UV EXPERIENCE FOR INACTIVATING *CRYPTOSPORIDIUM* IN SURFACE WATER PLANTS

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REGULATORY BACKGROUND

The disinfection of pathogenic microbes in drinking water has been successful over the last century largely 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 within the confines of technological and economic limitations to find a balance between the benefits of chlorination and its harmful side effects.

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 (THM's, a common disinfection by-product). 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 SWTR of 1989 produced an unacceptable level of risk and the SWTR was amended in 1996 to lower the level of DBP's. The new DBP standards have caused many plants to fall out of compliance, requiring either extensive plant modifications or new disinfection strategies. In addition, a major outbreak of cryptosporidiosis in Milwaukee in 1993, and other minor cryptosporidiosis and giardiasis outbreaks caused regulators to create a removal requirement for *Cryptosporidium* oocysts in the 1998 Interim Enhanced Surface Water Treatment Rule (IESWTR) and a further treatment requirement in the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) which was promulgated in December 2005. The LT2ESWTR includes a treatment requirement for *Cryptosporidium* and many surface water plants will fall out of compliance due to the very poor ability of chlorination to inactivate *Cryptosporidium.* A void was created for water treatment technologies that will inactivate protozoa and viruses, not create DBPs, and are economically feasible. One technology that meets all three criteria is ultraviolet (UV) disinfection.

Ultraviolet light has long been known to be effective for the inactivation of viruses and bacteria in drinking water and guidelines for the disinfection of viruses with UV light exist in the U.S. EPA Alternative Disinfectants and Oxidants Guidance Manual. However prior to 1998, UV was widely considered to be ineffective at economically feasible UV doses for encysted protozoa (like Giardia and Cryptosporidium), as it was thought that UV would have to rupture the cyst membrane wall. Since *Giardia* was the controlling microbe for the determination of the dose of chlorine and since the UV dose required for Giardia was believed to be completely too high to be considered, no reductions in chlorine usage could be gained by using UV. As a result, UV disinfection was not used for drinking water in North America; however it has been and continues to be used extensively in Europe for groundwater.

Breakthrough research conducted by Calgon Carbon Corporation in 1997 and 1998 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 U.S. EPA created a UV working group to report to the Federal Advisory Committee (FACA) on issues and costs related to UV disinfection, resulting in the development of the UV Disinfection Guidance Manual (UVDGM) by the U.S. EPA and the promulgation of the LT2ESWTR. Many utilities are now using or are considering UV disinfection in their plants as either an additional barrier for protozoa disinfection or to get disinfection credits for *Cryptosporidium* and/or *Giardia and* to lower chlorine doses to meet the 1998 DBP standards.

UV TERMINOLOGY

To provide guidance for the application of UV disinfection technologies, there must be general agreement on the use of UV terms and units. UV dose (often called UV Fluence) is the most important term because this defines the work done in a UV system to inactivate protozoa and viruses.

UV dose or fluence is the product of the average intensity or fluence rate acting on a microorganism from all directions and the exposure time. Units commonly used for UV dose are J/m^2, mJ/cm^2, and mWs/cm^2 ($10\ J/m^2 = 1\ mJ/cm^2 = 1\ mWs/cm^2$). The UV dose received by a waterborne microorganism in a reactor vessel accounts for the effects on UV intensity by the absorbance of the water and quartz sleeves; reflection and refraction of light from the water surface and reactor walls; and the germicidal effectiveness of the UV wavelengths. The UVDGM also uses the following terms that are related to UV dose:

- **UV Dose Distribution** – the distribution of UV doses that microorganisms receive in flowing through a UV reactor; typically shown as a histogram.
- **Reduction Equivalent Dose (RED)** – a dose derived for a flow through UV reactor that is based on biodosimetry (i.e., measuring the level of inactivation of a challenge microorganism with a known UV dose-response). The RED is equal to the UV dose in controlled laboratory exposures using a collimated beam of UV light (called a collimated beam test) that achieves the same level of inactivation of the challenge microorganism as measured for the UV reactor during biodosimetry testing. For example, if it is known that MS2 coliphage has a 2 log inactivation at a UV dose of 40 mJ/cm^2, and the observed

reduction of MS2 coliphage 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/cm^2 in that water at that flow rate.

