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Solid-State Lighting Program: Germicidal Ultraviolet (GUV) R&D Meeting

March 2022

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DOE Solid-State Lighting Program, "Germicidal Ultraviolet R&D Meeting," March 2022.

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Solid-State Lighting Program
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Comments

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1 Introduction

On October 20, 2021, sixteen subject matter experts on different aspects of germicidal ultraviolet (GUV) disinfection gathered at the invitation of the Department of Energy (DOE) Solid-State Lighting (SSL) Program to help identify critical research and development (R&D) topic areas in GUV from photobiology and application designs to luminaire products and UV sources. This small-group discussion meeting is one forum for experts to provide technical input to the DOE SSL Program. The DOE SSL Program also collects inputs from stakeholders at the annual Solid-State Lighting Workshop, via a Request for Information (RFI), and other means. The guidance provided by stakeholders in these various forums helps identify critical R&D areas that may be incorporated into DOE's technical roadmaps.

This year the meeting was held virtually due to travel difficulties and concerns related to the ongoing COVID-19 pandemic. The meeting commenced with "soapbox" presentations in which each participant was invited to give a short presentation describing what they believed to be the key technology challenges for GUV over the next three to five years. Presentations were followed by a general discussion of the most critical GUV technology challenges facing the industry today.

The meeting format provided an opportunity for experts across the research spectrum to exchange ideas and explore collaborative research concepts. Participants included experts in GUV relevant science and technology disciplines drawn from academia, national laboratories, government agencies, and industry.

This report summarizes the outcome of the discussions on critical technology challenges and identifies corresponding R&D tasks. Outlines of the participants' soapbox presentations and related remarks are included in Appendix A: Participant Presentations of the report.

1.1 Key Conclusions

The meeting format encouraged each of the attendees to participate and present his/her perspective on critical R&D challenges. The discussions that followed the soapbox presentations offered a variety of valuable insights into a range of research topics that could advance GUV technology; however, some recurring themes arose during these discussions regarding research areas that could lead to significant breakthroughs in technology development and implementation. The recurring themes are as follows and are outlined in more detail in Section 2:

- UV Light Emitting Diode (LED) Sources
- GUV Luminaire Development
- GUV Measurements & Standards
- Understanding Photobiological Effectiveness
- GUV Application Research & Guidance

2 Critical R&D Topic Areas

The COVID-19 pandemic has greatly increased the spotlight on GUV irradiation for air and surface disinfection. Considering the potential jump in electricity load with increased implementation of GUV in buildings, this area represents a growing opportunity to embed energy saving designs.

2.1 UV LED Sources

Participants discussed research and development paths for different aspects of GUV source technology, including ultraviolet C-band (UVC) LED sources. Today's UVC LEDs are less efficient than low pressure mercury vapor lamps (LPMV), though UV LEDs are catching up to the performance of LPMV lamps in terms of effective efficiency when the power supply efficiency, light utilization efficiency, and standby time deratings are applied. Additionally, UVC LEDs have more headroom to improve efficiency than the existing LPMV and excimer UV lamp technology. Participants highlighted the research efforts underway in UV LEDs and noted the remaining technical challenges to improving efficiency and lifetimes. To increase the power conversion efficiency of UV LEDs, materials research addressing both the optical and electrical operation of the LED is required. The device's poor electrical behavior can be attributed to dislocation density and epitaxial layer quality, series resistance in contacts and semiconductor layers, and thermal management. Optical behavior in current UVC LEDs is due to poor radiation extraction from the chip and package, low transparency p-contact layers, and low p-contact reflectivity. Often, the improvement in forward voltage led to a tradeoff with optical transparency performance, and vice versa. For example, improving optical extraction by replacing UV absorbing p-GaN contact layers with UV-transparent p-type AlGaN layers led to an improved optical performance, but the p-type AlGaN is more electrically resistive that p-GaN resulting in higher forward voltage. The gains in UVC LED performance over the past several years have been made by improving the optical transparency of the p-type semiconductor layers while simultaneously improving the electrical design of the p-type layers (employing strained p-AlN capping layers enhances tunneling leading to a high charge density at the p-AlN surface). Commercial UVC LEDs can achieve power conversion efficiencies of 3-6% at 280 nm, while top R&D results have reached 10% power conversion efficiency.

