Measurement and Assessment of Safety from Exposure to Spectra used for Disinfection

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Philip W. Brickner, MD, Professor of Medicine,
Founder of TB UV Research Studies (1928-2014)

- Collaborators:
  - Melvin W. First, ScD, Harvard School of Public Health
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TB Transmission—a model for other airborne pathogens

Infection control:
Observed practices due to design constraints

Administrative pressures drive Triage procedures

No departmental waiting areas. Health and safety compromised

No physical separation among patients until sputum smear results available

Disinfection in the Era of Ebola

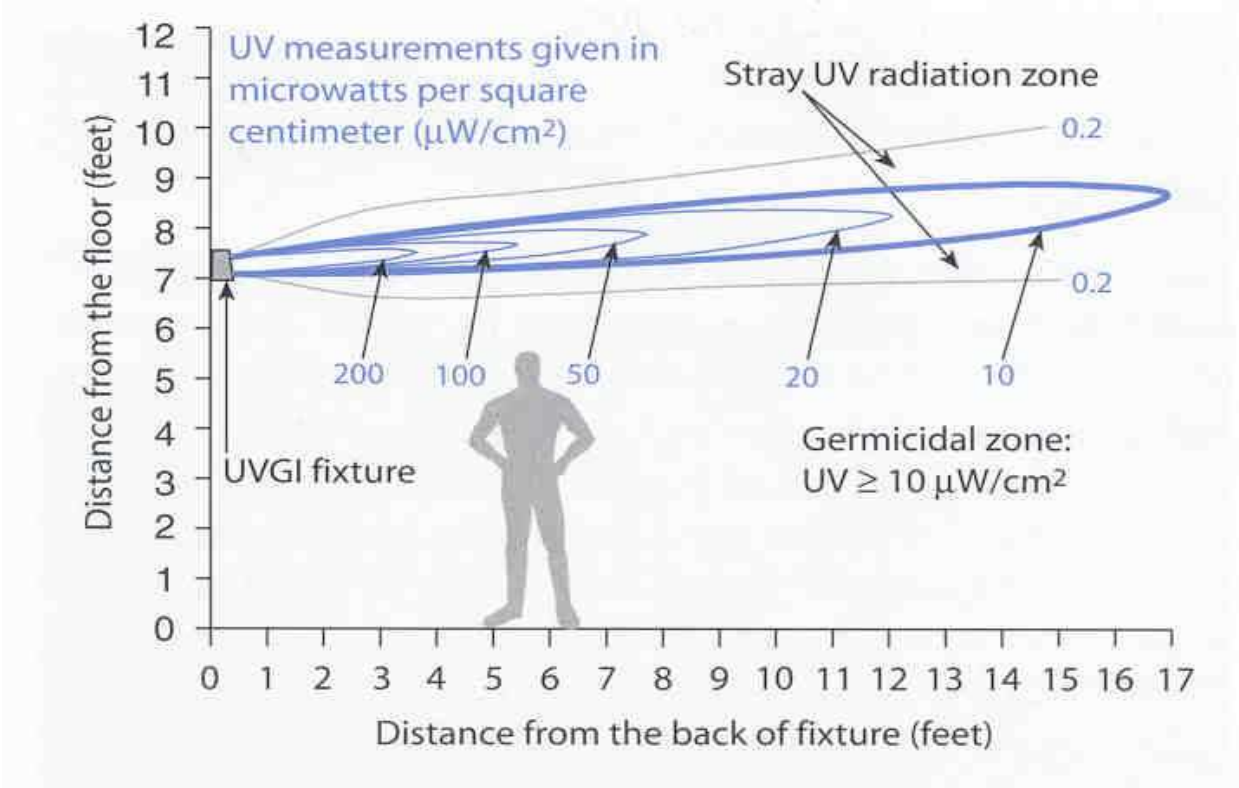
Airborne Pathogens of Concern

- Natural
  - Tuberculosis
  - Influenza
  - SARS
  - Measles
  - Adenovirus
  - MERS
- Bioterror aerosol
  - Smallpox
  - Anthrax
  - Glanders
  - Viral hemorrhagic fevers
  - Pneumonic plague
  - Tularemia
  - Drug resistant TB

