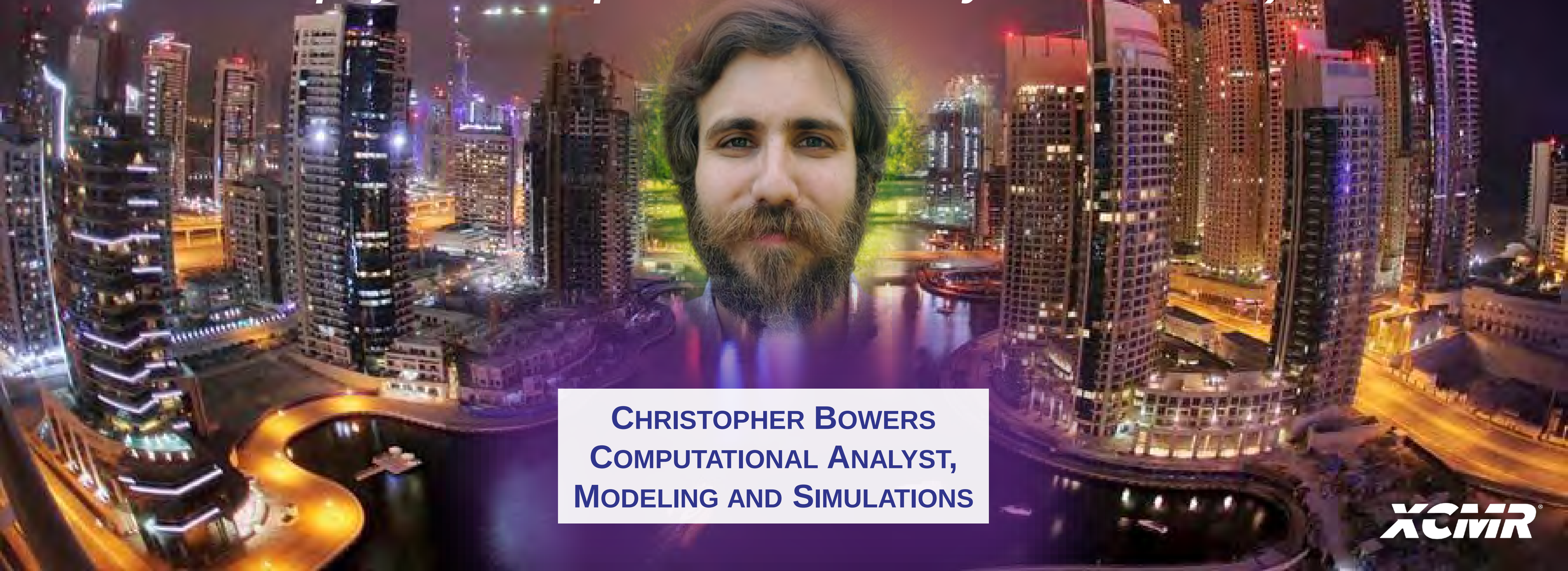
September 10-13, 2023

2023 IUVA WORLD CONGRESS

Festival City, Dubai, U.A.E.

Next Generation PPE for Real-time Inactivation of Airborne Biological Threats, Part II: Multi-physics computational fluid dynamics (CFD) simulation



CHRISTOPHER BOWERS
COMPUTATIONAL ANALYST, MODELING AND SIMULATIONS

XCMR

Personal Protective Equipment (PPE)

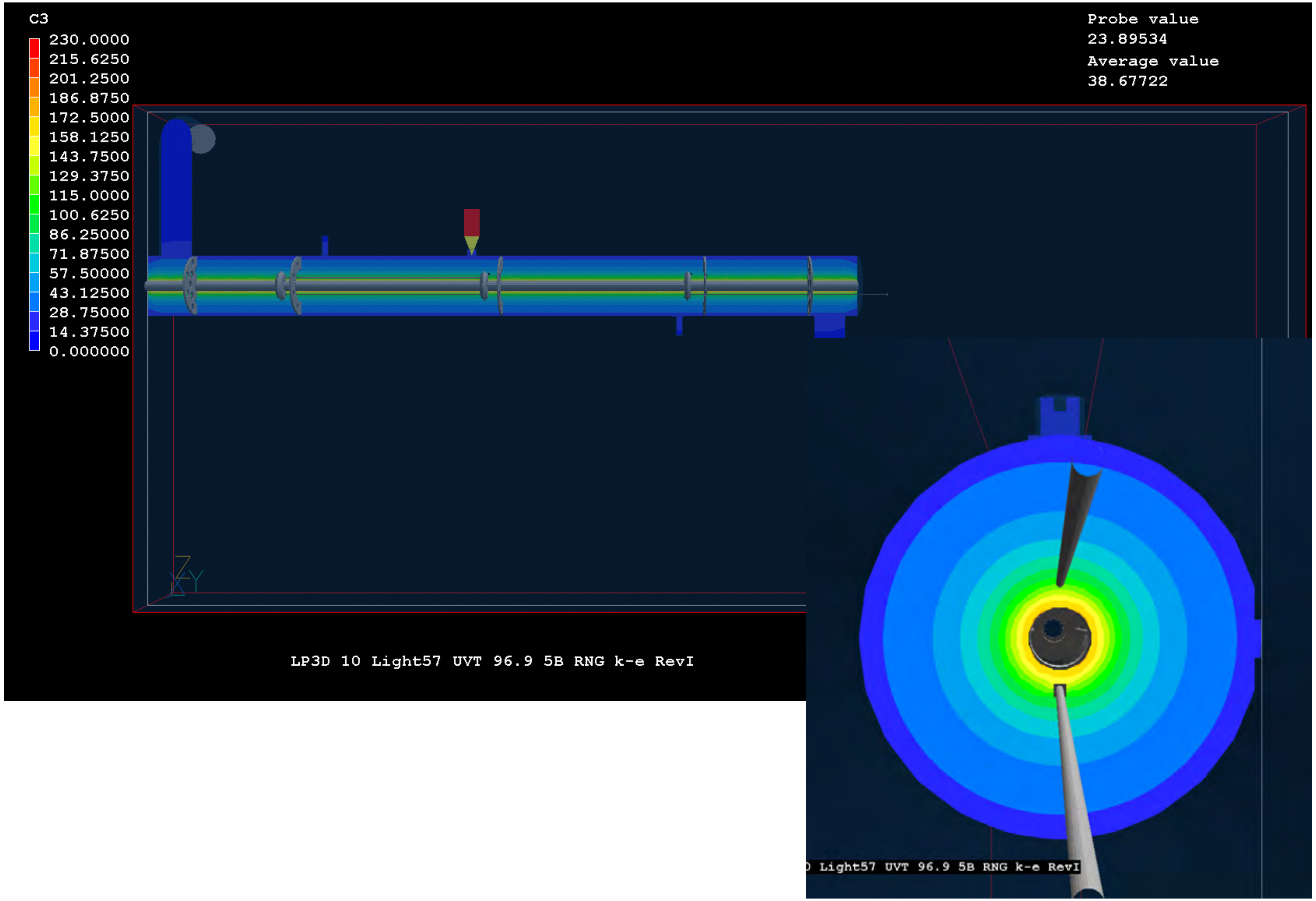
- Past PPE has used filtration to remove disease vectors.
- Filtration impacts breathability of these devices.

