

# Performance Validation of a UV Reactor for High and Low Dose Applications

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## Abstract

The Siemens Barrier Sunlight V-48E-A300 was validated in conformance with a recently developed test protocol that combines and updates the objectives and methods found in established UV disinfection guidance documents, including the NWRI/AwwaRF protocol (2003), the UVDGM (2006), and the USEPA-ETV protocol (2002). The UV disinfection system was tested at full-scale at a single power input, adjusted to simulate a combined fouling and lamp aging attenuation. Testing was conducted by HydroQual at the UV Validation and Research Center of New York (UV Center), located in Johnstown, NY. A unique feature of this project was the validation of the reactor in two RED regimes: using MS2 to develop MS2 RED performance data in the range 20 to 100 mJ/cm<sup>2</sup>, and using T1 coliphage to develop T1 RED performance data in the range 10 to 25 mJ/cm<sup>2</sup>. Because multiple surrogates were used to test the system, a dose algorithm was developed to combine the observed MS2 and T1 RED data and incorporate the sensitivity of each in order to differentiate their individual reaction at the specified operating conditions. The validation factor was established as a function of the interpolation uncertainty of the dose algorithm, wherein the QA goals were met and the RED bias was set to one, based on the premise that the sensitivity of the T1 is essentially equivalent to the sensitivity of the coliform groups, which are considered the targeted microbes for such applications. The commissioned system can then incorporate the sensitivity of the targeted pathogen (e.g., total or fecal coliforms, enterococcus, etc.) when calculating the RED delivered by the system. For plant design, the targeted disinfection performance can be achieved by using a number of reactors in series, such that their summed dose delivery will meet the design dose requirement, with the assumption that the commercial reactors are identical to the test reactor in all technical specifications.

*Key words:* Biosimetry, RED, RED bias, Ultraviolet, UV, UVDGM, UV sensitivity, validation.

## Introduction

The Siemens Barrier Sunlight V-48E-A300 was validated in conformance with the recently developed draft test protocol, “Validation of UV Reactors for Application to the Disinfection of Treated Wastewaters” (2008) that combines and updates the objectives and methods found in established UV disinfection guidance documents. The “Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse” by the National Water Research Institute and the American Water Works Association Research Foundation (NWRI/AwwaRF) (2003) was used as the primary guidance for the validation protocol. The United States Environmental Protection Agency

(USEPA) “Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule” (UVDGM, November 2006), and the “Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications” by NSF International and the USEPA under the Environmental Technology Verification Program (ETV, 2002) are also important references for the test protocol.

A unique feature of this project was the validation of the reactor in two RED regimes. First, using MS2 to develop MS2 RED performance data in the range 20 to 100 mJ/cm<sup>2</sup>. The second series of tests was directed to using T1 coliphage as the surrogate, developing T1 RED performance data in the range 10 to 25 mJ/cm<sup>2</sup>. A dose calculation algorithm was developed to incorporate the sensitivity of each surrogate so that the commissioned system can then incorporate the sensitivity of the targeted pathogen (e.g., total or fecal coliforms, enterococcus, etc.) when calculating the RED delivered by the system.

