

US EPA ARCHIVE DOCUMENT

September 2007  
NSF 06/25/EPADWCTR  
EPA/600/R-07/109

# Environmental Technology Verification Report


## Removal of Synthetic Organic Chemical Contaminants in Drinking Water

RASco, Inc.  
Advanced Simultaneous Oxidation Process  
(ASOP™)

Prepared by



NSF International

 Under a Cooperative Agreement with  
U.S. Environmental Protection Agency

ET ✓ ET ✓ ET ✓

# THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM



U.S. Environmental Protection Agency



NSF International

## ETV Joint Verification Statement

<b>TECHNOLOGY TYPE:</b>	<b>POINT-OF-ENTRY DRINKING WATER TREATMENT SYSTEM</b>
<b>APPLICATION:</b>	<b>REMOVAL OF SYNTHETIC ORGANIC CHEMICAL CONTAMINANTS IN DRINKING WATER</b>
<b>PRODUCT NAME:</b>	<b>ADVANCED SIMULTANEOUS OXIDATION PROCESS (ASOP™)</b>
<b>VENDOR:</b>	<b>RASCO, INC.</b>
<b>ADDRESS:</b>	<b>1635-2 WOODSIDE DRIVE WOODBIDGE, VA 22191</b>
<b>PHONE:</b>	<b>703-643-2952</b>
<b>FAX:</b>	<b>703-497-2905</b>
<b>EMAIL:</b>	<b>ADMIN@RASCOENGINEERS.COM</b>

NSF International (NSF) manages the Drinking Water Systems (DWS) Center under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. The DWS Center recently evaluated the performance of the RASCO, Inc. Advanced Simultaneous Oxidation Process (ASOP™) Drinking Water Treatment Module. NSF performed all of the testing activities and also authored the verification report and this verification statement. The verification report contains a comprehensive description of the testing activities.

The EPA 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 accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups (consisting of buyers, vendor organizations, and permittees), 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.

**ABSTRACT**

The RASco, Inc. ASOP Drinking Water Treatment Module was tested at NSF's Laboratory for the reduction of the following chemicals of concern: aldicarb, benzene, carbofuran, chloroform, dichlorvos, dicrotophos, methomyl, mevinphos, nicotine, oxamyl, paraquat, phorate, sodium fluoroacetate, and strychnine. The ASOP is a component of RASco's Hyd-RO-Secure™ Series 2 Anti-Terrorism/Force Protection Drinking Water Treatment System, which uses reverse osmosis (RO), the ASOP module, and a post-ASOP activated carbon filtration to treat drinking water. The ASOP module uses ultraviolet light (UV) and ozone to oxidize contaminants. An activated carbon filter was evaluated to demonstrate its capability to adsorb any oxidation byproducts and/or the amounts of challenge chemicals not oxidized by the ASOP module. The target chemical challenge concentration was 1,000 micrograms per liter ( $\mu\text{g/L}$ ), and each challenge was 30 minutes in length. Both the ASOP module and activated carbon filter were tested at the same time, with the carbon filter plumbed downstream of the ASOP module. Treated water samples were collected from both the ASOP and carbon filter effluents, so that the ASOP module's performance could be evaluated alone, and also combined with activated carbon treatment. The percent reductions for the ASOP module alone ranged from zero for carbofuran, chloroform, and mevinphos, to 98% for strychnine. The combination of the ASOP and activated carbon filter removed all challenge chemicals, except paraquat, by 94% or more.

**TECHNOLOGY DESCRIPTION**

The following technology description was provided by the manufacturer and has not been verified.

The patent-pending RASco, Inc. ASOP module is marketed as a component of the point-of-entry Hyd-RO-Secure Series 2 Anti-Terrorism/Force Protection Drinking Water Treatment System. A complete Hyd-RO-Secure system consists of an RO module, the ASOP module, and an optional post-ASOP activated carbon filter. The Hyd-RO-Secure is a modular system, with the RO and ASOP components on individual platforms. The RO and activated carbon components are not standard, but rather are selected based on the site-specific application. The main components of the ASOP module are an Aquafine model CSL-4R-UV UV unit, an Ozotech model OZ2BTUSL ozone generator, an Ozotech model PP Phoenix oxygen generator to supply oxygen to the ozone generator, and an ozone contact tank. A Pentek model RFC20-BB activated carbon filter supplied by RASco was tested to demonstrate the ability of an activated carbon filter to adsorb any oxidation by-products and/or the amounts of challenge chemicals not oxidized by the ASOP module. The carbon filter was plumbed downstream of the ASOP module. A sampling valve was installed between the ASOP module contact tank and carbon filter to allow sampling of both the ASOP effluent and carbon filter effluent.

The ASOP module offers simultaneous treatment with both UV light and ozone, plus a contact tank (volume varies depending on installation) to complete the ozone oxidation treatment. The ozone is injected into the UV reactor vessel to oxidize contaminants synergistically with the UV light. The UV light has an output of 30,000 microwatt-seconds/ $\text{cm}^2$ . Delivery of ozone into the reaction chamber is controlled by adjusting the flow of oxygen into the ozone generator. The ASOP module as tested did not include any sensors for UV intensity, but it did include an oxidation reduction potential (ORP) meter immediately downstream of the contact tank to indirectly measure the ozone residual. The contact tank volume for the test module was 3 gallons (gal). The system is programmed so that the ozone generator turns on when the ORP meter reaches a preset value, in this case 450 millivolts (mV) or less, and turns off when the ORP rises to another preset value, in this case 550 mV. The preset ORP values can be changed depending on the concentration of contaminants being treated. A green light on the system cabinet door indicates when the ozone generator is functioning. The UV unit inside the ASOP module cabinet has four lights to indicate whether each UV lamp is functioning.

## VERIFICATION TESTING DESCRIPTION

### *Test Site*

The testing site was the Drinking Water Treatment Systems Laboratory at NSF in Ann Arbor, Michigan. A description of the test apparatus can be found in the verification report.

### *Methods and Procedures*

The challenge tests followed the procedures described in the *Test/QA Plan for Verification Testing of the RASco Engineering, Inc. Hyd-RO-Secure™ Series 2 Anti-Terrorism/Force Protection Point-of-Entry Water Treatment System for Removal of Chemical Contaminants*. The chemical challenge protocol was adapted from the *ETV Protocol for Equipment Verification Testing for Removal of Synthetic Organic Chemical Contaminants*. Production of drinking water from an untreated source water was not evaluated; this verification only evaluated the system's ability to remove chemical contaminants from an otherwise potable drinking water. The challenge chemicals are listed in Table VS-1. Separate challenges were conducted for each chemical in the table. The target challenge concentration for each chemical was  $1,000 \pm 500 \mu\text{g/L}$ .

The ozone generator's oxygen delivery rate for the challenges was approximately 8 cubic feet per minute, as set by RASco personnel. The flow rate was controlled at  $5.0 \pm 0.5$  gallons per minute (gpm). According to Aquafine, at this flow rate the 85% theoretical hydraulic residence time for the UV chamber is 33 seconds. Dividing the contact tank volume (3 gal) by the flow rate, the theoretical hydraulic residence time for that component is 36 seconds.

The ASOP ozone generator was set to turn on when the ORP meter read 450 mV or less, and turn off when the ORP rose past 550 mV. The ORP can continue to rise for a period of time if the water has minimal ozone demand. To ensure that the ozone generator was on at the beginning of each chemical challenge, and each challenge was conducted under similar ORP conditions, each challenge, except for sodium fluoroacetate, officially began when the ORP meter read 450 mV. Prior to the start of each challenge, the ASOP module was turned on and deionized water was run through the unit for approximately one minute until the ORP rose to above 550 mV. Then the water supply was switched over to the chemical challenge water, and the ASOP module was operated using this water until the ORP dropped back down to 450 mV and the ozone generator turned on. The point where the ozone generator turned on was considered "time zero" for each challenge. The ASOP module was operated continuously for 30 minutes from time zero for each challenge. For the sodium fluoroacetate challenge, the lab technician started the challenge when the ORP was 854 mV. The technician attempted to lower the ORP to 450 mV, but it dropped very slowly, and there was concern that the tank of challenge water would be exhausted prior to 30 minutes of operation. The ORP only dropped to 483 mV after 30 minutes, so the ozone generator did not operate at all during the sodium fluoroacetate challenge.

Influent and effluent samples were collected for challenge chemical analysis after 15 and 30 minutes of operation. The ASOP effluent samples were collected downstream of the contact tank. At 30 minutes, samples were also collected for oxidation byproducts analysis. To accomplish this, two scans were conducted: base/neutrals and acids (BNA) according to EPA Method 625, and volatile organic compounds (VOC's) according to EPA Method 524.2. BNA scans were performed on both the ASOP and carbon filter effluent samples, but the VOC scan was only performed on the carbon filter effluent samples.

**VERIFICATION OF PERFORMANCE**

The chemical challenges data are presented in Table VS-1. The mean challenge chemical concentrations for the influents, ASOP effluents, and activated carbon filter effluents are presented, as well as the percent reductions calculated for the ASOP module alone and the ASOP and activated carbon filter treatment combined.

