# THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

# ETV Joint Verification Statement

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| TECHNOLOGY TYPE: | **LOW-PRESSURE ULTRAVIOLET RADIATION TECHNOLOGY USED IN DRINKING WATER TREATMENT** | |
| APPLICATION: | **INACTIVATION OF MS2 VIRUS IN DRINKING WATER** | |
| TECHNOLOGY NAME: | **MEGATRON UNIT MODEL M250** | |
| COMPANY: | **ATLANTIC ULTRAVIOLET CORPORATION** | |
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially 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; stakeholders 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.

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Systems (DWS) Center, one of six ETV Centers. The DWS Center recently evaluated the performance of a low-pressure ultraviolet radiation system used in drinking water treatment system applications. This verification statement provides a summary of the test results for the Atlantic Ultraviolet Corporation Megatron Unit Model M250. Montgomery Watson Harza (MWH), an NSF-qualified field testing organization (FTO), performed the verification testing.

## ABSTRACT

Verification testing of the Atlantic Ultraviolet Megatron M250 system was conducted over a 48-day period from 11/01/01 to 12/18/01 at the Otay Water Treatment Plant (OWTP) located in Chula Vista, California. The feedwater to the ultraviolet (UV) unit during the testing was effluent from the OWTP, which is a conventional plant with flocculation, sedimentation and dual-media filtration of Otay lake water. In the first part of the testing, microbial challenge tests were conducted on 11/14/01 at a flow rate of 350 ±10% gpm, lamp power of 100% and feed water UV-254 transmittance of 90.6%. During this experiment the log inactivation of MS2 virus ranged from 1.7 logs to 2.1 logs as shown in the following table.

**Table VS-1. MS2 Virus Seeding Summary**

| Parameter | Unit | Count | Median | Range | Average | Standard Deviation | 95% Confidence Interval |
|---|---|---|---|---|---|---|---|
| Feed MS2 conc. | pfu/100mL | 9 | 2.0E+05 | 1.6E+05 - 3.1E+05 | 2.1E+05 | 4.6E+04 | 2.0E+05 - 2.2E+05 |
| Effluent MS2 conc. | pfu/100mL | 9 | 2.4E+03 | 2.2E+03 - 3.2E+03 | 2.5E+03 | 3.7E+02 | 2.5E+03 - 2.5 E+03 |
| Log Inactivation | logs | 9 | 1.9 | 1.7 - 2.1 | 1.9 | 1.1E-01 | 1.9-1.9 |

During the second part of testing, the reactor was operated for a period of more than 27 days at a flow rate of 350 gpm ±10% and 100% lamp power setting with cleanings occurring automatically every six hours. During the first 320 hours the following operating parameters were monitored regularly: flow rate, total flow, UV sensor readings, lamp deaning frequency, lamp hours, lamp shut-down periods, system electric power consumption, operating pressure and the headloss through the UV unit. The data collected indicates that the system can operate reliably under these testing conditions. Water quality data collected from both the UV feedwater and UV effluent included: temperature, pH, total alkalinity, hardness, total organic carbon (TOC), UV-254 absorbance, turbidity, true color, nitrate, iron, free chlorine, total chlorine and Heterotrophic Plate Count (HPC). No significant change in these water quality parameters was seen from the feed water to the effluent water. It should be noted the HPC's were below the detection limit in both the feed and effluent water. The occurrence of lamp sleeve fouling was assessed at the end of the testing period by visual inspection of the lamp sleeve, which transmits UV light to the system UV irradiance sensor. Comparing the clarity of the used sleeve to that of a new sleeve revealed a white precipitate had formed along the length of the used sleeve during the testing period. Furthermore, a 35.5% increase in the UV irradiance was measured when the fouled lamp sleeve was replaced with a new lamp sleeve under similar feed water transmittance conditions. No inferences can be made regarding lamp aging over the testing period because the UV-254 transmittance was significantly higher at the end of testing than that measured in the beginning (*i.e.* new lamp). Lastly, the UV sensor drift over the entire testing period was minimal (*i.e.* ranged from 2.51% to 10.6%).