UV disinfection:
- Does not impact breathing,
- Inactivates rather than filters out disease vectors,
- Can inactivate unknown future micro-organisms.

Dyson Zone review: an absurd pair of air purifying ANC headphones - The Verge

Fluence Rate Field Modeling

- UV Modeling has been applied to water disinfection where transmittance can vary between 70-90%.
- Models seek to simulate fluence field in a reactor.
- Past methods include Discrete Ordinate (DO), Multiple Point Source Summation (MPSS), Line Source Integration (LSI).



Disinfection Modeling

Modeling disinfection is a Multiphysics problem involving:

1. Optical UV irradiance,
2. Computational fluid dynamics,
3. Inactivation kinetics

- For low transmittance media (e.g. water), reflectivity is less significant.
- For air, reflectivity can greatly impact disinfection
- Past methods were not originally designed for systems with high photon recycling.
- Optical ray tracing is an accurate way to simulate these systems

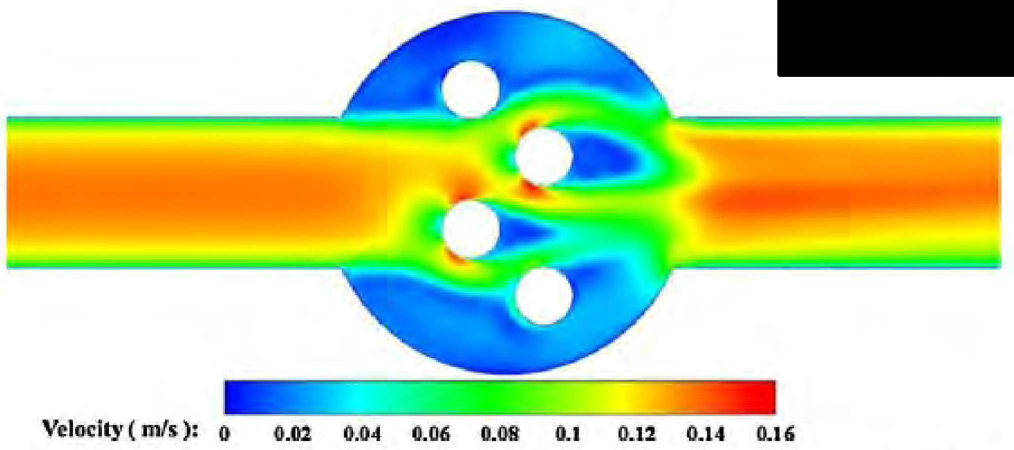


Fig. 6. The velocity field along the middle plane of the reactor using the SST k-ω model.

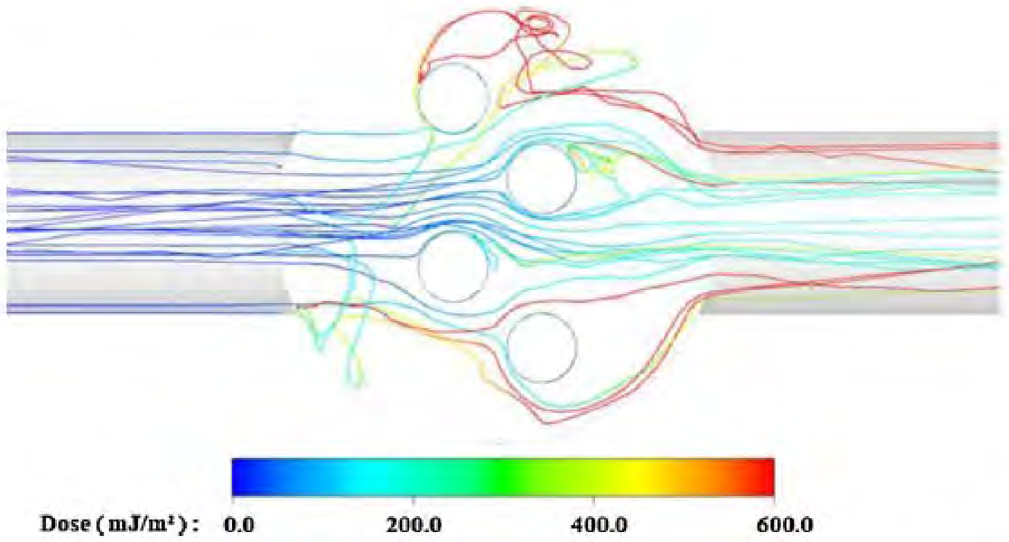


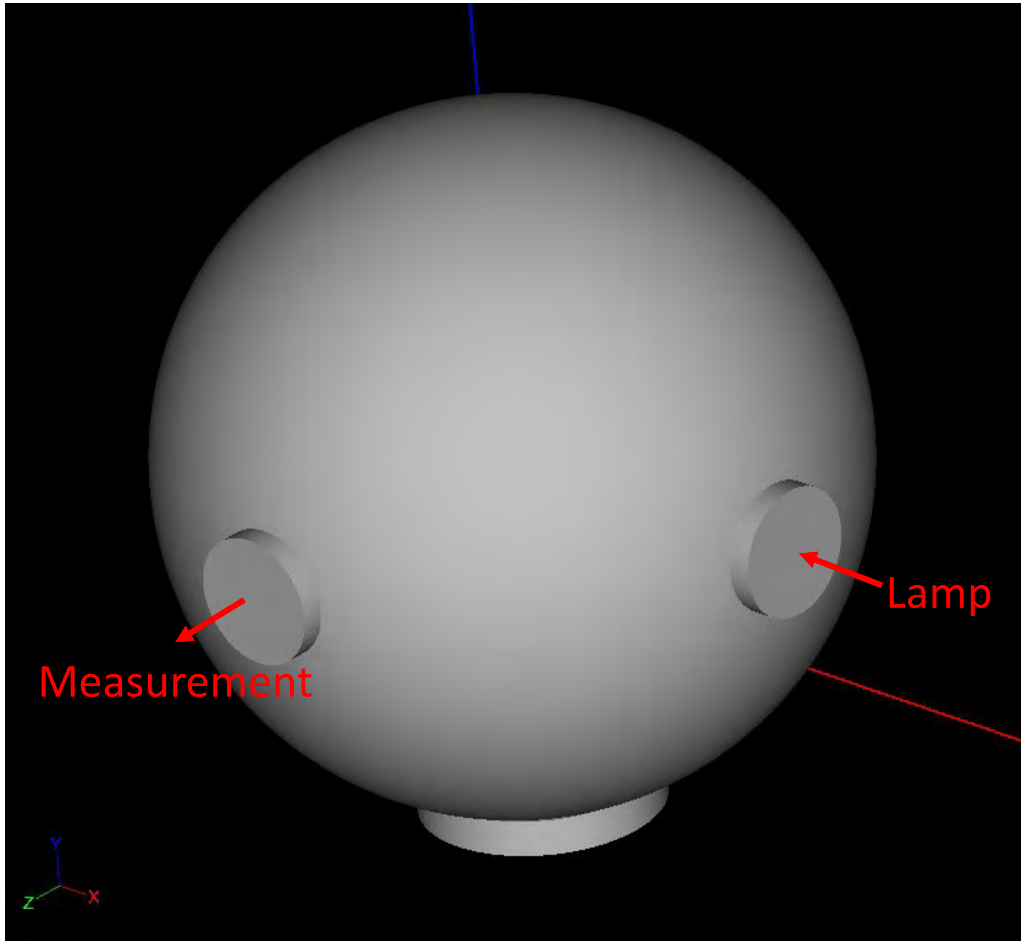
Fig. 7. The received dose of 25 random microorganisms along the motion path.