**Table VS-1. Chemical Challenge Results**

<b>Challenge Chemical</b>	<b>Mean Influent (µg/L)</b>	<b>Mean ASOP Effluent (µg/L)</b>	<b>ASOP % Reduction</b>	<b>Mean Carbon Effluent (µg/L)</b>	<b>ASOP + Carbon % Reduction</b>
Aldicarb	930	160	83	4	>99
Benzene	440	330	25	3.0	>99
Carbofuran	1100	1100	0	22	98
Chloroform	740	790	0	43	94
Dichlorvos	850	430	49	13	99
Dicrotophos	750	250	67	23	97
Methomyl	1200	830	31	8	>99
Mevinphos	940	1200	0	11	99
Nicotine	1200	80	93	4	>99
Oxamyl	1200	210	83	3	>99
Paraquat	700	600	14	340	51
Phorate	630	170	74	6	>99
Sodium Fluoroacetate	760	740	2.6	21	97
Strychnine	910	20	98	5	>99

The percent reductions for the ASOP module ranged from zero for carbofuran, chloroform, and mevinphos, to 98% for strychnine. The combination of the ASOP module and activated carbon filter removed all challenge chemicals, except paraquat, by 94% or more. However, as previously discussed, a complete Hyd-RO-Secure system employs an RO system in addition to the ASOP module and activated carbon filter, but there is no standard RO make and model employed. A previous ETV verification for the Watts Premier M-2400 POE RO system (EPA/600/R-06/101) demonstrated that the selected RO membrane reduced by more than 95%, 1 mg/L concentrations of various chemicals, including Paraquat and most of the chemicals used in this study. Therefore, it is feasible that a complete Hyd-RO-Secure configuration employing a high quality RO module may also be able to achieve significant chemical reductions.

As discussed in the Methods and Procedures section, 30-minute influent and effluent samples were analyzed for oxidation byproducts in addition to the challenge chemicals themselves. The BNA scans did qualitatively detect “tentatively identified” compounds (TIC) in the contact tank effluent samples, which may have been oxidation byproducts. However, many of the TICs were detected in both the influents and contact tank effluents, indicating that perhaps they were impurities in the challenge chemical solutions. The only compound detected above 10 µg/L in the contact tank effluent, but not in the influent, was methyl dimethylcarbamate for the oxamyl challenge. The activated carbon filter effluent samples did not yield any BNA scan TICs that could have been oxidation byproducts. However, the activated carbon filter effluent VOC scans found chloroform, chloromethane, methylene chloride, and total trihalomethanes, all at less than 10 µg/L.

**QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)**

NSF provided technical and quality assurance oversight of the verification testing as described in the verification report, including a review of 100% of the data. NSF QA personnel conducted a technical systems audit at the start of testing to ensure the testing was in compliance with the test plan. A complete description of the QA/QC procedures is provided in the verification report.

<i>Original signed by S. Gutierrez</i>	<i>08/14/07</i>	<i>Original signed by R.Ferguson</i>	<i>08/10/07</i>
Sally Gutierrez	Date	Robert Ferguson	Date
Director		Vice President	
National Risk Management Research		Water Systems	
Laboratory		NSF International	
Office of Research and Development			
United States Environmental Protection			
Agency			

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 an NSF Certification of the specific product mentioned herein.

**Availability of Supporting Documents**

Copies of the test protocol, the verification statement, and the verification report (NSF report # NSF 06/25/EPADWCTR) are available from the following sources:

1. ETV Drinking Water Systems Center Manager (order hard copy)  
 NSF International  
 P.O. Box 130140  
 Ann Arbor, Michigan 48113-0140
2. Electronic PDF copy  
 NSF web site: <http://www.nsf.org/info/etv>  
 EPA web site: <http://www.epa.gov/etv>

This page intentionally blank



## **Environmental Technology Verification Report**

### **Removal of Synthetic Organic Chemical Contaminants in Drinking Water**

**RASco, Incorporated**

### **Advanced Simultaneous Oxidation Process (ASOP™) Drinking Water Treatment Module**

Prepared by:

NSF International  
Ann Arbor, Michigan 48105

Under a cooperative agreement with the U.S. Environmental Protection Agency

Jeffrey Q. Adams, Project Officer  
National Risk Management Research Laboratory  
U.S. Environmental Protection Agency  
Cincinnati, Ohio 45268

## Notice

The U.S. Environmental Protection Agency (USEPA), through its Office of Research and Development, has financially supported and collaborated with NSF International (NSF) under Cooperative Agreement No. R-82833301. This verification effort was supported by the Drinking Water Systems (DWS) Center, operating under the Environmental Technology Verification (ETV) Program. This document has been peer-reviewed, reviewed by NSF and USEPA, and recommended for public release.

## Foreword

The U.S. Environmental Protection Agency (USEPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, USEPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by USEPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director  
National Risk Management Research Laboratory

## Table of Contents

Verification Statement .....	VS-i
Title Page .....	i
Notice .....	ii
Foreword .....	iii
Table of Contents .....	iv
List of Tables .....	vi
List of Figures .....	vi
Abbreviations and Acronyms .....	vii
Acknowledgements .....	viii
Chapter 1 Introduction .....	1
1.1 Environmental Technology Verification (ETV) Program Purpose and Operation .....	1
1.2 Purpose of Verification .....	1
1.3 Testing Participants and Responsibilities .....	2
1.3.1 NSF International .....	2
1.3.2 RASco, Inc. ....	2
1.3.3 U.S. Environmental Protection Agency .....	3
Chapter 2 Equipment Description .....	4
2.1 Introduction .....	4
2.2 Hyd-RO-Secure Equipment Description .....	4
2.3 Activated Carbon Filtration .....	7
2.4 ASOP Module Operation .....	8
2.5 Hyd-RO-Secure Operation and Maintenance Requirements .....	9
Chapter 3 Methods and Procedures .....	10
3.1 Introduction .....	10
3.2 Challenge Chemicals .....	10
3.3 Test Apparatus .....	10
3.4 Test Unit Set-Up .....	11
3.5 Chemical Challenge Test Procedure .....	11
3.5.1 Challenge Water .....	13
3.5.2 Challenge Procedure .....	13
3.6 Analytical Methods .....	14
3.6.1 Water Quality Analytical Methods .....	14
3.6.2 Challenge Chemical Analytical Methods .....	15
Chapter 4 Results and Discussion .....	16
4.1 Chemical Challenges .....	16
4.2 Oxidation Byproducts .....	18
Chapter 5 QA/QC .....	20
5.1 Introduction .....	20
5.2 Test Procedure QA/QC .....	20

5.3	Sample Handling.....	20
5.4	Chemistry Analytical Methods QA/QC.....	20
5.5	Documentation.....	20
5.6	Data Review.....	21
5.7	Data Quality Indicators.....	21
5.7.1	Representativeness.....	21
5.7.2	Accuracy.....	21
5.7.3	Precision.....	21
5.7.4	Completeness.....	22
5.7.4.1	Parameters with less than 100% Completeness.....	22
5.8	Measurements Outside of the Test/QA Plan Specifications.....	23
Chapter 6 References.....		25
Chapter 7 Vendor Comments.....		26

**List of Tables**

Table 2-1.	Hyd-RO-Secure Component Descriptions.....	6
Table 2-2.	Hyd-RO-Secure Equipment Specifications.....	6
Table 3-1.	Challenge Chemicals.....	10
Table 3-2.	Sampling Plan for Chemical Challenges.....	14
Table 4-1.	ASOP Module and Carbon Filter Challenge Data.....	17
Table 4-2.	Possible Oxidation Byproducts.....	19
Table 5-1.	Completeness Requirements.....	22

**List of Figures**

Figure 2-1.	Process diagram of the Hyd-RO-Secure system.....	5
Figure 2-2.	ASOP module ozone contact tank and activated carbon filter.....	7
Figure 2-3.	ASOP ORP meter display and system power switch on cabinet door.....	9
Figure 3-1.	Schematic diagram of the “tank rig” test station.....	11
Figure 3-2.	Hyd-RO-Secure ASOP module and carbon filter plumbed to test rig in NSF testing laboratory.....	12

## Abbreviations and Acronyms

ASOP	Advanced Simultaneous Oxidation Process
BNA	base/neutrals and acids
°C	degrees Celsius
CaCO <sub>3</sub>	calcium carbonate
CFU	colony forming units
cm	centimeter
DWS	Drinking Water Systems
ETV	Environmental Technology Verification
ft	foot(feet)
GC/MS	gas chromatography/mass spectrometry
gpm	gallons per minute
HCl	hydrochloric acid
HPC	heterotrophic plate count
HPLC	high pressure liquid chromatography
L	liter
lbs	pounds
mg	milligram
mL	milliliter
mV	millivolt
nm	nanometer
NaCl	sodium chloride
NaHCO <sub>3</sub>	sodium bicarbonate
NaOH	sodium hydroxide
NRMRL	National Risk Management Research Laboratory
NSF	NSF International (formerly National Sanitation Foundation)
NTU	nephelometric turbidity unit
ORP	oxidation reduction potential
OSHA	Occupational Safety and Health Administration
POE	point-of-entry
POU	point-of-use
psig	pounds per square inch, gauge
QA	quality assurance
QC	quality control
RO	reverse osmosis
RPD	relative percent difference
SOP	standard operating procedure
TIC	tentatively identified compound
TDS	total dissolved solids
TOC	total organic carbon
TWA	time weighted average
TWSG	Technical Support Working Group

## Abbreviations and Acronyms (continued)

μg	microgram
μS	microSiemen
USEPA	U. S. Environmental Protection Agency
UV	ultraviolet
VOC	volatile organic carbon

## Acknowledgments

NSF International was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation, and the preparation of this report.

