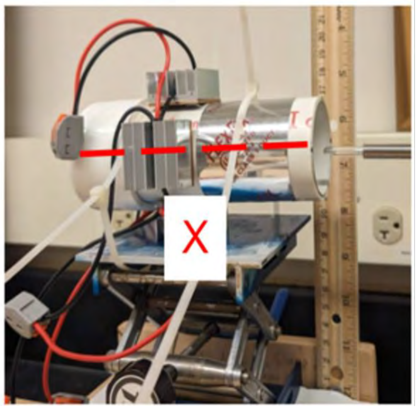


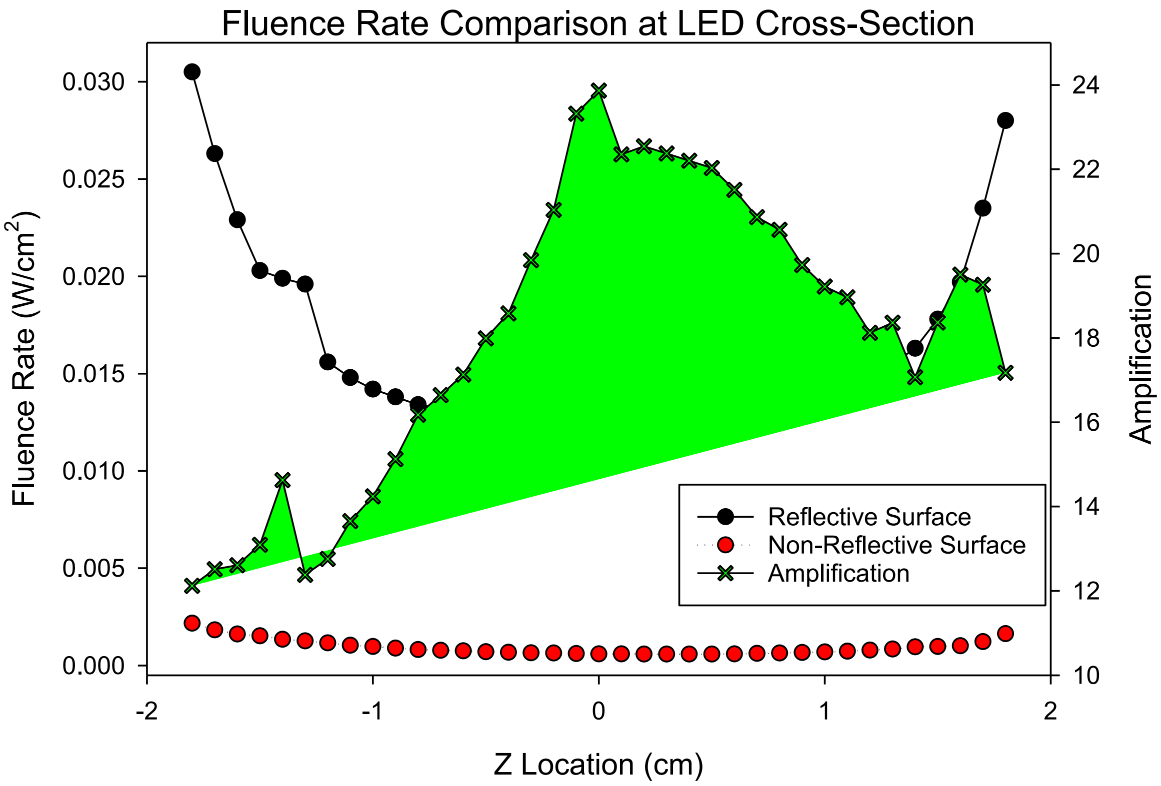
- Experimental measurements found a relatively uniform FR field
- Maximum FR values within a cross-section were observed near the centerline and the along the walls of the reactor
- Photon ‘recycling’ is critical to reactor performance

