ISSUE THEME

Reports and Articles from the UV Conferences in Karlsruhe and Tokyo

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IUVA's Web Page: www.IUVA.org
BUSY, BUSY, BUSY.

Bob Hulsey

Just like farmers across the Midwestern U.S. harvesting their fields, we have also had a busy fall season. Here’s a recap.

The conferences in Karlsruhe, Germany and Tokyo, Japan were both successes, providing a wealth of information on UV in its various areas of study and implementation. With over 100 participants at each, it was evident that the IUVA is helping to fill a needed role in the exchange of data and ideas dealing with ultraviolet radiation. Make sure to check the website if you would like to purchase the CD versions of the conference proceedings for your library.

These two conferences were followed by standing-room-only sessions at the AWWA Water Quality and Technology Conference in San Antonio, Texas. Again, many of our members gave presentations on new tools for estimating drinking water UV disinfection system costs, the results of basic research dealing with the impact of particles on disinfection efficacy, validation issues, and exciting developments in alternative lamp design. I have to admit, my favorite presentation dealt with work at Duke University that examined DNA damage with electrophoresis gels, furthering the work described at the Singapore and Tokyo conferences by Dr. Oguma. There is something about those fuzzy gel pictures that just fascinates me!

Finally, the Board has been hard at work. Items discussed at the board meeting covered a wide range of subjects relevant to maintaining the momentum achieved through our workshops and conferences. Here are some of the topics on which I would be interested in obtaining some feedback from our members.

- Possibility of an electronic technical journal to augment our print version of IUVA News. This would serve as a needed venue for some of the best research being conducted across the UV world.

- Potential to outsource IUVA News publication and distribution. The goal here would be to reduce the demands on Dr. Bolton’s time to enable him to concentrate more on his role as Executive Director.

- Several novel approaches to reduce the cost associated IUVA management.

- Establishing a task group to explore how to work more closely with our sister organizations, again, to reduce costs and increase the number of people “exposed” to our UV message.

If you’re interested in offering an opinion on these items or in making them a reality, please contact me or any of the board members. We would love to hear from you!
Hot UV News

29 November 2004: TDI Introduces Novel AlGaN Substrates for UV Semiconductor Emitters, Market Wire. [http://www.marketresearch.com/mw/release.html?release_id=76716] Technologies and Devices International, Inc. (TDI), a privately held Maryland corporation, today announced that a new product prototype, AlGaN-on-sapphire templates will be featured at the 2004 Material Research Society (MRS) Fall Meeting and Exhibits in Boston, MA, from November 30th through December 2nd, 2004. Novel AlGaN-on-sapphire materials are transparent in ultra violet (UV) spectrum region and are targeting substrate applications for high-power GaN-based UV light emitting diodes (LEDs) including deep UV emitters operating at a wavelength of 250 nm and longer...

26 November 2004: UVB to Blame for Skin Cancer, Yahoo News. [http://au.news.yahoo.com/041125/2/rwhs.html] Two new studies have strengthened the case that UVB exposure is most to blame for skin cancer.

Associate Professor Scott Menzies of Sydney University said his study and research by the George Washington University Medical Centre both pointed to UVB as the main culprit behind melanoma...

...The George Washington study used a mouse model and found that UVB exposure caused melanoma while UVA exposure had no effect...

8 November 2004: Danaher Corporation Completes Offer for Trojan Technologies Inc. [http://www.trojanuv.com/en/homeframe.htm] Trojan Technologies Inc. (TSX:TVU) announced today that Danaher Corporation, through its wholly owned subsidiary, Helen Nova Scotia Unlimited Liability Company (“Offeror”), has acquired approximately 94.3% of the outstanding common shares (on a fully diluted basis) of Trojan Technologies Inc. under its previously announced offer dated 1 October 2004.

Editor’s Note: The above announcement marks the completion of two major shifts in the worldwide UV industry. The two largest UV companies in the world are now US based: Trojan Technologies (based in Canada) has been acquired by Danaher Corporation of Washington, DC, and Wedeco AG Water Technology (based in Germany) has been acquired by ITT Industries of White Plains, NY.

For more UV News items go to the UV News Section in the Public Zone of the IUVA Web Site [www.iuva.org].

UV Industry News

2 December 2004: Trojan Technologies Inc. [http://www.trojanuv.com] introduces TrojanUV Logic™Pharma, London, ON, Canada. Trojan Technologies Inc. announced the revolutionary TrojanUV Logic™ Pharma - the first UV system designed for pharmaceutical applications that fully complies with every one of the stringent requirements of the industry. Developed in consultation with major original equipment manufacturers (OEMs) and pharmaceutical companies, it is an extension of Trojan’s worldwide leadership in the application of UV technology...

2 December 2004: Steril-Aire Inc. [http://www.sterilaire-usa.com] Burbank, Calif., and Research Products Corporation, Madison, Wisc., have entered into a worldwide non-exclusive license covering a number of Steril-Aire’s patents and Research Products’ Aprilaire (R) brand “UV Germicidal Lamp” for coil and drain pan irradiation in HVACR systems...

October 2004: UV SYSTEC GmbH [http://www.uv-systec-gmbh.de] introduces new long-life high-output UVC lamp. With the newly developed AC 4 LL series, the German lamp manufacturer UV SYSTEC GmbH offers an infinitely variable long-life high-output germicidal lamp which is today the most powerful low-pressure UVC lamp available in the market. The new lamp AC 4 LL will achieve more than double the useful lifetime as compared with its predecessor. Depending on the application, an extended useful lifetime of 10,000 hours and more at a constant UV output can be expected. Due to their outstanding UVC output, the new UV SYSTEC AC 4 LL lamps are excellently suited for large-scale water disinfection systems, for the treatment of murky wastewaters and for air disinfection...


For more UV Industry Announcements go to the UV Industry Announcements Section in the Public Zone of the IUVA Web Site [www.iuva.org].
News from IUVA

Member-Get-A-Member Drive

We have a new leader in the member get a member drive. Gerry Kolasser has brought in an O2 corporate membership putting him in the lead with 5 points. Member Philippe Boileau is in second place with 4 new members. In third place is Jen Clancy, Past President of IUVA, with one. Keep up the good work.

Just to remind the rest of our current Members, here’s how the contest works. Every issue of the IUVA News has Membership Information and application form. The same information is on the IUVA web site at http://www.iuva.org/. Make some copies of the form and put your name in the lower right hand corner of the form. Hand them out and encourage your friends and colleagues to join.

The First Prize for the IUVA Member that signs up the most New members is a Free Registration to the 3rd International Congress on Ultraviolet Technologies in Whistler, BC, Canada 24-27 May 2005. The two runners up will receive a Free One-Year IUVA Individual Membership. The contest ends January 31, 2005.

Upcoming Meetings of Interest to IUVA Members


24 - 27 May 2005: 3rd International Congress on Ultraviolet Technologies, Whistler, British Columbia, Canada, sponsored by IUVA. The first Brochure and Registration Forms are posted on the IUVA Web Site http://www.iuva.org/.


New Section in the IUVA Web Site

A new Section “UV Protocols” as been added to the Member Zone of the New Web Site. This Section will contain Experimental Protocols for UV Measurements as they are developed by IUVA. The first Protocol, which is now posted, is for Collimated Beam Measurements. This Protocol gives detailed instructions on how to conduct collimated beam measurements to determine the UV sensitivity of microorganisms. The user not only has detailed instructions, but also can download a series of Excel Spreadsheets that make the calculations easy to perform.

In the future, Protocols are planned for Calibration of Radiometers using Actinometry and Growth Protocols for UV surrogate Microorganisms. Anyone wishing to submit a Protocol should contact Jim Bolton (jbolton@iuva.org).

New Corporate Member

Please welcome UV Electric (http://www.uvelectric.com/) as a new 03 IUVA Corporate Member. The Contact Person for UV Electric is Laszio Laskai.
UV SOURCES - Basics, Properties and Applications

WOLFGANG HEERING

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ABSTRACT
Ultraviolet (UV) radiation is produced mainly by gas discharge lamps and light-emitting diodes (LEDs). Gas discharge sources are principally low pressure mercury lamps, manufactured as standard, amalgam or high output lamps, medium pressure mercury lamps, doped high pressure lamps, rare gas high pressure lamps and excimer lamps. These lamps strongly differ in dimension, spectral range, specific electrical power, radiant efficiency, lifetime and coupling to a power supply. Rather new developments are electrodeless medium frequency mercury induction lamps and some low pressure molecular gas discharge lamps, which emit in the UVB and UVA. The history of LEDs, which have a UV output beyond 100 mW, is just at the beginning. The structure and radiation mechanism of such UV LEDs will be presented. UV lamps are used not only in the field of disinfection of water, air and surfaces, but also for curing UV colors, lacquers and anti-corrosion layers, for advanced oxidation technologies to decompose pollutants in air and water and for therapeutic treatments.

KEYWORDS: UV LEDs; UV discharge lamps; UV applications; UV efficacy

BASICS
Up to now, nearly all ultraviolet (UV) lamps generate radiation by means of a gas discharge. They are produced with lengths varying between a few centimeters and four meters, specific electrical power between 0.1 W/cm and 400 W/cm, spectral emission from the deep vacuum UV (VUV) up to the long-wave UVA, radiant efficiencies between a few percent up to 60% and lifetimes from some hundred hours up to many thousands of hours. In a gas discharge, electrons are accelerated by an electric field of 1 to 100 V/cm. By collisions with atoms, molecules or ions, electrons, they transfer kinetic energy and excite some of the heavy gas particles; part of them return from excited states to states of lower energy under spontaneous emission of radiation. After some reabsorption, internally emitted radiation will pass through the lamp envelop to the outside. Among the most efficient UV radiators are low-pressure (LP) mercury lamps, made with either quartz glass or borosilicate (soft) glass, and medium pressure mercury lamps with a bulb of quartz glass and filled with much larger amounts of mercury and often also with certain dopants. If the mercury pressure is of the order of only 1 Pa, re-absorption is weak, and so the resonance lines at 184.9 and 253.7 nm are the principal ones emitted by a LP mercury lamp. Under these conditions, the ratio of the resonance line intensities is then about 1:5.

Figure 1. (a) Energy level diagram of mercury with probable radiant transitions and (b) UV spectrum of a standard low pressure lamp (type NN, Heraeus Noblelight).
The working principle of a UV light-emitting diode (LED) is demonstrated by an InGaN MQW Blue LED, as an example. Figure 2 presents the energy band diagram of such an LED. Applying a forward voltage bias to a semiconductor $p-n$ junction, electrons are injected from the $n$-type semiconductor ($n$-GaN) and holes from the $p$-type semiconductor ($p$-GaN) into the active layer (InGaN) between, the composition of which fluctuates and has a quantum well structure. Part of the injected carriers recombine within the quantum well under the emission of UV or blue radiation, if the band gap there is large enough. The UV radiation emerges through a wider band gap material (SiC or sapphire).

**InGaN-BASED UV LEDs**

III-V nitride based semiconductors have a direct band gap suitable for short-wave light-emitting devices. The bandgap energy for instance of AlGaNIn varies with composition between 6.2 and 1.89 eV at room temperature. If the active layer of the LED is GaN or AlGaN, the efficiency of LEDs is very low because there are many nonradiative recombination centers. However, by adding Indium (In), localized energy states are formed in which electrons and holes are preferably captured where they recombine radiatively. Thus the output power of a UV LED containing a small amount of In in the active layer, with emission at 380 nm, can be about 20 times higher than that containing no In with emission at 368 nm. When the emission becomes shorter than 371 nm, the output power decreases strongly because of self-absorption of radiation by the adjacent $n$- and $p$-type GaN layers. Figure 3 shows the external quantum efficiencies (ratio of the UV power to the electrical power) of InGaN-based LEDs and the emission spectra of some LEDs in the UVA.
Today surface-mounted UV LEDs are available with 100 mW radiant power output at 365 nm for a DC current of 500 mA and 4.5 V forward voltage at $T_c = 25^\circ$C.