The manufacturer of the equipment was:

RASco, Incorporated  
1635-2 Woodside Drive  
Woodbridge, VA 22191  
703-643-2952

NSF wishes to thank the members of the expert technical panel for their assistance with development of the test plan.



## Chapter 1 Introduction

### 1.1 Environmental Technology Verification (ETV) Program Purpose and Operation

The U.S. Environmental Protection Agency (USEPA) 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 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; with stakeholder groups consisting of buyers, vendor organizations, and permittees; 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; by conducting field or laboratory testing, collecting and analyzing data; and by 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.

The USEPA has partnered with NSF International (NSF) under the ETV Drinking Water Systems (DWS) Center to verify performance of drinking water treatment systems that benefit the public and small communities. It is important to note that verification of the equipment does not mean the equipment is “certified” by NSF or “accepted” by USEPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations under conditions specified in ETV protocols and test plans.

### 1.2 Purpose of Verification

USEPA’s *Water Security Research and Technical Support Action Plan* (USEPA, 2004) identifies the need to evaluate point-of-use (POU) and point-of-entry (POE) treatment system capabilities for removing likely contaminants from drinking water. The purpose of this verification was to evaluate treatment system performance under a simulated chemical contamination event. Because any contamination event would likely be short-lived, long-term performance of the system was not investigated. Each chemical or challenge was only one half-hour long.

By participating in this ETV, RASco has obtained USEPA- and NSF-verified independent test data indicating potential user protection against intentional or accidental chemical contamination of drinking water. This verification is a demonstration of possible performance. Verifications following an EPA approved test/quality assurance (QA) plan serve to notify the public of the possible level of protection against chemical contaminants afforded to them by the use of the verified system.

### 1.3 Testing Participants and Responsibilities

The ETV testing of the RASco, Inc. Advanced Simultaneous Oxidation Process (ASOP™) drinking water treatment module was a cooperative effort between the following participants:

NSF  
RASco, Inc.  
USEPA

The following is a brief description of each of the ETV participants and their roles and responsibilities.

#### 1.3.1 NSF International

NSF is a not-for-profit organization dedicated to public health and safety, and to 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. The USEPA partnered with NSF to verify the performance of drinking water treatment systems through the USEPA's ETV Program.

NSF performed all verification testing activities at its Ann Arbor location. NSF prepared the test/QA plan, performed all testing, managed, evaluated, interpreted, and reported on the data generated by the testing, and reported on the performance of the technology.

Contact Information:

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

#### 1.3.2 RASco, Inc.

RASco, Inc. is an engineering, consulting, and design firm. The company's mission is to "create physical infrastructure solutions that improve homeland security, force protection, public health, facilities operations, productivity, and the environment."

RASco, Inc. was responsible for supplying the test units and for providing logistical and technical support as needed.

Contact Information:

RASco, Inc,  
1635-2 Woodside Dr.  
Woodbridge, VA 22191  
Phone: 703-643-2952  
Fax: 703-497-2905  
Contact: Mr. Will Kirksey, P.E.  
Email: wkirksey@rascoengineers.com

**1.3.3 U.S. Environmental Protection Agency**

USEPA, 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 DWS Center, operating under the ETV Program. This document has been peer-reviewed, reviewed by USEPA, and recommended for public release.

## Chapter 2 Equipment Description

### 2.1 Introduction

The patent-pending RASco, Inc. ASOP module is marketed as part of the Hyd-RO-Secure POE water treatment system. The full Hyd-RO-Secure system consists of a reverse osmosis (RO) treatment module, the ASOP module, and an optional post-ASOP activated carbon filter.

The ASOP module uses ozone and UV light to oxidize chemical and microbiological contaminants. This verification evaluated the ASOP module only, because the RO and activated carbon components are not standard. RASco uses different RO systems and carbon filters depending on the site-specific application. As such, no RO unit was tested with the ASOP module, but an activated carbon filter supplied by RASco was evaluated to demonstrate the ability of an activated carbon filter to adsorb any oxidation byproducts and/or the amounts of challenge chemicals not oxidized by the ASOP module.

### 2.2 Hyd-RO-Secure Equipment Description

The Hyd-RO-Secure is a modular system, with the RO and ASOP components on individual platforms.

The main Hyd-RO-Secure system components are:

- Optional feed water booster pump;
- Optional sediment filter upstream of RO system;
- Centrifugal multi-stage pump for RO feed water;
- RO system;
- ASOP module;
- Contact tank downstream of the ASOP module;
- Optional post-ASOP carbon filtration; and
- Backwash pump for the RO system.

The main components of the ASOP module are:

- Aquafine CSL-4R-UV ultraviolet (UV) light unit;
- Ozotech OZ2BTUSL ozone generator; and
- Ozotech PP Phoenix oxygen generator.

The system as tested included one ASOP module with the components listed above, a three-gallon fiberglass contact tank downstream of the ASOP module, and a Pentek RFC20-BB granular activated carbon filter downstream of the contact tank. See Section 2.3 for further discussion about the activated carbon filter.

A process diagram of the Hyd-RO-Secure system is shown in Figure 2-1. Accompanying component descriptions are given in Table 2-1. The Hyd-RO-Secure operating specifications are listed in Table 2-2. The ozone contact tank and activated carbon filter are shown in Figure 2.2.

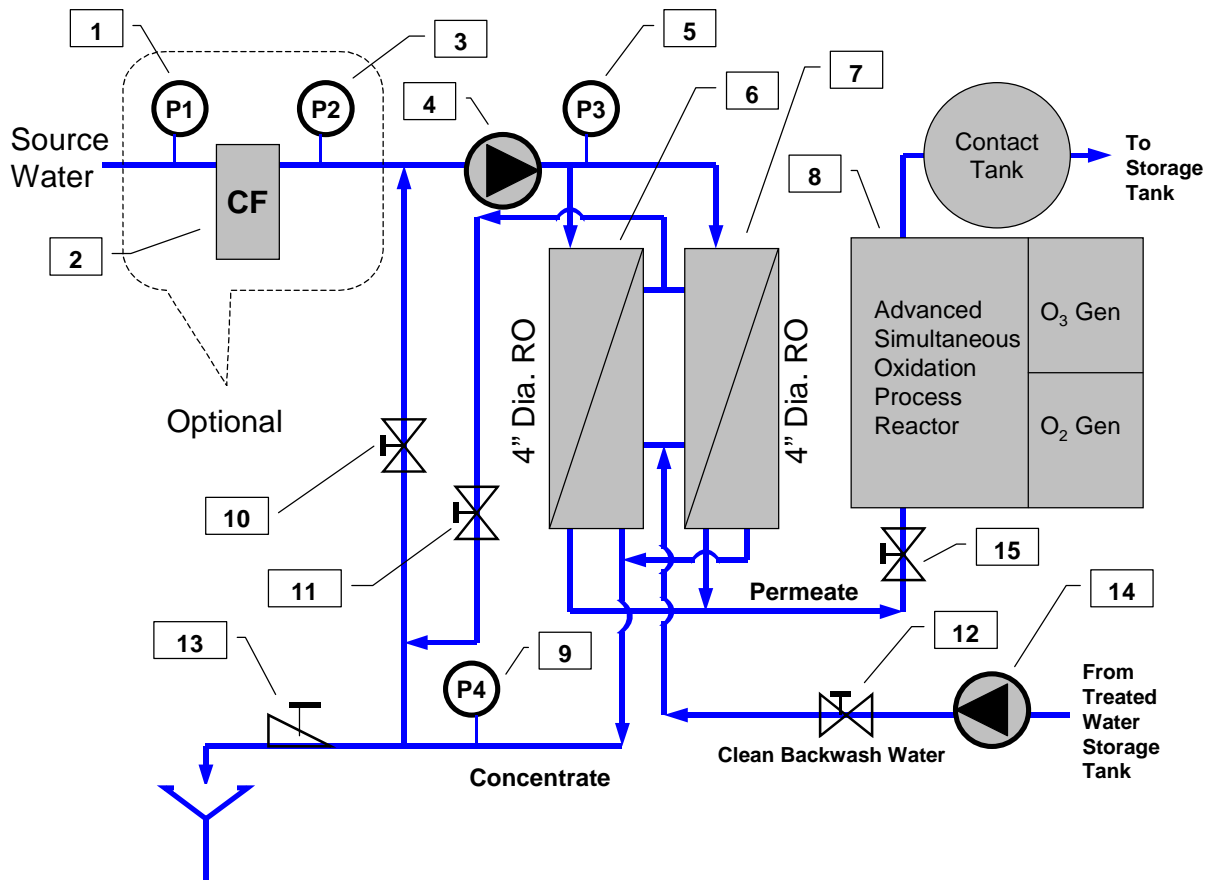


Figure 2-1. Process diagram of the Hyd-RO-Secure system.

