THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency **NSF International**

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**Ultraviolet (UV) Disinfection**	
APPLICATION:	**Secondary Effluent Treatment and Reuse**	
TECHNOLOGY NAME:	**Barrier Sunlight H-4XE-HO Open Channel UV System**	
TEST LOCATION:	**UV Validation and Research Center of New York**	
COMPANY:	**Siemens Water Technologies Corp.**	
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NSF International (NSF), in cooperation with the U.S. Environmental Protection Agency (EPA), operates the Water Quality Protection Center (WQPC), one of six centers under the Environmental Technology Verification Program (ETV). The WQPC recently evaluated the performance of the Barrier Sunlight H-4XE-HO Open Channel UV Disinfection System (4XE System), manufactured by Siemens Water Technologies Corp. The 4XE System was tested at the UV Validation and Research Center of New York located in Johnstown, NY. HydroQual, Inc. was the Testing Organization for this verification.

EPA created ETV to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The Program's goal is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

TECHNOLOGY DESCRIPTION

The following description of the Barrier Sunlight H-4XE-HO Open Channel UV (4XE) System was provided by the vendor and does not represent verified information.

The 4XE System utilizes 16 high-output, low-pressure lamps oriented horizontally and parallel to the direction of flow. The lamps are housed in two modules, each containing eight lamps. Each lamp has a UV output of approximately 60 Watts at 254nm and a total power draw of 175 Watts. The lamps are approximately 60 inches long. Each lamp is housed in a clear fused quartz sleeve to isolate and protect the lamp from the wastewater. The sleeves have only one open end, which are sealed with the lamp power cable plug. These quartz sleeves are 70 inches long, have an outer diameter of 28mm, a wall thickness of 1.5mm and a UV transmittance (UVT) of 91%. The 4XE System is equipped with automatic sleeve wiping systems, the performance of which was not verified during testing.

The lamps in the unit are powered from electronic ballasts mounted vertically in a remotely located enclosure. Each ballast powers two lamps in parallel so that one lamp failure does not cause the peer lamp to turn off. The 4XE System used for this verification was equipped with a SLS SiC004 UV intensity sensor certified to DVGW (German Technical and Scientific Association for Gas and Water) Standards. One sensor was installed on the top cover of the lamp rack, approximately 2 cm from a lamp sleeve in the top row. The sensor includes a remote, dedicated amplifier that operates on a 4-20 mA signal. The sensor has a wavelength selectivity of 96% between 200 nm and 300 nm, a linear (1%) working range of 0.01 to 20 mW/cm^2, and a stability of 5% over 10 hours and a temperature range of 2 to 30°C. The commercial unit is typically designed to operate at 100% input power (no lamp dimming).

The total intensity attenuation factor was set by Siemens for this verification at 80%, based on the combined effects of a sleeve-fouling factor of 90% and a lamp-aging factor (end-of-lamp-life factor) of 90%. This lamp-aging factor is set based on a minimum of 12,000 operating hours. The 4XE System verified in this ETV test is designed to operate at flow rates of up to 868 gallons per minute (gpm), equal to 1.25 million gallons per day (mgd).

VERIFICATION TESTING DESCRIPTION - METHODS AND PROCEDURES

The objective of this verification was to verify the performance of the system within broad operational limits, taking into account flow rate, UV sensor reading, and UV sensitivity. Information found in several sections of the USEPA *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* (2006) (UVDGM), support that operation within these limits should result in successful disinfection for the targeted organisms. The testing included measuring or calculating the following:

1. Performance difference of the system between power turndown and UVT turndown at the same operation conditions to mimic the total attenuation factor. The method that yielded the lower Reduction Equivalent Dose (RED) was selected to simulate the total attenuation factor in the verification.
2. Flow-dose relationship for the system at a nominal UVT of 50% to 80% for a dose range of 5 to 25 mJ/cm^2 using a biological surrogate with relatively high sensitivity to UV (T1 coliphage).
3. Flow-dose relationship for the system at a nominal UVT of 50% to 80% for a dose range of 10 to 40 mJ/cm^2 using a biological surrogate with medium sensitivity to UV (Qβ coliphage).
4. Flow-dose relationship for the system at a nominal UVT of 50% to 80% for a dose range of 20 to 80 mJ/cm^2 using a biological surrogate with relatively low sensitivity to UV (MS2 coliphage).
5. Adjusted observed RED performance results by a Validation Factor (VF) to account for uncertainties associated with the verification tests.
6. Power consumption and head loss.

