

IUVA NEWS

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FEATURES

Articles:

- Report on the UV Congress in Whistler, BC
- How can IUVA help small water systems?
- Weighted Fluence-based Parameters...
- Accurate Measurement of UV Lamp Output

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Ursula Obst (center), Christina Jungfer (right) and Jutta Eggers (left) at the UV Congress Opening Reception (photo taken by Ingrid Crowther).



UV Congress delegates enjoying the bright sunshine at the UV Congress Banquet near the top of Whistler Mountain (phototaken by Leo Schowalter).

IN THE NEXT ISSUE...

Articles on UV disinfection of fruit juices and other interesting UV topics.



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Editor in Chief: **Dr. James R. Bolton**

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A Message from the President

**“Let’s Move on”
by
Andreas Kolch**

We have received a lot of positive feedback about the conference in Whistler. Jim’s survey clearly indicates the great appreciation of everyone regarding the quality of this event. However, Jim’s email blast a couple of weeks ago already showed you, that in one part the conference wasn’t successful as compared to other parts, and this was the surplus (about \$15,000), which was much below our budget and thus will have an impact on our budget for this year and the next year.

The Executive Committee took immediate action on this, analyzed the recent cost structure and came to the conclusion that the current financial reserve should be able to take us through the coming years. In addition to that, any upcoming costs will go through a stringent review before any money will be spent. This may affect some of our activities, but for the sake of the future of the association, we may have to think differently in some areas.

One example is IUVA News, which could be transferred from a printed version into an electronic version and thus could save money. We are currently investigating this possibility.

I would also like to take the opportunity here and encourage you to give us your comments about this.

On the revenue side of things Jim already took action and focuses on activities, which are clearly dedicated to this. I have to thank all the volunteers, who contacted Jim offering help to maintain the website.

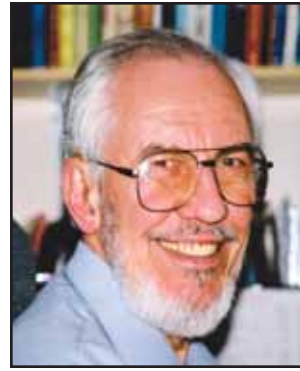
In Whistler I also spoke about some changes. Some of them are on the way: We are trying to set up a manufacturer’s panel to better serve and understand the needs of our corporate members. I will keep you updated about this.

We have reduced the number of committees to the minimum number that is absolutely necessary and will work more with ad hoc workgroups in the future.

We are setting up more workshops than ever and at the same time, these workshops are focussed on hot topics, which we think, will get the attention of people and thus would increase our membership base.

At this point I have again to thank all the people who offered help to organize and conduct the workshops. It is amazing to see, how many people are engaged in that process at the moment.

We will announce new board members shortly coming from the regulatory and the operational side. These will be



Editorial

**By Jim Bolton
Editor-in-Chief**

As your new IUVA President, Andreas Kolch, has indicated, the surplus from the UV Congress in Whistler was much below the budgeted amount. There were two principal reasons: the number of delegates (231) was much below the previous Congress in Vienna (275) and the number of companies that chose to exhibit was much below our expectations. One of the consequences of the low surplus was that the Executive Operating Committee asked me to concentrate my efforts on activities that would generate revenue. Thus, I will be directing a large part of my work to improving the advertising revenue from IUVA News, organizing Workshops and Conferences, increasing Membership and finding ways to generate more revenue from our Web Site. What had to go was the time I have been devoting to updating many of the pages on the Web Site. Fortunately, as a result of an email blast to the Membership, I am very thankful that several volunteers have stepped forward to help. I wish to express my sincere thanks to: Amos Au, Philippe Boileau, Jennifer Brunn, Rhen Zuo Chen, Shanshan Jin, Joan Oppenheimer, David Rindall, Larry Randall and Siva Sarathy.

On a more positive note, the UV Congress in Whistler, as the Congress survey indicated, was an outstanding success from a technical and personal standpoint. See my Report later in this Issue. I wish to thank the Congress Committee and especially Kathy Harvey for their hard work and enthusiastic support.

In order to save costs on IUVA News, we have gone to a lighter grade of paper without significantly decreasing the quality. This saves not only in the cost of the paper but also in mailing costs.

We continue to receive high quality articles, as this issue demonstrates. If you would like to write an article, or can recommend someone who should write an article for IUVA News, please let me know (jbolton@iuva.org) and I’ll send the “Instructions to Authors”.

a big plus to the board and I will tell you more about this next time.

The congress 2007 planning is well under way and the cooperation with IOA regarding this works fine.

Finally we are well under way to get the association ready for the future and a lot of activities happen at the moment. Financial control and improvement activities have been set up to make this sustainable. Let’s move on...

Hot UV News

The following are some of the more interesting items from the UV News page on the IUVA Web Site (http://iuva.org/public/uv_news.htm). The Editor is pleased to announce that IUVA Board Member, Joan Oppenheimer, from MWH Applied Research Dept. in Pasadena, CA has volunteered to help with selecting items for UV News. Thank you, Joan!

2002: Mr. Csaba Purszki has brought to my attention a very interesting article: "UV Absorbance of the Human Cornea in the 240- to 400-nm Range" by L. Kolozsvári et al., Invest. Ophthalm. Visual Sci. 2002, 43:2165-2168. (available online at <http://www.iovs.org/cgi/content/full/43/7/2165#F4>). This article shows that the UVB (which they define as 280-330 nm) is absorbed most strongly in the upper 100 μ m of the cornea. These results suggest that the anterior corneal layers are particularly important in preventing damage by UV-B radiation.

7 August 2005: Protecting Public Spaces From Chemical Attack – Bioterrorism (http://www.rednova.com/news/display/?id=199698&source=r_science), RedNova.com

IN PROTECTING PUBLIC, an ounce of prevention may be worth a pound of sensing. Since the deadly 2001 anthrax mailings, research has focused on developing improved sensors to detect potential chemical or biological terror agents. However, these devices alone cannot head off terrorist attacks, and reliance on such technology can create a false sense of security, warns a Georgia Institute of Technology, Atlanta, researcher... "Almost every public building in the United States has a heating and air conditioning system that circulates the air," Janata relates. "Not only does that refresh the air, but it provides a vehicle for introducing both chemical and biological agents. The concept would be to insert into that HVAC system a sterilization chamber that would disable the biological agents and decompose the chemical agents." A chamber exposing the air to **ultraviolet light** could inactivate most biological agents. Because of their reactive nature, most chemical agents could be neutralized with a small number of chemical processes built into filtering systems. "With some additional development [to existing technologies]" Janata says, "they could be implemented in public spaces..."

18 July 2005: World's biggest UV water treatment plant coming (<http://www.thejournalnews.com/apps/pbcs.dll/article?AID=/20050718/NEWS02/507180349/1017>), by Len Maniace, Westchester Journal News, Westchester, NY.

Work is scheduled to begin by September on the world's largest **ultraviolet** water treatment plant, a nearly \$600 million facility designed to sterilize two pesky parasites that have roots in a disease outbreak that sickened 400,000 people in Milwaukee a dozen years ago. To be built on the Grasslands reservation next to the county jail in Mount Pleasant, the UV plant can treat up to 2.4 billion gallons of water a day from New York City's two largest reservoir systems, the Catskill and the Delaware, which are the source of most water used by Westchester and New York City. This will mean other \$2.3 million annually in tax revenue for the town of Mount Pleasant, the Pocantico Hills schools and Westchester County. The massive project

UV Industry News

The following are some of the more interesting items from the UV Industry Announcements page on the IUVA Web Site (https://secure.nelixstore.com/iuva/public/uv_industry_announcements.htm).

10 August 2005: UV Process Supply announces the release of UV FastCheck Strips.

We have recently released the UV FastCheck Strips. The customer response to these UV dose measurement strips has been nothing short of astounding. We have had so much positive feedback on this product. Please visit the online version of the Product Spotlight at: <http://www.uvprocess.com/spotlight>.

8 August 2005: Megola Inc. Receives Initial Order for Indoor Air Quality Units (<http://www.primezone.com/newsroom/news.html?d=83457>)

CORUNNA, Ontario, Aug. 8, 2005 (PRIMEZONE) -- Megola Inc. (OTCBB:MGOA), a leading environmental solution provider in physical water treatment, air purification, microbiological control, and wastewater treatment, is pleased to announce that has received an order for 1,000 indoor air quality units from its Air Purification Division from BuyMax LLC...Megola's indoor air quality unit, which BuyMax will private label for distribution to their membership, is a uniquely engineered, integrated dual wavelength Ultraviolet Energy system designed to dramatically reduce and control airborne toxic compounds such as mold, fungus, formaldehyde, xylene gases and tobacco smoke along with infectious agents such as bacteria, influenza, hemolytic streptococci and many others for commercial and residential applications...

19 July 2005: Nick Labansky will join UV Pure Technologies, Inc. (<http://www.puresafewater.com/>) of Toronto, Canada as the company's new northeast business development manager, according to a company press release.

Labansky, a graduate of the University of Wisconsin-Whitewater holds a Bachelor of Arts in organizational communication with a minor in marketing. Labansky was previously general manager for Dalee Water Systems, an independent Culligan dealer in Whitewater, WI. Labansky will be responsible for northeast business development, training and support for UV Pure...

stems from a campaign against two single-cell organisms — *Giardia* and *Cryptosporidium*. Though these parasites may have little or no effect on healthy people, they can cause severe diarrhea and other gastrointestinal symptoms, which can kill individuals with impaired immune systems. The presence of these two organisms led to a brief water alert two weeks ago in New York City after a torrential rain washed soil and some parasites into the Kensico Reservoir. That alert called for the elderly, the very young and others with weakened immune systems to boil tap water or drink bottled water... Construction of the UV plant will be a massive project not expected to be complete until 2010. The two-story UV plant will be a large building, 410 feet by 200 feet. One floor will be underground and the other above ground level, varying in height from 30 to 50 feet...

News from IUVA

General Assembly: This biennial Meeting of the IUVA Members was held at the UV Congress in Whistler. The principal business was the election of the new **IUVA Board of Directors**. Following the Report of the Nominating Committee from **Joop Kruithof**, the following were elected for a two-year term: **Jamal Awad** (USA), **Keith Bircher** (Canada), **Zia Bukhari** (USA), **Alexander Cabaj** (Austria), **Lloyd Chapman** (USA), **Jennifer Clancy** (USA), **Christine Cotton** (USA), **Gil Crozes** (USA), **Bertrand Dussert** (USA), **Mohamed Gamal El-Din** (Canada), **Henk Giller** (Netherlands), **Linda Gowman** (Canada), **Ron Hofmann** (Canada), **Oluf Hoyer** (Germany), **Richard Hubel** (USA), **Bob Hulsey** (USA), **Andreas Kolch** (Germany), **Wladyslaw Kowalski** (USA), **Joop Kruithof** (Netherlands), **Karl Linden** (USA), **Jim Malley** (USA), **Jon McClean** (USA), **Alex Mofidi** (USA), **Dennis Mutti** (Canada), **Jeff Neemann** (USA), **Kumiko Oguma** (Japan), **Joan Oppenheimer** (USA), **Christopher Owen** (USA), **Karl Scheible** (USA), **Chris Schulz** (USA), **Regina Sommer** (Austria), **Richard Stowe** (USA), **Matthew Valade** (USA), **Elliott Whitby** (Canada), **Rongjing Xie** (Singapore) and **Jim Bolton** (ex officio).

