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On-site GUV Measurements Using Radiometer and Compared with Actinometry Results

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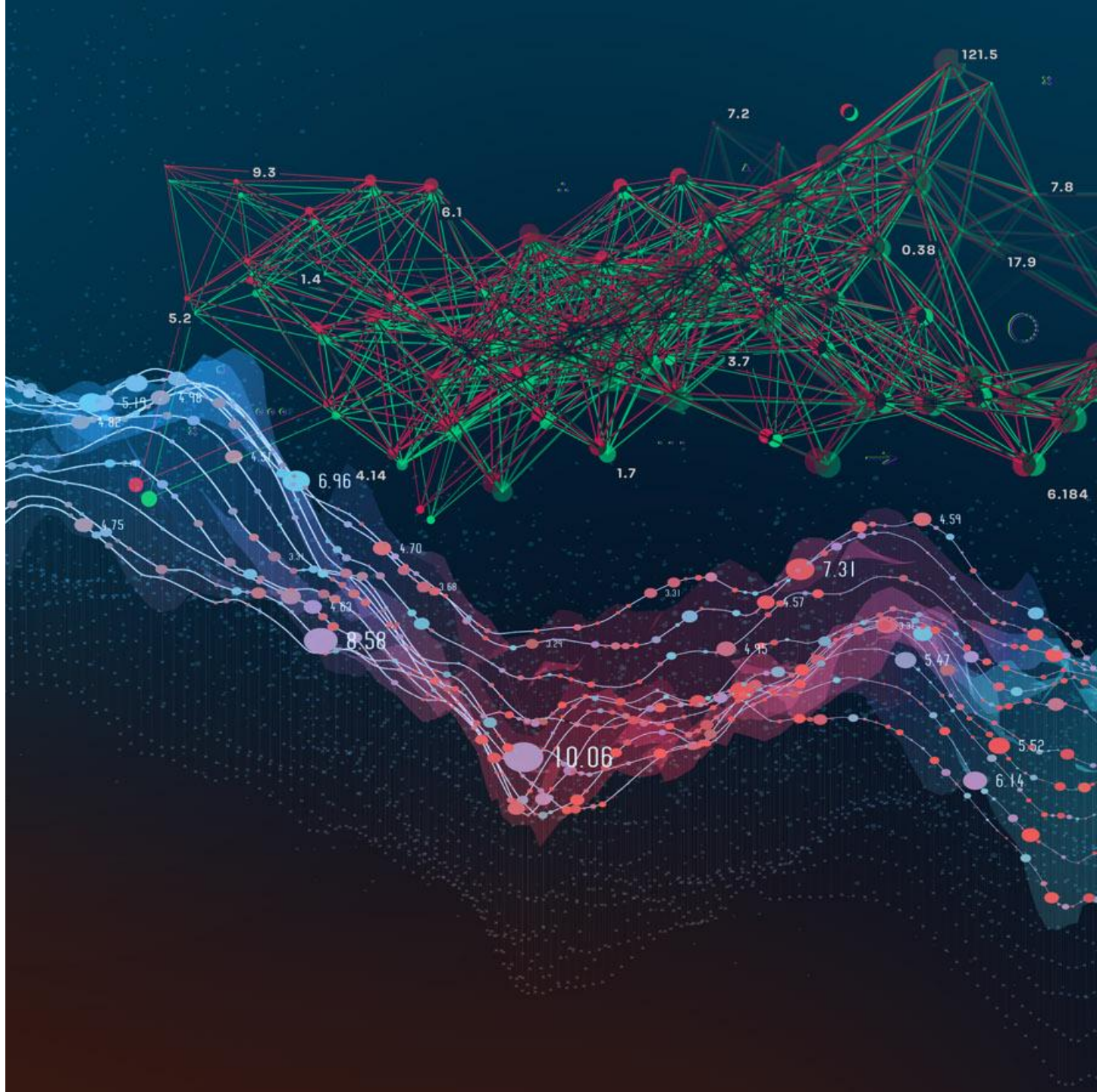

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Background

- Germicidal ultraviolet (GUV) has been used in hospital settings for decades
- Upper-room GUV (UR-GUV) systems have been most common, so most past studies focused on them
- Whole-room GUV (WR-GUV) systems are newer and becoming more popular. WR can systems vary in applications for vacant or occupied.
- Effectiveness and safety of the GUV system depend on various factors, including GUV fluence rate and irradiance.
- Providing an effective GUV fluence rate, while not exceeding safety limitations, is crucial for GUV system design

Upper-room (UR) GUV

Whole-room (WR) GUV

Motivation

- Accurately measuring fluence rate and irradiance are key for GUV system commissioning

- Inaccuracies in field measurements can have greater health and safety implications for GUV than for visible light

