Ray-tracing and CFD simulation for aiding design of Far UV-C based PPE

Christopher Bowers[1,2], Christopher Jones[2], Eric Prast[2], Ernest Blatchley[2,3], Karl G. Linden[3,4], Richard A. Rasansky[2], Joel Ducoste[1,2]

[1]North Carolina State University, Department of Civil, Construction, and Environmental Engineering; [2]XCMR Inc.; [3]Purdue University, Lyles, School of Engineering; [4]University of Colorado, Boulder

Introduction

- There has been increased interest by the public and policymakers in the development of public health intervention technologies due to the recent global pandemic.
- N95 masks are currently the best defense against the spread of disease; however, under best-case scenarios, these only filter out pathogens.
- Personal Protection Equipment (PPE) that disinfects the air in close-proximity would provide more effective treatment and safeguard against unknown future pathogens.
- The purpose of this work is to use experimentally validated numerical simulations to explore alternative PPE designs that use Far UV-C to inactivate airborne pathogens.

Optical Characterization

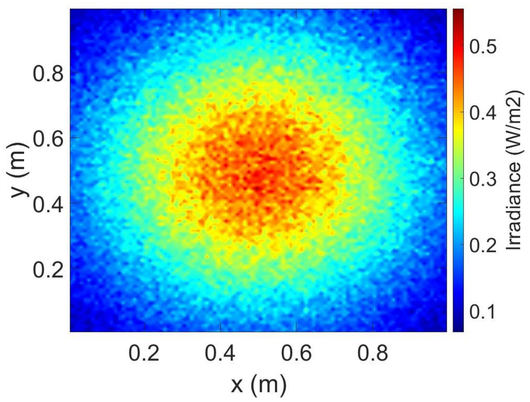

Fig. 3 Optical Characterization Irradiance

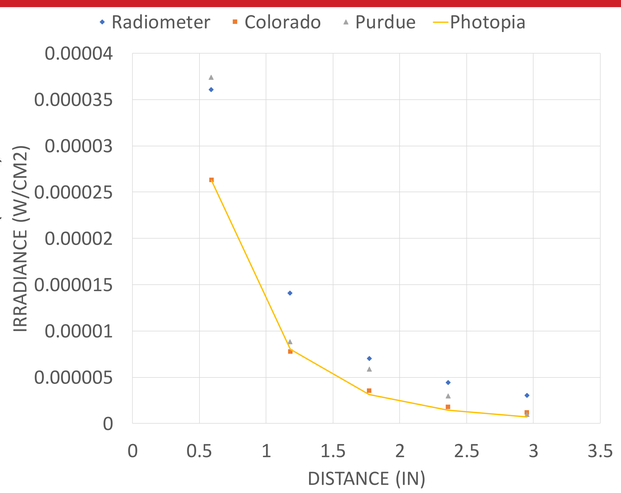

Fig. 4 Optical Characterization Results

Rate of Convergence

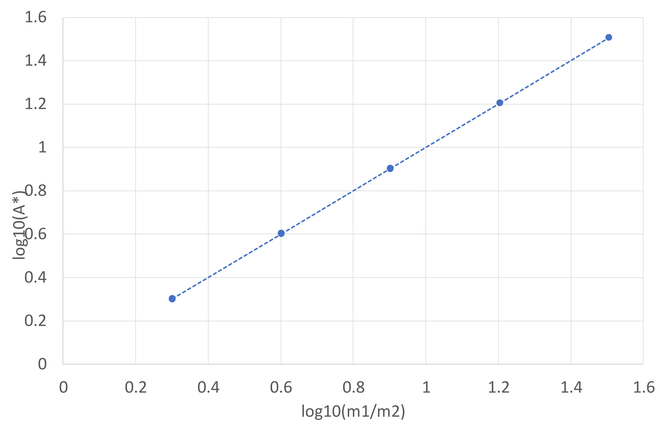

Fig. 10 Rate of Convergence Study

$$k_\infty \approx \frac{k_{m1}\left(m1/m2\right)^n - k_{m2}}{\left(m1/m2\right)^n - 1} \xrightarrow{\text{If n=1}} \log_{10}(A^*) = \log_{10}(m1/m2),\quad A^* = \frac{k_\infty\left[\left(m1/m2\right) - 1\right] + k_{m2}}{k_{m1}}$$

Methods

There are three facets of the work presented here:

1. The custom Eden Park lamp being use,
2. Experimental characterization of the lamp,
3. Optical and fluid simulation of the lamp within a sample reactor.

