Discussion of UV Antimicrobial Devices in Medical Facilities

Minimizing Collimated Beam Uncertainty
Because clean water is a matter of trust: Think UV. Think Heraeus.

Contact us at: hng-uv@heraeus.com
www.heraeus-noblelight.com
Features

4 UV Antimicrobial Devices Used to Combat HAIs in Medical Facilities: Is There a Need to Establish Voluntary Industry Efficacy Standards for Their Use?
by Troy E. Cowan, Vision Based Consulting, LLC

9 Minimizing Collimated Beam Uncertainty
by Shawn Verhoeven, Conrad Odegaard and Shawn Hess, GAP EnviroMicrobial Services Ltd.

Departments

2 President's Letter
2 From the Editor-in-Chief
19 Association News
21 Application Note
22 UV Industry News
24 Calendar
24 Ad Index
Winter is upon us, and there has been a lot of work on great IUVA activities since the last IUVA News. Our president-elect, Oliver Lawal, and his team organized a special UV workshop in conjunction with Confluence, one of the most successful EPA Water Cluster programs, based in Cincinnati, Ohio. The workshop, “UV Disinfection, Innovation and Operation Symposium,” was held Nov. 9 and featured speakers from the EPA, the Confluence Water Cluster, Ohio and Kentucky water districts, plus industry and academia experts with the latest on UV technology and regulatory trends. The workshop ended with a tour of the Greater Cincinnati Water Works (GCWW) Richard Miller Treatment Plant, which hosts one of the largest drinking water UV disinfection systems in the country. Thanks to all of the staff at GCWW for participating and hosting the tour.

Looking ahead, the 2017 IUVA Americas Conference will be held Feb. 5-7 in Austin, Texas. This meeting will host two special workshops, one on UV-LED technologies and one on UV-AOP. With a strong technical program, including a special session on how to use UV for preventing hospital-acquired infections, we anticipate great attendance, so book your reservation before the IUVA room block is sold out. In the EU, IUVA will hold a drinking water workshop being planned by our EMEA co-chairs in the UK in conjunction with CIWEM. These events lead up the IUVA World Congress 2017 to be held at the Valamar Hotel in Dubrovnik, Croatia, on Sept. 17-20. We look forward to a big crowd in a beautiful location where we will welcome Oliver Lawal as our next IUVA president. A call for abstracts for the 2017 World Congress will be released following the Americas Conference.

With the success of an Asia workshop held in Japan earlier this year, another Asia event is planned for Singapore on Nov. 6, 2017. These and other IUVA events continue to be opportunities for education and networking. There are always technical issues and regulatory challenges, and our organization is critically important for providing an opportunity to address issues that potentially have significant impact on the application of UV. Both the education committee and the technical committee are active in collaborations to address these issues. These kinds of activities are excellent ways for IUVA to increase its visibility, so if you are interested in volunteering a few hours to increase IUVA’s visibility in the wastewater industry, please contact Gary Cohen (gcohen@iuva.org) with your contact information, and we can look for the best opportunity to connect you with IUVA.

We are excited about 2017 being another great year of UV with events across the globe that support a meaningful, scientific approach to providing UV solutions. So, get out your boots and cowboy hats, and I’ll look forward to seeing y’all in Austin, Texas, in February!

Happy holidays to all, and please remember to thank our support staff, in particular Jim Bolton, Gary Cohen, Mickey Fortune and James Kerich, who help IUVA deliver some really terrific benefits to our members.

Kati Bell, IUVA president
Water Reuse Practice Leader at MWH Global

This IUVA News issue features two excellent articles – one on UV air treatment and another on collimated beam testing. Additionally, there is an Application Note from one of our corporate members.

The IUVA News Editorial Board has approved expanding the coverage of IUVA News by allowing free access, for utilities and university and institute libraries, to the IUVA News website at www.iuvanews.com, where present and past issues, as well as individual articles, can be viewed and/or downloaded. Please help us get the word out if you know of a suitable contact.

IUVA News is your quarterly ultraviolet magazine, so please take some time to read it through, and don’t forget the ads. The ads make it possible to publish IUVA News, so please support our advertisers by clicking through to their web sites or contacting them for further information. If you are a marketing manager in a UV company, I encourage you to advertise in IUVA News. You will not only attract direct sales but also enhance your image in the UV community. Send me an email at editorinchief@iuva.org, and I’ll send you the IUVA News Media Kit. Also note that IUVA News publishes short Application Notes highlighting novel and ground-breaking applications of a UV company’s technology.

Finally, I wish you all a very Happy New Year for 2017!

Jim Bolton, IUVA News editor-in-chief
Intelligent Lamp Drivers for Medium Pressure Lamps 1 - 36kW. Highly recommended for UV ballast water systems.

Many options, one leading concept.

UVuerte

Nedap Inc. | 14A Industrial Way | Atkinson, NH 03811 | USA
T +1 603.458.2089  |  F +1 603.458.5652  | info@nedap-uv.com  | www.nedap-uv.com

UV Photodiodes and UV-LEDs

High reliability, high performance, and affordable UV SiC sensors, from sglux; and Deep UV-LEDs from Nikkiso. Boston Electronics is your single source for these superior UV devices.

www.boselec.com  uv16@boselec.com

American Air & Water®

UVC SYSTEMS FOR A HEALTHIER INDOOR ENVIRONMENT

American Air & Water®, Inc.
Your Solution Provider for all Air, Surface & Water Disinfection Needs

www.americanairandwater.com

Toll Free: 888-378-4892  * Fax: 843-785-2064

High reliability, high performance, and affordable UV SiC sensors, from sglux; and Deep UV-LEDs from Nikkiso. Boston Electronics is your single source for these superior UV devices.

www.boselec.com  uv16@boselec.com

UV Photodiodes and UV-LEDs

High reliability, high performance, and affordable UV SiC sensors, from sglux; and Deep UV-LEDs from Nikkiso. Boston Electronics is your single source for these superior UV devices.

www.boselec.com  uv16@boselec.com

UV Photodiodes and UV-LEDs

High reliability, high performance, and affordable UV SiC sensors, from sglux; and Deep UV-LEDs from Nikkiso. Boston Electronics is your single source for these superior UV devices.

www.boselec.com  uv16@boselec.com

UV Photodiodes and UV-LEDs

High reliability, high performance, and affordable UV SiC sensors, from sglux; and Deep UV-LEDs from Nikkiso. Boston Electronics is your single source for these superior UV devices.

www.boselec.com  uv16@boselec.com
UV Antimicrobial Devices Used to Combat HAIs in Medical Facilities: Is There a Need to Establish Voluntary Industry Efficacy Standards for Their Use?

Troy E. Cowan
Vision Based Consulting, LLC, Lexington Park, MD
Contact: Troy E. Cowan (troy@visionbasedconsulting.us)

Introduction
It is well documented and highly publicized that health care-associated infections (HAIs) are a serious, preventable health problem (Cowan 2016). In its session on June 26, 2014, the US House of Representatives Subcommittee on Research and Technology found that HAIs are the most common complication of hospital care. Estimates from the Centers for Disease Control and Prevention (CDC) indicate that HAIs cause or contribute to upwards of 99,000 deaths annually in the US.

The CDC has stated recently that one in every 25 hospital patients will be treated for an HAI. Of all the HAIs that are caused by pathogens, the two that are hardest to treat are *Clostridium difficile* (*C. diff*), which causes nearly 14,000 deaths per year, and methicillin-resistant *Staphylococcus aureus* (MRSA), which causes more than 11,000 deaths per year (White House 2014).

Infectious disease research demonstrates that HAIs can be reduced by incorporating antimicrobial ultraviolet (UV) devices into cleaning protocols; however, the health care community has been slow to adopt their application. Failure to embrace the technology may well be caused by the uncertainties about the efficacy of the devices vs. the cost to acquire and implement, requiring additional research and motivation to overcome the resulting inertia. The intent of this article is to stimulate dialogue on ways the UV industry can help overcome that inertia.

**UV treatment is an effective way to combat HAIs**
For more than a century, UV light in the shorter wavelengths (e.g., 200-290 nm, or the UV-C band) has been known to inactivate pathogens’ DNA, preventing the pathogens from multiplying without harmful side effects. UV-C devices were well used in the health care industry of the 1940s and 1950s, typically to control tuberculosis. Over time, costs for sustaining the equipment safely when compared to advances in tubercular medications ultimately led to a decline in the popularity of UV technology.