Highlights of the IUVA Board Meetings: Two Board Meetings were held at the UV Congress in Whistler: the “Old” Board Meeting on Tuesday, 24 May and the “New” Board Meeting on Friday, 27 May. The following are some of the highlights of those meetings:

- Consider converting IUVA News to an electronic edition but advertisers will be surveyed first.
- Approved the draft “Memorandum of Cooperation” with the IOA.
- The following were elected to the Executive Committee (* means a Member of the Executive Operating Committee): **Andreas Kolch***, President; **Bob Hulsey***, Past President; **Rich Hubel***, Secretary; **Chris Schulz***, Treasurer and Vice Presidents **Oluf Hoyer**, **Jim Malley**, **Karl Linden**, **Regina Sommer** and **Elliott Whitby**.
- **Chris Schulz** reported that IUVA needs more Workshops to keep a healthy financial status.
- UV Workshops are being planned for the WQTC in Quebec City (Adenovirus), the Ohio/Kentucky region and one on Operations & Maintenance issues
- A UV Session is being planned by **Oluf Hoyer** at the next Wasser Berlin Conference in April, 2006.
- The Bylaws for the UV Air Treatment Topical Group were approved
- **Bertrand Dussert** agreed to chair a Manufacturers Panel.

UV Air Treatment Group Board Meeting: This Meeting was held on Friday, 24 May at the UV Congress. The following are some highlights:

- A set of Guidelines and Standards for UV Air Treatment was considered. Copies of these drafts can be obtained from the Editor (jbolton@iuva.org).
- The 3rd UV Air Treatment Conference will be held in Chicago early in 2006.

Retirement of the IUVA Executive Director: Jim Bolton announced at the UV Congress that he will be retiring as Executive Director in 2007. This will give the Executive Committee and the Board time to plan for a new administration of IUVA.

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Application Note

Editor: UV companies are welcome to submit "Application Notes" for this column. Send to jbolton@iuva.org.

The Use of UV for Swimming Pool Water Treatment
from Ben F. Kalisvaart, Berson UV techniek.
(www.bersonuv.com).

UV technology is widely used to disinfect water in small, private swimming pools. The owners of these pools are free to choose what treatment method they use, and tens of thousands around the world use small, domestic UV systems as an alternative to chlorination.

Operators of public pools and aqua parks, however, are required by law to use chemical treatment methods such as chlorination or ozonation as their main treatment method. Ozone has its own drawbacks, which are outside the scope of this discussion, but chlorination also has many health related downsides. The main ones are the strong 'chlorine smell' and unpleasant eye irritations associated with chlorinated indoor public pools. This smell is caused by chlorine reacting with organic substances – such as sweat and urine —introduced into the water by bathers, to form chloramines (also known as bounded chlorine or combined chlorine). In particular, trichloramine is a powerful irritant with a strong, unpleasant odor at very low concentrations.

Chloramines are known to absorb, and be destroyed by, UV light in the spectral region 200–400 nm. The use of medium pressure UV lamps dramatically reduces the concentration of chloramines in pool water (sometimes to as low as 0.1 ppm), resulting in a much more pleasant and healthy environment around the pool.

Of course, medium pressure UV is also a powerful disinfectant that inactivates most water-borne microorganisms. This means pool operators can reduce their reliance on chlorine for primary disinfection to just a residual amount. Other benefits include a reduction in freshwater use (for flushing) as well as reduced heating and maintenance costs.

Berson UV-techniek, based in the Netherlands, uses a combination of its patented, long-life Berson MultiWave® UV lamps with self-cleaning quartz sleeves. Comparison trials have shown that the 'Berson UV concept' for pool water treatment reduces chloramines with the lowest energy consumption per gallon of treated pool water.



UV FAQ's

Editor: I often get questions about UV. I have collected the Questions and Answers in the UVFAQ's page on the IUVA Web Site (<http://www.iuva.org/public/faqs.htm>). The following are some recent interesting items.

QUESTION: Is it possible for the sun's rays to be a danger to the skin even in cloudy weather? (submitted and answered by Joe Murgo, CenterDaily.com).

ANSWER: The sun radiates a broad stream of energy to our planet. Most people think that the bright sunshine we see is the harmful stuff, but that's not quite the truth.

The energy that is most harmful to our skin is **ultraviolet** and is not visible to our eyes. It is this radiation that can damage our eyes and skin, increasing the chance for skin cancer and wrinkles. Like the visible light, clouds do absorb and scatter some of this ultraviolet radiation. But, even when it's cloudy, enough of this energy comes down to your skin to cause harm.

If you spend a lot of time in the outdoors, you should protect yourself — even if it's cloudy.

Although it's not the visible light that does the damage, you can use it to determine your danger from ultraviolet radiation. A good rule of thumb is that if you can see your shadow and its length is shorter than your height, you should avoid exposure to the sun or wear sunscreen with an SPF of at least 30.

If your shadow is not visible, then the odds are that the clouds are thick enough to significantly reduce the amount of UV energy reaching the ground. Short-term exposure won't be harmful in this case, but when outside for a long period, sunscreen is still recommended.

QUESTION: I wish to find out if all UVC lamps contain mercury in order to be germicidal, and do all UVC lamps produce an ozone smell?

ANSWER: Most UV lamps used for UV disinfection contain mercury. In the case of low-pressure lamps, only a few milligrams of mercury are present. In the case of medium pressure lamps, which are much higher power, a few grams are present.

Low pressure and medium pressure lamps do generate ozone if they have an envelop made of very pure (synthetic) quartz, which allows the 185 nm mercury emission to enter the air. This UV light is absorbed by oxygen in the air, which leads to the generation of ozone. Most UV lamps are made from a form of quartz that contains impurities that absorb the 185 nm emission entirely, so that they produce no ozone.

Report on the 3rd International Congress on Ultraviolet Technologies, Whistler, BC, Canada, 24 - 27 May 2005



Jim Bolton, Congress Organizer

As my wife, Ingrid Crowther, and I were driving through the beautiful Rocky Mountain scenery of British Columbia toward Whistler, I worried about the weather because it was cloudy and raining occasionally. I should not have worried; when we got to Whistler, the sun was shining and continued to shine throughout the entire UV Congress. Some delegates commented that I must have “connections upstairs”! Judging by the response to the survey I sent out, this UV Congress was an outstanding success from both a technical and personal viewpoint. Here are some of the comments I received: “Thanks to the organizers for an excellent conference!”, “Thoroughly enjoyable and educational. The information I received will be applied in our possible selection of UV Disinfection.”, “A rousing success, fantastic resource to the UV community, and important to our civilization in general.”, “I attend a lot of conferences. This was one of the best. Nice work!”, “An informative and interesting Congress. Great opportunity to network.”, “Being new to the industry and technology, I thought it was extremely helpful and very well orchestrated. Great Job!!”



A UV Congress does not happen without a lot of work behind the scenes. I wish to thank particularly **Kathy Harvey** (Manager of the IUVA Head Office), who worked hundreds of overtime hours to make sure that registration organization, facilities arrangements, travel arrangements and many other details assured a smooth operation of the Congress. Thank you, Kathy!

Finally, thanks to **Sam Jeyanayagam** for soliciting sponsorships, **Inder Singh** and **Dennis Mutti** for arranging the Post Congress Tour, **Ingrid Crowther** for helping at the Registration Desk, **Chris Schulz**, the Congress Treasurer and **Bob Hulsey**, IUVA President, and the students (**Jeff Brandy**, **Ray Cantwell**, **Jim Collins**, **Yangang Feng**, **Dave Gaithuma**, **Yu-Jen Liang**, **Hongfei Lin**, **Faisal Mahmud**, **Siva Sarathy**, **Dennis Uvbiana**, and **Changlong Wu**) who helped make sure that there were few technical hitches in the lecture rooms.

The UV Congress had 125 papers presented and 4 Plenary Speakers (two of the Plenary Talks are published in this issue) and comments from the Survey (“Very informative and highlighting the current UV treatment practices”; “Most presentations were well done and Q&A sessions were handled very well”) indicated that it was a great success. Thanks to **Steve Craik** and **Ron Hofmann** for the great job of organizing the Technical Program!



At the General Assembly, The new Board of Directors was elected (see News from IUVA). **Bob Hulsey** stepped down as IUVA President and introduced **Andreas Kolch** from Wedeco ITT Industries as the new IUVA President for 2005 – 2007.

A UV Congress could not operate without the support of sponsors. Thank you to **Aquafine**, **Associated Engineering**, **Black & Veatch**, **Calgon Carbon**, **Greater Vancouver Regional District**, **Hazen & Sawyer**, **Hydroqual**, **Infilco Delegremont**, **Malcolm Pirnie**, **Stantec**, **Trojan Technologies** and **Wedeco ITT Industries** for their support.

The Congress Banquet was held up a 20 min gondola ride (including a view of bears!) near the top of Whistler Mountain. Again from the comments received in the Survey (“Great food, awesome atmosphere”; “Awesome banquet – lots of fun and what a wonderful location!”), everyone had a great time!



On the financial side, the picture is not so rosy. Because the number of delegates (231) was considerably less than previous Congresses and also because the number of companies (15) that choose to exhibit was much less than had been anticipated. IUVA cannot operate on the basis of Membership revenue alone and relies on surpluses from Congresses, Conferences and Workshops to provide a major part of the IUVA annual revenue.

At the UV Congress Closing Session it was announced that the next UV Congress will be held jointly with the International Ozone Association (IOA). **Joop Kruithof** (President of IOA) and I signed a “Memorandum of Cooperation”. Current plans are to have the joint IUVA/IOA Congress on the Northeastern seaboard of the US sometime in August 2007.

Photo credits: Greg M’Lot, Ingrid Crowther, Ludwig Dinkloh and Tim Walton.

HOW CAN IUVA HELP SMALL WATER SYSTEMS?

JAMES P. MALLEY, JR.

Environmental Research Group, University of New Hampshire, Room 344 Gregg Hall, 5 Colovos Road, Durham, NH 03824-3591; E-Mail: jim.malley@unh.edu.

Note from the Editor: This article comes from the plenary presentation made by Jim Malley at the UV Congress in Whistler, BC, Canada in May 2005.

ABSTRACT

Often our attention is captured by very large environmental challenges such as providing billions of gallons per day of clean, safe drinking water for very large cities. However, the larger global public health challenge often lies with the small systems. Conservative estimates suggest that the lives of 2.5 billion people worldwide (the population of roughly 300 New York Cities) could be dramatically improved if organizations like the IUVA could provide technical knowledge and support to improve the applications of UV disinfection to small and very small water systems around the world.

