IUVA NEWS

ISSN 1528-2017
VOLUME 9/NO. 1 APRIL 2007

FEATURES

ARTICLES

Special Issue on the Ultraviolet Disinfection Guidance Manual

State Perspective

Impact on Large Systems

Overview of Validation

A New Validation Method

Operations and Maintenance

UV Disinfection Facility at the Water Treatment Plant in Winnipeg, MB, Canada (130 MGD)

UV Disinfection Facility at the Water Treatment Plant in Seattle, WA (180 MGD)

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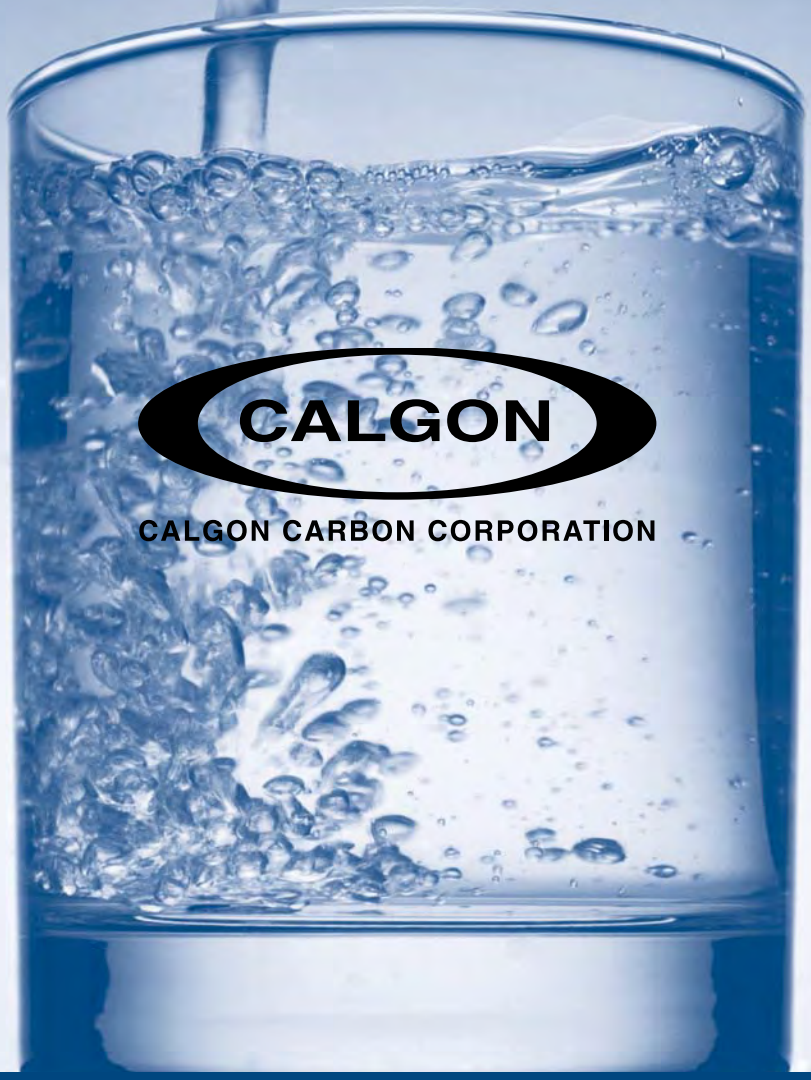
INTERNATIONAL IUVA ULTRAVIOLET ASSOCIATION

in the next issue . . .

An article on UV LEDs plus others

Activated Carbon and UV Oxidation

Total Solutions for Taste & Odor Control



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

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Editorial Office: Department of Civil and Enviornmental Engineering,
University of Alberta
Edmonton, AB, Canada T6G 2G8
Tel: (780) 439-4709 Fax: (780) 439-7792
Email: jim.bolton@iuva.org

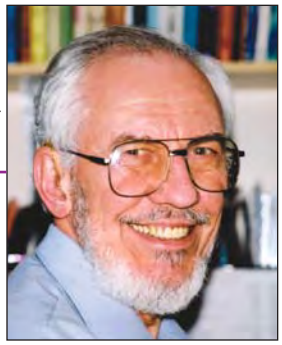
For IUVA membership information, go to the IUVA Web Site http://www.iuva.org/ or contact **Kathy Harvey** *(see below)*

For advertising in IUVA News, contact **Jim Bolton** (jim.bolton@iuva.org)
Tel: (780) 439-4709

For other IUVA matters, contact:
Dr. James Bolton, Executive Director (jim.bolton@iuva.org) or **Kathy Harvey** Manager IUVA Head Office (kathy.harvey@iuva.org) at the International Headquarters Office
PO Box 29060, Barrie, ON, Canada L4N 7W7
Tel: (705) 812-2146 Fax: (705) 812-2147

IUVA's Web Page: www.IUVA.org

EDITORIAL
by Jim Bolton
Editor-in-Chief



This is a Special Issue of IUVA News devoted to an analysis of the new UVDGM and other water treatment rules. Dr. Christine Cotton of Malcolm Pirnie agreed to be the Special Editor for this issue. Her editorial is below.

Planning for the *World Congress on Ozone and Ultraviolet Technologies* continues to move forward. This exciting event will take place at the Hyatt Century Plaza Hotel in Los Angeles, CA 25 – 30 August 2007. This issue has the Preliminary Program with many 'Mini-Symposia', each organized by a specialist in that field. The deadline for receipt of full papers is **15 May 2007**. You will not want to miss this exciting Congress.

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 (jim.bolton@iuva.org) and I'll send you the "Instructions to Authors".

Editorial by Christine Cotton

The United States Environmental Protection Agency's (USEPA's) Ultraviolet Disinfection Guidance Manual (UVDGM) is finally complete after six years of development. In 2000, the USEPA and UVDGM team had a great challenge before them and were tasked with creating detailed guidance for a new and developing technology where the water industry seemed to learn more about it every day. Keeping up with research, UV equipment developments, and hands-on experiences was a monumental task. In the end, the USEPA and UVDGM team hopes the UVDGM is a user-friendly document that utilities, states, and consultants can use to assist with designing, validating, installing, and operating UV facilities to improve public health. Thank you to all who contributed to the UVDGM; many of whom wrote articles for this Special IUVA News.

The articles in this IUVA News special issue provide insight on some of the major changes in the UVDGM and from the water industry on how the UVDGM will affect utilities, states, and research. Thank you to the contributors of this IUVA Special Issue, and I hope the UVDGM and these articles help our IUVA members implement UV disinfection of drinking water.

Christine Cotton, Malcolm Pirnie, Tucson, AZ

A MESSAGE
from the president
Andreas Kolch

First Wrap-up . . .

When Jim asked me to write the President's Message for the first quarter I looked at the format of the world document with this picture attached (Whistler 2005). Then it appeared to me that my regular two-year term would normally end this May, and that this would be my last message before Linda Gowman takes over as President in August (actually, I will have one more "message" for the June issue of IUVA News).

These two years have rushed by, and while I was thinking about that I also realized how much we have changed and are still going to change. The best indicator to illustrate that is indeed the fact that we will have a joint IUVA/IOA Congress in August which even prolonged my President's term as a "side effect". While it therefore might be a little early to prepare a "good-bye" message, I really would like to take the opportunity this time to first of all thank you all for the support and help I faced during the last two years. I really enjoyed working for our association in that position and I enjoyed friendship, support and professional spirit in a multi-discipline and multi cultural environment. It will be for sure one of the journeys in life which one will never forget and last but not least it was fun.

During the two years I always did two things with the opportunity to publish this message: trying to encourage active participation and announcing achievements.

Because I do not want to break with that tradition now, I would like to once again raise your attention about the World Congress in August, which will be THE EVENT for our association even in the short history of IUVA. If successful as planned, it could be a financial and organizational breakthrough for us that can lift IUVA to another dimension in terms of ability to finance activities and grow internationally. So, if you haven't already registered or considered to register: Please do! It will be a great venue with loads of high quality papers and an ideal place for networking and interesting talks.

Wraping up, I also wish my successor Linda all the best and a "lucky hand" for steering the boat further. There still is a lot of work ahead of us. I am sure she will do well and be successful.

Hope to see all of you in LA soon.

All the best

Andreas

HOT UV NEWS

The following are some of the more interesting items from the UV News page on the IUVA Web Site (http://www.iuva.org/public/uv_news.php).

20 April 2007: Stretching DNA to the Limit: DNA damage in a new light

http://www.physorg.com/news96273161.html

It has long been known that UV light can damage DNA, reducing its ability to replicate and interact with proteins, and often resulting in the development of skin cancers. However, not much is known about how the elasticity of DNA strands is altered upon exposure to **UV light**. Now a group of researchers at Duke University have developed a method to measure changes in the mechanical properties of DNA upon irradiation with **UV light**.

Piotr Marszalek and his colleagues have conducted single-molecule force spectroscopy measurements on viral DNA, which show the unraveling of the DNA double helix upon exposure to UV irradiation. The researchers essentially pick up individual DNA molecules with the tip of a scanning probe microscope and stretch it while measuring the forces generated…

12 April 2007: Study: La Verne water plant vulnerable as terrorist target, by Harrison Sheppard, La Verne Daily Bulletin, La Verne, CA

http://www.dailybulletin.com/news/ci_5647597

A water treatment plant in La Verne is among the dozens nationwide susceptible to terrorist attack because it uses deadly chlorine gas and transports it by unprotected rail cars, according to a new report.

The study by a progressive think tank identified 37 plants that use chlorine gas transported by rail, leaving them vulnerable to attack and jeopardizing millions of residents nearby…

The study noted there are alternatives for purifying water, including liquid chlorine bleach - which does not disperse into the air if spilled - and **ultraviolet light…**

11 April 2007: "Glossary of Terms used in Photochemistry" has been published by IUPAC

http://www.iupac.org/publications/pac/2007/7903/7903x0293.html

6 March 2007: Calgon Carbon and Trojan Settle US Patent Disputes

http://www.calgoncarbon.com/company/news/index.cfm?mode=detail&id=28ECC9D1-A2DC-86F0-FC0A18F1CD1C49FB

PITTSBURGH, PA Calgon Carbon Corporation (NYSE:CCC) announced today that it has reached an agreement with Trojan Technologies (Trojan) regarding legal disputes related to certain Calgon Carbon patents for the use of ultraviolet light to disinfect drinking water (the "Calgon Carbon UV Patents"). This agreement resolves any and all claims by and between Calgon Carbon, Trojan, its customers, and consultants in the litigations that were pending in the Western District of New York and in Canada.

In exchange for an undisclosed cash payment by Trojan, Calgon Carbon will grant Trojan worldwide immunity from all current and future legal action related to the Calgon Carbon UV Patents....

UV INDUSTRY NEWS

The following are some of the more interesting items from the UV Industry Announcements page on the IUVA Web Site (http://www.iuva.org/public/uv_industry_announcements.php).

25 April 2007: Halo Technologies, Inc. to Debut Superior Cleaning Technology at Michigan International Women's Show

http://www.emediawire.com/releases/2007/4/emw521247.htm

Halo Technologies, Inc. will debut its new Halo™ UVX **Ultraviolet** Vacuum at the Real Savvy Moms™ health and wellness exhibit at the upcoming Michigan International Women's Show. The show will be held at the Rock Financial Center in Novi, Mich. on May 3-6. This will be the first time consumers will be able to test drive the only vacuum that uses ultraviolet light to safely and instantly kill dust mites, molds, bacteria, viruses, lice, fleas and other allergens that lurk in your home's carpets and mattresses.

The Halo ultraviolet vacuum "Cleans what you see, Kills what you can't™" and will be featured exclusively in the Real Savvy Moms exhibit. There will be hands-on product demonstrations, video presentations and online pre-sale of the revolutionary new UVX vacuum throughout the event. In addition, up to two Halo UVX Ultraviolet Vacuums will be provided as prizes to attendees each day of the event…

17 April 2007: UVDI Announces Hiring of Katja Auer as Applications Engineer

http://uvdi.com/pdfs/press_releases/katja_auer_press_release.pdf

Valencia, California – April 17, 2007 — UltraViolet Devices, Inc. (UVDI), a leading manufacturer of UV and molecular filtration products for air and water treatment is pleased to announce the hiring of Katja Auer as Applications Engineer. Katja will have responsibility for providing technical support and application expertise to UVDI's channel partners and major OEM customers…

For further information, visit www.uvdi.com

30 March 2007: American Ultraviolet Company Adds 55 Years of Germicidal Air Experience

(Lebanon, Indiana) – **American Ultraviolet Company** is extremely pleased to welcome **Roger Stamper** as Vice President Sales & Marketing and **Glenda Dawson-Cooper** as Central Region Sales Manager for the Germicidal Air Disinfection Products Division.

Mr. Stamper has more than 35 years of sales and marketing experience in the air conditioning air filtration and UVC disinfection businesses with companies that include American Air Filter, Farr Company, and, prior to joining American Ultraviolet Company, Steril-Aire, Inc., where Roger served as Vice President of Sales & Marketing for 11 years.