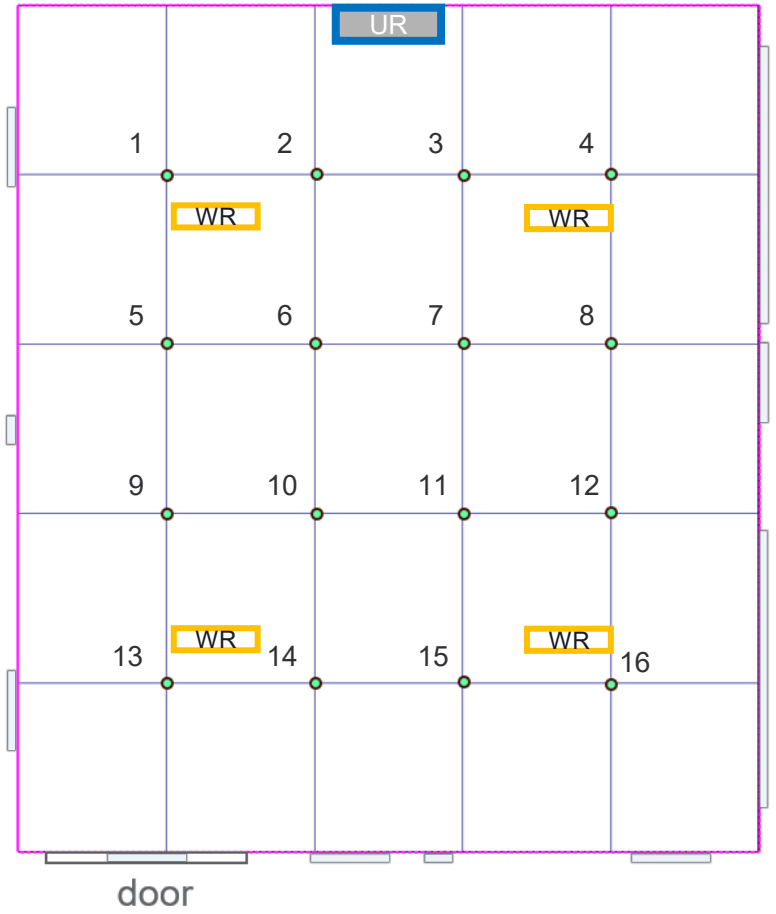
Goal of study

- To evaluate two measurement techniques against chemical actinometry in an experimental chamber for UR-GUV and WR-GUV systems

Experimental setup

- Indoor Air Quality (IAQ) Chamber
  - 14’ W x 16’ L x 8.92’ H
  - White painted walls and ceiling
  - Concrete floor
  - Polycarbonate windows, metal and wooden panels
- GUV luminaires
  - **Whole room** – 222 nm peak wavelength
  - **Upper room** – 254 nm peak wavelength
- Measurement grids
  - 2.8’ x 3.2’ spacing
  - Fluence rate
    - 18 inches below ceiling
    - 36 inches below ceiling

- Measurement points



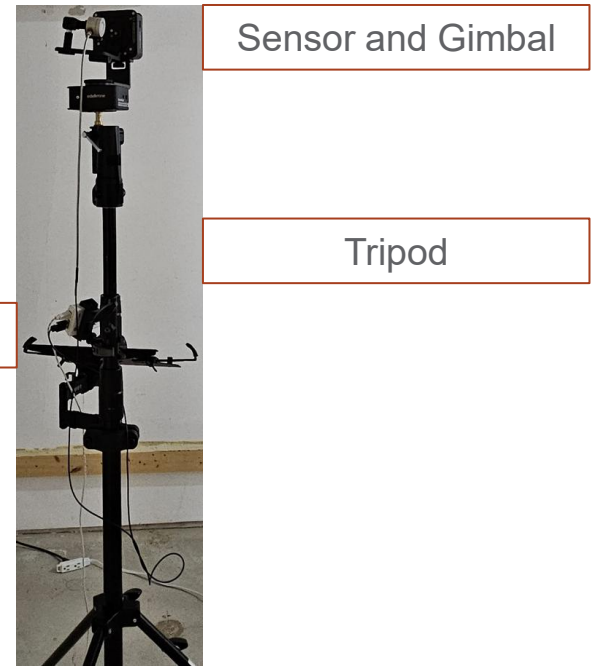
Tools for Experiment

Measurement Tools

- Irradiance meter
- Spectroradiometer
- Tripod system
- Gimbal system
- Ozone concentration meter