Images from Heidarinejad et al., Journal of Water Process Engineering (2020)

Optical UV Modeling

- Optical ray-tracing simulations carried out with Photopia and Ansys Speos.
- Numerical analysis using integrating sphere. Analytical solution with Sumpner's Principle below.
- Ray-tracing inputs include:
  - Solid mesh discretization,
  - Number of rays,
  - Number of ray interactions.

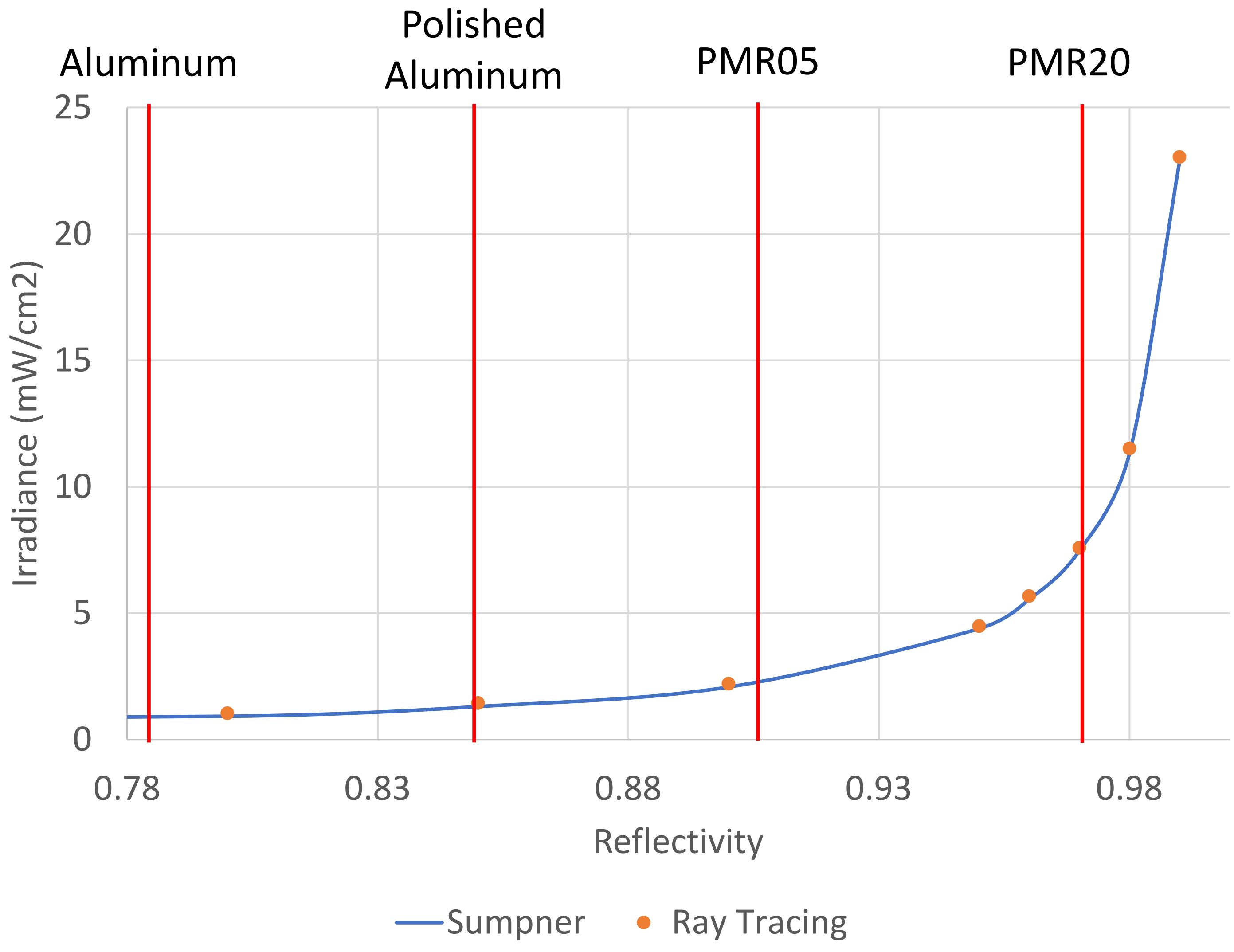
$$E = \frac{\Phi}{\pi D^2} \frac{r_\Phi}{1 - r_\Phi}$$