**Table 2-1: Hyd-RO-Secure Component Descriptions**

Item	Description	Manufacturer & Model	Function
1	Pressure Gauge #1	N/A	Measures inlet pressure
2	Cartridge Filter	N/A	Feed water filter -- sediment/particle
3	Pressure Gauge #2	N/A	Measures pressure at cartridge filter effluent
4	High Pressure Pump	Sta-Rite Dura-Glas, P2RA5D ¾ hp, VAC 115/230	Boosts inlet pressure to RO membranes
5	Pressure Gauge #3	N/A	Measures pump pressure boost
6	RO Unit #1	Various	Water treatment
7	RO Unit #2	Various	Water treatment
8	ASOP Module	1. Aquafine UV Lamp, Model CSL-4R	Water treatment
		2. Ozotech O <sub>2</sub> Generator, Model PP	
		3. Ozotech, O <sub>3</sub> Unit, #OZ2BTUSL	
9	Pressure Gauge #4	N/A	Measures stream pressure
10	Recirculation Valve	N/A	Recirculates system concentrate
11	Reject Needle Valve	N/A	Allows membrane element pressurization
12	Backwash Valve	N/A	Provides clean backwash water
13	Drain Valve	N/A	Allows waste to drain
14	Backwash Pump	Sta-Rite Dura-Glas, P2RA5D ¾ hp, VAC 115/230	Forces clean water across membranes in reverse flow to wash off debris
15	Product Water Valve	N/A	Allows product water line pressurization/control

**Table 2-2. Hyd-RO-Secure Equipment Specifications**

Parameter	Specification
Dry Weight	500-600 pounds (lbs.)
Wet Weight	1500-1750 lbs.
Feed Water:	
Temperature	0.2 to 40°C (33 to 104°F)
Max. Feed Flow Rate	Variable <sup>(1)</sup>
Inlet Pressure	30 to 60 pounds per square inch, gauge (psig)
pH	5.5 to 8.5
Chlorine	Non-detect
Silt Density Index	≤ 5 without pre-treatment
ASOP Electrical Requirements:	208 volts, 20 amp, single phase

(1) The maximum feed flow rate varies, depending on the RO system used, and the desired ozone and UV contact time. The flow rate was set at five gallons per minute (gpm) for testing, as requested by RASco.



**Figure 2-2. ASOP module ozone contact tank and activated carbon filter.**

### **2.3 Activated Carbon Filtration**

As discussed in Section 2.1, an activated carbon filter was tested along with the ASOP module. The activated carbon filter supplied by RASco was the Pentek RFC20-BB granular activated carbon filter. The RFC20-BB is a 4.5" x 20" radial flow cartridge. Pentek states that the RFC20-BB is effective at removing chlorine, tastes, and odors with a filter life of 70,000 gallons or greater at a flow rate of 4 gpm. The manufacturer makes no claims about removal of organic chemicals or pesticides, as used for verification testing. The filter was not evaluated over its effective lifespan. Please note that this filter was included with the test equipment only to examine the effectiveness of an activated carbon filter to adsorb any oxidation byproducts and/or the amounts of challenge chemicals not oxidized by the ASOP module. Using a different activated carbon filter with a different carbon type, contact time, or lifespan may affect performance of the Hyd-RO-Secure system.

## 2.4 ASOP Module Operation

The ASOP module offers simultaneous treatment with both UV light and ozone, plus a contact tank to complete the ozone oxidation treatment. The oxygen generator collects and concentrates oxygen from the ambient air. The oxygen is sent to the ozone generator, which converts the oxygen to ozone using electrical arcs. The ozone generator also includes an air dryer. The ozone is injected into the UV reactor vessel to oxidize contaminants synergistically with the UV light. The UV light has an output of 30,000 microwatt-seconds per square centimeter. Delivery of ozone into the reaction chamber is controlled by adjusting the flow of oxygen into the ozone generator. The ASOP module as tested did not include any sensors for UV intensity, but it did include an oxidation reduction potential (ORP) meter immediately downstream of the contact tank to indirectly measure the ozone residual. The system is programmed so that the ozone generator turns on when the ORP meter reaches a preset value, in this case 450 millivolts (mV) or less, and turns off when the ORP rises to another preset value, in this case 550 mV. The preset ORP values can vary depending on the concentration of contaminants being treated. A green light on the system cabinet door indicates when the ozone generator is functioning. The UV unit inside the ASOP module cabinet has four lights to indicate whether each UV bulb is functioning. The ORP meter display, ozone generator indicator light, and ASOP component on/off switch on the cabinet door are shown in Figure 2-3.

The ASOP module was operated at approximately 5 gpm for verification testing, as requested by RASco, Inc. According to Aquafine, at this flow rate the 85% theoretical hydraulic residence time (residence time for 85% of the water molecules) for the UV chamber is 33 seconds. Simply dividing the contact tank volume by the flow rate, the theoretical hydraulic residence time for that component is 36 seconds.

Note that for the full Hyd-RO-Secure system, the RO module permeate rate will dictate the flow rate through the ASOP module. Also, the volume of the post-ASOP contact tank will determine the ozone contact time before the water is discharged. The ASOP flow rate and ozone contact time are critical operational parameters for oxidation treatment.





Figure 2-3. ASOP ORP meter display and system power switch on cabinet door.

## 2.5 Hyd-RO-Secure Operation and Maintenance Requirements

No routine maintenance of the ASOP module was required during this verification. RASco advises the user to follow the maintenance requirements for the RO system and individual ASOP module components. There are no special licensing requirements to operate the Hyd-RO-Secure system.

## Chapter 3 Methods and Procedures

### 3.1 Introduction

The challenge tests followed the procedures described in the *Test/QA Plan for Verification Testing of the RASco Engineering, Inc. Hyd-RO-Secure™ Series 2 Anti-Terrorism/Force Protection Point-of-Entry Water Treatment System for Removal of Chemical Contaminants* (NSF, 2006a). The chemical challenge protocol was adapted from the *ETV Protocol for Equipment Verification Testing for Removal of Synthetic Organic Chemical Contaminants* (USEPA and NSF, 2004).

The purpose of this verification was to assess the ASOP module’s synthetic organic chemical oxidation performance. An activated carbon filter was included to demonstrate the ability of an activated carbon to adsorb any oxidation byproducts and/or the amounts of the challenge chemicals not oxidized by the ASOP module. Production of drinking water from an untreated source water was not evaluated; this verification only evaluated the system’s ability to remove synthetic organic chemical contaminants from an otherwise potable drinking water.

One Hyd-RO-Secure ASOP module and one Pentek RFC20-BB activated carbon filter were tested.

### 3.2 Challenge Chemicals

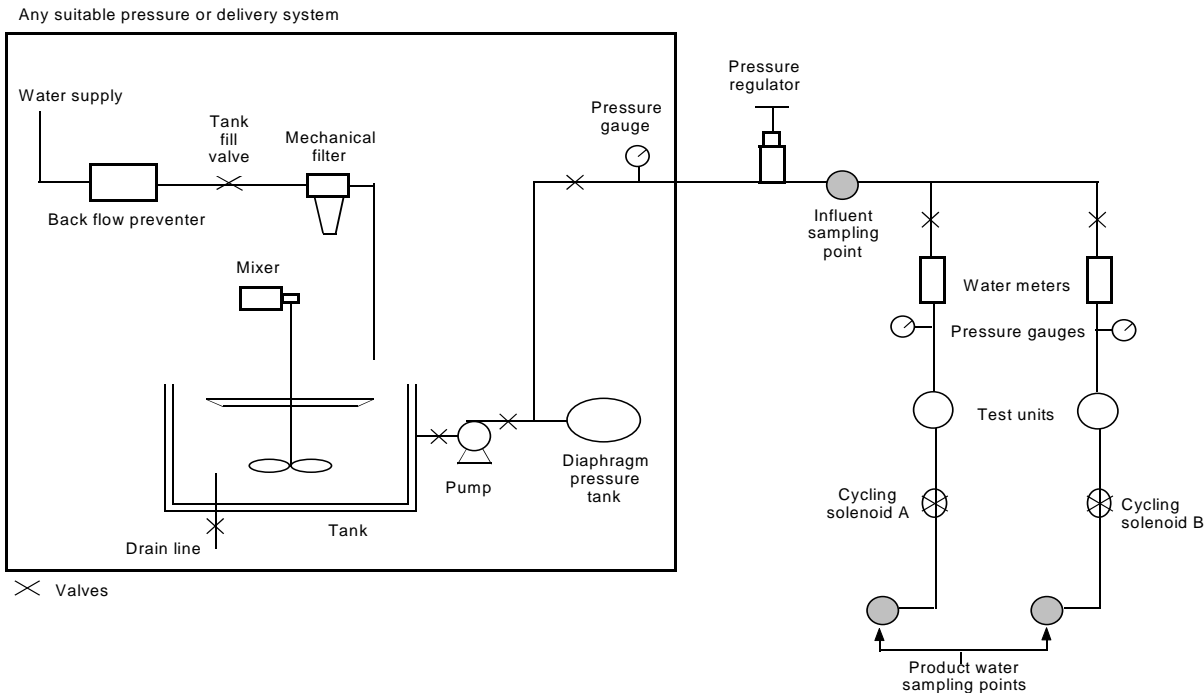
The challenge chemicals used in this product verification are listed in Table 3-1. They were chosen as chemicals of interest by the EPA.