Safety Gear

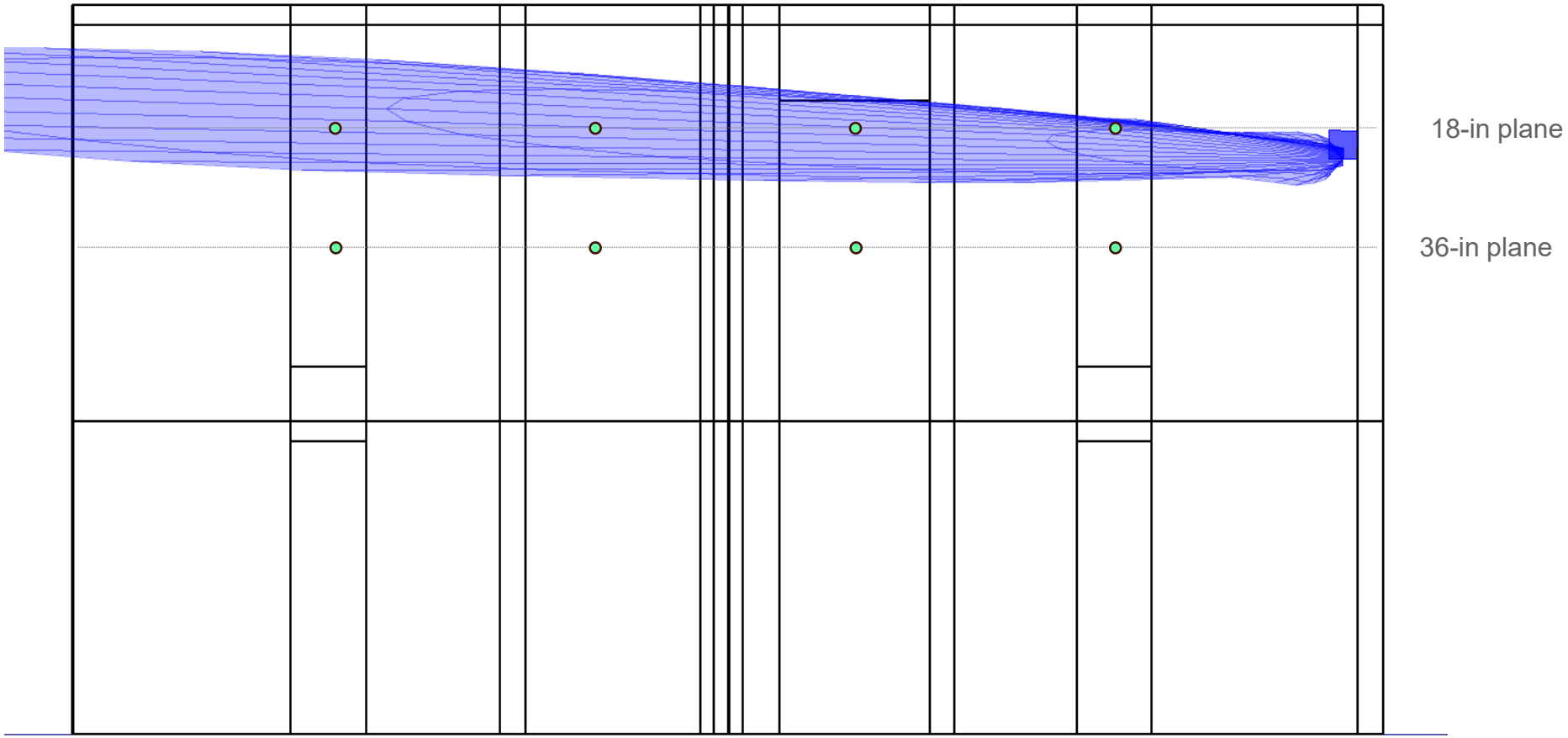
- UV rated goggles (ANSI Z87.1+U6)
- UV rated face shield (ANSI Z87.1+U6)
- Nitrile gloves
- Long sleeves and pants



