Environmental Technology Verification Report

Inactivation of MS2 Virus in Drinking Water

Atlantic Ultraviolet Corporation
Megatron Unit, Model M250
Chula Vista, California

Prepared by

NSF International

Under a Cooperative Agreement with

EPA U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

⊛EPA
U.S. Environmental Protection Agency

NSF
NSF International

ETV Joint Verification Statement

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.

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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

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[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.

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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:

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[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.

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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) $\pm$ 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.

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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

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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 1.6×10^5 plaque forming units (pfu)/100mL to 3.1×10^5 pfu/100mL, while the effluent MS2 concentration ranged from 2.2×10^3 pfu/100mL to 3.2×10^3 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.

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

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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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for E. Timothy Oppelt   *7/9/02*

E. Timothy Oppelt   Date
Director
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Original Signed by
Gordon Bellen   *7/15/02*

Gordon Bellen   Date
Vice President
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NSF International

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report is not a NSF Certification of the specific product mentioned herein.

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)

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Environmental Technology Verification Report

Inactivation of MS2 Virus in Drinking Water

Atlantic Ultraviolet Corporation Megatron System Model M250
Chula Vista, California

Prepared for:

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Prepared by:

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Notice

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for the NSF International (NSF) and the United States Environmental Protection Agency (EPA) by MWH in cooperation with Atlantic Ultraviolet Corporation. The test was conducted in November and December 2001 at the Aqua 2000 Research Center in Chula Vista, California.

Throughout its history, the EPA has evaluated the effectiveness of innovative technologies to protect human health and the environment. The ETV Program has been instituted to verify the performance of innovative technical solutions to environmental pollution or human health threats. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. Verifiable, high quality data on the performance of new technologies are made available to regulators, developers, consulting engineers, and those in the public health and environmental protection industries. This encourages more rapid availability of approaches to better protect the environment.

The EPA has partnered with NSF, an independent, not-for-profit testing and certification organization dedicated to public health, safety and protection of the environment, to verify performance of small drinking water systems that serve small communities under the Drinking Water Systems (DWS) ETV Center. A goal of verification testing is to enhance and facilitate the acceptance of small drinking water treatment equipment by state drinking water regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF will meet this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTO) to conduct verification testing under the approved protocols.

The ETV DWS Center is being conducted by NSF with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, Cincinnati, Ohio. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

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Abbreviations and Acronyms

°C	Celsius degrees	mg/L	Milligram(s) per liter
CDHS	California Department of Health Services	min	Minute(s)
		mJ	MilliJoules
CFD	Computational Fluid Dynamics	mL	Milliliter(s)
cfu	Colony forming unit(s)	Mn	Manganese
cm	Centimeter	MPN	Most probable number
cm^2	Square-centimeter	NO_3	Nitrate
d	Day(s)	Nm	Nanometer
DOC	Dissolved organic carbon	NSF	NSF International (formerly known as the National Sanitation Foundation)
DBP(s)	Disinfection byproduct(s)		
DWS	Drinking Water System		
EPA	Environmental Protection Agency	NTU	Nephelometric turbidity unit(s)
		OWTP	Otay water treatment plant
ESWTR	Enhanced Surface Water Treatment Rule	PCo. CU	Platinum Cobalt Color Units
		PE	Performance evaluation
ETV	Environmental Technology Verification	pfu	Plaque forming units
		PLC	Programmable logic controller
ft^2	Square foot (feet)	PSTP	Product Specific Test Plan
FTO	Field Testing Organization	psi	Pound(s) per square inch
gpm	Gallon(s) per minute	QA	Quality assurance
Hp	Horsepower	QC	Quality control
HPC	Heterotrophic Plate Count	RPM	revolutions per minute
hr	Hour(s)	RPD	relative percent difference
HRT	Hydraulic Retention Time	sec	Second(s)
Hz	Hertz	SWTR	Surface Water Treatment Rule
ICR	Information Collection Rule	T	Temperature
IL	Intensity light	TC	Total coliform bacteria
In	Inches	TDS	Total dissolved solids
in Hg	Inch(es) of Mercury	TOC	Total organic carbon
kg	Kilogram(s)	TSS	Total suspended solids
kW	Kilowatts	UV-254	Ultraviolet light absorbance at 254 nanometers
L	Liter(s)		
lb	Pounds	UV	Ultraviolet
m^2	Square meter(s)	V	Volt
m^3/d	Cubic meter(s) per day	W	Watt
mgd	Million gallons per day		

Acknowledgements

Chapter 1
Introduction

1.1   Environmental Technology Verification (ETV) Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the 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 testing (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 12 technology areas under ETV. This DWS Center evaluated the performance of the Atlantic Ultraviolet Corporation (Atlantic) Megatron ultraviolet (UV) radiation system Model M250 used in drinking water treatment system applications. The evaluation was performed to assess the level of log inactivation of MS2 virus in a filtered water with a transmittance of $85 \pm 3\%$ and a turbidity less than 5 NTU when operated at approximately 350 gpm (0.5 mgd) and 100% lamp power. This document provides the verification test results for the Atlantic Megatron unit Model M250.

1.2   Project Participants

Figure 1-1 is an organization chart showing the project participants and the lines of communication established for the ETV. The Field Testing Organization (FTO) was Montgomery Watson Harza (MWH), a NSF-qualified FTO, which provided the overall management of the ETV test through the project manager. The ultraviolet radiation system manufacturer was Atlantic Ultraviolet Corporation. The operations management and staff were from the test site at the City of San Diego Water Department, Aqua 2000 Research Center in Chula Vista, California. Water quality analyses were provided by the City of San Diego State-certified analytical and marine microbiology laboratories. Data management and final report preparation were performed by the FTO, MWH.

1

1.3   Definition of Roles and Responsibilities of Project Participants

1.3.1   Field Testing Organization Responsibilities

The specific responsibilities of the FTO, MWH, were to:

- Provide the overall management of the ETV through the project manager and the project engineers.
- Provide all needed logistical support, the project communication network, and all scheduling and coordination of the activities of all participants.
- Evaluate the performance of the low-pressure ultraviolet radiation technology according to the Product Specific Test Plan (PSTP) and the testing, operations, quality assurance/quality control (QA/QC), data management and safety protocols contained therein.
- Manage and report on data generated in the ETV.
- Provide all quality control (QC) information in the ETV report.
- Provide all data generated during the ETV in hard copy and electronic form in a common spreadsheet or database format.

Contact Information:
MWH
555 East Walnut Avenue
Pasadena, CA 91101
Phone: 626-568-6751
Fax: 626-568-6323
Contact: Samer Adham, Client Manager
Email: samer.adham@mwhglobal.com

1.3.2   Manufacturer Responsibilities

The specific responsibilities of the ultraviolet radiation system manufacturer, Atlantic, were to:

- Provide complete, field-ready equipment for the ETV at the testing site.
- Provide logistical and technical support as required throughout the ETV.
- Provide partial funding for the project.
- Attend project meetings as necessary.

Contact Information:
Atlantic Ultraviolet Corporation
375 Marcus Boulevard
Hauppauge, NY 11788
Phone: 631-273-0500
Fax: 631-273-0771/0780
Contact: Mark Wyckoff
Email: mw@atlanticuv.com

1.3.3 City of San Diego Staff Responsibilities

The specific responsibilities of the staff from the City of San Diego Water Department were to:

- Provide the necessary and appropriate space for the equipment to be tested in the ETV.
- Provide all necessary electrical power, feedwater and other utilities as required for the ETV.
- Provide all necessary drains to the test site.

1.3.4 Water Quality Analyst Responsibilities

The specific responsibilities of the water quality analytical staff from the City of San Diego Analytical Laboratory and Marine Microbiology Laboratory were to:

- Provide all off-site water quality analyses prescribed in the PSTP according to the QA/QC protocols contained therein.
- Provide reports with the analytical results to the data manager.
- Provide detailed information on the analytical procedures implemented.

Contact Information:
    City of San Diego Analytical Laboratory
    5540 Kiowa Drive
    La Mesa, CA 91942
    Phone: 619-668-3233
    Fax: 619-668-3250
    Contact: John Chaffin, Laboratory Manager

1.3.5 NSF Responsibilities

NSF is a not-for-profit testing and certification organization dedicated to public health safety and the protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF Name, Logo, and/or Mark meet those standards. The EPA partnered with NSF to verify the performance of drinking water treatment systems through EPA's ETV Program. NSF is responsible for administration of the DWS ETV testing program. Specific responsibilities of the NSF were to:

- Develop test protocols and qualify FTOs.
- Review and approve PSTPs.
- Conduct inspections and make recommendations based on inspections.
- Conduct financial administration of the project.
- Review of all quality assurance data for laboratory procedures.
- Review all project reports and deliverables.

Contact Information:
    NSF International
    789 N. Dixboro Rd.
    Ann Arbor, MI 48105
    Phone: 734-769-8010
    Fax: 734-769-0109
    Contact: Bruce Bartley, Project Manager
    Email: bartley@nsf.org

1.3.6   EPA Responsibilities

The EPA through its Office of Research and Development has financially supported and collaborated with NSF under Cooperative Agreement No. R-82833301. This verification effort was supported by the Drinking Water Systems Center operating under the ETV Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release. The specific responsibilities of EPA were to:

- Initiate the ETV program.
- Provide significant project funding.
- Review PSTPs and final reports.

1.4   Verification Testing Site

The verification testing was conducted at the City of San Diego's Aqua 2000 Research Center at the Otay Water Treatment Plant (OWTP) at 1500 Wueste Road in Chula Vista, California. The site provided sufficient water supply, electrical power, pipelines and drainage. An operations trailer was provided that included office space and on-site laboratory facilities. The UV manufacturer provided the UV equipment required for the verification testing.

Below is a list of the facilities and equipment that were available at the pilot site.

Structural
- Enclosures appropriate to the NEMA rating of the unit.
- Potable water connections.
- Chemical containment area.
- Full electrical supply.
- Chemical feed systems used during MS2 seedings.
- Chemical safety shower and eyewash.
- Operations trailer with office space and on-site laboratory facilities.

Onsite Analytical Equipment
- Hach Pocket Colorimeter for chlorine analysis

- Hach 2100P Turbidimeter
- Accumet AR15 pH meter
- Reference sensor supplied by manufacturer
- NIST certified immersion thermometer manufactured by ERTCO

1.4.1 Source Water

Particles and dissolved contaminants can interfere with UV light transmission and reduce inactivation efficiency. The NSF protocol is therefore applicable to the use of UV technology for treating high quality water (<5 NTU turbidity and >80% transmittance at 1 cm) sources including treated surface water supplies of consistent high quality. The feedwater for the UV testing was full-scale plant effluent water from the OWTP. OWTP is a conventional water treatment plant with a design capacity of 40 MGD. The plant operates at an average flow rate of 30 MGD. The plant draws water from two sources: Otay Lake and the County Water Authority Aqueduct. The blend ratio can vary throughout the year based on demand and CWA water credits granted to the OWTP. The feed water of the plant is dosed with potassium permanganate which serves as a pre-oxidant when necessary for taste and odor control. The water is then dosed with ferric chloride and cationic polymer at the rapid mix, and passed through flocculation basins to a sedimentation basin. The sedimentation basin effluent is dosed again with cationic polymer to act as a filter aid, and chlorinated. The water is then filtered through sand and anthracite filter beds, and then ammonium hydroxide and chlorine are added for chloramine formation, and the pH is adjusted to 8 with caustic for corrosion control. Feed water for the UV unit was plant effluent water, obtained directly after the filters and following the addition of ammonium hydroxide and chlorine to achieve a combined chlorine residual of 2.5 mg/L. During MS2-virus seedings, sodium metabisulfite was added ahead of the UV system to quench residual combined chlorine.

Figure 1-2 illustrates UV system feed water (Otay Filtration treatment plant effluent water) quality for the period of November 14, 2001 through December 3, 2001. This time period incorporates the Task 1 Verification Testing Runs and the Routine Equipment Operations period. The stable quality of the water is apparent in all parameters illustrated in the figure. Total hardness ranged from 212 to 259 mg/L as $CaCO_3$, alkalinity ranged from 111 to 137 mg/L as $CaCO_3$ and calcium hardness ranged from 150 to 203 mg/L as $CaCO_3$. The hardness levels are quite high, with relatively high alkalinity as well. The UV-254 absorbance varied over a wide range from 0.042 cm^{-1} to 0.068 cm^{-1} corresponding to UV-254 transmittance values between 85.5% and 90.8%. The TOC ranged from 2.28 to 4.56 mg/L. The variance in UV-254 absorbance and TOC observed during the ETV testing period is due to increases and decreases in the blend ratio of Otay Lake water and CWA water used as feed water for OWTP.

1.4.2 Pilot Effluent Discharge

All of the UV unit effluent was directed to the plant washwater recovery basin and returned to Otay Lake. UV effluent water was chlorinated and dechlorinated before discharge into Otay Lake during MS2 virus seeding tasks.

Chapter 2
Equipment Description and Operating Processes

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 modular design consisting of the disinfection chamber and the electronic control enclosure. The Megatron Model M250 has a 12-in diameter stainless steel chamber and the complete unit has dimensions of 101-in length, 21-in width, and 26-in height. Water enters the chamber and flows into the space between the quartz sleeves and chamber wall. The inlet and outlet of the chamber consist of 4-in lap joint flange (150#). The chamber contains nineteen (19) G64T5L lamps stacked in a configuration of 3 lamps per wiper assembly. Lamps are 1.5-in apart. Each lamp has one power setting (100% lamp output), with a lamp wattage of 65 W. Figure 2-1 is a cross-section of the chamber showing the lamp configuration.