The article provides an overview of the numbers and types of small systems including Point of Entry and Point of Use systems and reviews the challenges faced by small systems. A successful case study of using UV to improve small system water quality is also presented. The article closes with suggestions for how IUVA can proceed to help Small Systems worldwide with the long term goal of improving the lives of billions of people.

Ultraviolet (UV) disinfection has been applied to small systems for several decades and has attracted scores of small, medium and large companies supplying this market. This article is aimed at defining what is meant by a “small system”, how is this market addressed and regulated and where is it going.

SMALL SYSTEMS – WHERE HAVE WE BEEN?

The USEPA (2005) has defined size categories for drinking water treatment systems:

- Very Small Water Systems – serve 25 –500 people
- Small Water Systems – serve 501 –3,300 people
- Medium Water Systems – serve 3,301 –10,000 people
- Large Water Systems – serve 10,001 – 100,000 people
- Very Large Water Systems – serve >100,000 people

Table 1: Analysis of Small and Very Small Water Systems

Region	Number of Systems	Lives Affected (millions)
USA	159,400	122
North America	187,900	175
Globally	1,320,000	2,500

Typical water flow rates for Small Water Systems are 2 – 700 gpm (8 – 2,650 L/min).

As Table 1 shows, Small and Very Small Water Systems affect the lives of about 2.5 billion people annually.

The biggest problem facing small drinking water systems is lack of resources (WHO 2005). There is a scarcity of knowledgeable personnel, time and money (USEPA 2003); furthermore:

- Small System information is plentiful and can be obtained from numerous sources, but the Small System has no personnel to collect or download that information and no time to make sense of it.
- There can be a very high degree of misinformation, ignorance and apathy in small systems (“nothing wrong with our water”; “leave us alone”; “requiring treatment is just a money making scheme and is no benefit”).
- Small System infrastructure is heterogeneous, often low quality when purchased and not maintained until total system failure.
- Finally, Small Systems often have severe space constraints for locating any treatment (Klevens 2005).

Figure 1 illustrates that often Small Systems also face space constraints.



Figure 1: Illustration of the tight quarters in a Small Water System in New Hampshire (photo courtesy of Cynthia Klevens, New Hampshire Department of Environmental Services).

WHY MIGHT ULTRAVIOLET TECHNOLOGY BE SO HELPFUL TO SMALL SYSTEMS?

Ultraviolet disinfection systems have many advantages for Small Water Systems:

- Compact
- Chemical free
- Essentially operator free (plug and play)
- Relatively easy to maintain
- Minimal moving parts
- Relatively easy to monitor lamp output
- Relatively inexpensive
- A well developed point-of-entry (POE) and point-of-use (POU) product

The only regulations concerning UV disinfection systems for Small Water Systems are those developed by the National Sanitation Foundation (NSF International) in their NSF Standard 55 (Lubitz 2005). In that standard,

Point-of-entry (POE) systems are defined as (See Figure 2):

A system used to treat all or part of the water for the facility at the point where drinking water comes into the facility. For Class A systems, a single family shall be considered a facility.

Point-of-use (POU) systems are defined as:

A system used to treat water at a single tap or multi-taps but not for the entire facility.

SMALL SYSTEM UV PROBLEMS

UV disinfection systems are sometimes manufactured by small companies with little expertise. The buyers of these systems are often given few instructions on how to operate the units and do not understand the need for maintenance. Finally, there is the lack of regulations for small UV systems in most jurisdictions. This has led to many problems:

- Hundreds of small UV systems have been installed without any water quality information; for example, percent transmittances (UVT) values <10% and turbidities >NTU.
- Thousands of UV systems have been installed without any method to control flow; for example, a 2 gpm unit being operated at 10 gpm.
- UV systems have been operated with lamps down to 10% of their new output, completely burned out or just turned off!
- UV Systems have been installed without any sensor or even a means to determine if the UV lamp is on.
- UV reactors have been found operating filled with mud/sediments that are covering the lamps.
- UV sensors have been found reading 100% all the time, even when the lamp is removed from the reactor.

Then there is outright fraud and rip-offs:

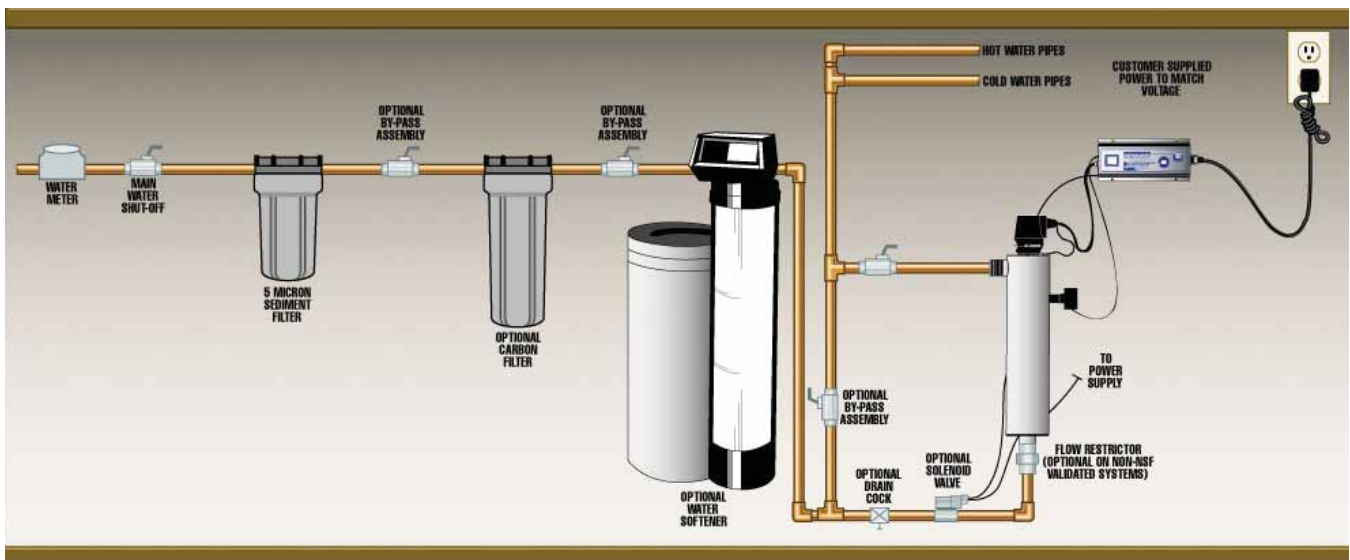


Figure 2: Example of a Point-of-Entry UV systems (diagram courtesy of Melissa Lubitz of R-Can Environmental, Inc. Guelph, ON, Canada).

- No UV lamp in the system at all
- No germicidal lamp “black light” in the system
- No power supply – sometimes not even a plug
- UV Lamps installed without sleeves

HOW CAN IUVA HELP SMALL SYSTEMS?

IUVA has the key resource – dedicated volunteer personnel with large amounts of UV technology experience. IUVA has the ability to provide outreach and help with the education and to answer questions posed by small system personnel. It is true that “no one has the time”, but when dedicated volunteers decide the cause is worth doing they make the time.

WHERE DOES IUVA GO FROM HERE?

Plans began in 2004 to establish the “IUVA Small Systems Topical Group”. In the past year the group has provided:

- educational seminars to three rural water associations in the US
- an educational seminar at the Water Quality Association (WQA) Annual Meeting in March-April 2005.

The goal should be to double the Group’s Activities during this next year. IUVA experts can help Small Systems with the selection, design, and operation of UV disinfection units.

ONE EXAMPLE OF HELPING A SMALL SYSTEM

As reported in a study by Protasowicki and Malley (2002), the town of Norfolk is a semi-rural suburban community located on an upper valley of the Charles River about 20 miles southwest of Boston, MA. Norfolk is supplied by groundwater pumped from two wells – the Gold Street Well and the Spruce Road Well. Both wells draw from the

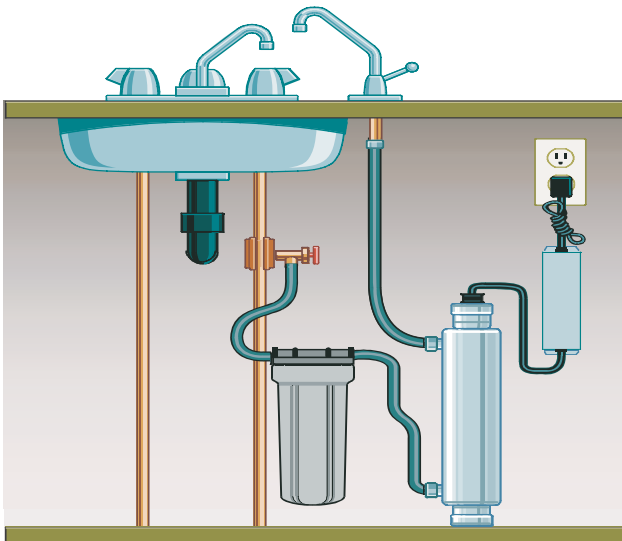


Figure 3: Example of a Point-of-Use (POU) UV System (diagram courtesy of Melissa Lubitz of R-Can Environmental, Inc. Guelph, ON, Canada).

Charles River watershed. Spruce Road is Norfolk’s primary water supply and is typically operated at 500 gpm with a maximum flow of 600 gpm and the total annual water production in 2003 was 197 million gallons (~2,800 people served).

High copper levels in 1999-2000 prompted Massachusetts Department of Environmental Protection (MADEP) to issue a State Administrative Consent Order requiring Norfolk to optimize its corrosion control measures. Norfolk hired Dufresne-Henry to evaluate alternatives and recommend optimization for the Spruce Road Well. Dufresne-Henry recommended venturi aeration to drive off CO₂ and augment the existing KOH feed system. Since aeration represents a break in the hydraulics and potential for microbial contamination, it was also recommended that UV disinfection be implemented following the venturi system.

The MADEP indicated that both venturi aeration and UV disinfection represented innovative technologies and required a pilot study prior to approval to proceed with full scale design. Dufresne-Henry performed the venturi aeration pilot work and worked with the University of New Hampshire (UNH) to perform the UV disinfection pilot study simultaneously. Figure 4 shows the setup for the UNH pilot study.

Pilot Testing

The pilot testing was conducted at 2 to 10 gpm. In the parallel venturi pilot study, the aeration system was monitored for changes in pH and dissolved oxygen of the water as well as mechanical and operational reliability.

The UV system was run at a delivered UV Dose of 60 mJ/cm² to be consistent with another state approved groundwater UV disinfection system (Westford, MA). The UV system was monitored for:

- Changes in groundwater quality tastes and odors (TAO), UVT.
- Sensor window and sleeve fouling rate
- UV lamp sensor response
- Bacterial inactivation
- Mechanical and operational reliability
- Delivered UV Dose

The venturi aeration system provided reliable and cost effective removal of CO₂ raising the pH to neutral values while attaining dissolved oxygen saturation of the water. The UV pilot demonstrated:

- Reliable operation with no detectable changes in the taste, odor and color of the water;
- Consistent and stable power and UV lamp output;
- Minimal UV sleeve and quartz window fouling rate;
- Consistently high influent UVT values;
- UV effluent bacterial counts of 0/100 mL throughout;

The Full-scale Facility

Based on the pilot testing results the MADEP approved the full-scale design of venturi aeration and UV disinfection for Norfolk's Spruce Road Well facility. The Spruce Road Treatment Facility was retrofit with dual pressurized Venturi aerators and a Wedeco-Ideal Horizons LPHO Series B300 UV Reactor at maximum flow rate of 600 gpm to deliver a UV dose of 60 mJ/cm² at end of lamp life at a minimum %UVT of 95%. Figure 5 shows the installed UV reactor.