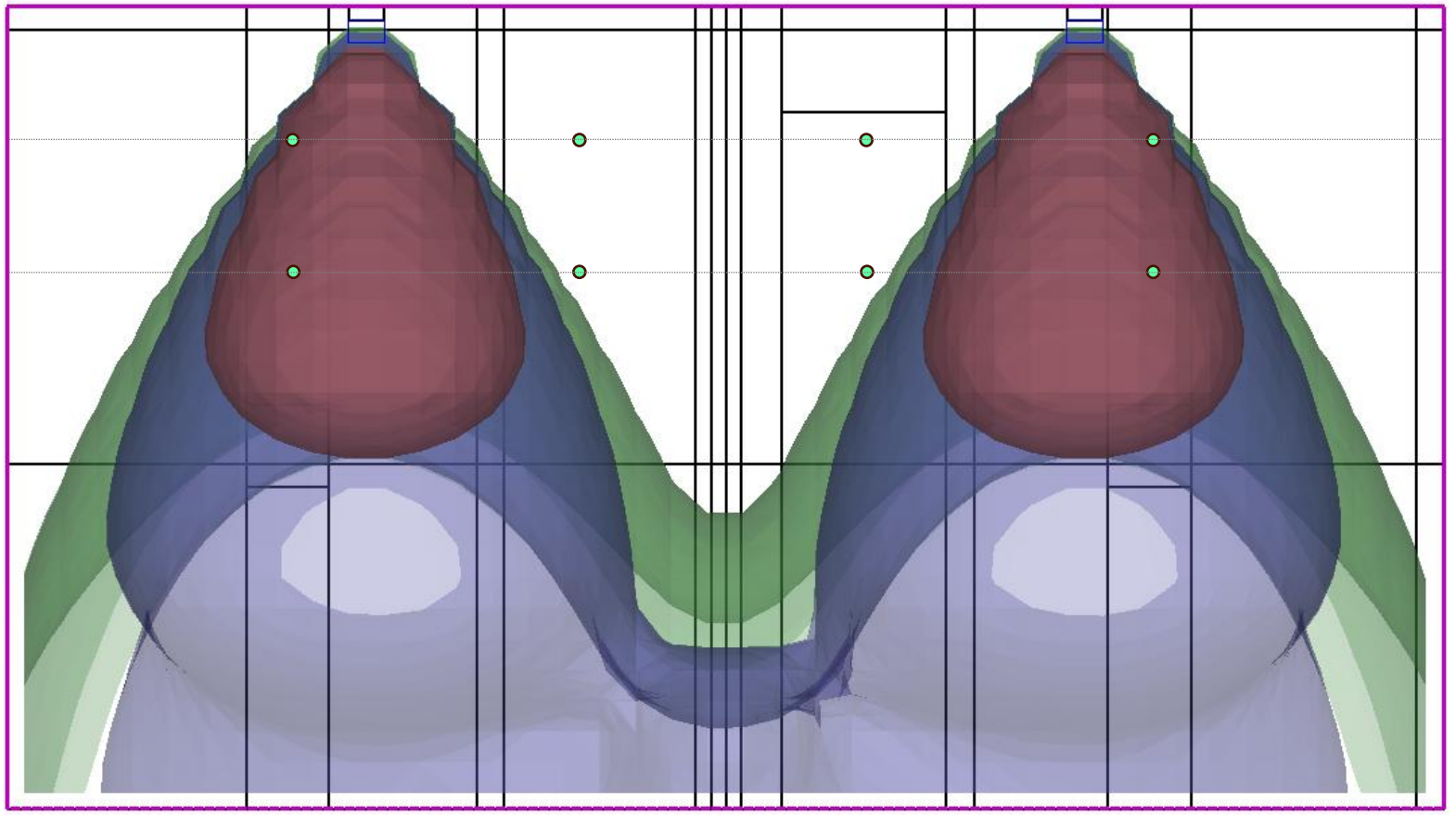
Procedure for Radiometric Measurements

- Define a grid to determine measurement locations across the space for both planes
- Put on personal protective equipment
- Take spectral distribution measurements to verify the peak wavelength for both the UR-GUV and WR-GUV
- Mount the radiometer on the tripod and prepare for measurements
- Take irradiance measurements at the grid points in both planes
- Compare radiometric results to actinometry

Upper Room – Luminaire Radiant Intensity Distribution



Whole Room - Fluence Rate Distribution



18-in plane

36-in plane

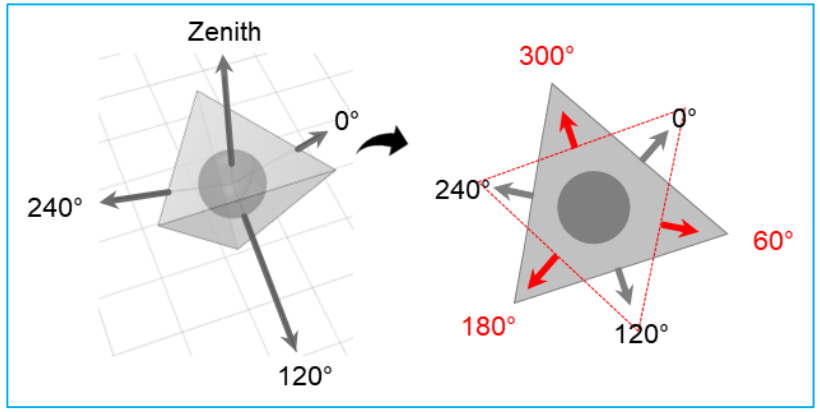
- Fluence rate & irradiance points

Measurement techniques comparisons

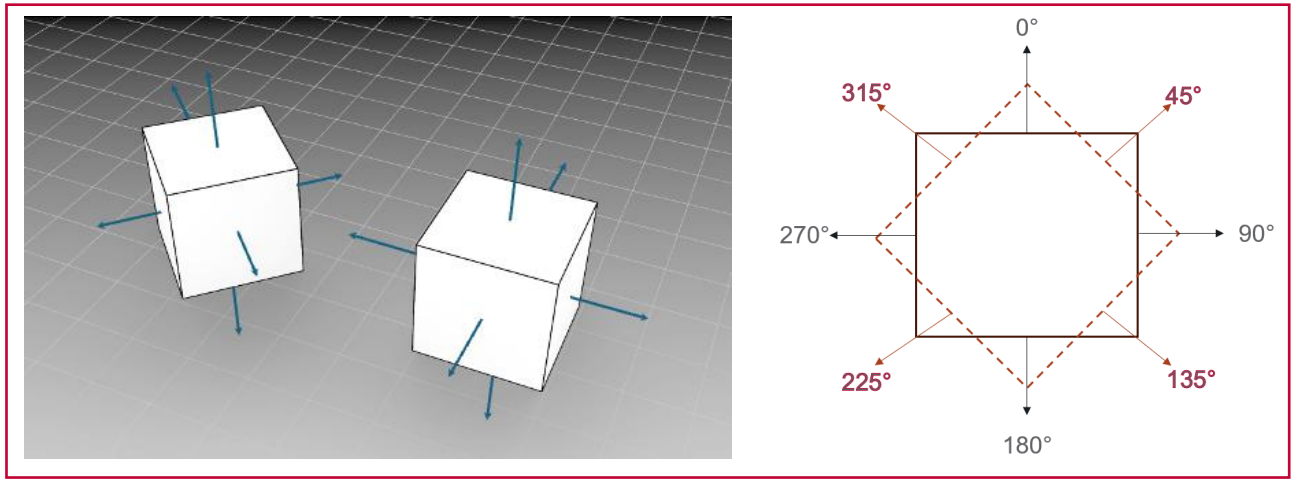
Fluence Rate:

- Tetrahedron vs Actinometry
- Cube vs Actinometry

Tetrahedron



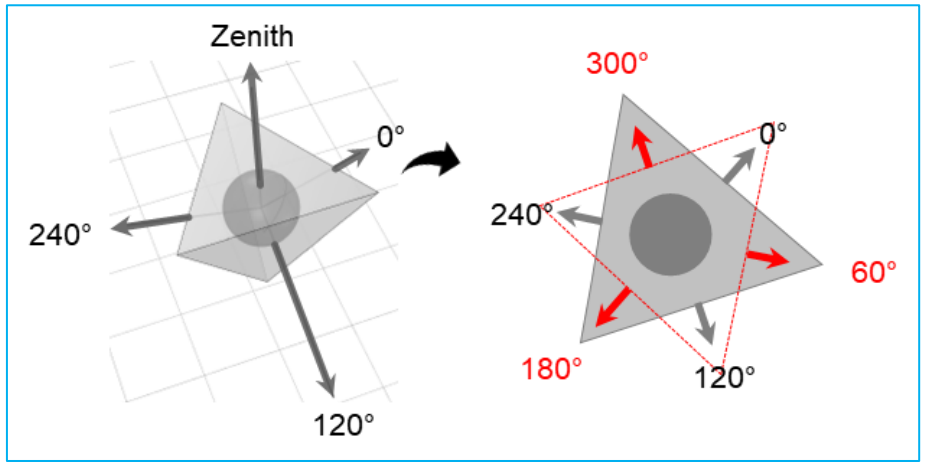
Cube



Radiometry - Tetrahedron

Fluence Rate

- 180° Field of View
- 19.5° below horizontal 360° scan
  - From the scanning, 6 points that are 60° apart are used.
- Vertical measurement taken with detector aimed at zenith
- Two planes
  - 18 in below ceiling
  - 36 in below ceiling

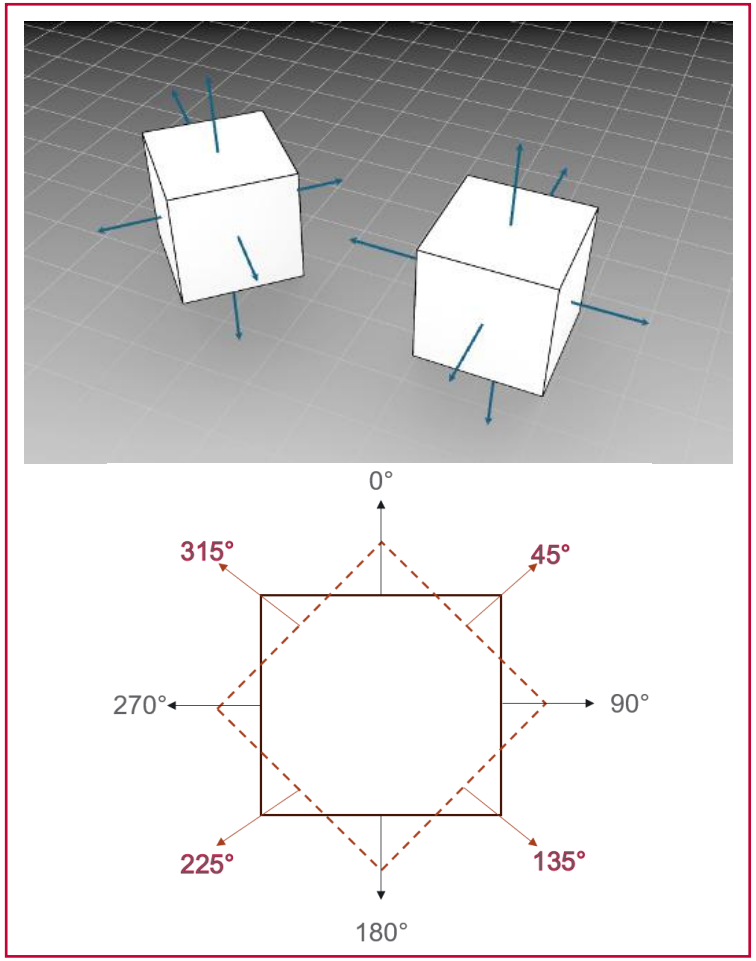


Björn LO. Estimation of fluence rate from irradiance measurements with a cosine-corrected sensor. J Photochem Photobiol B Biol. 1995;29(2):179–83.

Radiometry - Cube

Fluence Rate

- 180° Field of View
- Horizontal 360° scan
  - From the scanning, 8 points that are 45° apart are used.
- Vertical measurements taken with detector aimed at zenith and nadir
- Two planes
  - 18 in below ceiling
  - 36 in below ceiling