## **Method and Materials**

### **Barrier Sunlight V-48E-A300 UV Disinfection System**

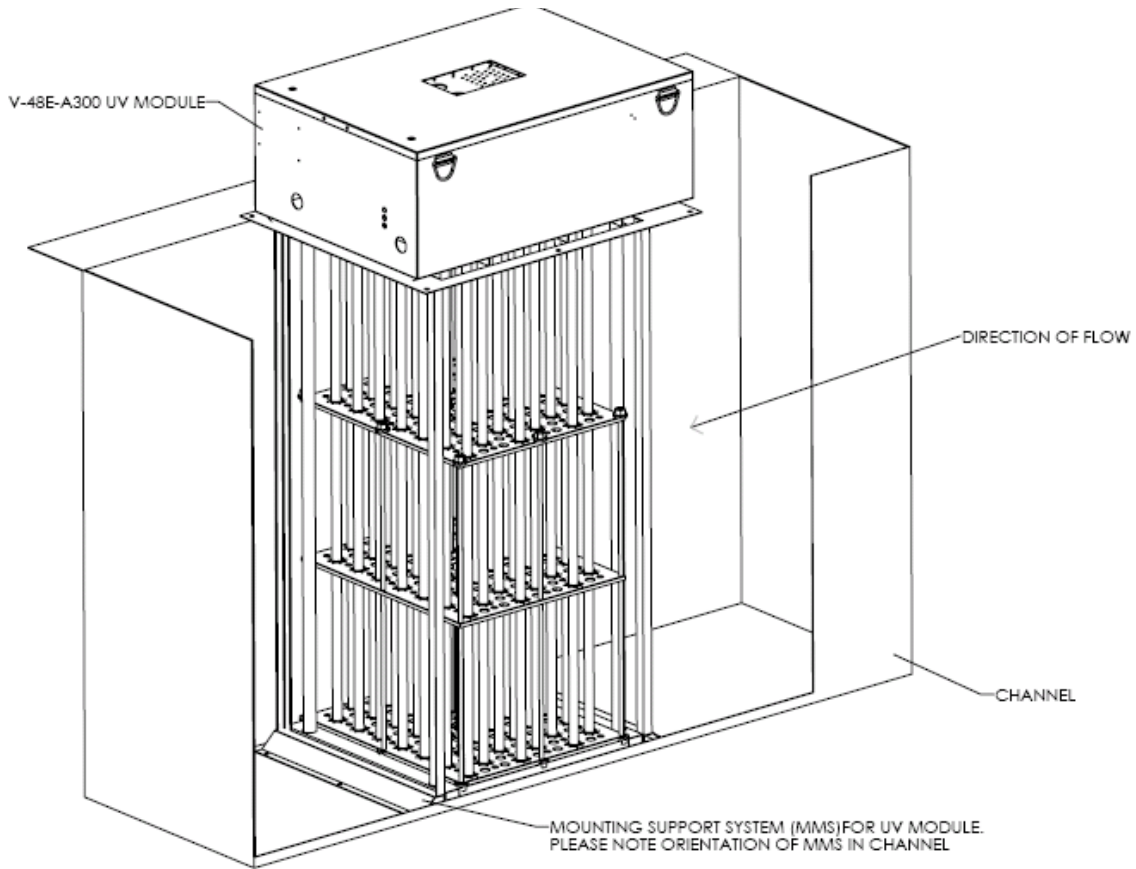
The Barrier Sunlight V-48E-A300 UV disinfection system (V-48E-A300) was tested at full-scale. A flow-spreader baffle and perforated baffle plate were positioned downstream of the inlet to simulate reactor inlet flow conditions that are representative of commercial channel design. An adjustable weir was installed downstream of the reactor to maintain a constant, prescribed water depth inside the channel. The reactor contained 48 low-pressure, high-output amalgam lamps oriented vertically in the direction longitudinal to the flow. A rendering of the system is presented in Figure 1. The validation was conducted at a single power input, adjusted to simulate a combined fouling and lamp aging attenuation of 80%. The reactor was divided into two 24-lamp sectors, each equipped with one duty UV intensity sensor. The operating strategy for the V-48E-A300 uses reactors in series and parallel that are brought into service (with 24 or 48 lamps) on demand based on flow and water quality (UVI).

### **UV Validation and Research Center**

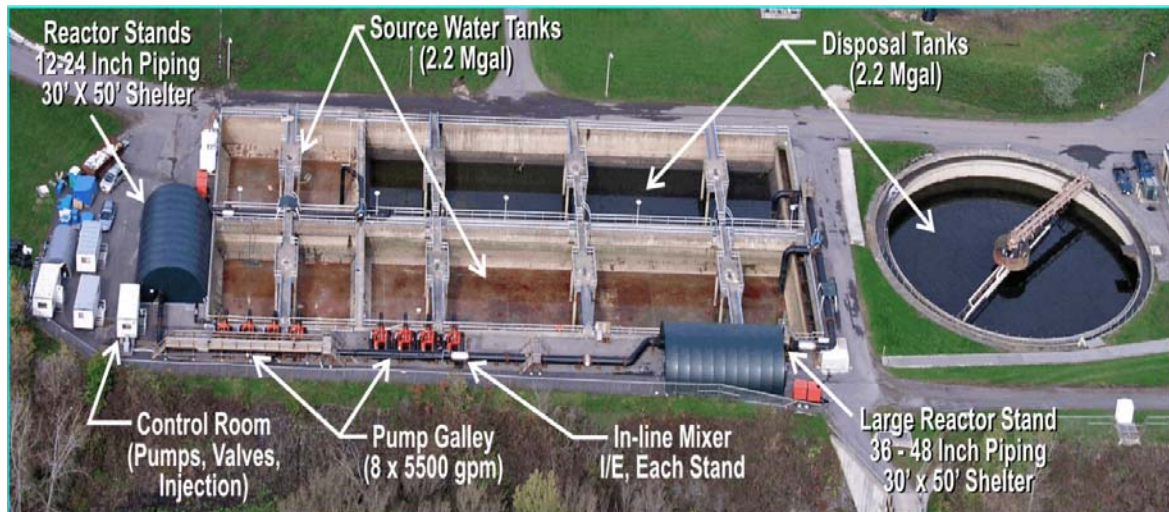
The UV Validation and Research Center of New York (UV Center) is located at the Gloversville-Johnstown Joint Wastewater Treatment Facility, Johnstown, NY. The UV Center, which is operated by HydroQual, was installed at the plant under the auspices of the New York State Energy Research and Development Authority (NYSERDA). Direct funding participation is also provided by a number of UV equipment manufacturers, including Siemens Water Technologies Corp. The facility consists of several functionally-similar test stands that are defined by the nominal size of their respective delivery piping. These range from 2-inch through 36-inch, capable of processing flows from very low gpm levels to as high as 45,000 gpm, or 65 mgd.