The lamp is a custom, miniature KrCl microplasma design (Eden Park) that emits germicidal UV at a 222nm wavelength. (Fig. 1)

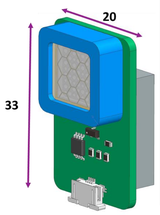

Fig. 1

Experimental Characterization was carried out using a pair of custom micro-fluorescent silica detectors (MFSDs). (Fig. 2)

Optical simulations were performed using LTI Optics Photopia for a set of test reactors with KrCl microplasma lamp.

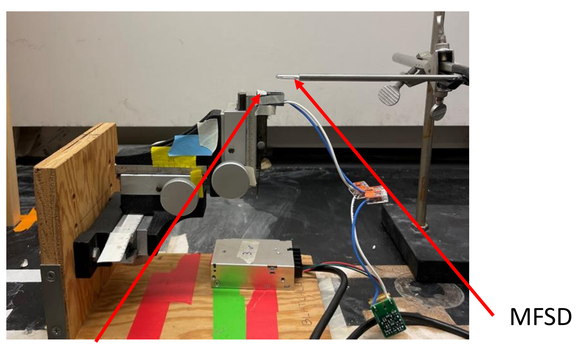

Fig. 2

Test Reactor

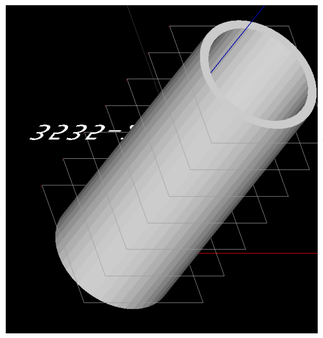

Fig. 5 Open Test Reactor Exterior

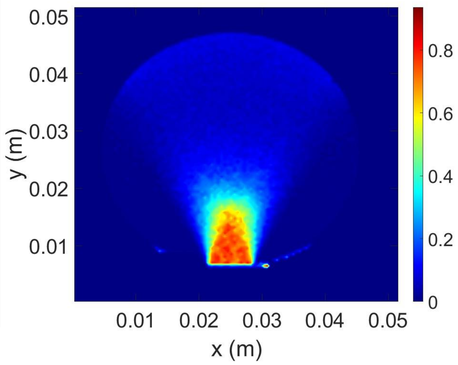

Fig. 6 Open Reactor Irradiance

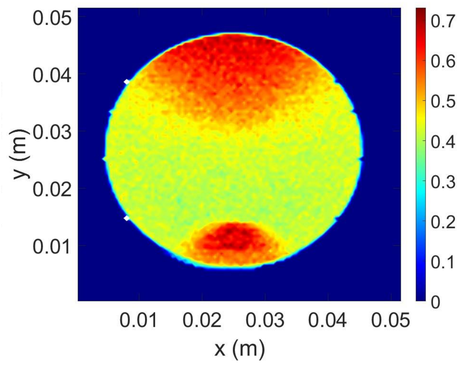

Fig. 7 Closed Reactor Irradiance

Average Irradiance

Fig. 11 Irradiance vs. Reflectivity

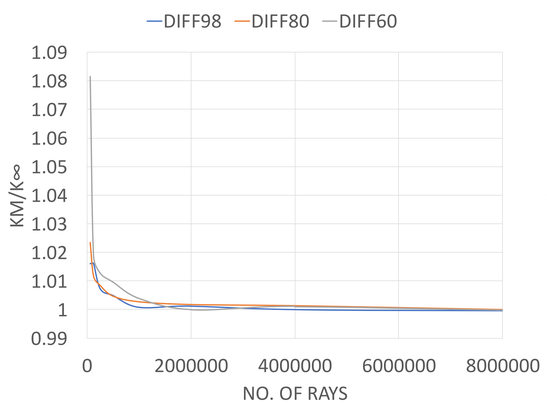

Fig. 8 Ray Convergence Study

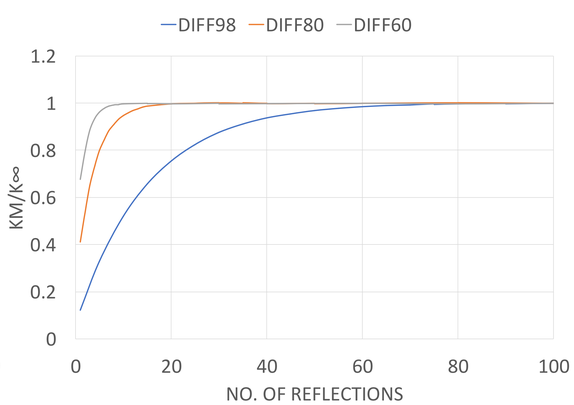

Fig. 9 Reflection Convergence Study

Summary

- Optical simulations are able to match laboratory measurement.
- Design has a significant impact on UV dosage when designing PPE.
- Diffuse reflective material provides higher improvement to UV dose compared to specular reflective material.
- Ray-tracing simulations display roughly first order convergence when increasing number of rays during simulation.