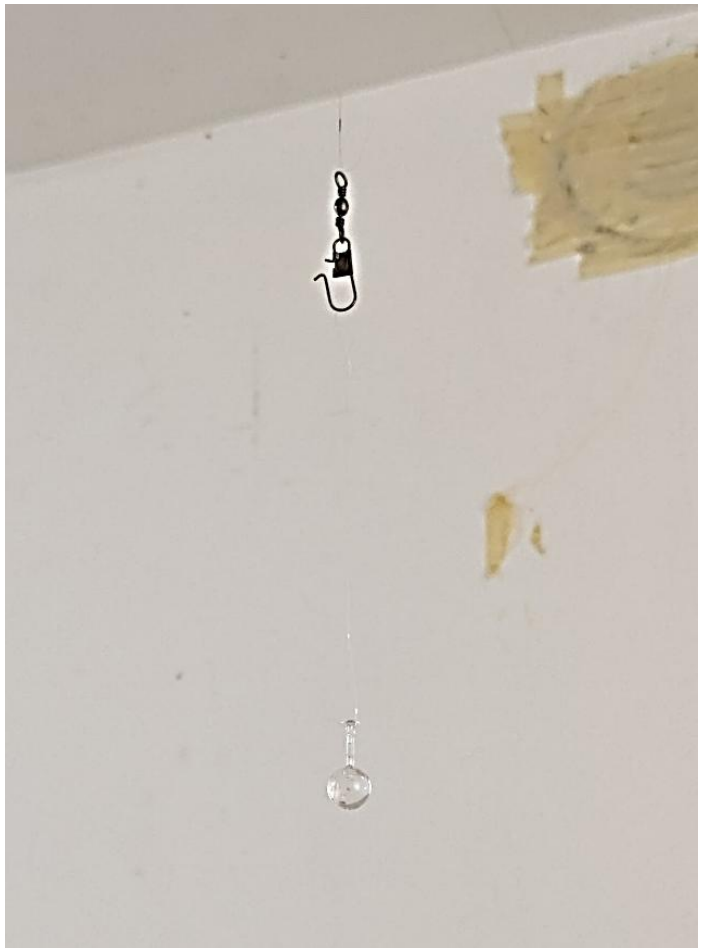


Ronald 0. Rahn et al. Dosimetry of Room-Air Germicidal (254 nm) Radiation Using Spherical Actinometry. Photochemistry and Photobiology, 1999, 70(3): 31 4-31 8

Spherical Actinometry

"An actinometer is a chemical system or a physical device by which the number of photons in a beam absorbed into the defined space of a chemical reactor can be determined integrally or per time." (Kuhn *et al*., 2004, Pure Appl. Chem., **76**, 12, 2105-2146).

Spherical actinometry allows measurement of local fluence rate in a system.



<u>Experiment details:</u>

- Iodide/Iodate solution
- 1 cm diameter quartz spheres
- UV_{222} exposure time: 3 hours
- UV_{254} exposure time: 25 minutes

Statistical methods for validation

- Median Relative Bias Error (MRBE)

$$\frac{Predicted - Measured}{Measured} X\ 100\%$$

- Modified Bland-Altman plot

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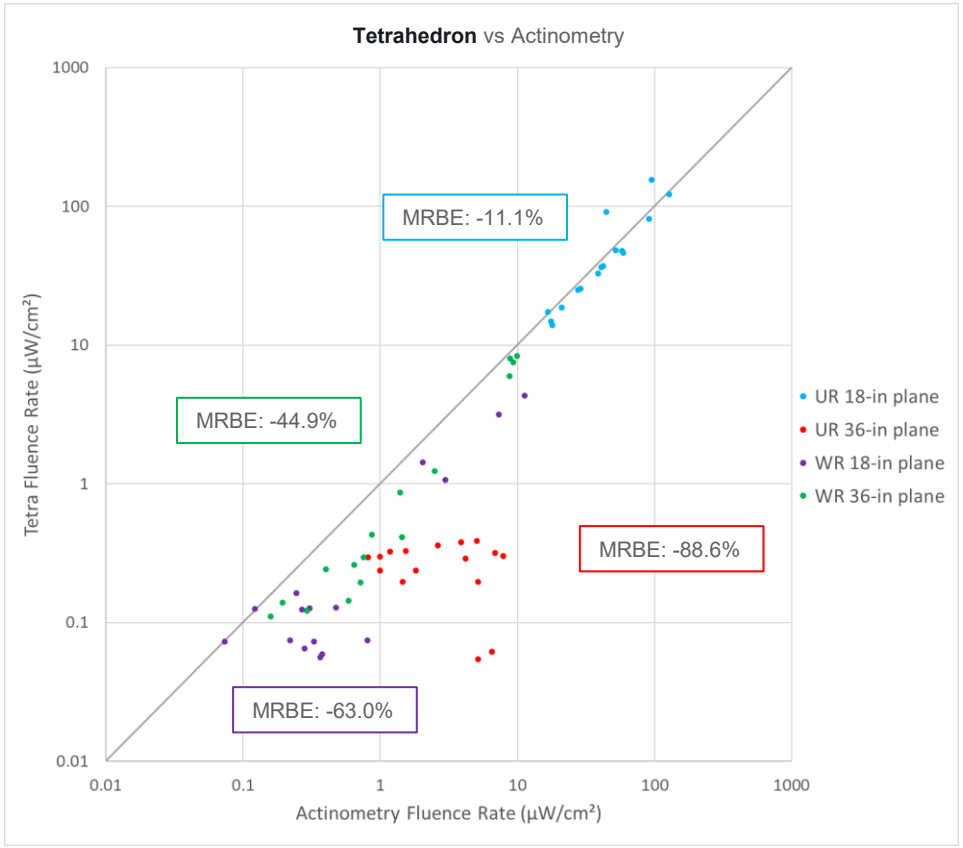
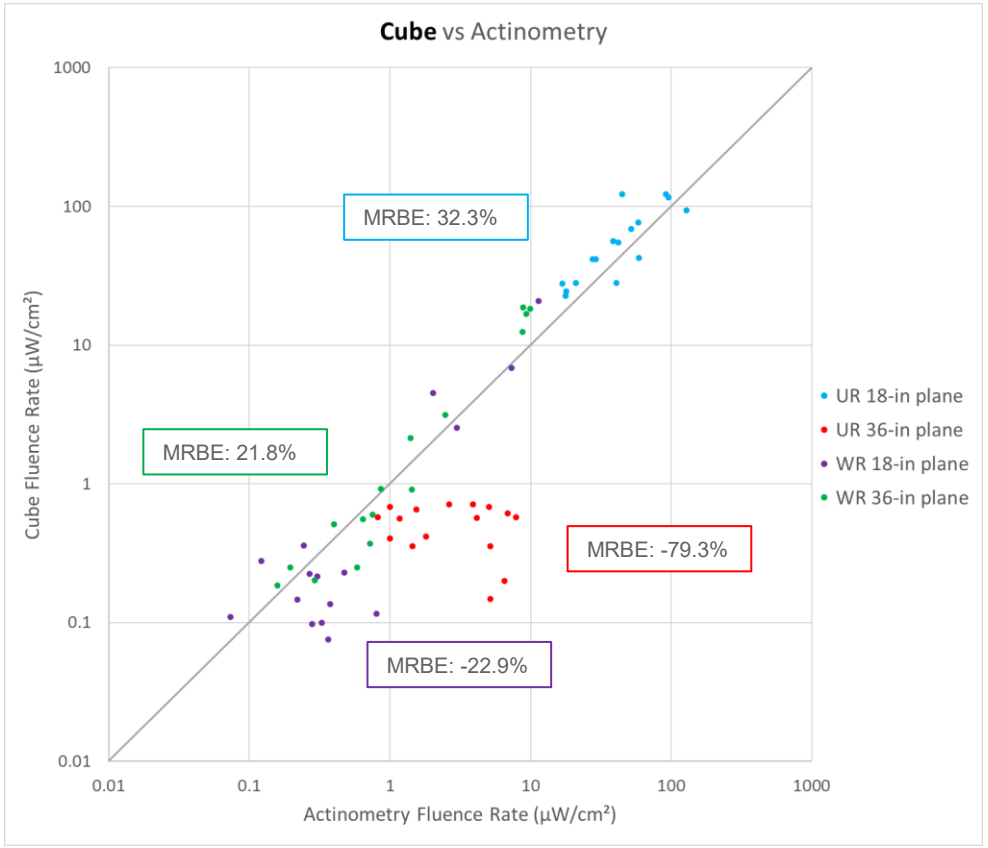
Tetrahedron & Cube Fluence Rate Results