Ms. Dawson-Cooper has served the HVAC Industry for more than 20 years, providing sales and marketing experience to companies that include Allied Technology, CESCO Products, Gorgen Company, Glacier Technology, and, since 2003, Steril-Aire, Inc., where Glenda was North Central Region Sales Manager…

For further information, visit www.americanultraviolet.com

NEWS FROM *IUVA*

Change of Address for the IUVA Head Office

Kathy Harvey, IUVA's Office Manager has moved from Ayr, ON to Barrie, ON, so, of course, IUVA's Head Office had to move too. The new contact information is:

International Ultraviolet Association

P.O. Box 29060, Barrie, ON, Canada L4N 7W7
Tel: 705-812-2146; Fax: 705-812-2147
Email: Kathy.Harvey@iuva.org

IUVA Manufacturers' Council: A Common Voice

By Jennifer Muller, TrojanUV and Bertrand Dussert, Siemens Water Technologies

The Idea: To bring together a group of leaders from the UV manufacturing world.

The Goal: To represent the common interests of manufacturers in order to provide input on policies, encourage the establishment of standards and protocols which accomplish a legitimate and legal purpose, and make recommendations to the IUVA Board, its members and the industry overall.

The Result: A seasoned group of people from 21 UV equipment and UV equipment-related manufacturers, working together on key projects.

In November 2005, a Manufacturers' Council was formed within the IUVA to provide a common voice and leadership for member companies that manufacture UV equipment and related technical components such as UV lamps and ballasts, for water, air and surface/curing applications. At AWWA's ACE06, the Council held their first meeting to discuss several topics and opportunities for how the Council could make the most significant contribution within the industry.

"The cohesion within the group happened quite easily; the energy and enthusiasm were remarkable from the infancy of the Council," says Oliver Lawal, Director of Engineering, Wedeco ITT. "We quickly realized that there were many topics of interest that we could tackle and bring to light for our industry. We felt that by drawing upon the collective knowledge and experience of the Council, that our projects will benefit IUVA members and through operations, efficiency and safety.

Working to establish standards and recommend practical protocols, the Council was able to short-list five key issues and opportunities. These exciting projects were selected because they address confusing issues or safety concerns, and identify opportunities for efficiency gains in system design or operation. A few of these projects are profiled in the following Project List.

PULL QUOTE

"The people and organizations that make up this group have their finger on the pulse of what is happening in our industry today. This means they are a valuable resource, working together for mutual benefit."

– Jim

Upcoming IUVA-sponsored Conferences and Workshops

25-30 August 2007: World UV/Ozone Congress, Hyatt Century Plaza Hotel, Los Angeles, CA – See Call for Papers later in this Issue. The deadline for Papers is **15 May 2007**.

General Assembly – Official Notice of Meeting

The General Assembly of IUVA Members will take place at 5:15 pm, Tuesday, 28 August 2007 at the World UV/Ozone Congress in the Hyatt Century Plaza Hotel, Los Angeles, CA in the Los Angeles Room.

The principal item on the agenda will be the election of the new Board of Directors. Dr. Joop Kruithof has been appointed Chair of the Nominating Committee. If you would like to nominate someone for the Board (even yourself), send an email message and a short bio to joop.kruithof@planet.nl.

As always, comments on the web Site are most welcome – send either to **Jim Bolton** (jim.bolton@iuva.org) or the Webmaster **Kevin Wright** (ask@iuva.org).

2007 Joint World Congress

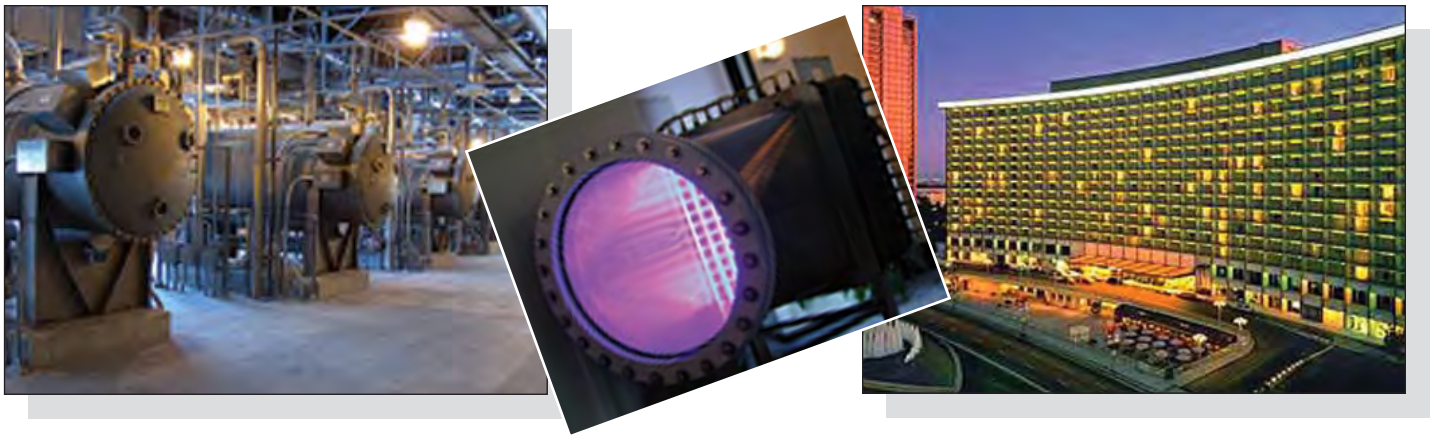
International Ozone Association
International Ultraviolet Association

27-30 August 2007

Hyatt Century Plaza Hotel, Los Angeles, California USA

http://www.ioa-iuva-wchollywood.org/

You can register onlice on the World Congress Web Site.



Preliminary Program

MONDAY - 27 August

8:30 - 10:35 AM

Opening Plenary Session

BREAK
10:35 - 11:15 AM

Opening Plenary Session

11:15 - Noon

LUNCH: Noon - 1:30 PM

MonPM1	MonPM2	MonPM3	MonPM4	MonPM5	MonPM6	MonPM7	MonPM8
31 Advanced Oxidation Technologies	3 Water Treatment Ozone	11 Bromate Control (O3)	42 UV Large Systems	1 Ozone & UV - Water Industry	2 Water Treatment Ozone - LA	21 Industrial Applications Ozone	4 Pre-oxididation Municipal Water

BREAK: 3:05 - 3:50 PM

31 Advanced Oxidation Technologies	3 Water Treatment Ozone	11 Bromate Control (O3)	42 UV Large Systems	1 Ozone & UV - Water Industry	2 Water Treatment Ozone - LA	21 Industrial Applications Ozone	4 Pre-oxididation Municipal Water

3:50 - 5:10 PM

TUESDAY - 28 August

8:30 - 10:05 AM

TueAM1	TueAM2	TueAM3	TueAM4	TueAM5	TuePM6	TueAM7	TueAM8	TueAM9
24 Emerging Contaminants (O_3)	3 Water Treatment Ozone	25 Emerging Contamin-ants (UV)	32 Ozone & AOT System Design	6 Wastewater Treatment Ozone	14-15-16 Ag-Food-Bev Applications O3 & UV	21 Industrial Applications Ozone	30 UV Measure-ment	35 Ozone Generation

BREAK: 10:05 - 10:55 AM

24 Emerging Contaminants (O_3)	3 Water Treatment Ozone	25 Emerging Contamin-ants (UV)	32 Ozone & AOT System Design	6 Wastewater Treatment Ozone	14-15-16 Ag-Food-Bev Applications O3 & UV	21 Industrial Applications Ozone	30 UV Measure-ment	35 Ozone Generation

LUNCH: Noon - 1:30 PM

TuePM1	TuePM2	TuePM3	TuePM4	TuePM5	TuePM6	TuePM7	TuePM8	TuePM9
24 Emerging Contaminants (O_3)	9 UV Disinfection	25 Emerging Contamin-ants (UV)	32 Ozone & AOT System Design	7 Wastewater Treatment UV	14-15-16 Ag-Food-Bev Applications O3 & UV	28 UV Chem/ Biochem. Reactions	37 UV Source Technologies	27 Ozone Chem. & Solubility

BREAK: 3:05 - 3:50 PM

24 Emerging Contaminants (O_3)	9 UV Disinfection	44 General Sessions	32 Ozone & AOT System Design	7 Wastewater Treatment UV	14-15-16 Ag-Food-Bev Applications O3 & UV	28 UV Chem/ Biochem. Reactions	37 UV Source Technologies	36 Ozone Contacting

3:50 - 5:10 PM

WEDNESDAY - 29 August

8:30 - 10:05 AM

WedPM1	WedAM2	WedAM3	WedAM4	WedAM5	WedAM6	WedAM7	WedAM8
31 Advanced Oxidation Technologies	9 UV Disinfection	33 UV Reactor Design/Mod/ Verification	20 Soil & Groundwater Treatment	6 Wastewater Treatment Ozone	14-15-16 Ag-Food-Bev Applications O3 & UV	39 Ozone Operations Forum	45 UV Operations Forum

BREAK: 10:05 - 10:55 AM

31 Advanced Oxidation Technologies	44 General Sessions	33 UV Reactor Design/Mod/ Verification	20 Soil & Groundwater Treatment	6 Wastewater Treatment Ozone	14-15-16 Ag-Food-Bev Applications O3 & UV	39 Ozone Operations Forum	45 UV Operations Forum

LUNCH: Noon - 1:30 PM

WedPM1	WedPM2	WedPM3	WedPM4	WedPM5	WedPM6	WedPM7	WedPM8
31 Advanced Oxidation Technologies	12 Adenovirus UV Inactivation	33 UV Reactor Design/Mod/ Verification	19 Air & Surface Treatment (UV)	5 Ozone & UV - Waste Water	14-15-16 Ag-Food-Bev Applications O3 & UV	39 Ozone Operations Forum	45 UV Operations Forum

BREAK: 3:05 - 3:50 PM

31 Advanced Oxidation Technologies	12 Adenovirus UV Inactivation		19 Air & Surface Treatment (UV)	5 Ozone & UV - Waste Water		39 Ozone Operations Forum	45 UV Operations Forum

3:50 - 5:10 PM

Conference Schedule at a Glance

World Congress on Ozone & Ultraviolet Technologies

	Saturday 8/25/2007	Sunday 8/26/2007	Monday 8/27/2007	Tuesday 8/28/2007	Wednesday 8/29/2007	Thursday 8/30/2007
7:30-8:00 am		Registration (Noon - 7:00 pm)	Registration (until 5:00 pm)	Registration (until 1:00 p.m.)	Registration (until 1:00 p.m.)	
8:00-8:30 am			Registration (until 5:00 pm)	Registration (until 1:00 p.m.)	Registration (until 1:00 p.m.)	9:00 - 10:30 am IUVA Board Meeting
						10:30 - 11:30 am IUVA-IOA Board Mtg.
8:30 - 10:05 am	Committee & Task Force Meetings	PAG Board Mtg IUVA Board UV & O3 Workshops	Welcome Plenary Speaker 1 Pleanary Speaker 2	Choice of 9 Concurrent Technical Sessions	Choice of 8 Concurrent Technical Sessions	*Operation Workshop *3 x Technical Tours *(limited to 50 per tour)
10:05 - 10:55 am	Committee & Task Force Meetings	PAG Board Mtg IUVA Board UV & O3 Workshops	Coffee Break & Exhibits	Coffee Break & Exhibits	Coffee Break & Exhibits	*Operation Workshop *3 x Technical Tours *(limited to 50 per tour)
10:55- 12:00 noon	Committee & Task Force Meetings	PAG Board Mtg IUVA Board UV & O3 Workshops	Plenary Speaker 3	Choice of 9 Concurrent Technical Sessions	Choice of 8 Concurrent Technical Sessions	*Operation Workshop *3 x Technical Tours *(limited to 50 per tour)
12:00-1:30 pm	Executive Boards Lunch		Lunch & Exhibits	Lunch & Exhibits	Lunch & Exhibits	*Operation Workshop *3 x Technical Tours *(limited to 50 per tour)
1:30-3:05 pm	Committee & Air Task Force Meetings	IOA Board Mtg UV Workshop O3 Workshop	Choice of 8 Concurrent Technical Sessions	Choice of 9 Concurrent Technical Sessions	Choice of 8 Concurrent Technical Sessions	Check Online for Tour Options
3:05 - 3:50 pm	Committee & Agri/Food Task Force Meetings	IOA Board Mtg UV Workshop O3 Workshop	Coffee Break & Exhibits	Coffee Break & Exhibits	Coffee Break & Exhibits	
3:50-5:10 pm	Committee & Task Force Meetings	IOA Board Mtg UV Workshop O3 Workshop	Choice of 8 Concurrent Technical Sessions	Choice of 9 Concurrent Technical Sessions	Choice of 8 Concurrent Technical Sessions	
5:10 - 5:30 pm			IOA General Assembly	IUVA General Assembly		
5:30 - 7:00 pm			"Meet & Greet" Exhibitor Hall			
7:00 - 9:00 pm		Welcome Reception	"Meet & Greet" Exhibitor Hall	LA Dodgers Game (Optional 150 MAX.) or -On Your Own-	Banquet	

www.ioa-iuva-wchollywood.org

Board Meetings

Technical Program

Conference Item

Social Program

Exhibitors
Setup Sunday Noon to 6:00 pm
Tear down Wed. 3:50 to 6:00 pm

The Final UV Disinfection Guidance Manual: Operations and Maintenance Summary

James Collins,[1*] Laurel Passantino, P.E.,[2] Christine Cotton, P.E.[1]

1. Malcolm Pirnie, Tucson, AZ
2. Malcolm Pirnie, Phoenix, AZ

***Corresponding author, 1 S. Church Ave., Suite 1120, Tucson, AZ 85701 Email: jcollins@pirnie.com**

ABSTRACT

The number of public water systems (PWSs) implementing ultraviolet (UV) disinfection is increasing due to recent regulations promulgated by the United States Environmental Protection Agency (USEPA). UV disinfection fundamentally differs from the chemical disinfectants traditionally used in drinking water treatment, which makes UV disinfection attractive to meet microbial requirements without creating regulated disinfection byproducts. However, these differences between chemical disinfectants and UV disinfection necessitate operations and maintenance tasks that are different from the activities traditionally performed by water treatment operators. As such, many PWS operators are unfamiliar with the types of tasks needed to keep UV facilities functioning in compliance with the regulatory requirements. The USEPA recognized the need to provide technical information related to all aspects of UV disinfection, including operations and maintenance tasks, and supported the development of the UV Disinfection Guidance Manual (UVDGM). This article summarizes the requirements and recommendations for UV facility operations, maintenance, monitoring, recording, and reporting that are described in detail in Chapter 6 of the UVDGM (USEPA, 2006).