**LOW PRESSURE GAS DISCHARGE LAMPS**

The diffuse low pressure mercury lamp still has the highest UV radiant efficiency in air. The resonance line emission is at a maximum at a saturated mercury vapor pressure of 0.8 Pa for tube diameters of 26 and 38 mm, which is reached at a cold spot temperature of 315 K (42$^\circ$C). Under such conditions, the radiant efficiency of the plasma at 254 nm can be up to 60% for an Ar buffer gas pressure of about 300 Pa and a current of 430 mA. Unfortunately, these optimum discharge conditions can be only maintained at quite low power densities < 0.5 W/cm. The specific radiant power at 254 nm can then increase up to 2 W/cm into a tube with a reduced diameter. The amalgam will provide for nearly the same mercury pressure at a lamp temperature that is about 40 K higher than the optimum vapor temperature at 315 K. Specific radiant UV powers of 0.5 W/cm, which are between those of standard low pressure mercury T5 lamps (0.2 W/cm) and amalgam T10 lamps (0.8 W/cm), are emitted from the so-called low pressure high output (LPHO) lamps (Altena et al. 2001). This is achieved at larger diameters of 26 or even 33 mm. Comparable with the development of fluorescent lamps, there is a trend to smaller mercury (5 mg) filling. Reduced fillings became possible using better methods of mercury dispensing and by a protective glass coating of Al$_2$O$_3$, CeO$_2$ or Y$_2$O$_3$, which prevents mercury penetration into the glass tube and thus helps to maintain the UV output.

![Figure 4: Two different designs of inductive coupling to a mercury LP lamp.](image)

Radiant efficiencies at 254 nm for power densities up to 2 W/cm, which are comparable with those of amalgam lamps, can be achieved using a new kind of low pressure mercury lamp, the low and respectively medium frequency induction lamp. These lamps have much longer life times of about 60,000 h, instead of 9,000 h for standard low pressure mercury lamps, because they do not contain electrodes in the interior of the bulb. The lamp type in the left half of Figure 4 has been developed by Godyak and Shaffer (1998) to be an efficient fluorescent light source and can be used as a UV lamp if the bulb is made of UV transmitting quartz glass. The lamp is a closed tubular ring that is driven by two externally mounted toroidal ferrite cores. Each ferrite core is provided with windings of wire connected to a 100 – 500 kHz power source. A 7.2 cm long lamp with diameter of 5.4 cm and filled with mercury and krypton as buffer gas is operated with high current of 7.1 A and discharge power of 138 W. The electrodeless LP mercury lamp in the right half of Figure 4 needs no ferrite cores with proper cooling structures. An induction coil with 2 – 14 turns is positioned on the outer tube wall in axial direction of the lamp with diameter of 5.0 – 7.6 cm and length of 30 – 50 cm. Popov et al. (2004) operated such lamps with frequencies between 250 kHz and 15 MHz and powers of 60 to 250 W. The efficiency decreases with the power coupled into the lamp.

For all LP mercury lamps there are many phosphors available that are deposited on the inner surface of the lamp bulb and transform the resonance line radiation to longer wavelengths in the UV. They are chosen so that desired therapeutic, cosmetic or curing effects of the radiation are at a maximum.

![Figure 5: Molecular emission from the OH radical (Hilbig et al. 2004).](image)

There are some other LP gas discharges that are free from mercury and emit in the UV. As Hatta (2004) has experienced, diffuse and stable discharges can be realized with carbon monoxide (CO) for a CO partial pressure of greater than 1000 Pa. They emit molecular radiation in the region from 150 to 210 nm. Other molecular discharges with broadband UV emission have been realized with sulfur as well as in water vapor (Figure 5: Hilbig et al. 2004). In water vapor, the UV radiation is from the A-excited state of the OH radical, which is created by electron collisions with water molecules and recombines with itself to water and oxygen. A new powerful mercury-free RF-excited low-pressure discharge, which emits a strong molybdenum spectrum in the UVB and UVA regions, has been developed by Giuliani and Petrov (2004). An RF power of up to 200 W is coupled by a spiral coil around the lamp at a fre-
frequency of 13.56 MHz into a spherical bulb of 2.3 cm diameter which contains MoO$_3$ powder and Ar (at 2 mbar). Evaporative sublimation of the powder occurs at a wall temperature of about 800 K. The measured spectrum is shown in Figure 6.

**MEDIUM PRESSURE GAS DISCHARGES**

Much higher UV power densities, up to 30 W/cm in the UV-C, can be obtained from mercury arc discharges that are operated at medium pressure of a few bar. Figure 7 presents the UV spectrum and estimated values of spectral radiance and irradiance (at a distance of about 10 cm) for a 4 kW high pressure mercury lamp with specific electrical power density of 200 W/cm and a bulb diameter of 2.6 cm. Such a lamp type is widely used for UV curing because the UV efficiency is fairly high. Lambrecht (1998) found that up to 14% of the electric lamp power is converted to UVC, about 7% into UVB and other 7% into UVA radiation. As demonstrated in Figure 8, the spectrum of a high pressure mercury lamp below the 254 nm resonance line can be strongly influenced by the mercury pressure which correlates with the specific lamp voltage. That means that the high current type will emit more radiation below 215 nm than the high voltage type at the same specific electrical lamp power. This may be explained by two effects. Firstly, an increasing part of the long-wave wing of the 185 nm mercury resonance line is reabsorbed with increasing mercury pressure. Secondly, the emission maximum at about 225 nm increases with increasing mercury pressure. This emission is generated by the radiative recombination of free electrons with mercury ions forming the metastable level $6^3P_2$ excited state of the mercury atoms.

As large parts of the lamp power are emitted at wavelengths outside the germicidal range, the optimized medium pressure mercury lamp has a germicidal UV efficiency of only 12% (i.e., about one third of that of a low pressure mercury lamp). By using foils coated with molybdenum, using a better quality of quartz glass and operating lamps with an electronic power supply, the lifetime can be prolonged from 2,000 to 8,000 h.

By adding small amounts of silver (Ag), gallium (Ga), indium (In), lead (Pb), antimony (Sb), bismuth (Bi), manganese (Mn), iron (Fe), cobalt (Co) and/or nickel (Ni) to the mercury as metal iodides or bromides, the mercury spectrum can be changed strongly principally in the UV-A but also in the UV-B and UV-C. Doping Ga and In gives intense lines at 403 and 417 nm and at 410 and 451 nm, respectively. Iron iodide strongly raises the spectral radiative power by introducing many closely bunched iron lines in the range from 358 to 388 nm, which lowers the UV-B and UV-C efficiency significantly. Decreasing the UVC and partially the UVB is a general trend when iodides are added because they absorb principally the short-wave UV. However, in comparison to the pure mercury arc, the UV-A can be enhanced by up to a factor of 2 by iron and up to about 1.6 by manganese (Heering 2001).
Medium pressure discharges are operated with electrodes by means of a choke or transformer or are driven by an electronic power supply at higher frequencies. Electrode-free lamps can be energized by means of microwaves. We have experienced an intense emission in the spectral range of 340 – 420 nm from a kind of molecular lamp filled with CoI\textsubscript{2} and operated at a high load of 340 W/cm\textsuperscript{3} using a microwave generator.

If extremely high but only transient UV irradiances and high penetration depths of radiation are needed, pulsed xenon high pressure lamps producing flash radiation in the UV, visible and infrared (IR) can be applied, for instance for curing highly pigmented and/or thick lacquer layers. Linear or circular tubes with lengths up to 500 mm are filled with xenon with pressures between 100 mbar and a few bar. Pulse energies from a few joules to more than 1000 joules are obtained from large capacitors which are discharged by the lamp. Discharge voltages are a few kV, pulse widths between 10 and 500 \(\mu\)s and pulse rate from 3 to 120 per second. Pulse peak powers may exceed 1 MW (Capobianco 2002). Beside spectral lines in the blue visible and in the near IR, an intense recombination continuum of radiation is emitted, which is described by a Planck curve with associated temperatures between 7,000 and 12,000 K. This can be raised and narrowed as well as shifted to shorter wavelengths with increasing current densities (up to 100 kA/cm\textsuperscript{2}). Though up to 60% of the energy input can be converted into radiation from 200 to 1000 nm, the germicidal efficiency is lower than that of LP mercury lamps and not higher than that of HP mercury lamps. The lifetime of such lamps is strongly dependent on pulse energy per volume and repetition rate. Depending on operating conditions, pulsed xenon lamps have to be replaced after \(10^6\) to \(10^8\) flashes.

**EXCIMER LAMPS**

A novel kind of high pressure gas discharge is the excimer lamp, which emits quasi-monochromatic radiation. Here, the electrodes are not positioned in the gas space, but they are separated by a dielectric barrier, usually quartz glass, from the gas. The coaxial quartz tube arrangement, shown in Figure 9, is quite often used because it is mechanically robust and can easily be manufactured. Inner and outer quartz tubes are connected with one another at the rims, and the volume between them is filled with a gas mixture for the desired formation of excimers (molecules that are stable only in the excited state). The outer electrode is a metal grid in order to transmit the radiation generated by the excimers in the gas space. Because of the dielectric barrier, a high alternating voltage of several kV with frequency between 30 and 500 kHz has to be fed to the outer electrodes. Thus many self-extinguishing micro discharges are generated at gas pressures about 1 bar under non local thermal equilibrium (NLTE) conditions. The micro channels are statistically distributed over time and space and exist only over times of about 10 – 20 ns. As the electric fields are quite high in the gap between the electrodes, even rare gas atoms can be excited efficiently by impacts with fast electrons. The excited rare gas atoms can then form excimers with other rare gas, metal or halogen atoms. These excimers dissociate with a corresponding emission having a width of 10 – 20 nm.

![Excimer Lamp Diagram](chart.png)

**Figure 9:** Coaxial excimer lamp geometry and spectra of Kr\textsubscript{2}\textsuperscript{*}, Xe\textsubscript{2}\textsuperscript{*} and KrCl\textsuperscript{*}.

The most efficient rare gas halide systems are found to be ArF\textsuperscript{*}, KrCl\textsuperscript{*}, KrF\textsuperscript{*}, XeBr\textsuperscript{*}, XeCl\textsuperscript{*}, XeF\textsuperscript{*}, which emit at 193, 222, 248, 282, 308, 351 nm, respectively. In pure rare gas fillings, emission of Ar\textsubscript{2}\textsuperscript{*}, Kr\textsubscript{2}\textsuperscript{*}, Xe\textsubscript{2}\textsuperscript{*} is observed at 126, 146, 172 nm respectively (Figure 9). Radiant efficiencies of up to 14% respectively 18% are reported from commercial XeCl and KrCl lamps which are operated with an HF sinus drive (Altena et al. 2001). A more efficient excimer lamp is the Xe\textsubscript{2}\textsuperscript{*} dielectric barrier discharge if the electrical power input per unit of surface area is moderate. The electrical energy that is coupled into a micro discharge...
must be limited if thermalization of electron energy is not to become the dominating process. Radiant efficiency can be further enhanced by a square wave shape driving voltage instead of a sinusoidal wave shape. Short-time records of the dielectric barrier discharge in xenon reveal that many more micro discharges are formed in a period during square wave operation. Hence, the energy per micro discharge is lowered and the radiant efficiency increased. Daub and Heering (2004) have experienced even higher efficacies of xenon dielectric barrier discharges if the voltage pulses are unipolar with rise and fall times of less than about 200 ns and pulse widths between 1 and 3 \( \mu \text{s} \). Then the discharge reignites on the falling edge, further raising the radiant output. Thus UV irradiances at 172 nm with power densities up to 0.5 W/cm\(^2\) can be produced with a lamp efficiency of about 20%. The lifetime of commercial xenon filled excimer lamps is now up to 5,000 h, and is not limited by any reaction between the quartz glass and the fill gas but by oxygen out gassing from the glass wall and by color centers that are formed in the quartz by low wavelength UV radiation. The xenon excimer radiation can be converted efficiently, by means of phosphors, into the germicidal spectral range. Preferably the phosphor contains praseodymium and lanthanum. Such a phosphor emits UVC radiation in two bands at 220 and 265 nm (Jüstel et al. 2002).

**APPLICATIONS**

First, the spectral emission of the lamp should be adapted to the photochemical process. Second, the actinic radiation should be produced efficiently. And last but not least, the maintenance and lifetime of the lamp must be guaranteed over thousands of hours. Often there is a trade-off between UV output per unit lamp volume and UV efficiency. This is realized especially in low-pressure mercury lamps, which are filled with a metal amalgam for a higher output per unit of arc length. Medium pressure mercury lamps, which emit the same UV power, can be made much more compact, though at the cost of lower disinfecting performance. LP mercury discharge lamps are mainly used for the disinfection of drinking water, as well as of surfaces, because the 254 nm resonance line is near the maximum of the action spectrum for disinfection at 265 nm. Medium pressure mercury lamps are applied for curing coatings in graphic arts and the automotive industry. UV curing gives high gloss, high chemical and high scratch resistance coatings at extremely short curing times. For highly pigmented and/or thick layers, an iron-doped medium pressure lamp may be the better alternative because UVA radiation is less strongly absorbed.