Figure 2 is an aerial photo of the UV Center (Scheible and Shen, 2007). The facility employs several large tanks that are used to prepare source water for challenge testing, or to accept testing effluent for disposal. The pumps and main valve actuators are controlled from a central location, which receives input from the flow meters and the manifold/effluent pressure gauges. A pre-mix system for injection of microbes, UV absorbers, or other materials is contained in the control room, which also houses a laboratory-grade double beam UV-Visible spectrophotometer, a turbidimeter, a

chlorine residual analyzer, and a pH meter. Filtered, high-quality surface waters (90 to 97% UVT at 254 nm) are delivered by the Johnstown Water Company via a local hydrant. Dechlorination is



**Figure 1. Barrier Sunlight V-48E-A300 Full-scale Test Reactor**



**Figure 2. Aerial Photo of UV Center System Installation**

achieved at the point of discharge into the source water tanks, using sodium sulfite. Lignin sulfonate was used for downward UVT adjustment. A diesel-fired generator is used on-site exclusively to power the UV test units.

The Barrier Sunlight V-48E-A300 UV disinfection unit was installed in a test channel at the UV Center, fed through the facility's 24-inch and 12-inch feed pipe test stands, serviced by up to eight diesel-powered, centrifugal pumps. Flow direction valves, up- and downstream in-line static mixers, an electromagnetic flow meter, and air-relief valves comprise key elements of the test stand, in conformance with current validation protocols. A pre-mix injection system was connected to the test stream to facilitate the addition of challenge microorganisms and water modifiers.



**Figure 3. Photo of the Installed Barrier Sunlight V-48E-A300 in Validation Test Channel**

### **Biodosimetry Testing**

The coliphage used for the biodosimetric flow tests were: MS2 (ATCC 15597-B1), and a T1 isolate from GAP EnviroMicrobial Services (London, Ontario, Canada). MS2 was grown and assayed using *E. coli* ATCC 23631 as the host organism, and T1 was assayed with *E. coli* CN13 ATCC 700609. The methodology for growth, detection and enumeration of F-specific RNA bacteriophage was based on ISO Method 10705-1 (ISO, 1995) and Appendix A of the UVDGM. All microbial propagation and enumerations were conducted at HydroQual's laboratory.

Dose-response data were acquired using field-seeded influent samples collected during the biodosimetric testing. Based on the sensitivities of different challenge phages, the maximum doses used for MS2 and T1 in dose-response characterization are 120 and 30 mJ/cm<sup>2</sup>, respectively. The

collimated beam dose was calculated using Equation C.1 in the UVDGM. Exposures were performed in triplicate.

Field biodosimetric tests for the UV system were conducted at UVT levels from 50% to 80% over the range of designed flow rates. All testing was conducted with the ballasts operating at an input power equivalent to the total intensity attenuation factor set by Siemens. This attenuation was accomplished by lamp-power turndown until the sensor was reading 80% of the sensor value observed at 100% input power. Power turndown was determined to be a more conservative approach for attenuation (yielding a lower RED), as opposed to adjusting the UVT until an equivalent sensor ratio was reached. Data were collected with all lamps in operation and with one-half the reactor in operation. The lag sector was operating when the half-reactor tests were conducted. QA/QC protocols stated in the UVDGM, NWRI/AwwaRF protocol, and ETV protocol, were strictly followed.