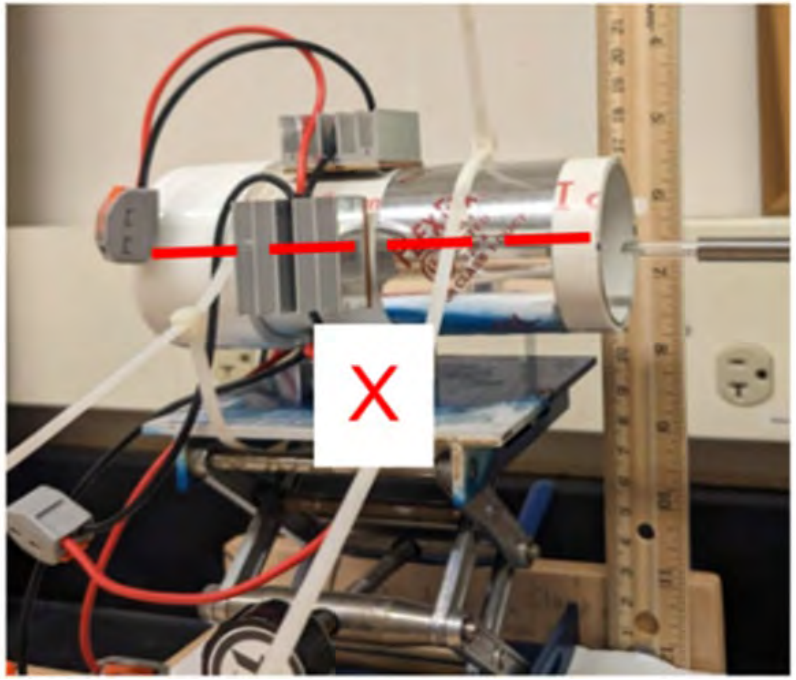
Integrating Sphere Model

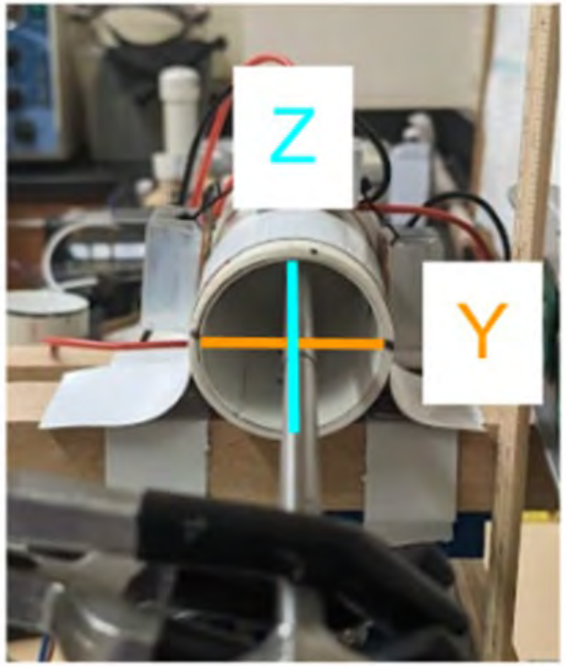
Integrating Sphere Summary

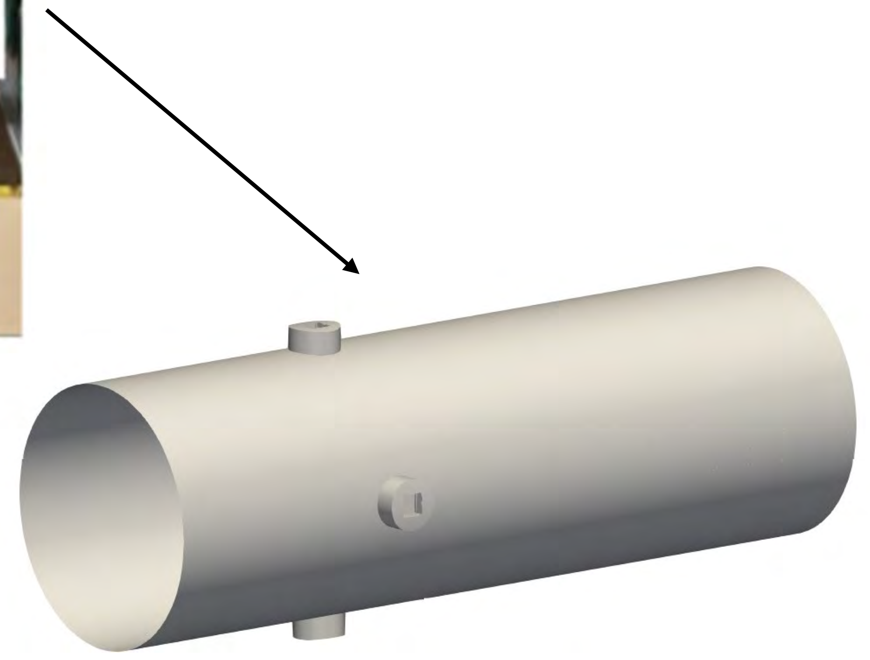
- Optical ray-tracing matches Sumpner's principle well
- There is a consistent residual in the data
- Compared to 80% reflectivity, we see a 4x increase at 90%, 7x at 97%, and 21x at 99%
- Reflective material may greatly increase disinfection potential.



