UV EXPERIENCE FOR INACTIVATING CRYPTOSPORIDIUM IN SURFACE WATER PLANTS

Authors: Daniel Brooks, Gary Van Stone and Wayne Lem
Calgon Carbon Corporation
P.O. Box 717
Pittsburgh, PA 15230-0717

EXECUTIVE SUMMARY

The disinfection of pathogenic microbes in drinking water has been largely successful over the last century due to the use of chlorination. However, research conducted in the 1970’s revealed that by-products formed during the chlorination process are potentially carcinogenic and that there is a direct correlation between the concentration of chlorination by-products and the probability of certain cancers and other health problems. Following these discoveries, drinking water regulators have struggled to find a balance between the benefits of chlorination and the harmful side effects caused by chlorination, within the confines of technological and economic limitations.

In the U.S.A., the Surface Water Treatment Rule (SWTR) of 1989 mandates inactivation levels for *giardia* cysts and enteric viruses, and also sets treatment standards for Trihalomethanes (THMs). The SWTR provides guidance to drinking water facilities through “CT” tables that prescribe the inactivation efficacy of various processes under varying water quality conditions. By following this guidance, most water treatment plants were able to provide an adequate degree of disinfection while not compromising their Disinfection By-Product (DBP) limits and without requiring major changes to their plants. However, continuing DBP health effect research indicated that even the DBP standards required in the 1989 SWTR produced an unacceptable level of risk and the SWTR was amended in 1996 to further lower DBP standards. In addition, a major outbreak of cryptosporidiosis in Milwaukee in 1993, and other minor cryptosporidiosis outbreaks caused regulators to create a removal requirement for *cryptosporidium* oocysts in the 1998 Interim Enhanced Surface Water Treatment Rule (IESWTR) and most likely a disinfection requirement in the final ESWTR (LT2ESWTR). The new DBP standards have caused many plants to fall out of compliance, requiring either extensive plant modifications or new disinfection strategies. The LT2ESWTR will include a *cryptosporidium* disinfection requirement and many surface water plants will fall out of compliance due to the very poor efficacy of chlorination for *cryptosporidium*. Therefore, due to these apparently conflicting conditions, a void was created for a water treatment technology that is effective for protozoa and viruses, does not create DBPs, and is economically feasible.

UV technologies have long been known to be effective for viruses and bacteria in drinking water and guidelines for the disinfection of viruses exist in the Alternative Disinfectants and Oxidants Guidance Manual. However, UV was widely considered to be ineffective for encysted protozoa
as it was thought that the UV light would not penetrate the cyst membrane, and since *giardia* is the controlling microbe for chlorine dose determinations, no reductions in chlorine usage could be gained by using UV. Therefore, UV Disinfection was not used for surface waters in North America.

New breakthrough research conducted by Calgon Carbon Corporation in 1998 however proved that UV disinfection is, in fact, very effective for inactivating *cryptosporidium* and *giardia* at low UV doses. Subsequent to Calgon Carbon’s research, the USEPA created a UV subworkgroup to report to the Federal Advisory Committee (FACA) on issues and costs related to UV disinfection. In advance of new guidance manuals for UV disinfection, many utilities have begun to consider UV disinfection in their plants either as an additional barrier for protozoa disinfection or to get “CT” credits for UV for *giardia* so that chlorine doses can be lowered to meet the 1998 DBP standards.

**UV DOSE**

In order to provide guidance for the application of UV disinfection technologies, there must be general agreement on the use of UV terms and units. For example, a practical guidance manual might advise utilities to provide a “UV Dose of 40 mJ/cm² to provide 3 log inactivation of *giardia*”. In fact, the term “UV Dose” could have several meanings.

In the simplest terms, **UV Dose** is defined as the product of the average UV Irradiance (expressed in mW/cm²) and the average exposure time (expressed in seconds) with the resultant units of mW-s/cm² or more commonly expressed as mJ/cm². More precisely, **UV Dose** is the total radiant energy of all germicidal wavelengths incident from all directions on an infinitesimally small sphere of cross-sectional area dA, divided by dA. Furthermore, since different light wavelengths will act differently on the target DNA, UV dose is further refined in a term called the “**Germicidal UV Dose**” which is the UV Dose weighted by the relative absorbance of DNA with a weighting factor of 1.00 at 254 nm.