The full-scale facility upgrade also included:

- A new generator to provide backup power
- An upgraded instrumentation and control system
- New internal and external facility security systems
- Improved facility piping and access

The MADEP required that the UV System be validated. Thus an onsite full-scale UV system validation, using protocols consistent with the USEPA UV Disinfection Guidance Manual, was performed by UNH using the MS-2 bacteriophage virus. The UV System passed validation and has been in operation since 2003.

Cost and Financing

The Project capital cost was about \$1.00 per gallon per day of capacity (\$720,000). The Project operation and maintenance costs are \$0.04 per 1,000 gallons treated. Finally, financing was achieved through a zero interest loan from the State Safe Drinking Water Act Revolving Loan Fund.

A Real Winner

Norfolk's New Water Treatment Facility using innovative technologies to control corrosion and to provide disinfection received the 2003 American Consulting Engineer's Council – Massachusetts Chapters' Engineering Excellence Platinum Award.

WHERE DOES IUVA GO FROM HERE TO HELP SMALL SYSTEMS?

Many organizations have been concerned with and are attempting to help small systems worldwide. The issue presents very large challenges from among technical, social and geopolitical aspects. Clearly, the issues of



Figure 4: Setup for the UV disinfection pilot study at Norfolk, MA .



Figure 5: Wedeco – Ideal Horizons UV reactor installed at the Norfolk Spruce Road Well facility.

assisting small and very small systems in North American and in most of what is commonly referred to as the developed nations is very, very different than addressing issues in third world countries. Here are just a few initial ideas on how IUVA can proceed:

- A Small Systems Hotline or Website?
- Dedicated and motivated volunteers from IUVA to assist small systems directly
- Outreach to colleagues in academia and in businesses in third world nations to promote the development and use of UV systems at the local level
- We have established the beginning of a Small System Topical Group which is open to all IUVA Members – everyone can play if you are interested, and can make the time please contact Jim Malley at jim.malley@unh.edu.
- 2.5 billion people are waiting for your help !

ACKNOWLEDGEMENTS

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WEIGHTED FLUENCE-BASED PARAMETERS for Assessing UV and UV/H₂O₂ Performance and Transferring Bench-Scale Results to Full-Scale Water Treatment Reactor Models

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Note from the Editor: This article comes from the plenary presentation made by Charles Sharpless at the UV Congress in Whistler, BC, Canada in May 2005.

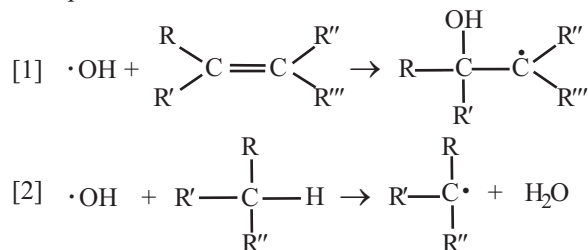
ABSTRACT

The lack of a standard approach for presenting contaminant remediation kinetics using the UV/H₂O₂ advanced oxidation process (AOP) for water treatment hampers efforts to cross-interpret results and apply literature data for the prediction of treatment efficiencies in new experimental settings. Properly weighted UV fluence rates can be used to define parameters for assessing the UV/H₂O₂ AOP that models predict to be essentially invariant with reactor geometry and lamp type. A pollutant action spectrum-weighted average fluence-based rate constant characterizes the direct photolysis portion of the reaction, while an H₂O₂ action spectrum-weighted average fluence rate-normalized ·OH concentration characterizes the indirect photolysis portion of the reaction. Experimental data for the photolysis of atrazine gathered at two different laboratories support the validity of the model. Using these parameters, a relatively simple kinetic model is presented that allows prediction of pollutant degradation rates in any reactor for which the pollutant and H₂O₂ weighted fluence rates can be calculated.

Keywords: Advanced oxidation process; water treatment; UV; hydrogen peroxide; atrazine; kinetics; photochemical modeling.

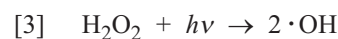
INTRODUCTION

Advanced Oxidation Processes (AOPs) continue to attract interest from academia, industry, and government for their potential to destroy hazardous air and water pollutants. There are several available AOPs, all of which have as a common feature generation of the hydroxyl radical (·OH). These radicals react rapidly and nonspecifically with organic chemicals via one of two mechanisms, addition to multiple bonds or H-atom abstraction:



These reactions generate carbon-centered radicals that undergo further reaction with molecular oxygen to destroy the organic molecule. In theory, AOPs are capable of completely mineralizing organic chemicals, with the end products being only CO₂, H₂O, and mineral acids. In practice, the amount of time and/or forcing conditions required make this goal unattainable, and best practice dictates that the reaction only be carried out until non-hazardous by-products are present.

Of the AOPs that involve ultraviolet (UV), two are particularly noteworthy for the frequency with which they appear in research journals and their practicality for application to water treatment. Semiconductor photocatalysis using UV in combination with solid TiO₂ particles has been studied for use in water and air treatment (Fujishima and Rao 1998). In water, the heterogeneous nature of the process raises several practical issues that appear to make it uneconomical on large scales. Chief among these are the limited extent to which light can penetrate the heterogeneous suspensions making it possible to treat only a relatively small volume of water per photon. Additionally, the process efficiency is closely associated with the extent to which pollutants adsorb on the semiconductor surface, and fouling of the surface by natural water constituents will disrupt the process. Finally, semiconductors also display low quantum yields of ·OH (Sun and Bolton, 1996). These limitations are not faced by another popular UV-based AOP, the UV/H₂O₂ process. Hydrogen peroxide is soluble in water and undergoes direct photolysis to produce dissolved ·OH:



Approximately 50% of the liberated ·OH radicals rapidly recombine in the water “solvent cage”. Thus, the yield of ·OH is one mole per mole of H₂O₂ photolyzed (Baxendale

and Wilson 1957). The UV/H₂O₂ process is homogenous, in contrast to the UV/TiO₂ process, and the main factors that determine its efficiency are the rate at which the pollutant reacts with ·OH and the extent to which the water matrix screens light from H₂O₂ and competes with the pollutant for ·OH. As a homogenous process, UV/H₂O₂ is especially simple to apply for treating large volumes of water. For this reason, it is in current use for full-scale water treatment and will likely see increased use in the future (Water and Wastes Digest 2003).

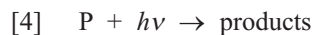
To evaluate the effectiveness of UV/H₂O₂ and to optimize its use, some researchers employ bench-scale experiments while others use pilot-scale reactors. Unfortunately, there has been little work done to facilitate interpretation of bench-scale results so that they may be used to predict reactor performance. In this regard, two issues are noteworthy. First, bench-scale researchers often present their results in terms of parameters that either are not directly transferable to full-scale reactors (e.g., time-based rate constants) or require fairly complex models to use in predicting reactor performance (e.g., quantum yields). Second, the terminology and units used by photochemists and water treatment engineers are not always consistent. For example, in current engineering practice the photonic energy delivered to solution is usually expressed in fluence units (e.g., mJ cm⁻²), while photochemists often use photon flux (einsteins L⁻¹). Thus, it is desirable to bridge the gap between these two camps and to make it simpler for water treatment engineers to use bench-scale experimental results in reactor models.

This article introduces two new parameters designed to make bench-scale UV/H₂O₂ results transferable to reactor models based on the average fluence rate in the reactor. To do this, it is necessary to specify two different fluence rates: one weighted by the pollutant action spectrum, and one weighted by the H₂O₂ action spectrum. Bench scale results that must be specified in terms of these fluence rates are the direct photolysis rate constant and the steady-state ·OH radical concentration. Given the ability to accurately model fluence rates in a reactor, these parameters can be used in a simple model to predict photodegradation rates in any reactor. Furthermore, these parameters are independent of optical pathlength and are relatively insensitive to the lamp spectrum. The major restriction is their applicability to a specific pollutant and water type.

CHARACTERIZING THE UV/H₂O₂ PROCESS PERFORMANCE

Many researchers characterize AOP performance by comparing overall rates of pollutant degradation. This can be a useful approach in some cases, but it does not allow different researchers, using different conditions, to compare their results or understand why their results may differ. For the UV/H₂O₂ process, a more thorough approach exam-

ines the rates at which two simultaneous reactions occur, direct photolysis of the target pollutant (P) and reaction of the pollutant with ·OH, or indirect photolysis.



Any scheme for characterizing the UV/H₂O₂ process performance should involve quantifying the rates (or extents of reaction) of both of these reactions, individually, under the test circumstances. While this may sound simple, it requires a bit of calculation that derives from basic photochemical theory. A thorough description of the mathematical model involved can be found elsewhere (Sharpless and Linden 2003), and only a brief outline is given here.

Reactions 4 and 5 are elementary (i.e., they show the mechanism). For low concentrations of P in a batch reactor, the overall pollutant destruction rate can be written as follows:

$$[6] \quad \frac{d[P]}{dt} = (k'_d + k_{\text{OH}}[\cdot\text{OH}])[P] = k'_t[P]$$

Here, k'_t is the observed first-order rate constant (units are usually s⁻¹), k'_d is the pseudo-first order rate constant for direct photolysis, k_{OH} is the second order rate constant for reaction between P and ·OH (units of M⁻¹ s⁻¹), and the square brackets represent molar concentrations. This equation integrates to give first-order kinetics in the presence and absence of H₂O₂, and representative data are shown in

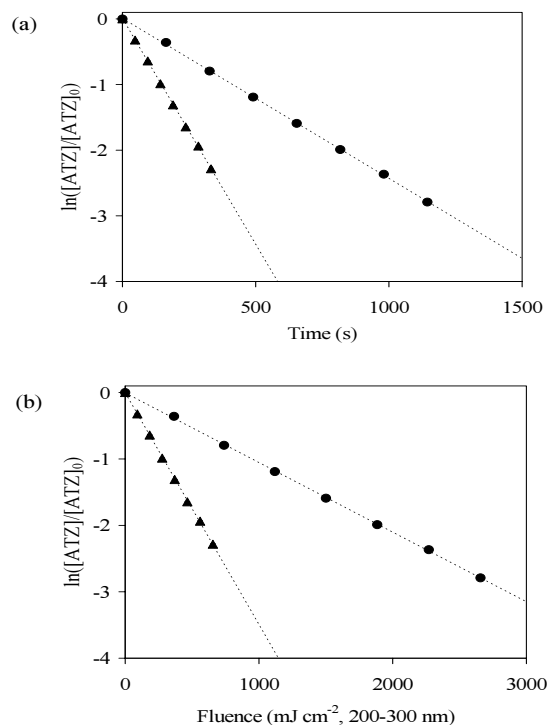


Figure 1: First order kinetic analysis for ATZ photolysis with a medium pressure Hg lamp in synthetic drinking water: direct photolysis (●), with 2.9 mM H₂O₂ (▲). (a) time-based analysis; (b) fluence-based analysis.