Test Reactor

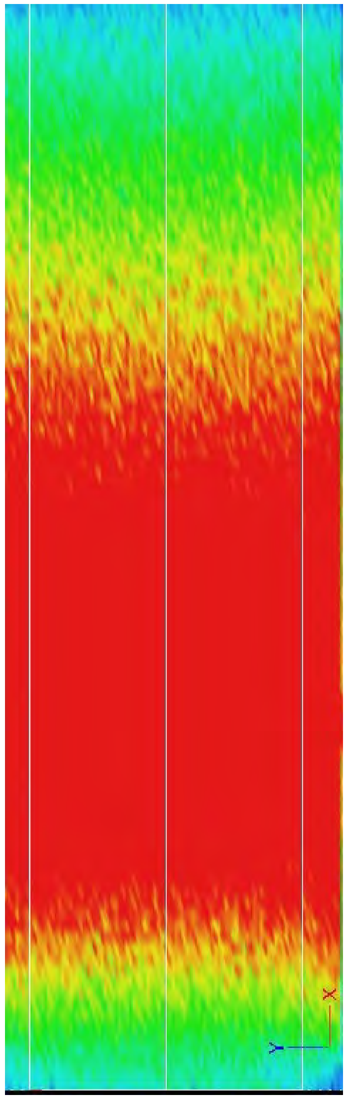


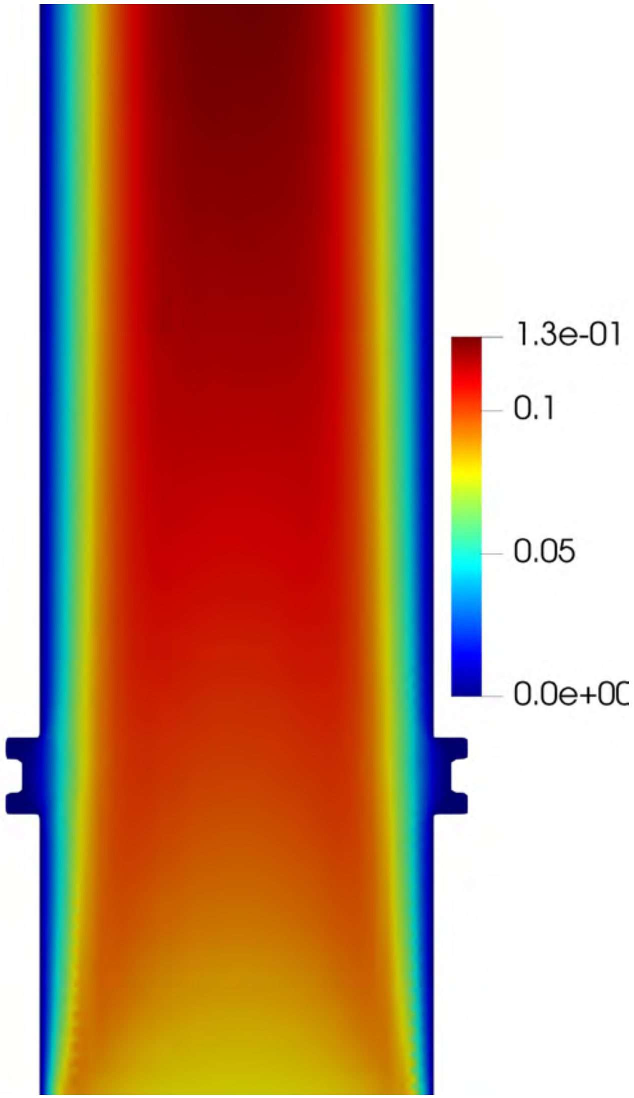


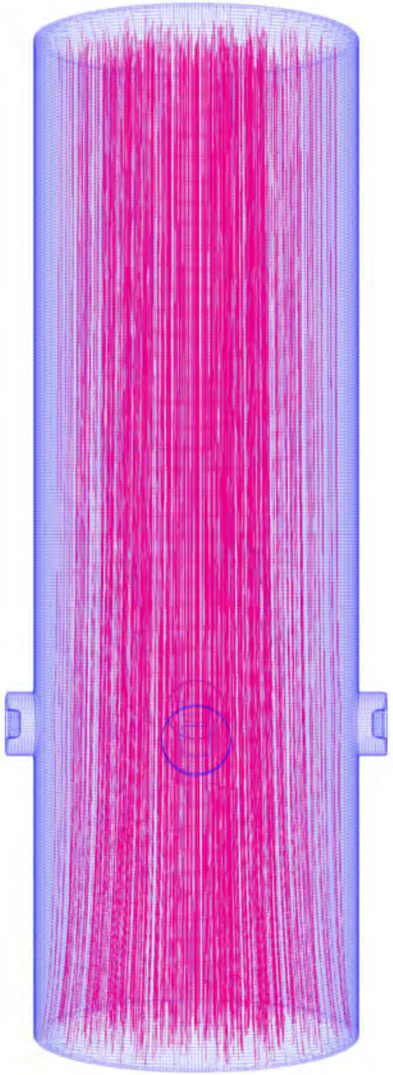


- A Simplified test reactor was created to test multiple light sources (Nichia LEDs, Ushio LPMs)
- UV fluence rate field measured in the laboratory and compared to simulations