In the 50 years that followed the advent of multiple drug resistant organisms (MDROs) and their evolving antibiotic immu-
nities, UV-C’s known capability to inactivate such pathogens, including those causing HAIs, has become increasingly important, especially as MDROs neither build up a tolerance to UV-C effects nor develop mutations with UV-C resistance (Jinadatha et al. 2014). The source of UV-C light (mercury, xenon, LEDs, etc.) is not as important, as long as the appropriate UV-C wavelength light is delivered in the correct antimicrobial dose, defined in terms of the UV-C device’s power, time of exposure and distance from the target, specific to each pathogen of interest (Bolton and Cotton 2008).

While resources identifying the required UV doses for inactivating various pathogens can be found in numerous publications and studies, no one scientific standard exists.

**UV antimicrobial technologies and devices are multiplying rapidly**

A typical internet search can readily find more than 40 manufacturers of “UV sterilizers” of all types (air, water and surface), to include as many as 17 makers of UV antimicrobial devices, intended for surface disinfection primarily in health care facilities, each with its own advantages and disadvantages. What can be discovered is interesting:

- Most used “traditional” low-pressure mercury lamp light sources that continuously emit UV-C primarily at 253.7 nm.
- At least two manufacturers utilize newer technology xenon lamps, which emit broad spectrum light (including UV-C) in short, intense pulses.
- Several firms use light emitting diodes (LEDs) to create very small UV-C devices, enabling increased design flexibility in their application, albeit at a lower power. LEDs can be “tuned” to emit UV wavelengths other than 254 nm by varying the materials used in their manufacture, enabling even more application options.

In part, thanks to the spectral diversity found in the newer UV sources, there has been an increased interest in finding additional wavelengths of interest — from vacuum-UV (100-200 nm) to violet-blue light (>400 nm) that may produce antimicrobial benefits.

- Vacuum-UV (a.k.a., Far-UV) used in portable, handheld devices have led to claims of achieving 99.9% disinfection rates in a matter of seconds, rather than minutes. This is attributed to the more energetic radiation in the shorter wavelengths and the reduced distance to the target (~10 cm). In some cases, these devices require additional user-safety precautions (e.g., protective eyewear) due to exposure of the operator to direct UV emissions during operation (Nerandzic et al. 2012).
- Violet-blue light at 405 nm was used in a high-intensity, narrow-spectrum light environmental disinfection system (HINS-light EDS), tested as an alternative to UV-C in disinfecting rooms (both air and surfaces). The main advantage was – if proven effective – this wavelength would have minimal harmful effects to people, enabling its use 24/7 in occupied areas (Maclean et al. 2014).

**Current UV antimicrobial device standards are many, but none cover “efficacy”**

**Existing federal protections**

Due to jurisdictional and statutory responsibilities, a number of governmental agencies are addressing the use of microbial UV radiation within the boundaries of their chartered and/or regulatory purvey. These are primarily found in the Environmental Protection Agency (EPA) and the Department of Health and Human Services (HHS), with each having multiple, sometimes overlapping roles in multiple offices.

Within the EPA there are three offices with primary responsibility for UV applications — Office of Resource Conservation and Recovery (ORCR), within the Office of Land and Emergency Management; the Office of Water (OW), and the Office of Pesticide Programs (OPP), within the Office of Chemical Safety and Pollution Prevention. Each has developed guidance or rules generally based on media and the legislation covering that media. For treating solid wastes and any hazardous materials or waste media covered by RCRA/CERCLA, ORCR governs the approved use of UV radiation in guidance for cleaning up chemical and biological materials. EPA’s OW, acting under the Clean Water Act, has developed UV radiation guidance and methods for sanitizing wastewater and drinking water.

Perhaps more significantly for addressing HAIs, EPA’s OPP works on UV radiation as an antimicrobial pesticide under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). It also has created and oversees the guidance for cleanup and sanitization of indoor spaces, such as hospitals and clinics using "The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) Section 7 requires that production of pesticides, active ingredients or devices be conducted in a registered pesticide-producing or device-producing establishment. (‘Production’ includes formulation, packaging, repackaging, labeling and relabeling.) Production in an unregistered establishment is a violation of the law.” (EPA 2016)
antimicrobial biocides and pesticides, and oversees the registration of antimicrobial devices and factories producing those devices.

In this regard, uniform standardization for UV-C’s for disinfection is an admitted responsibility of the EPA, and moreover, one that the EPA Office of Inspector General (OIG) has noticed and a corrective action promised in the form of uniform standards for hospital level disinfection. In the EPA Inspector General’s Office issued Report No. 11-P-0029, it was recommended that EPA redesign “…its process to verify antimicrobial effectiveness.” (EPA 2010) After the administrator signed off on the Final OIG Report and its funded Corrective Action Plan, it would seem that OPP would have been empowered to establish efficacy standards for UV-C antimicrobial devices; unfortunately, the EPA would in hindsight appear to have been unaware of the UV-C impacts on antimicrobials and this has not been done.

So, in response to the administrator’s Corrective Action Plan, EPA concentrated on creating efficacy standards for chemicals used in antimicrobial disinfection. Today there is a broad range of disinfection products from metals (copper protocols) to chemicals and unregistered but yet otherwise FIFRA-compliant UV-C devices. As it turns out few UV devices have registered their manufacturing facilities compliant with FIFRA regulations. Fewer still have actually been officially determined to be antimicrobial devices.

HHS has several groups that have roles and responsibilities. The Food and Drug Administration (FDA) reviews all devices used in medical treatment and alternative food processing technologies using UV radiation to disinfect. HHS’ CDC has responsibility for monitoring bacteriological and viral vectors and their impact on human populations and have been conducting studies to discover applied solutions to stop epidemic outbreaks. Within CDC, the National Institute for Occupational Safety and Health (NIOSH) is concerned with workplace and worker safety and has developed guidance and standards for UV radiation, including exposure limits for humans.

This overlaps with other FDA requirements under Federal Food, Drug and Cosmetic Act (Chapter 5, Subchapter C: Electronic Product Radiation Control), where the FDA’s Center for Devices and Radiological Health (CDRH) is responsible for regulating radiation-emitting electronic products to protect the public from hazardous and unnecessary exposure to radiation (FDA 2016).

What is the government doing?
Jurisdictionally for HAIs, there is the potential for substantial overlap between the use of UV-C’s for disinfection (EPA) and those that actually are used on patients during a medical procedure (FDA). Several governmental and nongovernmental organizations have worked on or around these issues. Typically, the efforts are incremental, and the outcome is that there are no uniform efficacy standards.

Figure 2. Electromagnetic spectrum
The Antimicrobials Division of EPA’s OPP is the statutory responsible party for FIFRA compliance. As it relates to antimicrobials, they have established efficacy standards for chemical disinfectants, which require the antimicrobial chemical industry to list the recommended treatment protocols and the efficacy expected by individual pathogen claimed to be covered, backed up by third-party laboratory tests. No similar rules exist governing the efficacy of UV antimicrobial devices, either generically or by pathogen.

Professional societies, industry associations and other NGOs
Several nongovernmental organizations (NGOs) and professional societies have conducted research, testing of devices and protocols, and voluntarily developed industry-accepted guidance and standards for UV radiation on some media types like air and water. UL/ANSI (Underwriters Laboratory/American National Standards Institute) has addressed waterborne bacteria and viruses by developing minimum requirements for water media and UV radiation exposures to control bacteria and viruses. ASHRAE has developed design and building standards that includes an entire chapter in its handbook on UV air and surface treatment. Voluntary industry standards often are incorporated into government regulations (e.g., building codes) and used to further provide scientific and engineering substance to regulations by reference.

To date, this standard setting has not been done in the UV community, as evidenced by lack of industry-wide consensus on product credibility. This is demonstrated by recent Federal Trade Commission (FTC) rulings against two start-up UV companies for making efficacy claims without any scientific justification (FTC 2015). Another example of the lack of defined industry norms of efficacy and performance is found in the multiple court suits between vendors (Becker’s Hospital Review 2015), where both sides successfully argued the other’s advertising was misleading in its comparisons against the competitor.

Consumers’ dilemma
The use of UV-C devices in disinfection protocols to reduce infectious pathogens is increasing. Airliners soon may have bathrooms with UV-C LED strips to reduce pathogens while in flight. Hospital beds are being designed with built-in UV-C lighting to reduce pathogens between room cleanings. Surgical suites, infectious disease wards, hallways and cafeterias and health care facility bathrooms are being modified to adapt UV devices into their mammoth facility air returns to control airborne pathogens. All could be rapidly implemented, given a consistent set of standards for UV pathogen reduction, to save billions of dollars and save countless lives. Consumers of any new technology are always concerned about how to ensure they get devices that work as advertised, and that they’re getting the right technology and device to fit their requirements. Absent a credible industry standard, what can consumers use to make safe, prudent decisions?