Medium pressure mercury lamps are also used in other fields of photochemistry; for example, the photolysis of: \( \text{H}_2\text{O}_2 \) (190 – 240 nm) yielding hydroxyl radicals, \( \text{O}_3 \) (240 – 280 nm) yielding atomic oxygen, and C-F and C-Cl bonds (\(< 190 \) nm and 210 – 230 nm, respectively), etc. Excimer lamps produce nearly monochromatic radiation in the UV. The 282 nm radiation of the XeBr excimer lamp is surely the best choice for vitamin D\(_3\) synthesis. The 172 nm radiation of the Xe\(_2\) dielectric barrier discharge can remove polymers, activate surface bonds, adjust wetting angles, induce metallization and chemical vapor deposition (CVD) and directly dissociate molecular oxygen. By an appropriate phosphor, the 172 nm radiation can be efficiently converted into the spectral range of disinfection.

Furthermore, UV radiation is needed for the cosmetic treatment of the human skin as well as for phototherapy. Figure 10 shows some respective action spectra. UV lamps that are fit to such applications are fluorescent lamps with special phosphors and filtered metal halide short arc lamps.

![Figure 10: Action spectra of vitamin D\(_3\) synthesis, psoriasis, bilirubin isomerization, photo-chemotherapy with PUV A (8-methoxypsoralen and UVA exposure), skin pigmentation and UV erythema.](image-url)


Water/Wastewater UV Disinfection
Wastewater Reclamation
Analytical Techniques for UV Measurements
UV Bench and Pilot Testing
Application of UV in North America and USEPA Guidance Manual for UV Disinfection

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ABSTRACT

The USEPA has issued a proposed version of the LT2ESWTR which includes information on the use of ultraviolet (UV) radiation for the inactivation of Cryptosporidium, and a draft Guidance Manual to provide the US with direction on the proper installation and operation of UV disinfection systems. The final versions of these documents are expected to be published in 2005. Still, utilities have been installing or making plans to install UV disinfection systems. This technology holds great promise to provide sufficient protection against pathogens to meet the latest round of regulations, but hurdles remain to be overcome to ensure proper design and operation. One of these involves validating the UV dose under certain operating conditions. To address this issue, a procedure is proposed for either performing the validation tests at the utility’s water treatment plant or having them conducted by third parties.

KEYWORDS: ultraviolet, disinfection, water, regulations, validation

INTRODUCTION

The use of UV light for disinfection of municipal water and wastewater was pioneered by a number of communities in both the United States and Europe in the early 1900’s (O’Brien et al. 1994). Like the use of ozone, these early experiments apparently met with difficulties and were abandoned in favor of chlorine (Hill and Rice 1982), which was both more economical and easier to use. Now the use of UV disinfection is undergoing a resurgence as a result of its efficacy for inactivation of Cryptosporidium, availability of more reliable equipment, and an impetus driven by regulations aimed at inactivation of Cryptosporidium as well as limiting chlorinated and brominated disinfection byproducts in drinking water.

The proposed Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) contains requirements for increased Cryptosporidium removal or inactivation at utilities whose raw water supply contains this pathogen. A companion UV Disinfection Guidance Manual (UVDGM) (USEPA 2003b) is available for state regulators as assistance in interpreting the regulations and how UV disinfection can be used to achieve compliance. The EPA has held two workshops to give UV experts from around the country an opportunity to provide input on the UV portion of the LT2ESWTR and the UVDGM and their implementation. While the regulation in its final form is not expected to be promulgated until October 2005, many utilities are already designing or installing UV facilities.

BACKGROUND

Masschelein (2002) reports that according to his research, the earliest use of UV disinfection in the United States was in 1916 in Henderson, Kentucky. Jepson (1973) states that by 1928, four utilities were using UV light for disinfection. However, they further note that by the late 1930s, these systems were out of service in favor of chlorination. The use of UV light as a potential disinfectant for surface water was revisited during development of the Surface Water Treatment Rule (SWTR). The Guidance Manual for this rule (USEPA 1989) contains CT values for obtaining virus inactivation credit for compliance with the SWTR. These values, listed in Table 1, were based on work completed with Hepatitis A virus and included a safety factor of 3.

Table 1. Surface Water Treatment Rule Guidance Manual CT* Values for Inactivation of Viruses by UV

<table>
<thead>
<tr>
<th>Log Inactivation</th>
<th>CT Value (mW-sec/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
</tr>
</tbody>
</table>

*CT = concentration multiplied by exposure time

While its use for surface water disinfection was limited, several studies of groundwater treatment facilities in the
early 1990s showed that it had caught on for municipalities that desired to disinfect groundwater but did not use chlorine. For example, USEPA (1996) mentions a study by the Office of Drinking Water and Groundwater indicating that 843 small groundwater treatment plants in Pennsylvania (80 percent serving less than 200 people) used UV light for disinfection. Of these, only 26 plants also disinfected with chlorine. A survey conducted in 1995 in New York State found that 264 out of 4,141 groundwater systems had utilized UV light as part of their treatment scheme. In the proposed Ground Water Rule (USEPA 2000), UV light is considered to be capable of achieving 4-log inactivation of viruses; although its use in groundwater treatment will be dependent on the virus used to determine compliance.

**UNITED STATES FEDERAL REGULATIONS**

LT2ESWTR is expected to require systems that use surface water or groundwater under direct influence of surface water, to monitor for Cryptosporidium if no historical monitoring data is available. Filtered water systems would be classified into one of four bins based on the average Cryptosporidium concentration in the source water. Bin 3 and 4 systems would be required to achieve at least 1-log of the required treatment using ozone, chlorine dioxide, UV light, membranes, bag/cartridge filters, or bank filtration.

If the LT2ESWTR is promulgated in its current form, unfiltered water systems will be classified into one of two bins based on the average Cryptosporidium concentration in source water. If the mean concentration of Cryptosporidium is less than 0.01 oocysts/L, unfiltered systems would need to provide at least 2-log inactivation (Bin 1). However, if the mean concentration of Cryptosporidium exceeds 0.01 oocysts/L, then unfiltered systems must provide at least 3-log inactivation (Bin 2).

If UV disinfection is used to receive credit for Cryptosporidium inactivation, the UV reactors must fulfill three requirements: apply UV light at a UV dose in accordance with the regulation, have undergone validation testing, and have their operation monitored and reported to the State. Operators of both filtered and unfiltered systems would be required to submit their validation test results to the State, including monthly reports on the volume of water that enter the distribution without being treated by the UV reactors within validated conditions.

While the proposed rule may still be modified, the remainder of this manuscript will assume that both the rule and UVDGM will be adopted as currently proposed. Comments on the implications of this approach will be included in italics.

**UV DOSE**

The UV dose is estimated for full-scale application as the reduction equivalent dose (RED). UV dose delivery in a flow-through reactor is a function of UV absorbance, flow rate, UV spectral output, and hydraulic characteristics. Table 2 presents a summary of the UV dose requirements in the proposed regulation. These requirements take into account the uncertainty associated with the dose-response of the microorganisms and the variation in experimental designs and analytical assays. However, this UV dose table does not include safety factors for uncertainties, such as hydraulic effects and monitoring approach. These factors are taken into account through reactor validation.

### Table 2: UV dose Requirements

<table>
<thead>
<tr>
<th>Target Pathogen</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>3.5</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptosporidium</td>
<td>1.6</td>
<td>2.5</td>
<td>3.9</td>
<td>5.8</td>
<td>8.5</td>
<td>12</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Giardia</td>
<td>1.5</td>
<td>2.1</td>
<td>3.0</td>
<td>5.2</td>
<td>7.7</td>
<td>11</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Viruses</td>
<td>39</td>
<td>58</td>
<td>79</td>
<td>100</td>
<td>121</td>
<td>143</td>
<td>163</td>
<td>186</td>
</tr>
</tbody>
</table>

*The UV doses shown for viruses are based on adenovirus. The EPA has noted that these are much higher than those shown in Table 1, for poliovirus. The EPA has been investigating the occurrence and the importance of the selection of adenovirus for groundwater (GW) applications, and has indicated that it was attempting to develop information on illness related to adenovirus and drinking water, although it was not planned to differentiate between surface water and groundwater. The application of higher virus IT values will have a strong impact on small systems that utilize UV light alone as the disinfection barrier. If the system is using chlorine in addition to UV light, there may be little impact.*

1Similar to the CT concept, except the “I” is for intensity rather than of concentration.

**REACTOR VALIDATION**

Validation testing is required for both filtered and unfiltered systems to receive disinfection credit. The test conditions for validation must include flow rate, UV light intensity, and lamp status. Validation of the UV reactors must also take into account the following factors:

- **UVT** of the water
- Lamp fouling and aging
- Measurement uncertainty of on-line UV intensity sensors
• UV dose distributions arising from the velocity profiles through the reactor
• Failure of UV lamps or other critical components
• Configuration of inlet and outlet piping

Unless the State approves an alternative approach, validation testing must involve the following:
• Full-scale testing of a UV reactor that conforms uniformly to the reactors used by the utility.
• Inactivation of a test microorganism whose dose-response characteristics have been quantified with a low-pressure (LP) mercury vapor lamp.

Appendix C of the UVDGM includes guidance for several possible approaches to reactor validation. Reactors previously validated under the DVGW and ÖNORM protocols (German and Austrian standards, respectively) should receive 3-log inactivation credit for *Cryptosporidium* and *Giardia*. Reactors that are validated according to the procedure in the UVDGM can receive 3-log inactivation credit for *Cryptosporidium* at a UV dose of 36 mJ/cm² from a low-pressure high-output (LPHO) UV system or at a UV dose of 42 mJ/cm² from a medium pressure (MP) UV system.

Validation testing must be conducted on-site or off-site, on a UV reactor that conforms uniformly to the reactors used by the utility. Prior to validation all lamps must undergo 100 hours of burn-in. Acceptable test organisms include *Bacillus subtilis* and MS2 phage or an organism with dose-response characteristics quantified by a LP mercury vapor lamp. Validation test results must be submitted to the State.

The UVDGM recommends that in the validation, at least one of three hydraulic configurations is met.
• The inlet and outlet configurations of the validation reactor are the same as those of the installed reactor for 10 diameters upstream and 5 diameters downstream.
• If the validation reactor has a 90 degree bend upstream from the reactor, then there should be a minimum of 5 pipe diameters of straight piping between the installed reactor and any upstream hydraulic configuration.
• Velocity at validation is measured at evenly spaced points through a given cross section of flow, upstream and downstream. The same is true for the installation but must be within 20 percent of theoretical velocity determined during validation.

According to the UVDGM, there is a two-tiered approach to establishing inactivation credit. The Tier 1 approach provides reduction equivalent dose (RED) target values as listed in Table 3, that correspond to the log inactivation credit to be met during validation. The RED values incorporate predetermined safety and uncertainty factors based on the characteristics of the UV reactor and validation testing.

<table>
<thead>
<tr>
<th>Log Credit</th>
<th>Low Pressure / LPHO</th>
<th>Medium Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Giardia</td>
<td>Crypto</td>
</tr>
<tr>
<td>0.5</td>
<td>6.8</td>
<td>6.6</td>
</tr>
<tr>
<td>1.0</td>
<td>11</td>
<td>9.7</td>
</tr>
<tr>
<td>1.5</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>2.0</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>2.5</td>
<td>28</td>
<td>26</td>
</tr>
<tr>
<td>3.0</td>
<td>36</td>
<td>34</td>
</tr>
<tr>
<td>3.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The intent of the two-tiered approach was to provide a simple version for which validation conditions could be easily met (Tier 1). In order for Tier 1 inactivation credit to be appropriate, certain assumptions were made as to RED bias, polychromatic bias, and other variables. In addition, the validation conditions for Tier 1 include the following:
• Number of sensors, location, spectral response, NIST-traceability.
• Uncertainty of UV transmittance measurement
• Deviation of lamp-to-lamp output
• Uncertainty of flow measurement and calculated UV dose
• UV sensitivity of challenge microorganism (≤ 25 mJ/cm² per log inactivation)
• Biodosimetry sampling number and standard deviation

The Tier 2 approach requires the user to calculate the safety and uncertainty factors from UV dose delivery monitoring, validation bias, and uncertainties:

• RED bias and measured RED
• Polychromatic bias (for MP reactors)
• Interpolation of RED as a function of flow rate, UVT, or UV intensity
• Sensors used during validation (UV intensity, UVT)
• On-line and reference sensors used at WTP (UV intensity, UVT)
• Lamp output quantification

It is likely that the two-tiered approach presented in the draft UVDGM will be eliminated in the final version. Comments submitted to the EPA by AWWA and others have expressed concern that the safety factors used were excessive, that the conditions to meet Tier 1 values were not easily attained, and that it added confusion to the implementation of UV disinfection. It is likely that the tiered approach will be reduced to a single methodology to interpret validation results.