Figure 1a for atrazine (ATZ) photolysis with a 1 kW medium pressure mercury lamp in a synthetic drinking water.

The quantities k_d and $[\cdot\text{OH}]$ are functions of the spectral distribution of the UV light and its intensity in the water, and they can be predicted from photochemical theory using the following equations:

$$[7] \quad k_d = \sum_{\lambda} k_{a,\lambda} \Phi_{\lambda}$$

$$[8] \quad [\cdot\text{OH}] = \frac{\sum_{\lambda} k_{a(\text{H}_2\text{O}_2),\lambda} \Phi_{\text{OH},\lambda} [\text{H}_2\text{O}_2]}{\sum_i k_{s,i}}$$

Here, $k_{a,\lambda}$ is the specific rate of light absorption by P (einstains $\text{mol}^{-1} \text{s}^{-1}$), Φ_{λ} is the direct photolysis quantum yield (the fraction of molecules that absorb light and undergo photolysis, mol einstein^{-1}), $k_{a(\text{H}_2\text{O}_2),\lambda}$ is the specific rate of light absorption by H_2O_2 , $\Phi_{\text{OH},\lambda}$ is the hydroxyl radical quantum yield (1.0 in water), and $k_{s,i}$ are pseudo-first order rate constants for reaction of $\cdot\text{OH}$ with water constituents other than P. For monochromatic light the summations over wavelength do not apply.

To quantify the individual rates of reactions 4 and 5, k_t is measured experimentally. Then, k_a for P is calculated and equation 7 is used to find the value of k_d . This approach requires knowledge of the intensity and spectral distribution of the UV source, the absorption spectrum of P, the direct photolysis quantum yield(s), and the optical path-length in solution (Sharpless and Linden 2003). Once k_d is calculated, the product $k_{\text{OH}}[\cdot\text{OH}]$ is found by difference from k_t . The value of k_{OH} may be known or measured, allowing calculation of $[\cdot\text{OH}]$.

Experiments may then be compared on the basis of the rates of reactions 4 and 5 or by comparing the experimental k_d and $[\cdot\text{OH}]$ values.

FLUENCE-BASED ASSESSMENT PARAMETERS

Many reports of photodegradation kinetics express k_t and k_d in units of inverse time, leading this author to use the subscript t on the overall rate constant above. While this is a simple parameter to measure, several authors have recently emphasized its lack of value as a predictor of reaction rates that will be obtained with different reactor geometries (Bolton and Stefan 2002; Sharpless and Linden 2003); k_t is a function of solution transmittance and the incident irradiance, which vary with experimental conditions, leading to a variable rate “constant”. In an effort to facilitate comparisons of rate constants between labs, some researchers have presented results in terms of average fluence-based rate constants (k_f). These represent the extent of degradation per unit of fluence (e.g., mJ cm^{-2}) delivered to the solution over a specified wavelength range, corrected for light screening by the water matrix. The average flu-

ence rate (E'_{avg}) may be calculated from the incident fluence rate (E'_0), the solution absorption spectrum, and the optical pathlength using established procedures (Morowitz 1950). Once E'_{avg} is specified, k_t and k_f can be related by,

$$[9] \quad k_f = \frac{k_t}{E'_{\text{avg}}}$$

The data analysis with respect to fluence also leads to first-order kinetics as shown in Figure 1b, which uses the same ATZ photolysis data in Figure 1a.

For direct photolysis with *monochromatic* radiation, Bolton and Stefan (2002) have shown that k_f is invariant with experimental geometry and water transmittance. For *polychromatic* radiation, the equations involve summations over wavelength in both the numerator and denominator of equation 9. Importantly, this implies that k_f for polychromatic radiation will only be constant with changing conditions if k_a for P changes by the same percent as does E'_{avg} .

The results of an inter-laboratory study of ATZ degradation illustrate some of these points (Stefan et al., 2001). Two different labs, one at Duke University and one at Bolton Photosciences Inc. (BPI), conducted fluence-based kinetic studies of ATZ removal in the same water and in the absence and presence of 2.9 mM H_2O_2 (100 mg/L). Each lab used a different ATZ concentration and different solution depths. With the fluence rate defined over 200 to 300 nm, the results in Table 1 were obtained. With low-pressure mercury lamps (monochromatic at 254 nm), very good agreement between k_f values was obtained, in keeping with the expected invariance for monochromatic radiation. However, a large discrepancy exists between the values obtained with medium-pressure mercury lamps (polychromatic radiation).

Measurements showed that the lamp spectra differed between Duke and BPI (Figure 2a). This fact, and the different solution depths, resulted in k_a for ATZ being higher per unit E'_{avg} at BPI than at Duke. Calculated k_a values for $E'_{\text{avg}} = 2.4 \text{ mW cm}^{-2}$ are shown in Figure 2b. Under these conditions, more ATZ is destroyed per unit E'_{avg} at BPI. A similar situation holds in the presence of H_2O_2 , although

Table 1: Fluence-based rate constants for ATZ removal ($\text{cm}^2/\text{mJ} \times 10^3$, over the wavelength range 200–300 nm)

	LP	LPH	MP	MPH
Duke	0.54	4.1	1.1	3.7
BPI	0.52	3.8	1.5	5.4

LP = low pressure mercury lamp; MP = medium pressure mercury lamp.

LPH = LP + 2.9 mM H_2O_2 ; MPH = MP + 2.9 mM H_2O_2 .

in this case both equations 7 and 8 must be used to model the experimental data. This requires measurement of Φ_λ for ATZ. Estimates and direct measurements indicate that below 250 nm $\Phi_\lambda \sim 0.055$ and above 250 nm $\Phi_\lambda \sim 0.038$ (Stefan et al. 2001; Sharpless et al. 2003). Using these parameters, it is possible to model accurately the effects of H_2O_2 observed at both Duke and BPI (Stefan et al. 2001). These results show that k'_f , as defined here, may not be the best parameter for comparing UV and UV/ H_2O_2 results. Furthermore, no simple procedure emerged from these studies to quantify the indirect photolysis efficiency.

To establish a fluence-based means for assessing indirect photolysis rates, Rosenfeldt and Linden (2005) recently introduced the R_{OH} concept, which specifies the $\cdot\text{OH}$ concentration obtained for a given E'_{avg} . This quantity can be measured by using a probe chemical that reacts with $\cdot\text{OH}$ but does not undergo substantial direct photolysis under the test conditions. Application of equation 6 then allows calculation of $[\cdot\text{OH}]$, and dividing by E'_{avg} yields R_{OH} . In any water, as the H_2O_2 concentration is increased, R_{OH} will increase. Waters high in $\cdot\text{OH}$ scavengers or of low transmittance will have lower R_{OH} values than clear waters (where light absorption by H_2O_2 is high) or waters that are low in $\cdot\text{OH}$ scavengers. This concept is extremely

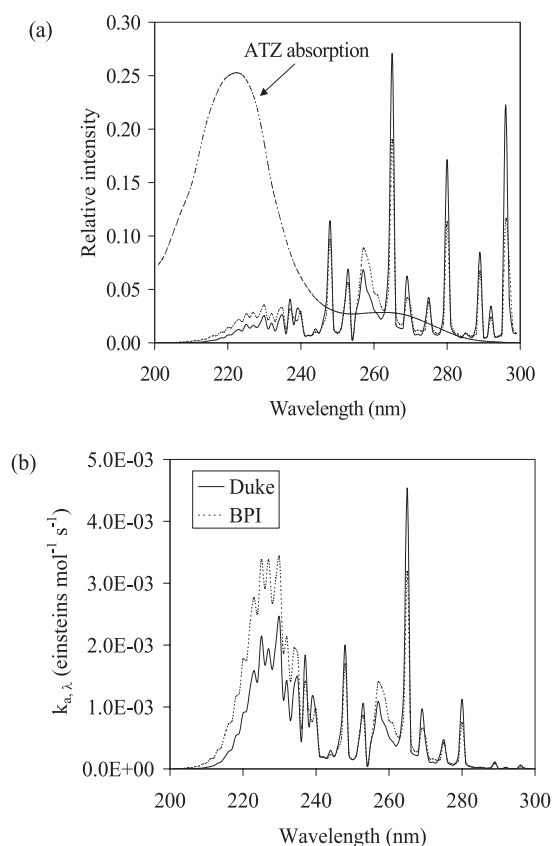


Figure 2: (a) Lamp spectra at Duke (—) and BPI (---) with ATZ absorption spectrum overlain; (b) calculated specific rates of light absorption with lamps at Duke and BPI for 1 μM ATZ for equal average irradiance levels (2.4 mW cm^{-2}).

useful in that it specifies a required fluence rate to achieve a certain $\cdot\text{OH}$ concentration for a given water. However, unless the fluence rate is properly defined, R_{OH} may be just as variable between experimental arrangements as is k'_f .

WEIGHTED FLUENCE-BASED ASSESSMENT PARAMETERS

It is possible to define k'_f and R_{OH} values for a given pollutant that are relatively invariant with experimental parameters except the water matrix. This requires specification of two different E'_{avg} values: one weighted by the pollutant action spectrum, and the other weighted by the H_2O_2 action spectrum. The first is used to determine pollutant-weighted k'_f values (k_f^w), and the second is used to determine H_2O_2 -weighted R_{OH} values (R_{OH}^w). The weighting procedure is identical to that used in UV disinfection, where E'_{avg} values are weighted by the pathogen action spectrum or the DNA absorbance spectrum (Linden and Darby 1997). To use this approach, one must know the action spectrum (the relative degradation rate versus wavelength) of the pollutant and H_2O_2 . In photochemical parlance, the absorption spectrum and the quantum yield are distinguished. The absorption spectrum specifies the strength of light absorption, usually in terms of the molar absorption coefficient, ϵ ($\text{M}^{-1} \text{ cm}^{-1}$). The quantum yield, Φ (mol einstein^{-1}) specifies the fraction of molecules that are destroyed per photon. The product $\epsilon \Phi$ versus wavelength gives the action spectrum. The action spectrum for H_2O_2 is identical to its absorption spectrum because $\Phi_{\text{OH}} = 1.0$ over the wavelength range of interest (Baxendale and Wilson 1957). In practice, one may measure both ϵ and Φ , or the action spectrum may be measured directly as the relative rate (per photon) versus wavelength.