Calgon Carbon engineers use a Computational Fluid Dynamic (CFD) model. The CFD model begins by randomly selecting a particle that enters the UV reactor and determining the UV Dose delivered to that particle. This process is then repeated by the processor until enough particles are considered to provide a high confidence in the dose predictions. The CFD model also takes into consideration the UV transmittance of the subject water and certain efficiency factors inherent in UV systems. The efficiency factors and design parameters can be described as follows:

**Electrical Power Efficiency**: UV systems convert electrical energy to light energy. However, this conversion is not 100% efficient as a certain amount of energy is lost as heat. Calgon Carbons’ electromagnetic ballasts have a 92% efficiency at converting electrical energy into light energy.
**UVC (Germicidal) Output:** Medium pressure UV lamps produce light energy over a broad spectrum of wavelengths, only some of which are in the germicidal range. Therefore, only the wavelengths that are in the germicidal range (200 – 300 nm) can be used in calculating the UV dose.

**Lamp Aging Factor:** All UV lamps gradually lose their output as they age. Typically, a medium pressure lamp will have a life of 3000 to 5000 hours, at which point it will have dropped to 80% of its original output. Calgon Carbon sizes its UV systems based on its useful life at the end of lamp life.

**Quartz Transmission Factor:** The quartz sleeve used to house the UV lamp cuts out 11% of UVC light.

**% Transmittance:** The percent transmittance of the water is necessary to indicate the degree in which UV light between 200 nm and 300 nm penetrates the water. The higher the transmittance, the easier it is to deliver the dose to the desired particle. Typical %T values for drinking water are greater than 90%.

The **Reduction Equivalent Dose (RED)** is a term used in the biodosimetry validation of UV reactors. As the name implies, the RED is the UV dose that provides an observed reduction of a marker organism with a known dose-response curve. For example, if it is known that *Bacillus subtilis* has a 2 log inactivation at a UV dose of 40 mJ/cm², and the observed reduction of *b. subtilis* in the UV reactor for the subject water is 2 logs, then the UV reactor is said to be delivering an RED of 40 mJ/cm² in that water at that flow rate.
UV RESPONSE DATA

At the time of publication of the Alternative Disinfectants and Oxidants Guidance Manual sufficient data on the efficacy of UV for *giardia* did not exist and so no guidance is provided. However, subsequent testing UV disinfection of protozoa parasites by multiple researchers has provided a large volume of data for regulators to provide guidance. The UV testing can be summarized in the following table, and supporting publications are attached.

<table>
<thead>
<tr>
<th>Organism</th>
<th>Reference</th>
<th>UV Dose Requirement (mj/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1-log</td>
</tr>
<tr>
<td><em>cryptosporidium</em></td>
<td>Bukari et al., JAWWA 1999</td>
<td></td>
</tr>
<tr>
<td><em>cryptosporidium</em></td>
<td>Clancy et al. submitted for publication in JAWWA</td>
<td></td>
</tr>
<tr>
<td><em>cryptosporidium</em></td>
<td>Finch et al. submitted for publication in Water Research</td>
<td>&lt;5</td>
</tr>
<tr>
<td><em>cryptosporidium</em></td>
<td>Mofidi et al. WQTC, 1999</td>
<td>6</td>
</tr>
<tr>
<td><em>cryptosporidium</em></td>
<td>Sobsey et al. WQTC 1999</td>
<td></td>
</tr>
<tr>
<td><em>giardia</em></td>
<td>Finch et al</td>
<td>&lt;5</td>
</tr>
<tr>
<td><em>giardia</em></td>
<td>Sobsey et al 1999</td>
<td>&lt;10</td>
</tr>
<tr>
<td><em>giardia</em></td>
<td>Malley et al 2000</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

U.S. REGULATORY STATUS
Although the EPA regulations regarding the discharge quality of drinking water are numerous, the regulations relating to the allowable disinfection by-products (DBP) levels and microbial control are the most pertinent. In order to address the significance of these issues, an understanding of the formation of DBPs needs to occur.

Different DBPs are produced in a drinking water plant when certain chemical disinfectants come into contact with specific organic precursors. Many of these DBPs have been found to be carcinogenic or producers of other health problems and hence the regulatory interest. Some common disinfectants and their by-products are:

Chlorine – THMs and HAAs  
Chlorine Dioxide – Chlorite  
Ozone - Bromate

In addition to the regulatory concern over the presence of these compounds, there is also a drive to further protect the public against microbial contamination. The conflict rests in the fact that to increase microbial control with chemical disinfectants, one needs to increase chemical addition, which may serve to increase the production of these harmful DBPs.