The equipment that was tested in the ETV is the Atlantic Ultraviolet Megatron Model M250, depicted in Figure 2-2. The unit utilizes low-pressure lamps that produce ultraviolet wavelengths that inactivate microorganisms. Approximately 95% of the ultraviolet energy emitted from the lamps is at the mercury resonance line of 254 nanometers. The Megatron Model M250 system is designed to disinfect waterborne microorganisms including viruses, bacteria, and protozoa. Resistant waterborne pathogens such as rotovirus undergo extensive inactivation at doses of 40 mJ/cm^2, the current dose cited for use of UV in municipal water applications (Modifi et al., 2001; Cotton, et al., 2001).

A schematic diagram of plan and profile views of the Megatron Model M250 system process is shown in Figure 2-3. The Megatron Model M250 inactivation reactor is 12-inches in diameter and approximately 60-inches in length with axial inlet and outlet. The Megatron unit incorporates a UV Guardian Monitor within its enclosure. The UV Monitor visually indicates the level of UV energy that is measured by the UV irradiance sensor once it 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) decrease in ultraviolet transmission through the water, and 3) decrease in lamp output due to age. The UV Monitor has two operating modes identified as "Factory Preset" and "User Adjust". The UV irradiance displayed in the former mode is based on a factory calibration using a digital radiometer under laboratory conditions. When operated in the latter mode, the UV irradiance displayed by the UV Monitor directly corresponds to the UV irradiance, but at a user assigned value. The UV irradiance sensor is connected to one of the nineteen lamps (Lamp No. 2) to monitor fouling of the quartz sleeve and changes in water quality affecting system performance. It is assumed that all lamps are equivalent in terms of fouling and UV output. The UV sensor is housed within a protective sensor probe. The sensor probe is equipped with a UV transmitting quartz window. The sensor generates an electrical signal based on the amount of UV light that penetrates the quartz window. This signal is then sent to the UV Monitor, which displays the corresponding value of the UV irradiance. An additional sensor was provided and manufactured by the Atlantic Corporation to verify the performance of the

installed sensors and provide a cross-check for the vendor-calibrated-sensor. Both sensors have been factory-tested to read within 5% of each other.

The Megatron Model M250 is designed to treat water at flow rates ranging from 335 gpm to 560 gpm. The nineteen low-pressure UV lamps have a total lamp power of 1235 W (at 65 W per lamp). The maximum system pressure is 125 psi (8.3 bar).

The Megatron M250 unit employs an automatic wiper cleaning mechanism for each lamp in the reactor. The wiper mechanism physically removes deposits from the quartz sleeve surrounding each lamp. The cleaning system consists of pneumatic cylinders operated by an air compressor. Each pneumatic cylinder cleans three lamps. 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 by compressed air. This cleaning system operates on-line while the UV reactor is in operation (providing disinfection). The cleaning system is set to operate at a fixed time interval by programming the wiper controller located on the panel.

2.1   Description of the Treatment Train and Unit Processes

The treatment train that was tested included the following:

- Feed pump.
- Chemical feed pump (metabisulfite addition for chloramine residual).
- Magmeter type flowmeter with flow totalizer.
- Virus injection port.
- UV influent sample port.
- Influent pressure gauge.
- Influent temperature gauge.
- Differential pressure gauge.
- Atlantic Megatron UV reactor.
- Effluent pressure gauge.
- UV effluent sample port.
- Flow rate control valve.
- Chemical feed pump (NaOCl addition for virus inactivation).
- Chlorine contact tank.
- Chemical feed pump (metabisulfite addition for free chlorine).
- Data logger for flow rate and UV sensor outputs.
- Discharge to washwater recovery basin.

Figure 2-4 shows the experimental setup for the verification testing. Sodium metabisulfite is injected into the feed line immediately after the pump for dechloramination of the plant effluent. The virus injection port is located downstream of the metabisulfite injection port followed by an insertion type magmeter (flowmeter). There is a flow control valve downstream of the flowmeter followed by the

influent sample port. Pressure gauges are placed in line at the 4-inch inlet and outlet of the reactor chamber to allow the determination of differential drop across the reactor and the system pressure. The effluent sample port is downstream from the reactor, followed by a second flow control valve. Sodium hypochlorite is injected after this point for inactivation of any remaining virus. The contact time for this inactivation is provided by the contact tank. Sodium metabisulfite is injected into the overflow from this tank to dechlorinate the water before discharging it into the washwater basin.

2.2   Description of Physical Construction/Components of the Equipment

2.2.1   UV Reactor

Typical operating parameters for the Megatron M250 are provided below:

- Treated flow: 335 to 560 gpm
- Maximum system pressure: 125 psi (8.3 bar)
- Dose: 40 mJ/cm^2
- UV transmittance: 80% to 99%
- Head loss: 2.56 ft with 4-in inlet/outlet based on 400 gpm
- Water temperature: 10°C to 50°C   (50°F to 122°F).

The UV reactor is made of corrosion-resistant materials, including a type 316 electropolished stainless steel chamber, rubber and teflon materials for the seals, teflon washers and wiper segments, and quartz sleeves. The system provides a 0-10 V analog output from the UV monitor, suitable for input to a dataloggers. The UV system has a total dry weight of 900 pounds. For shipping purposes, can be moved with a forklift and mounted on flatbed trucks. The system requires 14 amps at 120 volts, single phase.

A description of the important components of the treatment train, excluding the UV reactor that was described previously, follows:

2.2.2   Flowmeter

UV reactor flow measurements were made during verification testing with a Signet 2550 insertion magmeter. The magmeter was factory calibrated before installation, and had repeatable flow measurements of ± 2 percent. The 4-20 mA magmeter output signal was wired to an electronic flow totalizer with digital display of both instantaneous flow and totalized flow. A 4-20 mA flow signal was also transmitted to the datalogger for storage.

2.2.3   Virus Injection

The virus injection port was located in a section of 8-inch (20-cm) diameter pipe before the UV reactor. The virus feed solution was added to the process flow through ¼ -inch stainless steel tubing extended 3 to 4 inches (7.6 to 10 cm) into the process pipe. Downstream piping components, that

provided mixing before the UV reactor influent sample port, included 3-30 degree elbows, an 8-inch to 4-inch pipe reducer, six 90 degree elbows, and 8 feet of 4-inch diameter pipe. A peristaltic pump, with a maximum capacity of 250 revolutions per minute RPM, was used to add MS2 virus to the UV influent water during the microbial inactivation task. This pump was operated between 150 and 200 RPM during virus seeding tasks to minimize variations in the virus feed rate.

2.2.4   Sample Ports

UV reactor influent and effluent water was sampled from flammable ports constructed from ¼inch stainless steel. The stainless tubing extended 3 to 4 inches into the process stream for the effluent port and 1-2 inches for the influent sample port. The influent sample port was located 1 feet (0.3m) before the UV reactor and the effluent sample port was located 13 feet (3.96 m) after the UV reactor. Piping components upstream of the effluent sample port include three 90 degree elbows, and a 4 inch to 8 inch pipe coupling. The sample ports were flamed using a propane torch before microbial sampling was conducted.

2.2.5   Pressure and Temperature

The operating pressures at the influent and effluent of the UV reactor were measured using Ashcroft 0-15 psi (0-1.04 bar) inline pressure gauges. The gauges are certified to have accuracy of $\pm$ 0.5% and resolution of 0.1 psi.

The feed and the effluent temperatures were measured by directing the UV reactor influent and effluent flows into insulated containers and measuring the temperature of the water in the container with a NIST certified immersion thermometer. The thermometer was manufactured by ERTCO, with a scale from –2 to 68 °C graduated in 0.2 °C increments.

2.2.6   Datalogger

An ACR 12-bit, 4-20 milliamp portable process datalogger was used to acquire and store flow rate data from the magmeter and UV irradiance signals from the UV irradiance sensor in the Megatron unit. The datalogger was set to store readings every 2 minutes.

Chapter 3
Methods and Procedures

3.1   Environmental Technology Verification Testing Plan

This section describes the tasks completed for the ETV testing. The test equipment was operated 24 hours a day, seven days a week, with operations staff on-site Monday through Friday for one 8-hour shift each day and for 4-hour shifts during the weekend. Tasks that were performed by the operations and engineering staff are listed below:

Task A: Characterization of Feedwater Quality
Task B: Initial Operations
Task 1:   Verification Testing Runs and Routine Equipment Operation
Task 2:   Test Runs for Feed Water and Effluent Water Quality
Task 3:   Documentation of Operating Conditions and Treatment Equipment Performance
Task 4:   Documentation of Equipment Performance - Microbial Inactivation
Task 5:   Data Management
Task 6:   Quality Assurance/Quality Control

An overview of each task is provided below.

3.1.1   Task A: Characterization of Feedwater Quality

The objective of this recommended Initial Operations task was to obtain a chemical, biological and physical characterization of the feed water. Chapter 1 of this report includes the description of the source water quality during the course of the ETV testing in terms of key water quality parameters including: UV-254 absorbance and transmittance, total chlorine, and total organic carbon, total alkalinity, calcium, magnesium, and hardness.

3.1.2   Task B: Initial Operations

During this two-week shake-down period, the equipment Manufacturer verified the proper operation of the UV unit. The determination of the minimum irradiance below which equipment shutoff should occur to assure adequate inactivation at all times was also determined during the Initial Testing period. When the irradiance drops below this value, flow can be shut off or a signal given to the operator indicating the need for cleaning or lamp replacement. UV-254 absorbance was measured daily during the 2-week initial operations period. The UV reactor operating conditions employed during the remainder of verification testing were established during the Initial Operations period.

All other components of the treatment train were tested. The range of achievable flows was determined and magmeter flow readings were verified volumetrically. Flow and UV intensity data acquired with the

data logger was verified against digital readouts and calibration data. Chemical feed systems for dechloramination, chlorination and dechlorination were also tested to verify adequate control.

3.1.3 Task 1: Verification Testing Runs and Routine Equipment Operation

The objective of this task was to characterize the technology in terms of efficiency and reliability. The UV disinfection treatment system, which includes the UV lamps, reactor and UV irradiance sensor, was operated for Verification Testing purposes. The testing was conducted under the operational parameters established from the results of the Initial Operations testing period (Task B) and provided by in the Atlantic Ultraviolet Corporation's statement of performance capabilities. Atlantic's unit is designed to operate at 335 gpm to 560 gpm. The testing was done using a flow rate of 350 gpm during the course of the study.

After set-up and shakedown of the UV equipment, UV operation was established at the flowrate condition being verified in this ETV. Task 1 testing took place over one 13 day test period plus one 8-hr shift (320 hours). Measurements of the UV feedwater flowrate and UV irradiance were collected every two hours. The frequency of lamp cleaning was recorded. Lamp hours and system power were recorded on a daily basis.

3.1.4 Task 2: Test Runs for Feed Water and Effluent Water Quality

The objective of this task was to evaluate the quality of the water produced by the UV system and the effect the system has on feed water quality. Water quality data was collected for the feed water and effluent water. Some of the water quality parameters described in this task were measured on-site. Analysis of the remaining water quality parameters was performed by the City of San Diego Laboratory, a State-certified analytical laboratory and the City of San Diego Marine Microbiology Laboratory, also State-certified. All analyses were conducted using Standard Methods (APHA, AWWA, and WPCF 1992 and 1999) and EPA Methods.

The parameters monitored during the ETV and the methods used for their measurement are listed in Table 3-1. Effluent water quality was evaluated relative to feedwater water quality and operational conditions, using the Atlantic UV Megatron unit.

3.1.5 Task 3: Documentation of Operating Conditions and Treatment Equipment Performance

The objective of Task 3 was to characterize the Atlantic Megatron unit with respect to efficiency and reliability while operating under the conditions established during the Initial Operations period and within the design specification of the unit. The operation and performance of the UV equipment were documented over a 27-day test period.

The performance of the Atlantic Megatron unit Model M250 System was documented. The parameters documented included: total water throughput (from a totalizer), total power usage (current

supplied to the lamps was measured using an amp-clamp), UV Irradiance as measured by the manufacturer's UV irradiance sensor (sensor signal inputted into a data logger), hours of lamp operation (included on the panel), decrease in intensity output (a measure of the fouling rate), and frequency and type of mechanical cleaning. The performance of the automatic mechanical wipers was assessed by recording the UV intensity before and after cleaning. Table 3-2 provides the schedule of operating data recording.

3.1.6 *Task 4: Documentation of Equipment Performance - Microbial Inactivation*

The objective of Task 4 was to characterize the Atlantic Megatron M250 unit in terms of efficacy at inactivation of microorganisms. Inactivation of microorganisms is the primary purpose of UV drinking water treatment modules. To accomplish this, a bench-scale collimated beam test was conducted to determine the UV sensitivity of the seed organism. In addition, a full-scale challenge test was conducted to determine the inactivation of the same seed organism by the Megatron M250. The measurement of inactivation was calculated as the difference between the log concentration of viable organisms in the feed stream and the log concentration of viable organisms in the UV unit effluent.

Organisms for Seeding Experiments
The organism selected for seeding experiments was MS2 virus. MS2 virus is not a human pathogen; however, this organism is similar in size (0.025 microns), shape (icosahedron) and nucleic acid (RNA) to polio virus and hepatitis virus. Because MS2 is not a human pathogen, live MS2 virus was used in the seeding experiments. Organism stocks received from the supplier were stored at 4°C in the dark until use (approximately 3 months) in the seeding experiments. The ATCC catalog number of the virus was 15597 and the bacterial host used was *E. Coli* ATCC catalog number 700891-B. A memo describing the procedures used in the propagation, harvesting, enumeration, shipping, handling and storage of the virus used for the seeding experiments is provided in Appendix A.