INTRODUCTION

The use of UV light for the disinfection of drinking water is increasing in part because of regulations promulgated by the United States Environmental Protection Agency (USEPA) in January 2006. Public water systems (PWSs) with occurrences of *Cryptosporidium* in their source water may be particularly interested in implementing UV disinfection as an affordable and effective treatment technique for compliance with the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR).

Although UV disinfection has been prevalent in Europe for many decades, the use of UV disinfection in North America is relatively new. As such, USEPA recognized the need to provide technical information on the design, validation, and operation of UV facilities and facilitated the development of the UV Disinfection Guidance Manual (UVDGM) to assist PWSs, consulting engineers, and regulatory agencies.

One of the fundamental differences between chemical disinfectants and UV disinfection is UV disinfection doses can not be directly measured to monitor performance. As the dose delivery and monitoring procedures for UV disinfection are significantly different from the procedures familiar to operators of PWSs, it was essential to develop guidance for operators to properly monitor and maintain UV disinfection facilities. This article summarizes the requirements and recommendations for facility operations, maintenance, monitoring, recording, and reporting that are needed on a continuous, daily, weekly, monthly, and annual basis. More details on the tasks outlined in this article are provided in Chapter 6 of the UVDGM (USEPA, 2006).

OPERATIONAL REQUIREMENTS

An important distinction to make in this article and in the UVDGM is the difference between activities that are *required* versus activities that are *recommended*, as described below.

- **Requirements** are tasks and activities that are required by the LT2ESWTR in order to receive disinfection credit for the UV facility.
- **Recommendations** are tasks and activities that are included in the UVDGM as suggestions for improving operation and monitoring of UV facilities. Recommendations are not required by the LT2ESWTR but may be adopted as requirements by individual states.

According to the LT2ESWTR, a UV facility is required to operate within the validated limits to receive inactivation credit. A reactor is operating outside of the validated limits if any of the following conditions occur:

- Flow rate is greater than the highest validated flow rate;
- UV transmittance (UVT) is lower than the lowest validated UVT;
- UV intensity or calculated dose is lower than the required intensity or dose necessary for the target log inactivation;
- The number of energized lamps is different from the validated number;
- The UV intensity sensor is not calibrated (see monitoring section); and
- The UVT analyzer (if used for UV dose calculation) is not calibrated (see monitoring section).

If a UV reactor is operating outside of the validated limits, it is considered to be operating off-specification. The LT2ESWTR requires 95 percent of the water delivered to the public each month to be within validated limits (i.e., on-specification). The 95 percent value is calculated using the total volume of water treated each month and the volume of off-specification water produced. The off-specification calculation is based on the entire facility and not individual reactors.

MAINTENANCE OF UV REACTORS

There are no specific regulatory requirements for maintaining UV reactors; however, proper maintenance can reduce the potential for operating outside the validated limits and, therefore, reduce the potential for producing off-specification water. The recommended maintenance tasks are summarized in Table 1. The maintenance tasks and the frequency of performing them can be specific to the UV reactor installed. As such, the UV manufacturer should be consulted when determining the maintenance schedule. See section 6.3 of the UVDGM for detailed descriptions of the recommended maintenance tasks.

Table 1. *Recommended Maintenance Tasks (Adapted from Table 6.4 of the UVDGM)*

General Task	Frequency
Check cleaning efficiency	Monthly (no cleaning or OCC) Semi-annually (OMC or OMCC)
Check reactor housing, sleeves, and wiper seals for leaks	Monthly
Check intensity of UV lamps and lamp output variability	Bimonthly (MP lamps) Quarterly (LP and LPHO lamps)
Check cleaning fluid reservoir (if provided)	Semi-annually (OMCC)
Calibrate reference UV sensor	Annually
Test-trip Ground Fault Interrupter	Annually
Replace or recalibrate duty UV sensors	When duty UV sensors fail calibration
Check thermometer and/or water level indicator	Manufacturer's recommended frequency
Replace lamp	Lamp/ manufacturer specific
Replace sleeve	Sleeve/ Manufacturer specific
Clean UVT analyzer and replace parts	Manufacturer's recommended frequency
Inspect OMC or OMCC drive mechanism	Manufacturer's recommended frequency
Inspect ballast cooling fan	Manufacturer's recommended frequency

OMC = on-line mechanical cleaning;
OMCC = on-line mechanical chemical cleaning; and
OCC = off-line chemical cleaning.

MONITORING PARAMETERS

To ensure that the UV reactors are operating within the validated limits, the LT2ESWTR requires that select parameters be monitored. PWSs must at a minimum monitor UV intensity, flow rate, and lamp status. States may require additional monitoring. In addition to monitoring the selected parameters, it is also required for a PWS to monitor the calibration of the UV sensors and UVT analyzers (if used to calculate UV dose).

MONITORING UV SENSOR CALIBRATION

USEPA recommends verifying the calibration of duty UV sensors against a reference UV sensor on a monthly basis. Reference sensors are off-line UV sensors that should be at least as accurate as the duty UV sensors and should be constructed identically to the duty UV sensors (except for any modifications to make the reference UV sensor more accurate).

At a minimum, UV sensors in all UV reactors in use (i.e., duty reactors) should be monitored. Monitoring of UV sensors in any stand-by reactors is beneficial because the UV reactor will be operating off-specification if any UV sensors are not in calibration when the reactor is turned on. Verifying the calibration of all duty and stand-by UV reactors allows for all reactors to be ready for use, which provides better operational flexibility.

A duty UV sensor is considered to be in calibration if it reads less than 20 percent higher than the reference sensor (Equation 1).

$$[1] \quad \left(\frac{S_{Duty}}{S_{Ref}}\right) \leq 1.2$$

where:

S_{Duty} =
Intensity measured with the duty UV sensor (mW/cm^2)

S_{Ref} =
Intensity measured with the reference UV sensor (mW/cm^2)

Note that Equation 1 does not include an absolute value. This allows a UV facility to continue operating if the duty UV sensor reading is more than 20 percent lower than the reference sensor. However, this will result in inefficient operation of the UV reactor because more power will be needed to meet the required UV dose or UV intensity than if a calibrated UV sensor was used.

If the calibration ratio is greater than 1.2, one of the following corrective actions should be taken to avoid the reactor being off specification:

- Replace the failed UV sensor with a spare UV sensor;
- Apply a UV sensor Correction Factor (CF) to the affected UV reactor.

A detailed description of how to calculate a CF is in section 6.4.1.1 of the UVDGM. The CF is applied to the required UV intensity or required UV dose. This corrective action is not energy efficient, but it will allow the facility to continue operation until the failed UV sensor(s) can be replaced.

MONITORING UVT ANALYZER CALIBRATION

Monitoring the UVT analyzer calibration is only required when UVT is used to calculate the UV dose during operation (e.g., Calculated Dose Approach). The calibration of an on-line UVT analyzer is evaluated by comparing the reading of the on-line UVT analyzer to that of a calibrated bench-top spectrophotometer using Equation 2.

$$[2] \quad \left| UVT_{on\text{-}line}(\%) - UVT_{bench}(\%) \right| \leq 2 \text{ percent UVT}$$

In this equation, it is important to use the absolute value in the calculations because inaccuracies in the dose calculation can result from both conservative and non-conservative errors in UVT measurements.

The USEPA recommends that on-line UVT analyzers be monitored at least weekly. The monitoring frequency should be adjusted based on the calibration results obtained over the first year of operation and approved by the state. The UVT analyzer can be calibrated on-site using the UV manufacturer's recommended approach if it fails the criterion in Equation 2. If the UVT analyzer fails calibration in four consecutive weeks, USEPA recommends that the UVT analyzer be monitored on a daily basis. If the UVT analyzer can not maintain calibration for 24 hours, the PWS should consider one of the following options to minimize the production of off-specification water:

- Enter manual UVT measurements into the reactor's programmable logic controller (PLC) every four hours and use this measurement in the monitoring strategy;
- Enter the design UVT value into the PLC and verify daily using a bench-top spectrophotometer that the UVT of the water is less than the design UVT.

These options are not intended for long-term use and should not be used for longer than six months.

UV Sensor Check Being Performed on a Medium Pressure UV Reactor

OFF-SPECIFICATION EVENTS

PWSs are required to monitor for off-specification events to calculate the volume of off-specification water produced. The following events trigger off-specification operation:

- Reactor is operating outside of validated limits (e.g., flow rate, UVT, UV intensity, UV dose, number of lamps energized);
- UV sensor is out of calibration and it is not replaced or a CF is not applied;
- UVT analyzer is out of calibration (if required for dose-monitoring strategy) and it is not recalibrated or remedial actions are not taken; and
- UV equipment is not the same or better than the equipment used in validation testing.

Three methods are available for calculating the off-specification volume produced:

- A flow totalizer that automatically records off-specification events can be used;
- The PLC can calculate the volume based on the flow rate in one-minute or less intervals during the off-specification event; and
- The PLC can calculate the volume based on the maximum flow rate during the off-specification event if this method is approved by the state.

These off-specification volumes are divided by the total volume treated to determine the percent off-specification volume produced, which cannot exceed 5 percent.

MONITORING AND RECORDING FREQUENCIES

The LT2ESWTR requires that certain parameters be monitored, but it does not specify the frequency for monitoring. USEPA has recommended that the validated parameters (e.g., flow rate, UV intensity, validated dose (if applicable), and lamp status) be monitored at least every 5 minutes, which is considered to be continuously. These parameters are monitored continuously to ensure the reactors are operating within specification, but the measurements only need to be recorded every 4 hours. Recommended monitoring and recording frequencies for required and recommended monitoring parameters are shown in Table 2 and Table 3, respectively.

Off-specification alarms should be recorded at a minimum of 5 minute intervals. The off-specification alarm should start as soon as the first off-specification condition is monitored and should continue until the reactor returns to within validated limits. It should be noted that the off-specification event may start before it is first monitored and may end before the reactor is monitored as being on-specification. USEPA assumed that the underestimation and overestimation of off-specification water will off-set over time, thereby minimizing any errors in the calculation of off-specification volume. If the monitoring frequency increases, the accuracy of the off-specification calculation also increases.

Table 2. *Recommended Monitoring and Recording Frequency for Required Monitoring Parameters (Adapted from Table 6.7 of the UVDGM)*

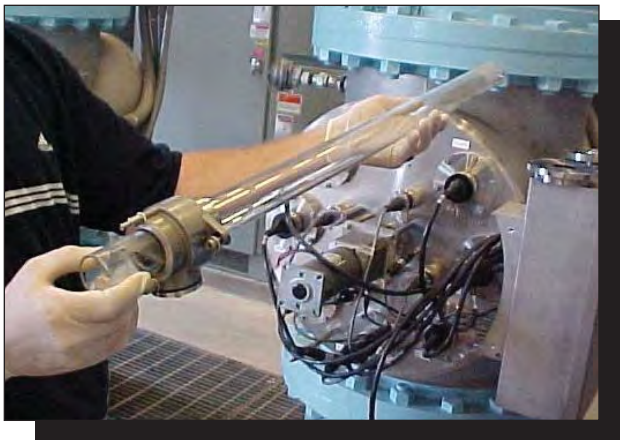
Required Parameter to be Monitored	Monitoring Frequency	Recording Frequency
Off-specification Alarm	Continuous	Minimum of every 5 minutes until the reactor is on-specification
UV Intensity	Continuous	Every 4 hours
UVT*	Continuous	Every 4 hours
Validated Dose*	Continuous	Every 4 hours
Lamp Status	Continuous	Every 4 hours
Flow Rate	Continuous	Every 4 hours
Production Volume	Continuous	Off-specification events and monthly total
Calibration of UV Sensors	Monthly	Monthly
Calibration of On-line UVT Analyzer*	Weekly	Weekly†

*Required only if necessary for the dose-monitoring strategy (i.e., the Calculated Dose Approach).