The testing methods and procedures employed during the study were outlined in the *Verification Test Plan for the Siemens Water Technologies V-40R-A150 and HE-2E4-HO Open Channel UV Systems for Reuse and Secondary Effluent Applications* (August 2008). A full-scale 4XE System (the system model designation was changed from the HE-2E4-HO prior to the start of the ETV test) was installed in a test channel at the UV Validation and Research Center of New York (UV Center), located in Johnstown, NY. Further details on the testing procedures, analytical methodology, and QA/QC information are provided in the final report.

Biodosimetric tests were conducted at a simulated total attenuation factor of 80%, representing the combined effects of the end-of-lamp-life (EOLL) factor and the fouling factor. The total attenuation factor for the 4XE System was simulated by lowering the water transmittance. For the three nominal UVT values tested for this verification, 80%, 65%, and 50%, the actual UVT levels that were needed to include simulation of the 80% sensor attenuation were 74.5%, 60.4% and 45.8%, respectively. The reported RED is based on the collimated-beam dose-response curve generated on a seeded influent sample from the same day of testing. A total of 31 flow tests, using three different coliphage (MS2, Qβ and T1), were conducted for this ETV test. These tests were successfully completed during the verification, which resulted in development of a RED performance algorithm that described the performance of the UV system over a range of observed RED. A validation factor was determined to account for biases and experimental uncertainty that allows determination of the credited RED for various UV transmittances.

PERFORMANCE VERIFICATION

Performance verification was accomplished by determining the system's RED, the dose equivalent to that delivered by a collimated beam to achieve the same log inactivation. The biodosimetric RED data were determined as a function of flow per lamp, as presented in Figure VS-1 for each challenge phage at their respective nominal UVT levels. The bounds described by these data represent the validated operating envelope for the UV system:

Flow:	134 to 866 gpm;
Flow/Lamp:	8.37 to 54.14 gpm/Lamp;
UVT:	50 to 80%; and
Power:	100 at PLC, or 100% input (2.75 kW/16 Lamps, or 171 W/Lamp).

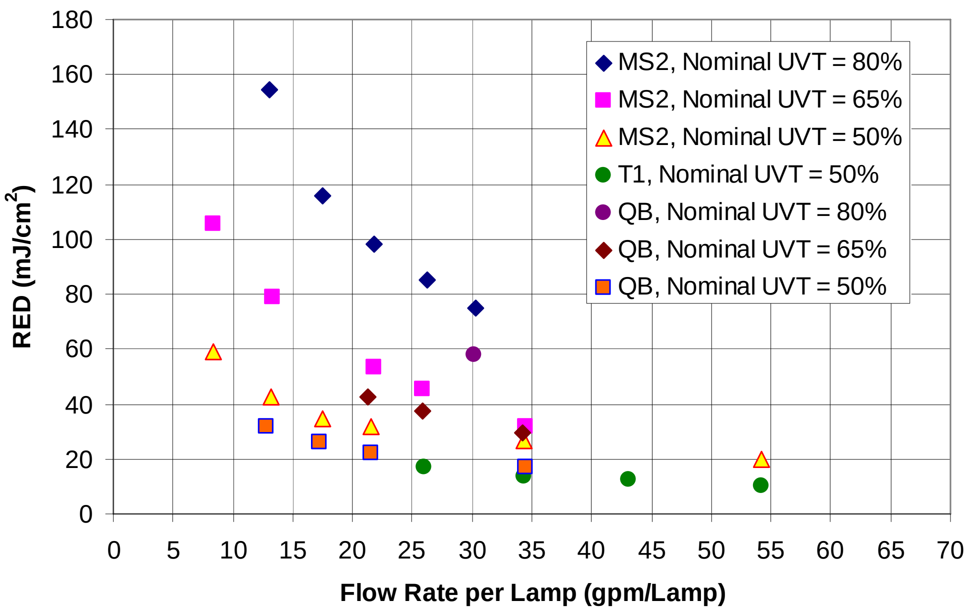

Figure VS-1. MS2, T1 and Qβ RED as a function of UVT and flow/lamp.