## Results

### Biodosimetry and Dose Calculation Equation

The MS2 and T1 biodosimetric data are presented as performance curves for the 24- and 48-lamp configurations in Figure 4 and Figure 5, respectively. A dose algorithm was developed to correlate the observed MS2 and T1 RED data with the reactor's primary operating variables. These are the number of lamps, N, the flow rate, Q, and the sensor reading, S, relative to the nominal sensor reading, S<sub>0</sub>. These variables are known on a real-time basis by the PLC and can be programmed into the software to monitor and control the UV system. Because multiple surrogates were used to test the system, the dose algorithm incorporated the sensitivity of each surrogate to estimate the RED in order to differentiate their individual reaction at the specified operating conditions. The algorithm is expressed as follows:

$$RED = 10^a \cdot \left(\frac{N}{48}\right)^b \cdot Q^c \cdot \left(\frac{S}{S_0}\right)^d \cdot UVS^e$$

Where,

- N = Number of lamps;
- Q = Flow rate, gpm;
- S = Sensor Reading (%)
- S<sub>0</sub> = Nominal Sensor Reading (%)
- UVS = UV Sensitivity (mJ/cm<sup>2</sup>/Log Inactivation)
- a, b, c, d, e = Equation coefficients.

Based on a multiple linear regression analysis in the form of the dose equation, the coefficients were determined and can be programmed into the system control panel to monitor and control the UV system. The algorithm-calculated REDs versus the observed MS2 and T1 REDs are plotted in Figure 6; good agreement is observed between the predicted and observed RED.