Impact of Reflective Material on Fluence Rate Field

Reflective Material provided amplification of 12X to 24X, average 18X

Center peak was present only in reflective material measurements



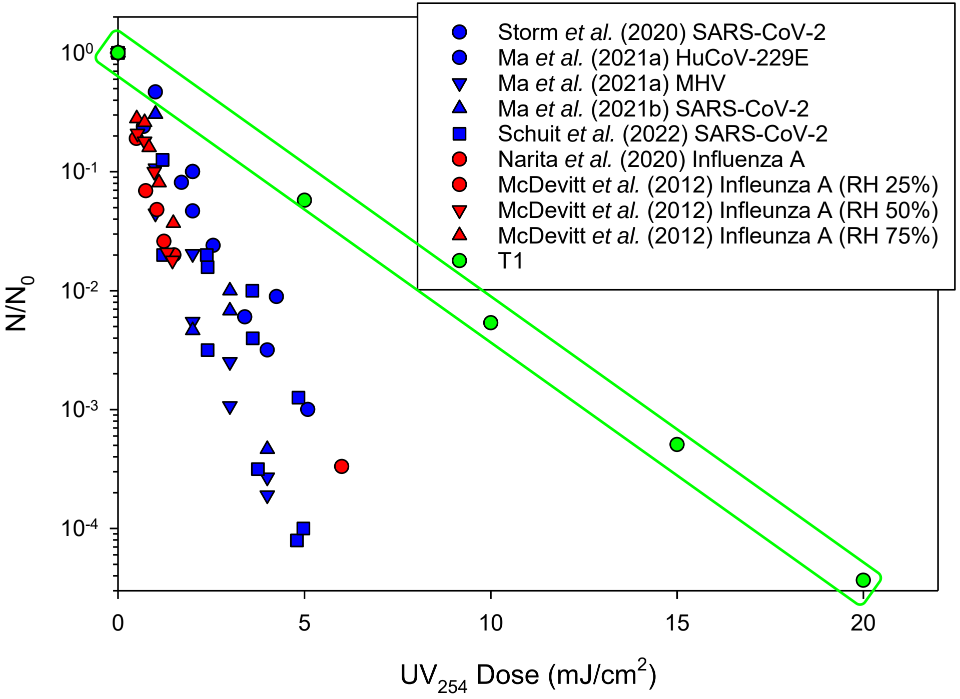


Biological Experiments to Test Inactivation

Experiments were conducted to quantify inactivation of an aerosolized challenge agent by the reactors

T1 Bacteriophage was selected as the challenge agent

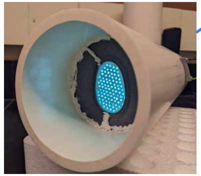
UVC inactivation of T1 provides a conservative estimate of disinfection efficacy against coronaviruses and most other airborne pathogens



Challenge Agent Experiments Setup

1-Port Collison Nebulizer | Reactor | Impinger Bioaerosol Sampler and Water Trap | Flow Meter | Vacuum Pump

Results from Direct Flow Reactor Tests (Q_{air} = 2.5 L/min)



Reactor	Test 1 Inactivation ($-\log_{10}(N/N_0)$)	Test 2 Inactivation ($-\log_{10}(N/N_0)$)	Average Inactivation ($-\log_{10}(N/N_0)$)
Barber Pole LED (277 nm)	1.54	2.12	1.83
Nichia LED (282 nm)	2.69	2.11	2.40
LP Hg Pod (254 nm)	3.11	2.66	2.89

N95 Masks: **$-\log_{10}(N/N_0) \approx 1.30$**

‘Pod’ Reactor Experiments

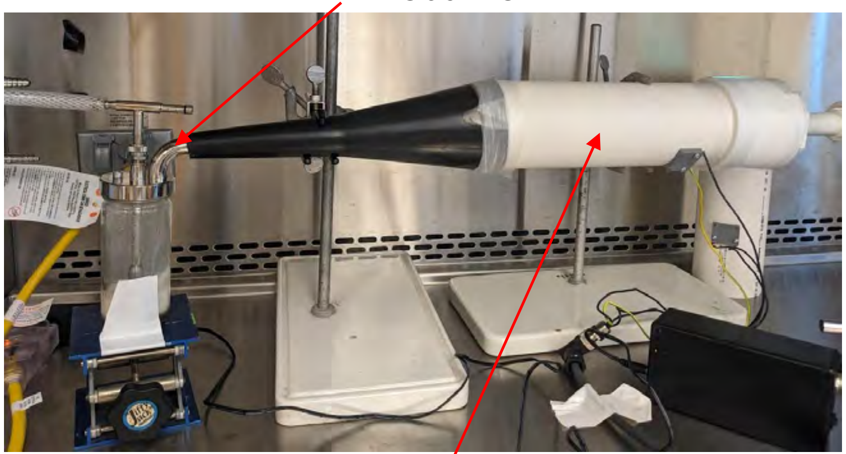
Goal is to provide physically-meaningful measurements of airborne challenge agent (T1) inactivation using a geometrically-relevant test setup