By looking at the existing and proposed regulations, we can better understand the need for effective Giardia and Cryptosporidium protection while minimizing or eliminating the risk from DBP formation:

1989 Surface Water Treatment Rule:  
• log removal of giardia

1998 Stage I Disinfection By-product Rule  
• 80 ppb allowable THM  
• 60 ppb allowable HAA  
• 10 ppb allowable bromate  
• 1 ppm allowable chlorite

1998 Interim Enhanced Surface Water Treatment Rule  
• 2 log removal of Cryptosporidium

2002 Stage II Disinfection By-Product Rule  
• Decreased allowable DBPs (Likely outcome)

2002 LT2ESWTR  
• Inactivation requirement for Cryptosporidium (Likely outcome)
The EPA will also be developing the following information for use by the industry:
1. UV dose tables
2. Validation protocol
3. Monitoring requirements
4. UV Guidance manual

WATER QUALITY ISSUES

The two water quality issues of concern are; A) What impact does UV irradiance have on water quality, and, B) What impact does water quality have on UV disinfection efficacy.

IMPACT OF UV ON WATER QUALITY

Disinfection Byproducts

Early research conducted by Kruithof (1992), Hoyer (1998) and Malley (1995) investigated the byproduct formation potential of low pressure UV systems in various groundwaters and surface waters. Zheng (1999) studied the impact of medium pressure UV systems on byproduct formation. The following summarizes the results of this research:

- UV disinfection does not create significant increases in THMs and HAAs.
- UV disinfection does not significantly increase AOC
- At high UV doses and high nitrate concentrations, there is the potential for nitrite formation from nitrate
- Free chlorine concentration is not significantly altered at normal UV doses

IMPACT OF WATER QUALITY ON UV DISINFECTION EFFICACY

The main water quality parameters that impact UV Disinfection efficacy are the presence of solids (turbidity) and the UV transmission of the water. Minerals such as dissolved iron, manganese and carbonates may indirectly impact UV Disinfection efficacy by oxidizing on the surface of the protective quartz sleeve and thus prevent transmission of the UV light into the water. Although turbidity is a major concern for wastewater systems and unfiltered water systems, Malley (1998) showed that UV disinfection efficacy is not impacted by turbidities of less than 2 NTU, and therefore, if the system is satisfying the SWTR, turbidity is not an issue for UV disinfection. UV transmission (%T) can vary greatly from system to system, and needs to be considered in sizing and monitoring UV systems. Systems considering UV disinfection should measure UV transmission over a variety of weather and seasonal conditions, and should design the UV system based on the worst observed %T as a conservative assumption.
**REACTOR VALIDATION**

As previously discussed, there are significant differences in the UV dose applied and the UV dose delivered due to design differences UV reactors. This section will provide a sufficient background on the state-of-the-art of UV reactor validation from Europe and, in the absence of certified reactor validation facilities in the USA, how to size and scale-up UV reactors with from existing data.

*German DVGW Standard W294 UV Reactor Protocols*

The widespread use of UV disinfection of drinking water proceeded faster in Northern Europe than in North America. In the late 1980’s and early 1990’s, the German Water Protection Agency (DVGW) was faced with the same regulatory issues facing US state and federal agencies today. In response, an association consisting of German research institutes, manufacturers, and government agencies launched a joint research project on the fundamentals for safe, large-scale UV installations. The results of this research concluded that: 1) the required UV dose for 4-log bacteria and virus inactivation is 40 mJ/cm² 2) no significant by-products or water quality changes occur with this UV dose and 3) a reactor certification laboratory must be created to certify large-scale UV reactors under uniform and worse case conditions.

Hoyer (2000) described the reactor certification process in a paper presented at the NWRI “UV 2000” Technical Symposium, which is included in the appendices. In general, Hoyer describes a 4-step process to certification as follows:

**Support documentation** must be provided for the UV lamp (spectral characteristics), quartz sleeve (UV transmission, dimensions), and sensor (range, selectivity, precision, linearity, temperature and time stability, and calibration requirements)

**UV Sensors** must provide continuous monitoring of the UV lamp with the measurements verifiable with a reference sensor. The UV sensors are tested for certification.

**On-line Command and Control** to continuously monitor water flow rate and UV sensor output and responds to ensure UV dose delivery is maintained.

**Challenge Test** involves seeding a challenge microbe into the UV disinfection unit and measuring the inactivation achieved by the reactor at full flow rates. Specifically, the challenge test has two
objectives: 1) determine the UV sensor set point, and 2) assign a UV dose equivalent to the reactor model.