RED Performance Algorithm

A dose algorithm was developed to correlate the observed MS2, T1 and Qβ RED data with the reactor's primary operating variables, namely, the flow rate per lamp (Q/L) and sensor reading (S – a function of the lamp output and the UVT). In an operating system, these variables are known on a real-time basis by the PLC and can be programmed into software to monitor and control the UV system. Because multiple surrogates were used to test the system, it is possible to combine the test results and incorporate the sensitivity of each to differentiate their individual reactions at the specified operating conditions. The commissioned system can then incorporate the sensitivity of the targeted pathogen (e.g., total or fecal coliform, enterococcus, etc.) when calculating the RED delivered by the system. The dose algorithm to estimate the RED is expressed as:

$$RED = 10^{a} \cdot (Q/L)^{b} \cdot S^{c} \cdot UVS^{d}$$

Where:	Q	= Flow rate, gpm;
	L	= Number of Lamps;
	S	= Sensor Reading (%);
	UVS	= UV Sensitivity (mJ/cm^2/Log Inactivation (LI)); and
	a, b, c, d	= Equation coefficients.

It is critical to note that *the same sensors and their installed conditions, such as model type, position relative to the lamp, sleeve clarity, etc., must be used to apply this algorithm. This algorithm is valid if sensor readings are confirmed to meet the modeled results as a function of UVT and power setting.* Based on the multiple linear regression analysis of this RED equation, the coefficients were determined and are summarized in Table VS-1. The algorithm-calculated REDs versus the observed MS2, T1 and Qβ REDs are plotted in Figure VS-2. Good agreement is observed between the predicted and observed RED.

Table VS-1. H-4XE-HO (2W-1B-1C) Dose-Algorithm Regression Constants

Coefficient	a	b	c	d
Value	0.950550	-0.609884	0.683241	0.398391

Validation Factor (VF)

The Validation Factor (VF) quantitatively accounts for certain biases and experimental uncertainties to assure that a minimum disinfection performance level can be confidently maintained. VF components RED bias (B_{RED}), polychromatic bias (B_{POLY}) and validation uncertainty (U_{Val}) were assessed. B_{RED} can be set at 1.0 as long as the sensitivity of the targeted pathogen or pathogen indicator is within the range of 5 and 20 mJ/cm^2/LI (log inactivation), and the sensitivity used in the RED algorithm is equal to or less than the sensitivity of the targeted microbe. B_{POLY} is set to 1.0 because the system uses low-pressure monochromatic lamps.

Within the U_{Val}, the uncertainties associated with the sensors (U_S) and the collimated beam tests (U_{DR}) can be ignored because QA criteria were met, leaving only the uncertainty of interpolation (U_{IN}). The VF can be expressed as a function of the U_{IN}, which is related to a statistical evaluation of the verification data set. The VF reduces to the following expression as a function of the calculated RED (RED_{Calc}):

$$VF = 1 + (6.017/RED_{Calc})$$

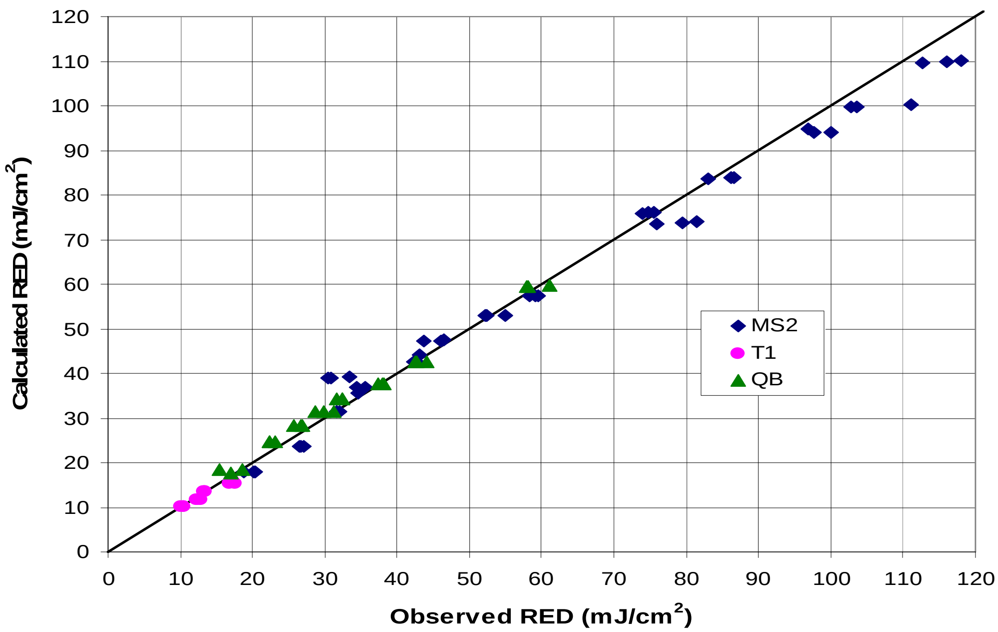

Figure VS-2. Algorithm calculated RED versus observed RED.