***Lamp Aging Factor**:* All UV lamps gradually lose their output as they age. Typically, a medium pressure lamp will have a life of 5000 hours at which point the UV output will have dropped to 80 to 95% of its original value. Calgon Carbon sizes its UV systems based on its output at the end of lamp life.

***Quartz Sleeve Transmission Factor**:* The quartz sleeve used to house the UV lamp cuts out approximately 9% of the UVC light.

% Transmittance: The percent transmittance of the water indicates the degree to 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 pathogen. Typical %T values for drinking water are greater than 90%.

UV DOSE RESPONSE DATA FOR *CRYPTOSPORIDIUM* AND *GIARDIA*

As part of the development of the UVDGM (Ultraviolet Disinfection Guidance Manual), dose response data for *Cryptosporidium* and Giardia was collected and is presented in Figures 1 and 2 respectively.

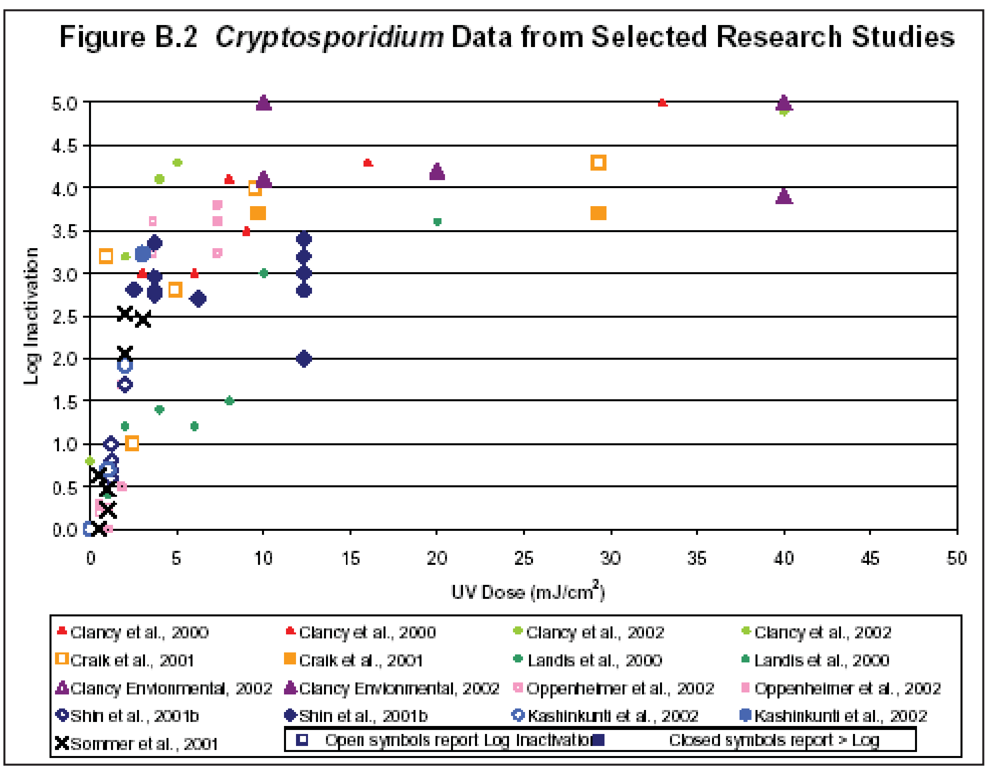

Figure 1: ***Cryptosporidium* modeled data and predictive credible intervals from the UVDGM (U.S. EPA, 2003)**