The exact protocols for performing these tests are documented by Hoyer (2000). Calgon Carbon’s design philosophy has been guided by the German DVGW W294 model.

**Reactor Performance Modeling**

In addition to biodosimetry performance validation, several reactor performance models exist (Blatchley, 2000). Dose distribution models are used as excellent guides for optimizing UV reactors for electrical efficiency, and for interpolating between biodosimetry data or extrapolating above biodosimetry data. Calgon Carbon uses a dose distribution model to extrapolate results from both internal and third party biodosimetry testing of various size reactors.

**Scale up Safety Factors**

The UV system sizing is based on conservative design assumptions and worst-case conditions. Safety factors are cumulative and taken together offer a very large safety factor. Some of the more obvious safety factors are discussed below:

**UV Dose:** Two published studies and one unpublished study report that 1-log inactivation of *giardia* occurs at a UV dose of less than 5 mJ/cm². Typically, UV systems are conservatively designed to deliver a UV dose of 40 mJ/cm².

**UV Transmission (%T):** A typical filtered water plant may observe changes in its %T by as much as 5% - 7% over the course of several seasons. This %T change could change the power requirement by 50% or more. In current practice, the design is based on the worst-case observed %T which adds a safety factor of 20% - 100% or more under typical %T conditions.

**Flow rate:** The design flow rate is based on the daily peak or plant capacity. Since plants typically operate at well below their maximum, there is a considerable safety factor that typically amounts to 50% - 200%.

**End of Lamp Life:** UV power requirements are based on the efficiency of the UV lamp at the end of its useful life (typically >3000 hours), when the lamps power efficiency may have dropped by as much as 30%. Therefore, on average there is approximately a 15% safety factor built into this assumption.

**FULL SCALE INSTALLATIONS**
Multiple data points now confirm that UV is an acceptable disinfection technology for encysted protozoa and viruses, and good protocols for dose validation have been developed by German researchers and will likely be adopted by North American regulators and industry. The final information required for State regulators to grant disinfection credits for UV technologies is operational data.

This Section covers the practical engineering design issues based on Calgon Carbon Corporation’s UV installation experience, as well as operational issues such as control and command features, system maintenance and operator training. This experience is derived from over 250 medium pressure UV installations treating municipal wastewater, contaminated groundwater, industrial wastewater, and most recently, drinking water. Sentinel™ is Calgon Carbon Corporation’s unique UV disinfection system designed specifically for the drinking water industry.

The purpose of this Section is to provide regulators with an understanding of the engineering basis for design and the degree of training and maintenance typically required for operating a UV system in order to provide the regulator with a level of comfort that a system is installed and maintained properly.

**Design Considerations**

**Location:** The UV system should ideally be placed after the filtration step in a plant (unless plant does not utilize filtration), although other locations such as after sedimentation or after the clearwell could be considered. For placing the UV system after the filters (in the pipe gallery), there are several options depending on the plant layout. Ideally, if the plant has an exposed and accessible common pipe, then the UV system could be placed in the common line. This reduces costs and operator requirements, and minimizes pressure drop for the overall system. If a common line is not exposed or accessible, then it is possible to place a UV system on the effluent line from each filter. This option increases the overall costs and may present its own access or hydraulic concerns. If either of these options is not available, it is possible to place the UV system after the clearwell, either in the suction side of the service pumps (preferable) or the pressure side of the service pumps. If the suction side is considered, then a careful hydraulic profile must be considered and the pressure drop through the UV system minimized to avoid cavitating the service pumps. If the high pressure side of the service pump is considered, then care must be taken, that the line pressure does not exceed the pressure rating of the equipment. Also, precautions would need to be taken to prevent water hammer to the UV system during pump shut down. Finally, if none of these options are possible then more extensive capital modifications should be considered, such as the construction of an additional building to accommodate the UV system in its optimum location.

**Pressure Drop:** The pressure drop across the Sentinel system is dependent on the reactor geometry (diameter, length), the water flow rate, and the internal mixing devices used to promote mixing and therefore increase the electrical efficiency of the system. In general, the Calgon
Carbon design engineer has design freedom with the reactor geometry and the internal mixing devices and targets a pressure drop of no more than 1-2 psi at maximum flow rate. In general, however, the greater the pressure drop the greater the overall efficiency. However, care must be taken not to exceed the overall pressure drop tolerances of the plant.