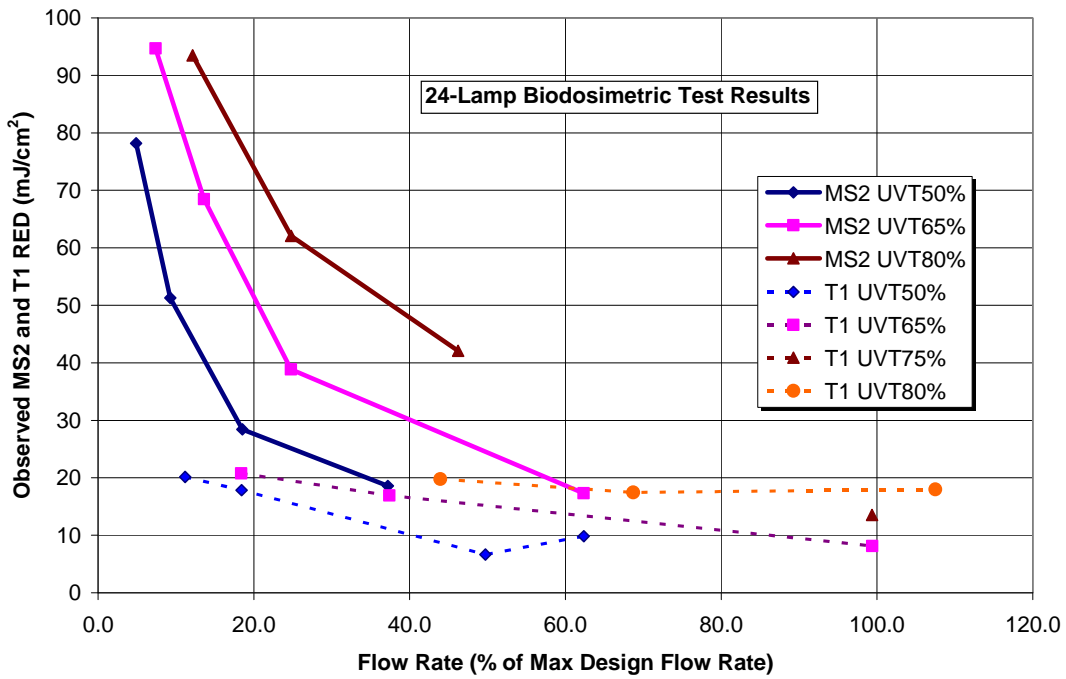


Figure 4. MS2 and T1 RED versus Flow Rate for 24-Lamp Lag Sector

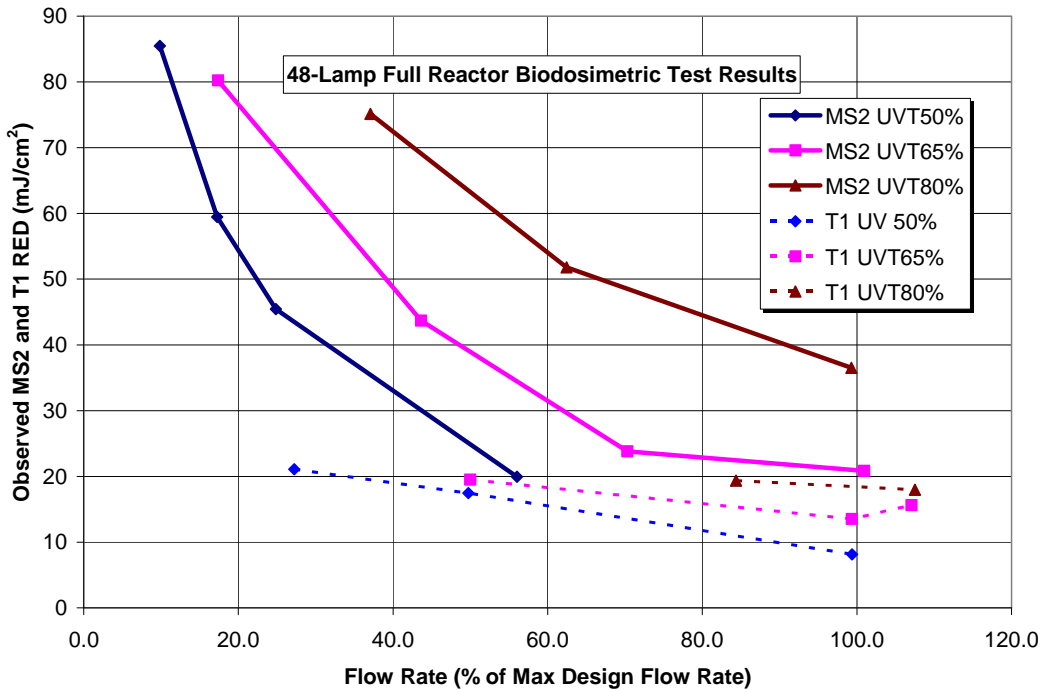


Figure 5. MS2 and T1 RED versus Flow Rate for 48-Lamp Reactor

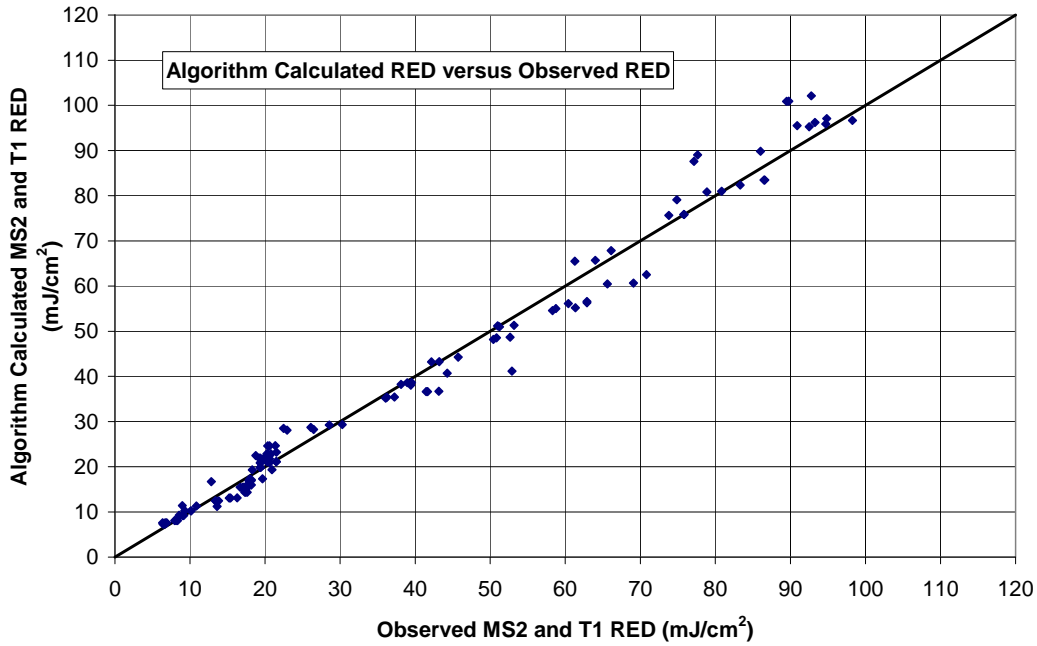


Figure 6. Algorithm Calculated versus Observed MS2 and T1 RED

### Validation Factor and Credited RED

The validation factor (VF) components  $B_{RED}$ ,  $B_{POLY}$  and  $U_{Val}$  were assessed. The RED bias,  $B_{RED}$ , 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  $mJ/cm^2/Log$  Inactivation (LI), and the sensitivity used on 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  $U_{Val}$ , 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 ( $U_{IN}$ ). With its specific elements assessed and