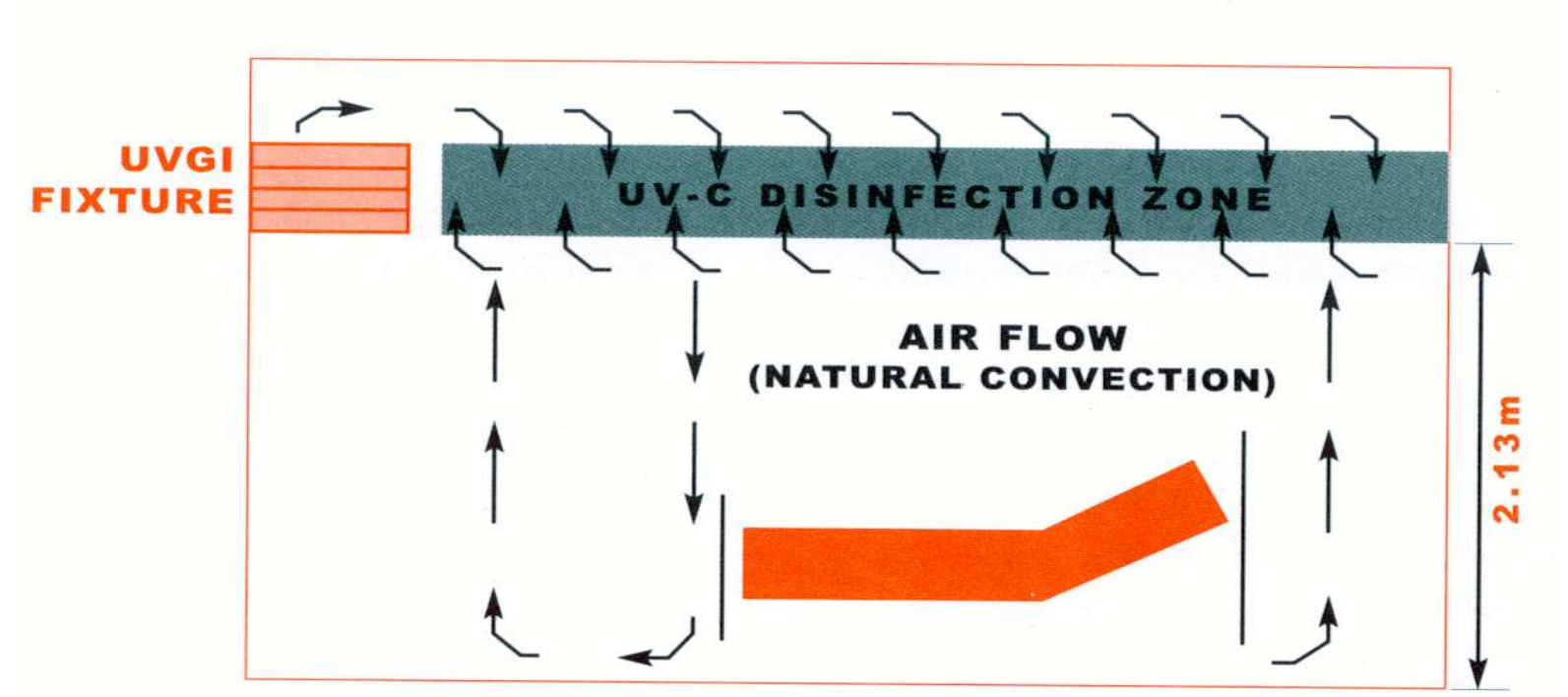
Why Upper Room UVGI Now?

- Large volumes of room air can be treated for less energy than increasing dilutional mechanical ventilation rates
- UVGI works against a wide range of airborne pathogens (regardless of the drug-resistance of the strain)
- Maintenance of systems is relatively simple
- Human safety can be achieved with proper design, installation, commissioning, operation and maintenance.