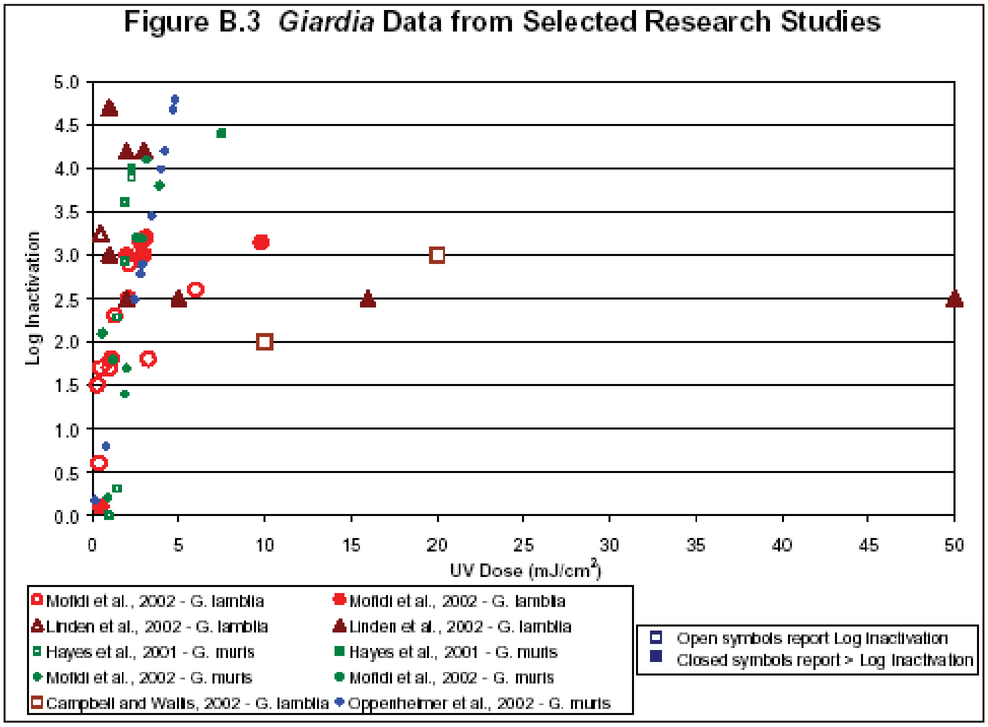

Figure 2: Giardia modeled data and predictive credible intervals from the UVDGM (U.S. EPA, 2003)

Statistical analysis of these data results in three log inactivation of *Cryptosporidium* and *Giardia* at UV doses of 12 and 11 mJ/cm^2 respectively. Doses for other log inactivation credits are given in the UVDGM as shown below. This analysis proves that UV light energy delivered at low doses is effective and economical for inactivation of pathogens such as *Cryptosporidium* and *Giardia.*

Table B.2 UV Dose Requirements for Inactivation of *Cryptosporidium*, *Giardia* and Viruses During Validation Testing

	Log Inactivation							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	-	-
Giardia	1.5	2.1	3.0	5.2	7.7	11	-	-
Virus	39	58	79	100	121	143	163	186

The dose response data presented in this table represents controlled laboratory experiments which reflect the inherent sensitivity of these microorganisms to UV radiation. In practice, the actual doses that would be applied in the treatment of drinking water will be higher to take into account safety factors that are required based on variables associated with the UV disinfection equipment and reactor validation.

REACTOR DESIGN AND VALIDATION

COMPUTATIONAL FLUID DYNAMICS

To optimize dose delivery, Calgon Carbon conducts Computational Fluid Dynamics (CFD) analysis of a reactor to simulate its performance during its development stage or if it is being installed in a drinking water plant with an unfavorable layout. The CFD analysis is performed with CFX software by ANSYS, Inc.

Flow dynamics are solved by the CFD code based on an inlet velocity profile and internal flow barriers, such as baffles and lamp sleeves. These dynamics are then coupled with the UVCalc irradiance model produced by Bolton Photosciences to simulate effective germicidal UV doses.