The collimated beam test and virus challenge test for evaluating the effectiveness of UV disinfection of MS2 virus are described below. UV estimated dose using MS2 virus is used as an indicator to obtain the log inactivation of other microorganisms such as *Cryptosporidium* and *Giardia*. The seeding experiments were performed at the test site and the samples collected during the seeding experiments were submitted to the City of San Diego Marine Microbiology Lab, a State-certified laboratory, for analysis of the seeded microorganisms.

<u>Collimated Beam Testing</u>

The collimated beam apparatus consists of a single UV lamp and ballast with the lamp enclosed in a box with a hollow cylinder projecting from the central part. This cylinder delivers the collimated beam from the lamp to a sample that is placed in line with the cylinder. The box and cylinder can be raised or lowered using a rotating handle to deliver different levels of irradiance to the sample. Collimated beam testing was conducted to ensure the integrity of the microbial cultures used to test the reactor. The purity of the MS2 virus stock was checked by a dose-response bioassay. To establish a dose-response curve, collimated-beam apparatus tests were carried out with the feed water used during

seeding challenges within 24 hours of the challenge test. The initial concentration of MS2 was approximately 2 logs higher than the number of logs of inactivation that should be achieved at the maximum UV dose to have a target concentration of 100 pfu/100 mL or more in the irradiated samples. Six (6) sub-samples, prepared by pouring 50 mL of the MS2 virus stock into crystallizing dishes, were exposed for a range of times calculated to achieve a range of UV-254 doses from 20 to 145 mJ/cm^2, with a minimum interval of 25 mJ/cm^2. The exposed samples were then plated on the same day as the collimated beam apparatus test using the specific plating procedure provided in Appendix A. Lastly, the water quality matrix used for collimated-beam apparatus testing was identical to that used in the UV reactor validation. The UV dose was calculated as follows:

$$D = I_o t \ [(1-e^{-kd})/kd]$$

Where :
D = UV dose at 254 nm (mJ/cm^2)
t = Exposure time (seconds)
I_o = Incident intensity at the surface of the sample (mW/cm^2)
k = Absorbance coefficient (1/cm)
d = Depth of the sample (cm) = 2.5

The collimated-beam results were plotted on a graph of the UV dose (mJ/cm^2) versus the log inactivation.

Microbial Challenge Tests

All microbial challenge experiments were conducted with 100% lamp power at a constant flow rate of 350 gpm ±10%, which was anticipated to achieve 2-log inactivation of the MS2 virus.

During each MS2 seeding experiment, three samples from the UV feedwater and three samples of UV effluent water were collected. The first sample during each treatment cycle was collected after a minimum of five theoretical hydraulic detention times had passed through the system from injection point to sampling port. The hydraulic detention time was calculated by dividing the volume of pipe from the injection port to the sampling port by the flow rate. Each sample was collected in sterile 250-mL bottles, stored at 1°C and processed within 24 hours. MS2 virus was continuously added to the influent sample stream using a 0 to 250 RPM peristaltic pump. The pump was operated at a high rate (> 150 RPM) during seeding to minimize the effects of pulsing. Samples were collected from flamed stainless steel sample ports over a period of 5 to 10 seconds. Both sample ports were adjusted to approximately the same flow rate to ensure that both feed and effluent samples represented the same aliquot of water and the sampling from both the ports was conducted at the same time. A seed stock sample was taken from the seeding tank and the sample diluted 25 times as a trip control. The seeding tank was kept continuously mixed during the seeding test. A seed start sample was taken from the seeding tank (no dilution).

Three experiments (replicates) were performed, plus one additional seeding challenge with all reactor lamps turned off, for a total of 24 MS2 samples (Table 3-3). In addition, two negative control samples were taken from the feed sample port to enumerate the indigenous phage count. After the seeding the lamps were turned off, three samples each were taken from the feed and effluent sample port as a positive control. Next, a final seed stock (e.g. seed stop) sample was collected from the seeding tank (no dilution). After this, chlorine was added to the seeding tank and the system was disinfected. After five minutes, chlorine addition was stopped and two samples were taken from the effluent to show that the system was completely disinfected. Each challenge was hydraulically independent of any previous challenge because a minimum of five theoretical hydraulic detention times were allowed between challenge experiments.

3.1.7 Task 5: Data Management

The objective of this task was to establish the protocol for management of all data produced in the ETV testing and for data transmission between the FTO and NSF.

A datalogger was used for automatic acquisition of on-line process flow rate and UV irradiance sensor data to computer databases. This data was then downloaded for importation into Excel as a comma delimited file. In spreadsheet form, data were manipulated into a convenient framework to allow analysis of ultraviolet equipment operations. For those parameters not recorded by the datalogger, field-testing operators recorded data and calculations by hand in laboratory notebooks. Daily measurements were recorded on specially prepared data log sheets as appropriate.

The database for the project was set up in the form of custom-designed spreadsheets. The spreadsheets were capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. Data from the log sheets were entered into the appropriate spreadsheet. Following data entry, the spreadsheet was printed out and the printout was checked against the handwritten data sheet. Any corrections were noted on the hard copies and corrected on the screen, and then a corrected version of the spreadsheet was printed out. Each step of the verification process was initialed by the field testing operator or engineer performing the entry or verification step.

Data from the outside laboratory were received and reviewed by the field testing operator. Data from the onsite lab and City of San Diego Marine Microbiology lab were entered into the data spreadsheets, corrected, and verified in the same manner as the field data. Data from the City of San Diego Water Quality lab were received both electronically and in hardcopy printouts generated from the electronic data.

3.1.8   Task 6: Quality Assurance/Quality Control

An important aspect of verification testing was the protocol developed for quality assurance and quality control. The objective of this task was to assure the high quality of all measurements of operational and water quality parameters during the ETV.

Equipment flow rates and associated signals were documented and recorded on a routine basis. A routine daily walk-through during testing was performed to verify that each piece of equipment or instrumentation was operating properly. On-line monitoring equipment, such as flow meters and UV-irradiance sensor signals, were checked to confirm that the read-out matched the actual measurement (e.g., flow rate or UV output on the control panel) and that the signal being recorded was correct. Below is a list of the verifications conducted.

Monitoring Equipment

System Flow Rate
System flow rate was verified volumetrically on a weekly basis and near the beginning and end of the testing period. System flow to the 1100-gallon chlorine contact tank was monitored for approximately two minutes. The measured flow rate was compared with flows indicated on the flowmeter.

UV Sensors
UV irradiance sensor readings were verified weekly against a calibrated reference sensor that was provided and manufactured by the Atlantic Corporation.

System Piping Components
All system piping, tubing and valves were examined every day during the walkthrough inspection to ensure that no leaks were present.

Pressure Gauges
The pre and post reactor pressure gauges were verified against a standard Ashcroft test gauge during the testing period.

Analytical Methods

pH
An Accumet Research Model AR15 laboratory pH meter was used to conduct routine pH readings at the test facility. Analyses for pH were performed according to Standard Method 4500-H+. A three-point calibration of the pH meter used in this study was performed once a day when the instrument was in use. Certified pH buffers in the expected range (4.0, 7.0 and 10.0) were used. The slope obtained after calibration was recorded. The temperature of the sample when reading sample pH was also recorded. The pH probe was stored in the appropriate solution as defined in the instrument manual.

Temperature

Feed and effluent water temperatures were obtained at least once daily. All temperature measurements conducted during the testing period were measured with a thermometer certified by the National Institute of Standards and Technology (NIST). Readings for temperature were conducted in accordance with Standard Method 2550B.

Turbidity

A Hach 2100N desktop turbidimeter was used to perform onsite turbidity analyses of feed water and effluent samples in accordance with Standard Method 2130B. Readings were recorded in non-ratio operating mode. The following quality assurance and quality control procedures were followed to ensure the integrity and accuracy of onsite laboratory turbidity data.

Initial and weekly calibration was performed with primary standards of 0.1, 20, 100 and 800 NTU. Secondary standard calibration verification was performed on a daily basis. Three secondary standards (approx. 5.69 NTU, 56 NTU and 544 NTU) were recorded after primary calibration and on a daily basis for the remaining 6 days until the next primary calibration. Proficiency samples with a known turbidity were purchased from a commercial supplier. Turbidity proficiency samples were prepared and analyzed every week.

Chemical and Microbial Water Quality Parameters

The analytical work for the testing was performed by the City of San Diego Analytical and Marine Microbiology Laboratories, which are State of California certified water laboratories. All water samples were collected in appropriate containers (containing preservatives as applicable) prepared by the City of San Diego Analytical Laboratory. Samples for Heterotrophic Plate Count (HPC) analysis were collected in bottles supplied by the City of San Diego Marine Microbiology Laboratory and transported with an internal cooler temperature of approximately 2 to 8°C to the laboratory. All samples were preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times. All reported results had acceptable QA and met EPA QC guidelines, which was confirmed by letters from the City of San Diego Laboratory (Appendix A).

3.2 Calculation of UV Operating Parameters

3.2.1 UV Irradiance

UV irradiance is the rate at which UV energy is incident on a unit area (e.g., 1 cm^2) in the water and described in terms of UV power per unit area, e.g., microwatts per square centimeter (μW/cm^2) or milliwatts per square centimeter (mW/cm^2). The UV irradiance was measured using irradiance sensors provided by the manufacturer and verified through weekly cross-checks with the reference sensor.

3.2.2   UV Dose

The UV energy is quantified to a dose by multiplying the UV Irradiance by the actual exposure time:

Dose (μW sec/cm^2) = UV Irradiance (μW/cm^2) x Time (seconds)

The definition of dose provided is a theoretical definition and the dose was not calculated during the testing.

3.2.3   UV Transmittance

Transmittance is the ability of water to transmit UV light. Transmittance of a water sample is generally measured as the percentage (%T) of transmitted light (I) to incident light (I$_o$) through an operationally defined pathlength (L). Many commercially available spectrophotometers actually report the Absorbance (A) for a fixed pathlength (L) of the sample. Percent Transmittance and Absorbance can be related as:

$$\%T = 100 \text{ x } 10^{-(A/L)}$$

Many naturally occurring organic and inorganic constituents (e.g., natural organic matter, iron, and nitrate) will absorb energy in the UV wavelengths, thus reducing the transmittance of the water. This reduced transmittance often interferes with the inactivation efficiency of UV systems.

3.3   Calculation of Data Quality Indicators

3.3.1   Precision

As specified in Standard Method 1030 C, precision is the standard deviation of the results of replicate analyses. An example of replicate analyses in this ETV was the weekly analysis of turbidity proficiency samples. The overall precision of a study includes the random errors involved in sampling as well as the errors in sample preparation and analysis. Precision was calculated for the water quality parameters monitored with eight or more samples.

$$\text{Precision = Standard Deviation} = \left(\left[\sum_{I=1}^{N} (\overline{X}_I - \overline{})^2 \div (n-1) \right] \right)^{1/2}$$

where: $\overline{}$ = sample mean
$\overline{}_I$ = ith data point in the data set
n = number of data points in the data set

3.3.2   Relative Percent Deviation

For this ETV, duplicate samples were analyzed to determine the overall precision of an analysis using relative percent deviation. An example of duplicate sampling in this ETV is the daily duplicate analysis of turbidity samples using the bench-top turbidimeter.

$$\text{Relative Percent Deviation} = 100 \times [(x_1 - x_2) \div \overline{X}]$$

where
$\overline{X}$ = sample mean
x_1 = first data point of the set of two duplicate data points
x_2 = second data point of the set of two duplicate data points

3.3.3   Accuracy

Accuracy is quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. An example of an accuracy determination in this ETV was the analysis of a turbidity proficiency sample and comparison of the measured turbidity to the known level of turbidity in the sample.

$$\text{Accuracy} = \text{Percent Recovery} = 100 \times [(X_{measured}) \div X_{known}]$$

where
X_{known} = known concentration of measured parameter
$X_{measured}$ = measured concentration of parameter

3.3.4   Statistical Uncertainty

For the water quality parameters monitored with eight or more samples, 95 percent confidence intervals were be calculated. The following equation was be used for confidence interval calculations:

$$\text{Confidence Interval} = \overline{X} \pm [t_{n-1, 1 - (\alpha/2)} \times (S/\sqrt{n})]$$

where:
$\overline{X}$ = sample mean
S = sample standard deviation
n = number of independent measurements included in the data set
t = Student's t distribution value with n-1 degrees of freedom
α = significance level, defined for 95 percent confidence as: $1 - 0.95 = 0.05$

According to the 95 percent confidence interval approach, the α term is defined to have the value of 0.05, thus simplifying the equation for the 95 percent confidence interval in the following manner:

$$\text{95 Percent Confidence Interval} = \overline{} \pm [t_{n-1, 0.975} \times (S/\sqrt{n})]$$

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3.3.5 Data Completeness and Representativeness

Data completeness refers to the amount of data collected during the ETV study as compared to the amount of data that were proposed in the PSTP. Calculation of data completeness was made for onsite water quality measurements, laboratory water quality measurements, and operational data recording. These calculations are presented in Appendix A of this report.

All water quality samples were collected according to the sampling procedures specified by the NSF protocols, which ensured the samples were representative.

3.4   Testing Schedule

The ETV schedule is illustrated in Figure 3-1. The field testing program took place in November and December, 2001. One testing period was conducted.

Chapter 4
Results and Discussion

This chapter presents the data obtained under each task of the ETV program of the Atlantic UV Megatron system.