† Frequency could be reduced depending on monitoring results

REPORTING REQUIREMENTS

PWSs must prepare and submit monthly reports to the state that detail the percentage of off-specification water produced, the percentage of UV sensors checked for calibration, and the daily low validated dose or low UV intensity. The state may also have additional reporting requirements. Example reporting forms that may be adopted by individual states are included in Section 6.5.2 of the UVDGM.



Visual Inspection of Cleaning Efficiency of UV Lamp Sleeve

Table 3. ***Recommended Monitoring and Recording Frequency for Recommended Monitoring Parameters (adapted from Table 6.8 of the UVDGM)***

Parameter	Monitoring Frequency	Recording Frequency
Power Draw	Continuous	Every 4 hours
Water Temperature (Only for MP Reactors)	Continuous	Daily
UV Lamp On/Off Cycles	Continuous	Weekly (Total cycles per week)
Turbidity (In Addition to Monitoring Otherwise Required Under Subpart H)	Daily	Weekly
pH, Iron, Calcium, Alkalinity Hardness, Oxygen Reduction Potential	Weekly (reduce if fouling is not prevalent)	Weekly
UVT Analyzer Calibration (if not required for dose-monitoring strategy)	Weekly (reduce if appropriate based on operational experience)	Weekly
Operational Age of the Following Equipment: • Lamp • Ballast • Sleeve • UV Sensor	Monthly	Monthly
Calibration of Flow Meter	Monthly	Monthly

SUMMARY

The final UVDGM describes in detail the required and recommended operations, maintenance, monitoring, recording, and reporting necessary to receive inactivation credit with UV disinfection. Included in these recommendations are options if a UV sensor or UVT analyzer fails the recommended criteria, which provide operational flexibility to allow a UV facility to keep operating for a limited time even if the UV sensor or UVT analyzer do not meet criteria.

DISCLAIMER

The information provided in this article is only an overview of the types of operation, maintenance, monitoring, recording, and reporting activities that should be completed for UV facilities. The article is not intended to be a comprehensive discussion of the operations and maintenance requirements and recommendations. For a more thorough presentation of the requirements and recommendations, including step-by-step procedures for completing the tasks and activities, please refer to Chapter 6 of the UVDGM (USEPA, 2006).

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Lagrangian Actinometry Using Dyed Microspheres – A New UV Validation Method

E.R. Blatchley III,[1] C. Shen[2] and O.K. Scheible[2]*

[1]School of Civil Engineering, Purdue University, West Lafayette, IN

[2]HydroQual, Inc., Mahwah, NJ 07430

***Corresponding Author, Email:** kscheible@hydroqual.com

ABSTRACT

Lagrangian actinometry using dyed microspheres has been developed as a new method for validation of ultraviolet (UV) reactor systems. When properly applied, Lagrangian actinometry allows measurement of the UV dose distribution delivered by a UV reactor for a given operating condition. This method has been successfully applied to a series of UV disinfection systems, which were validated by biodosimetry as well. Excellent agreement was evident between the results from Lagrangian actinometry and biodosimetry, as well as those from corresponding numerical simulations. The ability of Lagrangian actinometry to physically measure UV dose distribution is extremely beneficial to the UV disinfection industry because it eliminates much of the uncertainty associated with conventional reactor validation approaches which depend solely on the application of biodosimetry. The combined application of Lagrangian actinometry, biodosimetry, and numerical simulation is therefore being proposed as a superior UV validation strategy to provide a more in-depth description of reactor performance than any of these methods individually, or in other combinations.

KEYWORDS: Disinfection, UV dose distribution, Lagrangian actinometry, dyed microspheres, ultraviolet, UV, validation.

INTRODUCTION

In drinking water and water reuse applications, ultraviolet (UV) disinfection systems must be validated based on physical measurements to ensure adequate performance relative to a treatment objective. Several protocols have been developed to describe appropriate methods for reactor validation; in all cases, the default method for reactor validation is biodosimetry (ÖNORM 2001, 2003; DVGW 2003; USEPA/UVDGM 2006; NWRI/AWWARF 2003). The primary advantage of biodosimetry is widespread familiarity with the method among the community of engineers and scientists involved in water treatment applications. However, biodosimetry assays all suffer from the inability to provide a measure of the UV dose distribution delivered by a UV reactor system. Because of this, the results of biodosimetry cannot be used to develop quantitative predictions of the inactivation response of any organism other than the challenge organism, unless the organism of interest has identical UV dose-response behavior to that of the challenge organism. As such, generous factors of safety are usually applied to the results of biodosimetric testing.

Previously, the only methods available to estimate UV dose distributions involved integrated numerical simulations of fluid mechanical behavior [usually based on Computational Fluid Dynamics (CFD)] and the UV intensity field; collectively, these models are now referred to as CFD-I simulations. However, the use of numerical models is complicated by uncertainty in the values of some critical input parameters and the complex nature of the models themselves. In addition, the results of numerical simulations must be validated against measured system behavior. Therefore, the development of an experiment-based method for measurement of the UV dose distribution delivered by a UV disinfection reactor represents a potentially important advance.

To address this need, a new method of UV reactor validation was developed based on the application of dyed microspheres (DMS). This method, termed "Lagrangian actinometry", allows measurement of the UV dose distribution delivered by a UV reactor for a given set of operating conditions. Currently, Lagrangian actinometry has been successfully applied to different types of UV systems under a range of operation conditions. UV reactor testing by Lagrangian actinometry has been shown to provide accurate measurements of UV dose distributions delivered by UV disinfection systems and to provide excellent agreement with results from biodosimetry as well as numerical simulations.

Dyed Microspheres

Dyed microspheres involved in Lagrangian actinometry are prepared through conjugation of a biotinyllated compound to streptavidin-coated polystyrene microspheres (Polysciences, Inc., Warrington, PA) as described previously (Blatchley et al. 2006). The compound, *(E)*-5-[2-(methoxycarbonyl)-ethenyl]cytidine (hereafter referred to as S), yields a single photoproduct 3-β-D-ribofuranosyl-2,7-dioxopyrido[2,3-*d*]pyrimidine (hereafter referred to as P) when subjected to germicidal UV radiation (Bergstrom et al. 1982). This reaction has been shown to have a high quantum yield across the germicidal UV spectrum (Shen et al. 2005); therefore, the S→P system is an effective actinometer for germicidal UV radiation. In addition, the stable photoproduct P is brightly fluorescent with an excitation maximum at 330 nm and an emission maximum at 385 nm, whereas the starting material (S) is not. This allows the photoconversion of S to P to be quantitatively measured as an increase in fluorescence intensity (FI), which in turn allows measurement of UV dose delivery to an individual microsphere.

Dyed microspheres used in Lagrangian actinometry have a specific gravity of 1.05 and a mean diameter of 5.6 μm, which are similar to the physical properties of some waterborne microorganisms (e.g., protozoan (oo)cysts). Therefore, the trajectories of DMS are assumed to be similar to those of microorganisms when traveling through UV disinfection systems. Moreover, the action spectrum of DMS is also similar to that of several relevant waterborne microorganisms (and DNA) (see Shen et al. 2007). It has been hypothesized that such similarity should allow the exposure of DMS to polychromatic radiation to mimic the responses of challenge microbes when subjected to polychromatic UV radiation, and the results of DMS applications to polychromatic reactors support this hypothesis (Shen et al. 2007). Therefore, the application of a large population of DMS to a UV system, with appropriate sample collection downstream of the irradiated zone, allows measurement of the UV dose distribution. Figure 1 provides a conceptual representation of Lagrangian actinometry through the use of dyed microspheres.

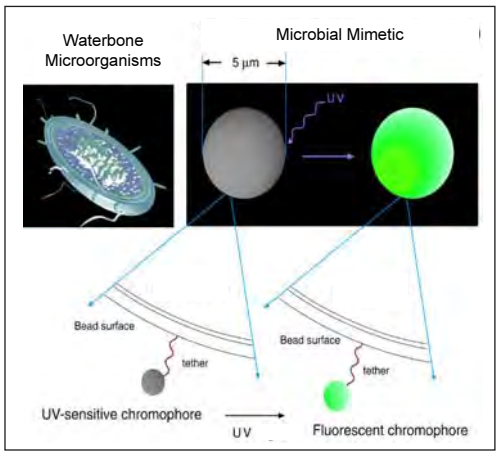

Figure 1. *Schematic Illustration of a dyed microsphere*

The fluorescence intensity (FI) of dyed microspheres is quantified through flow cytometry. Thousands of DMS are analyzed individually in a matter of seconds, and the collected information will yield a distribution of FI. The FI distribution may be presented in the form of a histogram (see Figure 2).

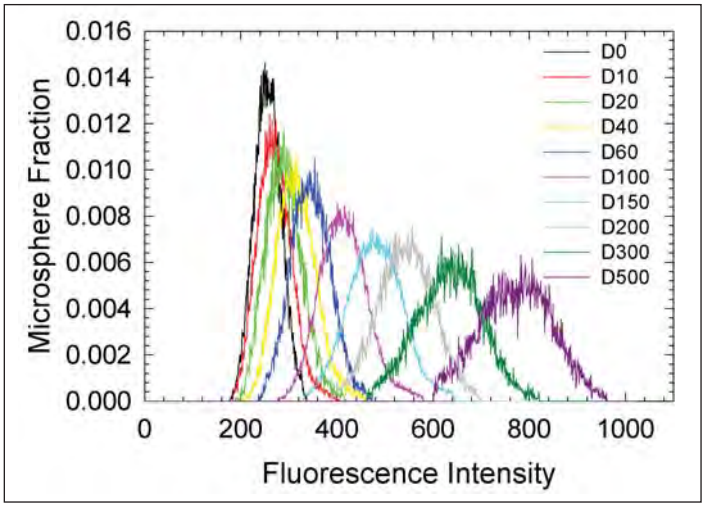

Figure 2. *Fluorescence intensity distribution from a set of dyed microsphere DR samples.*

UV Dose Distribution Estimation by Lagrangian Actinometry

Lagrangian actinometry requires definition of the UV dose-response (DR) behavior of DMS. DR testing of DMS is quantified by typical collimated beam experiments (USEPA/UVDGM 2006) using a low-pressure collimated beam apparatus with monochromatic output at wavelength of 254 nm. Results from the collimated-beam experiments (Figure 2) provide detailed information regarding the FI distribution behavior of the DMS over the range of relevant UV doses for the reactor system of interest. Non-linear regression is applied to the DR data to allow interpolation of DMS DR behavior at UV doses that fall between those used in the actual DR experiment.

DMS are also imposed on a continuous-flow reactor and collected downstream of the irradiated zone of the reactor that is being validated. The flow-cytometric analysis of a DMS testing sample will also generate a FI distribution (see Figure 3). Numerical deconvolution of these data and the DR results allows estimation of the UV dose distribution delivered by a reactor for the operating conditions corresponding to the test (see example in Figure 4).

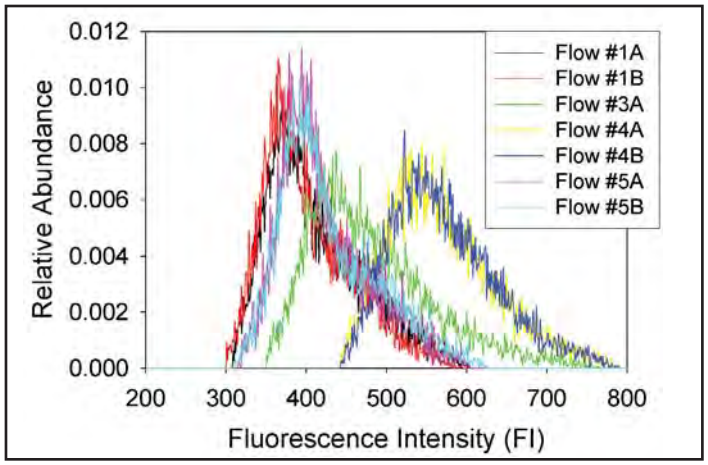

Figure 3. *FI Distribution from analysis of dyed microsphere samples by flow cytometry.*

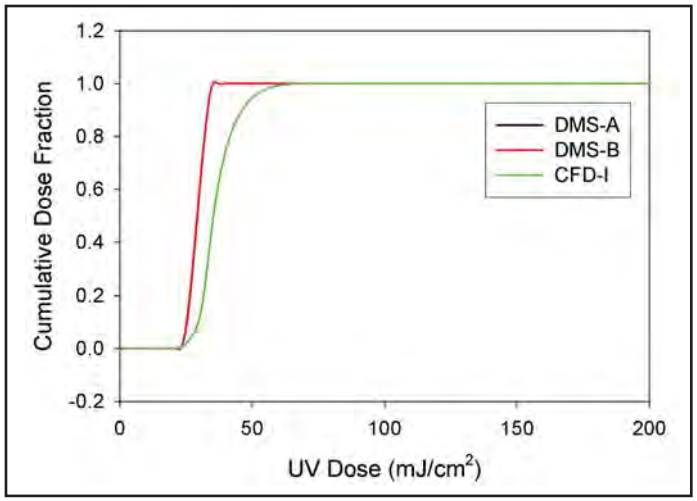

Figure 4. *Estimates of UV dose distribution (as cumulative UV dose fraction) delivered by ITT/Wedeco reactor at operation conditions of 32 mgd (5000 m3/h), 50% power, and UVT (1 cm path length) of 90%. Note the estimates from DMS samples A and B are overlapped on top of each other.*