UVCalc simulates a germicidal fluence rate field based on DNA absorbance, lamp characteristics, water transmittance and quartz transmittance. The fluence rates from the irradiance model are interpolated onto CFD mesh nodes within the reactor model and input into the CFX material balance equations to simulate an operating reactor. The fluence rates are used as source terms in the species balance to give the UV dose within each reactor mesh element. A coupled solver is used to solve the dose balance simultaneously with a mass balance of MS2 coliphage (*Cryptosporidium* surrogate organism typically used in large scale validation) based on an assumed inactivation constant of $-0.05 cm^2/mJ$ in the following mass balance equation:

$$\frac{\partial C}{\partial t} + \nabla \bullet (UC) + \nabla \bullet (\Gamma \nabla C) = -\frac{0.05}{\log e} E' C \qquad \textbf{Equation 1}$$

Where: C = MS2 concentration in liquid phase

U = Velocity (Calculated by CFX)

Γ = MS2 Diffusion coefficient

E' = Fluence Rate

A similar equation for dose models the accumulation within each volume element due to the fluid paths and the light intensity within the reactor volume:

$$\frac{\partial H}{\partial t} + \nabla \bullet (UH) = E' \qquad \textbf{Equation 2}$$

Where: H = Dose

U = Velocity (Calculated by CFX)

E' = Fluence rate

Equation 1 uses the results of Equation 2 to determine an average inactivation of MS2 throughout the reactor by integrating the inactivation within each of the ~3,600,000 mesh elements over the entire reactor volume as shown in Figure 3.

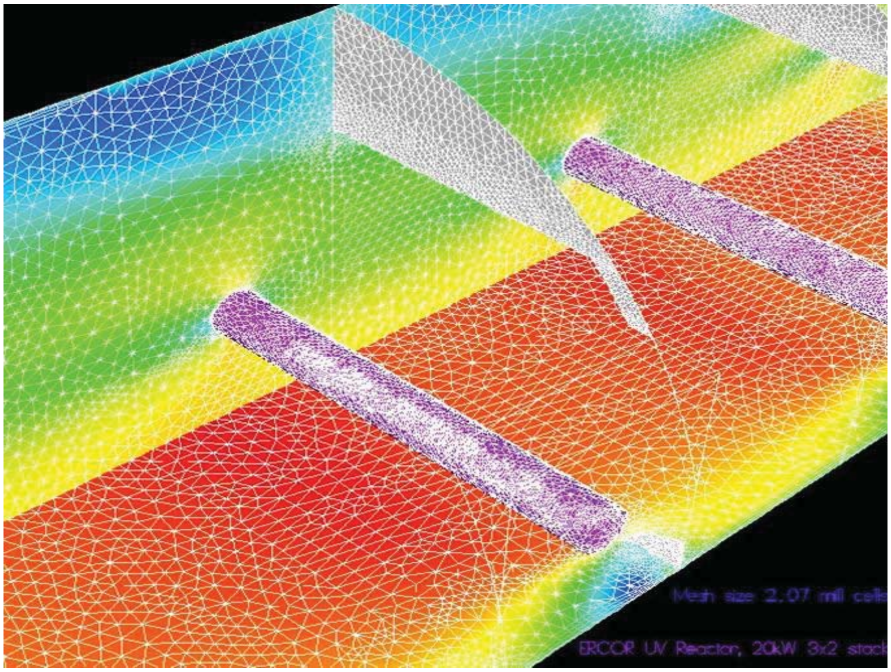

Figure 3: Typical Mesh used for CFD analysis of a UV reactor

The MS2 profile at the exit of the piping is averaged on a mass flow basis over the outlet plane to obtain an exiting MS2 concentration. The RED of MS2 is determined using this final exit concentration along with the initial input concentration (10^7 organisms/m^3) and knowledge of the inactivation kinetics.

This information can then be used to modify a reactor that is being developed to optimize the UV dose or it can be utilized to confirm that inlet conditions to a reactor are acceptable and won't prevent effective treatment. The design also takes into account the efficiency factors and design parameters described below:

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.