Efficacy is multidimensional
In the attempt of any group to address efficacy, there is the hope that a variety of conditions and applications can be covered with one broad stroke of a pen. But there are obviously many dimensions to be addressed, from the choice of target pathogens, to the choice of testing environments and protocols. With little uniformity, it is difficult to compare units and select the best fit for applications which run the gamut from hospital rooms, clinics, elder care facilities to ambulances and medivacs.

This appears to be a daunting task. Likely the “let the government do it” approach will not see the allocation of resources or time for such an effort even though the need is compelling. Nor will industry be able to impact the outcome.

What can industry do?
Causal observation of what government has done over the years confirms that the process is time-consuming, incremental and likely expensive. One wishes to make the process simpler and more focused. This is particularly true with the urgency of the issue, and truly, with lives hanging in the balance awaiting the creation of standards for efficacy and the testing of UV-C devices.
One approach that has been successful in a variety of situations is for industry and professional societies to develop guidance and standards and establish a certification process using those standards. Industry standardization can be completed in a timely manner, especially compared to government-driven efforts. The industrial certification approach delivers a consensus result. Through leadership by industry and professional societies, respected and knowledgeable colleagues can craft guidance, protocols, testing and standards. The professional societies (IUVA, UL/ANSI, IEEE, AAMI, et al.) can contribute knowledge and research, and supply peer review to the development and acceptance of the guidance and standards.

The resulting guidance and standards can be nested with government needs. Government through reference can incorporate guidance and standards.

Conclusion
Given that governmental efforts are present but limited and incremental, it remains to industry and health care professionals and professional societies to approach and address HAIs through UV radiation treatment guidance and efficacy standards. A consensus approach can be successful, timely, cost-efficient and generate results with known statistical efficiency and known costs of implementation and operation.

Efficacy standards need to bypass the system’s intrinsic inertia and implement through the industry’s leadership and good works of our professional societies.

What are you willing to do?

References
Becker’s Hospital Review. 2015. Xenex gets temporary restraining order against rival UV disinfection company Tru-D, Becker’s Infection Control & Clinical Quality, Oct. 6.
Minimizing Collimated Beam Uncertainty

Shawn Verhoeven, Conrad Odegaard and Shawn Hess, GAP EnviroMicrobial Services Ltd.
1020 Hargrieve Rd., Unit 14, London, ON, Canada

Abstract
Collimated beam-generated standard curves are an important step in determining the fluence applied by an ultraviolet (UV) disinfection system whereby a bioassay-measured microbe log inactivation is translated to a reduction equivalent UV fluence (RED). This RED then is used to properly size a system to meet disinfection requirements for a target pathogen or pathogen of interest at an installation site. Proper calculation of this fluence (UV dose) when performing a collimated beam test is thus extremely important for making decisions on UV reactor sizing; wherein there lies a problem. Without proper quality control, each of the factors used in the collimated beam fluence calculation equation introduces error. Minimizing the error in each of these factors is thus pivotal to producing an accurate fluence response curve for proper UV system sizing. Additionally, there are three equations for the calculation of collimated beam fluence that exist in North American guidance. This adds to the confusion as to how to properly perform a collimated beam test.

Keywords: Collimated beam, petri factor, UVDGM, NWRI, NSF, reflection, fluence, UV dose

Introduction
Regulations around the world require UV system manufacturers to validate the performance of their UV reactors. Various guidance manuals and validation protocols exist from groups including in the US Environmental Protection Agency with their Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule (UVDGM), the German Technical and Scientific Association for Gas and Water (DVGW), the National Water Research Institute’s (NWRI) Ultraviolet Disinfection Guidelines and the NSF International Standard/American National Standard for Drinking Water Treatment Units – Ultraviolet microbiological water treatment systems (NSF 55). All of these documents outline protocols for the validation of drinking water systems; some also cover water reuse and wastewater systems. These protocols use the [log] inactivation of non-pathogenic surrogate microorganism(s), measured under a defined set of conditions, to characterize the system performance. Alone, this log inactivation does not provide a great deal of information regarding performance, as these surrogates generally do not display identical UV sensitivity to the pathogens targeted in a particular installation. In order to relate the performance of the UV system to inactivation of a target pathogen, the measured log inactivation of the surrogate microorganism is converted to a fluence, or UV dose, by “back calculating” using a collimated beam generated fluence response standard curve to give a reduction equivalent fluence (RED). The collimated beam procedure is thus an intimately important process in properly validating a UV system.

A collimated beam apparatus, more accurately called a quasi-collimated beam apparatus, typically contains one or more low-pressure mercury lamps mounted horizontally within an enclosure. The bottom side of the enclosure has a circular opening, or aperture, that allows UV light to be transmitted to a suspension of microbes located below the opening. The angle of incidence of the UV light on the suspension of microbes is minimized using a series of apertures or collimating tube located below the lamps. Examples of both of these configurations can be found in the paper titled “Standardization of Methods for Fluence (UV Dose) Determination in Bench-Scale UV Experiments” (Bolton et al. 2003). The fluence delivered to the suspension is calculated using an equation that takes into account a number of measurable factors, including the incident irradiance, uniformity of the irradiance field, the ultraviolet transmittance of the sample, reflection off the sample surface and divergence of the beam upon entering the sample.

The protocol or guidance chosen for validating a UV reactor will impact the equation that is selected for calculating UV fluence in the collimated beam test. All fluence calculations are based on the Beer-Lambert Law, where the fluence is defined as the average irradiance through a water layer multiplied by the exposure time in seconds.

The protocol or guidance chosen for validating a UV reactor will impact the equation that is selected for calculating UV fluence in the collimated beam test. All fluence calculations are based on the Beer-Lambert Law, where the fluence is defined as the average irradiance through a water layer multiplied by the exposure time in seconds.
the exposure time in seconds. This takes into account the incident irradiance, the UV transmittance of the water sample and the exposure time, with each protocol implementing the definition in different ways. The implementation of this definition can be found in equations [1], [2] and [3] below.

\[ D = I_0 \times P_f \times (1 - R) \times \frac{L}{d + L} \times \frac{1 - 10^{-ad}}{Ad \ln(10)} \times t \]  

**UVDMG [1]**

\[ D = 0.98 \times \left[ \frac{I_0}{d} \times \frac{(1 - A)^d}{\ln(1 - A)} \right] \times t \]  

**NSF 55 [2]**

\[ D = (1 - R) \times I_0 \times \left[ \frac{(1 - e^{-kd})}{kd} \right] \times t \]  

**NWRI [3]**

In the UVDGM approach outlined in equation [1], D is the fluence (or UV dose), \( I_0 \) is the incident irradiance (in mW/cm²) as measured using a radiometer at a location corresponding to the center of the surface of the sample, \( P_f \) is termed the Petri factor and defined as the ratio of the irradiance measured at the center of the sample surface to the average irradiance measured across the sample surface, \( (1 - R) \) is termed the reflection factor where R is the reflection coefficient of UV light at 253.7 nm at the air-surface interface (typically \( R = 0.025 \)), \( L/(d + L) \) is termed the divergence factor where L is the distance from the lamp centerline to the sample surface and d is the sample depth, and \( (1 - 10^{-ad})/(ad \ln(10)) \) is termed the absorbance factor where a is the UV absorption coefficient (absorbance in 1 cm) of the suspension at 253.7 nm. Time is represented by t in seconds (UVDGM 2006).

The NSF implementation in Equation [2] uses some of the same factors as in Equation [1] but assumes the reflection is only 2% (resulting in a 0.98 factor) and does not take into account a divergence factor or petri factor. The NWRI implementation in Equation [3], similar to Equation [2], also does not take into account the divergence or petri factors, and uses an absorbance coefficient \( k \), which is equivalent to 2.3a (NWRI 2012); but through the rearrangement of the equation, there is a high level of similarity to the UVDGM equation [1].

Inherent in the number of factors taken into account in these three fluence calculations lies the possibility that a large amount of error can be introduced with imprecise or incorrect measurement of one, or a number of the factors. The UVDGM outlines the suggested levels of uncertainty for all factors used in Equation [1], but there is opportunity to reduce the uncertainty and increase measurement accuracy even further than is suggested in this guideline. Other sources of error also exist that are not factored into any of these equations that may lead to miscalculation of the UV fluence. These factors include reflected light off the reaction vessel walls to increase the incident light at the periphery. A parallax effect also may be introduced when trying to match the height of a sample surface to the calibration plane of a radiometer. It is not necessary to include these factors in the fluence calculation but rather, every effort should be made to eliminate them altogether such that they have no impact on the calculation.