4.1   Task B: Initial Operations

The initial operation testing was conducted between 11/1/01 and 11/13/01. During this testing phase the manufacturer's representative and the FTO field personnel evaluated equipment operations under various operating conditions to determine operational conditions for the verification test. Specific operating conditions evaluated included flow rates, power settings, and cleaning frequency. Based on these initial tests the following conditions were recommended by the manufacturer for verification testing:

- Flow rate at 350 gpm ±10% during verification testing and during microbial seeding tests.
- Lamp power at 100% for the entire testing period.
- Lamp sleeve cleaning to occur automatically four times per day (specific times = 4:00, 10:00, 16:00, 22:00).
- Wipe or replace UV sensor window weekly.
- Daily UV intensity values to be recorded in both the "User adjust" and "Factory preset" mode.
- The value of UV intensity in the "User adjust" mode should be adjusted to match the value in the "Factory preset" mode if the values differ by $\geq 5\%$.
- Allow the system to warm up for approximately 15 minutes after start up following a shutdown before recording UV intensity.
- Set the UV low set point at 4.0 mJ/cm^2 .
- UV sensor should be tightened until the edge is 3"-3/8" inches from the reactor chamber.

Samples for several onsite and laboratory water quality parameters were also collected to verify sampling and laboratory procedures. QA/QC procedures were also followed during this period.

The chemical feed and MS2 virus addition pumps used during the microbial inactivation testing were also set up and tested during this period. The flow rates and concentrations required for the chemical pumps were calculated and tested to ensure the feed water to the UV reactor was dechloraminated before addition of MS2 virus and that adequate free chlorine residuals were achieved through the chlorine contact tank for virus inactivation.

An inspection of field operations, sampling activities and on-site analyses was conducted, at the end of this phase, by NSF Project staff. All procedures were found to be satisfactory. A copy of the inspection report provided by NSF is provided in Appendix A. The sampling and analysis schedules and the data collection forms were also finalized during the on-site inspection.

4.2   Task 1: Verification Testing Runs and Routine Equipment Operation

The verification testing run was conducted between 11/14/01 and 12/3/01 for a period exceeding 320 hours of lamp operation.   During this period the unit was operated at the operating conditions determined by the manufacturer during the initial testing period. The system was operated continuously during the verification testing with the exception of shutdowns resulting from the OWTP being offline, implementation of weekly operational QA/QC procedures and cleaning of the UV sensor window. A list of these shutdown periods is provided in Appendix C. Onsite water quality parameters and laboratory water quality parameters were also sampled for during this period. The summary of these parameters is provided in Section 4.3.

The operational data collected during this period included flow rates and UV irradiance collected by the data logger. This data is presented in Figure 4-1. The flow was maintained within 10% of 350 gpm during the entire length of the testing, except for periods of shutdowns and low flow. Periods of low flow (100-150 gpm) occurred on 11/21/01, 11/30/01, 12/03/01 and 12/04/01 due to power failures of the pump supplying water to the UV unit. As shown in Figure 4-1, the extreme low values of UV irradiance and flow serve to indicate system shutdowns.   The dark squares shown on Figure 4-1 indicate times when the system was shutdown to clean the UV irradiance sensor window. As shown, the sensor was cleaned daily during the time period of 11/14/01 through 11/29/01 and weekly thereafter. In addition, the low points of UV irradiance, near 1 mW/cm^2, shown in Figure 4-1 can be explained as follows. During the testing period it was observed that the initial value of UV irradiance immediately after start up following a system shutdown was less than 0.5 mW/cm^2. However, as the lamps warmed up the value would increase rapidly and stabilize after approximately 15 minutes. Because the data logger recorded UV intensity values every two minutes there were instances where low UV values were recorded during periods of lamp warm up. Furthermore, extreme high values of irradiance (*i.e.* > 10 mW/cm^2) which occurred on 11/21/01 and 11/26/01 are shown as vertical spikes on Figure 4-1. These values resulted from failure of the irradiance sensor, which may have resulted from exposure to water during cleaning of the sensor window. Details on this occurrence are provided in Section 4.8.3.

The lamp cleaning cycles are also indicated in Figure 4-1. The system was operated with four regularly spaced automatic mechanical cleanings per day throughout the entire testing period.   During each weekday of operation the irradiance (mW/cm^2) was recorded before and after a minimum of one automatic cleaning cycle.   In addition to cleaning automatically, cleanings were also occasionally performed manually to test the cleaning system.   It should be noted a manual cleaning was also conducted just prior to the virus inactivation challenge testing (See Section 4.5). Both cleaning modes (auto and manual) were found to operate reliably throughout the entire testing period. Table 4-1 provides specific details of the lamp cleanings that were recorded during the testing period including the cleaning type (e.g. Auto or Manual), lamp hour and the UV irradiance before and after cleaning. As shown, the percent change in irradiance after each recorded cleaning ranged from –1.53% to +1.28% with an average change of +0.23%. Such data indicates that the cleanings had an insignificant effect on UV irradiance.

It was observed early in the testing that the UV irradiance was decreasing significantly. The manufacturer was consulted and recommended manually wiping the UV sensor window with alcohol, or replacing the window, on a daily basis to eliminate the possibility of sensor window fouling causing the observed decrease in UV irradiance. Accordingly, the sensor window was wiped with alcohol daily between 11/15/01 and 11/27/01. In addition, the sensor window was replaced once per week during the weekly QA/QC procedures carried out throughout the testing period.

Table 4-2 contains values of UV irradiance recorded before and after each UV sensor window cleaning and replacement conducted during the entire testing period. As shown, the effect of cleaning and or replacement of the window sensor on UV irradiance is not consistent; seven observations indicated the irradiance increased (ranging from 1.10% to 19.61%) and nine observations indicated the irradiance actually decreased (ranging from 1.25% to 8.32%). Lastly, as shown in Table 4-2, the sensor window was also cleaned using acid on 11/28/01 and 11/29/01. As shown the effect on UV irradiance following these two cleanings were also inconsistent with an increase of 11.99% and decrease of 3.52%, respectively. As a result, daily sensor window cleaning was terminated for the remainder of the testing (11/30/01 to 12/17/01) and the sensor window only replaced weekly during normal QA/QC operations. As indicated in Table 4-2, the sensor window was cleaned with alcohol on 12/11/01 as part of the weekly sensor calibration procedure.

The UV-254 transmittance of the feed water was measured onsite and the UV sensor irradiance and transmittance data is presented against hours of lamp operation in Figure 4-2. Shutdown periods are not displayed in Figure 4-2 since the lamp hours did not change during shutdown periods. Figure 4-2 shows that UV irradiance was directly related to the UV-254 transmittance of the feed water. As shown, increases and decreases in UV irradiance corresponded with increases and decreases in UV-254 transmittance throughout the testing period. In general, the sensitivity of UV irradiance to changes in UV-254 transmittance becomes less pronounced due to factors such as long term lamp fouling and lamp aging. The minimum values of irradiance shown in Figure 4-2 were recorded by the data logger at times immediately following start up of the system when the lamps were warming up.

The system UV irradiance sensor readings were compared against a calibrated reference sensor weekly during the testing period. The percent difference between the system sensor and the reference sensor readings are presented in Table 4-3. As shown, the output difference between the system sensor and the reference sensor increased from an initial value of 2.51% to a maximum of 10.6 % and settled to 4.96% after 1035 hours of lamp operation. The variability and lack of a consistent trend in the data indicates there was no significant change in system UV irradiance sensor performance during the test period. As indicated in Table 4-3, the repaired system sensor (See Section 4.8.3 for details) was returned on 11/27/01 and installed during the weekly sensor calibration conducted on 11/28/01.

After the completion of testing, the extent of lamp sleeve fouling was assessed by removing and visually examining the lamp sleeve affecting the UV irradiance sensor (*i.e.* Lamp No. 2). White deposits were noted along the length of the lamp sleeve. To quantify the extent of fouling a set of UV irradiance readings were taken using the used lamp sleeve and a new lamp sleeve. The first reading was taken with the used lamp sleeve. Next, the lamp sleeve was replaced with a new sleeve and the UV irradiance

was again recorded. The lamp sleeve fouling data is presented in Table 4-4. As shown, the UV irradiance increased by 35.5% (2.51 to 3.40 mW/cm^2) when the used lamp sleeve was replaced with the new lamp sleeve. The UV-254 transmittance of the feed water was similar during both readings.

An attempt was also made to quantify the effect of lamp aging on lamp performance by comparing the irradiance measurements taken near the beginning of the testing to that taken at the end of the testing. To isolate the effect of lamp aging on performance, both measurements were recorded with a new UV sensor window and lamp sleeve (Lamp No. 2). The lamp aging data is provided in Table 4-5. As presented, the UV irradiance decreased by 34.9% (5.22 to 3.40 mW/cm^2) after approximately 1004 hours of lamp operation. However, this decrease in UV irradiance cannot be attributed to lamp aging. As shown in the Table 4-5, the UV-254 transmittance of the feed water was significantly higher during the initial measurement than during the final measurement (88.2% after 49.1 hours of lamp operation and 83.2% after 1053 hours of lamp operation). This decrease in UV-254 transmittance also decreases UV irradiance, and as a result, no inferences can be made regarding the effect of lamp aging on performance.

4.3 Task 2: Test Runs for Feed Water and Effluent Water Quality

Several water quality parameters were monitored during the UV testing. The following provides a summary of the water quality data collected over the testing period.

4.3.1 UV-254 Absorbance and UV-254 Transmittance

Figure 4-3 and Appendix A presents feed and effluent values, respectively for UV-254 Absorbance and UV-254 Transmittance as provided by the City of San Diego Laboratory for samples taken throughout the testing period. As shown in Figure 4-3, feed water UV-254 absorbance (UV-254 transmittance) values measured between 11/14/01 and 12/3/01 ranged from 0.042 cm^{-1} (90.8%) to 0.068 cm^{-1} (85.5%). Effluent UV-254 absorbance (UV-254 transmittance) ranged from 0.044 cm^{-1} (90.4%) to 0.076 cm^{-1} (83.9%). Comparison of the feed and effluent UV-254 absorbance indicate the UV-254 absorbance was not altered as the water passed through the Atlantic Megatron reactor.

4.3.2 Indigenous Bacterial Inactivation

The inactivation of naturally occurring bacteria present in the feed water was also monitored during the ETV study. Table 4-6 provides results from the Marine Micro Laboratory for all HPC samples taken during the test period. As indicated, all measurements of HPC bacteria in both the feed and effluent water were ≤ 1 cfu/mL, which is the detection limit. The absence of HPC is expected since the feed water to the UV reactor, Otay Treatment Plant effluent, had been exposed to free chlorine through the full-scale plant filters.

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4.3.3 Other Water Quality Parameters

Table 4-7 summarizes the results of all water quality parameters sampled in the feed water and effluent of the Atlantic UV system during the test period. The table presents count, median, range, average, standard deviation and 95 percent confidence interval of the water quality parameters sampled. Based on the results, the feed water to the UV system over the testing period can be characterized as moderate in alkalinity and high in hardness with significant levels of iron and low levels of manganese. The feed water pH ranged from 7.6 to 8.6. Organic parameters are also relatively high, with TOC ranging from 2.28 mg/L to 4.56 mg/L. In addition, the UV-254 absorbance (cm^{-1}) ranged from 0.042 to 0.068, corresponding to a range of UV-254 transmittance (%) from 90.8 to 85.5, respectively. The turbidity was very low, as expected for filtered water, averaging 0.10 NTU. Lastly, the free chlorine present in the feed water ranged from 0.07 mg/L to 3.20 mg/L. As indicated in Figure 4-7, the broad range of free chlorine is due to a measurement of 3.20 mg/L which occurred on 11/20/01 due to failure of the effluent pump at the Otay Water Filtration plant. No significant change was observed in the alkalinity, total hardness, calcium hardness, iron, manganese, nitrate, and color across the reactor. In addition, there was no apparent reduction of TOC or UV-254 observed.

4.4   Task 3: Documentation of Operating Conditions and Treatment Equipment

The Atlantic Megatron M250 disinfection system was operated at a flow rate of 350 gpm ± 10% and a power setting of 100%, with four automatic cleanings per day, for a period of more than 27 days (720 hours). System flow and UV irradiance data were collected every two minutes using a datalogger. Power consumption, pressure loss through the UV reactor (differential pressure) and feed pressure were also collected. The operational data is summarized in Table 4-8. The table presents count, median, range, average, standard deviation and 95 percent confidence interval of the operational parameters monitored. The operational data summarized includes the total power consumption of the system, which was measured with an amp clamp and voltmeter. The total system power was used to assess the total lamp power because it was not feasible to measure the power requirement of each of the 19 lamps individually. The manufacturer verified that the power requirement of other standard system components such as the LED display, elapsed timer indicator, internal blower, compressor, and the UV Monitor, are negligible and therefore the total system power requirement was an accurate measure of the lamp power requirement. A memorandum from Atlantic Ultraviolet Corporation addressing the Megatron M250 power consumption is presented in Appendix A. As shown in Table 4-8, the system power requirement remained stable for the entire testing period. The system feed pressure was a function of the relative positioning of valves before and after the UV unit and varied slightly with each adjustment. It should be noted that on 11/16/01 a significant adjustment was made to the position of the valves before and after the UV unit to lower the system pressure. This adjustment was necessary because the system pressure was approaching the limit of the pre and post reactor pressure gauges. As shown in Table 4-8, this resulted in the system pressure to range from 6 to 13 psi over the entire testing period.

