Quantification of Viral Aerosol UV_{222} Dose-Response Behavior Using a Square Quartz Channel Reactor

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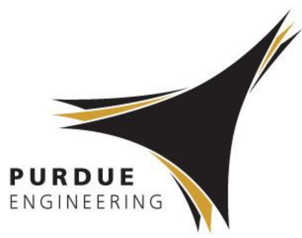


Introduction

Far UVC radiation has gained attention for its potential use in occupied spaces. At present, the dominant source of Far UVC radiation is the optically-filtered krypton chloride excimer (KrCl*) lamp, which emits a primary peak centered at 222 nm. Measurement of UV_{222} dose-response behavior for aerosolized pathogens and challenge agents is not well-developed or standardized. This study presents a method for quantification of UV_{222} dose-response behavior of aerosolized viruses using a continuous-flow, square quartz channel reactor.

Methods

Experiment setup: Figure 1 illustrates the device used to conduct these experiments. The device comprises a fused silica channel with a square cross-section (5 cm x 5 cm). Four opposing pairs of optically-filtered, flat-panel plasma KrCl* lamps (5 cm x 5 cm) were mounted to the exterior wall of the square quartz channel. In any given experiment, 0, 1, 2, 3, or 4 of these opposing lamp pairs were illuminated to allow variation of the UV_{222} dose applied to the aerosolized suspension of viruses, which was introduced to the continuous-flow reactor using a 1-port Collison nebulizer. The entire air flow from the device passed through a bioaerosol sampler at a fixed flow rate to capture UV_{222}-irradiated, aerosolized viruses.

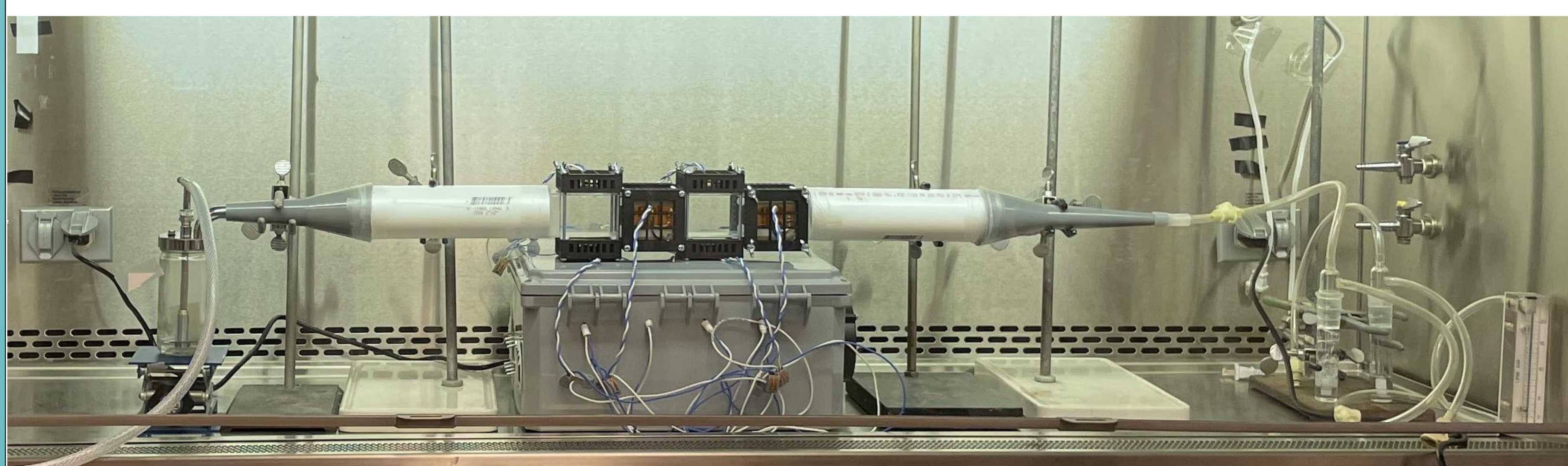


Figure 1. Square quartz channel reactor system. From left to right: 1-port Collison nebulizer for introduction of aerosolized challenge agent; conical transition section and PVC transfer tube for upstream flow conditioning; square quartz channel section with four pairs of opposing, optically-filtered KrCl* flat panel lamps; PVC transfer tube and conical section for downstream flow conditioning; bioaerosol sampler; rotameter for air flow rate measurement.