MONITORING AND REPORTING
As part of maintaining compliance, the UV system must be monitored and the UV dose and operating conditions reported. The utility must monitor each reactor and report the amount of flow that passes through it under unvalidated conditions. In addition to the validation report, monthly reports must also be prepared and submitted to the State. The monthly reports must include the volume of water entering distribution that is not treated within validated conditions (off-specification water), based on at least 4-hour records for each reactor, as well as the percentage of sensors that were checked for calibration. The State may have additional requirements for what must be included in the report.

Unfiltered systems must treat 95 percent of the water delivered to the public each month by the UV reactors within validated conditions in order to meet the LT2ESWTR requirements for Cryptosporidium inactivation. Off-specification requirements for filtered systems are not stated in the LT2ESWTR; these requirements will be defined by each State. However, EPA recommends that the reactors be operated to minimize off-specification water.

Any UV dose monitoring method must be evaluated during reactor validation, and the outputs measured during validation will be part of the monitoring requirements. There are three approaches that can be utilized for UV dose monitoring: UV intensity set point, UV intensity and UVT set point, and calculated UV dose.

• The UV intensity set point is based on measurements made by the sensor, which are used to control the reactor. The sensor is positioned within the reactor so that it can respond to changes in the intensity output of the lamps and of the UVT of the water. The sensor output in combination with the flow rate is used to monitor the UV dose delivery. During validation testing, the set point value for UV intensity must be determined over a range of flow rates.

• The UV intensity and UVT set point method requires the sensor to be positioned close to the lamp to measure only the changes in lamp intensity output. Therefore, the UVT is monitored separately, typically with an on-line monitor that is available from most UV system manufacturers. The set points for the UV intensity and UVT must be determined during validation.

• For the calculated UV dose, the sensor is positioned close to the lamp. With this approach, the flow rate, UVT, and UV intensity are all monitored and used to calculate the UV dose based on the algorithms developed by the manufacturer.

In review meetings, the lack of guidance regarding the amount of off-specification water for filtered systems was discussed. It is likely that the final version of the rule will include this guidance. Another item that may be included in the final rule is differentiation between the period when all lamps are off and when the reactor is operating out of its validated range.

STATE REGULATIONS
The International Ultraviolet Association has published a review of State regulations pertaining to UV disinfection (IUVA 2004), which lists responses from 24 of the 50 states. According to these responses, many States have not yet addressed regulations for UV disinfection of surface water or of groundwater under the influence of surface water. Most States are waiting for the final regulations to be promulgated. Of those States that have regulations for UV, many utilize one of the following documents for UV system design and operation:

• National Water Research Institute (NWRI):
  Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse.
While the State regulations provide general guidance on the use of UV for disinfection of drinking water, only two of them include a design UV dose. None contain the depth of information published in the Federal regulations. When the LT2ESWTR is promulgated, the States will incorporate the more detailed procedures into their regulations and will be granted primacy to enforce the Federal regulation. Still, many States are granting permits for construction and operation of UV facilities, in some cases requiring validation and other tests.

VALIDATION FACILITIES
Validation is one of the main requirements of the regulations pertaining to UV disinfection of drinking water, not only in the United States, but around the world. Austria and Germany have led efforts in this area with validation test facilities in Vienna, Austria, and in Siegburg, Germany (Scheible et al. 2003). The Austrian facility can conduct validation tests for reactors with a flow capacity up to 520 m$^3$/h (3.3 mgd) while the German facility can go as high as 3000 m$^3$/h (19 mgd).

In North America, tests are being conducted either at the water treatment plant that is installing the UV reactors or at one of the three offsite testing facilities located in Johnstown, New York; Portland, Oregon; and Grand Bend, Ontario. The New York and Oregon testing facilities can operate at 6300 m$^3$/h (40 mgd), with the New York facility having been upgraded to approximately 9500 m$^3$/h (60 mgd) to test the reactors for the Catskill/Delaware UV system, which will be used to disinfect the primary water supply for New York City. Both of these testing facilities have been used by two of the major U.S. UV system suppliers, Wedeco AG and Calgon Carbon Corporation. The Ontario facility is used by Trojan Technologies for testing its smaller reactors.

While UV reactors have been validated at various testing facilities around the world, testing is also being conducted at the end user’s site in some cases. The following illustrates three approaches to on-site and off-site validation – where UV system suppliers are also allowed to submit alternative bids to best fit their reactors to the plant’s expected operating conditions.

WEST VALLEY WATER DISTRICT, CALIFORNIA
The West Valley Water District operates the Oliver Roemer Water Filtration Plant (RWFP) to supply 1570 m$^3$/h (10 mgd) to residents of West San Bernardino County, California. The plant is being expanded to 2350 m$^3$/h (15 mgd) and a UV system is being added. By adding the UV system, West Valley hopes to reduce its reliance on chlorine disinfection and to decrease the generation of chlorinated disinfection byproducts.

The UV system was bid so that the suppliers could show compliance with their bid values for power use and UV dose and could meet validation requirements in one of three ways:

- Bid a prevalidated reactor with confirmation and performance tests conducted on-site.
- Bid a reactor that would be validated off-site (after the bid date), followed by confirmation and performance testing on-site.
- Bid an unvalidated reactor, with validation tests to be conducted on-site at the prescribed testing conditions.

This approach enables the suppliers to bid reactors that would fit the utility’s size and operating characteristics properly while balancing testing costs. If the reactor is validated off-site, its operation would be confirmed by repeating one of the validation test conditions (flow rate, UV dose, UVT) in an on-site test. With the reactors being fairly small, on-site testing would be feasible; the facility will use three 1200-m$^3$/h (7.6-mgd) reactors to provide redundancy. This test would be followed by tests to determine the reactors’ performance and ability to meet power use and UV dose requirements at the normal plant flow rates. This procedure will provide a site-specific operating curve that the operator can use to set system conditions. The plant expansion is under construction, with testing expected in early 2005.

VANCOUVER, BRITISH COLUMBIA
To improve water quality for the Greater Vancouver Water District (GVWD), a new 81640 m$^3$/h (520 mgd) water treatment plant will be constructed that will process water from the Seymour and Capilano water supplies. The new treatment plant will use direct filtration, UV disinfection, and chlorination. The filter pipe gallery of the new plant will be large enough to accommodate the installation of UV reactors on each of the 24 individual filters, which resulted in substantial cost savings over providing a stand-alone UV facility. This plant is expected to be in operation in 2007.

For this UV system, the suppliers were required to perform validation testing off-site because of the large volume of

- NSF International: Standard 55 - “Ultraviolet Microbiological Water Treatment Systems”
- Water Supply Committee of the Great Lakes-Upper Mississippi River Board of State Public Health & Environment Managers: Recommended Standards for Water Works (also known as 10 States Standards).
water required to validate a 3900 m³/h (25 mgd) reactor. Performance tests to confirm the power use of the reactors will be conducted on-site.

**PHOENIX, ARIZONA**

The City of Phoenix is constructing a new water treatment plant to draw water at 12560 m³/h (80 mgd) from Lake Pleasant using the design-build-operate delivery method. The new facility will utilize preoxidation with chlorine dioxide (ClO₂), ballasted flocculation, ozonation, biological filtration, GAC adsorption, UV disinfection, and chlorination. The suppliers were required to bid prevalidated reactors but were allowed to submit alternative bids which could include different numbers of reactors. This method allowed the suppliers to “best-fit” their reactor to the water flow and quality at the expected operating conditions. No on-site testing will be conducted.

**PATENT**

While the use of UV for treatment of surface waters is a promising technology, the potential users of this technology are faced with a patent fee if it is to be used to inactivate *Cryptosporidium*. Calgon Carbon Corporation was issued a patent (Bolton et al. 2000) for using UV to inactivate potable water containing *Cryptosporidium*. The patent, which covers UV doses from 10 mJ/cm² to 175 mJ/cm² for UV in the range of 200 to 300 nm was later expanded (Bolton et al 2003) to cover a wider UV dose range, inactivation of *Giardia*, and to call specifically for the use of low-pressure UV lamps.

In letters to USEPA, AWWA, and others, Calgon Carbon has indicated that before a utility uses UV for inactivation of *Cryptosporidium*, it must obtain a license from Calgon Carbon Corporation. The licensing fee for water utilities using continuous wave UV technology that use UV has been established at $0.015 per 1,000 gallons treated. The licensing fee must be paid regardless of the type of UV equipment or the UV vendor, if the system will be used to inactivate *Cryptosporidium* within the UV dose range stated in the patent. The patent issue causes potential users of UV technology considerable uncertainty, and it has given rise to two lawsuits stemming from this patent which are moving forward and are being closely monitored by interested parties seeking to determine whether the fee is applicable on a case-by-case basis. Nevertheless, UV technology is gaining acceptance both in the United States and elsewhere.

**CONCLUSIONS**

UV disinfection is of great interest to utilities throughout North America, however, its widespread use in the United States will depend on the final version of the LT2ESWTR, the presence of *Cryptosporidium* in raw water, and the guidance on implementation provided in the final UV Disinfection Guidance Manual. The rule in its final version is expected to be promulgated in 2005. The proposed version of the rule and its guidance manual provide a great deal of information for utilities and regulators to use in selecting, designing, and implementing UV disinfection systems. Although the rule is still in draft form, many utilities are already installing UV disinfection and utilizing the procedures outlined in the manual for validation.

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USA AND EUROPE: Two Different Worlds of UV for Drinking Water Disinfection?

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ABSTRACT

The use of ultraviolet disinfection for drinking water as an alternative or supplement to chlorination is well recognized on both sides of the Atlantic Ocean. However, the backgrounds which led toward this development were different and therefore one can get the impression that there are two different worlds of UV for drinking water disinfection.

KEYWORDS: Cryptosporidium, DBPR, DVGW W 294, LTESWTR, Multi Barrier, ÖNorm M 5873, USEPA Guidance Manual

STATUS OF UV FOR DRINKING WATER DISINFECTION

Europe

In the early 1990’s German and Austrian research groups completed a study concerning UV disinfection in drinking water. This study was mainly financed by governmental authorities and was supposed to analyze the potential of UV disinfection for surface water treatment plants. Before that time, UV was considered to be an “exotic” option for small ground water supplies only.

After the successful completion of the research project, both countries moved into a standardization approach for the technology. This was headed by the local water supply organizations DVGW (German Association for Gas and Water) (DVGW 1997) and ÖVGW (Austrian Association for Gas and Water) (ÖNorm 2000), which are comparable to the AWWA in the US. In both standards, the core is biodosimetric evaluated systems that require large test facilities, which are located in Siegburg, Germany and in Vienna, Austria. Although the standards were already very similar in the first versions, some small differences were reason enough for not letting the test results of each facility be accepted by the other. Meanwhile both standards have gone through a revision and the latest status is that both organizations accept tests from the other.

Whereas the Austrian ÖNorm (ÖNorm 2000) had a binding character from the beginning, the German standard (DVGW 1997) had more the character of a guideline. However, most water supplies in Germany are following guidelines of their own association. Now, this has changed in Germany as well: UV is listed in the revised drinking water act. As a part of that act, starting from the end of 2005, every UV system has to comply with the German or Austrian Standard. Parts of the ÖNorm are now going to be implemented in a new European wide standard for point of use treatment systems. Today UV disinfection is a well received method for even large surface water supplies. Recently UV is facing competition from Membrane Filters. Other countries in Europe are currently showing increasing interest in the use of UV for drinking water, e.g., France and UK. In Norway, Sweden and Finland, UV technology has also gained market share in recent years, but was already used for drinking water disinfection for decades in small water supplies similar to Germany and Austria.

USA

In contrast to Europe, UV disinfection was well established in waste water, but had more or less no existence in drinking water in the early 1990’s. This situation dramatically changed at the end of the decade:

After the Cryptosporidium outbreak in Milwaukee, UV disinfection faced a tremendous amount of interest. Furthermore, regulations introduced by EPA on the reduction of disinfection by products caused by chlorination were additional reasons for the fastest growing UV market in the world at present. Coming from almost zero at the beginning of the decade, the amount of UV disinfected drinking water is probably already higher than anywhere else in the world, and large cities, such as New York, are not even in that comparison. Although the plans to implement UV there are already a reality. Nevertheless, the percentage of water supplies using alternative methods to chlorination is still low. This is because of the fact that the new regulations are not yet officially in place and that those who switch to alternative disinfection technologies, are somehow under pressure of public or regulative bodies. The standardization of the technology and its application is undergoing a detailed EPA approach (USEPA 1998, 2003a). The UV Disinfection Guidelines (draft version)
has already been published (USEPA 2003b), and the goal is to have the final version available in 2005. Although the guidelines have not even been officially implemented, most of the water supplies already aim to install UV systems fully compliant to this standard.