4.5   Task 4: Documentation of Equipment Performance: Microbial Inactivation

To demonstrate the microbial inactivation ability of the Atlantic Megatron M250 disinfection system, three full-scale challenge tests were conducted with MS2 virus on 11/14/01. UV estimated dose using MS2 virus is used as an indicator to obtain the log inactivation of other microorganisms such as *Cryptosporidium* and *Giardia*. The MS2 challenge tests were conducted at a flow rate of 350 ±10% gpm, lamp power setting of 100% and feed water UV-254 transmittance of 90.6%. Three sets of feed and effluent samples were collected in each of the three challenge tests conducted. The feed and effluent concentrations and log removal of virus during the seeding are presented in Table 4-9. Figure 4-4 presents the log removal results graphically. The irradiance values recorded from the system during the three challenge experiments ranged from 4.79 to 4.80 mW/cm^2. During the three challenge experiments, the feed MS2 virus concentration ranged from 1.6×10^5 pfu/100mL to 3.1×10^5 pfu/100mL, while the effluent MS2 concentration ranged from 2.2×10^3 pfu/100mL to 3.2×10^3 pfu/100mL. The microbial inactivation observed during the challenge tests ranged from 1.7 to 2.1 logs, with a 95 percent confidence interval for MS2 virus log inactivation of 1.9 log. Lastly, as indicated in Table 4-9, the travel stock (trip control), consisting of a (1:25) dilution of the seed stock, contained 2.9×10^{11} pfu/100 ml. Multiplying this value by a factor of 25 indicates the travel stock (trip control) was approximately 7.3×10^{12}/100 ml. The purpose of the travel stock (trip control) was to measure the seed stock concentration used to generate the influent feed.

Negative control samples, without the addition of MS2 virus, demonstrated that no MS2 virus was present in the feed water to the UV system. Positive control samples, taken after the completion of the challenge tests, demonstrated there was no inactivation of MS2 virus with the system UV lamps turned off.

A collimated beam test was conducted on the same day (11/14/01) as the challenge tests to ensure the integrity of the MS2 stock and to estimate the effective dose achieved during the flow through challenge study. The water used for the test was collected from the UV system feed during the same time period as the challenge testing. The results of the test indicate 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. A memo explaining the occurrence and copies of the raw data sheets documenting the over dilution were obtained from the Marine Micro lab and are presented in Appendix A and B, respectively. Analysis of this collimated beam data indicates the results do not meet the quality control criteria outlined in the NWRI Ultraviolet Disinfection Guidance Manual (NWRI, AWWARF 2000), which requires 80% of the data to fall in the area bounded by the following equations:

$$-\log_{10}(N/N_0) = 0.040 * [\text{UV dose, mJ/cm}^2] + 0.64$$
$$-\log_{10}(N/N_0) = 0.033 * [\text{UV dose, mJ/cm}^2] + 0.20$$

Where:

      N = Concentration of infective MS-2 after UV exposure

      N_0 = Concentration of infective MS-2 at dose zero.

As a result, it was decided the results were inadequate to predict the effective dose achieved during the flow through reactor testing. 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. The results of this collimated beam test are presented in Table 4-10. A dose response curve was constructed based on the results and is presented in Figure 4-5. Based on the dose response relationship shown in Figure 4-5, 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 decision to use the collimated beam data from 9/14/01 was supported by the fact that the dose response data meets the NWRI quality control requirements described above. In addition, both the collimated beam and flow through reactor challenge tests were conducted using effluent from the OTWTP and seed stock from the same batch. It should be noted, due to seasonal changes in feed water quality to the OTWTP, there was a difference of UV transmittance (i.e. 90.6% vs. 83.1%) during the flow through reactor challenge test and the collimated beam test used to predict the effective dose. However, this variation does not impact the accuracy of the estimated effective dose because the equation used to calculate dose for the collimated beam test includes a correction factor for UV transmittance (%). Lastly, the viability of the seed used during the flow through challenge study was verified by comparing the variability of travel stock samples (1:25) dilution taken on 9/14/01 and 11/14/01. The seed stock viability was considered acceptable if the relative percent difference (RPD) between these travel stock samples (36.6%) was less than the maximum RPD (81.8%) of all the feed and positive control samples measured during the flow through challenge study.

4.6   Task 5: Data Management

4.6.1   Data Recording

Data were recorded manually on operational and water quality data sheets prepared specifically for the study. In addition, other data and observations such as the system calibration results were recorded manually on data forms and laboratory notebooks. All of the raw data sheets are included in Appendix B of this report.

4.6.2   Data Entry, Validation, and Reduction

Data were first entered from raw data sheets into similarly designed data entry forms in a spreadsheet. Following data entry, the spreadsheet was printed and checked against handwritten datasheets. All corrections were noted on the electronic hard copies and then corrected on the screen. The hardcopy of the electronic data are included in Appendix C of this report.

4.7   Task 6: Quality Assurance/Quality Control (QA/QC)

The objective of this task is to assure the high quality and integrity of all measurements of operational and water quality parameters during the ETV program. Below is a summary of the analyses conducted to ensure the correctness of the data.

4.7.1 Data Correctness

Data correctness refers to data quality, for which there are five indicators:

- Representativeness
- Statistical Uncertainty
- Completeness
- Accuracy
- Precision

Calculation of the above data quality indicators were outlined in the Methods and Procedures section (Chapter 3). All water quality samples were collected according to the sampling procedures specified by the NSF protocols, which ensured the representativeness of the samples. Below is a summary of the calculated indicators.

4.7.2 Statistical Uncertainty

Ninety-five percent confidence intervals were calculated for water quality parameters sampled from the feed and effluent of the Atlantic Megatron Model M250 unit for which eight or more samples were collected. These include data from parameters measured onsite including pH, temperature, turbidity, free and total chlorine; and laboratory data including UV254, total organic carbon (TOC) and HPC. Ninety-five percent confidence intervals were presented in the summary tables referenced in Section 4.3.

4.7.3 Completeness

Data completeness refers to the amount of data collected during the ETV study as compared to the amount of data that were proposed in the PSTP. Calculation of data completeness was made for onsite water quality measurements, laboratory water quality measurements, and operational data recording. The data collected for all parameters was 100% complete and for many parameters additional samples were collected. These calculations are presented in Appendix A of this report.

4.7.4 Accuracy

Accuracy is quantified as the percent recovery of a parameter in a sample to which a known quantity of that parameter was added. An example of an accuracy determination in this ETV is the analysis of a turbidity proficiency sample and comparison of the measured turbidity to the known level of turbidity in the sample. Calculations of data accuracy were made to ensure the accuracy of the onsite desktop turbidimeter used in the study. All calculations were within 15% of the proficiency sample values. The accuracy calculations made throughout the study are presented in Appendix A.

4.7.5   Precision and Relative Percent Deviation

Duplicate water quality samples were analyzed to determine the consistency of sampling and analysis using relative percent deviation. Relative percent deviation calculations were also performed on online and desktop turbidity measurements. Calculations of relative percent deviation are included in Appendix A of this report. Precision was calculated from the standard deviation of replicate analysis.

4.8 Additional ETV Program Requirements

4.8.1   Operation and Maintenance (O&M) Manual

The O&M manual for the Atlantic Megatron M250 Disinfection system supplied by the manufacturer was reviewed during the ETV testing program. The review comments for the O&M manual is presented in Table 4-11. The review found the O&M manual to be a useful resource to obtain information on the configuration, operation, maintenance and trouble shooting the system. The manual makes excellent use of tables and graphics to organize and clarify the presentation of material.

4.8.2   System Efficiencies and Chemical Consumption

The system efficiency can be defined in terms of the power input to the system that produces unit inactivation of the virus during the challenge tests. From Table 4-8, the average system power input was 1.1 kW corresponding to 100% lamp power. The time required to treat 1000 gallons at a flow of 350 gpm will be 1000/(350*60) = 0.048 hours. So, energy supplied to this volume = 1.1*0.048= 0.053 kWh.

The average log inactivation achieved during the challenge tests was 1.9 log inactivation of MS2 virus. Therefore, the efficiency of the UV unit during the challenge tests was 0.03 kWh/log virus inactivation / 1000 gallons treated. The UV-254 transmittance of the feed water was 90.6% during the virus seeding.

During the testing period, a small amount of alcohol and acid were used to wipe the irradiance sensor window. No other chemical consumption was associated with the Atlantic Megatron UV system.

4.8.3   Equipment Deficiencies Experienced During the ETV Program

On 11/21/01 the UV irradiance increased to 16.6 mW/cm^2 following start up, after the sensor had been removed from the system to clean the sensor window. After discussing with the manufacturer, it is believed that water was splashed to the inside of the sensor when it was removed for cleaning causing it to short circuit and read the maximum value. It should be noted that during typical operation of UV systems it is necessary to remove and replace the system UV irradiance sensor with a reference sensor on a regular basis to verify the performance of the system sensor. The sensor was sent to the manufacture for repair and returned on 11/27/01. The precision of the repaired system sensor was then verified by comparing the irradiance value to that of a reference sensor, which was also provided by the manufacturer at the onset of the testing.

As stated in Section 4.2, wiping of the UV irradiance sensor window requires the sensor to be removed from the system. Currently, the Megatron M250 system uses a tapered pipe thread to establish a hydraulic seal between the UV irradiance sensor and the pressure vessel. As a result, small variations can occur in the distance between the UV irradiance sensor and the UV lamp each time the sensor is removed and replaced. This variation may impact the amount of UV intensity measured by the UV irradiance sensor. A memo provided by the Atlantic Ultraviolet Corporation which addressees this issue and provides plans for an improved design is located in Appendix A.

No other equipment deficiencies were experienced from the Atlantic Megatron Model M250 UV System during the testing period. However, minor problems associated with external equipment and general operational problems which occurred during the testing period are presented, along with any corrective actions taken, in Appendix A.

4.8.4   Audit Reports
A copy of the audit report is included in Appendix A of this report.

Chapter 5
References

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Tables and Figures

Table 3-1. Water Quality Analytical Methods.

Parameter	Sample Frequency	Facility	Method
General Water Quality			
pH	Twice Daily	On-Site	SM 4500H+
Total Alkalinity	Semi Weekly	Laboratory	SM 2320 B
Total Hardness	Semi Weekly	Laboratory	SM 2340 C
Temperature	Twice Daily	On-Site	SM 2550 B
Iron	Semi Weekly	Laboratory	SM 3111 B
Manganese	Semi Weekly	Laboratory	EPA 200.8
Nitrate	Semi Weekly	Laboratory	EPA 300 A
Free and Total Chlorine	Twice Daily	On-Site	Hach/ SM 4500 CL:G
Particle Characterization			
Turbidity (Bench-Top)	Twice Daily	On-Site	SM 2130 B
Organic Material			
TOC	Daily	Laboratory	SM 5310 C
True Color	Semi Weekly	Laboratory	SM 2120 at 455 nm
UV Absorbance at 254 nm	Daily	Laboratory	SM 5910 B
Microbiological Analyses			
HPC	Daily	Laboratory	SM 9215 B
MS2 Virus	During seeding	Laboratory	SM 9224 F

Table 3-2. UV Disinfection System Operating Data Recording Schedule.

Operations Parameter	Action
Flow Rate	Checked and recorded at least 3 times a day on weekdays and once a day on weekends. Recorded on a datalogger every 2 minutes. Adjusted when 10% above or below target. Recorded both before and after adjustment.
Exposure Time*	Recorded retention or cycle times when applicable. If variable, record degree of variation.
UV Irradiance	Checked and recorded at least 3 times a day on weekdays and once a day on weekends. Recorded on a datalogger every 2 minutes.
UV Sensor	Recorded output from in-line monitors. Recorded changes in lamp UV irradiance following each cleaning. Verified internal UV sensors against a reference sensor on a weekly basis.
Lamp Fouling/Cleaning System	Recorded frequency of sleeve cleaning.
Lamp Hours	Recorded daily for each lamp
Electric Power	Recorded daily the power level that reactor was operating at and recorded current use by each lamp and voltage across each lamp.
Lamp Cycles	Recorded frequency of lamp on/off cycles

* Exposure time was determined from the internal volume of UV inactivation chamber (24.4 US gallons) and the flowrate.

Table 3-3. Seeding Challenge Details.

Experiment	# Feedwater Samples	# Effluent Samples
Negative Control (no virus)	2	0
Challenge # 1	3	3
Challenge # 2	3	3
Challenge # 3	3	3
Positive Control (lamps off)	3	3

Table 4-1. Lamp Cleaning Data.