defined, the validation factor for the Barrier Sunlight V-48E-A300 can be expressed as a function of the  $U_{IN}$ . Figure 7 presents a series of solutions for VF at a UVT of 65%, 48 lamps and sensitivities ranging between 5 and 20  $mJ/cm^2/LI$ . VF is shown as a function of flow 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. Thus, 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. The validated RED ( $RED_{Val}$ ), is then calculated as:

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

Figure 8 presents solutions for the 48-lamp configuration at a UVT of 65%, across the same range of UV sensitivity.

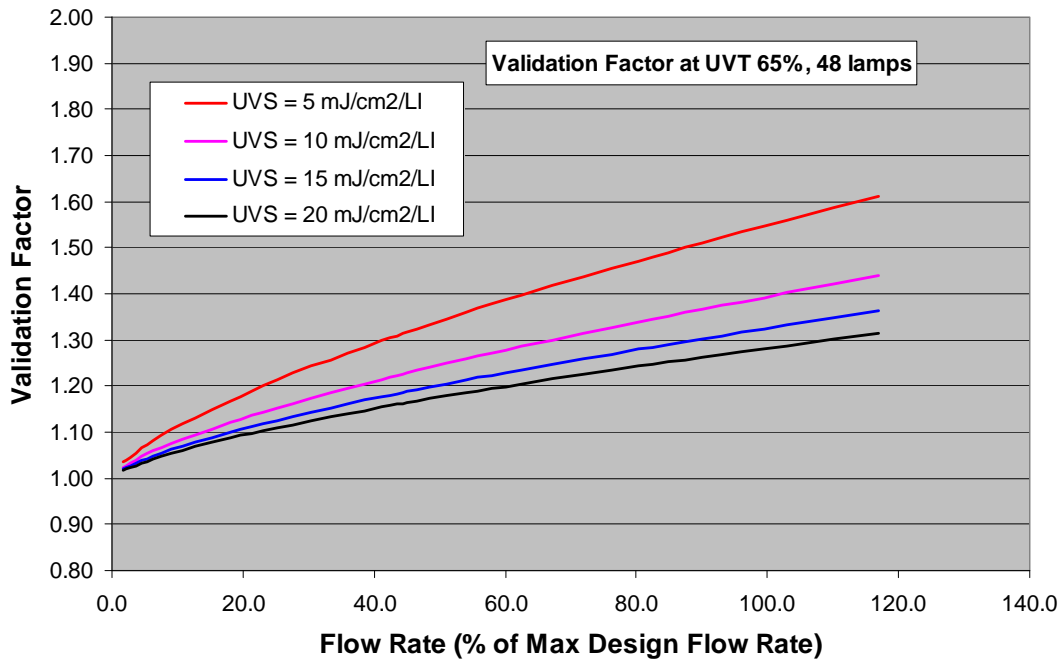


Figure 7. Example Solutions for Validation Factor at Fixed Operating Conditions and a Range of UV Sensitivity.