## TECHNOLOGY DESCRIPTION

The technology tested during the ETV testing was the Atlantic UV Megatron System, Model M250. The Megatron system utilizes UV light to disinfect waterborne microorganisms and is designed specifically for municipal drinking water applications. UV light is capable of disinfecting waterborne organisms including viruses, bacteria and protozoa[1]. UV light accomplishes disinfection by altering the genetic material of the microbes and thus eliminating their ability to reproduce and cause infection[2]. *Giardia* and

[1] Modifi, A., Baribeau, H., Rochelle, P., De Leon, R., Coffey, B., and Green, J. Disinfection of Cryptosporidium with Polychromatic UV Light. *Journal AWWA*, 93(6): 95-109 (2001).

[2] Jagger, J. *Introduction to Research in Ultraviolet Photobiology*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1967.

*Cryptosporidium*, two waterborne pathogens that are relatively resistant to chemical disinfection, are particularly susceptible to UV disinfection[3]. This makes the use of UV technology an attractive alternative for drinking water treatment, especially in cases where the potential for formation of disinfection by-products, from chemical disinfectants, is high. UV units are typically tested for proper performance using surrogate microbes such as MS2 virus. The estimated effective dose using MS2 virus is used as an indicator to obtain the inactivation of other microorganisms such as *Cryptosporidium* and *Giardia*.

The Atlantic Ultraviolet Megatron family of disinfection systems are reactors with low-pressure UV lamps housed in 20 mm × 22 mm quartz sleeves. Lamps are set parallel to the flow of the water and are 64-in in length. The Megatron Model M250 has a 12-in diameter stainless steel chamber. The chamber contains nineteen (19) G64T5L lamps stacked in a configuration of 3 lamps per cleaning assembly with total lamp power of 1235 W. Lamps are 1.5 inches apart. Each lamp has one power setting (100% lamp output). To control lamp fouling, the Megatron M250 unit employs an automatic wiper cleaning mechanism for each lamp in the reactor. The cleaning mechanisms are operated by pneumatic cylinders driven with compressed air. A patented Teflon wiper blade is fitted around each quartz sleeve and all wipers are driven along the length of the sleeve, at the same time. This cleaning system operates on-line while the UV reactor is in operation (providing disinfection). The cleaning mechanism can be set to run at regular intervals. The UV reactor incorporates one sensor connected to one of the nineteen lamps to monitor fouling of the quartz lamp sleeve and changes in water quality affecting system performance. The Megatron unit also incorporates a UV Guardian Monitor within its enclosure. The monitor visually indicates the level of UV energy that penetrates the quartz sleeve and the water within the disinfection chamber. Reduction of UV levels may be caused by 1) fouling of quartz sleeves, 2) decreases in ultraviolet transmission through the water, and 3) decreases in lamp output due to aging.

## VERIFICATION TESTING DESCRIPTION

### *Test Site*

The verification test site was the City of San Diego's Aqua 2000 Research Center located at the Otay Water Treatment Plant, 1500 Wueste Road, Chula Vista, California. The Research Center includes an office and lab trailer, a covered test pad, and a dedicated operations staff with substantial experience. The source water for testing was Otay Lake water. Otay Lake receives water from natural runoff. In addition, Otay Lake can receive diversions from other reservoirs and the San Diego Aqueduct system, when needed.