Cleaning Date	Lamp Hours (field recorded)	Lamp Hours (actual)	UV Irradiance (mW/cm^2)		% Change	Cleaning Type	Cleaning Interval (lamp hours)
			Before Cleaning	After Cleaning			
11/14/01	769.6	258.4	4.77	4.78	0.21%	Manual	17
11/15/01	793.8	282.6	4.20	4.20	0.00%	Auto	24
11/16/01	817.5	306.3	4.59	4.58	-0.22%	Auto	24
11/16/01	822.1	310.9	3.69	3.69	0.00%	Manual	5
11/18/01	865.2	354.0	4.75	4.75	0.00%	Auto	43
11/19/01	889	377.8	4.26	4.25	-0.23%	Auto	24
11/20/01	912.1	400.9	6.25	6.23	-0.32%	Manual	23
11/20/01	917.8	406.6	4.65	4.66	0.22%	Auto	6
11/23/01	986.2	475.0	4.81	4.82	0.21%	Auto	68
11/24/01	1004.1	492.9	4.99	5.01	0.40%	Auto	18
11/26/01	1051.9	540.7	4.61	4.61	0.00%	Auto	48
11/26/01	1056.9	545.7	4.51	4.51	0.00%	Auto	5
11/27/01	1075.6	564.4	4.28	4.27	-0.23%	Auto	19
11/28/01	1099.1	587.9	4.11	4.13	0.49%	Auto	24
11/29/01	1116.8	605.6	3.78	3.79	0.26%	Auto	18
11/30/01	1140.8	629.6	4.15	4.15	0.00%	Auto	24
12/4/01	1236.8	725.6	4.78	4.78	0.00%	Auto	96
12/5/01	1260.1	748.9	4.78	4.84	1.26%	Auto	23
12/6/01	1284.1	772.9	4.85	4.88	0.62%	Auto	24
12/6/01	1290.1	778.9	4.76	4.78	0.42%	Auto	6
12/7/01	1308.1	796.9	4.62	4.63	0.22%	Auto	18
12/7/01	1312.1	800.9	4.57	4.50	-1.53%	Auto	4
12/8/01	1332.1	820.9	4.61	4.62	0.22%	Auto	20
12/9/01	1356.1	844.9	4.50	4.53	0.67%	Auto	24
12/10/01	1380.1	868.9	3.21	3.21	0.00%	Auto	24
12/10/01	1386.1	874.9	3.03	3.04	0.33%	Auto	6
12/11/01	1404.1	892.9	3.15	3.18	0.95%	Auto	18
12/11/01	1409.5	898.3	3.03	3.04	0.33%	Auto	5
12/12/01	1427.5	916.3	3.01	3.02	0.33%	Auto	18
12/12/01	1433.5	922.3	3.42	3.44	0.58%	Auto	6
12/13/01	1451.5	940.3	2.99	3.00	0.33%	Auto	18
12/13/01	1457.5	946.3	2.75	2.75	0.00%	Auto	6
12/14/01	1475.1	963.9	2.56	2.59	1.17%	Auto	18
12/14/01	1481.5	970.3	2.58	2.59	0.39%	Auto	6
12/17/01	1541.7	1030.5	2.33	2.33	0.00%	Auto	60
12/17/01	1547.6	1036.4	2.35	2.38	1.28%	Auto	6
				Average % Change:	0.23%		

Note: "actual lamp hours" are determined by subtracting the initial lamp hours displayed on the system run clock (i.e. 511.2) at the time of installing the lamps from the "field recorded lamp hours" which were recorded from the system run clock during scheduled cleanings; Irradiance values for cleanings that occurred on a fixed interval are shown in Figure 4-2.

Table 4-2. Irradiance Sensor Window Cleaning Data.

Date	Lamp Hours	UV Irradiance (mW/cm^2)		Cleaning Method	% Change
		before cleaning	after cleaning		
11/15/01	286.8	4.08	4.33	Wipe/Alcohol	6.13%
11/16/01	306.6	4.58	4.32	Wipe/Alcohol	-5.68%
11/17/01	327.7	4.71	4.79	Wipe/Alcohol	1.70%
11/18/01	354.1	4.75	4.45	Wipe/Alcohol	-6.32%
11/19/01	383.1	4.13	4.94	Wipe/Alcohol	19.61%
11/20/01	404.3	4.80	4.74	Replaced Window	-1.25%
11/21/01	423.6	5.81	[1] 5.35	Wipe/Alcohol	-7.92%
11/22/01	446.8	5.69	5.50	Wipe/Alcohol	-3.34%
11/23/01	470.7	5.05	4.63	Wipe/Alcohol	-8.32%
11/24/01	493.7	5.01	4.70	Wipe/Alcohol	-6.19%
11/25/01	523.8	4.84	4.52	Wipe/Alcohol	-6.61%
11/26/01	542.2	4.56	4.61	Wipe/Alcohol	1.10%
11/27/01	563.6	4.18	4.26	Replaced Window	1.91%
11/28/01	587.9	3.67	4.11	Wipe/Acid	11.99%
11/29/01	605.6	3.98	3.84	Wipe/Acid	-3.52%
12/4/01	726.1	4.78	4.89	Replaced Window	2.30%
12/11/01	893.1	2.91	3.04	Wipe/Alcohol	4.47%
12/17/01	1035.8	2.44	2.38	Replaced Window	-2.46%
				Average	-0.13%

[1] Replaced reference sensor with orginal (repaired sensor).

Table 4-3. Sensor Calibration Data.

Date	Lamp Hours	UV Irradiance (mW/cm^2)		% Difference
		Sensor	Reference Sensor	
10/25/01	0	6.37	6.21	2.51
11/6/01	124.2	4.94	4.65	5.87
11/13/01	239.0	4.42	4.89	10.6
11/20/01	405.2	4.75	4.36	8.21
11/28/01	583.6	3.85	4.13	7.27 [1]
12/4/01	726.1	4.78	5.07	6.07
12/11/01	893.1	2.91	3.09	6.19
12/17/01	1035.4	2.42	2.54	4.96

[1] Note: Used the repaired sensor provided by the manufacturer on 11/27/01.

Table 4-4. Lamp Sleeve Fouling Data.

Configuration	UV Irradiance (mW/cm²)	% Increase	%UVT	Hours of Operation
Old lamp sleeve No. 2, new sensor window	2.51	reference	82.7	1053.4
New lamp sleeve No. 2, new sensor window	3.40	35.5	83.2	1053.5

Note: The irradiance value for the new lamp sleeve was recorded ~20 minutes after start up. The same lamp was used during both readings. Hours of operation shown represent the actual hours the lamp was operated after receipt from manufacturer.

Table 4-5. Lamp Aging Data.

Condition	UV Irradiance (mW/cm²)	% Decrease	UVT (%)
Initial (49.1 hours)	5.22	reference	88.2
Final (1053.5 hours)	3.40	34.9	83.2

Note: Initial reading values were taken on 11/3/01, 9:52 AM.

New Lamp Sleeve was used for final reading

Table 4-6. Summary of Microbiological Water Quality Parameters for the Atlantic Megatron M250 System.

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95 Percent Confidence Interval
Feed							
HPC	cfu/mL	16	<1	<1 - <1	<1	0	NA
Effluent							
HPC	cfu/mL	16	<1	<1 - <1	<1	0	NA

Table 4-7. Summary of General Water Quality Parameters for the Atlantic Megatron M250 System (November 14 - December 3, 2001).

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	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	3.52-3.62
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	0.057-0.057
pH	std. Unit	34	8.3	7.6-8.6	8.3	0.2	8.3-8.3
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	19.0-19.0
Free Chlorine	mg/L	34	0.14	[1] 0.07 - 3.20	0.24	0.53	0.22-0.26
Total Chlorine	mg/L	34	2.36	1.56 - 3.34	2.29	0.37	2.28-2.30
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	3.48-3.56
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	0.060-0.062
pH	std. Unit	34	8.3	7.4 - 8.7	8.3	0.2	8.3-8.3
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	19.1-19.1
Free Chlorine	mg/L	34	0.11	[1] 0.05 - 2.68	0.19	0.44	0.18-0.20
Total Chlorine	mg/L	34	2.34	1.66 - 3.14	2.25	0.29	2.24-2.26

[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.

Table 4-8. Operational Data Summary for the Atlantic Megatron M250 System.

Parameter	Unit	Count	Median	Range	Average	Standard Deviation	95% Confidence Interval
Total Power	kW	34	1.1	1.0 - 1.1	1.1	0.039	1.1 - 1.1
Differential Pressure	in of water	116	1.4	0.70 - 1.9	1.3	0.23	1.3 - 1.3
Feed Pressure	psi	116	6.6	6.0 - 13	7.1	1.7	6.8 - 7.4
UV Irradiance	mW/cm2	23891	4.5	0.21 - 16	4.1	0.90	4.1 - 4.1
Flow	gpm	23473	350	13 - 390	340	32	340 - 340

Power kW = Voltage (V) x Current (I) X Power Factor (0.98)/1000

Table 4-9. MS2 Virus Microbial Challenge Results for the Atlantic Megatron M250 System (November 14, 2001).

Flow Rate: 350 gpm +/- 10%
Lamp Power : 100%
Feedwater UVT: 90.6%

Sample #	Feed (pfu/100ml)	Effluent (pfu/100mL)	Log Inactivation
Negative Control			
1	<1	N/A	N/A
2	<1	N/A	N/A
Challenge 1			
1	2.0E+05	2.5E+03	1.9
2	1.6E+05	3.0E+03	1.7
3	2.0E+05	3.2E+03	1.8
Challenge 2			
1	1.9E+05	2.2E+03	1.9
2	2.5E+05	2.3E+03	2.0
3	1.9E+05	2.3E+03	1.9
Challenge 3			
1	2.4E+05	2.8E+03	1.9
2	3.1E+05	2.4E+03	2.1
3	1.8E+05	2.2E+03	1.9
Positive Control (Lamps off) *			
1	1.3E+05	1.5E+05	-0.06
2	2.6E+05	2.5E+05	0.02
3	1.9E+05	2.0E+05	-0.02

* Positive control results are considered acceptable if the maximum difference between the feed
 and effluent values (2.0 E+04) are less than the maximum variable in the feed concentration during the
challenge and positive control experiments (1.8 E+05).

Note: feed and effleunt samples were time matched. Travel Stock (1:25 dilution) = 2.9E+11 pfu/100 ml.

Table 4-10. Collimated Beam Testing Results (September 14, 2001).

UV Dose mJ/cm2	MS2 Count MS2/100mL	Log Inactivation
20	4.6E+08	1.0
45	3.4E+07	2.2
70	4.6E+06	3.0
95	3.4E+05	4.2
120	5.7E+04	5.0
145	3.2E+03	6.2
Feed 1	3.9E+09	
Feed 2	6.3E+09	
Feed Average	5.1E+09	

Table 4-11. Review of Manufacturer's Operations and Maintenance Manual for the Atlantic Megatron M250 System

O & M Manual	Grade	Comment
Overall Organization	+	• The O&M manual is well organized. The table of contents includes the following main sections: Warning Statement, Safety Instructions, Product Application, Installation, Maintenance, Trouble Shooting, Technical Specifications, Replacement Parts List and Warranty.
Operations Sections	+	• The *Product Application* section of the manual provides a general description of how the system is constructed and operated. The general operating principles described include water flow through the system, explanation of status display lights, details on the wiping mechanism and the state of water exiting the system. • Further operational information is provided under the *Installation* section of the manual. This section provides information regarding the initial set up of the system including details on positioning & plumbing of the system and lamp installation. The section also contains detailed information regarding the ultraviolet monitor with digital meter. This includes a description of the two operating modes of the system: "User Adjust" and "Factory Preset". A step by step procedure for making adjustments in the "User Adjust" mode is also provided which allows the user to set the UV Low set point. Lastly, information is provided regarding the operation of the automatic quartz sleeve wiper controller, which is optionally provided with the system. An outlined procedure for setting the times and days at which the sleeves will be automatically wiped is also provided. • The operations sections are well organized and make good use of tables, labeled photos and examples.
Ancillary Equipment Information	-	• The manual does not include literature on ancillary equipment. However, a table containing a list of replacement parts is included which contains specific part numbers, which can be used to order via the mfg.
Labeled Photos and Diagrams	+	• Makes excellent use of labeled photos and diagrams to identify various system components.
Use of Tables	+	• Manual makes good use of tables to organize and present information.
OVERALL COMMENT	+	• An excellent O&M manual. It is very well organized, well written, clear and complete. An excellent table of contents makes locating information in the manual a simple process. • The manual includes an good use of graphics to assist the reader's understanding.