**Table 3-1. Challenge Chemicals**

Aldicarb	Mevinphos
Benzene	Nicotine
Carbofuran	Oxamyl
Chloroform	Paraquat
Dichlorvos	Phorate
Dicrotophos	Sodium Fluoroacetate
Methomyl	Strychnine

### 3.3 Test Apparatus

The unit to be tested was plumbed to a “tank rig” test station in the NSF testing laboratory. The tank rig uses a 500-gallon polyethylene tank to hold the challenge water. See Figure 3-1 for a schematic diagram of the tank rig. Figure 3-2 shows the test unit plumbed to a tank rig test station.



**Figure 3-1. Schematic diagram of the “tank rig” test station.**

### 3.4 Test Unit Set-Up

The ASOP module and activated carbon filter were delivered to NSF by RASco personnel. The RASco representatives worked with NSF lab technicians to plumb the test equipment to the test rig. No shakedown testing was conducted, but the equipment was operated using municipal drinking water and was configured by the RASco personnel to their satisfaction. The oxygen delivery rate to the ozone generator was set at eight cubic feet per minute (ft<sup>3</sup>/min). The test equipment was not conditioned on site prior to the challenge tests.

The system’s ORP meter was located on the contact tank effluent pipe, upstream of the carbon filter. ORP was recorded for each challenge, however the calibration of the meter was not verified as part of the testing. A sampling valve was located immediately downstream of the contact tank for sampling the ASOP module effluent.

### 3.5 Chemical Challenge Test Procedure

Separate challenges were conducted for each chemical in Table 3-1. Each chemical was added to the test water described below in Section 3.5.1 to make the challenge water. The target challenge concentration for each chemical was 1 ± 0.5 milligrams per liter (mg/L).

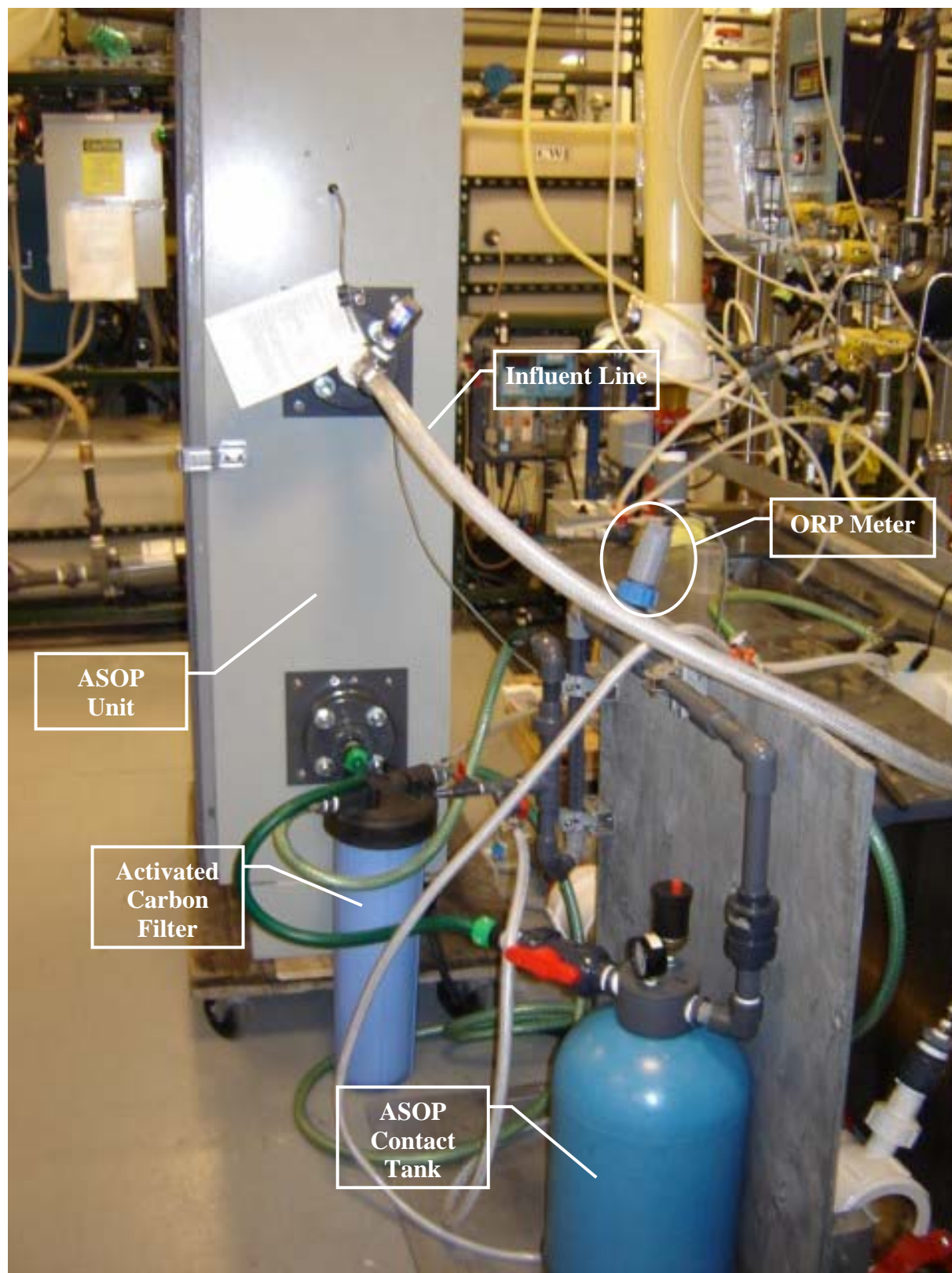


Figure 3-2. Hyd-RO-Secure ASOP module and carbon filter plumbed to test rig in NSF testing laboratory.

### 3.5.1 Challenge Water

Since the Hyd-RO-Secure system includes RO treatment upstream of the ASOP module under normal operation, the test water did not need to contain organic content at a level that imparted a significant ozone and UV demand. Therefore, the base test water was local municipal drinking water treated by carbon filtration, RO, and deionization. The base water had the following characteristics:

- Conductivity  $\leq 2$  microSiemens per centimeter ( $\mu\text{S}/\text{cm}$ ) at  $25^\circ\text{C}$ ;
- Total organic carbon (TOC)  $< 100$  micrograms per liter ( $\mu\text{g}/\text{L}$ );
- Total chlorine  $< 0.05$  mg/L; and
- Heterotrophic bacteria plate count (HPC)  $< 100$  Colony Forming Units per milliliter (CFU/mL).

The parameters are measured periodically by NSF as part of an internal quality assurance/quality control (QA/QC) program for water used for testing purposes.

From the base water above, the challenge water was created with the following characteristics to simulate an RO effluent water:

- Target alkalinity (as  $\text{CaCO}_3$ ) of  $10 \pm 5$  mg/L prior to pH adjustment;
- Target total dissolved solids (TDS) level of  $20 \pm 5$  mg/L;
- pH of  $7.5 \pm 0.5$ ;
- Temperature of  $20 \pm 2.5^\circ\text{C}$ ; and
- Challenge chemical at  $1,000 \pm 500$   $\mu\text{g}/\text{L}$ .

Sodium bicarbonate ( $\text{NaHCO}_3$ ) was used to add alkalinity to the water. Sodium chloride ( $\text{NaCl}$ ) was used for TDS. The pH was adjusted with either hydrochloric acid ( $\text{HCl}$ ) or sodium hydroxide ( $\text{NaOH}$ ). Grab samples were collected during each challenge for analysis for alkalinity, pH, temperature, total chlorine, TDS, TOC, and turbidity. See Table 3-2 for the sampling plan.

This challenge water was used for all tests except the sodium fluoroacetate challenge. During a previous ETV test, NSF discovered that  $\text{NaCl}$  interfered with the ion chromatography procedure for measuring sodium fluoroacetate. Therefore, no  $\text{NaCl}$  was added to the tank of sodium fluoroacetate challenge water. Also, no sodium bicarbonate was added as a precaution.

### 3.5.2 Challenge Procedure

The inlet water pressure was set at  $50 \pm 3$  psig, and the flow rate was controlled at  $5.0 \pm 0.5$  gpm. As discussed in Section 2.4, the ASOP ozone generator was set to turn on when the ORP meter read 450 mV or less, and turn off when the ORP rose past 550 mV. The ORP can continue to rise for a period of time if the water has minimal ozone demand. To ensure that the ozone generator was on at the beginning of each chemical challenge, and each challenge was conducted under similar ORP conditions, each challenge, except sodium fluoroacetate, officially began when the ORP meter read 450 mV. Prior to the official start of each challenge, the ASOP module was turned on, and deionized water was run through the unit for approximately one minute until the ORP rose to above 550 mV. Then the water supply was switched over to the

chemical challenge water, and the ASOP module was operated using this water until the ORP dropped back down to 450 mV and the ozone generator turned on. The point where the ozone generator turned on was considered “time zero”. The ASOP module was operated continuously for 30 minutes from time zero for each challenge. For the sodium fluoroacetate challenge, the lab technician started the challenge before the ORP dropped to 450 mV. The technician attempted to lower the ORP to 450 mV, but it dropped very slowly, and there was concern that the tank of challenge water would be exhausted prior to 30 minutes of operation.