**Which fluence calculation to use?**

All collimated beam fluence calculations are based on the Beer-Lambert Law, but unfortunately the equations apply this in a few different ways. Although all of the equations outlined in [1], [2] and [3] appear to differ greatly, if the correction factors are removed, Equation [1] and [3] do provide very similar results, with Equation [2] also providing similar results in many instances. If conditions are selected to nearly eliminate the effect of the petri and divergence factors, we can see exactly how similar the equations truly are. If one assumes a thin film (1 mm) irradiation with a perfectly uniform irradiance field (petri factor equals 1), in nearly transparent water (99% transmittance at 253.7 nm), the NSF Equation [2] calculates a fluence 0.5% higher and the NWRI Equation [3] calculates an fluence less than 0.1% higher than the UVDGM Equation [1]. At first glance any one of these iterations of the fluence calculation in a collimated beam setup seems like it would be acceptable, but this assumption deteriorates once more commonly encountered factors are applied to the equations. Table 1 below outlines a few results using a typical petri factor found at GAP of 0.99, a sample depth of 0.5 cm, a distance of 45 cm from the lamp centerline to the sample surface, and an incident irradiance of 150 \( \mu \)W/cm².

From these numbers it becomes evident that the UVDGM equation is always providing a lower fluence when using the equivalent factors among the equations; this is to say that the UVDGM equation is the most conservative when it comes to calculating the fluence provided by a UV reactor. If the divergence factor and petri factor are added to the NWRI calcula-
tion, the resulting fluence is corrected by 0.979, completely eliminating the 2.1% fluence increase seen in Table 1.

For the NSF calculation there isn’t a single factor or set of factors that can be isolated as the reason for the higher calculated fluence we are observing. This is not necessarily an issue though, as the NSF protocol is looking at a defined set of conditions that are identical for all units being certified using this procedure. As a result of these conditions being static for all reactors, the exact form of the equation becomes somewhat irrelevant, as we are simply comparing all reactors to the same pass/fail criteria. With this being said, it would not be appropriate to use this equation for a fluence calculation outside of the NSF protocol, including making decisions on reactor sizing or in a regulatory situation to determine the sensitivity of a pathogen.

Table 1. The fluence calculated using an incident irradiance of 150 μW/cm², a petri factor of 0.99, a sample depth of 0.5 cm and a distance of 45 cm from lamp centerline to sample surface. With UVT varied and a time selected (to the nearest second) to achieve a fluence as close as possible to 20 mJ/cm² using the UVDGM equation. Numbers in parentheses are the percent increase of the NSF or NWRI fluence as compared to the UVDGM fluence calculation.

<table>
<thead>
<tr>
<th>UVT (%/cm)</th>
<th>Time (sec)</th>
<th>UVDGM</th>
<th>NSF (% incr.)</th>
<th>NWRI (% incr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99.9</td>
<td>140</td>
<td>20.04</td>
<td>20.58 (2.7%)</td>
<td>20.47 (2.1%)</td>
</tr>
<tr>
<td>90</td>
<td>143</td>
<td>19.95</td>
<td>20.78 (4.2%)</td>
<td>20.37 (2.1%)</td>
</tr>
<tr>
<td>80</td>
<td>148</td>
<td>20.05</td>
<td>21.21 (5.8%)</td>
<td>20.5 (2.1%)</td>
</tr>
<tr>
<td>70</td>
<td>152</td>
<td>19.94</td>
<td>21.43 (7.5%)</td>
<td>20.36 (2.1%)</td>
</tr>
</tbody>
</table>

Although each of the three fluence calculations used in North American UV validations provide unique results, this does not mean that one is best for all situations. They all have their applications in their given protocols, with the UVDGM calculation providing the most conservative fluence due to the number of correction factors employed. One recommendation is to use the NWRI and NSF calculation only where these standards are stipulated and to use the UVDGM calculation in all other instances. This approach is suggested because of the conservative nature of the fluence calculation presented by the UVDGM, there is an inherent conservatism (or a safety factor) when designing and sizing UV reactors using this equation to err on the side of public safety. The UVDGM fluence calculation also recently has been endorsed by the IUVA Board of Directors as part of the “Protocol for the determination of fluence (UV Dose) using a low-pressure or low-pressure, high-output UV lamp in bench-scale collimated beam ultraviolet experiments” (Bolton et al., 2015a).

Unrelated to the equation chosen to calculate fluence, it is incredibly important to properly implement the equation. If the factors entered into the equation are incorrect, then it does not matter which equation has been selected – an incorrect fluence is still being calculated. Each factor has a level of uncertainty associated with it, and care must be taken to ensure that this uncertainty is minimized. The UVDGM outlines what level of uncertainty is expected for each factor used in Equation [1] and Bolton et al. (2015a) have provided a step-by-step protocol in an effort to limit uncertainty; however, in many instances it is possible to reduce uncertainty below suggested levels. Steps have been outlined in the following sections as a guideline to improve accuracy and uncertainty.

Radiometers
The incident irradiance as measured by a radiometer is the single greatest source of uncertainty in the collimated beam fluence calculation. The UVDGM suggests that the error associated with the “Average incident irradiance” (I₀) in the fluence calculation in Equation [1] be less than or equal to 8%. As long as a radiometer is calibrated by the manufacturer it should be received with a transfer uncertainty of 6.5% and a NIST uncertainty of 1% for a combined uncertainty of 6.58%. This is well within the recommended 8% (UVDGM 2006), but any error introduced here translates one to one as error in the final fluence calculation. The UVDGM does go on to suggest that the radiometer used for measuring the incident irradiance should be verified using a second radiometer at least at the beginning and end of the collimated beam test, with a third radiometer used under certain circumstances (UVDGM 2006). What is not specified, but should be assumed, is that all of these radiometers are to be calibrated against a NIST standard within the past 12 months (Bolton et al. 2015a). Using this comparison, the radiometers are to read within 5% of one another, otherwise it is suggested that at least one radiometer is out of calibration. The main issue with this statement is that having two radiometers that read more than 5% different does not necessarily mean that one is out of calibration, but what is likely meant by this statement is that one radiometer is reading less accurately.

When the radiometers are compared using the method outlined in the UVDGM, there is no definitive way to determine which radiometer is reading most accurately, but there are some procedures that can be implemented to improve the
confidence in the incident irradiance reading, including use of three calibrated radiometers at all times. As long as the difference from the highest reading radiometer to the lowest reading radiometer is less than 5%, then a correction factor should be calculated to adjust the incident irradiance reading used in the fluence calculation to the average reading of all three radiometers. If the highest to lowest reading radiometers do not agree within 5%, then the UVDGM (2006) outlines how to select the radiometers to use to obtain the correction factor which will provide the most conservative result.

Although using the average radiometer reading does help improve confidence in the accuracy of the irradiance readings, simply using this procedure blindly will not provide the best estimate of the true incident irradiance. If all radiometers are from the same manufacturer, calibrated by the same source, at the same time and under the same conditions there may be bias. To ensure random error, it is suggested that a selection of radiometers from different manufacturers, calibrated by different parties at different times throughout the year be used to minimize any potential bias. It is also critical that the calibrations are current, with an interval of one year at maximum.

A second way that the radiometer readings can be verified is by using chemical actinometry. A simple method for performing this check is outlined in a paper titled *Determination of the Quantum Yields of the Potassium Ferrioxalate and Potassium Iodide-Iodate Actinometers and a Method for the Calibration of Radiometer Detectors* (Bolton et al. 2011). This method determines a correction factor that can be applied to the radiometer to obtain the true incident irradiance on a sample. This method does require special care to be taken, including tight user control of measurements using calibrated instruments, such as a caliper, balance and thermometer, and the use of new reagents. It has been the experience of GAP that use of reagents that have been allowed to sit for an extended period of time does influence the initial $A_{350}$ and $A_{390}$ measurements. This in turn appears to have an effect on the final calculated correction factor, unrelated to the photochemistry of the actinometer. Uncertainty is still associated with this procedure due to calibrated instrumentation being used, and it would need to be taken into account in the final collimated beam uncertainty calculation. The advantage of this method is that it does not require expensive annual calibration of radiometers, but it does pose a problem when attempting to calibrate a radiometer over a range of wavelengths, since the quantum yield is wavelength-dependent.

Another concept that has recently been suggested by Li et al. (2011) is the use of a micro fluorescent silica detector to replace the radiometer entirely in the collimated beam procedure. Calibration of this instrument would be achieved using chemical actinometry, as noted above, but an advantage is that continuous measurement of the incident irradiance would be possible. This would allow for more accurate measurement of the fluence applied to the sample over the entire exposure time without the assumption of the linear response currently used where the average of the pre and post exposure radiometer readings are taken and used in the fluence calculation. This technology is still in development and more time is required before it can be fully implemented in collimated beam procedures. This will include comparison to current methods, and round robin testing.