Note: Grade of "+" indicates acceptable level of detail and presentation, grade of "-" indicates the manual would benefit from improvement in this area.
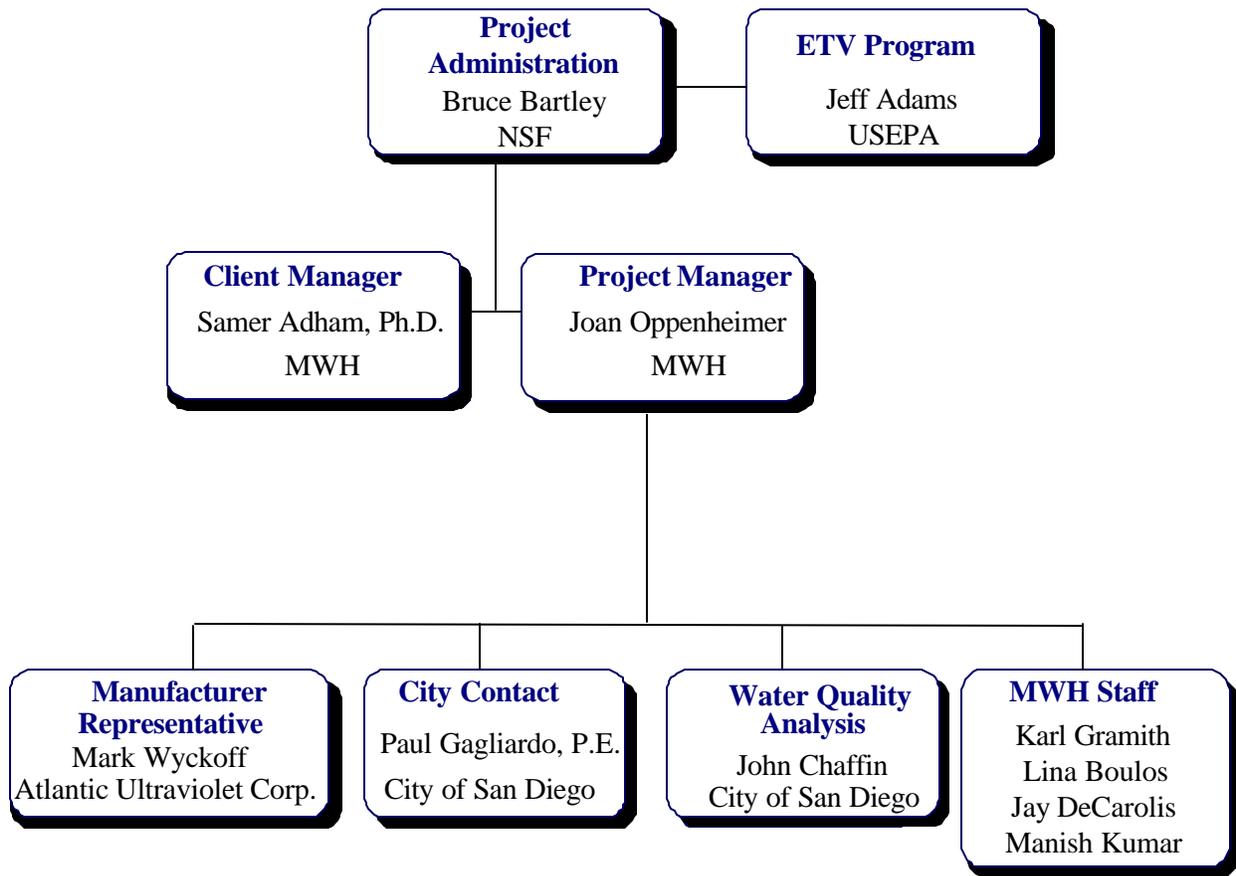
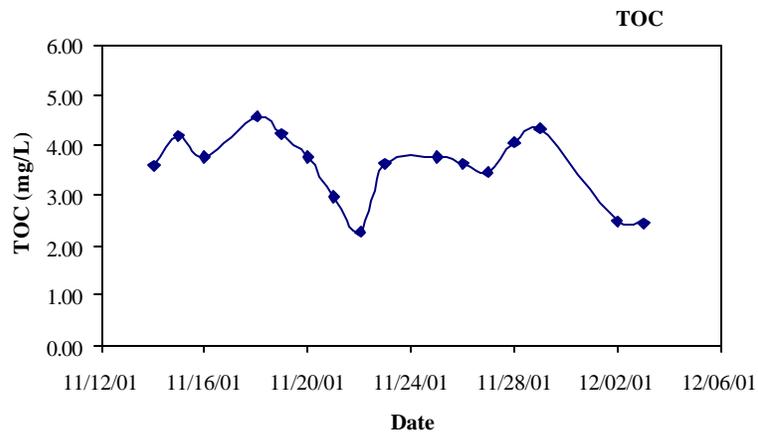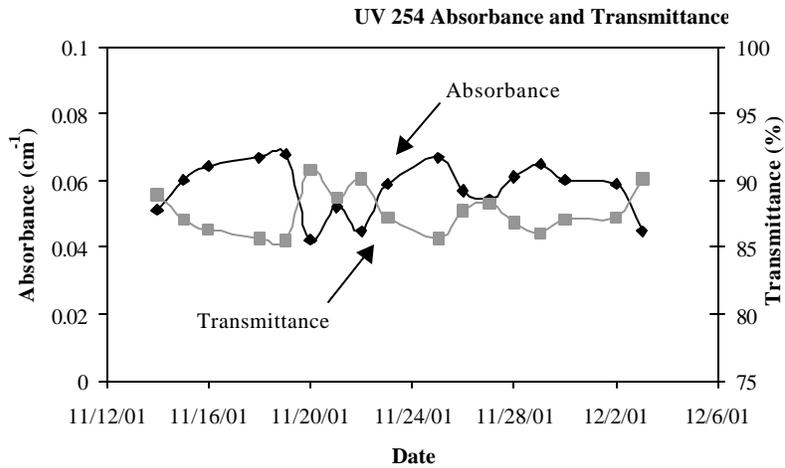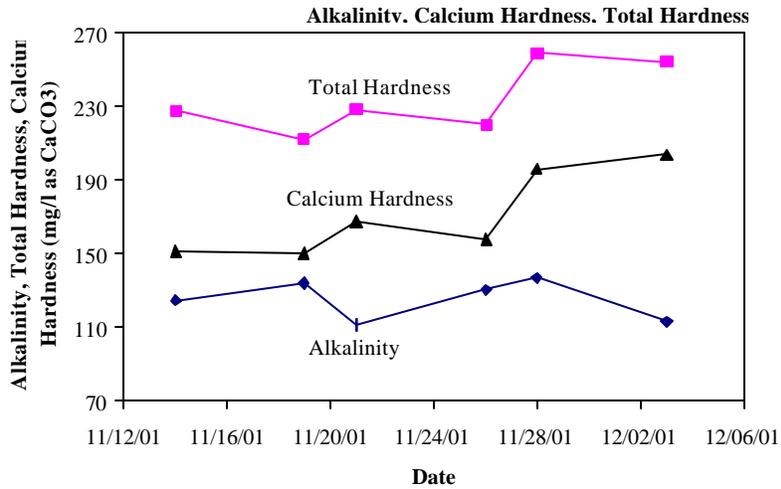**Figure 1-1. Organizational Chart Showing Lines of Communication.**

Figure 1-2. UV System Feed Water Characteristics: Atlantic Megatron M250 Verification Testing (11/14/01 – 12/03/01).
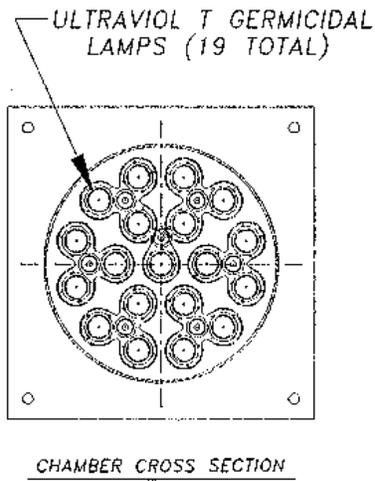
Figure 2-1. Lamp Configuration: Atlantic Megatron M250 System

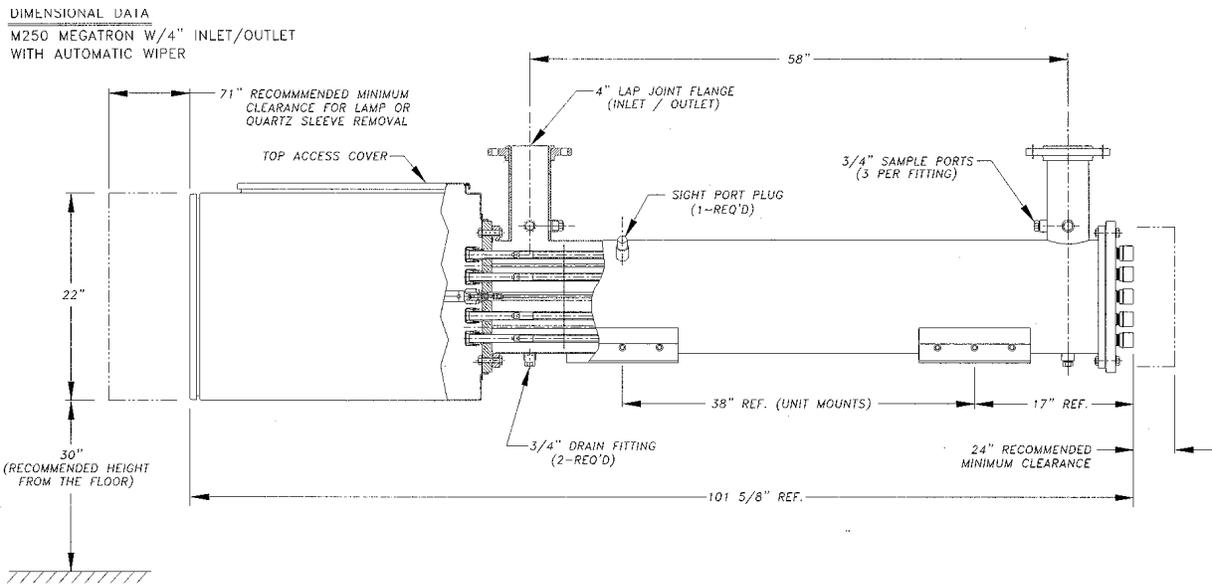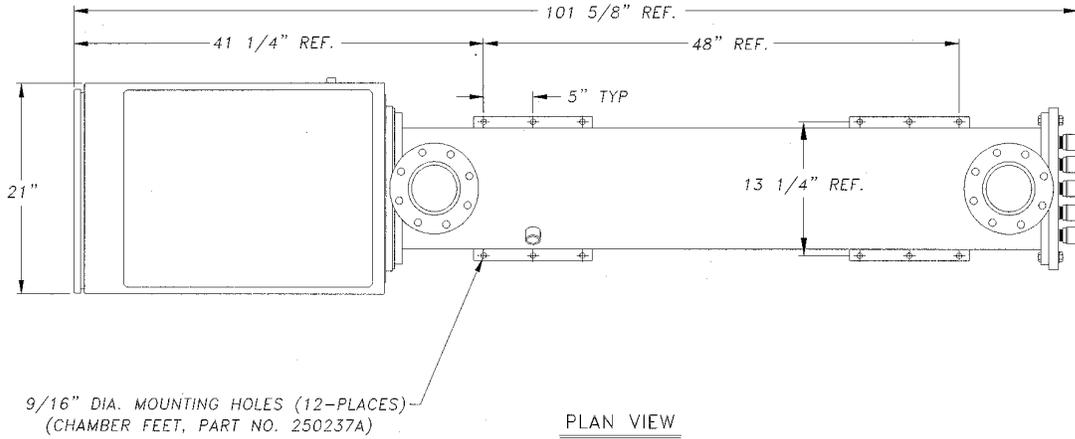

Figure 2-2. Photograph of the Atlantic Megatron M250 System.

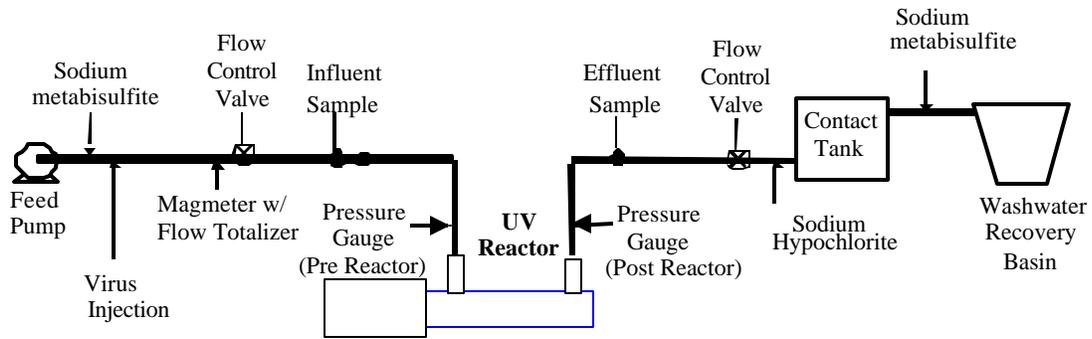**Figure 2-3. Schematic Diagram of the Atlantic Megatron M250 System.**

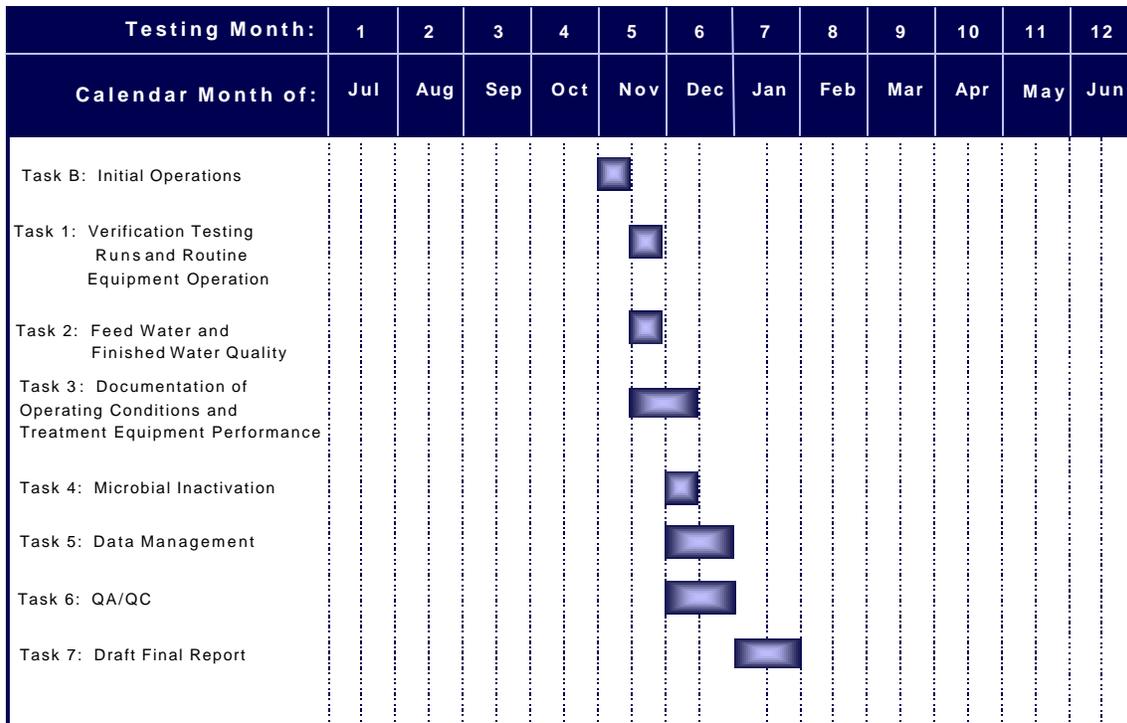**Figure 2-4. Schematic Atlantic Megatron M250 ETV Testing Treatment Process.**

Testing Month:	1	2	3	4	5	6	7	8	9	10	11	12
Calendar Month of:	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Task B: Initial Operations					■							
Task 1: Verification Testing Runs and Routine Equipment Operation					■							
Task 2: Feed Water and Finished Water Quality					■							
Task 3: Documentation of Operating Conditions and Treatment Equipment Performance					■■							
Task 4: Microbial Inactivation						■						
Task 5: Data Management						■■						
Task 6: QA/QC						■■						
Task 7: Draft Final Report							■■					

Figure 3-1. Atlantic UV Verification Testing Schedule.