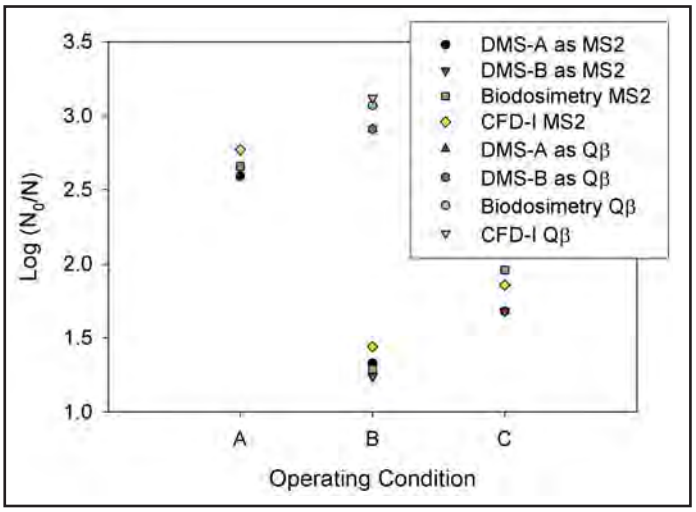

Figure 5. *Summary of predicted and measured inactivation responses for biodosimetry tests conducted on ITT/Wedeco reactor.*

APPLICATION OF LAGRANGIAN ACTINOMETRY TO UV DISINFECTION SYSTEMS

Lagrangian actinometry has been applied to several UV disinfection systems, ranging in size from bench-scale, single-lamp reactors to field-scale systems with hundreds of lamps. Lagrangian actinometry has been used to provide UV dose distribution estimates for UV reactors based on low-pressure (LP), LP high-output (LPHO) lamps, medium-pressure (MP), and excimer lamps. Operating conditions for these tests have covered wide ranges of flow rate, water transmittance (UVT), and system power levels. DMS tests have been conducted on UV reactors used for drinking water and water reuse applications. The results from these applications have demonstrated the validity and accuracy of Lagrangian actinometry. The method has also been demonstrated to provide highly repeatable results based on measurements of replicate samples collected from various reactors.

Perhaps the most important aspect of the results of Lagrangian actinometry experiments conducted to date is the fact that when combined with measured UV dose-response behavior for challenge organisms used in parallel or simultaneous biodosimetry experiments, the UV dose distribution estimates developed by Lagrangian actinometry yield excellent agreement with measured inactivation responses from the biodosimetry experiments. Moreover, these results have been in agreement with biodosimetry results even when more than one challenge organism was tested in a reactor for a given set of operating conditions. Figure 5 illustrates the results of such a comparison for a large-scale LPHO reactor tested for the NYC Catskill/Delaware UV disinfection facility; the predictions of challenge organism inactivation based on the UV dose distribution estimates from the DMS test were in excellent agreement with measured inactivation of coliphage MS-2 and Qβ for all operating conditions tested.

When available, UV dose distribution estimates by Lagrangian actinometry were also compared with the results from numerical simulations (CFD-I) using the same operating conditions as the simulation inputs. Again, good agreement was demonstrated among these methods of reactor characterization, as shown in Figure 4.

What can Lagrangian Actinometry Bring to Us?

As described previously, all existing validation protocols for UV reactors are based on biodosimetry. Because biodosimetry cannot yield a UV dose distribution measurement, validation protocols based on biodosimetry must employ uncertainty factors to define reactor operating conditions that will safely meet treatment objectives. These safety factors are intended to account for uncertainty in UV dose-distribution delivery by the reactor, as well as uncertainty associated with the use of microorganisms in a validation protocol.

In contrast with biodosimetry, Lagrangian actinometry yields an estimate of the UV dose distribution. In principle, the results of microspheres tests can be used to yield accurate predictions of the performance of a UV reactor for any microorganism, as long as reliable information regarding the UV dose-response behavior for the organism(s) of interest is available. To illustrate this point, the results of biodosimetry and Lagrangian actinometry conducted on the same ITT/Wedeco reactor were used to define the RED bias factor (B_{RED}) according to protocols defined in the UV Disinfection Guidance Manual (USEPA/UVDGM 2006). The UVDGM incorporates the "RED bias" (B_{RED}) as an uncertainty factor in calculating the credited RED or $\log_{10}$ inactivation of a target organism for a specific validated UV unit. This factor is a direct multiplier when sizing a UV system or in determining the operating status of a UV system.

Based on MS2 biodosimetry, B_{RED} for the system is approximately 1.7. An argument can be made that B_{RED} could be assigned a value of unity for the microspheres assay, given that the UV dose distribution is known by direct measurement. However, for purposes of this presentation, a conservative approach has been maintained. Following the protocols outlined in the UVDGM, a B_{RED} value of 1.1 was determined from the microspheres results. According to Table 1, a 35% reduction in electrical service requirement and an annual electricity cost saving of nearly $1,000,000 (based on a rate of $0.12/kWh) can be achieved for facility with operating flow of 1.5 BGD (235,000 m^3/h) by applying the lower B_{RED} derived from the microspheres results. Even considering a small facility with an average operating flow of 10 MGD (1,577 m^3/h), such annual energy cost saving could still approximate $6,000. Note that this analysis considers only the reduction in energy costs, and ignores other potential O&M cost reductions such as lamp replacement and labor, which could equal or exceed the energy savings associated with the reduced system operations. Additionally, the ability to reduce the size of the system by up to one-third would have obvious implications relative to capital costs. Therefore, Lagrangian actinometry is beneficial not only economically, but also environmentally in terms of energy conservation.

SUMMARY

Lagrangian actinometry using DMS represents the only available method to measure the UV dose distribution delivered by a UV reactor and reduce the uncertainty associated with predictions of process performance. Therefore, DMS tests represent a potential method for reducing the costs of UV disinfection by reducing the safety factors required for the current validation protocols. In addition, Lagrangian actinometry is also the only method whereby CFD-I numerical models can be validated at the level of the UV dose distribution. The method can be an invaluable tool in the optimization of an installed commercial system and in the development of new reactor designs.

A logical approach to reactor validation can involve the combined application of Lagrangian actinometry, biodosimetry, and numerical simulations. Specifically, Lagrangian actinometry and biodosimetry could be examined over the range of operating conditions for which the reactor is designed. The results of these tests can then be compared with each other for purposes of validation of the reactor, as well as the test methods. In turn, these results can also be used for validation of a numerical model. If properly validated over the range or relevant operating conditions, it should then be possible to develop accurate predictions of reactor performance at operating conditions that fall within the range of conditions over which the model was validated by comparing with results of Lagrangian actinometry and biodosimetry. Ultimately, one can suggest that the actinometric approach, when combined with well-developed collimated beam UV dose-response information for specific microbes, can satisfy in itself the validation requirements for new systems. CFD-I models that employ DMS UV dose-distribution data for calibration and verification will be enhanced, and gain greater confidence in their predictive use for reactor optimization and the commissioning of installed systems.

Table 1. *Examples of the impact of the DMS method for measurement of UV dose delivery with respect to electrical service demand and electrical power costs with LPHO UV systems.*

System	Average Service Flow (MGD)	Surrogate for Valiation	Required Power Service (kW)	Annual Power Cost ($ US)
Large Facility	1500	MS-2	2800	2,950,000
		DMS	1800	1,908,000
Small Facility	10	MS-2	18.7	19,000
		DMS	12.1	13,000

FUTURE WORK

A new project has been approved and is sponsored by New York State Energy Research and Development Authority (NYSERDA) and the American Water Works Association Research Foundation (AwwaRF), with direct participation of UV system manufacturers and major water utilities, including the NYCDEP. The objective of this work is to establish and demonstrate standardized protocols to directly measure the UV dose distribution of UV reactors by Lagrangian actinometry using DMS. The ultimate goal of this project is to incorporate these protocols into the context of the UVDGM, with regulatory consensus, eventually leading to a 'uniform' testing protocol that allows measurement of UV dose-distribution and UV dose-delivery with a combination of biodosimetry and actinometry. Further testing is incorporated into this project that will assess the method's response to alternate configurations, including the impact of alternate approach/exit hydraulic conditions. Subsequently, the intent is to incorporate the method into validations for large water utilities, providing substantial benefit to these entities with respect to cost-effective optimization of their systems, both in sizing and in operational strategies. These validation tests will also incorporate and support the calibration and verification of CFD-I models for the specific reactor (or line of reactors).

ACKNOWLEDGEMENTS

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A State Perspective on the USEPA UV Disinfection Guidance Manual

Stephen Deem, PE,[1] David Dziewulski, PhD,[2] Michael Montysko, PE,[3] and **Richard H. Sakaji, PhD, PE[4]***

Regional Engineer, Washington State Department of Health, Office of Drinking Water, Kent, WA
Research Scientist, New York State Department of Health, Bureau of Water Supply Protection, Troy, NY
Chief, Design Section, New York State Department of Health, Bureau of Water Supply Protection, Troy, NY
Senior Sanitary Engineer, California Department of Health Services, Division of Drinking Water and Environmental Management, 850 Marina Bay Pkwy, Bldg P, Richmond, CA 94804.

***Corresponding Author, Email:** rsakaji@dhs.ca.gov

ABSTRACT

IUVA posed three short, but broad questions to regulatory programs that have been implementing ultraviolet (UV) disinfection prior to promulgation of Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) and in the absence of a final UV Disinfection Guidance Manual (UVDGM), in an effort to evaluate how the UVDGM has or will affect the implementation of UV. While the overall consensus is that the UVDGM is a good document, it does not provide the definitive word on UV disinfection that many states would like. There are still unresolved issues and areas of concern, even for states that have accepted and permitted UV disinfection systems. The author's hope is that this article opens a dialog among state regulators in an effort to move UV disinfection forward as a viable treatment technology in a manner that is protective of public health.

INTRODUCTION

For several years, utilities and regulators knew that *Cryptosporidium* would be regulated as a drinking water contaminant because of the accord that was struck between utility and regulatory stakeholders during the USEPA's regulatory negotiations in the late 90's. Initial development of the Long Term 2 (LT2) Enhanced Surface Water Treatment Rule (LT2ESWTR) did not consider UV because, although it has been well known that UV is an effective disinfectant for bacteria and most viruses, it was widely held that the UV doses for protozoan inactivation would be too high and too costly to attain.

The landmark work of Bolton et al. (1998) demonstrated that previously held beliefs regarding the UV doses (medium pressure) needed for *Cryptosporidium* inactivation were incorrect and that much lower UV doses could achieve the desired public health objectives. With the release of subsequent studies validating and extending the findings of Bolton et al. (1998) to low pressure UV (Clancy et al. 2000; Craik et al. 2001; Shin et al. 2001), the water industry knew UV was going to be a viable treatment technology providing an alternative to traditional chemical oxidants for protozoan pathogen inactivation. Utilities recognizing this, and those under compliance orders or who were proactive and were in the midst of planning capital improvements, began to approach state drinking water programs about designing and building UV installations. Consequently some states, rather than putting the technology on hold to wait for a final guidance manual, began the journey toward implementing the technology in the absence of formal USEPA guidance.

Although the Surface Water Treatment Rule, promulgated in 1989, did include guidance (USEPA 1991, Table E-14) which recognized UV as being an effective disinfectant for viruses, the application of UV disinfection has been limited to low flow drinking water applications (e.g., point-of-use treatment or disinfection of small groundwater systems), and focused on virus and bacterial inactivation. Given the lack of overall experience with UV in the larger drinking water utilities, and the fact that it is generally recognized that the margin for error in larger scale plants can have a significant impact on the system performance and the costs, there was significant concern about how UV systems would be validated, designed, built, and operated to ensure pathogen inactivation objectives were met.

Bringing any new water treatment technology into the mainstream of the water industry is a daunting task. Regardless of how long a technology may have been used in another medium or in another environmental field, there is always a learning curve as regulators, consultants, and utilities familiarize themselves with the technology. UV disinfection is no exception, the three states participating in this short article have all taken different routes to gain their present state of knowledge and experience which,

along with many consultants, utilities, and manufacturers, has been used in providing feedback to the authors of the USEPA's UV Disinfection Guidance Manual (UVDGM) (USEPA 2006).

Now that the UVDGM has been finalized, IUVA posed three short, but broad questions to regulatory programs that have been implementing UV disinfection prior to promulgation of LT2ESWTR and in the absence of the UVDGM, in an effort to evaluate how the UVDGM has or will affect the implementation of UV.

The authors recognize the range of knowledge and zone of comfort with UV disinfection varies among regulatory agencies and utilities. Nevertheless, it is the intent of this article to stimulate an open dialog among regulators, consultants, and utilities as a means of finding solutions to those issues that remain hurdles to the use of UV as a disinfection technology.