Figure VS-3 presents a series of solutions for VF at a UVT of 50% and sensitivities ranging between 5 and 20 mJ/cm^2/LI. The VF is shown as a function of Q/L under these specific and fixed operating conditions. Similar calculations can be made at alternate operating conditions. These calculations are appropriate only when the UVS of the targeted pathogen is equal to or greater than the sensitivity chosen for the calculations. If the sensitivity of the organism of concern is 10 mJ/cm^2/LI, then UVS must be 10 or less when conducting the calculations for the VF. However, if this is not the case, then a RED bias term, similar to that described by the UVDGM, would have to be incorporated into the validation factor.

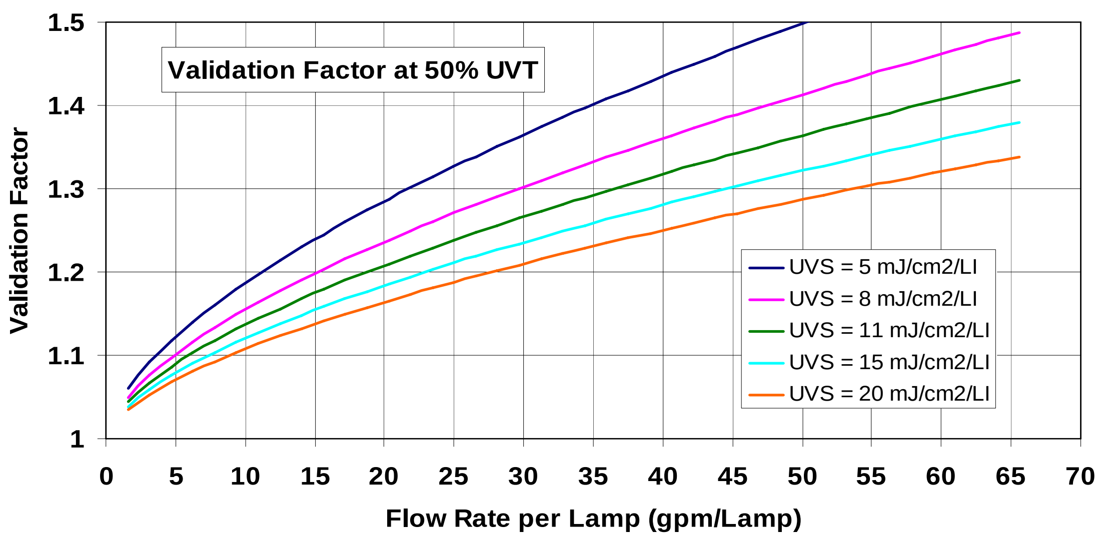

Figure VS-3. Example solutions for VF at fixed operating conditions and a range of UV sensitivities.

Credited RED Calculation

As outlined in the UVDGM, given the calculated RED results and the estimate of uncertainty associated with the experimental effort, the RED that can be applied, or credited, to the system at prescribed operating conditions can be determined. This credited RED, which is the same as RED_{Val}, is calculated as:

$$RED_{Val} = \frac{RED_{Calc}}{VF}$$

Figure VS-4 presents solutions for the 4XE System at a UVT of 50%, across the same range of UV sensitivities. Similar graphical plots can be generated by the user at alternate conditions. It is important to note that this assumes the system sensors have been confirmed to have the same output as in the validation. The solutions for credited RED (RED_{Val}), such as those shown on Figure VS-4, would be reported at the PLC of the 4XE System, based on monitored real-time operating conditions. Calculations and results for alternative UVT levels are presented in the final report, along with a design example.