REACTOR VALIDATION

The LT2ESWTR requires UV systems to demonstrate that the UV reactor can deliver the required dose through validation testing to receive a credit for *Cryptosporidium*, *Giardia* and/or virus inactivation. Validation testing must determine a set of operating conditions that can be monitored by the control system to ensure that the UV dose required for a given pathogen inactivation credit is consistently delivered during the operation of the UV system. The validation must be done at full scale and take into account the following operating conditions:

- Flow rate
- UV intensity measured by a UV intensity sensor
- Lamp status
- Lamp aging
- Lamp sleeve fouling
- UV Transmittance of the water
- Inlet and outlet piping
- Dose distributions arising from the velocity profiles through the reactor
- Failure of UV lamps or other critical components
- Inactivation of the surrogate microorganisms used during validation testing
- Relative inactivation of the target organism

Validation involves the use of surrogate organisms, such as MS2 coliphage, that are added to the water stream ahead of the UV reactor along with agents that decrease the UV transmittance of the water thereby simulating waters of different quality. Effluent samples are collected at different operating conditions of UV transmittance, flow, lamp power and number of lamps. The reduction in viable organisms is used to obtain a UV dose that can be correlated with the various operating parameters to generate operating curves for the reactor at a Water Treatment Plant (WTP).

The original draft of the UVDGM provided two methods for the calculation of a validated dose using a surrogate organism to achieve an equivalent dose for target organisms (*Cryptosporidium*, *Giardia* and viruses). The two methods were called Tier 1 and Tier 2.

Tier 1 Default safety factors (to cover uncertainty in validation and operation of the equipment) and biases (to adjust for polychromatic light and for the different rate constant or dose response of the surrogate organism to the target organism) were proposed. These were intended to cover worst case validation and operating conditions and hence were intentionally set high and result in a conservative dose set-point to obtain the required log reduction credits for the target organism.

Tier 2 Safety factors and biases that are calculated based on actual validation results were proposed. If the validation is performed well and the UV reactor is designed correctly (with a UV sensor responding to the germicidal action spectra and the UV sensor correctly placed in the reactor) utilizing Tier 2 results in lower validation doses for the log reduction credits of the target organism. This can lead to significant savings for the WTP.

However, revisions to the draft UVDGM have done away with Tier 1 and Tier 2 with all reactors now bearing factors stemming from their validation results. Therefore the validated MS2 dose that is required to achieve a specified disinfection credit will not be the same for all reactors, but will be reactor specific depending on the biases associated with each actual reactor validation.

TYPICAL VALIDATION PROCEDURE FOR CALGON CARBON'S SENTINEL® UV REACTORS

Validation normally takes place at an off site facility and covers all possible operating conditions of the full-scale UV reactor. This includes UV Transmittance from the minimum expected (70/80%T) up to the maximum (95/98%T), flows from the minimum to maximum and lamp output from the minimum to maximum. Test planning includes:

- The minimum and maximum flows under which the reactor is likely to be operated
- Flow increments to ensure that intermediate flow points are also tested
- The UVT range under which the unit will perform
- The performance is modeled using CFD and other means to determine the desired dose range so that only runs that are in the target dose range are performed.

Table 1 gives a typical test matrix for a UV reactor with six lamps operating. As can be seen, at each flow and UVT, three lamp powers are tested. Those combinations that result in the RED being outside of the target range are eliminated.

Table 1: A typical test matrix for a UV reactor with six lamps operating

Test ID	No of Lamps	Flow mgd	%T	Lamp Output %	UV Sensor W/m^2	Estimated RED mJ/cm^2
92	6	16	95	70%	219	60.0
93	6	16	95	55%	172	50.4
94	6	16	95	30%	94	32.3
102	6	16	90	30%	63	22.3
101	6	16	90	65%	137	40.9
100	6	16	90	100%	210	55.6
109	6	16	85	45%	61	23.2
108	6	16	85	75%	101	34.8
107	6	16	85	100%	128	43.0
114	6	16	80	65%	57	24.3
113	6	16	80	100%	88	34.2
80	6	8	95	30%	94	53.6
1	6	8	90	55%	123	59.6
4	6	8	90	30%	67	38.5
10	6	8	85	80%	120	60.2
11	6	8	85	55%	83	46.0
12	6	8	85	30%	45	29.3
17	6	8	80	100%	95	56.5
18	6	8	80	65%	62	41.5
19	6	8	80	30%	29	22.7