The execution of the biodosimetric testing process is different from Europe, where the test facilities are linked to the authorities, In the US, the test facilities are an “emerging market” owned predominantly by water industry consultant firms, which are also responsible to manage and conduct the tests according to the EPA guidelines.

DIFFERENCES

Concept

There are some conceptual differences between the European standards and the EPA guidelines: The European standards specify some technical features, e.g., the ultraviolet measurement system (sensor) to a highly detailed extent. In contrast, the US guidelines are more focussed on the functional specification rather than the technical solution. The European standards also specify one UV dose, whereas the US guideline uses a UV dose table. In the US standard, depending on the treatment situation at a certain location, UV dose requirements can be very different from case to case. Substantially different are the approaches of bias and safety factors, which shall not be explained in detail here. However interesting enough is, although the concepts are quite different about that point, the resulting required UV doses are similar in the end, which makes the required sizes for UV systems comparable.

Also worth mentioning is the fact that the US guidelines have incorporated parts of the European standards, which would make it possible to have the European standard accepted under the EPA validation rules but not vice versa.

Execution

Because of the major differences, the ways in which the standards are executed are should be explained in detail. The following process maps are illustrating the different approaches:

In Europe - as can be seen on the left view – it is more complex to go through the process:
- The manufacturer has to contract the agency with which the water association is related (DVGW or ÖVGW).
- This “test coordinator” contracts a test facility, which is in Germany and Austria there is just one each.
- The test facility writes a report to the coordinator after the tests have been conducted.
- Afterwards the coordinator sends a report to the manufacturer, who sends this to the association and applies for a certificate. This is what he needs for his customer to operate a UV system.
- The certificate then has to be sent to the local health authorities by a water supply utility.

In the US, the process is much less complex:
- The manufacturer contracts a consultant to validate a system according to the EPA protocol.
- The consultant company runs a test facility or runs the test at a certain water supply individually (on site).
- After test completion, the consultant sends a report back, which the manufacturer transfers to his client.
- There is no official approval involved (although something similar to Europe exists for some states, e.g. California).

BACKGROUND FOR DIFFERENCES

In order to understand the differences, one has to consider the circumstances under which the standards were established: Europe in the early 1990’s was not under pressure. Cryptosporidium was not an issue and any alternative to chlorine would not be “warmly welcomed”. Despite some public concerns on chlorine in general, pressure from this side was also comparably weak at that time.

It seems to be clear, that under those circumstances, a technology like UV would have to face enormous obstacles and would have to undergo detailed evaluation and standardization before one would use it. The central question was: Why should anybody use UV? Or in other words: Why should anyone risk the safe disinfection he has for something new? If so, it must be more than safe, it must be “certified” (something which nobody would ask for a chlorine disinfection, which is supposed to be safe).

What a difference in the US: After the worldwide most serious outbreak of Cryptosporidiosis, the water supply and health authorities were under tremendous pressure to

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1Actually, at present only Germany and Austria have defined regulations; however, other countries in Europe will probably follow the lead of Germany and Austria.
find alternatives to classic disinfection and treatment options. Several research groups and universities were looking for different options, while regulators are trying to manifest substantial changes in water treatment. With this background, it is understandable that the specification for alternative disinfection technologies would allow a maximum amount of flexibility in order not to delay or even stop any potential candidate on the way to solve the water treatment problem.

Maybe this aspect is not the only one to explain the major differences of the approach to standardize UV disinfection for drinking water. There were for sure some political and cultural differences as well. But different backgrounds like this have different consequences for handling the same issue: standardization of UV technology for drinking water disinfection.

Some other examples may support this thesis: The UK and France did not consider UV at the same time like Austria and Germany. Therefore they got aware about UV when the results about Cryptosporidium were published. Both countries had already some regulation in place for managing the Cryptosporidium problem, but UV seems to be an attractive option now. Under those circumstances, in both countries there is now some discussion about the standardization of UV disinfection. It seems that these efforts are also focused on a maximum of flexibility and therefore they follow the US approach.

It seems that there is a pre- and post Cryptosporidium time for UV disinfection, and that determines how regulators defined UV technology for drinking water disinfection.

THE MULTI BARRIER APPROACH

One major aspect to look at the standards is the perspective of a multi barrier approach, which is widely discussed in today’s “water treatment world”.

Surprisingly there seems to be a paradox: The US standard provides flexibility to a huge degree and therefore provides options to see a UV system in concert with others in a treatment train. Under US practical conditions in most of the cases UV would be a stand alone solution. It has to be combined with chlorination, but arguably this is not a “multi barrier treatment” in the sense of original meaning of the word. In contrast, the Austrian and German standards provide no flexibility, although in most of the cases the disinfection comes together with other treatment steps, which would allow and count for different options to use the UV disinfection system in terms of UV dose, log credits for various microorganisms, and other related issues. With that perspective, the existing German standard would be somehow probably better applied in the US, whereas the US standard would be a wonderful fit into the German “water world”.

MERGING THE UV WORLDS

The probability of finding a leverage to merge the different standards is high from the technical point of view. Starting with the point of view that the US guideline is already open to accept the German and Austrian validation results, it can be strongly recommended to find ways as to how this could be turned in the other direction. As a first step, it would be helpful if the DVGW and ÖVGW officials would accept the test facilities in the US. This would open the possibility to validate systems according to DVGW and ÖNorm standard at US locations. The second step would be to take results from different test locations and compare them. It makes no sense that different locations would come to different results based on the same biodosimetric validation approach. This would be a wrong way of creating competition between the test locations.

In a third step, and if all test locations are delivering the same results, there is no more reason to be reluctant to accept the standards and test locations of others. In this case, a UV manufacturer could go with any system to the US and get a German DVGW certificate or vice versa, whichever is easier.

Whether or not this scenario would be realistic cannot be answered, but for sure it would be a benefit to all stakeholders of the “UV world”: regulators, operators, consultants and manufacturers. Consulting companies and manufacturers work on a global scale these days, and it would be much faster and more cost efficient to have countries accepting each others’ standards. For regulators and operators there is also a safety issue: they can compare results and systems on a global scale and can share this information. In some countries, this is almost a reality: In Scandinavia, the health authorities accept US and European test reports, while not having their own national test facility. This shows that the above created “vision” is by no means completely unrealistic.

SUMMARY

Due to different “historical” backgrounds, different worlds of UV in Europe and the US exist to a certain extent. However, it might be worth to invest some effort on harmonization of the differences, which would be beneficial to all
stakeholders in the process. The harmonization would include acceptance of the standards in each of the countries, but could also be widened to some of the details in the standards, e.g. a common UV sensor approach (use DVGW) or more flexible UV dose requirements (use EPA guideline).

REFERENCES


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UV Drinking Water Disinfection - Requirements, Testing and Surveillance: Exemplified by the Austrian National Standards M 5873-1 and M 5873-2

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ABSTRACT

The increased acceptance of UV drinking water disinfection is attributed, amongst other things, to the better understanding of the process and the higher quality assurance of the UV disinfection plants. Establishment of quality standards on the requirements, as well as validation testing and certification of commercial UV plants, have provided the basis for the safe application of drinking water disinfection by UV irradiation. Two different techniques of UV irradiation are used for water disinfection: low pressure lamps with quasi monochromatic emission at 253.7 nm and medium pressure lamps with polychromatic emission. Due to the differences in lamp emission and the consequences thereof, it is advisable to deal with these two techniques separately. To describe the requirements on UV disinfection of water a three-step approach has been proven to be useful: (1) the knowledge of the UV resistance of health related microorganisms transmittable by water; (2) an objective careful evaluation of commercial UV plants and (3) the surveillance during practical application by means of defined alarm points and a calibrated UV sensor, which allows checks against official specifications. The latter provides the possibility of an independent, objective inspection, as, for example, demanded by certain health authorities.

We introduce in the following text the Austrian National Standards ÖNORM M 5873-1, low pressure systems (ÖNORM 2001) and ÖNORM M 5873-2, medium pressure systems (ÖNORM 2003) as an example for standards in which these aspects have been successfully included. In 1996 we established in Vienna, Austria, a test facility to validate UV reactors (a cooperation of Arsenal Research, the University of Veterinary Medicine Vienna and the Medical University Vienna). To document its reliability, our testing facility is internationally accredited according to ISO 17025.

KEYWORDS: drinking water disinfection; UV-irradiation; biodosimetry; low pressure UV systems, medium pressure UV systems, spectral sensitivity

INTRODUCTION

In the past few decades, UV irradiation for drinking water disinfection has gained remarkable popularity especially in Europe but also throughout the world. A survey predicts for the development of the application of UV water disinfection (worldwide) that in the time span from 1997 to 2005 the application of UV disinfection will increase from 10% to 30%, whereas the use of chlorine will decrease from 87% to 55% expressed as numbers of disinfection installations.

Remarkable arguments in favor of the use of UV water disinfection are:
• no addition of chemicals
• very short reaction time (parts of a second), therefore no need for a reaction vessel
• neither pH- nor temperature-dependent
• specific inactivation mechanism
• effective against parasites (e.g. Cryptosporidia)
Besides these advantages of the UV technology, it became evident that to date the UV fluence (dose) delivered by UV systems cannot yet be directly measured nor can it be calculated. This is because during UV irradiation in flow-through systems, several factors act in complex combination: the output of the UV lamps, the water flow, the transmittance of the water being irradiated and – especially important – the hydraulic properties of the UV device. As a consequence of inhomogeneous irradiation geometries and individual, unpredictable hydraulic behaviors, the fluence received by microorganisms exhibits a broad distribution. These facts make it still impossible to measure directly the disinfection performance of a specific UV plant.

Two principal UV technologies are in general use: low pressure systems with quasi monochromatic 253.7 nm emission and medium pressure systems emitting polychromatic radiation. In the latter case, it is even more complex to determine the microbicidal UV fluence, since the wavelengths account differently for the inactivation of microorganisms.

In view of the above factors, it was necessary to develop and establish standard protocols for testing the efficiency of UV disinfection systems. This has now been carried out by the Austrian Standards Institute (ÖNORM M 5873-1, low pressure systems 1996; (ÖNORM 2001) and ÖNORM M 5873-2, medium pressure systems (ÖNORM 2003), the US Environmental Protection Agency (USEPA 2003) and the German Association for Gas and Water (DVGW) (DVGW draft 2003).

The use of biodosimetry to evaluate commercial UV disinfection reactors is common to all three standards and testing protocols. Biodosimetry is included in a validation test, which is performed as a full scale test of a (commercial) UV disinfection plant either at a test stand or on site in the water work.

REQUIREMENTS FOR SAFE UV WATER DISINFECTION

The aim of drinking water disinfection is to prevent people from getting infected by pathogenic microorganisms that are transmitted through the water route. In water disinfection the microorganisms are inactivated; this means that these inactivated microorganisms have lost their infectivity and no longer pose a threat to humans. Techniques for water disinfection are: treatment with chlorine, ozone, heat (boiling) and by UV irradiation. The goal of sufficient drinking water disinfection has been set as a 4 log reduction of the concentration (99.99%) of bacterial and viral pathogens as well as a reduction of 3 log (99.9%) of protozoa (USEPA 1989).

To answer the question as to which conditions have to be fulfilled for a successful UV irradiation, a three-step approach has been proven to be useful:

1. Knowledge of the UV resistance of health related microorganisms transmittable by water: These investigations can only be performed under strictly controlled laboratory batch conditions; an example for a UV laboratory device is given in Figure 1. The irradiation equipment was evaluated for reliability in an international laboratory trial (Sommer et al. 1995). Data obtained from flow-through irradiation systems are not reliable in this respect since the conditions are not well controlled (occurrence of fluence distributions). For an overview on the UV-253.7 nm resistance of water relevant microorganisms see USEPA (2003).

2. Checking solely the presence of Escherichia coli and enterococci in 100 mL water volume – as is done in routine bacteriological water monitoring – has to be regarded as insufficient for the surveillance of disinfected waters. This is because these bacteria are much more sensitive to disinfection measures (UV, chlorine, ozone) compared to most of the water related pathogens (e.g., viruses). Therefore the surveillance of the disinfection process has to be carried out by checking the defined technical parameters (flow, reference irradiance, water transmittance) obtained during the validation test of the UV plant.