Upper Room UV-C Energy Distributed Over occupants heads for safety

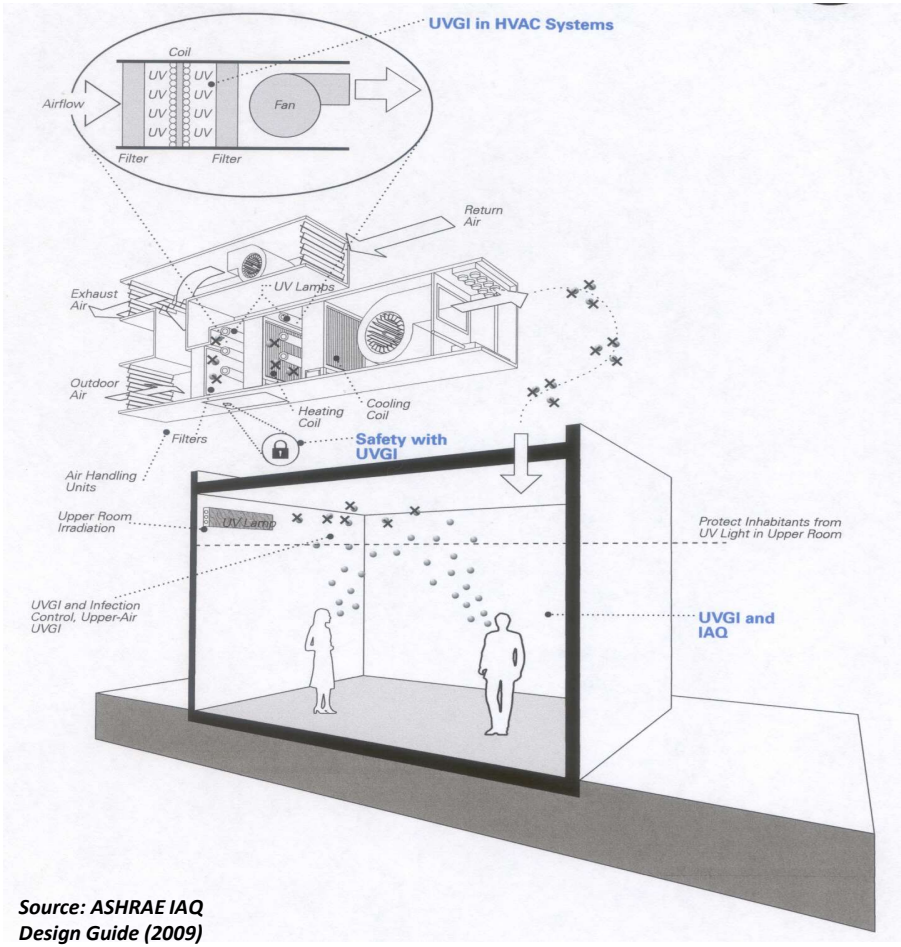


Upper-Room Ultraviolet Germicidal Irradiation (Section View in Hospital Room)



Source: South Africa
Medical Research Council

Plan to Disrupt Airborne Disease Transmission in Buildings



Source: ASHRAE IAQ Design Guide (2009)

- Most upper room installations are designed to interrupt TB transmission From—<u>Most</u> Important to—<u>Least</u> Important
  - Convection--sharing a room or adjacent space
  - Recirculation--anywhere in ventilation circuit
  - Close Proximity--being "coughed on"
- Consider a whole building approach where appropriate

Applying Upper Air UVGI in Congregate Settings—New York City

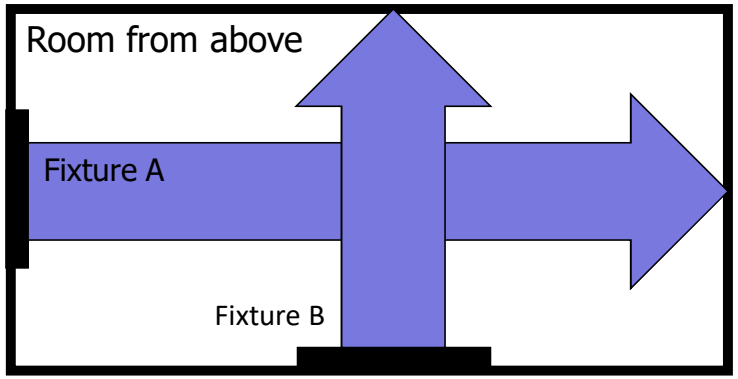
Fundamental Factors Affecting Upper-Room Ultraviolet Germicidal Irradiation—Part II. Predicting Effectiveness

Stephen N. Rudnick and Melvin W. First

Harvard School of Public Health, Boston, Massachusetts

Journal of Occupational and Environmental Hygiene, 2007; 4: 352–362 ISSN: 1545-9624 print

1. **UVGI Fluence rate for the <u>entire room volume</u>**
   (assumes good air mixing)



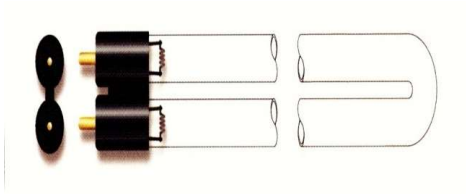
2. Mean UV ray length – effective until it is absorbed by a wall or ceiling.