The majority of participants agreed that UVC LEDs would benefit from government R&D investment because of the fundamental materials research that is still needed to improve device performance. UV LED development strategies include improving the power conversion efficiency, improving the flux density, and maintaining long lifetimes. More specific research areas include defect control in AlGaN heterostructure growth (point defects) and low dislocation density growth templates; UV reflective p-contact materials for flip chip structures; enhanced light (photon) extraction to reduce total internal reflection; UV transparent encapsulants (for packages); and improved thermal management in packages (which have 8~10x thermal load at the same current compared to white LEDs). Future performance targets discussed by participants include improving UVC LEDs devices to achieve power conversion efficiency of >15% by 2024 and >30% by 2030; L_{70} lifetimes (time for lumen maintenance to reach 70% of original radiant power) > 30,000 hours; and wavelength ranges down to 222 nm. Other related improvements include advancing UVC LED modules by improving the beam shaping optical design for UV radiation, integrating UV sensors into modules, and improving manufacturing processes for more cost-effective UV module solutions.

2.2 GUV Luminaire Development

Participants examined the status of the GUV luminaire technology and considered design improvement areas to advance the effective GUV delivery to the space. More effective GUV delivery requires improving optical beam shaping to provide desired distribution, while simultaneously reducing system losses to improve the overall energy effectiveness of GUV systems. Additionally, analyzing issues such as materials reliability during UVC exposure and occupant safety are essential for optimal GUV system design. Current louvered designs for optical control in GUV luminaires are very inefficient. Participants described how shaped optical distributions can enable better irradiance uniformity. A high uniformity (irradiance maximum/minimum) results in greater average fluence rate, and therefore greater germicidal efficacy at the same max irradiance.

The use of non-Lambertian optical distribution profiles, such as bat-wing distributions, can provide greater delivered irradiation uniformity. Small sources like UVC LEDs can be more effective for shaping the output distribution with relatively small optics. Other beam control technologies include nano-imprinting to create pillars or other nanostructures that direct the optical beam without the use of secondary optics (which are often polymer-based materials that can degrade with high energy UV irradiation). Metasurfaces comprise another novel research area with the potential to provide beam control without secondary optics. From the application perspective, better optical control can allow the luminaire to be directed to different surfaces in the room and provide another mechanism to deliver targeted GUV disinfection into the space. Developing application-level metrics that can incorporate uniformity and effectiveness in GUV would provide clearer guidance to describe luminaire system performance beyond just source efficiency or UV output power.

Materials stability under UVC irradiation is also a concern since many common polymers (e.g., fabrics, paint, and other organic materials) will undergo UV damage under prolonged exposure. The higher energy UVC photons can also degrade materials used in luminaire construction (optics or polymer based diffuse reflectors). As these luminaire and/or building materials degrade, there is the potential to generate airborne microplastics (MPs), which are of concern in the scientific community as a potential health hazard and environmental pollutant. Airborne MP concentrations indoors may theoretically increase when UV systems are used, as any polymers in close proximity to a UV source will eventually degrade. Participants suggested that research is needed to determine how much of a concern MPs should be to GUV system design. System designers and implementers should ensure the GUV systems can meet acceptable MP concentration levels in air and drinking water. Beyond just the safety status, the potential reduction of building material lifetimes under GUV irradiation should be considered. Overall, developing a better understanding of the environmental risks of widespread GUV technology adoption, with careful consideration for exposed plastics, is important.

Further advancements in modeling software are essential to aid the development of more efficient GUV luminaire designs. Accurate modeling can allow designers to determine whether GUV products in occupied spaces can be more energy efficient than increasing heating, ventilation, and air conditioning (HVAC) loads to increase air changes. Software must be able to calculate the radiometric UVC values (such as absorption/reflection and fluence) and leverage a catalog of architectural materials with surface reflectance data in the UVC wavelengths. Further, the ability to simulate the effectiveness of pathogen inactivation when dispersed in air requires harmonizing fluid dynamics modeling software with lighting software design packages. Developing full/upper room GUV analysis for pathogens requires further development of simulations tools.