3. An objective evaluation of commercial UV plants: Due to the lack of a method for the direct measurement of the microbicidal UV fluence in commercial water disinfection plants, it is necessary to establish a standardized procedure for the testing and evaluation of such plants to guarantee that only well functioning UV plants are on the market. Numerous microbiological investigations have been undertaken to evaluate the performance of commercial UV disinfection plants. Since most of these tests were not performed under standardized conditions, especially with respect to the test organisms used, different assessments were obtained, sometimes even for one and the same UV plant. Thus an objective evaluation of the microbicidal efficacy of UV
systems is the prerequisite for their reliable application in water disinfection.

3. The surveillance during practical application: from the data of the type test, admissible ranges of operation and alarm points are determined. Due to regular controls during the practical operation of the UV plant in the water works, it is assured that these parameters are complied with. To measure the reference irradiance, commercial UV plants have to be equipped with a calibrated UV sensor fixed at a standardized measuring window at a reference position in the irradiation chamber (sensor reading in W/m²). The sensor has to be removable during operation of the UV plant to enable a check against official specifications providing an independent, objective inspection, often demanded by health authorities.

We introduce in the following text the Austrian National Standards ÖNORM M 5873-1, low pressure systems (ÖNORM 2001) and ÖNORM M 5873-2, medium pressure systems (ÖNORM 2003) as an example for standard protocols in which these aspects have been successfully implemented.

**LOW PRESSURE AND MEDIUM PRESSURE SYSTEMS**

Mainly two different types of UV sources are used for water disinfection: low pressure lamps with quasi monochromatic emission at 253.7 nm and medium pressure lamps with polychromatic emission. Due to the differences in lamp emission and the consequences thereof, low and medium pressure systems have to be regarded as different techniques (Table 1).

No differences in the disinfection efficacy have been found between polychromatic and monochromatic UV irradiation, provided that the UV fluence has been measured properly.

Regarding water disinfection with medium pressure systems, additional requirements have to be established due to the polychromatic UV radiation: (1) The spectral UV sensitivities of pathogenic and indicator microorganisms have to be known, (2) the spectral sensitivity of the sensor has to resemble as close as possible the spectral sensitivity of relevant microorganisms and (3) a suitable UV absorbing substance for the adjustment of the spectral transmission of the water during the type test has to be applied.

In proficiency testing of UV plants, the biodosimeters established for the testing of low pressure systems are also applied for the evaluation of medium pressure systems. In the latter case the Reduction Equivalent Fluence is related to the wavelength of 253.7 nm. For the sake of reproducibility, the spectral UV sensitivity of the biodosimeter has to be known (ÖNORM 2003).

A further important question deals with the formation of undesired by-products due to the UV irradiation of water. This indicates a significant difference between irradiation with monochromatic low pressure systems (wavelength 253.7 nm) and polychromatic medium pressure systems. Numerous investigations on low pressure radiation have proven that no changes of the characteristics of the water to be irradiated have to be expected. However, it is known that the radiation of medium pressure lamps may cause nitrite formation from nitrate (wavelengths below 240 nm). Some investigations reveal data on the generation of other undesired substances, such as an increase of the assimilable organic carbon (causing microbiological instability of the water) or the formation of genotoxic substances (Haider et al. 2001, 2003; Ijpelaar et al. 2003). However, more investigations in this field are necessary. For the reasons described the ÖNORM M 5873-2 (ÖNORM 2003), the permissible UV radiation is restricted to wavelengths above 240 nm.

### Table 1: Some characteristics of low and medium pressure UV systems (excerpt).

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<th>MEDIUM PRESSURE</th>
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<td>quasi mono 253.7 nm</td>
<td>polychromatic 200 (240) – 400 nm</td>
</tr>
<tr>
<td>Energy consumption of the lamps</td>
<td>low (40 – 100 W)</td>
<td>high (e.g. 7 kW)</td>
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<tr>
<td>Water flow</td>
<td>lower water flows (&lt; 1000 m³/h)</td>
<td>higher water flows (&gt;1000 m³/h)</td>
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<tr>
<td>Percentage UVC</td>
<td>30%</td>
<td>10%</td>
</tr>
<tr>
<td>Heat development</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Influence on water components</td>
<td>so far known, no changes</td>
<td>Nitrite (&lt; 240 nm) Possible changes: Assimilable organic carbon (AOC)? Gentoxic effective substances?</td>
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**UV-253.7 NM RESISTANCE OF MICROORGANISMS**

In the past few decades, the UV-253.7 nm resistances of many pathogenic and indicator microorganisms with significance for water quality in public health have been investigated (for an overview see USEPA 2003). Some examples are given in Figures 2 and 3. Compared with the other test organisms shown, spores of *B. subtilis* revealed the most UV resistance, closely followed by the bacteriophage...
MS2. The three viruses, poliovirus, rotavirus, and phage B40-8, take an intermediate position, whereas phage PHI X 174 and E. coli represent the very most susceptible test organisms. The inactivation curve of B. subtilis spores consists of a shoulder followed by an exponential part. The latter part can be used for the quantitative measurement of the REF in the fluence range from 200 to 600 J/m² (ÖNORM 2001, 2003). Spores of B. subtilis and the bacteriophage MS2 have been proposed as biodosimeters for UV reactor validation.

Figure 2: UV-253.7 nm inactivation of pathogenic (poliovirus, rotavirus) and indicator microorganisms (bacteriophages PHI X 174, MS2, B40-8 and bacteria E. coli) under controlled and standardized batch conditions. (Sommer et al. 1989; Sommer et al. 2001).

Figure 3: UV-253.7 nm inactivation of spores of Bacillus subtilis used as calibration curve of the biodosimeter. Principle of the analysis for the measurement of the Reduction Equivalent Fluence during biodosimetric test.

It has to be emphasized that some bacteria possess the ability to repair damages caused by UV irradiation, including the pathogenic E. coli strains which we have investigated (Sommer et al. 2000). The most potent repair pathway is photoreactivation, which is caused by the enzyme photolyase. This enzyme has to be activated by light energy in the near-UV or violet-blue spectral range. For the most UV resistant E. coli strain in this study, about a 2.5-fold higher UV fluence (300 J/m²) was necessary to reduce this strain by 6 logs after photoreactivation compared with the inactivation without photoreactivation.

Considering the goal of safe water disinfection, represented by a reduction of the concentration of drinking water transmittable, relevant pathogenic viruses by 4 log, a UV fluence (253.7 nm) of 400 J/m² has to be demanded. Therefore this requirement was laid down in the Austrian National Standard M 5873-1 and -2. Recently this value was confirmed as sufficient for the inactivation of caliciviruses (De Roda Husman et al. 2004). This fluence value also covers the inactivation of human pathogenic bacteria under consideration of photo repair, such as enteropathogenic E. coli (Sommer et al. 2000).

UV RESISTANCE OF MICROORGANISMS AT DIFFERENT WAVELENGTHS

When polychromatic radiation is employed, knowledge about the spectral UV sensitivity of the relevant microorganisms is essential. For these investigations we have used a radiation source (400 W Cermax Xenon-lamp) together with a single monochromator (Jobin-Yvon HL). In the longer wavelength region, possible short wavelength components were filtered out by cut off filters. 20 mL of the spore suspension was added to 25 mL vessels and irradiated under continuous stirring. The spectral irradiance at the surface of the suspension was measured with a spectroradiometer (Bentham DTM300) equipped with a quartz light guide and a Teflon diffuser as entrance optics. The calibration of the spectro-radiometer was traceable to PTB (Physikalisch Technische Bundesanstalt, Braunschweig, Germany). The bandwidth of the monochromatic irradiations was 20 nm. These measurements were carried out before and after each irradiation and the mean of both spectra was used for further calculations. The resulting fluence for each experiment was calculated from the spectral irradiance by taking into account the spectral reflection of the radiation at the surface of the suspension and the spectral absorption of the suspension and the irradiation time. The spectral absorbance of the suspension was measured by means of a spectrophotometer (Hitachi U-3000).

The result of the spectral investigation of the ÖNORM biodosimeter is shown in Figure 4, where the UV fluence is given in a logarithmic scale. A 2-log reduction at a wavelength of 254 nm (low pressure) was reached at a fluence of 400 J/m², whereas for the same effect at a wavelength of 352 nm 8.0 million J/m² was needed.
The principle of UV biodosimetry is the use of carefully UV-253.7 nm calibrated microorganisms. *Bacillus subtilis* spores (bacterial spores) are typically used for UV reactor validation in Europe, while MS2 coliphage (t-RNA virus) is typically used for validation testing in the North America. Both microorganisms are non-pathogenic allowing their use in the field and they possess a sufficiently high UV resistance to be suitable as “biological UV radiometers”.

### Calibration of the biodosimeter at the wavelength 253.7 nm (low pressure lamp)

An inactivation curve of the biodosimeter is performed under controlled laboratory batch conditions (fluences from 100 to 800 J/m²). Subsequently the reduction log $(N/N_0)$ of the microorganism is calculated as a function of the UV fluence. The inactivation curve of microorganisms in semi-logarithmic presentation (decadic) can be expressed by using the following formula:

$$\log \frac{N}{N_0} = \log \left[ 1 - (1 - 10^{-kH} )^{d} \right]$$

where $(N/N_0)$ is the survival ratio

- $k$ is the slope of the linear part of the survival curve in m²/J (UV-sensitivity)
- $H$ is the fluence in J/m²
- $d$ is the distance between the intercept of the linear part with the ordinate and the origin

Since the fluence measured by biodosimetry can be affected by the UV sensitivity of the biodosimeter used it is necessary to define its calibration curve to enable traceability.

The constants $k$ and $d$ shall be in the following range (spores of *Bacillus subtilis* according to ÖNORM 2003)

- $k = 0.0065 \pm 20\%$ m²/J ($k = 0.0052 - 0.0078$ m²/J)
- $d = 0.7 \pm 30\%$ ($d = 0.49 - 0.91$)

It has been found that the UV resistance of bacterial spores strongly depends on the method for the spore production (Sommer and Cabaj 1993). Therefore a suitable method – a liquid fermentation technique – has been developed for the production of sufficiently UV resistant spores (Sommer 1991).

For the measurement of the UV fluence, the biodosimeter is exposed to an unknown field or space of UV radiation. After exposition the concentration of the microorganisms still able to multiply is determined. The reduction log$(N/N_0)$ is calculated. $N$ represents the concentration of biodosimeter after irradiation and $N_0$ stands for the starting concentration. By means of the UV-253.7 nm calibration

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**Figure 4**: UV Inactivation of the ÖNORM biodosimeter (spores of *B. subtilis* ATCC 6633) at different wavelengths (Cabaj et al. 2002).

**Figure 5**: Spectral sensitivity (relative to the wavelength of 253.7 nm) of *Bacillus subtilis* spores used as biodosimeter in the ÖNORM (2001, 2003) expressed as wavelength dependence of $k$, the UV sensitivity coefficient, and $d$, the shoulder breadth coefficient (Cabaj et al. 2002).

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**Biodosimetry**

Biodosimetry is defined as a method involving the application of a test microorganism for the measurement of the UV fluence in a UV plant. This method is already in wide use in the field of UV radiation. It has been proven useful for the measurement of solar radiation as well as for technical UV sources (Cabaj and Sommer 2000; Calkins and Barcelot 1979; Munakata et al. 1996; Qualls and Johnson 1983; Quintern et al. 1992; Ronto et al. 1994; Sommer and Cabaj 1993; Sommer et al. 1999; Tyrell 1995).
curve the reduction is calculated back to the corresponding UV-253.7 nm fluence (J/m²). The result of the biodosimeter method is called Reduction Equivalent Fluence, REF₂⁵₃.₇ nm (Cabaj et al. 1996).

The conversion of the reduction to the Reduction Equivalent Fluence is carried out by using the following formula:

\[
\text{REF} = \frac{1}{k} \cdot \log \left[ 1 - \left( 1 - 10^{\log \left( \frac{N}{N_0} \right) / 10} \right)^{10^{-d}} \right]
\]

where \(N/N_0\) is the survival rate caused by the UV-disinfection plant. A schematic representation of the procedure is given in Figure 3.

The REF is affected by the fluence distributions within the suspensions due to inhomogeneous radiation fields, the UV absorption of the water and the lamp power. In the case of polychromatic UV sources (medium pressure UV lamps) the individual spectral UV sensitivity of the particular microorganism also has to be taken into account. To obtain reproducible and reliable UV validation data, the spectral sensitivity of the biodosimeter applied has to be characterized, as it was performed for the biodosimeter (spores of Bacillus subtilis ATCC 6633) used in the Austrian National Standard M 5873-2 (Cabaj et al. 2002).