Test ID	No of Lamps	Flow mgd	%T	Lamp Output %	UV Sensor W/m^2	Estimated RED mJ/cm^2
88	6	8	75	40%	24	22.9
87	6	8	75	70%	42	35.6
86	6	8	75	100%	60	46.2
90	6	8	70	100%	37	38.2
91	6	8	70	65%	24	27.4
52	6	4	85	30%	42	49.0
60	6	4	80	55%	52	60.6
62	6	4	80	30%	29	39.2
69	6	4	75	30%	18	31.7
68	6	4	75	65%	39	55.8
75	6	4	70	90%	33	58.3
76	6	4	70	60%	22	43.6
77	6	4	70	30%	11	25.7
33	6	2	75	30%	18	52.7
39	6	2	70	30%	11	43.6

The validation report is divided into five main Sections:

1. Summary
2. UV Reactor Details
3. Validation Facility and Piping Arrangement
4. Methods
5. Results and Analysis

Appendix: Has the full raw data set that could be used in checking or re-analyzing the results.

The validation results include a simple, transparent model that is used to calculate the dose as a function of Flow, UV Sensor reading and UVT in the operating system. It includes a full statistical analysis to prove conformity to the UVDGM criteria and to provide dose requirements for achieving different levels of *Cryptosporidium* and *Giardia* inactivation. Proper operation at a Water Treatment Plant can be confirmed by using the equations that correlate the data to measured operating conditions (flow, UV Sensor irradiance, UV transmittance) during validation. The plant Operator, Engineer and/or Regulator can easily check the performance using the on-line flow and certified reference UV sensors. Ultimately, validation ensures that the Calgon Carbon UV system will work to protect the public from pathogens present in drinking water such as *Cryptosporidium* and *Giardia*.

FULL SCALE INSTALLATIONS

Research data and full scale installations have confirmed that UV is an acceptable disinfection technology for encysted protozoa and viruses, and good protocols for dose validation have been developed. The U.S. EPA has promulgated the LT2ESWTR so utilities will soon be able to get credits for using UV to meet the regulations. When the UVDGM is released in 2006, everything will be in place to fully define UV system's requirements.

DESIGN CONSIDERATIONS

Water Quality: The main water quality parameters that impact UV disinfection efficacy are the presence of solids (turbidity) and the UV Transmittance (UVT) of the water. Minerals such as dissolved iron, manganese and carbonates may indirectly impact UV disinfection efficacy by precipitating out on the surface of the protective quartz sleeves and thus preventing transmission of the UV light into the water. Although turbidity is a major concern for wastewater systems and unfiltered water systems, Passantino et al. (2004) 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 Transmittance can vary greatly from site to site, and needs to be carefully considered in sizing and monitoring UV systems. Utilities considering UV disinfection should measure UVT over a variety of weather and seasonal conditions, and should design the UV system based on the 95th percentile UVT as recommended in the UVDGM. UV equipment size and operating costs vary dramatically with UVT, so detailed knowledge of the UVT of the water is critical to a successful UV operation. As important as the design UVT is the average UVT at which the system will operate. The average UVT will be most representative of the actual operating costs in the present value calculation. The average UVT will determine the power and the number of lamps operating under real life situations. These two factors will have the largest impact on the overall operating and maintenance cost.

<u>Flow Rate:</u> Both design and average flow rates should be specified to properly size the system and to determine realistic operating costs. Flow rate is the second most important operational parameter and cost variable of acquiring and operating a UV system behind UVT.

<u>Log Inactivation:</u> Under the LT2ESWTR, utilities will fall into various bins based upon raw water monitoring for *Cryptosporidium* which will determine the log inactivation credits that will be required to meet the rule. The utility will be granted credits based on the existing water treatment processes in place such as bank filtration, flocculation, and filtration. The determination of the log inactivation credits required will dictate the dose which the UV system will be required to deliver. Under the current draft of the UVDGM, Tier 1 doses for different reactors at a specific log inactivation are identical (see table below). Tier 2 doses will vary as previously noted from system to system based on the system design and validation. Generally, the application of Tier 2 doses will result in significant operating and maintenance cost savings over Tier 1 with no decrease in system performance or safety.