For a given pollutant, the weighted E'_{avg} is defined here as:

$$[10] \quad E'_{\text{avg}}(\text{P}) = \sum_{\lambda} \frac{E'_{\text{avg},\lambda} \epsilon_{\lambda} \Phi_{\lambda}}{(\epsilon \Phi)_{\text{max}}}$$

A similar equation is used to obtain the H_2O_2 weighted E'_{avg} , except that the Φ values cancel (they are all 1.0) and the ϵ values are from the H_2O_2 absorption spectrum. Using the properly weighted E'_{avg} values, we define the parameters,

$$[11] \quad k_f^w = \frac{k'_t}{E'_{\text{avg}}[\text{P}]}$$

$$[12] \quad R_{\text{OH}}^w = \frac{R_{\text{OH}}}{E'_{\text{avg}}[\text{H}_2\text{O}_2]}$$

Here, k_f^w is the pollutant-weighted, average fluence-based rate constant, R_{OH}^w is the peroxide-weighted, average fluence-normalized R_{OH} value, and the other symbols have been previously defined. It is very important to note that

k_f^w must be determined from direct photolysis experiments to be useful in the model given below. The key feature of equations 11 and 12 is that the numerator and denominator vary at almost the same rate with changing optical pathlength and, within certain limits, lamp spectrum. This is because the weighted E'_{avg} values vary at almost the same rate as the k_a values making k_f^w and R_{OH}^w virtually constant.

For monochromatic radiation, a thorough derivation gives (Sharpless, manuscript in preparation):

$$[13] \quad k_f^w = \frac{\ln(10) (\varepsilon_P \Phi_P)_{\text{max}}}{U}$$

$$[14] \quad R_{\text{OH}}^w = \frac{\ln(10) [\text{H}_2\text{O}_2] (\varepsilon_{\text{H}_2\text{O}_2} \Phi_{\text{H}_2\text{O}_2})_{\text{max}}}{U \sum_i k_{s,i}}$$

Here, the subscripts P and H_2O_2 refer to the pollutant and H_2O_2 , respectively, $k_{s,i}$ values are pseudo first-order rate constants for scavenging of $\cdot\text{OH}$ by species i , and U is the photonic energy at the given wavelength (J einstein^{-1}). Equation 13 necessarily bears resemblance to the monochromatic expression for k_f presented by Bolton and Stefan (2002). In equation 13, the only parameter determining the value of k_f^w is the photon energy for a given wavelength; note that multiplying by U gives a truly invariant constant. In equation 14, only the nature of the water ($\cdot\text{OH}$ scavenging), the concentration of peroxide, and the photon energy for a given wavelength affect R_{OH}^w again, multiplying by U gives a true constant. For polychromatic radiation, the equations involve complex summations that lead to less compact final expressions. For both poly- and monochromatic radiation, these parameters vary with the photon energy for a given wavelength, unless appropriate corrections are made. However, there are few UV sources in actual application, with the result that for common lamps, the spectra are not so drastically different that major variations in k_f^w and R_{OH}^w will be seen on changing lamps.

The utility of these concepts can be seen by revisiting the Duke and BPI ATZ data. Recalculation of the direct photolysis rate constants using ATZ weighted fluence rates for the medium-pressure Hg lamps gives $k_f^w = 7.0 \times 10^{-3} \text{ cm}^2 \text{ mJ}^{-1}$ at Duke and $7.2 \times 10^{-3} \text{ cm}^2 \text{ mJ}^{-1}$ at BPI, a considerably better agreement than when unweighted fluence rates were used (Table 1). For the low-pressure lamps, both labs obtained $7.2 \times 10^{-3} \text{ cm}^2 \text{ mJ}^{-1}$. Thus, the k_f^w values from both labs, with both types of lamp, are identical within the error inherent in the experiments. Note that using equation 13, the k_f^w value at 254 nm is predicted to be $7.9 \times 10^{-3} \text{ cm}^2 \text{ mJ}^{-1}$, which is slightly higher than the experimental values. Although not shown here, k_f^w values for polychromatic radiation can also be calculated theoretically, and values of 7.5×10^{-3} and $7.4 \times 10^{-3} \text{ cm}^2 \text{ mJ}^{-1}$ are predicted for the medium-pressure lamps at Duke and BPI, respectively, in good agreement with the experimental values.

Although $\cdot\text{OH}$ concentrations were not measured in this study, they can be estimated using equation 8. Doing so allows calculation of the R_{OH}^w values obtained in each experiment. These data, along with the k_f^w values, are summarized in Table 2. Note that k_f^w values are not given for 2.9 mM H_2O_2 because the overall rate constant in this case contains a contribution from indirect photolysis, in which case k_f^w is not an appropriate evaluation parameter.

Model studies (Sharpless, manuscript in preparation) also show that the k_f^w and R_{OH}^w values vary little with the optical pathlength for polychromatic irradiation. For example, changing the solution depth from 1 to 100 cm in a model for ATZ using the spectrum of the medium-pressure lamp at BPI changes k_f^w from 7.3×10^{-3} to $7.4 \times 10^{-3} \text{ cm}^2 \text{ mJ}^{-1}$. With the same pathlengths and 2.9 mM H_2O_2 , the model predicts R_{OH}^w values of 1.3×10^{-11} and $1.4 \times 10^{-11} \text{ M cm}^2 \text{ mW}^{-1}$.

Finally, a model study of the effect of lamp spectrum shows that these parameters should be essentially constant

Table 2: Weighted fluence-based parameters for ATZ removal. Abbreviations are given in Table 1

		LP	LPH	MP	MPH
Duke	k_f^w ($\text{cm}^2 \text{ mJ}^{-1}$)	7.2×10^{-3}	N/A	7.0×10^{-3}	N/A
	R_{OH}^w ($\text{M cm}^2 \text{ mW}^{-1}$)	—	1.4×10^{-11}	—	1.4×10^{-11}
BPI	k_f^w ($\text{cm}^2 \text{ mJ}^{-1}$)	7.2×10^{-3}	N/A	7.2×10^{-3}	N/A
	R_{OH}^w ($\text{M cm}^2 \text{ mW}^{-1}$)	—	1.4×10^{-11}	—	1.4×10^{-11}

for all common lamp types in present operation. Figure 3 shows a set of lamp spectra (low- and medium-pressure Hg and a blackbody spectrum) overlain with a water absorption spectrum. Using these spectral data, assuming 1 mM ATZ, 0.29 μM H_2O_2 , some assumptions about $\cdot\text{OH}$ scavenging, and an optical pathlength of 5 cm, calculations give the k_f^w and R_{OH}^w values shown in Table 3. Even with these drastic changes in lamp spectrum, the weighted fluence-based parameters are incredibly constant. Thus, for practical purposes k_f^w can be considered a true constant that varies only with pollutant, and R_{OH}^w values can be considered to vary only with H_2O_2 concentration and water quality.

A WEIGHTED FLUENCE-BASED TRANSFERABLE MODEL

The weighted fluence-based parameters k_f^w and R_{OH}^w offer a powerful and simple way to transfer expected kinetic results between experimental arrangements. All that is required for applying them under new experimental conditions is that the weighted fluence rates, $E'_{\text{avg}}(P)$ and $E'_{\text{avg}}(\text{H}_2\text{O}_2)$ be calculable. With these parameters, the

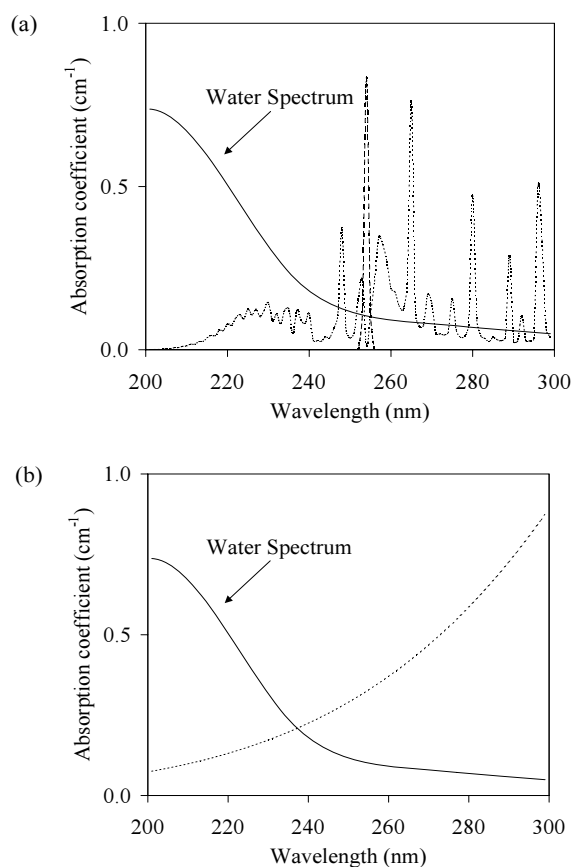


Figure 3: Model water and lamp spectra for calculating and for ATZ. Parameters described in detail in text: (a) water absorbance and low- (dashes) and medium-pressure (dots) lamp spectra; (b) water absorbance and blackbody emission spectrum

extents of pollutant degradation can be predicted for a given exposure time t using equation 15.

$$[15] \quad \ln\left(\frac{[P]_0}{[P]}\right) = \left[\left(k_f^w E'_{\text{avg}}(P) \right) + k_{\text{OH}} \left(R_{\text{OH}}^w E'_{\text{avg}}(\text{H}_2\text{O}_2) \right) \right] \times t$$

This equation accurately models the results with and without H_2O_2 for the Duke/BPI ATZ study, and further experimental tests of its validity should be conducted.

ACKNOWLEDGEMENTS

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Table 3: k_f^w ($\text{cm}^2 \text{mJ}^{-1}$) and R_{OH}^w ($\text{M cm}^2 \text{mW}^{-1}$) values calculated using spectral data in Figure 3 with $[\text{ATZ}] = 1 \mu\text{M}$, $[\text{H}_2\text{O}_2] = 0.29 \text{ mM}$, and a 5 cm pathlength.

	LP	MP	Blackbody
k_f^w	7.9×10^{-3}	7.4×10^{-3}	7.5×10^{-3}
R_{OH}^w	2.6×10^{-12}	2.3×10^{-12}	2.5×10^{-12}

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ACCURATE MEASUREMENT OF UV LAMP OUTPUT

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ABSTRACT

There are many sources of error in measuring UV output of a lamp. Through use of a goniometric measurement technique and careful selection of equipment, accurate, repeatable lamp measurements can be achieved. A protocol is provided that should allow multiple labs to achieve the same results. A number of problems and concerns – related to UV-measurement accuracy – are described and have been addressed in this draft protocol.

Keywords: UV Measurement, Standard Protocols, Sources of Error.

INTRODUCTION

Measurements of total output and efficiency of UV lamps often vary widely from one lab to another. The lack of a standard method is causing uncertainty and distrust in the UV industry. A standard, reproducible method would provide much needed consistency and the ability to compare claims by competing suppliers. This paper is intended to promote adoption of such a standard method. A suggested protocol is included in later in this article. This protocol is intended to facilitate reproducible, accurate measurements in many different laboratories. It is hoped that this protocol will serve to initiate the development of a widely accepted standard protocol for the UV industry.

THEORETICAL BASIS

The total power from a light source is often measured by placing the source inside an integrating sphere and comparing the resulting measurement with that of a calibrated source lamp. Unfortunately, most disinfection lamps are too large to use this method, and most spheres have poor reflectance and durability in the UVC wavelength range.