Participants identified opportunities for implementing sensors into GUV luminaires. Current sensors are lower-cost silicon-based sensors, which are broad spectrum and vulnerable to radiation in the room. AlGaN-based detectors will be more stable under UV irradiation. Additionally, the development of bioaerosol sensors to detect pathogens would be worthwhile research effort. Participants also suggested that DOE should support R&D to understand how a GUV system could be implemented and integrate with building automation systems (BAS) and HVAC systems since the sensors needs to be able to communicate with other building systems.

2.3 GUV Measurements & Standards

Participants discussed the current characterization methods and tools for accurate UV measurements, and provided updates on standards development. The National Institute of Standards and Technology (NIST) has improved UV measurement accuracies down to 200 nm wavelengths at less than 1% error and can calibrate LEDs for radiant intensity distribution (and radiant flux) from 200 to 1700 nm. While UV LED testing accuracy has improved, UV sensors and detectors performance still shows a lot of variability. Users must be careful on the geometry of the detector setup relative to how the detectors were calibrated since they can lead to large errors with incorrect geometry. More R&D is needed to improve sensor accuracy and correct implementation in GUV measurements.

Several UV-related standards are under development through the American National Standards (ANSI Standards) and the Illuminating Engineering Society (IES) in conjunction with the International Ultraviolet Association (IUVA), including ANSI/IES LM-92 - Approved Method for Electrical and Ultraviolet Measurement of Light Emitting Diodes (LEDs). Other standards are being developed for the electrical and UV measurement of different UV source types and the calibration and characterization of UVC detectors. Further, development of standardized labeling for GUV products is underway with general specifications such as nominal Watts, UV Watts, current draw, emission spectrum, ozone production, and mercury content being listed. Expansion of UV-related standards and labeling will allow reliable evaluation and comparison of products and increase industry accountability to provide accurate performance claims. Modifying previous DOE SSL programs aimed at developing white lighting products to address barriers for implementing safe and effective GUV systems was widely supported by participants. Pacific Northwest National Laboratory (PNNL) is adjusting the DOE SSL Program's CALiPER testing and Gateway Demonstrations to help address the challenges of GUV deployment for disinfection. There is a lack of understanding on how to compare or evaluate GUV products, little industry accountability, false performance claims, and safety risks that can lead to potential end-user disappointment, injuries, and slowed adoption. The CALiPER program independently tests and evaluates existing products and reports the performance, which serves to validate product performance claims and has been effective in addressing inaccurate performance claims, calling attention to low performing products, and educating stakeholders on how products should be tested and evaluated. Gateway Demonstration projects evaluate new technology and products in the field to help provide lessons learned and develop best practices for the targeted application areas. DOE can play a role in education and stakeholder engagement. Developing accessible materials like factsheets for people to better understand the technology, and authoring technical reports to better inform industry are both viable options.

2.4 Understanding Photobiological Effectiveness

Participants discussed the need to better understand the photobiological effectiveness of GUV by developing guidance for dose levels that can inactivate pathogens in various conditions (e.g. surrounding proteins, lipids, or liquids) at various UV wavelengths and in various room surfaces and materials, while providing a safe doses for occupants (skin and eyes). Research is needed to better understand the germicidal action spectra since the inactivation process of viruses and other bioaerosols are not fully known. There has been a standardized germicidal action spectrum peaked at 265 nm based on E.coli, though participants noted that recent studies show a range of action spectra and a few aerosols more readily inactivated by far UVC. This photobiological understanding is important to inform standards and labeling work – e.g., addressing product claims of 99.9% germicidal effectiveness. Without an understanding of the photobiological effectiveness of GUV on different pathogens in varying use environments, product claims cannot be validated. Participants supported research to develop a standard way to measure pathogen deactivation under standardized conditions that can then be translated to real-life application conditions. It is important to consider the pathogens in conditions such as the surrounding proteins, lipids, or liquids since that impacts their required inactivation dose at different UV wavelengths. Furthermore, the room environment and materials (e.g. Formica, vinyl, cloth, plastic) will also play a role in the effective dose for the application. These studies can lead to application-based reference designs for biological validation and optimization of GUV effectiveness.