Reactor Modeling

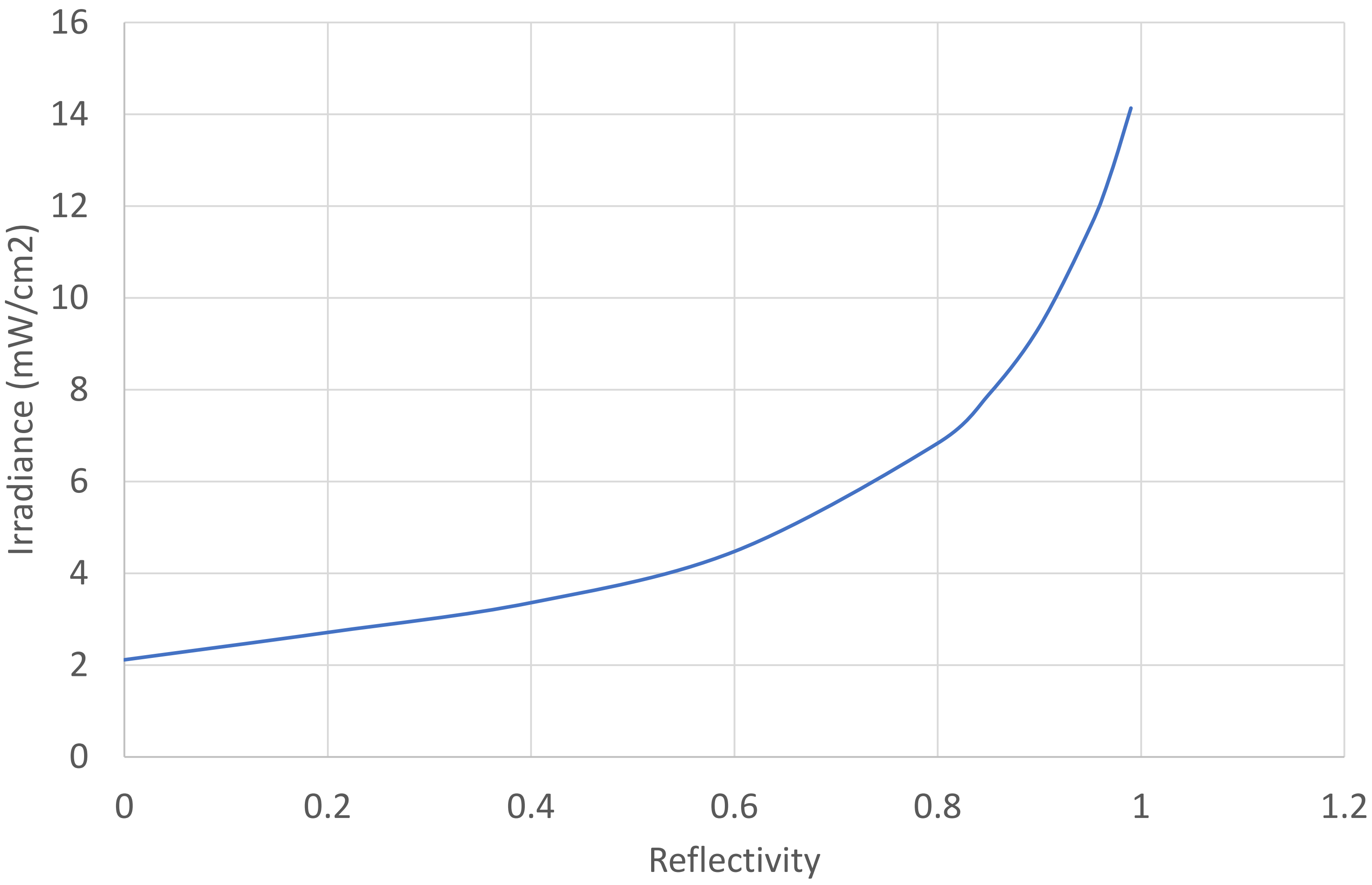






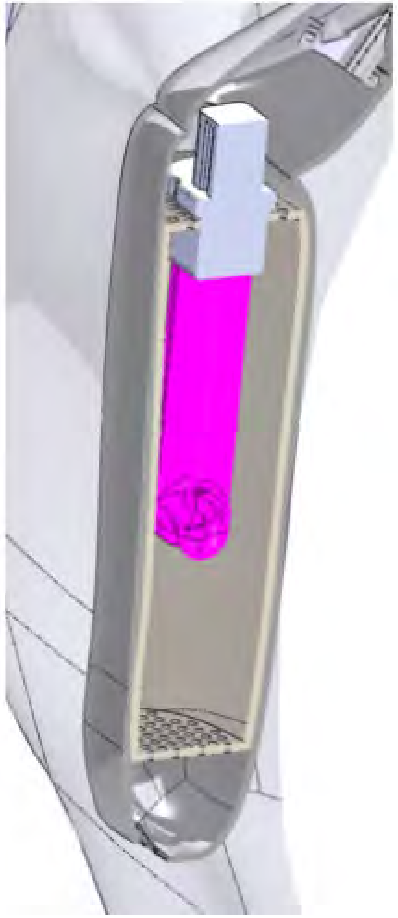
UV Modeling Results

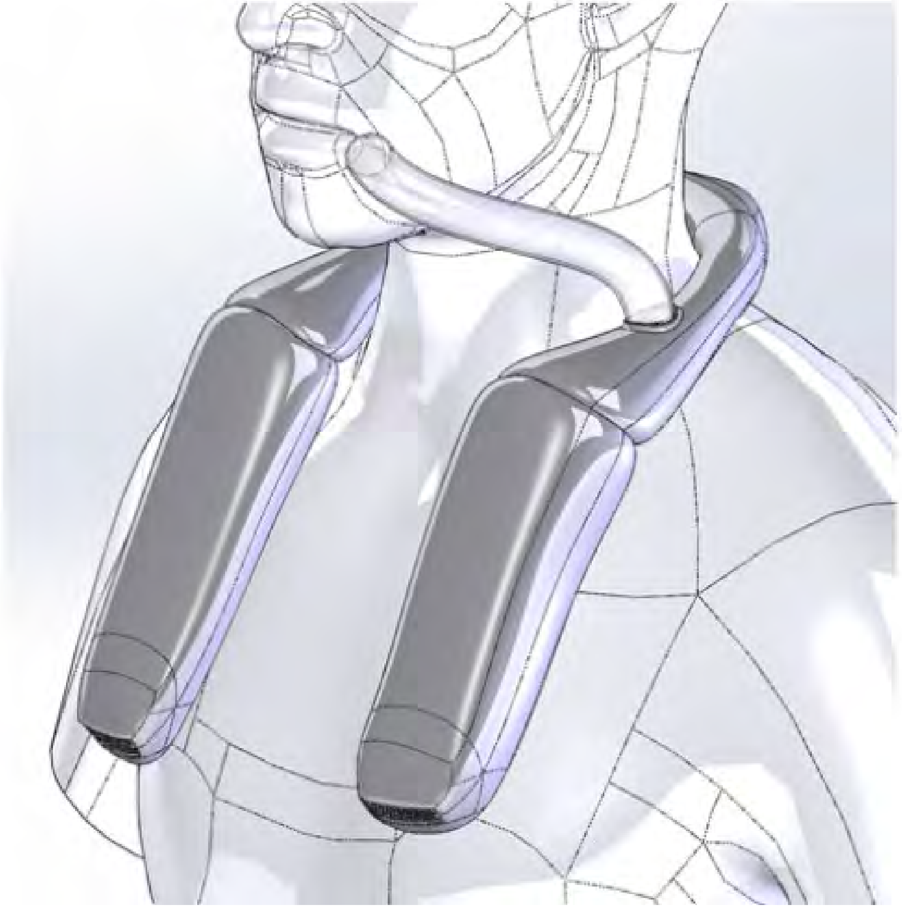
- Irradiance greatly increased with reflectivity, but not to the degree of the integrating sphere.
- Average fluence rate increased up to 7x for 99% reflective vs no reflectivity.
- Photons escaped out open ends, expect higher dose increases with optical baffles.
- Average dose ~18 mJ/cm2 for resting breathing rate.



Second Iteration Prototype

- Optical, flow and dose modelling of reactor pod prototype
- Porex PMR20 97% reflective material
- Ushio GPX5 1.2W UV output lamp





CFD Modeling of Prototype

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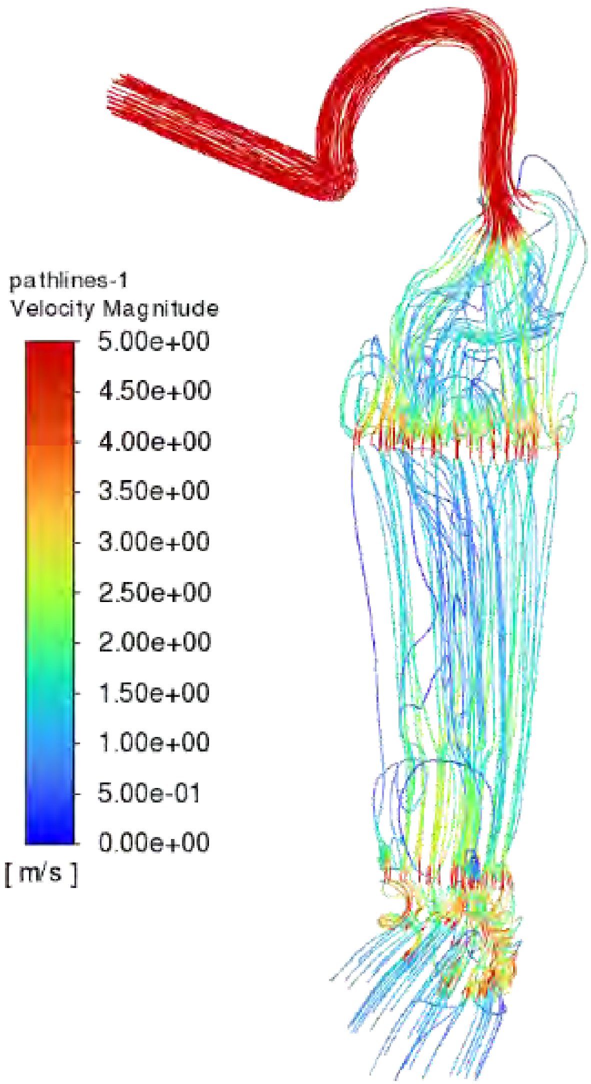
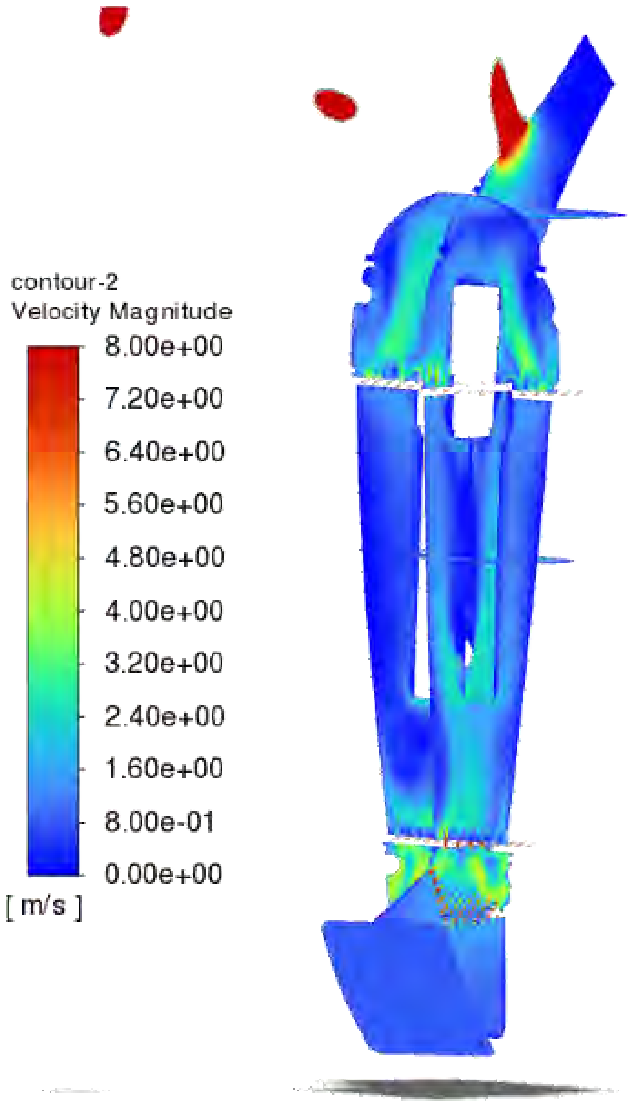
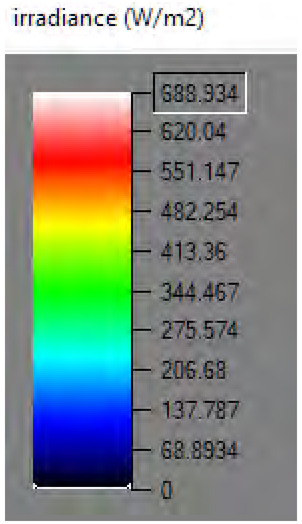
- Flow velocity path lines and contours at 90 l/min inhalation flow
- Lagrangian particle tracking for reactor