A suitable method for measuring total output of relatively large UV lamps is to use the divergence theorem, which can be paraphrased to state that the integral of irradiance over any closed surface is equal to the power output enclosed within the surface. There are several important points in using this theorem accurately:

1. The measured quantity must be irradiance, namely the total light power incident on a tiny area divided by that area. This requires that the sensor used must have a cosine response versus the angle of incident light beams.
2. The integration of the irradiance can be over any closed volume, but the irradiance must be known over the entire surface of this volume. This means

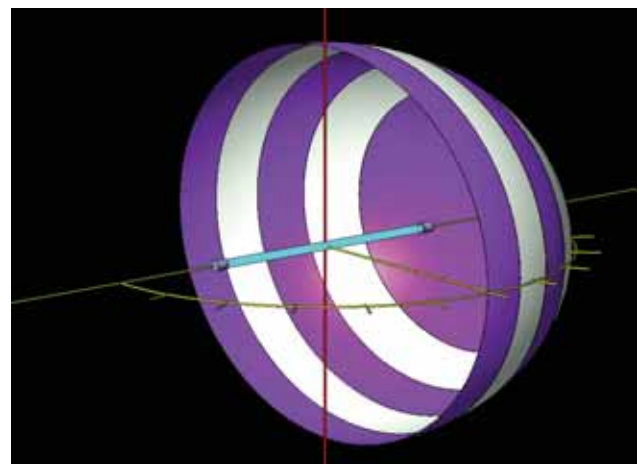
that a single point measurement is inadequate unless the spatial irradiance distribution is already known. The divergence theorem can be applied to lamp measurements by using goniometric techniques. If the lamp output is axisymmetric (a good approximation for a low-pressure mercury arc lamp), then the number of required measurements is relatively small.

Measurement Surface

The simplest integration surface for an axisymmetric lamp is a sphere large enough to enclose the lamp. By choosing a spherical integration volume the necessary measurements can be conducted quickly and accurately, simply by rotating a horizontal lamp about a vertical axis through its center. The integration volume can be seen in Figure 1. The irradiance is approximately constant for each circular strip.

Although a cylindrical volume could also be used, the required linear motion of the detector or lamp is more dif-

Figure 1: Schematic of the integration volume for a goniometric measurement.



ficult to achieve. Using multiple detectors in a linear array brings in additional errors.

Some laboratories have attempted to use the divergence theorem by taking a single irradiance measurement near the lamp and assuming the irradiance is constant over a surrounding cylindrical surface. This assumption is not necessarily correct and this method can lead to large errors. The area of the integration surface is directly proportional to the radius from the lamp center, which means that errors in area are larger for small radii. For example, a 1 mm error in the radial position of the detector represents a 4% error at 2.5 cm but only a 0.05% error at 200 cm. Clearly far-field measurements are preferable from this standpoint.

It has also been proposed that a spatial distribution model be used to calculate total lamp output from a single irradiance measurement. Our experience indicates that Point Source Summation method, commonly used in the disinfection industry, does not accurately predict the spatial distribution of irradiance or fluence rate around a lamp, and will result in large errors in calculated lamp output.

Detector Characteristics

As stated previously, a detector for goniometric measurements should have a Lambertian or cosine response with angle. This characteristic results in the detector weighting the incident radiation by the cosine of the angle of incidence. This is a necessary condition for applying the divergence theorem. The Lambertian characteristic must be met for angles up to that subtended by the lamp at the detector. Measurements taken near the lamp require an extremely good diffuser, since the lamp subtends a very large angle at the detector. By contrast, far-field measurements only require cosine response over a much smaller range of angles. All manufacturer's claims of cosine response must be verified in the UVC range.

CORRECTION FOR TEMPERATURE IN DISINFECTION

The output of a low pressure mercury vapor lamp is affected by the temperature of the lamp. This effect is well documented, but often ignored when reporting UV output of a disinfection lamp. There are large differences between the measurement conditions and operating conditions of a lamp used for disinfecting water. While lamps are measured in air, cooled by natural convection, they are typically operated inside a quartz sleeve submerged in water. The lamp temperature and resulting output will almost certainly be different under these two conditions.

While lamp temperature could be varied using forced convection, it has been found that this results in unstable and non-uniform UV output. A more satisfactory method was found using the same conditions the lamps would experi-

ence in a water treatment facility: inside a sealed sleeve, submerged in flowing water.

Thermocouples were mounted on the lamp, which was sealed inside a quartz sleeve and submerged in flowing, temperature-controlled, water. The temperature of this water was varied using a recirculating chiller, and the lamp temperature recorded along with measurements of UV taken using a fiber-optic probe. The results can be seen in Figure 2.

It can be seen from Figure 2 that the lamp output varies smoothly with temperature. This figure could be used for this lamp to extrapolate measurements taken at one lamp temperature to predict output at other temperatures. Our experience shows that placing the thermocouples more than 30 cm from the filament, on the lower lamp surface, results in consistent, representative readings. The temperature at which peak output is found may depend on lamp diameter and operating power, so a new test should be conducted for each lamp type.

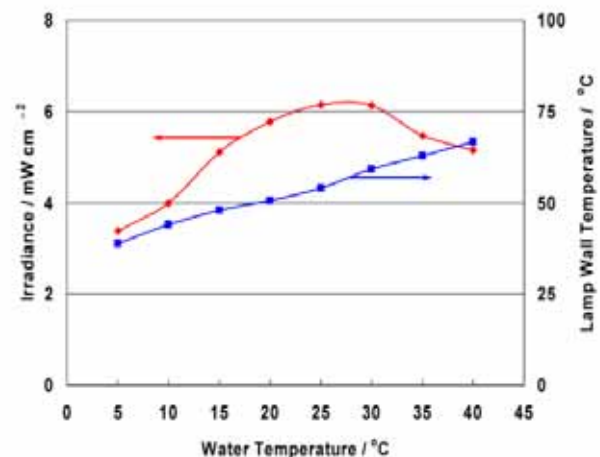
TROJAN'S EXPERIENCE: A CAUTIONARY TALE

Lambertian Response

Many so-called Lambertian detectors do not achieve cosine response in the ultraviolet range. Trojan has tested a number of detectors that are claimed to have Lambertian response, and most did not match their claims. The tests were conducted with a small UV pen-light that was revolved about the detector. Alternatively, the detector could have been rotated and the small lamp held stationary. The results for four different systems are shown in the following figure:

The angular response of the integrating sphere input optic caused significant measurement errors. Because the system is calibrated with a small calibration lamp (deuterium and QTH) positioned directly in front of the integrating sphere inlet port, the calibration is fairly accurate for a short lamp, but our long lamps subtend about 28° at the

Figure 2: Temperature response of a typical low-pressure mercury arc lamp.



integrating sphere, and so the system falsely inflated—by about 20%—measurements of our long lamps. Note that this sphere was specified and claimed to provide cosine response.

Detector Drift

Another vexing problem we have encountered with our monochromator system is measurement drift. When we started measuring relatively powerful lamps (10 kW electrical input), we noticed drift in the lamp output measurements of about 5% per day of testing. The drift was almost always upward, and was cumulative. Every component in the system was suspect, but none was considered—by the manufacturer or the supplier—likely to cause such a drift problem. After several months, off and on, of troubleshooting, we concluded that the drift was caused by changes in the integrating sphere. Near the end of our troubleshooting, we learned of a similar drift problem experienced by another lab testing UV lamps. That lab had decided to replace its integrating sphere with a disk diffuser, and we decided to do the same.

We tried a Teflon™ disk diffuser and an “opaque quartz glass” disk diffuser. Both these diffusers provide a good cosine response, but measurement drift still occurred with these diffusers installed when exposed to our high-output lamps. We are still using the opaque quartz diffuser in place of the integrating sphere; the rate of drift greatly decreased after initial exposure to intense UV. We also tried a third disk diffuser (taken from a radiometer detector), made of optical quartz with a flat front surface and a ground internal hemisphere, but the angular response was poor in this setup.

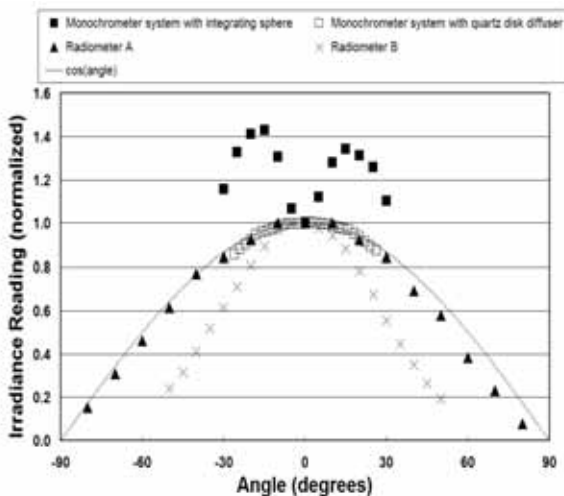


Figure 3: Representation of the measured angular response of four detectors: ideal response is $\cos(\text{angle})$ shown by the solid line. Solid squares show the response for an integrating sphere monochromator system, while the hollow squares represent the response of the monochromator with a quartz diffuser. Other symbols represent the response of various radiometer detectors with diffusers.

Reflections

We found that reflected UV (from the walls, ceiling, floor, and equipment) was augmenting our measurements, even though the room and the equipment were painted flat black. When the detector’s direct view of a test lamp was purposely blocked with a heavy cardboard sheet, the measured irradiance (which ideally would have been zero) was about 5% of the irradiance measured with no block in place between the lamp and the detector. To mitigate this problem easily and inexpensively, we installed curtains to act as a baffle. The curtains are drawn to leave a gap between them such that they allow direct UV from the lamp to the detector, while they block much of the reflected UV. This simple fix reduced reflections reaching the detector from about 5% to less than 2%. Other simple baffling systems can be envisioned. Additional possible fixes to the reflection problem may include repainting the room with a more UV absorbent paint, and installing a “light trap” behind the lamp to reduce reflections from the back wall.

Detector Calibration by Others

Trojan has had good experience with sensors calibrated by a single laboratory. At any one time, Trojan generally has between two and five detectors calibrated at 254 nm. Comparisons among these detectors show that they are within 3% when measuring the same lamp at the same time.

Conversely, Trojan has found much larger differences between detectors from different suppliers. Detectors from International Light, traceable to NIST, read approximately 10% lower than those from Gigahertz Optics, traceable to PTB, even after recalibration. The stated uncertainties for the two detectors can include this spread, but only at their maxima.

Calibration Lamps

A significant source of measurement uncertainty is the stability of lamps used for calibrating the system. We use a NIST-traceable 30 W deuterium lamp to calibrate the system in the wavelength range 200–350 nm, and a 1000 W quartz tungsten halogen (QTH) lamp to calibrate in the range 351–900 nm. The stated uncertainty in the output irradiance of the deuterium lamp is about 5%, and the stated uncertainty in the output irradiance of the QTH lamp is about 3%. (These uncertainties are somewhat dependent on wavelength, and refer to three standard deviations. In addition, lamp output drift over time increases the uncertainty.)

