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which includes information on the use of ultraviolet (UV) radiation for the inactivation of *Cryptosporidium*, and a draft Guidance Manual to provide the US with direction on the proper installation and operation of UV disinfection systems.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*

Log Inactivation	CT Value (mW-sec/cm^2)
2	21
3	36

*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*

	Log Inactivation							
Target Pathogen	**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	—	—
Viruses	39	58	79	100	121	143	163	186

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[1] 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.

[1]Similar 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/cm^2 from a low-pressure high-output (LPHO) UV system or at a UV dose of 42 mJ/cm^2 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 3: Tier 1 RED Target Values

	RED (mJ/cm2) – Tier 1					
	Low Pressure / LPHO			**Medium Pressure**		
Log Credit	**Giardia**	**Crypto**	**Viruses**	**Giardia**	**Crypto**	**Viruses**
0.5	6.8	6.6	55	7.7	7.5	63
1.0	11	9.7	81	12	11	94
1.5	15	13	110	17	15	128
2.0	21	20	139	24	23	161
2.5	28	26	169	32	30	195
3.0	36	34	199	42	40	231
3.5			227			263
4.0			259			300

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/cm^2 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 UV transmittance (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.

- 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).

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 water required to validate a 3900 m^3/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 m^3/h (80 mgd) from Lake Pleasant using the design-build-operate delivery method. The new facility will utilize preoxidation with chlorine dioxide (ClO_2), 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 disinfect potable water containing *Cryptosporidium*. The patent, which covers UV doses from 10 mJ/cm^2 to 175 mJ/cm^2 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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