**Redundancy:** In order to comply with the SWTR, the disinfection system must have complete redundancy or a strategy must be in place to deal with a UV system failure that would use an alternative disinfectant in the short term, or shut the system down. In most cases, system shut down is not an option. In some systems, a short-term alternate disinfectant could be an option, but in most cases, an n+1 UV system strategy is recommended.

**Mercury Release:** In the event of a catastrophic failure of both the UV lamp and the protective quartz sleeve, elemental mercury and/or mercury oxides would be released into the drinking water system. Depending on the UV lamp type, between 0.2 and 1.8 grams of mercury is available. Using conservative solubility and dilution assumptions, Calgon Carbon Corporation calculates that the maximum Hg concentration in the water would be below 1 ppb and would therefore be below the drinking water standard for chronic toxicity and well below the standard for acute toxicity. Furthermore, the released Hg would be a one-time release and would travel through the system as a plug that would dissipate after time. Catastrophic failures of this type are extremely unlikely. It is Calgon Carbon’s recommendation that special measures are not taken to contain Hg from lamp breakages due to the low probability of occurrence and the minimal impact on water quality in the event of Hg release. If this recommendation is unacceptable, a control strategy could be created to capture and waste several plant volumes until the Hg in the system has been exhausted.

**UV Lamps:** Calgon Carbon Corporation uses medium pressure UV lamps with a guaranteed life of between 3000 and 5000 hours (depending on lamp power rating). In general, UV lamp efficiency decreases linearly with time, and at the end of the guaranteed lifetime, the output has decreased to 80% of the original output at which point they should be replaced. The Sentinel control system gives an operator warning when lamp life exceeds the recommended lamp life.

**UV Dose Monitoring and Control**

**UV Sensors:** The device for monitoring the UV output of UV lamps is the UV sensor. The UV sensor gives a continuous, real time measurement of the UV irradiance at fixed points in a UV reactor. A single UV sensor is provided for each lamp. In general terms, a UV sensor is an optical device consisting of a photodiode that converts UV light energy into an electrical signal which is amplified and filtered to produce a 4-20 mA signal to a programmable logic controller which can then either translate this into a percentage or a “calculated” UV Dose on a display. Calgon Carbons’ UV sensors are accurate and precise over a wide range of environmental conditions, stable over time and robust for use in aggressive, high irradiance, and humid environments. These sensors are DVGW approved and manufactured by a third party to insure
confidence in the delivered value and hence be able to reliably predict delivered dose within the reactor. Calgon Carbon generally prescribes to the strategy described by Hoyer (2000) for establishing a UV sensor set-point based on biodosimetry testing, with actionable conditions should the UV sensor fall below the set-point. The measured irradiance could drop below the set-point for a number of reasons including; lamp-out or below 70% output, UV transmission below design value, fouling of the quartz tube, or sensor failure. Any of these problems should be addressed immediately. Action items include; reactor shut-down, ignition of a stand-by UV lamp (smart-start feature), automatic flow reduction, automatic increase in an alternate disinfectant etc.

**Sensor Calibration:** UV sensors will drift over time and require calibration to ensure long-term accuracy. Calgon Carbon has targeted a +/- 10%/year design specification for its sensor design. Calgon Carbon generally prescribes to the technique described by Hoyer (1998, 2000) for sensor calibration, whereby a reference sensor is used to provide a marker reading and the UV sensors are electronically zeroed against the reference.

**Controls and Instrumentation:** The Sentinel system control and instrumentation strategy is provided in the operation manual included with this reference manual. Some of the more important control features include:

- UV irradiance below set-points
- No current to lamp
- Reactor high temperature
- No flow
- Flow out of range
- Water leak detected
- UV covers opened without system shut-down
- Lamp age exceeds limit
- Quartz cleaner malfunction

**Reactor Maintenance**

An example of a Sentinel Operation Manual is provided which provides examples of operator training and maintenance schedules.

**Operator Training**

Operator training lasts from one to five days, depending on the complexity of the system, the operators familiarity with UV systems, and the system’s training budget, and consists of the following main elements:
Safety
System Overview
System Operation
Maintenance

Maintenance Schedules

Scheduled maintenance is recommended to all Sentinel customers with the following key maintenance items:

- UV sensor calibration
- UV lamp changes
- Quartz tube inspection, cleaning and replacement
- Quartz cleaner inspection and replacement
- Reactor assembly inspection
- Reactor cleaning
- Power supply inspection

Featured Calgon Carbon Installations:

**Grosse Point Farms in Michigan** became the first surface water plant in North America to install a UV system for cryptosporidium inactivation. This unit was installed in May 2000 as an additional barrier to microbial contamination of the water since there was no change to the drinking water treatment upstream of the Sentinel unit. A local hospital was extremely supportive of this effort and in fact contributes the funds to support the operating costs for the unit.