We had one deuterium lamp remeasured by the supplier about 9 months after the original calibration measurement. The lamp had been run for about 42 hours. The new calibration measurement indicated an increase in output of 2%–7%, depending on wavelength.

System calibration with the deuterium lamp was originally programmed with an integration time (i.e., the duration of UV accumulation for a single measurement) of 100 ms. We found that calibration became significantly more reproducible when the integration time was increased to 1000 ms.

MEASUREMENT PROTOCOL FOR LP AND AMALGAM MERCURY VAPOR LAMPS FOR UV DISINFECTION

This section provides a measuring protocol that Trojan Technologies has found to provide repeatable results. It is hoped that other laboratories will use this same protocol, and that inter-laboratory comparisons can be undertaken to improve the protocol.

Absolute Output Measurement

1. Operate the lamp for 100–130 hours at full rated electrical input power with amalgam spot (if any) oriented downward. Lamps may be operated in air or in water-cooled sleeves during this burn in. The purpose for this step is to fully condition the filaments and the envelope surface. Fluctuating and abnormally high or low output may be found for lamps without this burn-in.
2. Mount the lamp horizontally at least 75 cm from any surface. Amalgam spots (if any) are to be oriented downward. Support the lamp by the end-caps to minimize the amount of light being blocked.
3. Attach a thermocouple to the bottom surface of the lamp. Thermocouple must be at the amalgam spot, if any, or 35 cm from the filament for a low pressure lamp, or in the middle of a lamp less than 70 cm arc length.
4. Mount a detector at least 2.5 m from center of the lamp at the same elevation as the lamp.
5. Ignite the lamp and monitor current and voltage into the lamp.
6. Operate the lamp at full power until the temperature and electrical power into the lamp have stabilized and uniform UV output has been obtained from the entire arc – at least 15 min.
7. Measure the UV irradiance at the detector position.
8. Rotate the lamp about a vertical axis through the lamp center in increments of no more than 10° and repeat the measurements up to 90°. (Alternatively, the lamp could be fixed and the detector revolved around the lamp.)
9. Repeat the measurements from the normal position until –90°.
10. Calculate the total lamp output (see Calculation protocol).
11. Correct total lamp output to standard conditions (see Temperature Correlation).

Notes:

- a. Full rotation may not be necessary for subsequent tests of lamps with identical dimensions, as the relationship between the reading normal to the lamp and the total output should be the same.
- b. A standard lamp and ballast should be measured using this technique and the total output figure compared with that from other labs to ensure equipment accuracy.

Temperature Correlation

1. Attach a thermocouple to the lamp at the same position that was used in the measurement of total lamp output.
2. Install the lamp into a sleeve of the size and type used in the disinfection system.
3. Mount a submersible UV sensor on the sleeve with a minimum possible gap between the sleeve and sensor.
4. Submerge the lamp and sleeve into water of a controlled temperature.
5. Ensure that the water flow rate is sufficiently high that the inlet and outlet temperatures do not differ by more than 3°C.
6. Monitor lamp UV output, lamp wall temperature, and power into the lamp while varying water temperature in no more than 5-degree increments. Ensure that data are collected for water temperatures over the range of 10 to 30 degrees. Ensure that data are collected for lamp temperatures over a range of at least 5 degrees above and below the temperature measured in the Measurement Protocol. Power measurement at the same lamp temperature should match within 5%.
7. Plot the relative lamp output versus lamp temperature and vs. water temperature.
8. Use the graph to correct the absolute lamp output measurement figures obtained in the Measurement and Calculation Protocols to a total UV output at a standardized water temperature of 20°C.

Equipment specification:

The required equipment characteristics are:

1. Sensor Accuracy. Must be traceable to NIST or other national standards organization. Calibration must have been performed within 12 months. Total uncertainty of detection equipment must be stated.
2. All electrical and temperature measurement equipment must also be calibrated and traceable to a national laboratory.
3. Sensor Cosine correction. In order to apply the divergence theorem to calculate lamp output, the sensor must measure irradiance accurately. The response of the detector must not deviate from the Cosine function by more than 5% over the maximum viewing angle used in the testing. For example, a 1.5 m lamp measured at 3 m distance would correspond to a total included angle of 28 degrees.

The laboratory must provide proof of cosine response over the angle required by the measurement, at the wavelength of interest (e.g. 254 nm) .

4. Sensor Spectral selectivity: The sensor must not respond to output other than the disinfection line of the mercury vapor lamps. The laboratory must provide evidence that only the 254 nm line was detected during the measurements. This could be achieved with a narrow-bandpass filter centered at 254 nm. If a monochromator is used, care must be taken to accurately include the full 254 nm line but no other wavelengths.
5. Room temperature: must be stable within +/- 2°C over the duration of the testing, and should be as close as practical to the temperature at which the UV sensor was calibrated.
6. Reflection: reflected UV reaching the sensor from room boundaries and other components must be minimized. Reflection must be quantified by measuring UV with the lamp operating and an opaque baffle in front of the lamp to prevent UV from reaching the sensor directly. The baffle should be placed half way between the lamp and the detector, of diameter 1.5 – 3 times the lamp diameter, and of length no more than 1.1 times one-half the arc length. Reflected UV must be less than 2% of the signal without the baffle.

Calculation Protocol

Total output of the lamp is calculated based on an assumption that the UV distribution is symmetric about the lamp axis. Using the divergence theorem, one may integrate the irradiance E over an enclosing spherical surface of radius r : This may be accomplished by moving the sensor in an

arc about the lamp or by holding the sensor fixed and rotating the lamp. At each angle θ from the lamp normal, the differential area of the surrounding surface is given by:

$$dA = 2\pi r^2 \cos\theta d\theta$$

The total lamp output is then given by the integral of the irradiance times the differential area element. The measurements result in irradiance values at discrete angles, which can be collected in tabular form. A summation over these discrete values can be done to approximate the integral. Table 1 shows a sample data set.

Required Documentation:

1. Copy of UV detector calibration certificate.
2. Copy of electrical measurement device(s) calibration certificate(s).
3. Copy of temperature measurement device calibration certificate.
4. Graph of relative UV output vs. lamp temperature and water temperature along with statement of power levels and sleeve diameters used in testing.
5. Test results documenting cosine response of detector at 254 nm over range of angles used in test.
6. Test results documenting magnitude of reflected light for lamp under test.
7. Spectral response of detector used.
8. Raw measurement data: electrical RMS power, lamp temperature, UV irradiance at each measurement angle.
9. Total UV output calculation in far-field test.
10. Final corrected UV output for disinfection conditions at 20°C water temperature.

Table 1: Calculation template for determining total lamp output from a series of goniometric measurements. In order to fit the table on the page, one half of the values have been omitted.

Distance / m	3									
Lamp Temperature / °C	45									
Angle	-90	-80	-70	-60	-50	-40	-30	-20	-10	0
Irradiance / W m ⁻²	0.00	0.177	0.344	0.500	0.644	0.766	0.866	0.944	0.990	1.00
Electric Power / W	285	288	284	286	285	280	283	289	287	281
$2\pi r^2 \cos\theta$	0.00	9.82	19.3	28.3	36.4	43.3	49.0	53.1	557	56.6
dP / W	0.00	0.30	1.15	2.47	4.08	5.79	7.40	8.72	9.57	9.87
Total UVC Power / W	88.8									



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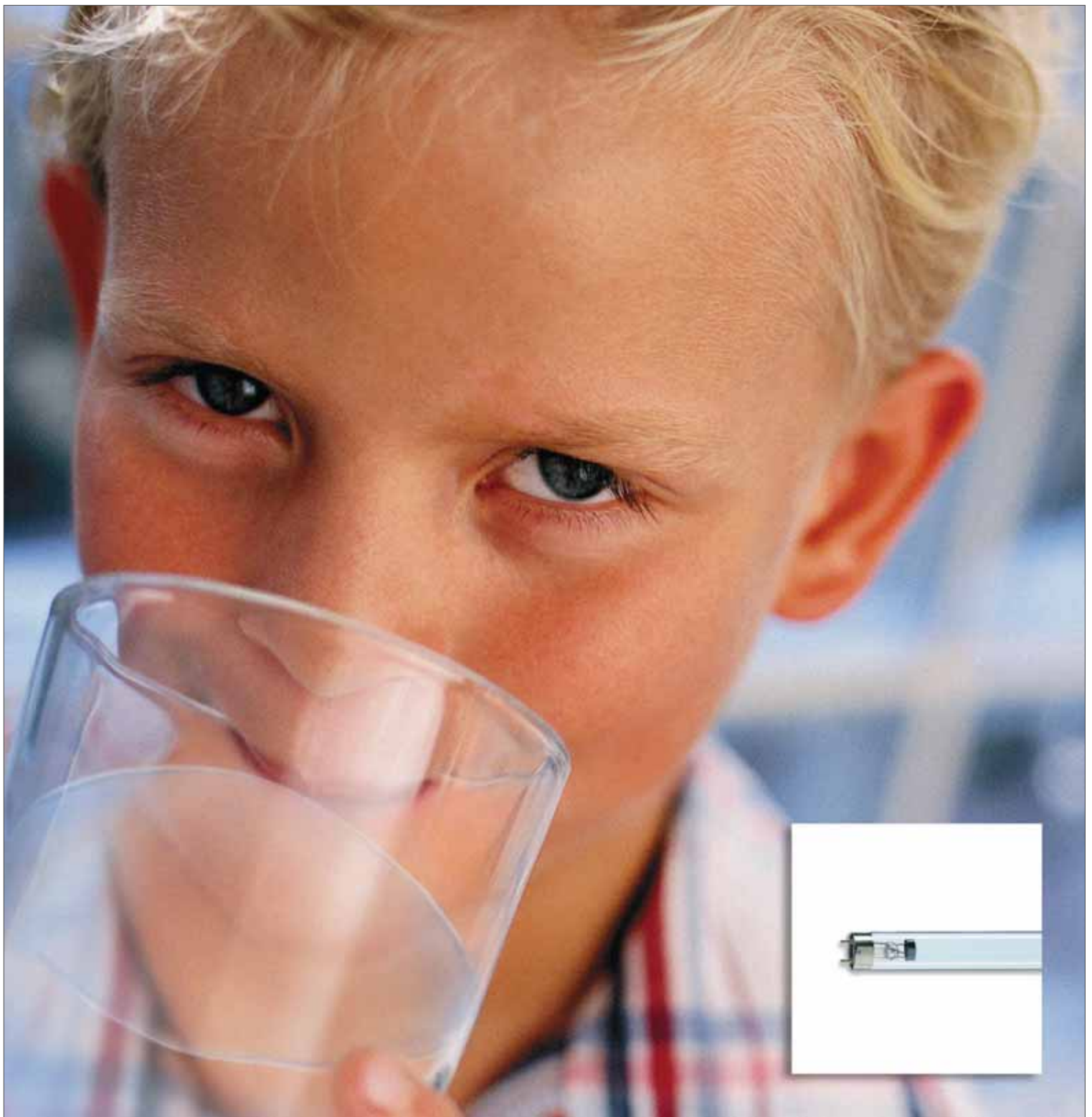


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