Fluence rate field measurements: A microfluorescent silica detector (MFSD)[1] was used to measure the fluence rate field within the irradiated zone of the reactor across a 3x3 square grid of sampling points at each of 12 sampling cross-sections (three cross-sections for each lamp pair; see Figure 2). Together with measurements of the internal dimensions of the reactor, measured air flow rate, and knowledge of the illuminated lamp pairs, this information was used to calculate the UV_{222} dose delivered to aerosolized viruses during each experiment.

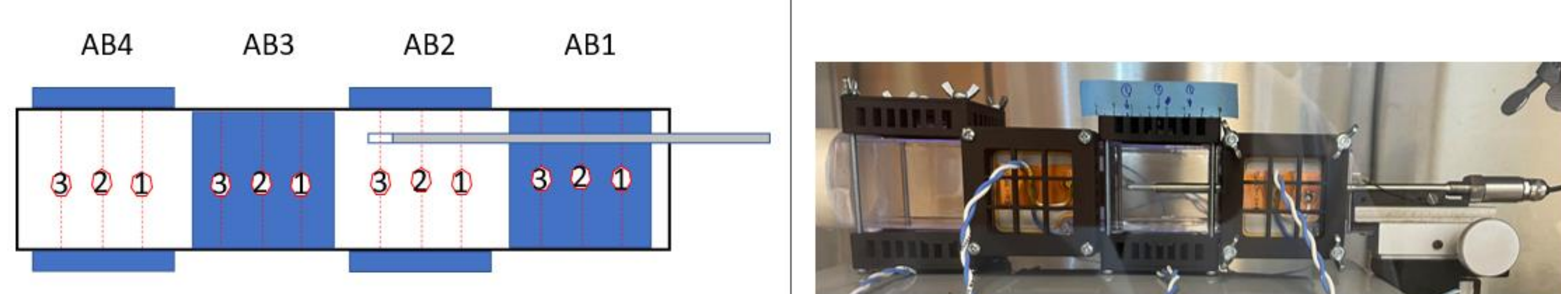
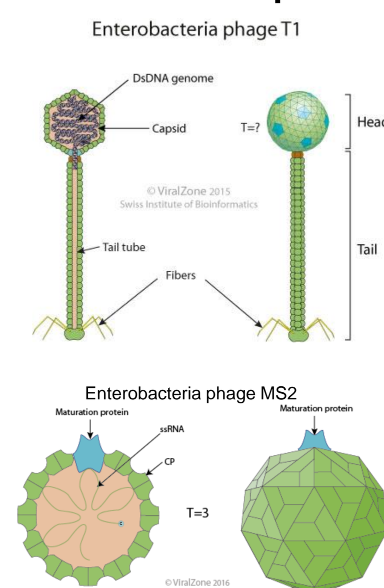


Figure 2. Fluence rate field measurement with MFSD.

Viral challenge agents: Aerosolized suspensions of viral challenge agents (phages T1 and MS2) were introduced to the square quartz channel reactor system, with analysis of sub-samples of bioaerosol sampler collection liquid using plaque assays.