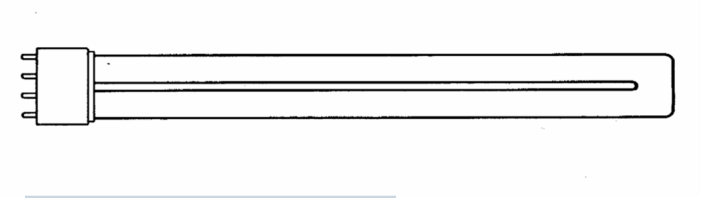
3. Room vertical air mixing – assumed to be "good" with the use of low-velocity paddle fans – direction and velocity do not appear to be critical.

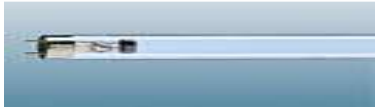
UVC LAMPS

Typical Germicidal Lamps

Linear, Folded, Low Hg





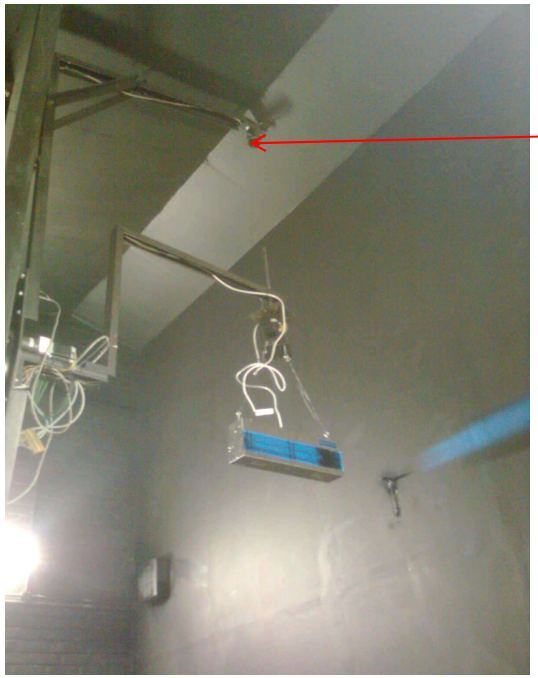


- Upper air UVGI is generated by a low pressure mercury vapor discharge lamp
  - 35% electrical input wattage is converted to UVC energy for which 253.7 nm is the strongest wavelength
- UVC irradiance is measured in $\mu W/cm^2$
- Electrical input to the UVC lamp is regulated by a ballast (magnetic and electronic)

1st Low Hg
Germicidal Lamps

Future LED
Germicidal Lamps

Gonioradiometry of the UVGI fixture



- **UVc detector at 2.5m**
- **Protocol by Zhang et al – 65 vertical angles, and 23 horizontal angles**
- **0.0174 error**

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A Radiometry Protocol for UVGI Fixtures Using a Moving-Mirror Type Gonioradiometer

John Zhang,[1] Robert Levin,[2] Robert Angelo,[3] Richard Vincent,[4] Philip Brickner,[4] Peter Ngai,[5] and Edward A. Nardell[6]