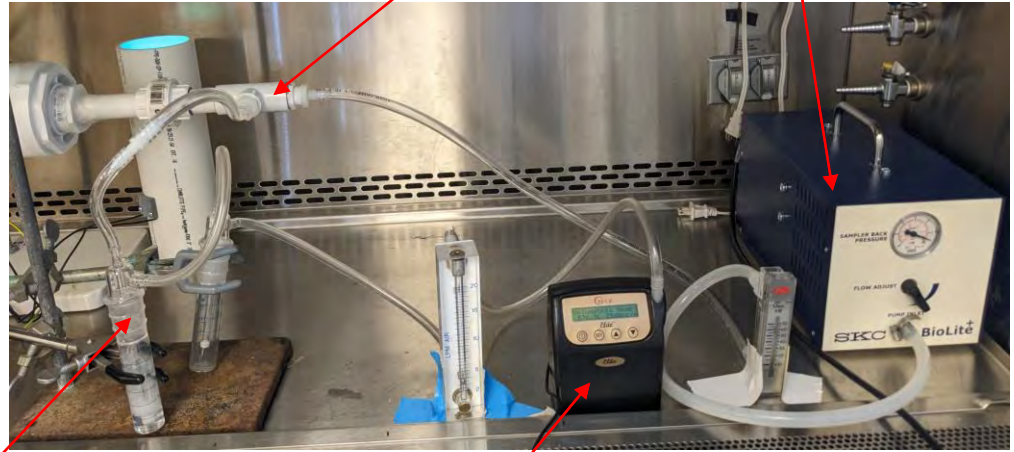
Range of air flow rates (5-50 L/min)