Improving the accuracy in the risk vs. benefit calculations for GUV is another significant research area. While the virucidal effects of UVC irradiation (to inactivate the pathogen) is maximized at ~ 260 nm, UV LEDs are less efficient at shorter wavelengths. Considering the optical power of 280 nm LEDs are substantially higher than at 260 nm (> 2x), the germicidal effectiveness can be higher at 280 nm even though the relative virucidal effect is lower (~ 60% at 260 nm compared to 280 nm). While longer UV wavelength LEDs are more efficient and may provide a higher virucidal effect, there is significant health risk to skin and eyes in the UVB range compared to UVC wavelengths. UVC wavelengths of 254-280 nm have a low dermal risk and the far UVC (~180-230 nm) has almost no dermal risk. Further research into balance of germicidal effectiveness benefit vs. dermal risk for UV LEDs with wavelengths centered 280 nm can help provide better guidance for GUV system designers and implementers. Finally, participants expressed the need for further GUV safety research to determine threshold limit values (TLVs) with time-weighted averaging (TWA) of realistic human exposure. Time-motion research is required for the rational application of UV exposure TLVs. Studies with film badges for different installations and different types of UV sources would be beneficial.

2.5 GUV Application Research and Guidance

Application research and guidance is needed to ensure that GUV systems will provide safe, energy-efficient GUV delivery designs within the built environment. Best practices for building integration including determining the best points of GUV insertion (e.g., upper room vs. whole room vs. HVAC duct) to maximize germicidal effectiveness while minimizing energy consumption are needed. One priority is learning the effectiveness of GUV systems in real-world settings. The inactivation of pathogens both in the air and on surfaces must be considered, as well as understanding where viral transmission is occurring – e.g., via the HVAC ventilation circuit or in the room environment. Controlled human-to-animal studies have led to evidence-based guidance for UV as a basis for dosing in experiments aimed at tuberculosis. A study of upper room GUV on tuberculosis transmission showed that GUV was 80% effective and added the equivalent of 24 air changes per hour into the room. Participants described that a controlled human-to-animal study is underway to repeat this type of transmission evaluation with SARS-CoV-2. Participants also spoke of the need for occupant monitoring studies to estimate the TWA occupancy of various spaces at various heights. Occupant movements in spaces determines how much potential GUV exposure is likely, yet there is very little monitoring information available to make estimates of time weighted averages. One study on 254 nm sources indicated the TWA was under 1/3rd of the TLV. Research is needed to better understand how spaces are being occupied and how much of the TLV is being reached in these various spaces. Dosimeters and artificial intelligence may help address these questions.

As GUV systems enter the field, there will be different UVC technologies and wavelengths in use. It is important to determine what protocols are needed for upper room application guidelines and how these protocols may vary for the different UV wavelengths and source technology. Research should answer whether UV LED, LPMV, and excimer sources are interchangeable in achieving microbial inactivation of pathogens (in air and on surfaces), and what impact airflow patterns have in GUV effectiveness for different UVC source types. R&D studies are needed to compare these effects with different UVC source technology to better understand how we can mix and match technology and the benefits each may provide. Also, the GUV application should be considered when determining which type of GUV technology is most effective.

Whole room GUV LED systems using direct irradiation below exposure limit (DIBEL) present new opportunities, but studies are needed to answer if they are equivalent to upper air GUV implementation. DIBEL systems can be operated up to 24 hour per day and this low-level constant irradiance provides disinfection at low energy consumption. While germicidal effectiveness is relatively constant over the range of 220 – 275 nm, lower wavelength enables greater doses and thus, greater germicidal activity. Understanding the exposure limit across the UV range is important to enable implementation of DIBEL systems. In practicality, there will be mixed-use systems that combine both DIBEL operation and more concentrated UV doses to achieve the correct disinfection mode for the particular status of the occupied space.