Irrelevant of the way in which accuracy of the radiometers is verified, it is clear the measurement of the incident irradiance is integral in the calculation of fluence. If an error of 5% is introduced at this step, then this directly translates to an error of 5% in the calculated fluence. If only a single factor should be more closely monitored and controlled during in the collimated beam, this should be the target for improvement.
Petri factor

The petri factor is another collimated beam correction factor that shows a one to one correlation in affecting the final calculated fluence. Fortunately, the chances of seeing a high magnitude of error in the petri factor are small compared to the incident irradiance measurement using a radiometer. To calculate the petri factor, repeated measurements are made on two perpendicular axes with these measurements used to estimate the intensity across the entire suspension surface. This assumption has been confirmed to be correct by measurement of the petri factor in this “X-Y” manner in comparison to radiometer measurements taken in a grid format over the entire petri dish area. Although the error here may be minimal, there is still opportunity to reduce any error that may exist. The UVDGM states that the error for this factor should be less than 5% (UVDGM 2006). At GAP we have calculated the error in our setup to be 1% using repeated calculations of the petri factor over time using the same L measurement (Equation [1]) and petri dish diameter. There are factors not accounted for using this method of error calculation though, and all portions of the calculation are looked at individually.

The two most obvious sources of error would be to ensure the spacing of measurements on the axes be accurate; this can be accomplished using a calibrated ruler. Secondly, it is important to ensure that the axes are perpendicular. This can be accomplished using the 3, 4, 5 technique commonly used in construction and based on the Pythagorean theorem, where the square of the side measurements of a right triangle equal the square of the hypotenuse. Again, the calibrated ruler would be important for this calculation.

Another way to minimize error in the petri factor calculation is to reduce the viewing window of the radiometer detector using a mask if the viewing window is greater than the distance between axes measurements, typically 5 mm (Bolton et al. 2003). This will reduce the magnitude of the readings measured by the radiometer, but this not a concern, as the petri factor compares readings relative to the origin, not absolute readings. This does not significantly impact the petri factor calculation if the irradiance field is relatively uniform without much decrease in irradiance at the edges of the petri dish. This would become an important step for a non-uniform irradiance field and when there is a significant drop in the irradiance when approaching the edge of the petri dish.

The largest opportunity for introducing error with this factor is in the forecasting of the irradiance filed based on measurements on the X and Y axis. A theoretical irradiance field is calculated to encompass the size of the petri dish, with measurements typically being taken at 5 mm increments a theoretical 5 mm grid is calculated. A two-fold problem arises by doing this. With all of the care being taken to accurately measure parameters, the size of the petri dish may be measured to a decimal precision. If there is an intensity decrease at the dish edge it may not be detected as the petri factor will always be determined by rounding down. Also, if there is a significant decrease in irradiance at the petri dish extremities, then the full impact of this decrease may not be accurately accounted for, again due to the 5 mm grid. Using a theoretical irradiance field created on a 5 mm x 5 mm grid, without interpolation to a smaller grid, provides a good example of how this can happen and is illustrated in Table 2 below.

Table 2a. Data input into the petri factor calculations

<table>
<thead>
<tr>
<th>Displacement from the origin</th>
<th>X axis reading</th>
<th>X axis ratio</th>
<th>Y axis reading</th>
<th>Y axis ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.0</td>
<td>0.83</td>
<td>0.129</td>
<td>0.83</td>
<td>0.129</td>
</tr>
<tr>
<td>-2.5</td>
<td>5.22</td>
<td>0.809</td>
<td>5.22</td>
<td>0.809</td>
</tr>
<tr>
<td>-2.0</td>
<td>6.38</td>
<td>0.989</td>
<td>6.38</td>
<td>0.989</td>
</tr>
<tr>
<td>-1.5</td>
<td>6.62</td>
<td>1.026</td>
<td>6.62</td>
<td>1.026</td>
</tr>
<tr>
<td>-1.0</td>
<td>6.66</td>
<td>1.032</td>
<td>6.66</td>
<td>1.032</td>
</tr>
<tr>
<td>-0.5</td>
<td>6.58</td>
<td>1.020</td>
<td>6.58</td>
<td>1.020</td>
</tr>
<tr>
<td>0.0</td>
<td>6.45</td>
<td>1.000</td>
<td>6.45</td>
<td>1.000</td>
</tr>
<tr>
<td>0.5</td>
<td>6.29</td>
<td>0.975</td>
<td>6.29</td>
<td>0.975</td>
</tr>
<tr>
<td>1.0</td>
<td>6.03</td>
<td>0.934</td>
<td>6.03</td>
<td>0.934</td>
</tr>
<tr>
<td>1.5</td>
<td>5.74</td>
<td>0.889</td>
<td>5.74</td>
<td>0.889</td>
</tr>
<tr>
<td>2.0</td>
<td>5.25</td>
<td>0.814</td>
<td>5.25</td>
<td>0.814</td>
</tr>
<tr>
<td>2.5</td>
<td>4.91</td>
<td>0.761</td>
<td>4.91</td>
<td>0.761</td>
</tr>
<tr>
<td>3.0</td>
<td>0.83</td>
<td>0.129</td>
<td>0.83</td>
<td>0.129</td>
</tr>
</tbody>
</table>

Table 2b. Petri factor calculation using different petri dish diameters, applied to a 5 mm x 5 mm grid and an interpolated 1 mm x 1 mm grid

<table>
<thead>
<tr>
<th>Petri dish diameter (cm)</th>
<th>5 mm x 5 mm grid</th>
<th>1 mm x 1 mm grid</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>0.9443</td>
<td>0.9458</td>
<td>0.15%</td>
</tr>
<tr>
<td>4.974</td>
<td>0.9443</td>
<td>0.9286</td>
<td>-1.57%</td>
</tr>
<tr>
<td>5.0</td>
<td>0.9284</td>
<td>0.9275</td>
<td>-0.90%</td>
</tr>
<tr>
<td>5.5</td>
<td>0.9035</td>
<td>0.8967</td>
<td>-0.68%</td>
</tr>
<tr>
<td>6.0</td>
<td>0.8621</td>
<td>0.8459</td>
<td>-1.62%</td>
</tr>
</tbody>
</table>

In this example two scenarios are looked at; one where the 5 mm x 5 mm grid without interpolation is calculated and one where the incident irradiance is measured in 5mm increments on the X and Y axis and forecast to a 1 mm x 1 mm grid. When using a diameter in multiples of 5 mm and well within the uniform portion of the irradiance field there is not much difference between both methods of calculation as can be seen with the 4.5 and 5.0 cm petri dish diameters being only 0.15% and 0.09% different from one another respectively. On the other hand, when the petri dish diameter is measured
4.974 cm using a calibrated caliper, the calculated petri factors differ by 1.57%. This is significant and would contribute to an error in the fluence calculation of exactly 1.57%. With the second scenario, of the irradiance field dropping off significantly at the edges of the petri dish, we can see the effect with the 6.0 cm dish. Using the 1 mm grid calculates a petri factor 1.62% lower than a 5 mm grid, as this calculation more fully captures the irradiance decrease at the edges over the entire perimeter of the dish.

The effects of improperly applying the petri factor calculation or not applying a mask to the radiometer detector can become insignificant sources of error so long as the irradiance field is sufficiently uniform and large over the entire area encompassed by the petri dish used for the collimated beam exposures. As long as these two conditions are met, then the petri factor itself likely is approaching 1.0 and that accomplishes two goals. First, it makes the petri factor calculation on a 5 mm x 5 mm grid without interpolation valid and narrows the difference between the UVDGM fluence calculation equation [1] and the NWRI equation [3]. This concern was addressed in the new IUVA guidance and spreadsheet for low-pressure UV collimated beams experiments (Bolton et al., 2015a) as interpolation from a 5 mm grid to a 2.5 mm grid is now used that provides four times the points with which to calculate the petri factor compared to past protocols.

**Absorbance measurement**

The UVDGM does not specify an error for the absorbance measurement with a spectrophotometer, but for the water factor, which included absorbance and is a maximum of 5% (UVDGM 2006). Having an error of this magnitude would have a large impact on the final fluence calculation, but an error of this magnitude is unlikely as long as appropriate controls are in place. The error calculated for the setup at GAP was only 0.41%, at maximum, and was dependent on the spectral absorbance of the sample and the sample absorbance at 253.7 nm.