1. STATE PERSPECTIVE ON UVDGM ON CURRENTLY OPERATING UV FACILITIES (e.g., SEATTLE)

Many utilities throughout the United States have already installed and are operating UV disinfection facilities. Some utilities have sought to increase public health protection for their customers with an additional or secondary barrier against *Cryptosporidium* and *Giardia* while positioning the utility to meet upcoming LT2 requirements. Ongoing operational regulatory requirements for these utilities are generally minimal or do not exist since LT2 operational requirements are not in effect. The UVDGM will aid these currently operating UV facilities and their respective state regulatory agencies in finalizing operational requirements needed to meet LT2.

Several utilities, however, have installed UV technology as a primary disinfectant to meet existing *Giardia* inactivation requirements under the Surface Water Treatment Rule (SWTR) and/or *Giardia* and *Cryptosporidium* inactivation requirements under the Enhanced SWTR. These utilities operate under daily and monthly operational requirements similar to utilities employing chlorination for primary disinfection under the SWTR. One example is the City of Seattle's efforts that began in 2001 to obtain Limited Alternative to Filtration (LAF - Unfiltered Status) designation for the Cedar River supply and the use of UV technology as a primary disinfectant for *Giardia* and *Cryptosporidium* inactivation. Under Washington State requirements for LAF, Seattle must provide 3-log *Cryptosporidium*; 4-log *Giardia* and 5-log viral inactivation using at least three separate disinfectants. UV technology provides 3-log *Cryptosporidium* and 3 log *Giardia* inactivation in this setting. The Cedar UV treatment facility has relatively stringent daily and monthly operational and reporting requirements including time based compliance computed every minute while the facility is operating. The UVDGM will not greatly affect these approved operating facilities since regulatory requirements are based on existing regulations founded on the SWTR and Enhanced SWTR regulations. However, we believe that the presence of national guidance for UV validation, design, operating and monitoring parameters will facilitate States and utilities allowing existing UV installations to gain credit for Giardia and Crypto inactivation credit under SWTR requirements.

Generally all water treatment facilities are required to monitor critical treatment parameters daily, to record parameter values and to submit monthly treatment reports to the State. Monitoring requirements for UV treatment facilities depend in part upon the rule application (i.e., SWTR vs. LT2ESWTR) and on the UV dose control method utilized. Set point control is simpler than UV dose control and requires less monitoring. Common monitoring parameters include monthly sensor checks, lamp hours, UV Transmittance, total volume of water treated, peak flows, hours operated, sensor readings, minimum UV doses and time operated outside of the validated range (off specification). Monthly treatment reports should also include information regarding any maintenance including cleaning, sensor calibration, lamp, sleeve, and ballast replacement. Utilities that have backup generator systems and / or uninterrupted power supply (UPS) need to document routine testing and maintenance activities for these critical systems.

2. STATE PERSPECTIVE ON HOW UVDGM WILL AFFECT PERMITTING FUTURE UV FACILITIES

Public health protection from waterborne pathogens that can cause acute diseases remains the primary purpose for UV disinfection. In order to ensure public health protection is not compromised by supply side economics, it is desirable to ensure economic advantages are not gained at the expense of public health protection. In order to meet the public health objectives with properly designed UV disinfection systems, the UVDGM establishes a standard test protocol under which performance of the UV system can be validated so UV systems can be compared equitably.

Because the UVDGM establishes a test protocol for the validation of UV systems, it should become easier to permit future UV facilities. By coupling the UVDGM content with lessons learned from the installation of earlier UV systems, future UV systems should be easier to permit as there will be increased confidence and comfort with the accuracy of the UV design, construction, and operation.

Acceptance of UV should only be provided for UV units that have demonstrated that they have been validated in accordance with the UVDGM either "on-site" or at a facility acceptable to the state. Ideally, UV units would be validated under a standard protocol by an independent testing organization. Certification or listing by the testing organization would be sufficient to ensure the unit was capable of meeting some minimum performance metric that would also reflect the public health objective, e.g., pathogen inactivation. This certification would also include testing under the conditions of installation so users would

know that the system was achieving the minimum levels of pathogen inactivation. NSF International has two programs that provide limited testing of UV devices. The ANSI/NSF standard 55 certification program covers the certification of small UV systems for point-of-use and point-of-entry applications, whereas, the USEPA/NSF ETV program certifies the quality of data in UV systems tested under the ETV protocols. To date neither of these programs has tested UV units for larger municipal systems as there are very few facilities capable of producing the large flows needed for the reactor tests.

In addition to the method outlined in the UVDGM, the UVDGM allows for the acceptance of units validated by the German Association for Gas and Water (UVGW), the Austrian Standards Institute (ÖNORM). At this time there are a limited number of remote testing facilities that have been accepted by the states authoring this article and they are the UVGW, ÖNORM, Johnstown, New York (Hydroqual Inc.) and the Portland, Oregon (Carollo Engineers) testing facilities.

In the past, some states have accepted the use of ANSI/NSF certified equipment validated by the ANSI/NSF Standard 55 (Class A) for small water systems. This standard is being reviewed and reevaluated by some state regulators including New York due to inconsistencies in the validation protocols between ANSI/NSF Standard 55 (Class A) and the USEPA UVDGM (USEPA 2006). As written, ANSI/NSF Standard 55 testing has been deemed unacceptable and not in conformance with the USEPA UVDGM in Washington State.

Although there are several validation protocols that are currently acceptable, States will have to decide if there are acceptable alternative surrogates to the MS2 or spores used in the validation work. Studies have shown that other bacteriophage viruses may approximate more closely the behavior of *Cryptosporidium* (Fallon et. al. 2007) with regard to UV dose response. The advantage is that with lethal UV doses closer to what will be needed for *Cryptosporidium*, surrogates more sensitive than MS2 would introduce smaller differences in the inactivation data obtained for the surrogate and *Cryptosporidium*. This, in turn, would require less of a correction factor between bioassay results and log-inactivation of the target organism during actual inactivation in the as-installed reactor (i.e. bias).

In addition, on-going work involving chemical actinometry may offer a standard for the future. Essentially, chemical dyes that are sensitive to UV would be used directly or coated onto a particle surface and introduced into reactors during validation work (Blatchley, et. al. 2006). Particles, for example, could be harvested after exposure and the extent of UV exposure determined via the extent of chemical change. This could also be a useful way of in situ testing of units that may have needed repair or upgrading.

With multiple testing facilities in operation and regardless of which microorganism or surrogate is used to validate a UV reactor, there are data quality issues. States may ask themselves, what constitutes an acceptable validation test? Quality control (QC) over the results produced by these testing facilities is important to ensure equity among the UV manufacturers so that UV reactor performance can be compared. The UVDGM provides criteria, such as the use of National Institute of Standards and Technology (NIST) traceable calibrated radiometers for the collimated beam tests. However, there are no quality assurance criteria, other than the calibration certificates, to determine if the radiometers used during the collimated beam portion of the validation testing are actually in calibration. It is simply assumed that the radiometers are in calibration. Since these tests are the basis for determining the UV dose delivered by UV reactor during validation testing, ensuring the radiometers are calibrated is critical for establishing the UV dose delivered to the microorganisms passing through the reactor.

Another source of variability in the collimated beam test are the microorganisms themselves. The UVDGM provides confidence intervals (Appendix A) for MS2 and *B. subtilis* to show the reader where the UV dose response curve for each of the organisms should reside. However, if one examines the UVDGM confidence intervals for MS2 and *B. subtilus*, one is struck by two observations. First, MS2 and *B. subtilis* exhibit very different responses to UV inactivation. Second, for a given UV dose, say 40 mJ/cm^2, the confidence intervals for MS2 and *B. subtilis* are not equal in magnitude, that is, the log inactivation confidence interval for *B. subtilis* is much wider than the confidence interval for MS2. However, since different manufacturers could choose to validate their reactor with different microorganisms, one could end up with very disparate results between manufacturers. If the discrepancy was large this would lead to a large difference between the size and performance of each manufacturer's UV reactor that would translate directly into capital and O&M costs.

Quality assurance and quality control (QA/QC) is important because without these criteria, the chance of accepting incorrect data increases as the inherent uncertainty of the data set increases. In an attempt to impose some degree of quality assurance and quality control, the National Water Research Institute (NWRI) and the American Water Works Research Foundation (AWWARF) established a set of QA/QC boundaries for MS2 (NWRI/AWWARF 2003). These boundaries are narrower than the confidence intervals for MS2 published in the UVDGM. Through the application of the NWRI and AWWARF QA/QC boundaries contaminated seed cultures (all microorganisms exhibit different UV dose responses to UV) and improperly calibrated radiometers have been observed and caught before the data could be used in the design and operation of the UV units. As the NWRI/AWWARF boundaries are more restrictive than the USEPA confidence intervals, states may elect to continue using these boundaries as a quality control check whenever MS2 is used in the validation testing.

The UVDGM allows for the introduction of bioassay surrogates allowing states to use other surrogates for the bioassay testing. However, the UVDGM does not provide the states with any guidance on how or what adequate QA/QC requirements might be used to accept test results. Regardless of which surrogate microorganism is selected, bioassays are expensive and complex undertakings, a task not suited to small water systems.

Depending on validated UV reactor results and corresponding safety factors, a UV dose of 40 mJ/cm^2 may be higher than needed for a specific log inactivation for the target organism. For some utilities the cost of power to operate at a higher UV dose than is needed may be significant. For smaller systems or systems that do not wish to deal with the expense and complexities associated with UV dose adjustment states may require that they operate their UV systems at a minimum UV dose of 40 mJ/cm^2. Since the power savings are far lower than conducting an on-site bioassay to optimize the UV dose, most small water systems will either choose to operate at the higher delivered UV dose or will be required to do so by the regulatory agency. Many small water systems will likely choose this option and the savings in energy associated with UV dose adjustment will not be significant enough to offset additional operation costs when compared to a constant UV dose operation. For some small water systems this could mean selecting an ÖNORM or DVGW validated reactor, which the USEPA UVDGM recommends as having demonstrated a UV dose delivery of 40 mJ/cm^2.

However, systems such as New York City's proposed 2.4 billion gallon per day plant may see significant energy cost savings in operation at a reduced UV dose. In larger water systems, a constant UV dose operating strategy can be expensive and wasteful so they may want to operate at narrower margins for power savings thereby reducing the O&M costs. The larger water systems may also have the managerial infrastructure to monitor their UV systems and process train more closely. The UVDGM allows larger utilities to optimize the operation of their UV systems by establishing the operating parameters for the UV reactor, using the validation test data.

For small water systems the easiest means of identifying a reactor might be to pick one off a list of validated reactors, something many design engineers would like to do also. However, at this time no such comprehensive list exists. The authors and numerous others have been considering and discussing this question for some time and there appears to be a great interest in the development of such a list from regulators, manufacturers, and consultants. Some of the major considerations for the development of a list are: maintenance of the list by a central organization, which states would accept it, and the process for including a unit on the list. Some ideas that have been discussed were to have an organization, such as the International Ultraviolet Association or NSF International, maintain a UV equipment list using a committee made up of academia, regulators, and consultants. The committee members would establish the detailed validation protocol, evaluate the validation reports, and determine if the UV units were validated appropriately. These discussions will continue and hopefully over time the issue will be resolved and a list will be developed.

3. AREAS WHERE STATES MAY DEVIATE FROM UVDGM

As mentioned earlier, validation and/or reactor approval process may be different for small systems and large systems. For example, it may be simpler for the states to accept a uniform standard that uses a fixed 40 mJ/cm^2 as the validated UV dose (i.e., the UV dose delivered by the UV reactor through validation testing) for smaller systems that do not wish to adjust UV dose. This approach would have the advantage that many UV reactors have already been validated by ÖNORM or UVGW for 40 mJ/cm^2 using a set point method of control. In a sense, this is similar to what was referred to as a Tier 1 criterion in the earlier draft UVDGM; the reactors would be validated using a range of UVT (e.g., 70 – 95%), a specified maximum flow rate and a specified lamp output. These 'off-the-shelf' units would be installed and run at the maximum intensity/UV dose. States, therefore, may choose to limit UV dose control operations for small systems due to its increased complexity and difficulties verifying ongoing accuracy.

Larger plants that may wish to adjust UV dose, those with customized designs, or high capacity UV reactors would likely have to do extensive testing and modeling to demonstrate that these untested (unvalidated) reactors can demonstrate that they are capable of delivering a specified validated UV dose under unique conditions. These conditions may be due to unusual inlet or outlet pipe geometries (e.g. retrofitting large plants), lower than expected UVT values that may coincide with peak demand, etc. Ultimately one goal of being able to adjust UV dose would be, as noted earlier, energy savings when multiple units with throughputs in the multi-million gallon level are installed.