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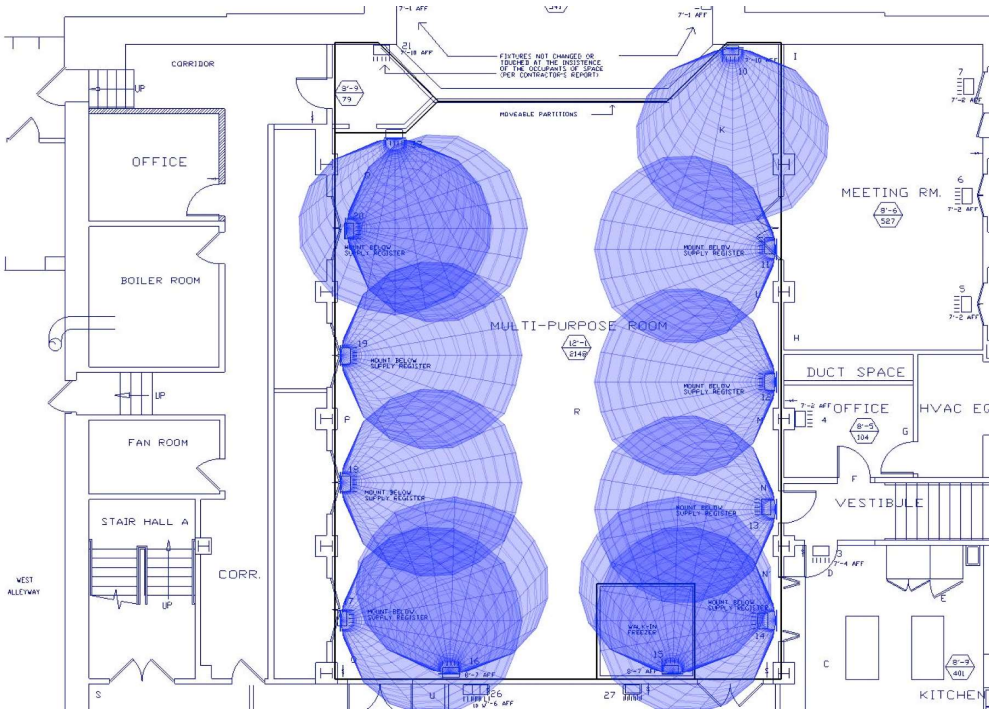
[3]Gigahertz-Optik, Newburyport, Massachusetts
[4]Mount Sinai School of Medicine, New York, New York
[5]Acuity Brands Lighting, Berkeley, California
[6]Partners in Health, Harvard School of Public Health, Boston, Massachusetts



CASE STUDY-TUSS Shelter NYC

Multi-purpose congregate setting with wall-mounted, UVGI fixtures

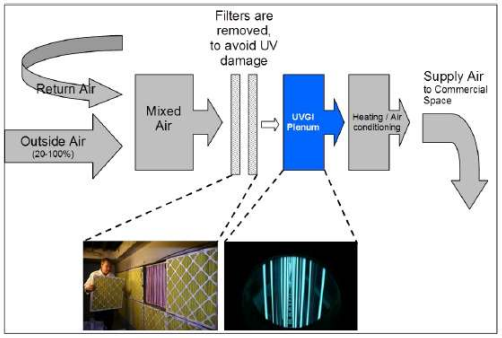
Commissioning for UV Output and Safety

Guidance

- WHO TB IC (being updated)
- CIE TC 6-52 Report—Testing Protocol GUV Luminaires (fixtures) –being voted upon for publication
- ASHRAE GCP 37—Consensus engineering upper room UVGI guidelines—being developed
- SA GUV Guidelines 2015 completed
- NIOSH 2009
- Training Courses—Harvard, CSIR, CDC, NGOs
- Evidence Based Research

Field Testing Induct UVGI Airstream Disinfection

- Field tested a calibrated portable UVC equipped duct to test installed UVGI Air-handling unit efficacy—88% effective against *B. subtilus* spore.
- Lamp output performance improved with addition of quartz sleeves



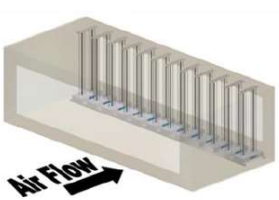


Table 1. Impact of Moving Air and Sleeve Enclosure on UV Irradiance (All conditions used redesigned lamps with shortened cathode supports)

Conditions	UV Output No sleeves $\mu W/cm^2$ ($T_{ambient}$ = 20°C)	UV Output With Sleeves $\mu W/cm^2$ ($T_{ambient}$ = 15°C)	Impact of sleeves
Blower OFF	6260	6149	–2%
Blower ON	3566	6040	+ 69%
Impact of blower	–43%	–2%	

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In-Place Testing of In-Duct Ultraviolet Germicidal Irradiation

Stephen N. Rudnick, DSc, CIH **Melvin W. First, DSc, PE, CIH**
Richard L. Vincent **Philip W. Brickner, MD**