Combined Fluence Rate (μW/cm²) Radiometry vs Actinometry

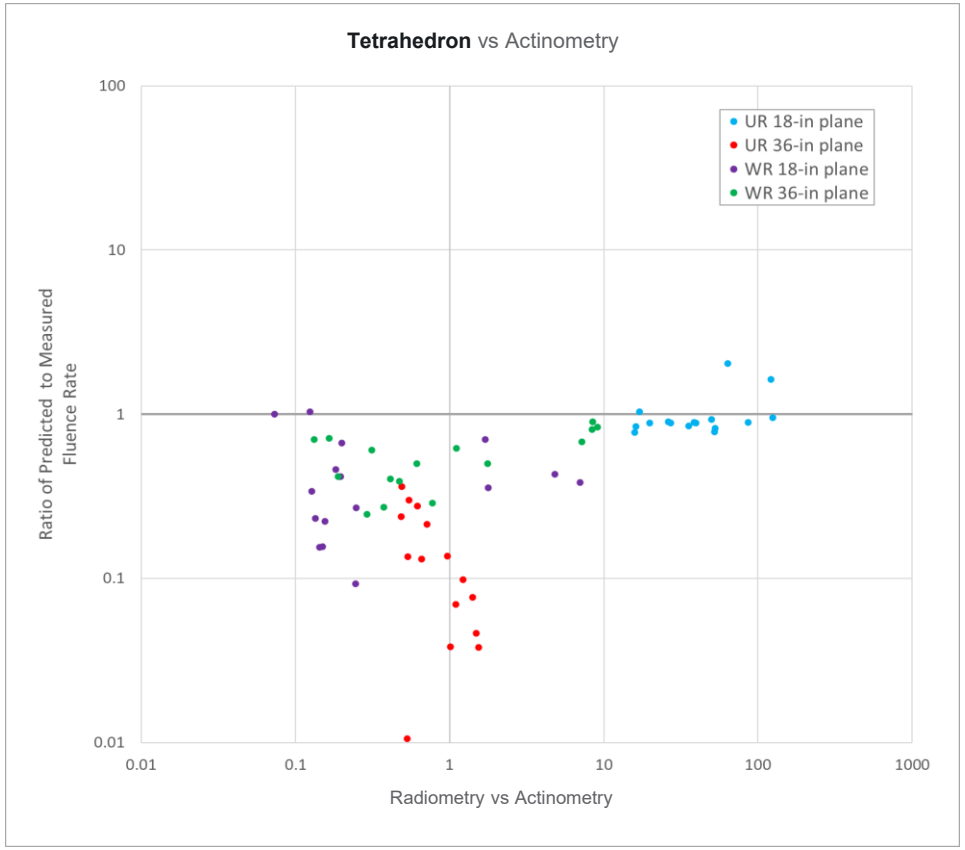




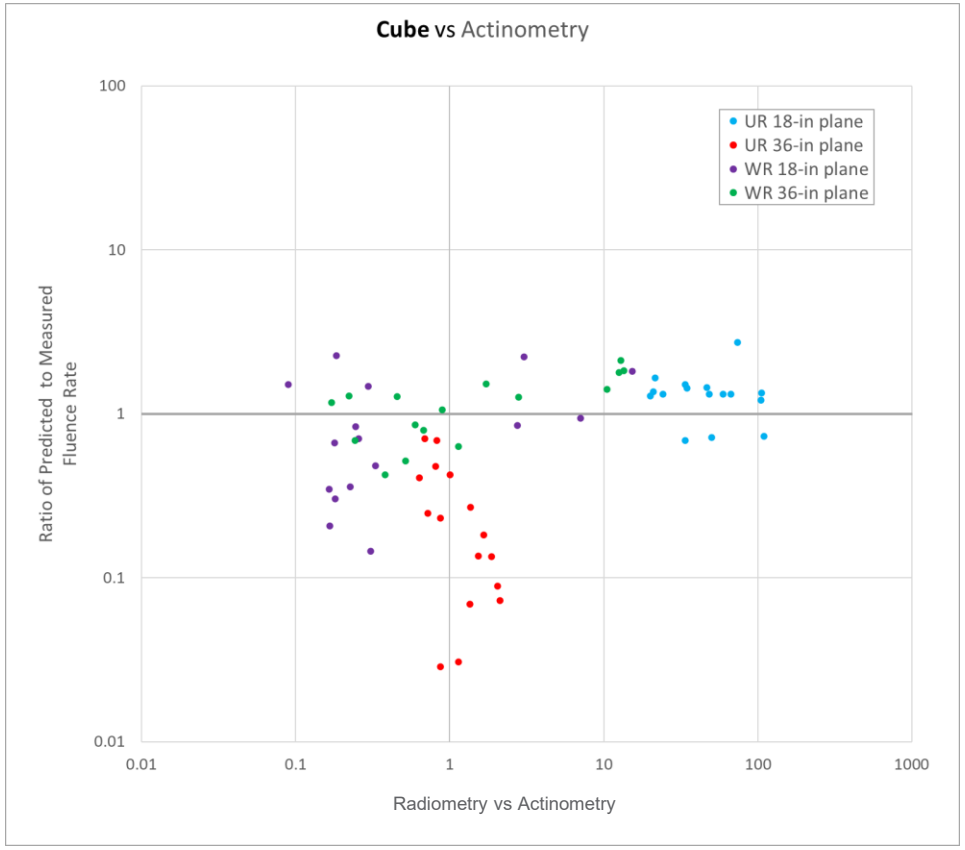
- Tetrahedron measurements are lower compared to actinometry measurements for most points.
- Closest agreement between tetrahedron and actinometry measurements is in the 18-in plane for upper room where the fluence rate is highest.
- The higher the fluence rate, the closer the agreement between tetrahedron and actinometry measurements, except for the upper room 36-in plane.

- Cubic measurements have closer relative agreement to actinometry than tetrahedron, but we anticipate them to overestimate fluence rate due to overlapping fields of view. Some points are lower, and some are higher than actinometry measurements.

Combined Fluence Rate ($\mu W/cm^2$) Radiometry vs Actinometry



Predicted / Measured range: 0.01 – 2.0



Predicted / Measured range: 0.03 – 2.7

- Tetrahedron measurements are lower compared to actinometry measurements for most points.
- Closest agreement between tetrahedron and actinometry measurements is in the 18-in plane for upper room where the fluence rate is highest.
- The higher the fluence rate, the closer the agreement between tetrahedron and actinometry measurements, except for the upper room 36-in plane.

- Cubic measurements have closer agreement to actinometry than tetrahedron, but we anticipate them to overestimate fluence rate due to overlapping surfaces. Some points are lower, and some are higher than actinometry measurements.

Average Fluence Rate Comparison ($\mu W/cm^2$)

WR	Tetrahedron	Cube	Actinometry
18 in	0.70	2.29	1.72
36 in	2.14	4.77	2.94
Average	1.42	3.53	2.33

UR	Tetrahedron	Cube	Actinometry
18 in	50.9	60.5	48.8
36 in	0.27	0.51	3.51
Average	25.6	30.5	26.2

- Average fluence rate values are consistent with the individual points analysis.
- The cubic measurements predict higher fluence rate compared to actinometry on average, and tetrahedron measurements predict lower fluence rate compared to actinometry on average.