The main sources of error – which many people often overlook – are to ensure that the cuvette being used for the absorbance measurement is properly cleaned prior to placing it in the spectrophotometer to take a reading and using the proper path length. Simply having a fingerprint, condensation or a streak of dirt on the outside of the cuvette for the zeroing procedure or while taking a reading can alter the result drastically. To prevent this from happening two good habits to practice are to look at the cuvette against a backlight to catch any obvious problems and to take more than one independent absorbance measurement to ensure agreement. The UVDGM (2006) and Bolton et al. (2015a) also suggest using a quartz cuvette with a path length of at least 4 cm whenever the sample UVT is greater than 90% per centimeter (absorbance of less than 0.0458).

Another source of error that can be introduced in the absorbance measurement is from the spectrophotometer itself. As with all instruments used in the collimated beam apparatus, it is important to ensure that the spectrophotometer is calibrated annually against NIST traceable standards. Calibration is by no means a guarantee that the instrument will read correctly over the calibration interval, so it is important to maintain a routine of verifications at appropriate intervals. The UVDGM outlines two recommended verifications – one wavelength verification using a certified holmium oxide standard and one absorbance verification using a certified potassium dichromate standard. At GAP we also employ a second wavelength verification using a certified rare earth standard that displays an absorbance peak more comparable to the low pressure mercury lamp output of 253.7 nm. All of these standards are available from Starna Cells as certified standards, which they recommend re-certifying every two years. Performing these additional verifications does add cost to the collimated beam procedure but are important if working with a sample with a large absorbance slope at 254 nm.

**Reaction vessel wall reflection**

Over 10 years ago Kuo et al. (2003) suggested that reflection of UV light off the petri dish walls may be an important factor not taken into account in the standardized collimated beam fluence calculation, and this may lead to an underestimation of the UV light irradiating the sample and this has been restated a number of times since (Kuo et al. 2003, Bolton and Linden

---

**Figure 1.** Standard UV fluence calculation does not account for UV light reflected from the vessel wall onto the microbial suspension.
This reflection may be a result of reflection within the water layer, but it has been observed here at GAP that reflection of the non-perpendicular light off the petri dish glass above the water layer has a greater impact on the fluence applied to the sample as is demonstrated in Figure 1. Determining a correction factor to apply to a fluence equation would not be the appropriate way to deal with this error; rather, the test should be sufficiently controlled to ensure that reflection does not play a role in the underestimation of the applied UV fluence. Depending on specific conditions it has been observed at GAP that sidewall reflection can account for an error greater than 10% with bacteriophage T1UV. The vessel diameter was 8.5 cm and height was 4.9 cm. The suspension depth was 0.87 cm. The UV sensitivity of T1UV phage with and without side wall reflection was 4.49 and 4.99 mJ/cm² per log inactivation. The ratio of the UV sensitivities with and without wall reflections with this example was 1.11.

One way to eliminate this effect would be to use a dish material that is non-reflective or to coat the dish with a non-reflective coating. A second method would be to ensure that the walls of the reaction vessel do not extend significantly past the solution surface (Wright et al. 2015). Combining these two strategies would provide the best strategy for eliminating the effect of reflection as it would also eliminate any possible reflection that may occur within the water layer.

Another method that has been suggested to eliminate side wall reflection is through the use of a mask or washer placed on top of the petri dish (Bolton et al. 2015b, Li et al. 2011). This effectively eliminates the potential for sidewall reflection by preventing any angular light from hitting the dish walls above the water line. All light that passes through the washer will impact the surface of the water, as the mask blocks any light that would impact the dish wall above the water line. If using this method to eliminate side wall reflection, a correction factor must be applied to the dose equation based on the area of the hole in the mask as compared to the water surface area. A photon based collimated beam fluence calculation (Bolton et al. 2015b) can also be used. This method recently has been suggested, and work is currently being performed to validate the method.

Sidewall reflection is one factor that is often overlooked when it comes to the design of a collimated beam apparatus. Simply by performing a collimated beam test under a variety of circumstances using changes in material or small changes in apparatus, then comparing results is a good way to determine if any error does exist in the method and allows you to break down the components to find out where the error is originating. This method is how it was determined that reflection was playing an important role in the underestimation of the UV dose under certain circumstances at GAP.

**Parallax effect**

Simply put, a parallax effect would be introduced any time there is an attempt to match the height of the sample surface to the calibration plane of the radiometer detector when switching between taking incident irradiance readings and performing the collimated beam exposures. This has traditionally been done by taking a measurement to match distances when switching between the detector and the sample; at GAP we use a lab jack to move the stir plate up and down to achieve this. When using the measurement method there is a chance that a small error can be made when making this switch and it is not possible to quantify this error, so all efforts should be
made to eliminate this factor. One way to do this is by using a laser level that is set to an arbitrary height and using lab jack to adjust the sample surface and radiometer calibration plane to this level. This method eliminates the parallax effect and is a much faster way to switch between sample irradiation and incident measurement using a radiometer.

Length measurements
The length measurements are often overlooked for the importance they play and number of times they appear in the fluence calculations. A slight error in this measurement does not necessarily result in a large error in the final fluence calculation but, like all measurements used in the fluence calculation, there are precautions and quality control steps that can be taken to ensure the error introduced by this measurement is minimized. One source of error is with the width measurement of petri dishes. These can be purchased in a variety of widths, with this diameter being used in the calculation of the petri factor and possibly sample depth. As with any manufacturing process these measurements are not exact, so it is important to measure the width of the dishes with a calibrated Vernier caliper. One suggestion is to take three random measurements across each dish and average them to obtain the average dish width. The standard deviation of the widths of all dishes then should be determined, and any dish that falls outside two times the standard deviation (95% confidence interval) should be removed from circulation. The average width of the remaining petri dishes then can be used in the fluence calculation.

A calibrated ruler is also an important instrument in measurement of collimated beam fluence calculation factors. It would be required for measurement of the petri factor X and Y axis intervals, to ensure that the entire irradiance field exposed in the reaction vessel is represented in the petri factor calculations. It also would be required for measurement of the distance from the lamp centerline to the sample surface used in the divergence factor of the UVDGM fluence calculation.

Length measurement instruments are and added expense, but fortunately routine calibration of a metal ruler is not required unless excessive wear or trauma to the instrument is evident, and calibration of a Vernier caliper is a widely performed, inexpensive, calibration procedure.

Time
As with length measurements, a calibrated instrument, in this case a stopwatch or timer, is required to minimization uncertainty. The collimated beam design, and whether it uses a manual or automatic shutter, plays a role in the uncertainty associated with time. A manual shutter will always have a larger uncertainty associated with it, as user input is required, but the effect can be minimized by ensuring that exposure time is sufficiently long so the time required to manually move the shutter is a small percentage of the total irradiance time. The UVDGM suggests exposures no shorter than 20 seconds, but longer minimum exposures should be used if possible.

If a manual shutter is used, or an automatic shutter that is calibrated to seconds and not milliseconds, then all final fluence values should be recalculated to this precision. Typically, the time required for an irradiance is calculated to the fraction of a second, but in practice all dosing is done to a one second precision. Performing this recalculation will provide minimal differences in the actual applied fluence, but is nonetheless important in the accuracy and uncertainty of the calculated fluence.

Limits
No matter how much effort and emphasis is placed on controlling for all possible sources of error when performing a collimated beam test there is still opportunity for an error to occur. This may be due to user error, water quality or some other factor that has never been accounted for in the past. To catch any of these unexpected errors, there needs to be some check in place to analyse the final results to see if they fall within the expected range. The UVDGM and the NWRI guidance both provide upper and lower limits for MS2 irradiations, but these limits are very wide, and a large amount of error is possible within these bounds. A better approach would be for each individual lab to produce their own set of upper and lower bounds for the surrogates being irradiated routinely. Figures 2 and 3 on page 17 show what the limits are for MS2 and T1UV irradiations at GAP. For the MS2 (Figure 2) it can be seen how much more restrictive GAP’s limits are when compared to the NWRI and especially the UVDGM limits.

How each individual lab handles these limits is not specified, but a suggestion is to see if the resulting dose response curve falls within the limits; individual points can fall outside the limits but the curve must fall inside the bounds. If the curve falls outside of the bounds then all of the measured parameters are verified, corrections are made to the calculated fluence values if necessary, and if the curve still falls out of bounds then the collimated beam test is repeated where time and sample volume permit. If the repeated collimated beam standard curve is still not within limits the client is made aware of the issue and results issued appropriately. The limits calculated at GAP are 95% confidence limits, so there is still a 5% opportunity for the curve to fall outside of the limits, but these limits do give us the opportunity to perform a final check to
Figure 2. The GAP 95% confidence limits for MS2 collimated beam irradiation (solid lines) labeled as UL (upper limit) and LL (lower limit) compared to the less constrictive limits provided in the USEPA guidance and NWRI guidance manuals.