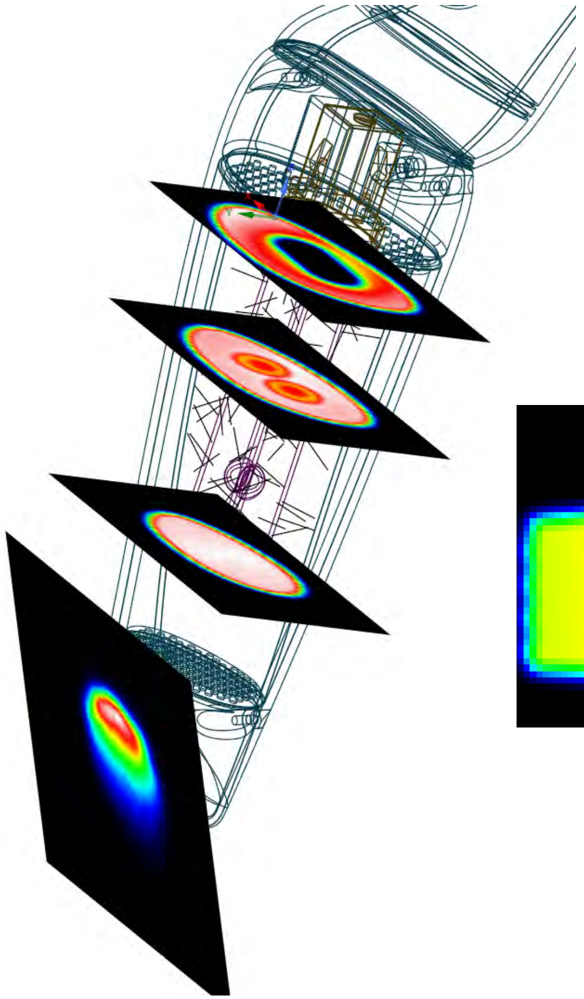


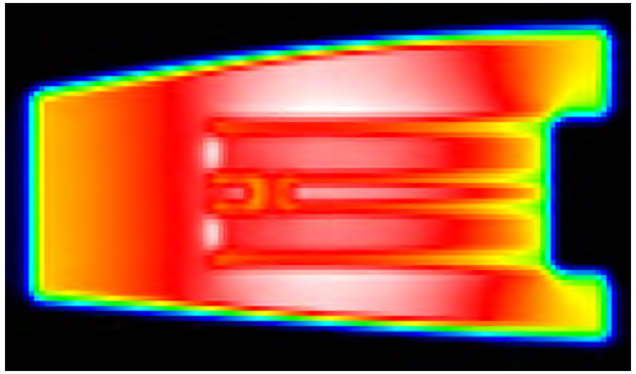


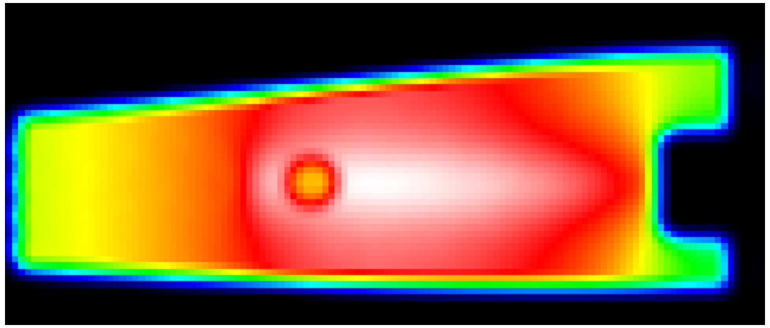
Optical Ray-Tracing Simulation

- Planar Irradiance results for the reactor pod (Maximum 68.8 mW/cm2)
- Pathline irradiance profile from the start of the reactor