### *Methods and Procedures*

After an initial operations period of approximately 2 weeks to establish operating conditions, the unit was operated for approximately 30 days with all tasks being conducted concurrently. The objective of Task 1 was the characterization of the UV technology in terms of efficiency and reliability using the OWTP effluent as the feedwater to the UV unit. The goal of this task was to operate the unit continuously for 320 hours or more. The following operating parameters were monitored regularly during this task: flow rate, total flow, UV sensor readings, lamp cleaning frequency, lamp hours, lamp shut-down periods, lamp electric power consumption, temperature of influent and effluent water, operating pressure and headloss through the UV unit. The objective of Task 2 was the characterization of the UV system feedwater and effluent. The following water quality parameters were sampled from both the UV feedwater and effluent:

[3] Bukhari, Z., Hargy, T.M., Bolton, J.R., Dussert, B., and Clancy, J.L. *Inactivation of Cryptosporidium parvum Oocysts using Medium Pressure Ultraviolet Light*. AWWA AC/E, Dallas, Texas, June 1998.

temperature, pH, total alkalinity, hardness, TOC, UV-254 absorbance, turbidity, color, nitrate, iron, free chlorine, total chlorine and HPC. Turbidity, pH and chlorine residuals were analyzed at an onsite laboratory. All other parameters were analyzed by City of San Diego water quality and microbiology laboratories, which are state-certified laboratories. All analyses were conducted using Standard Methods[4] and EPA Methods[5].

The objective of Task 3 was to evaluate the UV unit in terms of lamp fouling and cleaning efficiency. During this task, all parameters of Tasks 1 and 2 were monitored. In addition, UV sensor readings before and after cleaning, and changes in UV sensor readings that might indicate lamp fouling, lamp aging or sensor fouling were monitored.

Task 4, the inactivation of microorganisms by the UV system, was conducted on 11/14/01, prior to Tasks 2 and 3. Task 4 was conducted at a flow rate of 350 gpm (79.5 $m^3$/hr) ± 10%, and a lamp power setting of 100%. These conditions were selected based on the manufacturer's estimate that such conditions could produce a 2 log reduction of the challenge organism, MS2 virus. MS2 virus was selected as the challenge species because it is not a human pathogen[6] and is more resistant to UV light than *Giardia* and *Cryptosporidium*[7]. MS2 was continuously added to the UV feedwater to produce a concentration of approximately 4 to 5 logs MS2 /L. During Task 4, the 2.5 mg/L combined chlorine residual in the OWTP effluent was quenched, before virus addition, using sodium metabisulfite. After passing through the UV unit, sodium hypochlorite was added to inactivate any remaining MS2 virus before discharging the effluent. A set of negative control samples was collected with the UV lamps turned off, to confirm the absence of MS2 virus in the feedwater. Three challenge experiments were conducted. In each, three feed samples and three effluent samples were collected. A fourth set of samples was collected with the UV lamps turned off to demonstrate the inactivation of the challenge organism was due only to the UV light. A 1-2 liter sample of dechloraminated feedwater was collected for conducting collimated beam tests. The collimated beam test was performed by exposing samples of the UV feedwater containing MS2 virus to UV doses ranging from 20 to 145 millijoules per square centimeter (mJ/$cm^2$) using a collimated beam apparatus. The feed water samples used in the collimated beam testing were sampled during the full-scale challenge testing and the MS2 virus was acquired from same stock supply as that used during the full scale challenge testing. The dose-response curve generated from the collimated beam data served as a quality control check of the batch of MS2 virus used as the seed stock during the flow-through reactor challenge study.

The objective of Task 5 was a data management plan to ensure the accurate collection, transmission and compilation of all data generated during the ETV testing. The plan developed allowed for the tracing of all data from final report figures or summary tables to handwritten data collection form. Task 6 details the quality assurance and quality control (QA/QC) procedures followed during the ETV testing. These procedures ensure the defensibility of all operational and analytical results presented in the ETV report.

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[4] APHA, AWWA, and WPCF, *Standard Methods for the Examination of Water and Wastewater*. 18th Edition, Washington D.C., 1992.