Although energy savings would be one of the objectives of the large installed units; the path to those energy savings may take several steps. During validation there may be concerns related to turbidity or color peaks that may coincide with maximum demand. These unusual conditions need to be tested so that, when installed, the reactor always meets the required UV dose for the pathogen of concern (in most instances this will be *Cryptosporidium*). These conditions may be incompatible with any temporary energy savings. Consequently, any validation must account for these unusual conditions and any unusual flow geometries, etc. However, testing for each and every condition would be prohibitively expensive. One way to overcome this is by coincident validation and reactor modeling. Critical testing (and or modeling) would need to be done in order to run at the lower UV doses. Modeling (flow and UV dose elements) needs to be backed up by physical validation. For example, New York State participated in blind testing to determine the efficacy of modeling to predict UV dose in advance of full-scale validation. Test parameters (e.g. bioassay parameters, physical conditions of flow, UVT, etc.) were

supplied to the modeling group from a remote facility that was currently validating a reactor. The results of the field test were only supplied to third-party regulators. The modeling group then calculated the RED using the model and, once calculated, their results were compared the field test. Both fit and correlation between the two sets of data were excellent with the model overestimating the actual bioassay RED by a small amount at very high UV doses (80 mJ/cm^2). These results indicated that the model could be used to predict in-field testing and have the potential for use in anticipation of difficult events or operational control. More work needs to be done but it is possible that, modeling alone will never be considered a stand-alone gold standard.

One area where States may expand more than deviate from the UVDGM is in the application of UV technology as a primary disinfectant for compliance with the requirements of the SWTR and Enhanced SWTR. Use of UV for primary disinfection will require more stringent monitoring and reporting than is outlined in the UVDGM. Likewise this expansion may require 'time based' compliance determinations versus 'volume based' compliance determinations as specified in the UVDGM for LT2 compliance. In addition some states may also set more stringent performance goals to help minimize untreated or off specification events.

SUMMARY

The UVDGM is a good document. The testing protocol remains in guidance because many specifics regarding UV disinfection technology have not been resolved. As with any technology, the lack of specificity in the LT2ESWTR regulation can be viewed as providing an opportunity for the utilities using the technology to development other aspects of the technology, for example, the development of new bioassay surrogates. The lack of specificity also provides some design and operating flexibility under the rule, but everyone should exercise due diligence in their selection of approaches. The underlying theme of all self monitored regulatory programs is that all parties are expected to employ their best engineering skills and judgment to the final project design and construction and permitting to meet the water quality objectives.

Other states should not feel as though they are entirely on their own when issues arise, as there are states who have faced many of the issues you will be facing, we encourage our colleagues in other states to contact us with questions. We cannot guarantee we will have all the answers, but may be able to provide you with our thoughts or direct you other colleagues with additional resources (you may also bring to light issues that haven't been addressed. We look forward to working with you to bring this disinfection technology into the drinking water field.

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Overview of Validation

Harold Wright,* David Gaithuma, and Erin D. Mackey
Carollo Engineers, 12592 West Explorer Drive, Suite 200, Boise, Idaho, 83713

*** Corresponding Author, Email: hwright@carollo.com**

ABSTRACT

USEPA recently published the 2006 UV Disinfection Guidance Manual. Compared to the 2003 draft Guidance, the 2006 Guidance includes an updated section on UV reactor validation that reflects new developments in validation approaches and a modified approach for applying that validation data for defining pathogen inactivation credit. This paper describes what's new in the 2006 guidance and describes recent developments in UV validation methods which will impact how UV validation will be applied in the future.

KEYWORDS: UVDGM, UV disinfection, dose distributions, biodosimetry

INTRODUCTION

The 2006 USEPA *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* (UVDGM) (USEPA 2006) includes one chapter (Chapter 5) and five appendices (Appendices A, B, C, D and G) on UV validation. This article highlights some of the key differences between the Final 2006 UVDGM validation protocol and the 2003 Draft UVDGM, and discusses the impact of new advances in UV reactor validation methods.

What's New In The 2006 Validation Protocol?

The significant changes in the 2006 protocol were motivated by new knowledge in the art and science of UV validation and a desire to simplify the validation calculations.

The 2006 protocol specifies that the stability of the test microbe's concentration and UV dose-response should be verified during validation. This new guidance was added in response to numerous reports in the literature of phage die off during validation testing (e.g., Hargy et al. 2004).

The new protocol also lists T1, T7, and QB phages as alternates for MS2 phage for the validation of reactors for *Cryptosporidium* and *Giardia* credit. These "new" microbes are more sensitive to UV light than MS2 phage, and hence reduce the RED bias uncertainty associated with testing reactors for *Cryptosporidium* and *Giardia* credit. For UV reactors with relatively narrow UV dose distributions, the use of microbes such as T1, T7, and QB phage instead of MS2 will result in significant capital and O&M cost savings while maintaining public health protection. On the other hand, for UV reactors with UV dose distributions wider than those used to define the 2006 UVDGM RED Bias factors, a more sensitive microbe like T1 will better characterize the impact of the lower end of the reactor's UV dose distribution, and hence improve public health protection.

With the validation of polychromatic UV systems, the 2006 UVDGM specifies that the wavelength response or action spectra of the test microbe should be evaluated to determine if it matches that of the target pathogen (e.g., *Cryptosporidium*). A correction factor should be applied if the test microbe's wavelength response biases the measured RED to values higher than delivered to the pathogen. For example, action spectra data indicates that a factor of approximately 1.15 should be applied to T7 REDs measured with medium-pressure UV systems (Wright et al. 2007). Appendix D of the UVDGM provides one approach for calculating this bias.

The UVDGM states UV sensors should be germicidal. If non-germicidal UV sensors are used, the polychromatic bias caused by differences in the UVA spectrum during validation and the UVA spectrum at the WTP should be included in the calculation of the validation factor used to define pathogen credit. The guidance also states this bias should be accounted for if the germicidal sensor is located relatively far from the lamps (e.g., > 10 cm) and/or the reactor is used at low *UVT* (e.g., < 80%).

The UVDGM also provides more emphasis on the impact of non-uniform lamp aging based on the results of a recently completed Awwa Research Foundation study (Wright et al. 2007), which reported that UV dose delivery can be significantly over estimated if the UV sensors view

the lamps at locations that age the least over time. This issue should be considered by the UV system manufacturer when they locate the UV sensors within their reactors.

The 2006 UVDGM provides more emphasis on specifying the accuracy of measurements made during validation. For example, the accuracy of the flow rate and UVA measurements should be ±5 and ±10%, respectively. The protocol recommends the use of NIST[1]-traceable wavelength and absorbance standards and organic-free water to confirm UVA measurement accuracy. Duty UV sensors should match the average of two or more reference UV sensors within 10%. The accuracy of the reference sensors should be specified on the calibration certificate. Care should be taken confirming the accuracy of reference sensors. Data from another AwwaRF project, *Design and Performance Guidelines for UV Sensor Systems* shows reference sensor accuracy can vary by as much as 20 percent (Wright et al. 2005). Use of two sensors only reduces that uncertainty to (20 / $\sqrt{2}$ =) 14%. The use of three or more reference sensors is recommended.

Similar to the 2003 UVDGM, the RED of the test microbe is determined from the log inactivation measured through the reactor using the test microbe's UV dose-response curve. The new guidance, however, specifies that the most UV resistant UV dose-response curve measured on a given day should be used to determine REDs if the UV dose-response curves are statistically different at a 95-percent confidence level.

The 2003 UVDGM provided a lot of detail on the UV intensity and UVT/UV intensity setpoint UV dose-monitoring approaches but provided limited information on the calculated UV dose monitoring approach, primarily because algorithms used by UV vendors were proprietary. Since 2003, numerous validations supported by CFD-models have better defined the calculated UV dose-monitoring equations (e.g., Wright et al. 2005). As such, the new UVDGM describes a general equation for the calculated UV dose-monitoring approach:

$$[1] \qquad RED = 10^{a} \times UVA^{b} \times Q^{c} \times \left(S/S_0\right)^{d} \times B^{e}$$

where UVA is the UV Absorbance (corollary to UVT) measured using the on-line UVT monitor, Q is the flow rate through the reactor, S/S_0 is the relative lamp output[2], B is the number of operating banks of lamps, and a, b, c, d, and e are constants determined by fitting the equation to the validation data.

The specific form of this equation will vary with reactor technologies depending on which functions best describe the relations between RED and UVA, flow rate, UV sensor readings, and banks. The equation used should pass through the origin (0,0) and have fit coefficients that are statistically significant at a 95% confidence level. Furthermore, if the UV sensor is optimally located within the reactor, the equation can be defined at a *UVT* value that gives conservative REDs over a wide range of water *UVT*s. In that case, an on-line *UVT* monitor is not required.

The 2003 UVDGM specified that UV dose monitoring and reporting could be based on a target test microbe RED, where that RED is defined as the product of required UV dose for pathogen credit multiplied by a "safety factor". Furthermore, the 2003 UVDGM specified two approaches for defining that safety factor, termed the Tier 1 and Tier 2 approaches. The Tier 1 approach defined MS2 REDs for pathogen credit based on compliance of the reactor and its validation to a set of QA/QC criteria. The Tier 2 approach defined an approach for calculating the "safety factor" based on the accuracy of validation and UV dose monitoring specific to the reactor.

The new UVDGM specifies that the UV dose reporting should be based on the UV dose delivered to the pathogen RED as opposed to the test microbe RED. The UV dose delivered to the pathogen RED is defined as:

$$[2] \qquad \text{Validated Dose} = \frac{RED}{VF}$$

where VF is the validation factor defined as:

$$[3] \qquad VF = B_{RED} \times \left(1 + \frac{U_{Val}}{100}\right) \quad \text{Equation 3}$$

where B_{RED} is the RED bias uncertainty factor and U_{Val} is the uncertainty of validation. These equations can either be programmed into the UV system's PLC as part of the UV dose-monitoring algorithm, programmed into the water treatment plant's SCADA system, or used off-line to determine the UV dose reported to the State.

The RED Bias uncertainty factor is determined using Appendix G of the 2006 UVDGM, which tabulates RED bias values as a function of test microbe UV sensitivity and *UVT* for various levels of log inactivation credit for *Cryptosporidium*, *Giardia*, and viruses. The RED bias can be defined either at the lowest *UVT* that can occur with the application or as a function of *UVT* measured using the on-line *UVT* monitor. The UV sensitivity is defined as the maximum ratio of RED/log I observed with all test replicates measured during validation, *i.e.*, the maximum UV sensitivity is used to determine the RED bias uncertainty factor.

Compared to the 2003 UVDGM, the RED bias uncertainty factors now vary with *UVT*, with lower values at high *UVT* and higher values at low *UVT*. This will decrease the capital and O&M costs of UV systems used for high *UVT* applications but increase those costs for UV systems used for low *UVT* applications.

The UVDGM recommends that UV facilities use one value of the RED bias uncertainty factor based on the minimum operating *UVT* of the facility. However, if the water *UVT* drops below the *UVT* value used to select the RED bias uncertainty factor, then the UV system could under dose. For example, with a reactor validated with MS2 phage, the under dosing could be a factor of 2.22/1.73 = 1.28 if the RED bias uncertainty factor is based on 90% *UVT* but the actual *UVT* is 80%. The selection of the used to define the RED bias uncertainty factor will also impact UV dose

delivery under design conditions if that *UVT* is less than the design *UVT*.

The 2006 UVDGM also lets utilities define the RED bias uncertainty factor as a function of *UVT*. If the RED bias uncertainty factor varies with *UVT*, *UVT* monitor errors can lead to over and under estimations of the RED bias uncertainty factor. For example, if a *UVT* monitor reads 98% when the true *UVT* is 95% (an out of specification because the error is greater than 2%), a UV system validated with MS2 for 3-log *Cryptosporidium* credit could under dosed by a factor of 1.38/1.19 = 1.16.

Regardless of how the RED bias uncertainty factor is defined, validation with T1, T7, or QB instead of MS2 phage notably reduces these errors.

For UV systems using the UV intensity setpoint approach, the uncertainty of validation (U_{Val}) is set to:

[4] $$U_{Val} = U_{SP}$$

However, if the UV sensor uncertainty is greater than 10 percent or the uncertainty of the UV dose-response is greater than 30 percent at 1-log inactivation, U_{Val} is calculated using:

[5] $$U_{Val} = \left(U_{SP}^2 + U_S^2 + U_{DR}^2\right)^{1/2}$$

where U_{SP} is the uncertainty of the RED measured at the setpoint, U_S is the uncertainty of the UV sensor used during validation, and U_{DR} is the uncertainty of the validation microbe's UV dose-response curve.

The uncertainty of the setpoint is calculated using:

[6] $$U_{SP} = \frac{t \times SD_{RED}}{RED}$$

where RED is the average RED measured at the setpoint, SD_{RED} is the standard deviation of replicate REDs measured at the setpoint, and t is a t-statistic at a 95% confidence level.

For UV systems using the calculated UV dose approach, the uncertainty of validation is set to the uncertainty of the calculated UV dose-monitoring algorithm:

[7] $$U_{Val} = U_{IN}$$

Again, if either the sensor uncertainty or the uncertainty of the UV dose-response are greater than 10 percent and 30 percent at 1-log inactivation, respectively, U_{Val} would have to include these errors as well:

[8] $$U_{Val} = \left(U_{IN}^2 + U_S^2 + U_{DR}^2\right)^{1/2}$$

The uncertainty of the calculated UV dose-monitoring algorithm is calculated using a similar approach:

[9] $$U_{IN} = \frac{t \times SD}{RED}$$

where RED is the RED predicted by the UV dose-monitoring algorithm for a given flow rate, *UVT*, and UV lamp output, and SD is the standard deviation of the difference between the UV doses predicted by the algorithm for the validation test conditions and the measured REDs, including all replicate pairs. The calculation represents the 95th percentile prediction interval about the relation between measured and predicted RED.