Appendix A: Participant Presentations

Erik Swenson, Nichia: GUV LED Development

Erik Swenson, Vice President at Nichia America, discussed the development of UV LEDs for GUV applications. He started by comparing the performance of UVC LEDs to incumbent mercury discharge lamps. Swenson stated that UVC LEDs are catching up to the performance of UV mercury lamps in terms of effective efficiency when the power supply efficiency, light utilization efficiency, and standby time deratings are applied. Now is the time to start working on new system designs to take advantage of the unique properties of a UV LED source. Swenson described how the full application design is important to consider when selecting the best UV LED for the luminaire. While the virucidal effects of UVC irradiation (to inactivate the pathogen) are maximized at 260 nm, UV LEDs are less efficient at shorter wavelengths. Considering the optical power of 280 nm LEDs are substantially higher than at 260 nm (> 2x), the effective virucidal efficiency can be higher even though the relative virucidal effect is lower (~ 60% at 260 nm relative to 280 nm). UV LED development strategies include improving the power conversion efficiency, improving the flux density, and maintaining long lifetime. He closed by recommending the DOE encourage development of GUV LED performance just as it did with white LEDs for lighting. R&D efforts should focus on materials research so as not to sacrifice lifetime as power and efficiency levels rise.

Ling Zhou, BOLB: Ultraviolet C-band LEDs for Building Safety

Ling Zhou, Chief Executive Officer at BOLB, focused on the development of UVC LEDs for building safety. He began by discussing the benefits of GUV for building safety, which include a universal and future-proof disinfection technology without harmful chemicals or mercury (with incumbent UV lamps). GUV systems also have ability to improve smart sensor fusion for better building safety. Zhou explained that UVC LEDs would benefit from government R&D investment because of the challenging fundamental materials research still needed to improve performance. Additionally, further work is required to develop much needed standards, reduce false performance claims, and accelerate market education and adoption. He highlighted four main R&D focus areas to improve building air safety technology. 1) Improve UVC LED devices to achieve power conversion efficiency of > 15% by 2024 and > 30% by 2030, L_{70} lifetimes > 30,000 hours, and wavelengths down to 222 nm; 2) advance UVC LED modules by improving the beam shaping optical design for UV radiation, integrating sensors, and improving manufacturing processes to reduce cost. 3) Expand reference designs for biological validation and optimization of GUV effectiveness. 4) Develop best practices for building integration including best points of GUV insertion (e.g., upper room air vs. troffer vs. HVAC duct).

Carl Gibson, Sensor Electronic Technology – GUV Research Discussion

Carl Gibson, UV Technical Support and Design Manager at Sensor Electronic Technology, began by describing current UVC performance levels, with new UVC LED packages exceeding 100 mW. The commercial UVC LED performance continues to improve without sacrificing lifetime. Gibson continued by discussing solutions for indoor applications such as sterilization for water purification, sterilization inside appliances such as refrigerators and dishwashers, and spatial sterilization of indoor spaces including portable units and ceiling fixtures. He closed by highlighting another area for further research – airborne microplastics (MPs) created by GUV irradiation of polymers. MPs are of concern in the scientific community as a potential health hazard and environmental pollutant and an issue worthy of consideration when designing GUV systems. Airborne MP concentrations indoors may theoretically increase when UV systems are used, since any polymers in close proximity to a UV source will eventually degrade. Research is needed to determine acceptable MP concentration levels in air and drinking water. In addition, a better understanding of the environmental risks of widespread GUV technology adoption, including airborne MPs, should be considered.

Kevin Benner, GE Current: GUV R&D Directions

Kevin Benner, Lead Research Engineer at GE Current, discussed the efficacy and safety of whole room DIBEL, where GUV irradiation is deployed in occupied spaces as an approach to pathogen inactivation. These DIBEL GUV systems with low-level constant irradiance can be operated up to 24 hours per day and provide disinfection at low energy consumption. While germicidal effectiveness is relatively constant over the wavelength range of 220 – 275 nm, lower wavelengths enable greater doses, and thus, greater germicidal activity. Understanding the exposure limit across the UV range is important to be able to implement DIBEL systems. An optimized DIBEL system requires emitters with short wavelength, small size, long lifetime, and high power conversion efficiency. While UVC LEDs below 250 nm exist, they have low output power and short lifetimes, and require further R&D to improve performance and expand LED-based GUV opportunities. Benner also discussed how shaped optical distribution enables better irradiance uniformity. High uniformity (maximum/minimum irradiance) results in greater average fluence rate, and therefore greater germicidal efficacy at the same max irradiance. The use of non-Lambertian distribution profiles, such as bat-wing distributions, can provide greater uniformity. Small sources like UVC LEDs can be more effective in shaping the output distribution with relatively small optics. He finished by asking DOE to encourage application-level metrics that would incorporate uniformity and effectiveness in GUV applications.