Figure 3. The 95% confidence upper and lower limits (UL and LL) calculated using historical data for T1UV collimated beam irradiations.

Conclusions
Since most people rarely perform collimated beam tests, they are not necessarily aware of the care and accuracy that is required to properly perform collimated beam irradiations. If sufficient effort is taken to reduce uncertainty in all measurements entered in the collimated beam fluence calculation, there is still a question as to what fluence calculation to use. The UVDGM calculation provides the largest amount of safety by calculation of a conservative (lower) fluence applied by a UV reactor, but the NWRI equation is equivalent if working with a completely uniform irradiance field and if light divergence is minimized using a long “lamp centerline to sample surface” distance. The NSF equation is also appropriate when being used in the context of certifying a system to the NSF 55 standard as it allows direct comparison between systems where a pre-defined fluence is the target. With this being said, the NSF equation may not be appropriate for determining the dose response relationship on an emerging pathogen for regulatory purposes, and there is also indication that some NSF standards are heading towards the UVDGM fluence calculation in some of their updated methods.

By breaking down the elements that go into calculating the fluence in a collimated beam test the hope is that more care will be taken by labs and individuals by taking an in depth look at their collimated beam apparatus and their procedures to ensure that the data being produced using their system is as accurate as possible. Future revisions of the UVDGM and NWRI guidance should outline all of the possible sources of error and how they can be mitigated so a collimated beam dose response curve produced at one lab would agree with one produced by another lab. The IUVA Board of Directors has shown their commitment to this process with the release of the “Protocol for the determination of fluence (UV Dose) using a low-pressure or low-pressure high-output UV lamp in bench-scale collimated beam ultraviolet experiments” (Bolton et al., 2015a) and further discussion may bring other sources of error to light; the preceding analysis of collimated beam uncertainty can be used as a basis for this discussion. The field of UV
water disinfection is a growing industry, and all effort should be made to ensure knowledge and research continues to grow as well.

References


Bolton, J.R., Beck, S.E. and Linden, K.G. 2015a. Protocol for the determination of fluence (UV dose) using a low-pressure or low-pressure high-output UV lamp in bench-scale collimated beam ultraviolet experiments. IUVA News. 17(1): 11-16.

Bolton, J.R., Mayor-Smith, I. and Linden, K.G. 2015b. Rethinking the concepts of fluence (UV dose) and fluence rate: the importance of photon-based units – a systemic review. Photochem. Photobiol. 91: 1252-1262.


**IUVA/Confluence Water Cluster**

IUVA collaborated with the Confluence Water Technology Innovation Cluster to present the latest on UV technology in early November in Cincinnati, Ohio. The Confluence group was created as the result of an EPA initiative that recognizes the importance of harnessing regional expertise to encourage economic development and environmental and human health protection. The event featured presentations by the EPA, Great Cincinnati Water Works and IUVA members, including An Innovative Approach to Validation of Ultraviolet (UV) Reactors for Disinfection in Drinking Water Systems; Implications of the US Regulatory Framework; Operations & Maintenance of UV; and a review of the Cincinnati UV System Performance and O&M Costs. A lively panel discussion followed the presentations, offering attendees a unique perspective of how water operators and regulators view UV technology and the benefits of UV technology.

**IUVA at Pollution Prevention Event**

IUVA and RadTech International North America, the association for UV/EB technology, partnered to exhibit UV technology at the 19th annual Pollution Prevention Conference and Tradeshow in Indiana in late September. The event featured a special track on water treatment with over 200 individuals representing regulators, operators and manufacturing firms. While drawing a national audience, the event is sponsored by the Indiana Partners for Pollution Prevention, a group of businesses and other organizations established to promote pollution prevention and environmental stewardship in Indiana.

On a national level, IUVA VP of the Americas Jamal Awad helped coordinate IUVA participation in two events during fall 2016: the presentation of an IUVA specialty workshop at the 2016 Wateruse Symposium, with IUVA members offering a half-day pre-conference session on UV technology. Also, IUVA members volunteered to staff an IUVA booth at WEFTEC 2016, touting UV technology, IUVA membership and attendance at IUVA events.

**IUVA Americas Conference in Texas**

IUVA will head to the “Live Music Capital of the World” – Austin, Texas – to host several days of conference sessions, workshops, networking opportunities and tabletop exhibitions. On Sunday, Feb. 5, IUVA will host a workshop, UVC LED Review: Technology, Use, Products, from noon-4 p.m. featuring presenters from AquiSense Technologies and the University of Colorado at Boulder. Monday, Feb. 5, and Tuesday, Feb. 7, will include conference sessions on disinfection, LEDs, municipal treatment, fighting HAIs and more. On Wednesday, Feb. 8, IUVA will host a second workshop on advanced oxidation from 8:30 a.m.-1 p.m. featuring James Bolton and James Collins. Details are available at http://iuva-americas.com.

**IOA World Congress and Exposition**

The 23rd IOA World Ozone Congress and Exhibition will be held at the Gaylord National Resort & Convention Center in National Harbor, Maryland. This world congress will showcase leading technologies for aquarium use, municipal water, municipal wastewater and industrial process applications with special attention to ozone and AOP technologies.

**IUVA World Congress, Dubrovnik, Croatia**

If you have seen “Game of Thrones,” you are already familiar with Dubrovnik, a city along the coast of Croatia that faces the Adriatic Sea. Dubrovnik was used on the HBO series as a shooting location for King’s Landing. We are very excited to host the 2017 IUVA World Congress, Sept. 17-20, 2017, in Dubrovnik, Croatia. We will announce a call for abstracts in early 2017 and send out additional details soon.
IUVA News is seeking article submissions. News releases, product announcements, application notes and more are welcome. Email editorinchief@iuva.org.

Is your laboratory equipped for emerging LED research?

PearlBeam

- Selectable Wavelengths
- Intuitive Controls
- Instant On/Off
- Petri Dish Factor > 0.9

www.aquisense.com                      +1 859 869 4700

High Performance UVC LEDs

cisuvc.com/innovate
Keeping local drinking water treatment systems up and running in African countries is still extremely challenging. Maintenance and local attention to the systems are extremely important, besides the chronic shortage of financial resources. Nedap’s Naïade water purifier has proven to be a very reliable and cost-effective system for water treatment for schools in remote areas.

At the primary school Centre San Marco, in Kanombe, Kigali, Rwanda, a Naïade system was replaced after 10 years of operation, supplying safe drinking water to 240 children and 20 staff members of that school. The Naïade system is used in combination with rain water harvesting (see Figure 1).

Nedap distributor Impala Corporation is taking care of nine Naïade units in Rwanda and was set to install another nine units before the end of 2016, all located within 150 km of the distributor. All units were financed by the Dutch Soroptimist organization.

The 2013 IUVA Green UV Award winning Naïade water purifier has been designed especially for rural areas. With the integrated bag filters and solar-powered UV disinfection unit, the system can supply safe drinking water for hospitals, schools and small communities at very low costs down to $1.50 (US) per person per year. The system easily can supply up to 3,000 L/day for 400 people. At a school in Tanzania, the result of the Naïade system was very clear: Within two weeks, 40% more children attended school, released from the troubles caused by chronic diarrhea.

The Naïade also proved to work very well at natural disaster areas where clean water distribution systems have been disrupted. Temporally, use of Naïade systems could prevent outbreak of waterborne disease. Units have been in operation successfully in earthquake areas in China (Ludian, Yunnan Province) (see Figure 2) and Ecuador (near Portoviejo).

For a UNESCO-IHE performance report and more information, see www.nedap-naiaide.com.
Gigahertz-Optik Announces UV-LED Radiometer with Wand Probe – High-intensity UV and BLUE LED light sources are being employed in UV processes like UV and BLUE light curing.

Featuring a horizontally constructed photodetector assembly, which keeps the photodetector out of the hot zone, Gigahertz-Optik’s X1-1-RCH-116-4 UV and Blue Light LED Curing Radiometer is able to maintain stability in high-temperature and intense UV flood and spot curing environments.

The fully remote controllable 4-channel X1-1 meter features auto-ranging from 0.1 pA to 200 μA or manual range selection, CW, dose, run/stop, offset and peak hold functions, selectable integration time from 20 ms to 1 second, USB interface and a backlit LCD, and it is compatible with all other Gigahertz-Optik single and multisensor (up to four) light detector heads.

The RCH-116-4 wand-style detector consists of a RADIN (radiation integrator) coupled to a stainless steel rigid tube housing a quartz light guide that pipes the light signal to a detector capsule housing the photosensor/filter assembly. RADIN not only provides a cosine-corrected spatial response but along with the light guide and remote detector capsule provides signal attenuation and thermal isolation. The detector assembly is not subject to direct irradiation, which reduces ageing and saturation effects and allows the RCH detector to operate in temperatures up to 100°C (peaks up to 200°C).