The uncertainty of the UV sensors (U_S) used during validation is defined as the maximum difference between the duty and reference UV sensors observed during validation. This definition does not account for the measurement uncertainty of the reference UV sensors, which may be high. For example, if the difference between the duty and reference UV sensor is 5% but the measurement uncertainty of the reference sensor is 15 %, the accuracy of the duty UV sensor may be as high as 20%. Using multiple reference UV sensors minimizes these errors.

The uncertainty of the UV dose-response, U_{DR}, is defined in Appendix C as a 95-percent confidence interval about the fit to the UV dose-response data. While not mentioned in the UVDGM, confidence interval is calculated as (Draper and Smith 1998, page 80-93):

[10] $$CI = \left[\frac{1}{n} + \frac{(x_i - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})}\right]^{1/2} \times t \times \sigma$$

where n is the number of data sets of UV dose and log inactivation, x_i is a specific value of log inactivation, x is the mean value of log inactivation for the data set, y_i is the predicted UV dose for x_i, t is the Students T-statistic for n-1 degrees of freedom, and σ is the standard error of the difference between the predicted and measured UV doses.

Because of the challenge calculating confidence intervals using Equation 8, the UVDGM provides an alternate simplified calculation:

[11] $$U_{DR} = \frac{t \times SD}{UV\ Dose}$$

where SD is the standard deviation of the differences between the UV dose predicted using the fit to the UV dose response data and the measured UV dose delivered by the collimated beam apparatus for all test points in the UV dose-response curve. Compared to Equation 10, Equation 11 approximates a prediction interval and hence is conservative.

With U_{IN}, U_{SP}, and U_{DR}, the value of the uncertainty increases geometrically at lower REDs. For example, if U_{DR} is 30% at 1-log inactivation of MS2 phage, it is 60% at 0.5-log inactivation. Therefore, care should be taken calculating the validation factor for REDs less than that the equivalent RED for one log inactivation.

Lastly, unlike the 2003 UVDGM, the validation factor does not include terms for UV dose monitoring uncertainty at the WTP. Instead, Chapter 6 of the UVDGM specifies QA/QC criteria for UV dose monitoring. Duty UV sensors should match reference UV sensors within 20%, on-line *UVT* monitors should match lab *UVT* measurements within 2% *UVT*, and utilities using UV systems with fewer UV sensors than lamps (e.g,. most low-pressure high-output systems) should swap out lamps to ensure the UV sensors are not reading the lamp with the highest output. The

uncertainty due to a 2% error measuring *UVT* is small at low *UVT* but becomes significant at high *UVT*. For example, with one validated UV system, the UV dose-monitoring equation can predict a UV dose 1.8 times higher if the on-line *UVT* reads 98% but the actual *UVT* is 96%. The large error occurs because changes in *UVT* have a large impact on UV dose delivery at high *UVT*.

What's New In Validation?

The development of the UVDGM over the last five years was strongly influenced by developments in UV technologies, their validation, and the availability of data. In 2002, the only test facilities were in Germany and Austria and they only validated reactors using the UV intensity setpoint approach. Limited data was available on validation, calculated UV dose monitoring algorithms, properties of UV sensors, and the performance of installed drinking water systems. Today, North America has two validation test facilities, most vendors have validated their product lines, and AwwaRF and other research institutions have completed numerous drinking water UV disinfection projects. However, the world of UV disinfection continues to advance. Two advances in the last year are the use of T1 phage and the determination of UV dose distributions.

T1 phage has been used to validate at least eight UV reactor technologies over the last year. T1 phage has inactivation kinetics without curvature from 0 to 5-log inactivation. The UV sensitivity is approximately 5 mJ/cm^2 per log inactivation. Hence, the RED bias uncertainty factor for 3 log *Cryptosporidium* credit with T1 ranges from 1.05 at 98% *UVT* to 1.21 at 75% *UVT*. This is notably less than the RED bias uncertainty with MS2, which for 3-log *Cryptosporidium* credit, ranges from 1.18 at 98% *UVT* to 2.24 at 75% *UVT*. Because T1 phage is more sensitive to UV light than MS2 phage, it will better characterize reactors for *Cryptosporidium* and *Giardia* credit, evening the playing field between reactors with narrow UV dose distributions and those with wide UV dose distributions.

T1 phage has a notably lower uncertainty of validation than MS2 phage. Calculated UV dose monitoring algorithms that span a wide range of flow rates and *UVT*s have been developed using T1 phage with R-squared values of >0.98. The uncertainty of the UV dose-monitoring equation at a 95-percent prediction level is about 1 mJ/cm^2 with T1, which compares to 5 to 10 mJ/cm^2 with MS2 validation. The uncertainty of the UV dose-response is also notably lower.

Another development in UV validation has been the determination of UV dose distributions and the prediction of microbe log inactivation and RED using those UV dose distributions. Two methods have been developed. The first uses microspheres to measure the UV dose distribution (Shen et al. 2007). The second predicts UV dose distributions from biodosimetry data (Wright 2007). The second approach has been applied to a range of commercial LPHO and MP UV reactors. Figure 1 shows UV dose distributions predicted using MS2 biodosimetry. Figure 2 compares T1 REDs predicted using UV dose distributions determined from MS2 biodosimetry data to measured T1 REDs. Predicted T1 REDs are typically within 1 mJ/cm^2 of the measured values. Ideally, both the MS2 and T1 RED data would be used to determine the UV dose distributions to improve the accuracy of the method.

The ability to determine UV dose distributions provides a new paradigm for UV dose delivery and monitoring. In particular, UV dose-monitoring equations can be expressed in terms of log inactivation credit, instead of validated REDs that need to be correlated to log inactivation credit tables:

$$[12]\quad \text{Pathogen Log Credit} = \frac{10^{a} \times UVA^{b} \times \left(S/S_0\right)^{c} \times Q^{d} \times B^{e}}{1 + U}$$

where the constants *a, b, c, d,* and *e* are obtained by fitting the equation to pathogen log inactivation predicted from UV dose distributions defined as a function of flow rate, *UVT*, UV sensor readings, and banks of lamps. The pathogen UV dose requirements in the Long Term 2 Enhanced Surface Water Treatment Rule would be used to determine the log inactivation from the UV dose. The uncertainty factor *U* would account for the uncertainty of the UV dose distributions, the validation data, and the duty UV sensors used for UV dose monitoring at the WTP. While this method eliminates the need for an RED bias, a polychromatic bias may still apply if the action spectrum of the validation method differs from that of the pathogen.

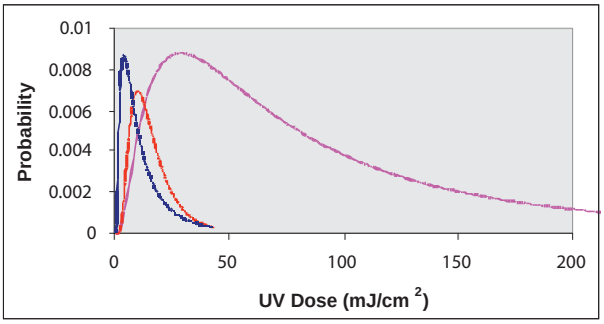

Figure 1. *UV dose distributions determined from MS2 biodosimetry.*

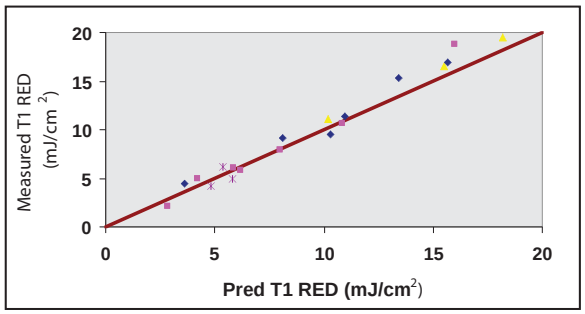

Figure 2. *Comparison of T1 REDs predicted using UV dose distributions determined using MS2 biodosimetry to measured T1 REDs.*

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[1] National Institute of Standards and Technology

[2] The expected UV sensor reading for that UVT with new lamps operating at 100% ballast power setting with clean sleeves and UV sensor port windows.

The Impacts of the UVDGM on Large Systems

Paul D. Swaim, P.E.

Global Technology Leader for Water Treatment CH2M HILL
9193 South Jamaica Street, Englewood, Colorado 80112
Email: pswaim@ch2m.com

ABSTRACT

The EPA's final Ultraviolet Disinfection Guidance Manual (UVDGM) provides a much-needed reference document for the water treatment community. Included within the UVDGM, are several key issues for consideration by large utilities.

INTRODUCTION

Congratulations to the EPA and its team for finalizing the Ultraviolet Disinfection Guidance Manual (UVDGM). This comprehensive document is a much-needed UV disinfection reference for regulators, utilities, consultants, and other interested parties. Perhaps no other treatment technology in the history of water treatment has had to withstand as much scrutiny, interest, comment, and debate as UV disinfection did during the process of UVDGM development.

Elements Of Interest For Large Utilities From The UVDGM

For large systems (i.e., those in the 50 to 100 million gallon per day range and larger), several elements of UVDGM may be of particular interest, including the following:

- As described in Chapter 3, *Planning Analyses for UV Facilities*, UV transmittance (UVT) is the most important water quality parameter for UV disinfection planning. All utilities considering the future implementation of UV disinfection should be monitoring UVT on a regular basis now. Rather than prescribe how much data to collect, how to analyze the data, and how to select a UVT value as the basis for UV disinfection design, however, the UVDGM leaves these decisions up to the utility. This approach allows flexibility and room for tailoring sampling plans to match the specific needs of a utility, including the ability to consider multiple source waters, seasonal differences, and upstream treatment impacts in developing an appropriate sampling plan.
- Chapter 4 of the UVDGM, *Design Considerations for UV Facilities*, addresses UV disinfection facility layout and electrical requirements. Although the UVDGM notes that "the continuous operation of the UV reactor is highly dependent on the power supply and its quality," the UVDGM does not specify requirements or guidelines with respect to the need for back-up power or power conditioning equipment. Utilities will need to evaluate the potential need for an uninterruptible power supply (UPS), or other power conditioning equipment, specific to their potential installation. With this approach, the UVDGM does not force expensive electrical requirements on utilities, but rather allows utilities to make appropriate decisions based on their own power quality and their own operating philosophy with respect to the potential for off-specification operation. Similarly, the location for UV disinfection is open for utilities to select the optimum post-filtration approach for their water treatment plant.
- Chapter 5 of the UVDGM, *Validation of UV Reactors*, has been simplified greatly to facilitate the ease of understanding and implementation by the industry. One over-riding principle that has been maintained is that it is essential that flexibility be provided for potential approaches to validation testing. The vast majority of installations will be able to use off-site validation results from validation test centers. However, there will be a small number of installations that will require site-specific validation testing. For example, on-site validation testing was conducted for Winnipeg, Manitoba, to supplement off-site test results so that test results covered the full range of UVT values that the utility expected to encounter. In evaluating

potential UV disinfection systems for installation, all utilities should closely examine test center validation results including the range of validated conditions (including UVT, flow rates, and doses) and the specific validation and installation piping configurations to verify the applicability of the results.

- Many large utilities elected to move forward prior to UVDGM publication and implement UV disinfection for the public health benefits it provides. The UVDGM incorporates caveats for systems already in operation to facilitate assessment of the validation factor for establishing operating boundaries and achieving regulatory approval. For example, a few large systems are already in operation and utilize medium-pressure lamps and "non-germicidal" sensors. While the UVDGM states that UV sensors should be germicidal, the document recognizes that some systems use non-germicidal sensors (see Page 5-15 of the UVDGM), and the UVDGM includes factors to determine an additional factor, the polychromatic bias, to incorporate in the validation factor for these installations.
- Chapter 6 of the UVDGM, Start-up and Operation of UV Facilities, describes the requirements and recommendations for operation, maintenance, monitoring, and reporting. For large systems, the O&M requirements will represent a substantial undertaking, with UVT analyzer evaluation recommended at least weekly, and calibration of each UV sensor with a reference sensor recommended at least monthly. Large systems should carefully review Chapter 6 to understand the implications. Operations plans should anticipate these UV system requirements, and requirements for UV system performance testing should incorporate the UV system components addressed by the UVDGM.
- The UVDGM is a formidable document. Many of the items described above result in flexibility, which will allow large systems to make the right UV disinfection decisions for their particular installation. To many state regulators, finding time to digest and implement the full contents of the UVDGM represents a daunting task. In addition, the flexibility means that state regulators will be faced with specific decisions in evaluating UV disinfection installations. As such, all utilities implementing UV disinfection should plan to work closely with their regulators to ensure a common understanding and agreement on key issues early in projects. Even with 436 pages of UVDGM details, there will be gray areas and decisions to make that aren't specifically addressed in the UVDGM, and regulator involvement will be critical.

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