Note that the 30-minute challenges specified by the test plan were not of sufficient length to measure the ambient ozone for comparison to the U.S. Occupational Safety and Health Administration (OSHA) allowable eight-hour time weighted average (TWA) exposure.

Samples were collected according to Table 3-2. To analyze for oxidation byproducts, NSF performed two scans: base/neutrals and acids (BNA) according to EPA Method 625, and volatile organic compounds (VOC) according to EPA Method 524.2. The VOC scan was only performed on carbon filter effluent samples.

**Table 3-2. Sampling Plan for Chemical Challenges**

Sample Point	Parameters	Samples to Collect	
		15 Minutes	30 Minutes
ASOP Influent	Water Chemistry	X	
	pH	X	X
	Challenge Chemical	X	X
	Oxidation Byproducts		X
ASOP Effluent	Challenge Chemical	X	X
	Oxidation Byproducts		X
	Residual Ozone	X	X
Carbon Filter Effluent	Challenge Chemical	X	X
	Oxidation Byproducts		X
	Residual Ozone	X	X

### 3.6 Analytical Methods

#### 3.6.1 Water Quality Analytical Methods

All analyses followed procedures detailed in NSF standard operating procedures (SOP). The following are the analytical methods used during verification testing:

- Alkalinity was measured according to EPA Method 310.2 with the SmartChem Discrete Analyzer. Alkalinity was expressed as mg/L CaCO<sub>3</sub>.
- Ozone – Ozone was measured colorimetrically according to Standard Method 4500-O<sub>3</sub> (APHA, AWWA, and WEF, Washington D.C.) using a Hach DR/2010 spectrophotometer and Hach Indigo AccuVac® ampules.

- pH measurements were made with a Beckman 350 pH meter. The meter was operated according to the manufacturer's instructions, which are based on Standard Method 4500-H<sup>+</sup>.
- TDS was measured gravimetrically using a method adapted from USEPA Methods 160.3 and 160.4. An appropriate amount of sample was placed in a pre-weighed evaporating dish. The sample was evaporated and dried at 103-105°C to a constant weight.
- Temperature was measured using an Omega model HH11 digital thermometer, or equivalent.
- TOC was measured according to Standard Method 5310C using a Teledyne Technologies Company Tekmar Dohrmann Phoenix 8000 UV-Persulfate TOC analyzer.
- Total chlorine was measured according to Standard Method 4500-Cl G using a Hach Model DR/2010 spectrophotometer and AccuVac ampules.
- Turbidity was measured according to Standard Method 2130 using a Hach 2100N turbidimeter.

### 3.6.2 Challenge Chemical Analytical Methods

- Aldicarb, carbofuran, methomyl, and oxamyl were measured by high-pressure liquid chromatography (HPLC) according to USEPA Method 531.1 or 531.2.
- Dichlorvos, dicrotophos, mevinphos, nicotine, and phorate were measured by gas chromatography/mass spectrometry (GC/MS) according to USEPA Method 525.2.
- Benzene and chloroform were measured by purge and trap capillary gas chromatography according to USEPA Method 502.2.
- There is no standard analytical method for strychnine. NSF developed and has used a method to measure it using reverse phase HPLC with ultraviolet lamp detection.
- Oxidation byproducts were measured by GC/MS according to USEPA Method 625 – Base/Neutrals and Acids, and by GC/MS according to USEPA Method 524.2.
- Paraquat was measured by HPLC according to USEPA Method 549.1.
- Sodium fluoroacetate was measured by ion chromatography according to USEPA Method 300.1.

## Chapter 4 Results and Discussion

### 4.1 Chemical Challenges

The chemical challenge data are presented below in Table 4-1. The challenge chemical concentrations for the influents, contact tank effluents, and carbon filter effluents are shown at the top of the table. From these numbers, percent reductions were calculated for the ozone and UV oxidation of the ASOP module alone, and also for ASOP and activated carbon treatment combined.

The percent reductions for the ASOP module ranged from zero for carbofuran, chloroform, and mevinphos, to ninety-eight for strychnine. The combination of the ASOP module and activated carbon filter removed all challenge chemicals, except paraquat, by 94% or more.

As discussed in Chapter 2, the full Hyd-RO-Secure system employs an RO system in addition to the ASOP module and an activated carbon filter, but no standard make or model is used. A previous ETV verification for the Watts Premier M-2400 POE RO system (EPA/600/R-06/101) demonstrated that the selected RO membrane reduced by more than 95%, 1 mg/L concentrations of various chemicals, including Paraquat and most of the chemicals used in this study (NSF, 2006b). Therefore, it is feasible that a complete Hyd-RO-Secure configuration employing a high quality RO module may also be able to achieve significant chemical reductions.

Underneath the challenge chemical data in Table 4-1 are the oxygen delivery rate settings, residual ozone measurements, and ORP meter readings for each challenge. Note that the residual ozone measurements from the three challenges conducted first (methomyl, oxamyl, and strychnine) are not reported due to analytical error. Also note that the ORP rose to 550 mV or above during the dichlorvos, dicrotophos, and methomyl challenges. As such, the ozone generator shut off during these tests. As discussed in Section 3.5.2, the sodium fluoroacetate challenge was started with the ORP above 450 mV. The ORP was 854 mV at time zero, and only dropped to 483 mV at 30 minutes, so the ozone generator did not operate during this challenge.

Also presented in Table 4-1 are the influent flow rate and pressure data, and the water chemistry data for each challenge. Note that no flow rate or pressure data is given for the phorate challenge, because the lab technician did not record the data. Also, all of the planned TOC samples were collected, but some were not analyzed due to miscommunication with the NSF Chemistry Laboratory.



**Table 4-1. ASOP Module and Activated Carbon Filter Chemical Challenge Data**

	Aldicarb	Benzene	Carbofuran	Chloroform	Dichlorvos	Dicrotophos	Methomyl
<b>Challenge Chemical Data (µg/L):</b>							
15-Minute Influent	860	450	1000	710	810	750	1200
15-Minute ASOP Effluent	260	340	1100	790	480	200	550
15-Minute Carbon Effluent	5	2.9	22	40	12	19	5
30-Minute Influent	990	430	1100	770	890	740	1200
30-Minute ASOP Effluent	53	310	1000	790	380	290	1100
30-Minute Carbon Effluent	2	3.0	21	45	13	26	10
<b>Influent</b>	<b>930</b>	<b>440</b>	<b>1100</b>	<b>740</b>	<b>850</b>	<b>750</b>	<b>1200</b>
<b>ASOP Effluent</b>	<b>160</b>	<b>330</b>	<b>1100</b>	<b>790</b>	<b>430</b>	<b>250</b>	<b>830</b>
<b>ASOP % Reduction</b>	<b>83</b>	<b>25</b>	<b>0</b>	<b>0</b>	<b>49</b>	<b>67</b>	<b>31</b>
<b>Carbon Filter Effluent</b>	<b>4</b>	<b>3.0</b>	<b>22</b>	<b>43</b>	<b>13</b>	<b>23</b>	<b>8</b>
<b>ASOP+Carbon % Reduction</b>	<b>&gt;99</b>	<b>&gt;99</b>	<b>98</b>	<b>94</b>	<b>99</b>	<b>97</b>	<b>&gt;99</b>
Oxygen Delivery (ft <sup>3</sup> /min)	9	8	8	8	8	8	8
<b>Residual Ozone (mg/L):</b>							
15-Minute ASOP Effluent	ND (0.05)	ND (0.05)	ND (0.05)	0.06	ND (0.05)	ND (0.05)	— <sup>(1)</sup>
30-Minute ASOP Effluent	ND (0.05)	0.07	ND (0.05)	0.19	ND (0.05)	0.19	— <sup>(1)</sup>
15-Minute Carbon Effluent	0.08	0.20	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	— <sup>(1)</sup>
30-Minute Carbon Effluent	0.06	ND (0.05)	0.06	0.07	ND (0.05)	0.13	— <sup>(1)</sup>
<b>ORP Meter Readings (mV):</b>							
Start-up	450	450	450	450	450	450	450
15 Minutes	515	203	238	372	818	220	512
30 Minutes	140	208	214	502	635	550	763
Start-up Influent Flow Rate (gpm)	5.15	5.10	5.15	5.29	5.08	5.11	5.00
Start-up Influent Pressure (psig)	50	50	60	50	50	50	50
30-Minute Influent Flow Rate (gpm)	4.95	5.00	5.20	5.20	5.11	5.16	5.05
<b>15-Minute Influent Water Chemistry</b>							
pH	7.9	7.8	7.5	7.7	7.3	7.5	7.3
Temperature (°C)	20	19	19	20	20	19	20
Turbidity (NTU)	ND (0.1)	0.1	ND (0.1)	0.1	ND (0.1)	0.1	0.3
Alkalinity (mg/L CaCO <sub>3</sub> )	23	21	23	29	21	22	26
TDS (mg/L)	19	30	11	30	36	34	40
TOC (mg/L)	— <sup>(2)</sup>	ND (0.1)	— <sup>(2)</sup>	ND (0.1)	ND(0.1)	ND (0.1)	— <sup>(2)</sup>
Total Chlorine (mg/L)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)
15-Minute ASOP pH	7.6	7.4	6.6	7.5	7.2	6.8	6.9
15-Minute Carbon Effluent pH	6.3	6.8	6.6	7.3	7.0	6.5	7.2
30-Minute Influent pH	7.7	7.5	6.9	7.6	7.1	7.2	7.3
30-Minute ASOP pH	7.6	7.1	6.9	7.2	7.0	6.8	7.0
30-Minute Carbon Effluent pH	6.8	7.0	6.9	6.9	6.8	6.8	7.3