This design conditions at this plant were as follows:

- Peak Flow: 14 mgd
- Average Flow: 4.5 mgd
- Pipe Size: 24” Common Line
- Water Source: Lake Saint Clair
- Turbidity: Less than 0.3 NTU
- %T: > 95%

No major maintenance has been performed on reactor since its installation. Typical maintenance requirement for this system is lamp replacement and internal inspection which occurs at regular intervals (every 3000 hours).
In order to conserve operating expense associated with lamps and electricity, the lamps are "paced" with flow. In other words, lamps are turned on as the flow increases in order to maintain treatment dose.

There were two site specific conditions that required some design modifications. At one point, a corrosion inhibitor was fed upstream of the Sentinel unit. This served to decrease UV transmittance as well as coat the sensor viewing quartz. This problem was rectified by first cleaning the sensor viewing quartz and then placing the injection point of the corrosion inhibitor downstream of the Sentinel unit.

Typical operation at Grosse Pointe involves a generator check every Friday afternoon. This momentary loss of power turned off the lamps in the UV reactor. The initial control scheme cycled through each lamp continuously until a lamp started which was a problem due to the fact that medium pressure lamps can not be restarted until they cool down (typically within 10 minutes). This cycling would produce a massive number of lamp starts until lamp operation was restored. Since lamp starts degrade the life of a UV lamps, this was not an efficient process. This situation was rectified by programming a start-up delay of 10 minutes following lamp outage. An alternative solution would have been to provide an UPS unit which would provide continuous power to the Sentinel system.

The Sentinel system is equipped with remote monitoring capabilities. Calgon Carbon can read all system parameters from Pittsburgh office and interact directly with PLC should any problems occur.

West View Water Authority in Pittsburgh became the largest surface water plant in North America to install UV disinfection when they installed a Sentinel system to disinfect a plant flow of 40 mgd in January of 2001. A 48” Sentinel reactor was utilized that employs six (6) 20 kW lamps within.

The Design Conditions at this plant are:
Peak Flow: 40 mgd
Average Flow: 22 mgd
Pipe size: 48”
Water Source: Ohio River
Turbidity: <0.3 NTU
%T: >91%T

Like Grosse Pointe Farms, West View Water installed the UV as an added treatment barrier with no change to their existing treatment process. The unit is installed following the clearwell in a common 48” line. Installation was extremely simple and was accomplished in only a 12 hour period during a scheduled plant shutdown.
This unit has been provided to West View Water with a complete service package in which all operating parameters are monitored from the Calgon Carbon office in Pittsburgh. Service technicians are prompted for routine maintenance items such as lamp replacement automatically based upon hours of operations. Also, in the event of an alarm condition, the service technician is automatically notified.

Both Grosse Pointe and West View hope to eventually gain disinfection credits so that the amount of chlorine added to their system can be reduced. For now, the UV system provides an added barrier of protection against pathogens entering the distribution system.

**CONCLUSIONS**

UV disinfection has become an accepted disinfection alternative for cryptosporidium and giarda in addition to viruses and bacteria. In addition, the practical aspects of UV application are being established and are currently in practice in surface water plants.

Specifically, the dose requirement for UV disinfection will most likely remain 40 mj/cm$^2$ for typical surface water disinfection applications. This level of UV is within a practical range and protects against all common pathogenic organisms. This level also sufficiently guards against potential photoreactivation.

Unlike other treatment process where influent and effluent measures of a specific contaminant can be obtained to assess effectiveness, this is not possible with a UV disinfection system. For this reason, the industry is turning to third party testing and proven modeling methods to increase confidence in manufacturers claims. Specifically, the German DVGW standard provides an excellent method of empirically quantifying the dose delivered within a reactor. CFD modeling currently serves as a tool to extrapolate these results to reactor sizes beyond the capabilities of the German test facility.

UV disinfection systems are now being installed in increasing numbers in North America due to the significant benefits this technology provides. Longer term, it is expected that a large portion of surface water plants will employ UV disinfection to meet both regulatory needs and public health concerns.