Nebulizer

Tee

Variable Flow Rate Pump





LP Hg Pod Reactor

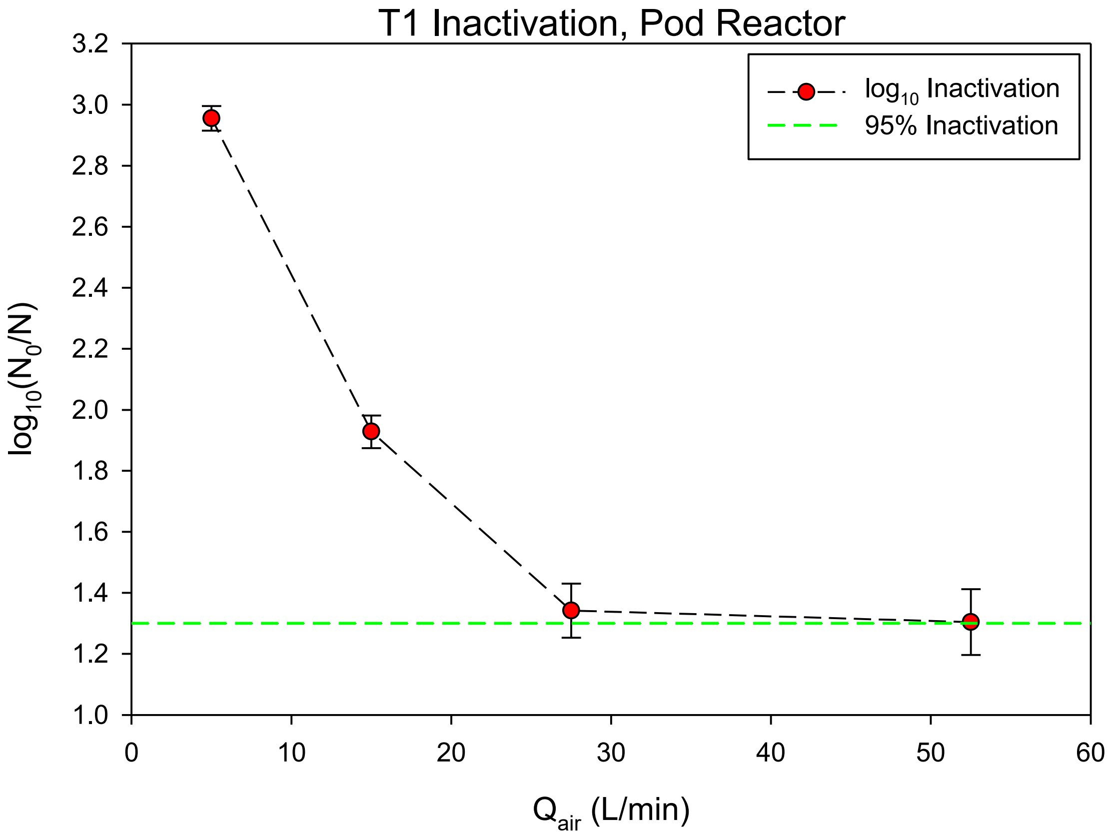
Bioaerosol Sampler

Sampling Pump (2.5 L/min)

Results of Pod Reactor Testing

- Inactivation of T1 as a challenge agent was inversely related to combined flow rate

- At all flow rates (5 to 52.5 L/min), the reactor was at least as effective as an N95 mask



Conclusions

- MFSD combined with positioning device allowed measurements of fluence rate field inside the reactors
- Measurements with and without reflective material demonstrated the impact of reflective material on photon recycling
- All three UVC reactors tested provided inactivation at higher rates than the filtration provided by N95 masks for T1 bacteriophage
- Pod reactor tests demonstrated that the Pod reactor provided effective inactivation at a range of flow rates representative of human respiration

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DEPARTMENT OF DEFENSE
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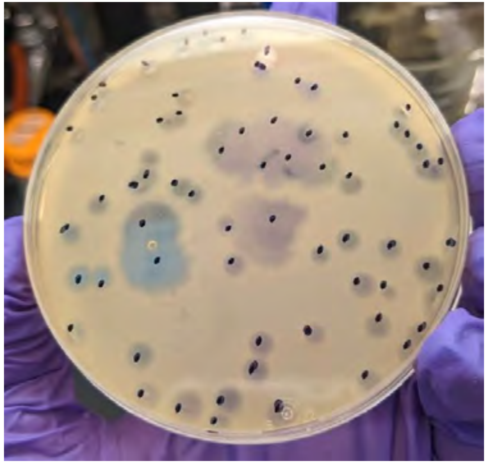
Supplemental Information

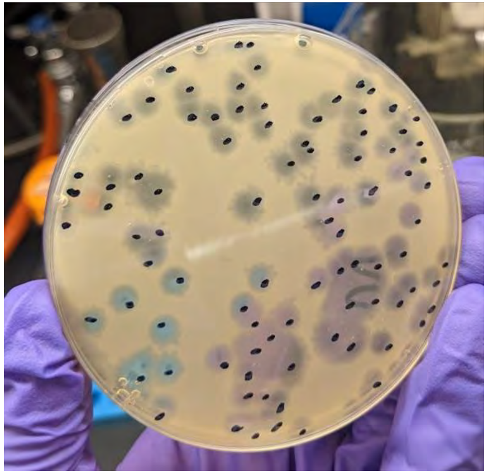
Double Agar Plaque Assay

Inactivation of T1 by the reactor was quantified by culturing both the UV On and UV Off samples using a Double Agar Plaque Assay