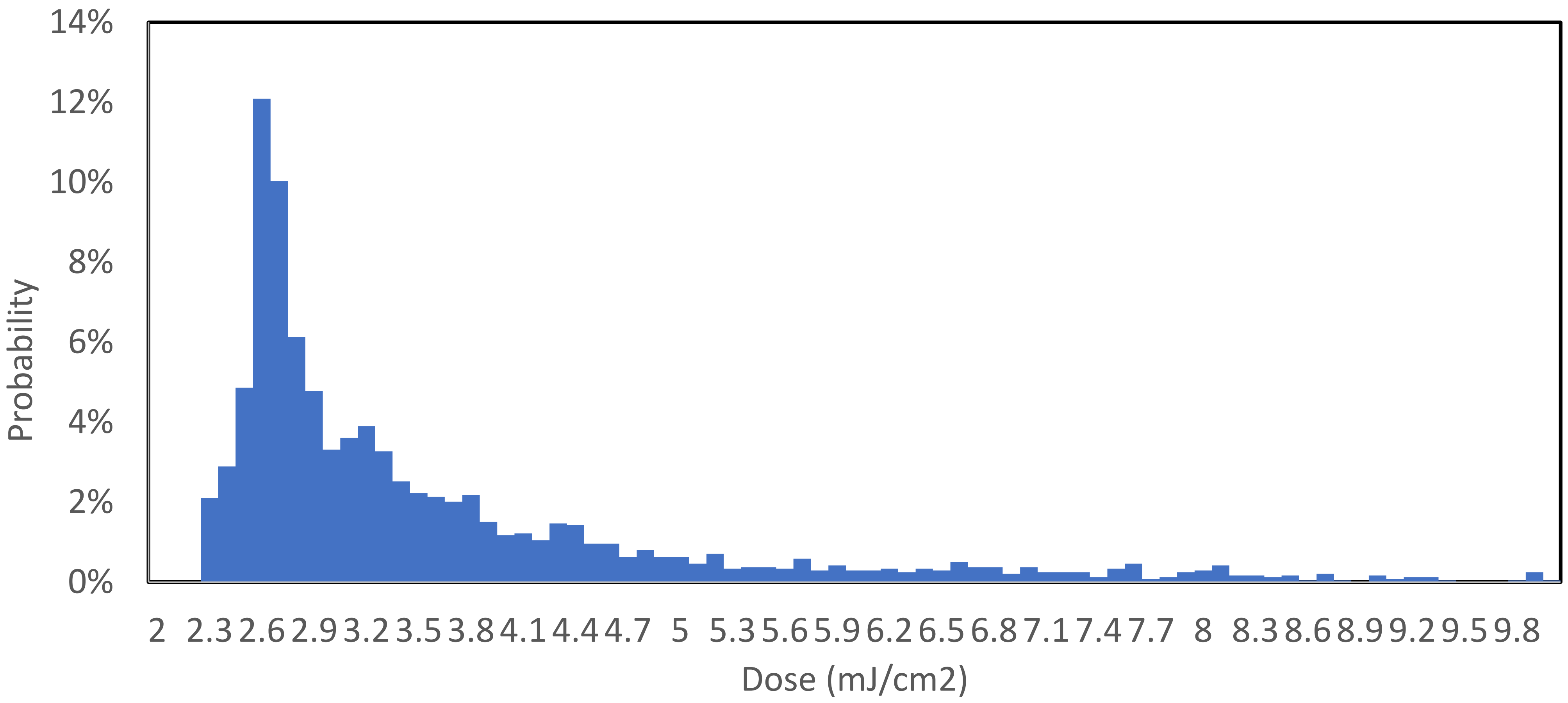






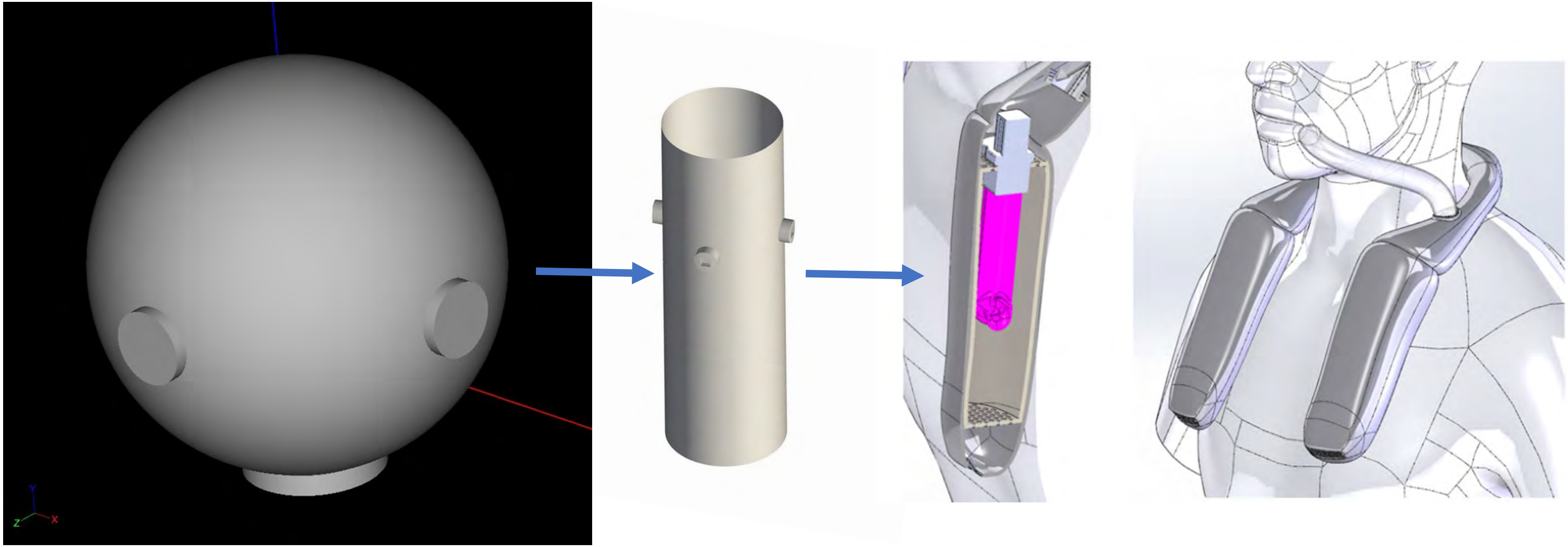


Dose Distribution at 90 L/min



- Combination of residence time and irradiance profile to determine dose distribution
- Minimum dose delivered was >2 mJ/cm2

Prototype Progression



By numerical prototyping, we were able to rapidly progress from a concept (photon recycling), to a simplified prototype, to an advanced prototype, without the need to generate intermediate physical prototypes.

Contributing Authors

XCMR™

Dr. Ernest R. Blatchley III

Principal Scientist, Process Engineering

Lee A. Rieth Professor, Environmental Engineering

PURDUE UNIVERSITY

Christopher Bowers

Computational Analyst, Modeling and Simulations

Completing PhD, UNC Chapel Hill; BSE in environmental engineering, Univ. of Michigan, Ann Arbor with a minor in mathematics

Dr. Joel J. Ducoste

Principal Engineer, Modeling and Simulations

Professor, Civil, Construction, and Environmental Engineering Department

NC STATE UNIVERSITY

Christopher Jones

Senior Technical Engineer

BEng (Chemistry) with Honors II.i (UK MSc Engineering equivalent) from Curtin University, Perth Australia

Dr. Karl G. Linden

Principal Scientist, Photobiology

Professor, Environmental Engineering
Mortenson Professor in Sustainable Development

University of Colorado **Boulder**

Eric Prast

VP Product Engineering

BA Electrical Engineering – Florida State University

Richard Rasansky

Chief Executive Officer

BS Entrepreneurial Management - Wharton, Computer Science & Electrical Engineering – UPenn

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Questions?