(1) Results not reported due to analytical error  
(2) Samples not analyzed for TOC

**Table 4-1. ASOP Module and Activated Carbon Filter Chemical Challenge Data (continued)**

	Mevinphos	Nicotine	Oxamyl	Paraquat	Phorate	Sodium Fluoroacetate	Strychnine
<b>Challenge Chemical Data (µg/L):</b>							
15-Minute Influent	960	1200	1200	750	640	760	910
15-Minute ASOP Effluent	1100	84	200	650	180	740	22
15-Minute Carbon Effluent	12	4	3	250	6	<b>20</b>	<b>5</b>
30-Minute Influent	910	1200	1200	640	620	760	910
30-Minute ASOP Effluent	1200	78	210	540	150	740	19
30-Minute Carbon Effluent	10	4	3	430	5	22	<b>5</b>
<b>Influent</b>	<b>940</b>	<b>1200</b>	<b>1200</b>	<b>700</b>	<b>630</b>	<b>760</b>	<b>910</b>
<b>ASOP Effluent</b>	<b>1200</b>	<b>80</b>	<b>210</b>	<b>600</b>	<b>170</b>	<b>740</b>	<b>20</b>
<b>ASOP % Reduction</b>	<b>0</b>	<b>93</b>	<b>83</b>	<b>14</b>	<b>74</b>	<b>2.6</b>	<b>98</b>
<b>Carbon Filter Effluent</b>	<b>11</b>	<b>4</b>	<b>3</b>	<b>340</b>	<b>6</b>	<b>21</b>	<b>5</b>
<b>ASOP+Carbon % Reduction</b>	<b>99</b>	<b>&gt;99</b>	<b>&gt;99</b>	<b>51</b>	<b>&gt;99</b>	<b>97</b>	<b>&gt;99</b>
Oxygen Delivery (ft <sup>3</sup> /min)	8	8	8	9	9	8	8
<b>Residual Ozone (mg/L):</b>							
15-Minute ASOP Effluent	0.06	ND (0.05)	— <sup>(1)</sup>	ND (0.05)	ND (0.05)	ND (0.05)	— <sup>(1)</sup>
30-Minute ASOP Effluent	ND (0.05)	ND (0.05)	— <sup>(1)</sup>	ND (0.05)	ND (0.05)	ND (0.05)	— <sup>(1)</sup>
15-Minute Carbon Effluent	ND (0.05)	ND (0.05)	— <sup>(1)</sup>	ND (0.05)	0.05	ND (0.05)	— <sup>(1)</sup>
30-Minute Carbon Effluent	ND (0.05)	ND (0.05)	— <sup>(1)</sup>	ND (0.05)	ND (0.05)	0.14	— <sup>(1)</sup>
<b>ORP Meter Readings (mV):</b>							
Start-up	450	450	450	450	450	854	450
15 Minutes	328	258	275	252	247	666	233
30 Minutes	360	251	455	439	246	483	235
Start-up Influent Flow Rate (gpm)	5.15	5.02	5.00	5.05	— <sup>(3)</sup>	5.05	5.05
Start-up Influent Pressure (psig)	50	50	50	50	— <sup>(3)</sup>	50	50
30-Minute Influent Flow Rate (gpm)	5.15	5.09	4.80	5.05	— <sup>(3)</sup>	5.00	5.10
<b>15-Minute Influent Water Chemistry</b>							
pH	7.9	7.4	7.2	7.1	7.4	5.8	7.3
Temperature (°C)	20	19	20	21	21	20	21
Turbidity (NTU)	0.1	0.2	0.2	ND (0.1)	0.5	0.1	0.1
Alkalinity (mg/L CaCO <sub>3</sub> )	28	24	59	17	24	ND (5)	25
TDS (mg/L)	30	18	42	31	18	6.0	45
TOC (mg/L)	ND (0.1)	ND (0.1)	— <sup>(2)</sup>	— <sup>(2)</sup>	ND (0.1)	— <sup>(2)</sup>	— <sup>(2)</sup>
Total Chlorine (mg/L)	ND (0.05)	ND (0.05)	ND (0.05)	ND (0.05)	0.05	ND (0.05)	ND (0.05)
15-Minute ASOP pH	7.7	7.0	7.2	6.9	7.2	5.7	5.1
15-Minute Carbon Effluent pH	7.1	6.9	7.1	6.9	7.0	6.3	— <sup>(4)</sup>
30-Minute Influent pH	7.9	6.9	6.8	6.7	7.2	5.4	7.1
30-Minute ASOP pH	7.8	6.9	6.8	6.8	7.0	5.2	7.0
30-Minute Carbon Effluent pH	7.2	6.9	6.9	6.9	7.0	5.7	7.6
(1) Results not reported due to analytical error							
(2) Samples not analyzed for TOC							
(3) Parameters not recorded							
(4) pH sample point missed							

## 4.2 Oxidation Byproducts

As discussed in Section 3.5.2, 30-minute influent and effluent samples were analyzed for oxidation byproducts in addition to the challenge chemicals themselves. The BNA scans according to EPA Method 625 did qualitatively detect “tentatively identified” compounds (TIC) in the contact tank effluent samples, which may have been oxidation byproducts. However, many of the TICs were detected in both the influents and contact tank effluents, indicating that perhaps they were impurities in the challenge chemical solutions. The compounds detected in the contact tank effluent, but not in the influent samples, are listed in Table 4-2. No chemicals were detected in the activated carbon filter effluent samples.

The only compounds detected in the carbon filter effluent VOC scans were chloroform, chloromethane, methylene chloride, and total trihalomethanes. All were measured at less than ten µg/L, so the data is not reported here.

**Table 4-2. Possible Oxidation Byproducts**

<b>Challenge</b>	<b>Detected TIC</b>	<b>Contact Tank Effluent (µg/L)</b>
Aldicarb	Oxygen compound with a molecular weight (MW) > 85	8
	Nitrogen compound with an MW > 85	5
	Dimethyl Disulfide	9
Dicrotophos	Nitrogen and oxygen compound #1 with an MW ≥ 129	5
	Nitrogen and oxygen compound #2 with anMW ≥ 129	5
Oxamyl	Methyl Dimethylcarbamate	30
	Nitrogen compound with an MW > 98	4

## Chapter 5 QA/QC

### 5.1 Introduction

An important aspect of verification testing is the QA/QC procedures and requirements. Careful adherence to the procedures ensured that the data presented in this report was of sound quality, defensible, and representative of the equipment performance. The primary areas of evaluation were representativeness, accuracy, precision, and completeness.

Because the ETV was conducted at the NSF testing lab, all laboratory activities were conducted in accordance with the provisions of the *NSF International Laboratories Quality Assurance Manual* (NSF 2004).

### 5.2 Test Procedure QA/QC

NSF testing laboratory staff conducted the tests by following a USEPA-approved test/QA plan created specifically for this verification. NSF QA Department staff performed an internal audit at the start of testing. The audit yielded no findings.

### 5.3 Sample Handling

All samples analyzed by the NSF Chemistry Laboratory were labeled with unique ID numbers. These ID numbers appear in the NSF laboratory reports for the tests. All samples were analyzed within allowable holding times.

### 5.4 Chemistry Analytical Methods QA/QC

The calibrations of all analytical instruments and the analyses of all parameters complied with the QA/QC provisions of the *NSF International Laboratories Quality Assurance Manual*.

The NSF QA/QC requirements are all compliant with those given in the USEPA method or Standard Method for the parameter. Also, each analytical instrument has an NSF SOP governing its use.

### 5.5 Documentation

All laboratory activities were documented using specially prepared laboratory bench sheets or NSF laboratory reports. Data from the bench sheets and laboratory reports were entered into Excel spreadsheets. These spreadsheets were used to calculate average influents and effluents, and percent reductions for each challenge. One hundred percent of the data entered into the spreadsheets was checked by a reviewer to confirm all data and calculations were correct.

## 5.6 Data Review

NSF QA/QC staff reviewed the raw data records for compliance with QA/QC requirements. NSF ETV staff checked 100% of the data in the NSF laboratory reports against the Chemistry Laboratory bench sheets.

## 5.7 Data Quality Indicators

The quality of data generated for this ETV is established through four indicators of data quality: representativeness, accuracy, precision, and completeness.