Received January 9, 2008; accepted January 19, 2009

This paper reports results from a field study designed to demonstrate a method for evaluating a building's in-duct ultraviolet germicidal irradiation (UVGI) system using naturally occurring airborne microorganisms and to evaluate its potential effectiveness against selected airborne microorganisms. Forty-eight 64 in. (1.63 m) long ultraviolet germicidal lamps were installed perpendicular to airflow and upstream of the cooling coils in a heating, ventilating, and air-conditioning (HVAC) system for a retail space in a large New York City office building. A portable in-duct UVGI apparatus was used to benchmark ultraviolet susceptibility of naturally occurring airborne microorganisms. Benchmarking was accomplished by measuring the portable apparatus's efficiency for inactivating UVGI-resistant microorganisms in the laboratory at various operating conditions. Inactivation efficiency for both the in-duct UVGI-equipped HVAC system and portable in-duct UVGI apparatus were then measured simultaneously using naturally occurring microorganisms. If the UVGI-equipped HVAC system had higher inactivation efficiency than the portable in-duct UVGI apparatus, then the UVGI-equipped HVAC system's efficiency for inactivating the UVGI-resistant microorganisms used in the laboratory would be expected to be higher than the efficiency of the portable in-duct UVGI apparatus. Based on the results for the tested UVGI-equipped HVAC system, the expected efficiency was at least 88% for Bacillus subtilis *var.* niger *spores, a common surrogate for* Bacillus anthracis *spores.*

Whole-Room Surface Decontamination

Two Different Technologies and Approaches

- UVGI Mobile Room Devices (UVC-254 nm)
- UV LED (260-270 nm)
- Narrow spectrum (405 nm) (white) light LED

Benchmarking UVC-254 nm Mobile Room Sanitizers

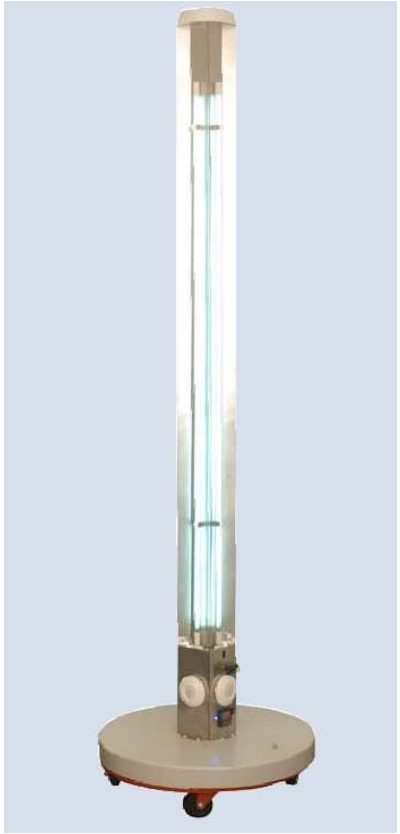
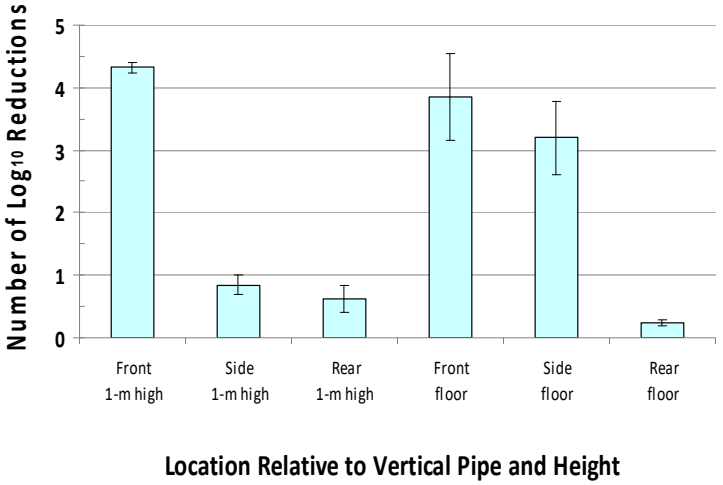


Figure 1
Surface Decontamination of B. atrophaeus spores
(Mean for 3 tests with error bars for standard deviation)



Study by Icahn School of Medicine and Harvard School of Public Health Unpublished data (2013).