BIODOSIMETRIC TYPE TEST ACCORDING TO THE AUSTRIAN NATIONAL STANDARD M 5873-1 AND M 5873-2

The type test at the test stand comprises five parts:

1. checking the compliance of the plant to be tested with the specifications given by the manufacturer;
2. general technical measurements during the test (flow, water temperature, electrical current, .....);
3. full scale microbiological test with the biodosimeter at a test stand under worst case conditions regarding flow and UV transmittance of the test water and lamp power (simulating aging of the lamp and fouling of the lamp sleeve); 6 defined test points
4. radiation physical measurement of the reference irradiance, test of the plant sensor;
5. evaluation of the UV disinfection plant and specification of the admissible operation range.

Adjustment of the test points

1. Determination of the relationship between the UV-transmittance of the water and the reference irradiance:
   a. The radiant power of the lamp is reduced (e.g. by lowering of the voltage) so that the radiant power at the end of the lamp utilization period is simulated (e.g. 30%).
   b. The UV-transmittance of the test water is adjusted with a transmission reducing substance (aqueous sodium thiosulfate solution for low pressure lamps, instant coffee solution for medium pressure lamps).
   c. Adjust the UV-transmittance that corresponds to the highest flow to be tested and measure the reference irradiance \(E_1\).
   d. Adjust the UV-transmittance that corresponds to the medium flow to be tested and measure the reference irradiance \(E_2\).
   e. Adjust the UV-transmittance that corresponds to the lowest flow to be tested and measure the reference irradiance \(E_3\).

The water flow may be kept low for these measurements (e.g. lowest flow to be tested), as the flow does not influence the measurement results.

2. Test points
   a. Test point 1*: highest flow to be tested, full lamp power, adjustment of the reference irradiance \(E_1\) by reduction of the UV-transmittance of the water.
   b. Test point 2*: medium flow to be tested, full lamp power, adjustment of the reference irradiance \(E_2\) by reduction of the UV-transmittance of the water.
   c. Test point 3*: lowest flow to be tested full lamp power, adjustment of the reference irradiance \(E_3\) by reduction of the UV-transmittance of the water.

The adjustment of the further test points is performed by using test water with a UV-transmittance of 80% to 90% and by reduction of the power of the UV lamp(s):

Test point 1*: highest flow to be tested, adjustment of the reference irradiance \(E_1\) by reduction of the lamp power.

Test point 2*: medium flow to be tested, adjustment of the reference irradiance \(E_2\) by reduction of the lamp power.
Test point 3*: lowest flow to be tested, adjustment of the reference irradiance $E_3$ by reduction of the lamp power.

Biodosimetric measurement of the Reduction Equivalent Fluence
As soon as stable conditions at the test point are reached, the stock solution of the biodosimeter (spores of $B. subtilis$) is pumped to the inlet flow of the UV plant tested. Optimum mixing is achieved by a static mixer (concentration of the biodosimeter after mixing about $10^6$ to $10^7$ spores per L). The samples after UV irradiation are also taken after a static mixer. During the test, there shall be a continuous flow through the sampling cocks. Per test point and test run, 5 samples are taken before and after UV irradiation respectively and the spore concentrations are analyzed quantitatively in triplicate using pour plate method.

This procedure results in 5 log-concentrations before and 5 log-concentrations after UV irradiation for each test point, of which the arithmetic mean is calculated ($\log N_0$: before irradiation, $\log N_1$: after irradiation). The standard deviation $s$ of the 5 parallel samples shall not exceed ±0.2, otherwise the test conditions are not considered to be stable (hydraulics, dosing, mixing). By calculating $\log N_1 - \log N_0$, the reduction at the test point is determined.

In terms of quality control during the type test, the UV-sensitivity of the biodosimeter must be checked in the standard laboratory batch apparatus (see above) with at least two samples of the test water containing the biodosimeter, in order to verify the stability of the biodosimeter. The two samples (with and without UV absorbing substances) must be irradiated with fluences of 200, 400 and 600 J/m², respectively. The values of $k$ and $d$ must be within the range of the values given in the standard. The inactivation function and the results of the verification test must be included in the test report.

Admissible range of operation and surveillance during practical operation
1. For establishing the admissible operating range the lower maximum flows at the same reference irradiance ($E_1$, $E_2$, $E_3$) that give a $\text{REF} \geq 400$ J/m² are used. The alarm points and the admissible operating range of the UV plant are determined from the data derived from flow and reference irradiance.

2. In the course of regular controls during the practical operation of the UV plant in the water works, it must be assured that these parameters comply with the specifications obtained in the validation test.

Considerations for medium pressure UV plants
Compared to low pressure systems, using almost solely monochromatic UV radiation at 253.7 nm, medium pressure UV plants with polychromatic UV sources represent a much more complex case. Therefore additional requirements have to be considered when testing and operating such a medium pressure UV disinfection system; these are:

1. Definition of the UV fluence caused by polychromatic radiation: three types have to be distinguished:
   a. the absolute fluence in J/m²,
   b. a weighted fluence related to a certain spectrum, e.g. to the spectral sensitivity of a microorganism or to the absorbance spectrum of the DNA,
   c. the $\text{REF}_{253.7 \text{ nm; biodosimeter}}$, as the result of biodosimetry, which is related to the UV-253.7 nm inactivation curve of the microorganism used as biodosimeter.

2. Spectrum of the lamp: The microbicidal effect of the UV lamp depends on the spectrum which is emitted.

3. UV-transmittance of the water ($%T_{100}$): The spectral transmission of the water influences the microbicidal efficiency of the UV radiation. This has to be taken into account when choosing a transmittance reducing substance for the biodosimeter test. For practical reasons the transmittance of the water being disinfected – as a measure of water quality – is determined at the wavelength of 253.7 nm.

4. Spectral sensitivity of microorganisms:
Microorganisms possess different spectral sensitivities; therefore these data for biodosimeters, as well as for water transmittable pathogens, are necessary for the establishment of medium pressure systems.

5. Spectral sensitivity of the reference and the plant sensor: For the surveillance of water disinfection the spectral sensitivity of the sensors should resemble as closely as possible the spectral sensitivity of microorganisms.

Examples for the results of biodosimetric testing are given in Table 2. For the majority of the UV plants tested, we found significantly lower $\text{REF}$ values than expected from the calculations made by the manufacturers (up to a factor of 2). In some rare cases we observed unexpectedly higher $\text{REF}$ values.
Microbiological testing performed simultaneously with Enterococcus faecium yielded reductions of $> \log 6$ under all conditions tested, even if the REF was far below 400 J/m². This strongly confirms the uncertainty of microbiological testing without considering the individual UV sensitivity of the test organism used.

Biodosimetry has proven eminently suitable to investigate quantitatively influences on the performance of UV disinfection, such as the water transmittance and the lamp intensity, reflection due to reflecting materials of the inner surface of the irradiation chamber and the hydraulic behavior of the device (Sommer and Cabaj 1993; Sommer et al. 1996; Sommer et al. 1997). The application of biodosimetrically tested UV plants ensures safe water disinfection and, moreover, can be used to optimize UV disinfection plants helping to save costs for energy and building material.

CONCLUSIONS

The following recommendations can be made for ensuring safe drinking water disinfection by UV irradiation:

1. A biodosimetric full scale test of UV plants using a biodosimeter (UV calibrated test organisms with a sufficient UV resistance compared to water transmittable microbial pathogens; non pathogenic; long-term UV stability) gives the Reduction Equivalent Fluences (J/m²) under worst case conditions (flow and UV transmittance of the water, lamp power, reference irradiance given as sensor reading in W/m²). Spores of Bacillus subtilis comply with all the demands for a biodosimeter.

2. If the test performance of the UV plant fulfills the microbicidal requirements alarm points and an approved range of application (maximum flow and minimum UV transmittance of the water as well as minimum reference irradiance) are fixed. These parameters serve as objective tools to check the performance of UV plants during practical operation.

3. Commercial UV plants have to be equipped with a calibrated UV sensor fixed at a standardized measuring window at a reference position in the irradiation chamber (sensor reading in W/m²). The sensor has to be removable during operation of the UV plant to enable the objective and independent inspection against official specifications.

4. Since routinely used bacteriological parameters (E. coli and enterococci) are too susceptible to serve as surrogates for health related water microorganisms the surveillance of disinfected water has to be based on well evaluated technical parameters which are controlled during practical operation in the water work.

5. To establish a minimum required Reduction Equivalent Fluence for safe drinking water disinfection, accurate data on the UV resistance of health related microorganisms are needed. Such data can only be obtained under well defined and controlled conditions in laboratory batch experiments. Based on our own findings and data from the literature a Reduction Equivalent Fluence of 400 J/m² has been fixed in the Austrian legislation. This fluence can be regarded as sufficient for a 4 log reduction (99.99%) of the majority of health related bacteria, viruses and protozoa.

6. When applying medium pressure systems the spectral UV sensitivity of the biodosimeter, the spectral sensitivity of the sensor, the suitable UV absorbing substance for adjusting the spectral transmission of the water dur-

<table>
<thead>
<tr>
<th>Flow (m³/h)</th>
<th>Water Transmittance % (253.7 nm; 100 mm)</th>
<th>Reference Irradiance (W/m²)</th>
<th>REF$^{1)}$ (J/m²) measured</th>
<th>UV Fluence (J/m²) calculated by the manufacturer</th>
<th>Reduction log($N/N_0$) of Enterococcus faecium</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>10</td>
<td>21</td>
<td>220</td>
<td>400</td>
<td>$&gt; 6$</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>21</td>
<td>230</td>
<td>400</td>
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<td>28</td>
<td>10</td>
<td>72</td>
<td>290</td>
<td>420</td>
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<td>28</td>
<td>88</td>
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<td>325</td>
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<td>84</td>
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<td>260</td>
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<tr>
<td>239</td>
<td>71</td>
<td>83</td>
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<td>239</td>
<td>84</td>
<td>83</td>
<td>390</td>
<td>400</td>
<td>$&gt; 6$</td>
</tr>
</tbody>
</table>

$^{1)}$ Reduction Equivalent Fluence
ing the type test have to be taken into consideration (ÖNORM 2003). Since these requirements for commercial UV plants with medium pressure lamps have to date not been completely realized medium pressure systems are not yet allowed for drinking water disinfection in Austria. More data about the spectral sensitivity of pathogenic and indicator microorganisms as well as studies on the possible formation of undesired by-products are urgently needed.

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CONFERENCE REPORTS:
Tokyo UV Conference

BY KUMIKO OGUMA AND OTHERS

University of Tokyo, Tokyo, Japan

This Conference (2nd Asia Conference on Ultraviolet Technologies for Environmental Applications) was held 4–6 October 2004 at the University of Tokyo, Tokyo, Japan and was organized by the Japan Society on Water Environment and the International Ultraviolet Association (IUVA). About 120 delegates attended in sessions where simultaneous translation (Japanese/English) was provided. This worked very well and allowed lively discussion following many of the papers.

Shinichiro Ohgaki, University of Tokyo, welcomed all participants and placed the conference as one of the leading meetings in Asia regarding UV research and application. Next plenary lectures were provided by seven outstanding researchers from five countries.

James Bolton (Canada), Executive Director of IUVA, gave a lecture on ultraviolet fundamentals as well as the recent advances in UV lamp technologies. His lecture was a wonderful reminder of UV basics and further provided the basis for broad discussion throughout the 3-day conference. Robert Hulsey (USA), Black & Veatch Co., presented the current status of UV applications in North America as well as the information on US EPA Ultraviolet Disinfection Guidance Manual. Regina Sommer (Austria), Medical University Vienna, presented and discussed the Austrian National Standards M 5873-1 and M 5873-2 which regulate UV disinfection for drinking water in Austria. RongJing Xie (Singapore), Centre for Advanced Water Technology, explained the current status and future trends in water production in Singapore, including the innovative systems at the NEWater plant.

After a break, Isao Somiya, Ryukoku University, Kyoto University, outlined the development, current status and future advances of UV irradiated ozonation methods in Japan. Yoshinobu Ishibashi, Tohoku-Gakuin University, outlined the current status of UV disinfection of drinking water in Japan. His lecture stimulated an active discussion on this issue. Shinichiro Ohgaki, University of Tokyo and representative of the UV specialist group of the Japan Society on Water Environment, presented the current status of environmental UV applications in Japan, particularly in Tokyo. He noted that the number of full-scale UV application sites is quite small, compared to North America and Europe.