Mark Hand, Acuity Brands: UV Lighting - A Fad or the Future?

Mark Hand, the Vice President of Engineering at Acuity Brands, began by discussing the variety of GUV products being launched in multiple applications (e.g. upper air GUV, occupied space and un-occupied space GUV) using multiple UV source technology (e.g. LPMV lamps, excimer lamps, and pulsed xenon lamps). He described some of the market dynamics for introducing GUV products and the complexity created by the required approvals/certifications from multiple bodies including Underwriters Laboratories, the Environmental Protection Agency, and the California Air Resource Board. Lighting designers are not used to navigating the conditions for use of GUV systems by these various approval bodies, which can vary between U.S. states. Hand then considered the research needed to advance GUV systems and their use in practice. More independent case studies are needed to develop critical application-level understanding. More research is needed in expanding UV and violet source comparisons in GUV applications, understanding building material impacts from GUV irradiation, developing full/upper room GUV and airflow fluid dynamics analysis for pathogens, harmonizing fluid dynamics modeling software with lighting software design packages, and determining if GUV products in occupied spaces can be more energy efficient than increasing ventilation loads. He concluded by recognizing that UV LEDs will require all of the criteria that are expected of LEDs in the visible light spectrum – long life, low cost, high efficiency, and accepted standards. An investment in UVC LED research is required to meet these expectations. Hand advocated for DOE to develop programs such as Lighting Facts and CALiPER (originally developed for SSL products) for use with GUV products to help prevent unregulated market conditions

Cameron Miller, National Institute of Standards and Technology: GUV Discussion

Cameron Miller, the Optical Radiation Group Leader at NIST (Sensor Science Division), covered some of the GUV related activities underway at NIST. First, Miller highlighted the UV-related standards activities including on developing ANSI/IES LM-92 - Approved Method for Electrical and Ultraviolet Measurement of Light Emitting Diodes (LEDs). Other standards are being developed for the electrical and UV measurement of different UV source types and the calibration and characterization of UVC detectors. NIST continues to see a lot of variability in UV sensor and detector performance. Users need to be careful on the geometry of the detector setup relative to how they are calibrated, since this type of discrepancy in use-orientation can lead to large errors with incorrect geometry. NIST is also improving their UV measurement accuracies with scale realization down to 200 nm at less than 1% error, and now has the capability to calibrate LEDs for radiant intensity distribution (and radiant flux) from 200 to 1700 nm. Miller then discussed how these UV devices will be labeled with general specifications such as nominal Watts, UV Watts, current draw, emission spectrum, ozone production, and mercury content. The challenge will be addressing products advertising 99.9% effectiveness. Studies validating the inactivation of pathogens by GUV should be measured under a standard condition and then translated to real-life application conditions. It is crucial to consider the pathogens in their surrounding proteins, lipids, or liquids, since this impacts the required inactivation dose at different UV wavelengths. Moreover, the room environment and materials (e.g. Formica, vinyl, cloth, plastic) will also play a role in the effective dose for the application.

Lynn Davis, RTI International: GUV Technologies - LEDs to Systems

Lynn Davis, Fellow at RTI International, addressed UVB and UVC LED challenges both in the optical and electrical performance of the devices. Poor electrical behavior of the LED device can be attributed to high dislocation density (leading to poor epitaxial layer quality), series resistance in contacts and semiconductor layers, and thermal management. Optical performance deficiencies in current devices are ascribed to poor radiation extraction from the chip and package, low transparency p-contact layers, and low contact reflectivity. Davis discussed a study his team performed benchmarking UV LEDs. A test matrix of 13 UV LED product types was tested across the UVA, UVB, and UVC bands. The study found that similar ceramic style packages are used for both mid-power and high-power UV sources. Most UV packages have a flat lens bonded to top of the package. UVB and UVC sources tend to be flip chipped, whereas UVA sources tend to be in wire bonded configurations. The threshold voltage level of a UVA LED is similar to its bandgap voltage (as seen in blue and white LEDs), although for UVB and UVC sources, the threshold voltage varies from 0.18 V to 1.5 V above band gap. The serial resistance was comparable for UVA and white LED products but varied from 2-50 ohms for UVB and UVC products. He concluded by mentioning considerations for GUV systems used for air cleaning and pathogen deactivation. Effective GUV technology must be complementary to building ventilation control and other mitigation methods. Increasing either ventilation rates and/or using GUV technology increases building energy use, but this extra energy must be used effectively. Treatment at the source is more effective than whole building treatment.