Table 2: US EPA Tier 1 MS2 Doses for *Cryptosporidium*, *Giardia* and virus removal

	Log Removal					
	0.5	1	1.5	2	2.5	3
Crypto	7.7	12	17	24	32	42
Giardia	7.5	11	15	23	30	40
Virus	63	94	128	161	195	231

Location: The UV system should ideally be placed after the filtration step in a plant (if any), 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 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 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 is possible then more extensive capital modifications should be considered, such as the construction of an additional building to accommodate the UV system in an optimum location.

Pressure Drop: The pressure drop across a UV system is dependent on the reactor geometry (diameter, length), the water flow rate, and the internal mixing devices used to increase the overall efficiency of the system. Care must be taken not to exceed the overall pressure drop tolerances of the plant.

Redundancy: To comply with the UVDGM/LT2SWTR, the disinfection system must have complete redundancy or a strategy must be in place to deal with a UV system failure. The utility could 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.

UV Lamps: Calgon Carbon Corporation uses medium pressure UV lamps with a guaranteed life of 5,000 hours. In general, UV lamp efficiency decreases with time, and at the end of the guaranteed lifetime, the output has decreased to 90 to 95% of the original output and they should be replaced. The Sentinel® control system gives the operator a warning when a lamp has exceeded its recommended life.

UV DOSE MONITORING AND CONTROL

Sensor Placement To operate a system solely on flow and sensor irradiance, it is important to design the reactor with a sensor position such that dose is proportional to irradiance regardless of water transmittance or lamp power/output. If sensors are placed too close to the lamps, lamp output dominates and if they are located too far away from the lamps, water UVT has the predominant impact. With the correct placement, both have an equal effect, proportional to dose as in Sentinel® UV Systems.

Standardization and Calibration of UV Sensors The German DVGW Standard W294 calls for a UV sensor design such that a regulator could show up on site with a reference sensor and insert it into a sensor well to ensure that the unit is operating in compliance with the validation parameters. A calibrated and certified reference sensor is supplied to each Calgon Carbon site and is used to check all of the on-line duty sensors. The duty and reference sensors supplied by Calgon are independently certified to conform to the DVGW standard providing additional assurance to the WTP operator and regulator that the system is operating in conformance with the validated conditions. In addition, the duty sensors can be automatically calibrated on-line. This assures that all duty sensors are reading close to each other and to the reference sensor thereby taking an additional level of uncertainty out of the operation.

Controls and Instrumentation: The Sentinel® system control and instrumentation strategy is provided in the operation manual that comes with every UV system. Some of the more important alarms include:

- UV irradiance and/or UV Dose 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

Operator Training

Operator training lasts from one to five days, depending on the complexity of the system, the operator's familiarity with UV systems 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

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.

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

West View Water installed the UV as an added treatment barrier with no change to their existing treatment process. The unit was 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 the hours of operation. Also, in the event of an alarm condition, the service technician is automatically notified.

Rossdale WTP in Edmonton, Alberta

Calgon Carbon's 36-in Sentinel® UV reactor was selected to provide disinfection at the Rossdale Water Treatment Plant (WTP) in Edmonton, Alberta. Nine Sentinel® reactors were designed to fit into the existing the filter gallery, one after each filter. Each reactor has three 10 kW medium pressure UV lamps. Due to the very restricted space, there was a need for the reactors to be mounted in a unique up-flow configuration with limited straight piping upstream and downstream of the reactors as shown in Figure 4.

The reactors were designed to achieve a 3-log *Cryptosporidium* reduction under the Tier 2 guidelines of the UVDGM at maximum design flow of the filters, 92% UV transmittance and a 70% End of Lamp Life/Fouling factor.