Plaques were counted manually and used to determine N/N_0



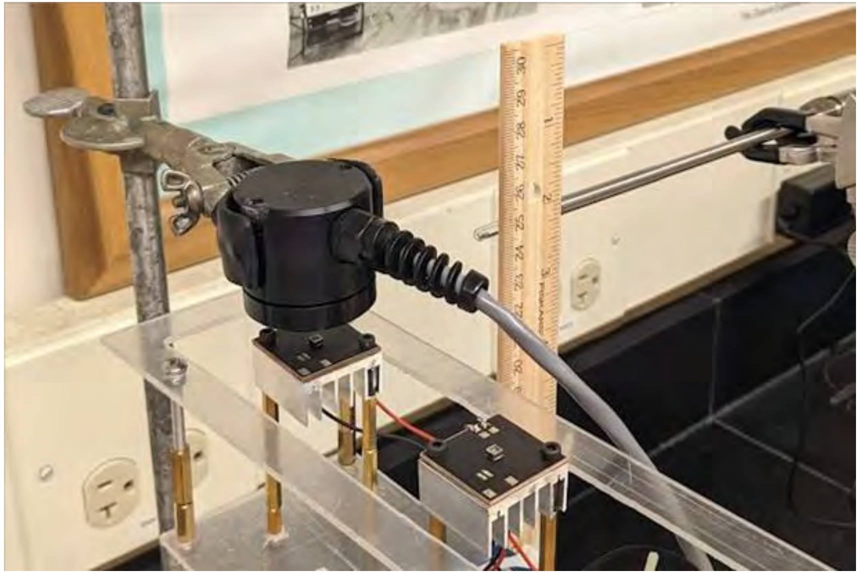
UV On, 10^{-1} Dilution



UV Off, 10^{-3} Dilution

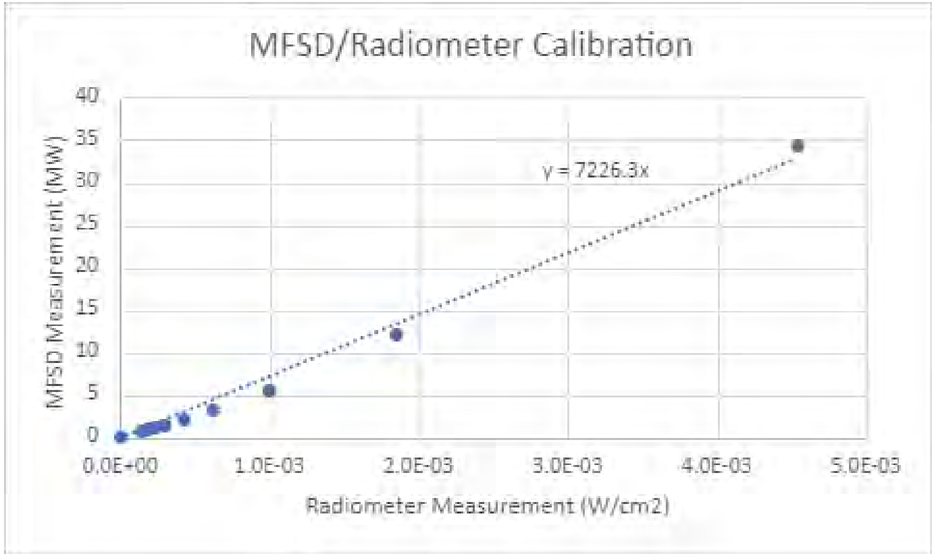
MFSD Calibration

Measurements from the MFSD were calibrated against NIST-calibrated radiometer using the same UVC source