Outline of LED Work by Nachiket Vaze, PhD and Edward A. Nardell, MD, Professor, Harvard HT Chan School of Public Health

- Introduction
- LED UV Custom Array
- Array Intensity Measurement
- Antimicrobial Testing, Determining the Z values
  - Single Pass Draw-through Chamber
  - “Meter Cube” Chamber

Continuous Disinfection *white* lighting technology enhanced with narrow spectrum (405-420 nm wavelength) LEDs that can safely provide environmental disinfection in healthcare facilities

- What is the best way to assess occupational safety of deep violet sources being applied in the work spaces when occupants can range from infants to adults?
- What is the best way to assess and report the dose being applied for disinfection?

CORM CR-10
Survey of UV Measurement Problems

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Renssalear Polytechnic Institute: Lighting Research Center

August 1, 2017

Survey

- The survey was sent to 59 people/organizations: IUVA, RadTech, UVGI Specialists, Medical and Research Labs, Military Labs, Canadian and US labs and companies, CIE and others.
- 14 responses were received, three of which did not provide any answers to the survey.
- 11 respondents provided input included in the follow summary slides.

CORM UV Measurements

UV measurement problems

Survey of potential UV measurement problems by CORM UV Measurements Committee (CR-10)

1. What is your application?

2. What is the problem?

3. What is the Wavelength?

4. Geometry fill in pertinent information

Distance from detector:

Source size:

Beam size:

Collimated Y/N

Divergent Y/N

Other

5. Time Scale (DC, AC, Transient):

6. Measurement Units:

7. Uncertainty:

8. Priority

- ◯ Low (future)
- ◯ Medium (could benefit now)
- ◯ High (critical to advancing)

9. Impact (stakeholders, $$$):

10. Information Source (optional)

- ◯ Personal Knowledge
- ◯ Communicated by others

Priority	What is the Application?	What is the Problem?	What is the Wavelength	What is the Impact? $$$
HIGH	• **Industrial UV processing**	*Difficulty in establishing consistent measurement procedure.*	**20-500 nm**	____
	• **Calibration of UV measuring instrumentation**	*Calibration Source Energy*	**254, 365,420, Simulating UVA and UVB Spectrums**	____
MEDIUM	• **UV transmission and reflection**	*Stability*	**58-121 nm**	____
	• **Spectral responsivity calibrations**	*Need Stable Commercially available detectors in the UV*	**200-400 nm**	*Client Calibrations*
	• **Upper-air, in-duct, in-room surface disinfection, collimated-beam studies**	*Accurate fluence measurement/determination*	**Primarily 254, 260-270 nm**	*Important to move the larger UV industry forward*
	• **UV inactivation of virus and bacteria**	*Calibration at same level as being used in the lab or field application*	**200 nm (or 210 nm) to 300 nm, 254 Hg line is used predominantly**	*Water treatment community, equipment manufacturers, researchers (university and government)*
	• **General UV processing and curing applications**	*LED Array radiometry*	**Currently from Vis(Ca. 455) to the shortest industrially viable wavelength (ca. 340 nm)**	*$$$ printers, industrial coatings, etc. multibillion dollar*
	• **Optical safety and germicidal radiation**	*Stray light and detector noise*	**180 nm to 315 nm (UV-C and UV-B)**	*Potentially millions*
	• **UV disinfection and pollutant treatment**	*Pathogens in water and air and pollutants in water and air*	**Generally 200-300 nm**	*???*
LOW	• **Spectral UV Irradiance, Flux and Radiance**	*Accurate Calibration Sources of high enough power to calibrate instruments*	**250-350 nm**	___
	• **Calibration**	*None*	**250-400 nm**	*Calibration & Testing Laboratory*

What is the Application?	What is the Problem?	What is the Wavelength	Geometry	Time Scale (DC, AC Transient	Measurement Units	Uncertainty
Industrial UV processing	*Difficulty in establishing consistent measurement procedure.*	**20-500 nm**	Distance to Detector-various-generally Near field Source Size: various Beam Size: various Collimated Y/N-N Divergent Y/N- Y Other Complicated by external Optics	Static (W) Dynamic (J)	W/nm (emission)	Undefined—not high priority
Calibration of UV measuring instrumentation	*Calibration Source Energy*	**254, 365,420, Simulating UVA and UVB Spectrums**	Distance to Detector 50 cm-1.5 m Source Size: n/a Beam Size 0.5cm-2.5 cm Collimated Y/N Y, sometimes dependent on instrumentation being calibrated Divergent Y/N dependent on instrumentation be sometimes ing calibrated Other	——	mW-1W, mW/cm^2-W/cm	>5%