### 5.7.1 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the expected performance of the equipment tested. Representativeness was ensured by consistent execution of the test protocol for each challenge, including timing of sample collection, sampling procedures, and sample preservation. Representativeness was also ensured by using each analytical method at its optimum capability to provide results that represent the most accurate and precise measurement it is capable of achieving.

### 5.7.2 Accuracy

Accuracy was quantified as the percent recovery of the parameter in a sample of known quantity. Accuracy was measured through use of both matrix spikes of a known quantity, and certified standards during calibration of an instrument. The following equation was used to calculate percent recovery:

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

where:  $X_{\text{known}}$  = known concentration of the measured parameter  
 $X_{\text{measured}}$  = measured concentration of parameter

Accuracy of the benchtop pH and turbidity meters, and the spectrophotometer used for total chlorine and ozone analyses, was checked daily during the calibration procedures using certified check standards. Alkalinity, TOC, and TDS were analyzed in batches with non-ETV samples. Certified QC standards and/or matrix spikes were run with each batch.

The percent recoveries of all matrix spikes and standards were within the allowable limits for all analytical methods.

### 5.7.3 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. One sample per batch was analyzed in duplicate for the TDS measurements. Duplicate municipal drinking water samples were analyzed for pH, total chlorine, and turbidity as part of the daily calibration process for the analytical instruments. One

out of every ten samples for alkalinity and TOC was analyzed in duplicate. As discussed in Section 5.7.2, samples for alkalinity, TDS, and TOC were batched for analysis with other non-ETV samples. Therefore, the duplicate analysis requirements apply to the whole batch, not just samples from this ETV. Precision of duplicate analyses was measured by use of the following equation to calculate relative percent difference (RPD):

$$RPD = \left| \frac{S_1 - S_2}{S_1 + S_2} \right| \times 200$$

where:

- $S_1$  = sample analysis result; and
- $S_2$  = sample duplicate analysis result.

All RPDs were within NSF’s established allowable limits for each parameter.

#### 5.7.4 Completeness

Completeness is the proportion of valid, acceptable data generated using each method as compared to the requirements of the test/QA plan. The completeness objective for data generated during verification testing is based on the number of samples collected and analyzed for each parameter and/or method. Table 5-1 presents the completeness requirements.

<b>Number of Samples per Parameter and/or Method</b>	<b>Percent Completeness</b>
0-10	80%
11-50	90%
> 50	95%

Completeness is defined as follows for all measurements:

$$\%C = (V/T) \times 100$$

where:

- %C = percent completeness;
- V = number of measurements judged valid; and
- T = total number of measurements.

##### 5.7.4.1 Parameters with less than 100% Completeness

- As discussed in Section 3.5.2, the contact tank effluent and carbon filter effluent were measured for ozone residual twice during each challenge, but the results were not reportable for three challenges due to analytical error. A total of 56 samples were collected for ozone analysis, but only 44 samples gave reportable results. This gives a

completeness of 79% for ozone. This completeness percentage does not meet the minimum completeness requirement in Table 5-1. The lack of ozone data does not invalidate the data for the three challenges in question, because the objective of the tests was to evaluate the ASOP module's ability to oxidize the challenge chemicals, and this objective was accomplished.

- As discussed in Section 4.1, some of the TOC samples were not analyzed due to miscommunication with the NSF Chemistry Laboratory. Fourteen samples were collected for TOC, but only seven were analyzed. This gives a completeness of 50%. A completeness of 50% does not meet the minimum requirement in Table 5-1 for this parameter. However, since the test water was created from municipal water treated by reverse osmosis and deionization, and the TOC measurements that were conducted were all non-detects, NSF is confident that TOC was near or below the detection limit of 0.1 mg/L for all challenges.
- One pH measurement was missed during the strychnine challenge, so 83 of the planned 84 pH measurements were taken. This gives a completeness of 99% for pH. The completeness for pH meets the requirement in Table 5-1.
- As discussed in Section 4.1, the influent flow rate and water pressure data were not recorded for the phorate challenge. The missed readings give a completeness of 93% for these parameters. The completeness for flow rate and pressure measurements meets the requirement in Table 5-1.

## 5.8 Measurements Outside of the Test/QA Plan Specifications

- As discussed in Section 3.5.1, the base test water without any sodium bicarbonate or NaCl added was used for the sodium fluoroacetate challenge. Therefore, the alkalinity, pH, and TDS are below the target ranges for these parameters. The missing salts limited the buffering capacity of the water, and likely caused the pH to be below the minimum target of 7.0. It is unknown what impact the low pH had on the ASOP module's ability to oxidize sodium fluoroacetate.
- For the challenge water, the alkalinity was targeted at  $10 \pm 5$  mg/L prior to pH adjustment, and TDS was targeted at  $20 \pm 5$  mg/L. However, the testing lab had difficulty keeping both parameters within these ranges due to the low specified levels and small target windows as compared to the large water volumes created for each test (approximately 500 gallons). Also, the alkalinity samples were collected after pH adjustment, so the data would be representative of the final challenge water. The alkalinity readings were all above 15 mg/L (excluding the phorate challenge), ranging from 17 mg/L to 59 mg/L. Most of the TDS levels were above 25 mg/L, ranging from 11 mg/L to 45 mg/L. It is unlikely that the higher levels of these parameters affected the test results in any way, they simply added more buffering capacity to the water. Also, the target ranges were set arbitrarily to simulate RO effluent water, as stated in Section 3.5.1. Water treated by RO could have higher levels of alkalinity and TDS up to, or beyond 50 mg/L.

- The benzene challenge was below the specified minimum level of 500 µg/L. The 15-minute influent sample was 450 µg/L, and the 30-minute influent sample was 430 µg/L. The low challenge level did not limit the measured percent reduction, since the ASOP module removed only 25% of the benzene.



## Chapter 6 References

- APHA, AWWA, and WEF. 1999. *Standard Methods for the Examination of Water and Wastewater*, 20<sup>th</sup> edition. Washington D.C., APHA, AWWA, and WEF.
- NSF International. 2004. *NSF International Laboratories Quality Assurance Manual*. Ann Arbor, NSF International.
- NSF International. 2006a. *Test/QA Plan for Verification Testing of the RASco Engineering, Inc. Hyd-RO-Secure™ Series 2 Anti-Terrorism/Force Protection Point-of-Entry Water Treatment System for Removal of Chemical Contaminants*. Ann Arbor, NSF International.
- NSF International. 2006b. *Environmental Technology Verification Report. Removal of Chemical and Microbial Contaminants in Drinking Water, Watts Premier, Inc. M-2400 Point-of-Entry Reverse Osmosis Drinking Water Treatment System*. EPA/600/R-06/101. Ann Arbor, NSF International.
- USEPA. 2004. *Water Security Research and Technical Support Action Plan*. EPA/600/R-04/063.
- USEPA and NSF International. 2004. *ETV Protocol for Equipment Verification Testing for Removal of Synthetic Organic Chemical Contaminants*. Ann Arbor, NSF International.

## Chapter 7 Vendor Comments

**RASco, Inc. submitted the following comments on the draft report. These comments have not been reviewed by NSF or EPA for accuracy, and do not necessarily reflect the opinions or views of NSF and EPA.**

RASco would like to thank the USEPA and NSF International for conducting the test of our ASOP unit in a professional and thorough manner. We also appreciate the opportunity to submit our own statement to accompany the report. Overall, we believe that the test results are very positive. The text below is intended to put the ASOP technology in context and provide relevant background on its development as well as discuss some of the ETV test results.

The most important aspect of understanding the technical context of the ASOP unit is that it is not intended to be used as a standalone drinking water treatment system. It will usually be integrated into a treatment train and its design will be tailored to perform in concert with the other components of that treatment train. The design, specific features, and settings will be adjusted in consideration of such factors as the characteristics of the incoming water, the design threats to be treated, and the other components of the treatment train.

The ASOP unit tested by NSF is one component of an integrated drinking water treatment system that was developed for high security, mission critical facilities. This system was developed in response to a Program Solicitation from the Technical Support Working Group (TWSG), Combating Terrorism Technology Support Office, U.S. Department of Defense. Along with TSWG, the U.S. Department of State was the proponent for this Solicitation for applied research and development support. The specific requirements of the solicitation were to “develop and test a package water treatment system for use at key overseas U.S. facilities to counter the threat of intentional chemical, biological, or radiological contamination.” During the applied research on the TSWG project, the ASOP unit was integrated into various alternative treatment trains and combined with a variety of pre-treatment and post-treatment technologies, to define optimum systems for various applications.

Regarding specific results of the ETV testing, the herbicide paraquat test produced destruction levels that were significantly less than expected. The ASOP has successfully destroyed similar chemicals in previous government sponsored testing at much higher levels of concentration. We are investigating the specifics of the chemical and test conditions to determine any particular reasons for this level of performance.

In summary, we believe that the results of this ETV testing have demonstrated the broad-based performance of the ASOP in destroying a wide range of chemical contaminants. When integrated with other appropriate treatment train components, the ASOP interacts synergistically as demonstrated in previous government sponsored third party testing.

Again, we appreciate the efforts and support of the USEPA and the ETV team in conducting this testing program.