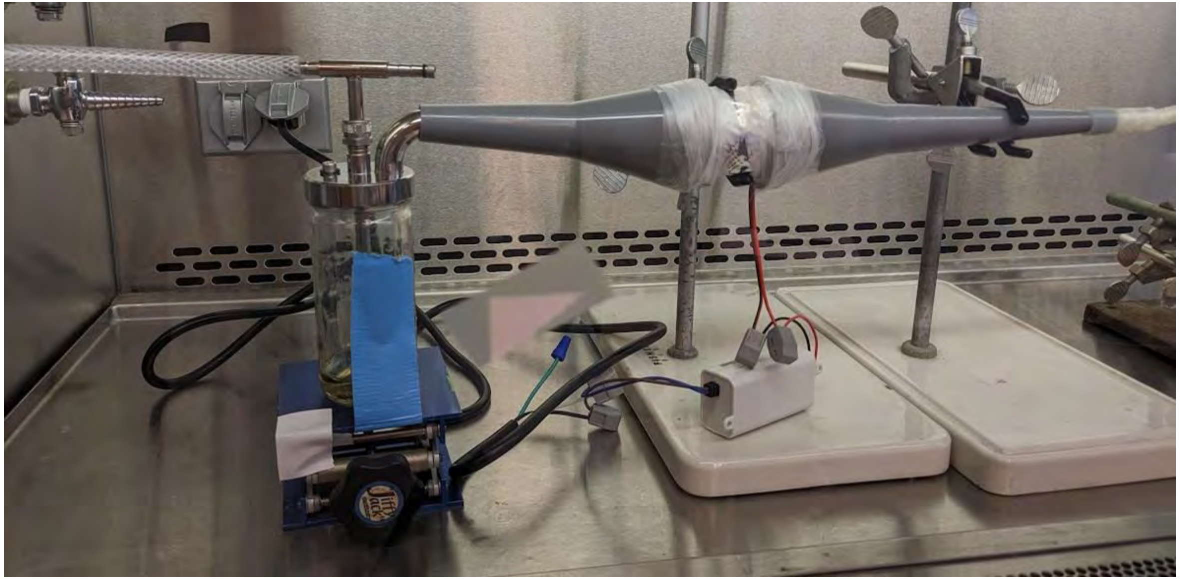


Calibration of 280 nm UVC LED

A calibration curve was developed for each UV source using measurements taken at increasing distance using both the MFSD and radiometer



Nebulizer and Reactor

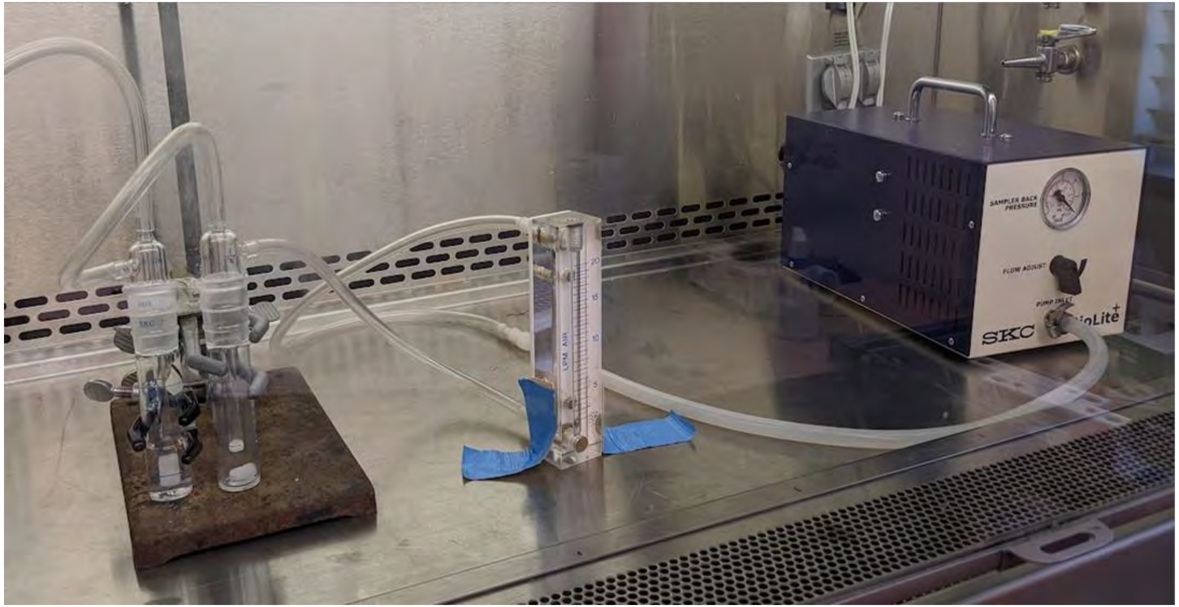


Nitrogen (20 psi) serves as the carrier gas for the aerosolized T1 in TSB.

Mass flow of TSB containing T1 is 0.05 g/min; gas flow is 2 L/min

Samples are collected for 10 minutes with the reactor powered and then with the reactor turned off.

Bioaerosol Sampler and Vacuum Pump



Samples are collected in a glass impinger containing 10 mL PBS

A flow meter is used to ensure the flow rate is kept constant at 2.5 LPM

A vacuum pump is used to pull the carrier gas and the aerosols containing T1