Virus Type	Virion size	Genome type	Genome size
T1	55-60 nm polyhedral head + 150 nm in length 7nm in diameter noncontractile tail	dsDNA	~50,000 base pairs
MS2	23-28 nm	ssRNA	3569 base pairs

Table 1. Characteristics of challenge agents used in experiments.[2-5]

Results

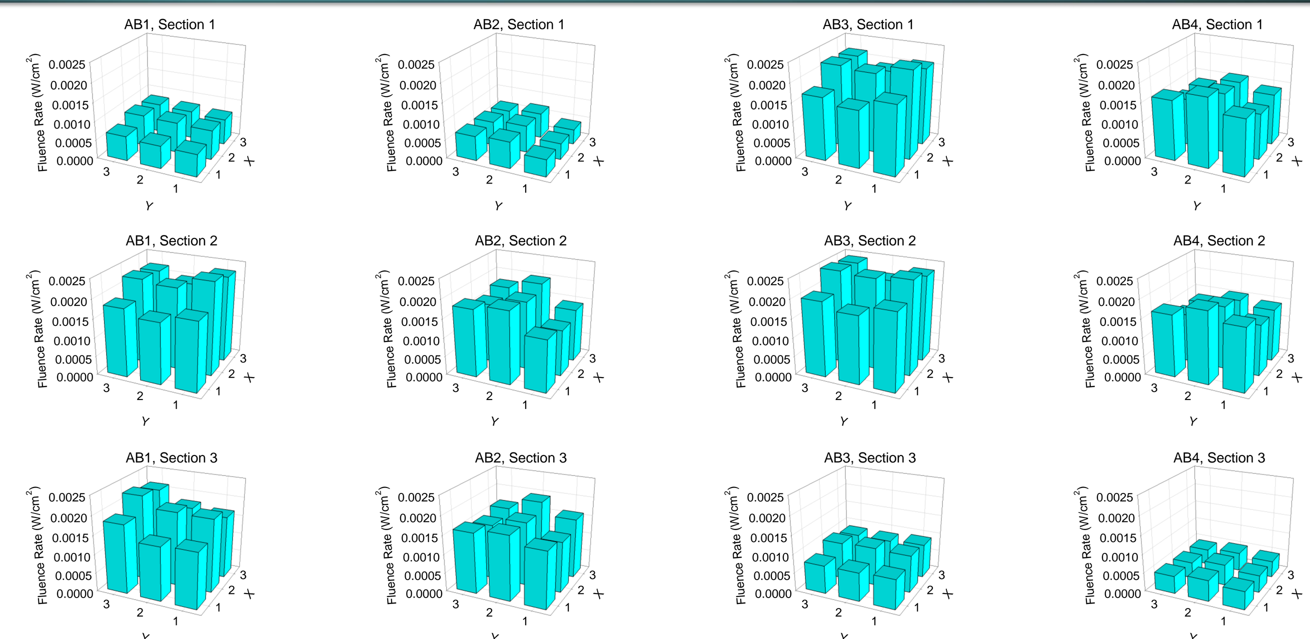


Figure 3. Fluence rate field measurements by MFSD.

Fluence rate field measurements (see Figure 2 for measurement locations):

- For each measurement location, local UV_{222} fluence rate was measured at each of 9 locations in a 3x3 cross-sectional grid.
- Values were relatively large in section 2 for each lamp pair; sections 1 and 3 that were not adjacent to other lamp pairs showed substantially lower local fluence rate.
- Fluence rate at section 2s were similar for all four lamp pairs.
- Average fluence rate for each lamp pair from all three sections was used to calculate applied UV_{222} dose.
- UV_{222} dose = average UV_{222} fluence rate*length air traveled/air velocity.