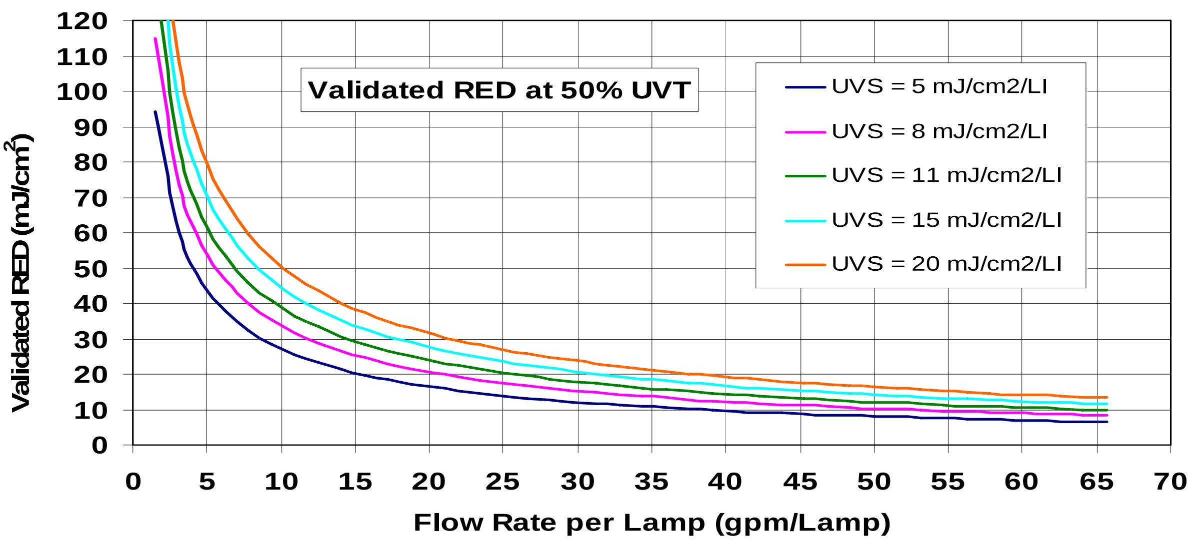

Figure VS-4. Credited RED at 50% UVT across a range of UV sensitivities.

Power Consumption

The power consumption of the Siemens H-4XE-HO (2W-1B-1C) system was continuously logged when operating. The mean total power input was 2.75 kW, or 171 W/Lamp.

Headloss

Headloss estimates were derived from the hydraulic profile data. Two pressure monitoring locations (immediately before and after the unit) were used at eight different flow rates, ranging from 0.2 to 1.26 mgd. The headloss for the unit can be estimated from the expression (should not be extrapolated outside tested range of flow rates):

$$Headloss\ (inches\ of\ water) = 3.160\ (flow,\ mgd)^2 - 0.938\ (flow,\ mgd) + 0.148$$

Velocity Profiles

Cross-sectional velocity measurements were taken at 0.2 and 0.8 mgd, short of the full flow range tested in the biodosimetry tests (0.2 to 1.25 mgd). The hydraulic conditions during validation represent a ‘worst’ case when compared to minimum full-scale commissioning requirements in the *NWRI/AWWARF Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse* (2003). Guidance states that the mean velocity at any measured cross-sectional point of a commissioned system should not vary by more than 20% from the theoretical average velocity (i.e., flow divided by the cross-sectional area). Further, the commissioned system should exhibit velocity profiles that are equivalent or better than those exhibited by the validated test unit. As such, the biodosimetry performance data can be considered conservative.

Overall, a general observation was that the velocity profiles were more variable at 0.8 mgd. The effluent measurements tended to be outside the targeted 20% range. The influent measurements at 0.8 mgd were fairly stable. At 0.2 mgd, velocity profiles were more stable, although the influent was outside of the variability guideline at the surface.

Use of Results

The data collected and verified from this testing is multi-variant and provides a flexible and detailed set of information to allow a knowledgeable engineer to design a UV disinfection system for secondary wastewater and water reuse applications. The detailed data presented in the full report is a critical component to understanding the above summary.

Quality Assurance/Quality Control

NSF completed a data quality audit of at least 10% of the test data to ensure that the reported data represented the data generated during testing. In addition to QA/QC audits performed by NSF, EPA personnel conducted an audit of NSF's QA Management Program.

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REFERENCED DOCUMENTS: The following documents were referenced in this statement:

USEPA: *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule,* EPA-815-R-06-007, 2006. Office of Water, Washington, DC.

National Water Research Institute (NWRI)/AWWA Research Foundation (AwwaRF): *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse*, Second Edition, 2003. Fountain Valley, CA.

Availability of Supporting Documents

Copies of the *Verification Test Plan for the Siemens Water Technologies V-40R-A150 and HE-2E4-HO Open Channel UV Systems for Reuse and Secondary Effluent Applications* (August 2008), the verification statement, and the verification report (NSF Report Number 09/32/WQPC-SWP) are available from:

ETV Water Quality Protection Center Program Manager (hard copy)
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NSF website: http://www.nsf.org/etv (electronic copy)
EPA website: http://www.epa.gov/etv (electronic copy)
Appendices are not included in the verification report, but are available from NSF upon request.