- The total average fluence rate for UR-GUV is dominated by the larger values of the 18-in plane. Even though the 36-in plane has a poor agreement between radiometric measurements & actinometry, the values are very low, not contributing as significantly to the total average.
- Close agreement between tetrahedron measurements and actinometry for the UR-GUV.

Summary

- Cube measurements were higher than tetrahedron measurements. Likely due to the overlap of the measurement planes from being 90° apart with 180° FoV.
- Tetrahedron measurements had lower values than actinometry measurements for most points.
- Agreement between tetrahedron measurements and actinometry is poor at low fluence rate values; it gets better as the fluence rate increases except for the 36-in (lower) plane for UR-GUV.
- The best agreement between measurements in terms of average fluence rate is between Tetrahedron and Actinometry for the upper room system.
- Higher fluence rate values were much more influential for average fluence rate prediction.

Preliminary Conclusions

- UR-GUV system design might be more accurate than WR-GUV system design due to higher fluence rates in the upper room
- Measurement points within the luminaire beam appeared to be most consistent when comparing radiometry and actinometry results.
- More work is needed to understand measurement accuracy in the low fluence rate values range.

Limitations

- One WR luminaire appeared to have lower output than the others, possibly due to manufacturing tolerances or service life.

Next steps

- Additional radiometric measurements under controlled environment.
- Further characterization of fluence rate response curve for actinometry.
- Develop manuscript to submit to peer-reviewed journal.
- Conduct similar experiment at second site, PNNL Lighting Science and Technology Laboratory, to compare findings.

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Thank you