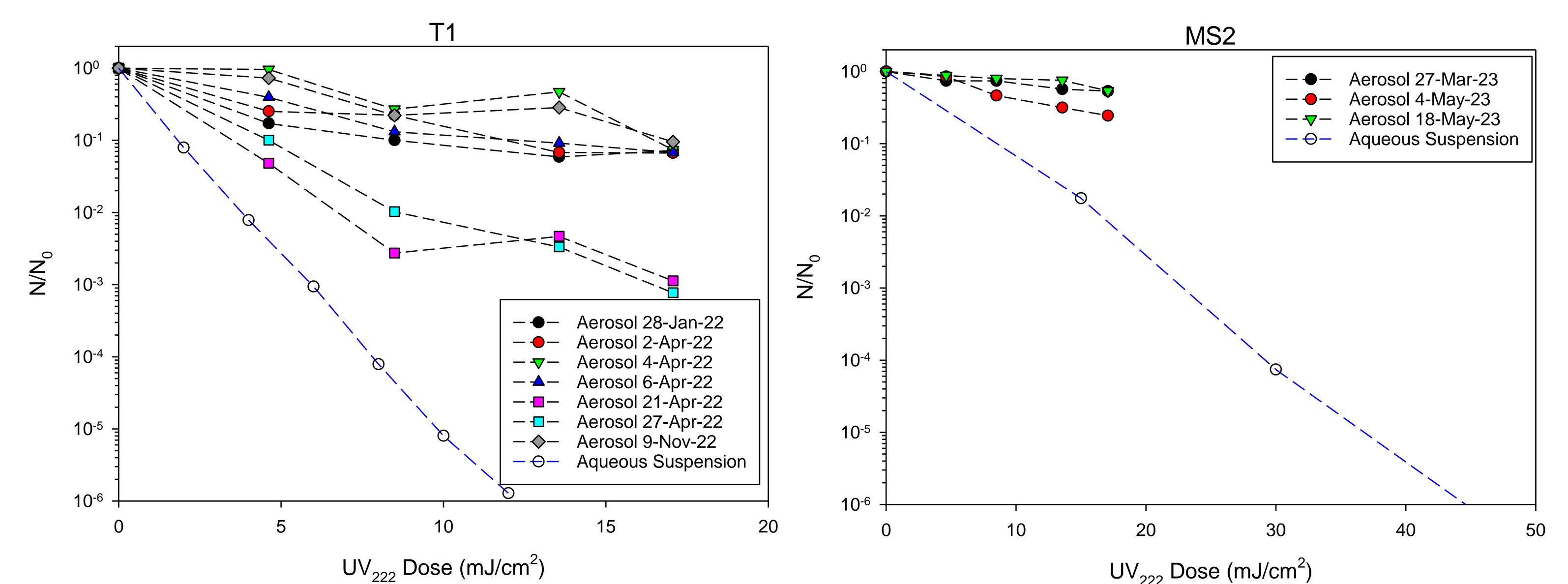


Figure 4. UV_{222} dose-response results for T1 and MS2

Viral challenge agents, UV_{222} dose-response results (see Figure 4 above):

- T1 more sensitive to UV_{222} than MS2 in aerosolized and aqueous suspensions.
- T1 and MS2 less sensitive to UV_{222} in aerosol suspension than aqueous.
- T1 and MS2 aerosol UV_{222} dose response behavior roughly linear (1st-order).
- UV_{222} dose-response behavior of aerosolized T1 and MS2 was variable.
- Collection of efficiencies of T1 and MS2 were low and variable (see Table 2 below).

$$Collection\ efficiency = \frac{\#virus\ in\ sampler}{\#virus\ emited\ from\ nebulizer} = \frac{virus\ concentration\ in\ sampler \times sample\ volume}{virus\ concentration\ in\ nebulizer \times volume\ of\ virus\ stock\ emited\ from\ nebulizer\ during\ sampling}$$

Virus Type	Average Collection Efficiency	Standard deviation of Collection Efficiency
T1	1.11E-02	8.59E-03
MS2	9.45E-02	4.26E-02

Table 2. Summary of collection efficiencies for T1 and MS2

Conclusions

The data from these experiments illustrate the intrinsic kinetics of aerosolized virus inactivation by exposure to UV_{222}. These data will be critical to development of systems based on KrCl* lamps for disinfection of indoor air, as well as for development of near-field protection devices based on Far UVC radiation.

The reactor system used in these experiments could easily be adapted to other sources of UVC radiation, including low-pressure mercury lamps and UV LEDs. Moreover, the same device could be used to quantify the intrinsic kinetics of UVC-based inactivation of other airborne challenge agents and pathogens, including other viruses and bacteria.

References

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