[5] U.S. Environmental Protection Agency, *Methods for the Determination of Metals in Environmental Samples - Supplement 1*, EPA-600/R-94-111, May 1994, EPA 200.8 rev.5.4 and U.S. Environmental Protection Agency, *EPA Methods for the Determination of Inorganic Substances in Environmental Samples*, Method 300.0, part A, EPA/600/R-93/100.

[6] Havelaar, A.H., et al, "Inactivation of Bacteriophage MS2 in Wastewater Effluent with Monochromatic and Polychromatic Ultraviolet Light", Water Res., vol. 24, no. 11, pp. 1387-1393 (1990).

[7] Stolarik, G., Christie, D., Prendergast, R., Gillogly, T., and Oppenheimer, J. "Long Term Performance and Reliability of a Demonstration-Scale UV Reactor." *In Proceedings of the first IUVA International Congress*, Washington D.C., 2001.

## VERIFICATION OF PERFORMANCE

### *System Operation*

Verification testing was conducted under manufacturer specified operating conditions. Accordingly, the system was operated at 350 ± 10% gpm during the entire testing period including the virus seeding experiments. The lamp power was 100% throughout the testing period and the lamps were cleaned four times per day at set times. The system ran for more than 700 hours under these operating conditions between 11/14/01 and 12/18/01. During the first 320 hours the following operating parameters were monitored regularly: flow rate, total flow, UV sensor readings, lamp cleaning frequency, lamp hours, lamp shut-down periods, lamp electric power consumption, operating pressure and head loss through the UV unit. The data collected indicates that the system can operate reliably under the testing conditions. Water quality data collected from both the UV feedwater and UV effluent included: temperature, pH, total alkalinity, hardness, total organic carbon (TOC), UV-254 absorbance, turbidity, color, nitrate, iron, free chlorine, total chlorine and HPC. No significant change in these water quality parameters was observed from the feed water to the effluent water. The results are summarized in the following table:

**Table VS-2. Summary of General Water Quality Parameters**

| Parameter | Unit | Count | Median | Range | Average | Standard Deviation | 95 Percent Confidence Interval |