The first general session (Decomposition of Pollutants) had five lectures concerning the photo-oxidation of pollutants, ranging from the application of the UV/H2O2 process to the degradation of textile azo-dyes and polychlorinated biphenyls to applications of vacuum UV (VUV) to treat cow stockbreeding wastewater and dye wastewater. The last paper concerned the UV decomposition of N-nitrosodimethylamine (NDMA).

The second session had four presentations, focused on disinfection and related problems concerning inactivation of C. parvum with a pulsed UV lamp, effect of various suspended solids in water on the disinfection of C. parvum, a new technology for detection of C. parvum and the disinfection of G. lamblia cysts in laboratory and field waters with low- and medium-pressure UV lamps.

The third session had five presentations related to the inactivation of microbes by UV irradiation and several issues concerning UV irradiation. Topics such as the relation of disinfection byproduct formation (DBP) to changes in the UV fluence, the enhancing effect of silver-sensitization on the photocatalytic action of TiO2 on the degradation M. lylae and the UV inactivation of M. aeruginosa concerning the quantitation of the DNA damage, and the study of seawater purification considering photoreactivation of coliforms were covered. The participants had an opportunity to inspect the equipment used in this study during the technical tour on the
last day of the conference (see photo below). The last paper examined low- or medium-pressure UV disinfection and subsequent repair of Legionella pneumophila.

The next session concerned advanced applications of UV technology, such as the application of UV in cleaning coils in air conditioning systems, and the treatment of wastewater using a new high-intensity low-pressure electrodeless mercury-argon lamp.

The final session concerned the characterization of UV-equipped water treatment systems, such as using CFD (computational fluid dynamics) for reactor validation, photochemical decomposition in flow-through reactors, microbial inactivation and photoreactivation in the UV reactors, comparison of open channel and closed pipe UV systems and the requirements of UV reactor validation.

More than twenty technical were presented in the Poster Sessions (see photo in the column to the left).

The Organizers wish to thank the many persons who helped make this such an excellent conference.

The Proceedings of UV-Tokyo Conference are available on CD-ROM and can be ordered from the IUVA Headquarters. Contact Kathy Harvey (kharvey@iuva.org).

Karlsruhe UV Conference

BY OLUF HOYER

DVGW Testing Facility for UV disinfection Devices, Siegburg, Germany

This Conference (European Conference on UV Radiation – Effects and Technologies) was held at the University of Karlsruhe, Karlsruhe, Germany, 22–24 September 2004 and organized by the German Academy for Photobiology und Photo Technology (DAfP), the International Ultraviolet Association (IUVA) and the German Association on Gas and Water (DVGW). It attracted 145 attendees from 15 countries as far away as Argentina, Australia and North America. On the day preceding the conference the 196th PTB-Workshop on Traceability in UV Dosimetry – Applications and Requirements was held by the German Federal Bureau for Physics and Mechanics (PTB). Lectures were given by W. Heering, University of Karlsruhe, R. Dreiskämper, Heraeus Noblelight Hanau, F. P. Wieringa, University of Leiden, A. Gugg-Helminger, Gigahertz Optics Puchheim, and J. Metzdorf, PTB Braunschweig. They covered the state of the art in measurement for high power radiation and the calibration with respect to adequate spectral responsivity.

Before the conference started on Thursday morning the Lord Mayor of Karlsruhe Mr. König (see photo above) welcomed the delegates to the city.

The Conference was opened by four public plenary lectures that encompassed the theme: “Ultraviolet Light – A Part of our Life and World”. F. de Grujil, University of Leiden, the various effects of UV radiation gas concerning disease and skin damage, but also a variety of possibilities to use radiation for therapy. D. P. Hader, University of Erlangen, focused on the biological issues of UV radiation in aquatic ecosystems. J. C. van der Leun, Utrecht, spoke on the basics of the ozone depletion in the atmosphere and its influence on climatic changes. Finally, R. G. Zepp, University of Miami, elucidated the photochemical reactions that occur in natural environments with examples from North American lakes and swamps.

The concept of the conference was to present and introduce in an interdisciplinary manner the most important fields in which UV radiation plays a role. Each session was introduced with key lectures from renowned experts and followed by original presentations on the current state of the art in re-search and technology. The set-up of the conference was very much appreciated by the exhibitors, who presented their equipment in the Tulla Hall Foyer where also the poster presentations (see photo above) and the breaks and lunch service took place.

Nigel Fox, British National Physical Laboratory, introduced the first thematic block on “Measurement of UV Radiation – Methods and Uncertainties” that was followed by six special presentations.
The second block, four special presentations, was commenced by Wolfgang Heering, Lighting Institute of the University of Karlsruhe, on "UV Sources - Basics, Properties and Applications".

The third block on photochemistry was opened by D. F. Eaton, formerly from DuPont USA, gave a brilliant lecture on "Photopolymers an Enabler of Industrial Innovation". This multiple facetted block encompassed 10 special contributions with a wide variety of sub topics, such as the UV treatment of lacquers, surfaces of nanotechnological components, UV induced bacteria fixation on surfaces and bio-matrices, and also processes using photo-oxidation.

On Friday, the first block focused on the application of UV in water treatment, a strongly expanding field in present days. Jim Bolton, Executive Director of IUVA, presented "Photo-chemical Technologies for Water Purification and Remediation" followed by six presentations on aqueous photo-oxidation.

The second block dealt with five papers on action of microorganisms in water under UV light and was introduced by Clemens von Sonntag, Mülheim a. d. Ruhr, on "The photochemical basis of UV-disinfection".

The last topic encompassed the practical aspects of UV disinfection in drinking water supplies, which is now booming all over the world. Oluf Hoyer, DVGW testing facility for UV disinfection devices, Siegburg, started this block with "Water Disinfection with UV Radiation – Requirements and Realization", which exemplified the German DVGW Standard W294. The six special papers dealt with issues on testing and monitoring but also on the differences in national concepts and regulations for the application of UV disinfection devices, especially in North America.

The Organizing Committee (Wolfgang Heering, Oluf Hoyer, Dieter Maier and Mathias Maier) would like to acknowledge the many helpers and contributors who supported the conference and were crucial for this success.

The Proceedings of UV-Karlsruhe 2004 are available on CD-ROM and can be ordered from the IUVA Headquarters. Contact Kathy Harvey (kharvey@iuva.org).
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New IUVA Web Site

JIM BOLTON

INTRODUCTION
The New Web Site has been split into three “zones”:

• **Public Zone**: This comprises all of the pages accessible from the Home Page (the first page that will be seen by anyone coming to www.iuva.org) except the Member Zone and the Board Room.

• **Member Zone**: This part of the web site is accessible only to IUVA Members with their assigned login and password.

• **Board Room**: This part of the web site is accessible only to Members of the IUVA Board of Directors.

THE PUBLIC ZONE
This Zone comprises all pages linked from the Home Page except the Member Zone and the Board Room.

**UV Industry Announcements**: This page is continually updated with announcements from the UV Industry.

**Advertisements**: All pages in the Public Zone will have a “rotating” ad in the bottom right corner. The revenue from these ads helps cover the web site maintenance.

**Hot News**: This Section (top right purple box) is where late breaking “Hot UV News” will be placed, as well as announcements of IUVA Conferences and Workshops.

**About Us**: This tab has four pages:
- Mission Statement
- Board Members: The list of the IUVA Board.
- Committees: A list of all IUVA Committees.
- ByLaws: A full recording of IUVA’s ByLaws.

**UV FAQs**: We often get questions about UV topics. Here you will find samples of the best questions with answers.

**Membership Information**: This Tab has three sections:
- Membership Benefits
- Membership Categories
- Membership Application: Here a potential new member can fill out an online application form and pay their membership by credit card.

**Events Registration**: This page allows anyone to register for IUVA Conferences or Workshops and pay for their registration on line.

**Corporate Members Links**: This page contains a list of all IUVA Corporate Members (organized by corporate member category), including links to their web pages.

**Contact Us**: This page provides contact information for the IUVA staff and allows anyone send an email comment.

THE MEMBER ZONE
This is the section of the IUVA Web Site that is the most valuable, since it contains a wealth of information and news of interest to IUVA Members.

**Member News**: This page contains news about IUVA activities. For example, the minutes of the latest Board Meeting will be posted here.

**IUVA News**: Past issues of IUVA News, IUVA’s ultraviolet magazine, will be posted as pdf files here, as well as files of individual articles. All may be downloaded for free.

**UV News**: This page contains the latest news about UV topics as gleaned by your Editor from the Internet.

**Buyer’s Guide**: This interactive page allows a Member to see lists of companies providing UV products or services. Links are provided to the company’s web site. This page will be continually updated.

**Reference Materials**:
- **Sensory Tables**: a compilation of the UV sensitivity of bacteria, viruses and protozoa.
- **UV Presentations**: Here you will find downloadable recent UV Presentations from UV professionals.
- **UV Patent List**: This continually updated page contains a list of UV patents (US only) since 2001.
- **UV Reference List**: This is a very comprehensive compilation of UV references (organized by topic) since 2001. It is continually updated.
- **UV Regulations**: This is a continually updated compilation of UV Regulations around the world.
- **UV Protocols**: This Section contains experimental Protocols for UV measurements.

THE BOARD ROOM
This section is accessible only to Board Members. For example, motions can be moved and seconded and an e-vote taken on the motion.

I welcome your comments and suggestions for improvements. Send to Jim Bolton (jbolton@iuva.org). I wish to thank Yvaine Schulz (IUVA’s webmaster), Kathy Harvey and Nelix Inc. for their considerable efforts in building this new site.
Update on the 3rd UV Congress

24 - 27 MAY 2005
WHISTLER CONVENTION CENTER
WHISTLER, BC, CANADA

IUVA’s 3rd International Congress on Ultraviolet Technologies will take place at the spectacular mountain site of the 2010 Winter Olympics. You will not want to miss this major UV event! IUVA has received 123 abstracts, so the Program will be rich and full of new insights in the UV world. This exciting venue promises to bring together many experts from all over the world to exchange and discuss the latest information on research and development in the field of UV technologies. An exhibition will give the delegates an opportunity to keep up-to-date with the latest industry trends, issues and developments. Enhancing an excellent technical and scientific program, the conference participants will have the opportunity to enjoy the beauty of the mountains surrounding the village of Whistler.

IUVA has negotiated very low hotel rates. The Congress dates are scheduled between the Canadian Victoria Day long weekend and the UV Memorial Day long weekend, so bring your family and enjoy a few extra days in this wonderful mountain environment!

Whistler is located a scenic 2 hour drive north of Vancouver airport. Most people will want to rent a car. We have negotiated special low car rental rates with Avis – call 1-800-331-1600 and give them the Avis Worldwide Discount number (AWD) J901115. Please visit www.mywhistler.com for driving directions and bus schedule information.

IUVA has negotiated airline discounts on:
Northwest/KLM – North American participants should call 1-800-328-1111 during business hours. Attendees from Europe/Asia may call the local Northwest/KLM reservations office in their country of origin. All callers must refer to the World File/ticket designator RBAPQ to obtain fare discounts.)

Air Canada – Participants should call 1-800-361-7585 and quote Convention Number CV053397 to obtain fare discounts.

SCIENTIFIC PROGRAM
Workshop
A pre-congress workshop will be offered on Tuesday, 24 May 2005. The focus will be a basic knowledge workshop covering topics such as Air Treatment, Curing and Water Treatment. The workshop will be given by well-known professionals in the UV world. The maximum number of participants for this workshop is 120.

Congress Program
The technical and scientific program of the congress will run from the morning of 25 May to Noon on 27 May. It will include plenary and parallel sessions as well as poster presentations. Four plenary speakers have been booked for the Congress:

Dr. Charles Sharpless
University of Mary Washington
Topic: Advanced Oxidation Applications

Dr. James P. Malley, Jr.
University of New Hampshire
Topic: UV for Small Water Treatment Systems

Ms. Christine Cotton
Malcolm Pirnie, Tucson, AZ
Topic: US EPA Guidelines

Dr. Wladyslaw Kowalski
The Pennsylvania State University,
Immune Building Systems, Inc.
Topic: UV for Air Treatment

VENUE
The Telus Whistler Convention Centre is the site for the technical program and exhibition. This beautiful newly renovated building is easy walking distance from the congress hotels and Whistler Village.

SOCIAL EVENTS
A Welcome Reception will be held in the exhibit hall for all attendees on Tuesday, 24 may 2005.

On Thursday, 26 May 2005, be sure to join us on the gondola ride to the top of Whistler mountain. There you will enjoy a Banquet Dinner and a spectacular view from the Roundhouse Lodge (see below). Casual dress is recommended for this event.

For further details and a registration form and hotel reservation information, please visit the IUVA Web Site (www.iuva.org).
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