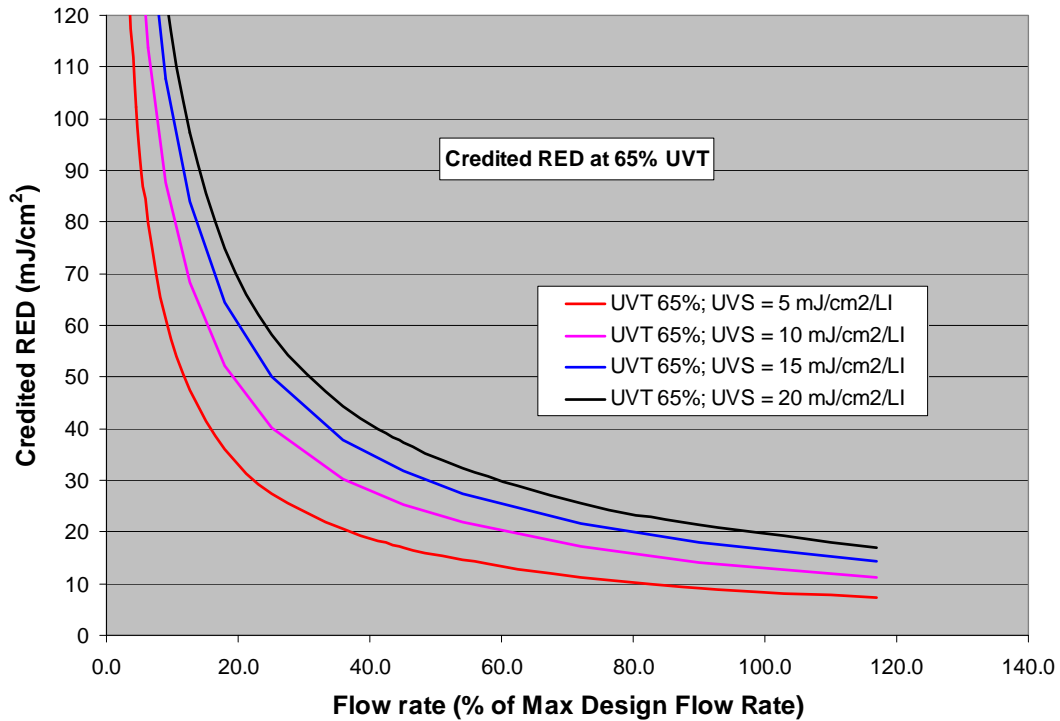


Figure 8. Credited RED at 65% UVT for a 48-Lamp System Across a range of UV Sensitivities

### Example Calculations for Sizing Barrier Sunlight V-48E-A300

The Siemens V-48E-A300 system was tested at full-scale to validate the dose delivery of commercial units. As such, the reactor dose-delivery calculated from the bioassay results can be applied directly to commercial plants without the need for any scale-up adjustments or considerations. For plant design, the targeted disinfection performance can be achieved by using a number of reactors in series, such that their summed dose delivery will meet the design dose requirement. Dose delivery by an individual V-48E-A300 can be computed by the dose algorithm developed in this validation, adjusted by the validation factor, with the assumption that the commercial reactors are identical to the test reactor in all technical specifications.

For secondary effluent disinfection, it is a “low-dose” application, directed at typical secondary effluents discharged from wastewater treatment plants. In such cases, collimated-beam measurements would be made to develop a dose-response relationship based on fecal coliforms (or other surrogate such as enterococcus, E. coli, or total coliform). An example of such site-specific dose-response data is shown in Figure 9. Taking the non-aggregated, linear portion of the dose-response curve, the UV sensitivity can be estimated. Such UV sensitivity is then incorporated into the dose algorithm to calculate solutions for  $RED_{Calc}$  as a function of flow. These must then be adjusted for the Validation Factor to estimate the credited RED,  $RED_{Val}$  as a function of flow rate. An example is presented in Figure 10. The credited RED at the design flow rate can be estimated for the UV system, and the number of commercial UV reactors required for the target dose performance can be determined.