|---|---|---|---|---|---|---|---|
| **Feed** | | | | | | | |
| Alkalinity | mg/L as $CaCO_3$ | 6 | 127 | 111 - 137 | 125 | N/A | N/A |
| Total Hardness | mg/L as $CaCO_3$ | 6 | 228 | 212 - 259 | 233 | N/A | N/A |
| Calcium Hardness | mg/L as $CaCO_3$ | 6 | 163 | 150 - 203 | 171 | N/A | N/A |
| Iron | µg/L | 6 | 50 | 50 - 57 | 51 | N/A | N/A |
| Managanese | µg/L | 6 | 0.6 | 0.5 - 1.8 | 0.9 | N/A | N/A |
| Nitrate | mg/L | 6 | 0.57 | 0.41-0.89 | 0.60 | N/A | N/A |
| TOC | mg/L | 16 | 3.70 | 2.28-4.56 | 3.57 | 0.70 | 3.23-3.91 |
| Color | Pt-Co | 6 | 3 | 1-3 | 2 | N/A | N/A |
| $UV_{254}$ | 1/cm | 17 | 0.059 | 0.042 - 0.068 | 0.057 | 0.008 | 0.054-0.061 |
| pH | std. Unit | 34 | 8.3 | 7.6-8.6 | 8.3 | 0.2 | 8.3-8.4 |
| Desktop Turbidity | NTU | 34 | 0.10 | 0.10-0.15 | 0.10 | 0.02 | 0.10 - 0.10 |
| Temperature | degC | 34 | 19.1 | 17.3 - 20.5 | 19.0 | 1.0 | 18.7 - 19.3 |
| Free Chlorine | mg/L | 34 | 0.14 | [1] 0.07 - 3.20 | 0.24 | 0.53 | 0.06-0.41 |
| Total Chlorine | mg/L | 34 | 2.36 | 1.56 - 3.34 | 2.29 | 0.37 | 2.17-2.42 |
| **Effluent** | | | | | | | |
| Alkalinity | mg/L as $CaCO_3$ | 6 | 136 | 110 - 141 | 131 | N/A | N/A |
| Total Hardness | mg/L as $CaCO_3$ | 6 | 226 | 218 - 275 | 238 | N/A | N/A |
| Calcium Hardness | mg/L as $CaCO_3$ | 6 | 153 | 142 - 196 | 158 | N/A | N/A |
| Iron | µg/L | 6 | 50 | 50 - 85 | 56 | N/A | N/A |
| Managanese | µg/L | 6 | 0.6 | 0.5 - 3.0 | 1.1 | N/A | N/A |
| Nitrate | mg/L | 6 | 0.57 | 0.41-0.89 | 0.60 | N/A | N/A |
| TOC | mg/L | 17 | 3.71 | 2.19-4.20 | 3.52 | 0.68 | 3.20-3.84 |
| Color | Pt-Co | 6 | 3 | 2-4 | 3 | N/A | N/A |
| $UV_{254}$ | 1/cm | 17 | 0.060 | 0.044 - 0.076 | 0.061 | 0.009 | 0.056-0.065 |
| pH | std. Unit | 34 | 8.3 | 7.4 - 8.7 | 8.3 | 0.2 | 8.2 - 8.4 |
| Desktop Turbidity | NTU | 34 | 0.10 | 0.10-0.15 | 0.10 | 0.02 | 0.10 - 0.10 |
| Temperature | degC | 34 | 19.2 | 17.3 - 20.6 | 19.1 | 1.0 | 18.7-19.4 |
| Free Chlorine | mg/L | 34 | 0.11 | [1] 0.05 - 2.68 | 0.19 | 0.44 | 0.04-0.34 |
| Total Chlorine | mg/L | 34 | 2.34 | 1.66 - 3.14 | 2.25 | 0.29 | 2.16-2.35 |