What is the Application?	What is the Problem?	What is the Wavelength	Geometry	Time Scale (DC, AC Transient	Measurement Units	Uncertainty
UV transmission and reflection	*Stability*	**58-121 nm**	Distance to Detector- 100 nm Source Size: 1mm D|A Beam Size: 10 mm pseudo collimated Collimated Y/N-Y (pseudo) Divergent Y/N- Y Other	DC	µA	n/a
Spectral Responsivity	*Need stable, commercially available detectors in the UV*	**200 – 400 nm**	Distance to Detector 50 cm-1 mm monichromator slits Source Size: n/a Beam Size 1 mm-4 mm Collimated Y/N n Divergent Y/N n Other focused beam	DC	A/W	2%

What is the Application?	What is the Problem?	What is the Wavelength	Geometry	Time Scale (DC, AC Transient	Measurement Units	Uncertainty
Upper-air, induct, in room surface disinfection, collimated beam studies	*Accurate fluence measurements/ determination*	**254 nm primarily; however, 260-265 nm LEDs and medium pressure Hg lamps**	Distance to Detector- any Source Size: 30-50 cm Beam Size: any size, and multiple sources Collimated Y/N-Y some Divergent Y/N- Y Other large 3D spaces	any	Irradiance µW/cm ^{2} Fluence mJ/cm^2 or equivalent	n/a
UV Inactivation of viruses and bacteria	*Calibration at same level as being used in lab or field application*	**200 (or 210 nm) to 300 nm 254 Hg line is used prominently**	Distance to Detector 30-50 cm Source Size: multiple Beam Size 5 cm Collimated Y/N n Divergent Y/N uniform diverging beam (10° half-angle) Other Irradiance 10 µW/cm2 to >100µW/cm2 and 1 mJ/cm2 to >100 mJ/cm	DC and Pulsed at 1000 Hz	µW/cm2 (irradiance); mJ/cm2(fluence or dose)	1%
UV Disinfection and pollutant treatment	*Pathogens in water and air and pollutants in water and air*	**Generally 200-300 nm**	Distance to Detector closer is better Source Size: about size of fluorescent lamp Beam Size full output Collimated Y/N Y and N Divergent Y/N usually beam (Other	AC	kmW/cm^2; W/m^2	Less than 2%

What is the Application?	What is the Problem?	What is the Wavelength	Geometry	Time Scale (DC, AC Transient	Measurement Units	Uncertainty
General UV processing and curing applications	*LED Array radiometry*	**Currently from Vis (ca. 455) to the shortest industrial viable wavelength (ca. 340 nm)**	Distance to Detector- varies by application Source Size: narrow 6" to wide 2m? Beam Size: multiple LED chips Collimated Y/N-Y lambertian sources Divergent Y/N- Some optics used by some vendors to control spread Other need the ability to pass under LED arrays to simulate exposure of industrial coatings/links, etc.	Generally DC	W/cm^2 and J/cm^2	Current radiometers ca. 10%
Optical safety and germicidal radiation	*Stray light and detector noise*	**180 to 315 nm (UV-C and UV-B)**	Distance to Detector all Source Size: all Beam Size all Collimated Y/N Y&N Divergent Y/N Y&N Other	Generally DC	Radiometric and Spectroradiometric	___

What is the Application?	What is the Problem?	What is the Wavelength	Geometry	Time Scale (DC, AC Transient	Measurement Units	Uncertainty
Spectral UV Irradiance, Flux and Radiance	*Accurate calibration sources of high enough power to calibrate instruments*	**250-350 nm**	Distance to Detector- ~20 cm Source Size: narrow 6" to wide 2m? Beam Size: 1 mm^2 to 1 cm^2 Collimated Y/N-Y not usually Divergent Y/N- Y Other	DC	W/nm, $W/(m^2/nm)$, $W/(m^2sr/nm)$	n/a
Calibration	*None*	**250-400 nm**	Distance to Detector vary Source Size: vary Beam Size vary Collimated Y/N Y Divergent Y/N N Other	DC	W/m^2	1.5%

Next Steps

- Discuss and prioritize
- Report to CORM on which topics to pursue

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- Heather Patrick, NIST for feedback and willingness to backstop this presentation