The detector covers the spectral range from 350-465 nm with calibration points at key LED wavelengths of 365, 375, 385, 395, 405 and 436 nm auto-ranging from one to 40 W/cm². The wavelength for measurement is selected using the X1-1 meter menu function. The low-profile RCH detector enables measurement just 8 mm above the exposure plane. Internationally traceable calibration certification describes the calibration procedure, responsivity and traceability. The X1-1-RCH-116-4 Radiometer includes the meter, detector, USB cable, calibration certificate and carrying case. Optional S-X1 software is available.


Boston Electronics, Nikkiso USA Sign Distribution Agreement – Boston Electronics Corporation (BEC), a leader in the distribution and advanced electro-optical products and solutions, announced a new partnership with Nikkiso USA. This partnership combines Boston Electronics’ presence in the ultraviolet (UV) market with Nikkiso’s advanced ultraviolet light emitting diode products (UV-LED). Under the new agreement BEC will distribute Nikkiso’s UV-LED products into the North American market.

“The partnership with Nikkiso is very exciting for Boston Electronics. We see growing demand for advantaged UV-LED products in the market, and we quickly recognized Nikkiso as a premier supplier of these products,” said Rick Mannello, CEO of Boston Electronics.

“Boston Electronics has the application and technical knowledge, strong North American market presence and a customer-focused culture that we were looking for,” commented Ruben Rivera, US vice president of sales and marketing at Nikkiso.

UV Technology Helping Treat, Disinfect and Clarify River – UV light is the final disinfection stage at the sewage treatment plants that feed wastewater back into the Isar River, where a City of Munich and State of Bavaria project makes the water safe to bathe in – even with strict European Union bathing water regulations.

UV radiation at a wavelength of 185 nanometers makes even higher energies available and allows oxidization processes, which can break down health-threatening chemicals in water.

The key to sustainability is UV lamp power, efficiency and durability. Specialist light source manufacturer Heraeus Noblelight has developed high-power, amalgam lamps that operate up to 16,000 hours with virtually constant UV output. A unique long-life coating doubles lamp life, and lamps can eliminate the transmission loss of quartz glass in conventional lamps, so constant disinfection is achieved over operating life. End users, such as waterworks and clarification plants, profit from the long operating life.

For more information, go to www.heraeus-noblelight.com.

Evoqua division launches controllers – Evoqua Water Technologies’ Aquatics & Disinfection Division announced the launch of Blu-Sentinel™ controllers, a line of advanced chemical controllers designed for commercial recreational water applications such as aquatic facilities and water parks.

The Blu-Sentinel™ Pro controller incorporates pool water treatment features, such as shock chlorination and economic mode operation, as well as the CEDOX control algorithm. The controller supports all chemical feed applications commonly found in pool water treatment, such as dosing pumps or relay control feeders, chlorine gas feed control and on-site electro-chlorination system operation, as well as a control signal to UV systems, flocculation and/or activated carbon slurry feed systems.

Blu-Sentinel™ Pro can measure and control the critical disinfection parameters of free chlorine, pH and ORP. The instrument also can measure combined and total chlorine, as well as conductivity and provides a control output for these measurements. With the total chlorine sensor installed, the controller can enable UV disinfection systems to reduce combined chlorine.

Water disinfection device developed – A device for disinfection of drinking water by radiation UV LEDs with flowrate 4 L/h was developed and tested by NPO ENT (St. Petersburg). Nine UV-LEDs with peak wavelength of 260 nm were placed on the axis of the device inside a quartz flask. Water is supplied through a lower pipe, passes through the helical channel, is irradiated by UV and exits through an upper pipe. The power supply is 6.5 V, 0.18 A. Dimensions of the device are 90 x 210 mm.

The water for microbiological testing of the device was contaminated by *E. coli* in concentration 1000 CFU/L. Water of volume 200 mL was passed through the device with different velocities. The *E. coli* were totally inactivated for flow rates from 2.4 to 3.6 L/h.

The device can used for disinfection of drinking water after of filtration in case there is no central water supply.
Call for Abstracts
2017 IUVA Americas Conference, Feb. 5-8
Austin, Texas
https://iuva-americas.com/abstracts

2017 IUVA Americas Conference, Feb. 5-8
Austin, Texas
https://iuva-americas.com

IUVA World Congress, Sept. 17-20
Dubrovnik, Croatia
More information coming soon.

IUVA Corporate Members

Large organization
Aquionics Incorporated
Calgon Carbon UV Technologies
Carollo Engineers, Inc.
CDM Smith Inc.
CH2M Hill Engineers, Inc.
Crystal IS
Evoqua Water Technologies
Fujian Newland EnTech Co. Ltd.
Hazan & Sawyer
HDR, Inc.
Heraeus Noblelight GmbH
Light Sources, Inc.
LIT UltraViolet Technology
NYC Dept. of Environmental Protection
Philips Lighting BV
Trojan Technologies
Xylem Inc.

Small organization
ABIOTEC Technologie UV
Advanced UV Inc.
Allanson Lighting Technologies, Inc.
American Air & Water, Inc.
Aquifer Technologies
Atlantium Technologies Ltd.
Australian Ultra Violet Services (Operations) Pty Ltd.
Boston Electronics
Dowa International Corporation
E. Vila Projects & Supplies, SL
Foshan Comwin Light & Electricity Co., Ltd.
Funatech Co., Ltd.
GAP EnviroMicrobial Services Ltd.
GHD Consulting Services, Inc.
Gigahertz-Optik Inc.

Medium organization
Alpha Cure
American Ultraviolet Company
atg UV Technology
Atlantic Ultraviolet Corporation
Berson UV-techniek
Bio-UV SA
da plus electronic GmbH
GHP Group Inc.

Very small organization
Bolton Photosciences Inc.
Fresh Appeal USA, Inc.
UV Resources

Crystal IS ........................................20
Dowa ..................................inside back cover
da plus electronic GmbH .............18
Heraeus Noblelight LLC .inside front cover
Light Sources ..........inside front cover
Nedap Light Controls ...............3
Neptune-Benson ......................23
Philips ................................back cover
UV Technik ................................18

Calendar

Ad Index
UV and LED lighting solutions designed for your unique specifications

Our solutions, which include UV ballasts for water and air purification systems, work across a number of applications, and are constantly growing to include UV-LED. We will also work closely with you to develop custom built components that are specific to your project needs.

www.allanson.com | cservice@allanson.com | T: 1.800.668.9162 | F: 416.752.6717
33 Cranfield Road, Toronto, ON Canada

---

**DOWA**

Deep UV LEDs 265nm-340nm

1. High Power Deep UV-LEDs
   - Typical Value at If=350mA
   - Available with Bare Die or SMDs

<table>
<thead>
<tr>
<th>Peak Wavelength</th>
<th>265nm</th>
<th>280nm</th>
<th>310nm</th>
<th>325nm</th>
<th>340nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Power</td>
<td>Coming Soon</td>
<td>26mW</td>
<td>36mW</td>
<td>30mW</td>
<td>30mW</td>
</tr>
<tr>
<td>Forward Voltage</td>
<td>6.5V</td>
<td>5.5V</td>
<td>5.0V</td>
<td>5.0V</td>
<td></td>
</tr>
</tbody>
</table>

2. Deep UV-LEDs with 3535 SMD
   - Typical Value at If=100mA
   - Available with Bare Die or SMDs

<table>
<thead>
<tr>
<th>Peak Wavelength</th>
<th>265nm</th>
<th>280nm</th>
<th>310nm</th>
<th>325nm</th>
<th>340nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Power</td>
<td>Coming Soon</td>
<td>11mW</td>
<td>13mW</td>
<td>12mW</td>
<td>12mW</td>
</tr>
<tr>
<td>Forward Voltage</td>
<td>6.5V</td>
<td>5.5V</td>
<td>4.5V</td>
<td>4.5V</td>
<td></td>
</tr>
</tbody>
</table>

http://www.ultraviolet-led.com
http://www.dowa-electronics.co.jp

For more information, please contact "electronics@dowa.co.jp"
Together we can be sure it’s pure

Water purification isn’t purely about satisfying the demand for clean water. Customers also have a thirst for ways to reduce energy and maintenance costs with solutions from a partner they trust. Like Philips. Our state-of-the-art UV lamps, drivers and modules are optimized for performance in a wide range of applications. They also come with exceptional development support, including microbiological performance testing. And we’re pioneering the development of UVC LED modules, so together we can be sure it’s pure, today and tomorrow.

Find out more at www.philips.com/uvpurification