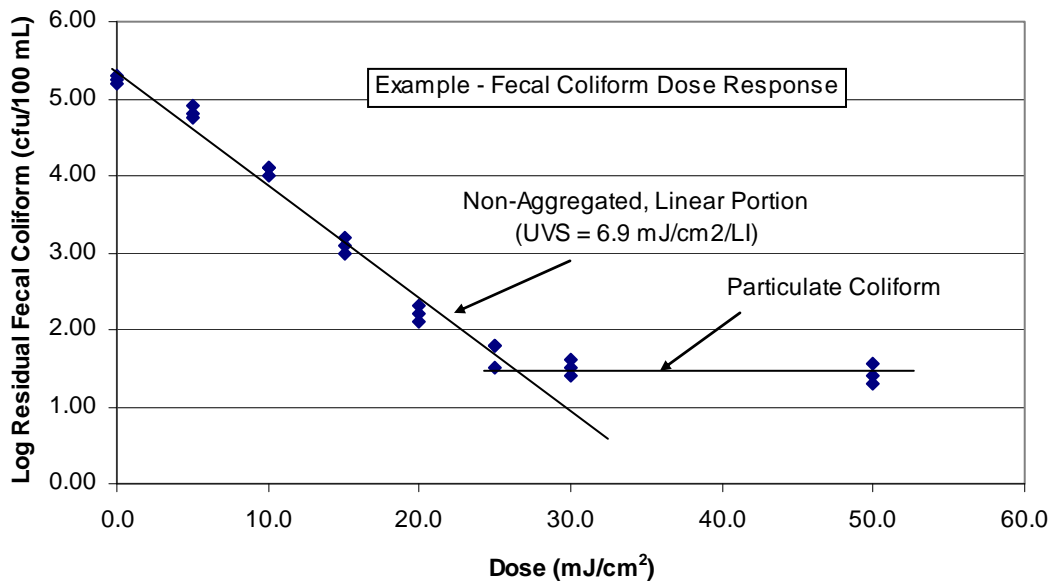
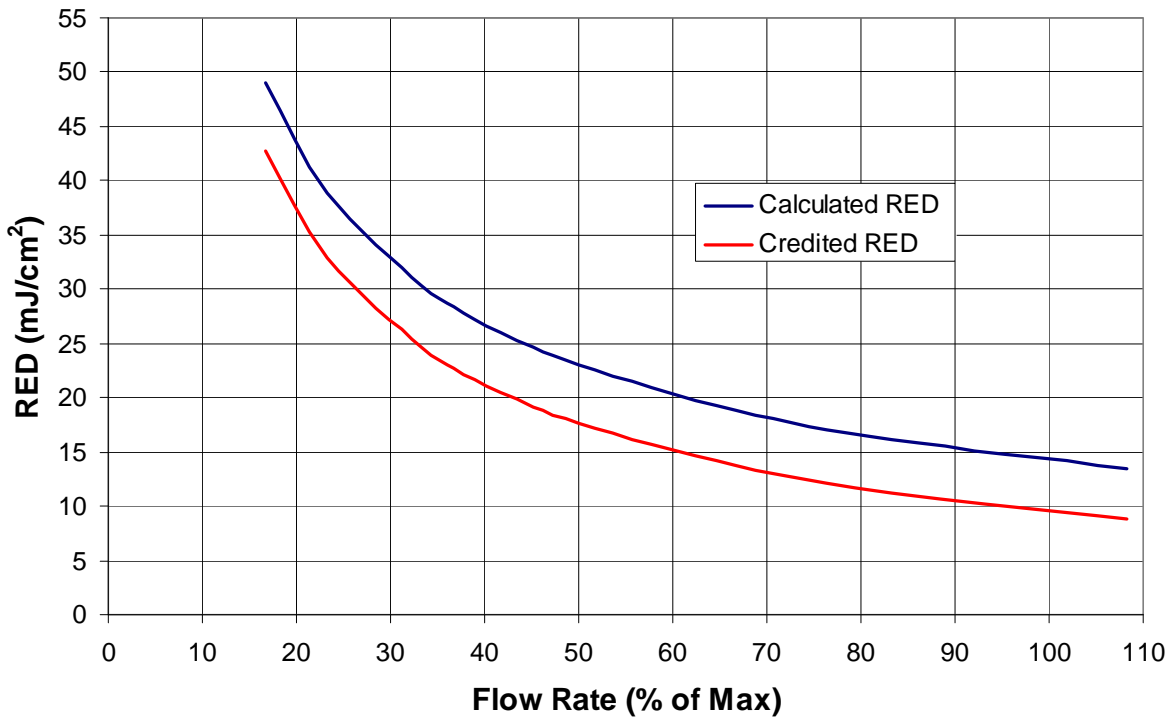


Figure 9. Example Fecal Coliforms Dose-Response Curves



**Figure 10. Example Calculation of RED as a Function of Flow at 65% UVT for a 48-Lamp Reactor in a Low-Dose Application**

For reuse applications, the performance requirement is typically to meet an MS2 RED; these are different, based on the level of upstream treatment (for example membrane filtered effluents must receive an MS2 RED greater than 80 mJ/cm<sup>2</sup>). The approach is the same as discussed above for the “low-dose” application, except that a MS2 UV sensitivity value is used.

## Conclusions

Validation of UV systems using multiple surrogates with different UV sensitivities has been conducted previously, but incorporating UV sensitivity of the challenge surrogates into the dose algorithm has not been widely practiced. The Siemens V-48E-A300 system is one of the first field-scale commercial UV systems whose dose control algorithm will incorporate UV sensitivity based on the biosimetric test data including multiple biological surrogates. UV reactors validated and evaluated through this approach can be credited a validated dose without being penalized by the RED bias defined in the UVDGM if the UV sensitivity of target pathogen is within the range of UV sensitivities used in the validation. RED bias would still need to be addressed if the target pathogen is more sensitive to UV than the challenge surrogate with highest UV sensitivity in validation testing.

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