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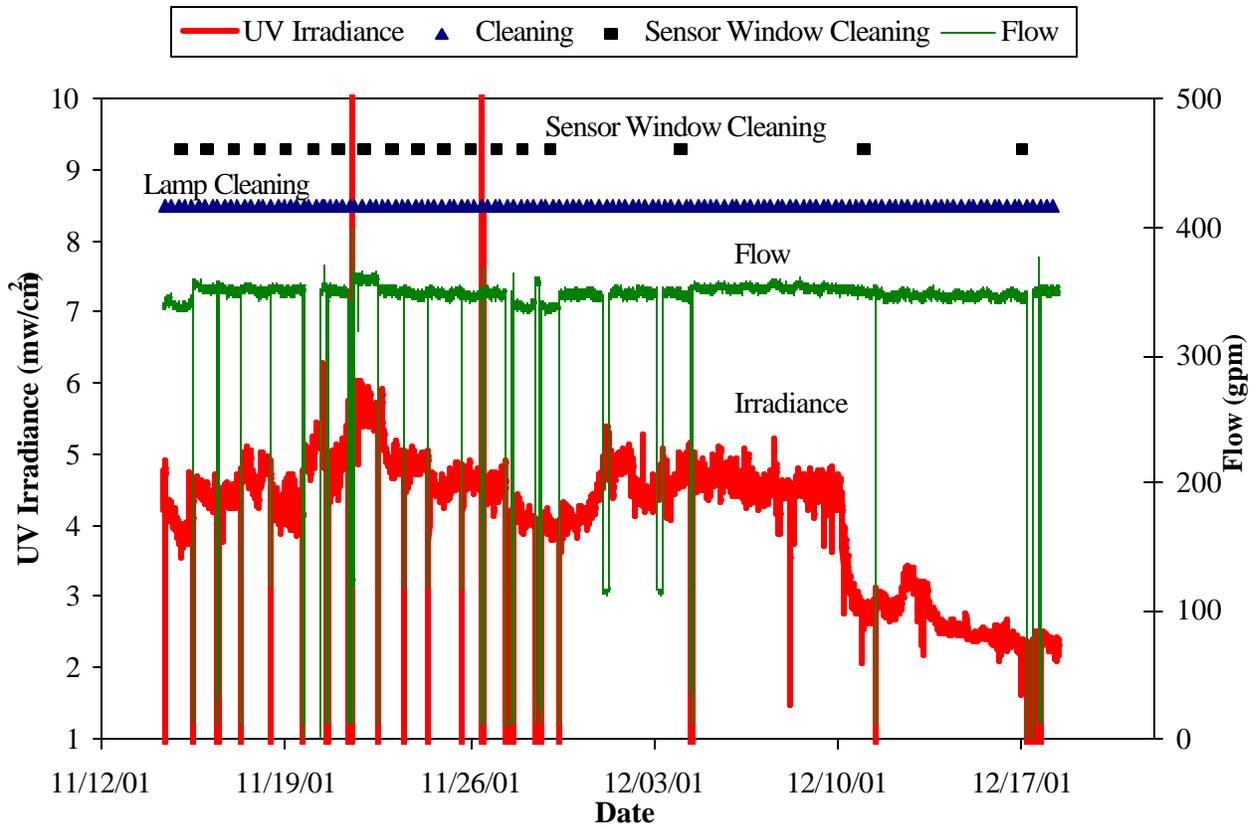
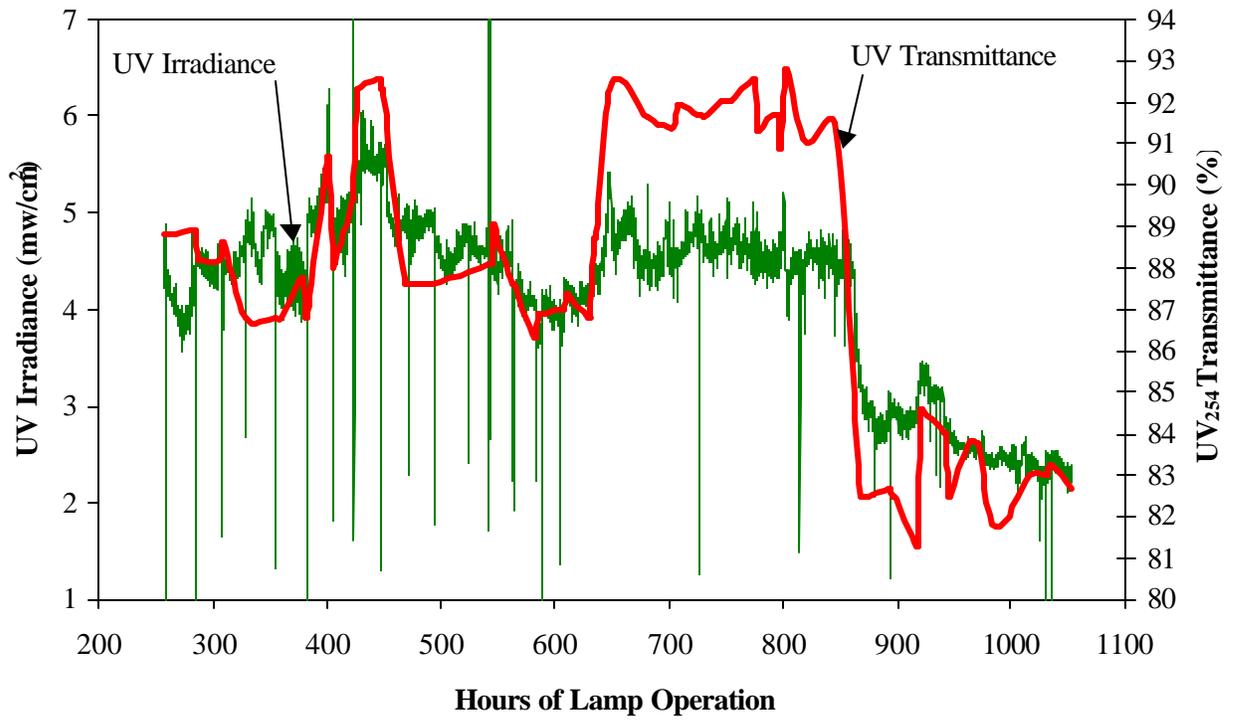**Figure 4-1. Operational Data During Atlantic Megatron M250 Testing Period.**

Figure 4-2. UV Irradiance and UV$_{254}$ Feed Water Transmittance During Testing Period.
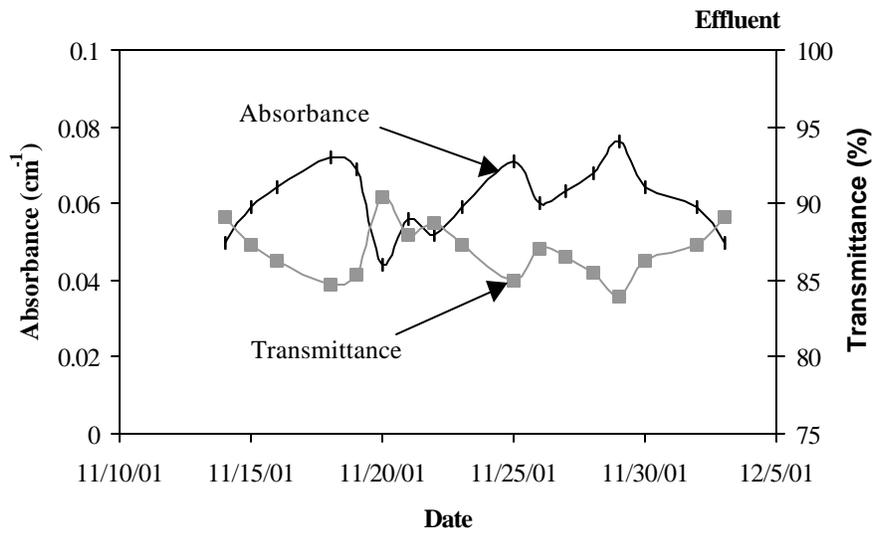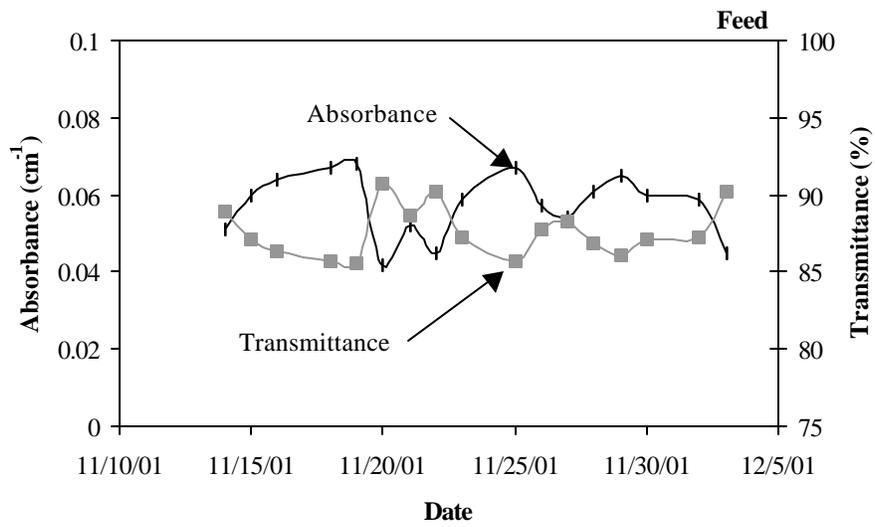
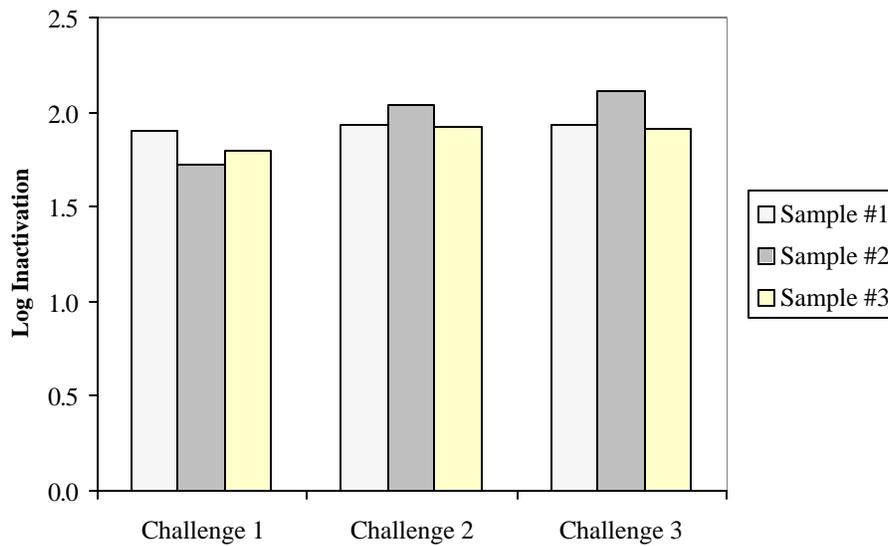**Figure 4-3. Laboratory UV Absorbance and Transmittance Feed and Effluent Water.**

**Figure 4-4. Virus Seeding Experiment Results
(November 14, 2001).**

$$y = 0.04x + 0.28$$
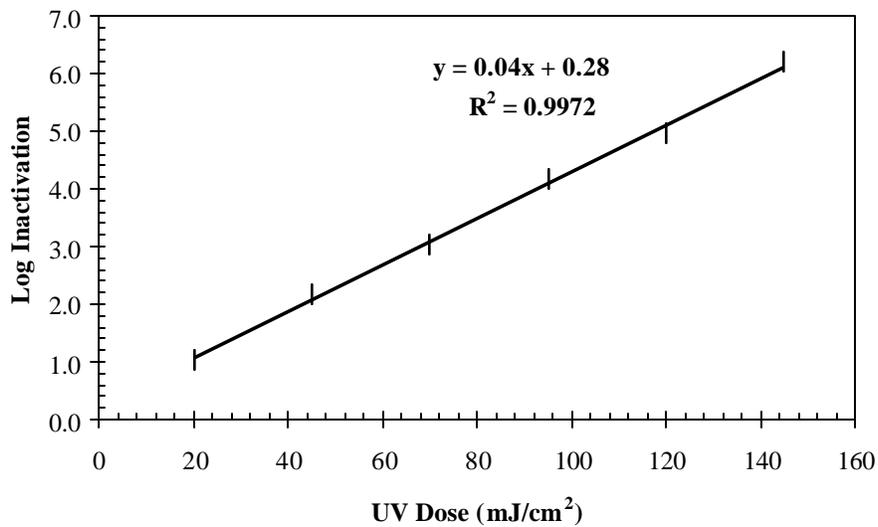$$R^2 = 0.9972$$

**Figure 4-5. Dose Response Curve from Collimated Beam Testing
(September 14, 2001).**