Gabe Arnold, Pacific Northwest National Laboratory: Proposed PNNL GUV/UVGI R&D Program

Gabe Arnold, Senior Engineer at Pacific Northwest National Laboratory, spoke about the challenges of implementing GUV systems for disinfection. These challenges include the lack of standardized test procedures, little understanding of how to evaluate or compare products, little industry accountability, false performance claims, and safety risks, all of which can lead to end-user disappointment, injuries, and slowed adoption. Arnold then discussed how the DOE can help with these challenges. Earlier DOE Solid-State Lighting Program efforts aimed at developing white lighting products can address some of these barriers for GUV systems. For example, the CALiPER testing program can be updated to independently test and evaluate existing GUV products and report the performance. CALiPER test reports, which validate product performance claims, are an effective tool in addressing inaccurate performance claims, calling attention to low performing products, and educating stakeholders on how products should be tested and evaluated. Another program that can be leveraged is Gateway Demonstrations, which evaluates new technology and products installed in the field. Arnold concluded by highlighting opportunities for DOE to play an important role in education and stakeholder engagement. Developing factsheets and publishing technical reports can better inform industry of GUV performance status and allow stakeholders to better understand GUV technology. These activities could also inform and support standards development. PNNL is in the early stages of revamping these DOE Solid-State Lighting efforts for GUV systems, starting with a technical report that will characterize current test methods, standards, and testing capabilities.

Ed Nardell, Harvard University: UV Air Disinfection – R&D Priorities

Ed Nardell, Professor at the Harvard Medical School and T. H. Chan School of Public Health, discussed key barriers to GUV acceptance and rollout for air disinfection. GUV has been used since the late 1980s in the U.S. to treat airborne illnesses such as tuberculosis in homeless shelters; however, there were not a lot of GUV products on the market until the COVID-19 pandemic spurred more manufacturers to develop GUV products. Nardell identified several R&D priorities, the first of which is understanding where viral transmission is occurring – via the building ventilation circuit or in the room. A second priority is learning the GUV efficacy in real-world settings. Nardell offered various examples of the types of studies that can be carried out to determine the effectiveness of the GUV system. One approach is to perform susceptibility studies. Tuberculosis susceptibility could be a good target since it is between viruses and fungi in terms of susceptibility, which would cover the majority of human-to-human infections. It is important not to target these GUV systems to any particular pathogen (e.g., SARS-CoV-2) since we don't know what the next pandemic will be. Modeling is being used to gauge GUV efficacy, but the results are heavily dependent on assumptions and must be validated. Chamber studies have limited statistics and are hard to transfer to real life applications. Clinical trials are extremely difficult in terms of controlling exposure to test site. Controlled human-to-animal experiments have led to evidence-based guidance for GUV as a basis for dosing for tuberculosis and are being converted to SARS-CoV-2. With more of the SARS-CoV-2 transmission likely occurring in the room instead of the ventilation ducting, we are left with three potential interventions – 1) more total ventilation, which can be difficult and cause financial strain; 2) room air cleaners, which may be flow-limited in the number of air changes they can achieve; and 3) upper room or whole room GUV. A study on the impact of upper room GUV on tuberculosis transmission showed that GUV was 80% effective and added the equivalent to 24 air changes per hour into the room. Nardell and his collaborators are starting a similar controlled human-to-animal study to repeat this transmission study with SARS-CoV-2.