Because the unique piping was anticipated to create an undesirable flow distribution into the installed reactors, Calgon Carbon Corporation conducted a Computational Fluid Dynamics (CFD) analysis of the proposed reactors to simulate their performance in all the various piping configurations at the plant. The CFD analysis evaluated the effect that the various piping scenarios had on flow dynamics and the resulting reactor performance. Because performance was threatened, possible flow correction solutions were also studied. The effects of different flow-correcting baffle arrangements and their locations were assessed to maximize dose delivery.

The typical velocity profile through the UV reactor is shown in Figure 4

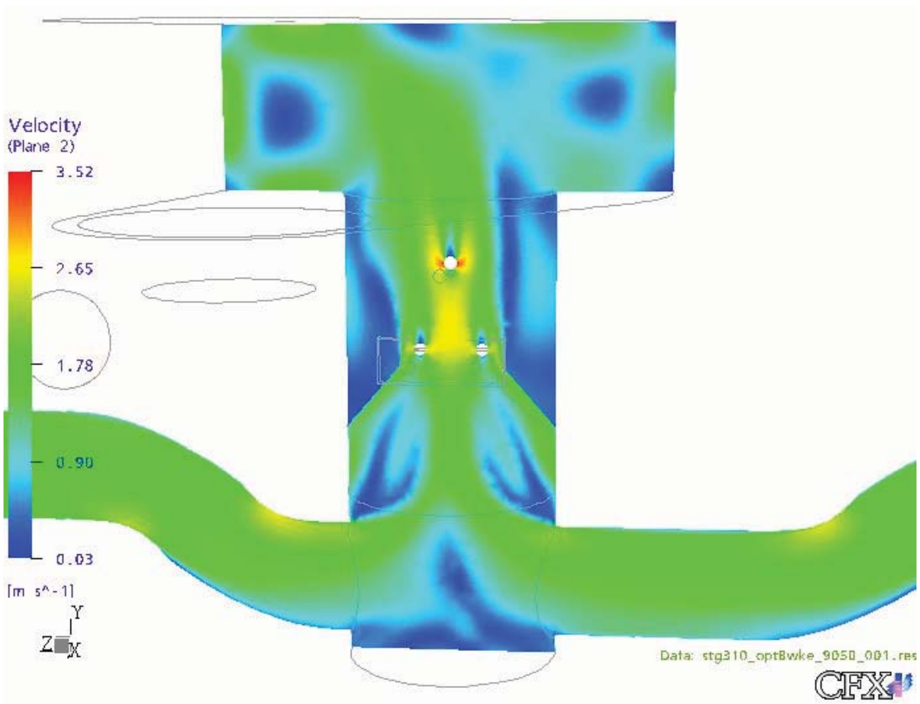

Figure 4: Velocity profile through Rossdale reactor.

The reactor performance was validated at the large-scale UV validation facility in Portland, OR, with actual piping used at the WTP. A test protocol was developed in accordance with the UVDGM that allowed interpolation of dose delivery and monitoring as a function of flow, UVT, and lamp output for measured reduction equivalent doses (RED) ranging from 17 to 69 mJ/cm^2.

Approximately 35 validation tests were performed at different lamp powers from 35 to 100%, UVT's of 86%T, 92%T and 96%T and flow from minimum to 110% of maximum design flow.

The reactor validation provided the operating equations and the UV Sensor set-point required to achieve the 3-log *Cryptosporidium* inactivation. The system was validated and installed at the WTP in 2004.

CONCLUSIONS

UV disinfection has become an accepted disinfection alternative for *Cryptosporidium* and *Giardia* in addition to viruses and bacteria. In addition, the practical aspects of applying UV are almost completely established and are currently in practice in surface water plants.

Unlike other treatment process where influent and effluent measures of a specific contaminant can be measured to assess effectiveness, this is not possible with a UV disinfection system. For this reason, the industry has turned to third party testing and proven modeling methods to increase confidence in manufacturers' claims. Specifically, the UVDGM provides an excellent method of empirically quantifying the dose delivered within a reactor.

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.

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