[1] Free chlorine ranges include meaurements (feed = 3.20 mg/L; effluent = 2.68 mg/L) taken on 11/20/01 during a plant upset.
Note: All calculations with below detection limit values used the detection limit value in the calculation as a conservative estimate.
N/A - indicates parameters were not calculated because less than 8 samples were collected during testing period.

Continuous monitoring of the UV irradiance indicated that the UV irradiance increased and decreased with changes in UV-254 feed water concentration throughout the testing period. The occurrence of lamp

sleeve fouling was verified at the end of the testing period by visual inspection of the lamp sleeve, which transmits UV light to the system UV sensor. Comparing the clarity of the used sleeve to that of a new sleeve revealed a white precipitate had formed on the used sleeve during the testing period. Furthermore, a 35.5% increase in the UV irradiance was measured when the fouled lamp sleeve was replaced with the new lamp sleeve under similar feed water transmittance conditions. No inferences can be made regarding lamp aging over the testing period because the UV-254 transmittance was significantly higher at the end of testing than that measured in the beginning (*i.e.* new lamp). Lastly, the UV sensor drift over the entire testing period was minimal (*i.e.* ranged from 2.51% to 10.6%).

***Microbial Inactivation Results***

To demonstrate the microbial inactivation ability of the Atlantic Megatron 250 System, one collimated beam test and one set of seeding experiments were conducted with MS2 virus on 11/14/01. The collimated beam test was conducted on the same day as the seeding tests with water collected during the same time period. This test was performed to determine the UV sensitivity of the microbial cultures used in the seeding experiment. A dose response curve was constructed based on the results of the collimated beam test. It should be noted that results of the test indicated that the inactivation values at doses of 70 and 95 $mJ/cm^2$ were indeterminate due to over dilution of the irradiated samples during laboratory analysis. Analysis of this collimated beam data indicates the results do not meet the quality control criteria outlined in the NWRI Ultraviolet Disinfection Guidance Manual[8]. As a result, the dose response curve generated from the collimated beam data was not used to predict the effective dose achieved during the flow through reactor challenge study. Alternatively, the range of effective dose achieved during the Atlantic flow through reactor challenge testing was estimated from collimated beam data generated during a similar UV ETV study conducted by the project team on 9/14/01 (Refer to Section 4.5 of ETV Report). The effective dose achieved during the Atlantic flow through challenge testing is estimated to have ranged from 35.5 to 45.5 $mJ/cm^2$. The MS2 seeding was conducted at a flow rate of 350 ±10% gpm, lamp power of 100% and feed water UV-254 transmittance of 90.6%. During the three challenge experiments, the feed MS2 virus concentration ranged from $1.6 \times 10^5$ plaque forming units (pfu)/100mL to $3.1 \times 10^5$ pfu/100mL, while the effluent MS2 concentration ranged from $2.2 \times 10^3$ pfu/100mL to $3.2 \times 10^3$ pfu/100mL. The microbial inactivation observed during the challenge tests ranged from 1.7 to 2.1 logs. No inactivation was observed during the positive control tests with lamps off.

***Operation and Maintenance Results***

The UV system was operated with a factory setting of 100% lamp power and cleanings were performed automatically every six hours. An automatic wiper controller provided on the system was programmed to initiate the automatic cleaning mechanism of the system daily at the following times: 4:00, 10:00, 16:00 and 22:00. The system was also cleaned periodically by manually activating the wiper controller to test that the cleaning system was functioning properly. The "UV Low" alarm set point was established at the beginning of the testing to be 4.0 $mW/cm^2$. On several occasions throughout the testing period the "UV Low" indicator was observed to illuminate a red light, indicating the irradiance fell below the set point. It was also observed that the light would turn off once the UV irradiance reached a value above the "UV Low" set point at which time the "UV Normal" indicator would illuminate a green light. Lastly, the "Lamp Out Indicator Array" provided on the system was checked during each day of testing to verify that each germicidal lamp or ballast was functioning properly. At no time during the testing did any of the LED's indicate a faulty lamp or ballast. The system power usage, based on data collected during the verification testing period, was 0.053 kWh/1000 gallons at a flow rate of 350 gpm and 100% lamp power.

[8] NWRI, AWWARF. Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, December 2000.

Small amounts of alcohol and/or acid were used throughout the testing period to manually wipe the small quartz sensor window contained within the UV irradiance sensor provided with the system. It should be noted the occurrence of fouling of the UV irradiance sensor window affects the amount of UV irradiance measured by the UV irradiance sensor and therefore may result in underestimating the actual delivered dose. Because the UV irradiance sensor must be removed to wipe the window the manufacturer is planning to modify the Megatron M250 disinfection system to allow for a quick, easy method of removing and replacing the UV irradiance sensor. The manufacturer also provided an Operations and Maintenance manual that was helpful in explaining the setup, operation and maintenance of the ETV test system.

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| *Original Signed by Clyde Dempsey for E. Timothy Oppelt* | *7/9/02* | *Original Signed by Gordon Bellen* | *7/15/02* |
| E. Timothy Oppelt | Date | Gordon Bellen | Date |
| Director | | Vice President | |
| National Risk Management Research Laboratory | | Federal Programs | |
| Office of Research and Development | | NSF International | |
| United States Environmental Protection Agency | | | |



**Availability of Supporting Documents**

Copies of the *ETV Protocol for Equipment Verification Testing for Inactivation of Microbiological Contaminants,* dated August 9, 1999, the Verification Statement, and the Verification Report (NSF Report #02/04/EPADWCTR) are available from the following sources:
(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

1. Drinking Water Systems ETV Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. NSF web site: http://www.nsf.org/etv/dws/dws_reports.html and from http://www.nsf.org/etv/dws/dws_project_documents.html (electronic copy)
3. EPA web site: http://www.epa.gov/etv (electronic copy)