Paul Jensen, Independent Consulting in Airborne Infection Prevention & Control: GUV Discussion

Paul Jensen, an Independent Consultant in Airborne Infection Prevention & Control, presented on four key research and development priority areas. The first priority area is understanding the secondary effects of UV systems on surface contamination. Two referenced studies showed a reduction of healthcare associated infections or a reduction in surface samples for bacteria. Jensen highlighted the importance of optimizing pathogen inactivation both in the air and on surfaces. Most studies only sample one or the other, but both should be considered. A second key R&D topic is designing multi-purpose GUV luminaires that can inactivate bacteria, fungi, and viruses both on surfaces and in air. Effective GUV systems should handle upper room disinfection, disinfection of surfaces, and have the ability to be used in occupied spaces. Jensen's third priority research topic is better understanding the benefits and pitfalls of mutagenicity caused by UVC systems. Mutagenicity is defined as altering a pathogen's DNA so that it cannot replicate; thus, inactivating the pathogen. Mutagenicity goes through different processes for bacteria and viruses. Jensen closed with a fourth priority recommending research to understand why the market uptake of UVC systems is so poor. He believes that the messaging on the benefits and pitfalls of UVC to the decision makers or consumers can be improved.

Richard Vincent, Mount Sinai Hospital New York: GUV Research Topics

Richard Vincent, Environmental Health Research Manager at Mount Sinai School of Medicine, discussed several key research areas for GUV systems and implementation. He began by exploring how to estimate safety within the occupied spaces since there is very little monitoring information available to make estimates of time weighted averages. Occupant monitoring studies are needed to estimate the TWA occupancy of various spaces at various heights, since occupant movements in spaces determine how much potential GUV exposure is likely. Research to better understand how spaces are being occupied can help determine how much of the TLV is being reached in these various spaces. Dosimeters and artificial intelligence may help address these questions. As GUV systems enter the field, reliable methods and measurement instruments are needed to verify performance, especially since different UVC wavelengths may be in use. It is important to determine what protocols are needed for upper room application guidelines, how these protocols may vary for the different UV wavelengths, and what instruments can be used. Vincent also asserted that researchers need to understand how and to what degree, do upper room GUV systems decontaminate room surfaces. Research should answer whether LPMV, UV LED, and excimer sources are interchangeable in achieving microbial inactivation of pathogens. Additionally, the impact of airflow patterns on GUV effectiveness should be compared for UV LEDs, traditional LPMV lamps, and newer excimer sources. R&D studies to compare GUV effectiveness using different UVC source technology would help the industry understand how to mix-and-match GUV technology, and the benefits of each. Vincent wrapped up by mentioning that whole room GUV LED systems (DIBEL) present new application opportunities; though, he noted that studies should establish whether DIBEL is equivalent to upper air GUV implementation. Mixed-use systems that combine DIBEL use and more concentrated UV doses can tailor the disinfection mode to the space and occupied time.

David Sliney, Independent Consulting Medical Physicist: Research Needs for Improved Implementation of Germicidal UV

David Sliney, an Independent Consulting Medical Physicist, discussed several research topics for air disinfection. He started by communicating a need to better understand the germicidal action spectra, including in different media. There has been a standardized germicidal action spectrum peaked at 265 nm for many years based on E.coli; however, recent studies show a range of action spectra and a few aerosols more readily inactivated by far UVC. The inactivation process of viruses and other bioaerosols are not fully known and should be studied further. Sliney then addressed improving GUV risk vs. benefit calculations and analysis. Germicidal effectiveness lies largely in the UVC, whereas the significant health risk is in the UVB range. UVC (254-280 nm) has a very low dermal risk and the far UVC (~180-230 nm) has almost no dermal risk, but interaction mechanism may be different. Current GUV LEDs at 280 nm may be a worrisome dermal risk due to additional UVB radiation, so further research on this topic would better clarify the safety risks. Additionally, GUV safety research is needed for TLVs with TWA of realistic human exposure. Studies with film badges for different installations and different types of UV sources would be beneficial. Sliney closed by considering the germicidal efficacy for different UV sources with varying radiant efficacy and implications for building energy consumption. Many GUV luminaire louver designs are highly inefficient and could benefit from better fixture designs. UV LEDs could solve the problem by using narrow-angle optics to replace the high optical losses from the louvers. More research in optimizing the system design of GUV luminaires would help improve system efficiency.

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