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Environmental Technology Verification Protocol

Drinking Water Systems Center

PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR INACTIVATION OF MICROBIOLOGICAL CONTAMINANTS

Prepared by

NSF International

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

EPA/NSF ETV
PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR INACTIVATION OF MICROBIOLOGICAL CONTAMINANTS

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Recommended by
the Steering Committee for the Verification of
Package Drinking Water Treatment Systems/Plants
on August 9, 1999
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With support from
the U.S. Environmental Protection Agency
Environmental Technology Verification Program

NSF INTERNATIONAL

Mission Statement:
NSF International (NSF), an independent, not-for-profit organization, is dedicated to public health safety and protection of the environment by developing standards, by providing education and providing superior third party conformity assessment services while representing the interests of all stakeholders.

NSF Purpose and Organization
For more than 52 years, NSF has been in the business of developing consensus standards that promote and protect public health and the environment and providing testing and certification services to ensure manufacturers and users alike that products meet those standards. Today, millions of products bear the NSF Name, Logo and/or Mark, symbols upon which the public can rely for assurance that equipment and products meet strict public health and performance criteria and standards.

Limitations of use of NSF Documents
This protocol is subject to revision; contact NSF to confirm this revision is current. The testing against this protocol does not constitute an NSF Certification of the product tested.

U.S. ENVIRONMENTAL PROTECTION AGENCY

Throughout its history, the U.S. Environmental Protection Agency (EPA) has evaluated technologies to determine their effectiveness in preventing, controlling, and cleaning up pollution. EPA is now expanding these efforts by instituting a new program, the Environmental Technology Verification Program---or ETV---to verify the performance of a larger universe of innovative technical solutions to problems that threaten human health or the environment. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. It supplies technology buyers and developers, consulting engineers, states, and U.S. EPA regions with high quality data on the performance of new technologies. This encourages more rapid availability of approaches to better protect the environment.

ETV Drinking Water Systems Center:
Concern about drinking water safety has accelerated in recent years due to much publicized outbreaks of waterborne disease and information linking ingestion of arsenic to cancer incidence. The U.S. EPA is authorized through the Safe Drinking Water Act to set numerical contaminant standards and treatment and monitoring requirements that will ensure the safety of public water supplies. However, small communities are often poorly equipped to comply with all of the requirements; less costly package treatment technologies may offer a solution. These package plants can be designed to deal with specific problems of a particular community; additionally, they may be installed on site more efficiently---requiring less start-up capital and time than traditionally constructed water treatment plants. The opportunity for the sales of such systems in other countries is also substantial.

The EPA has partnered with NSF, a nonprofit testing and certification organization, to verify performance of small drinking water systems that serve small communities. It is expected that

both the domestic and international markets for such systems are substantial. EPA and NSF have formed an oversight stakeholders group composed of buyers, sellers, and states (issuers of permits), to assist in formulating consensus testing protocols. 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 use is contemplated. NSF will meet this goal by working with equipment manufacturers and other agencies in planning and conducting equipment verification testing, evaluating data generated by such testing, and managing and disseminating information. The manufacturer is expected to secure the appropriate resources to support their part of the equipment verification process, including provision of equipment and technical support.

The verification process established by the EPA and NSF is intended to serve as a template for conducting water treatment verification tests that will generate high quality data for verification of equipment performance. The verification process is a model process that can help in moving small drinking water equipment into routine use more quickly. The verification of an equipment's performance involves five sequential steps:

1. Development of a verification/Product-Specific Test Plan;
2. Execution of verification testing;
3. Data reduction, analysis, and reporting;
4. Performance and cost (labor, chemicals, energy) verification;
5. Report preparation and information transfer.

This verification testing program is being conducted by NSF International with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development (ORD), National Risk Management Research Laboratory, Water Supply and Water Resources Division (WSWRD) - Cincinnati, Ohio. NSF's role is to provide technical and administrative leadership and support in conducting the testing. It is important to note that verification of the equipment does not mean that the equipment is “certified” by NSF or EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

Partnerships

The U.S. EPA and NSF cooperatively organized and developed the ETV Drinking Water Systems Center to meet community and commercial needs. NSF and the Association of State Drinking Water Administrators have an understanding to assist each other in promoting and communicating the benefits and results of the project.

ORGANIZATION AND INTENDED USE OF PROTOCOL AND TEST PLANS

NSF encourages the user of this protocol to also read and understand the policies related to the verification and testing of package drinking water treatment systems and equipment.

The first Chapter of this document describes the Protocol required in all studies verifying the performance of equipment or systems inactivating microbiological contaminants, the public health goal of the Protocol. The remaining chapters describe the additional requirements for equipment and systems using specific technologies to attain the goals and objectives of the Protocol: the inactivation of microbiological contaminants.

Prior to the verification testing of a package drinking water treatment systems, plants and/or equipment, the equipment manufacturer and/or supplier must select an NSF-qualified Field Testing Organization (FTO). This designated FTO must write a "Product-Specific Test Plan". The equipment manufacturer and/or supplier will need this protocol and the test plans herein and other ETV Protocols and Test Plans to develop the Product-Specific Test Plan depending on the treatment technologies used in the unit processes or treatment train of the equipment or system. More than one protocol and/or test plan may be necessary to address the equipment's capabilities in the treatment of drinking water.

Testing shall be conducted by an NSF-qualified FTO that is selected by the Manufacturer. Water quality analytical work to be completed as a part of an ETV Testing Plan shall be contracted with a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e., NSF), or the U.S. EPA. For information on a listing of NSF-qualified FTOs and State, third-party organization (i.e., NSF), or the U.S. EPA- accredited laboratories, contact NSF.

ACKNOWLEDGMENTS

The U.S. EPA and NSF would like to acknowledge those persons who participated in the preparation, review and approval of this Protocol. Without their hard work and dedication to the project, this document would not have been approved through the process which has been set forth for this ETV project.

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CHAPTER 1

EPA/NSF ETV
PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR INACTIVATION OF MICROBIOLOGICAL CONTAMINANTS

REQUIREMENTS FOR ALL STUDIES

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1.0 INTRODUCTION

This document is the protocol to be used for verification testing of equipment designed to achieve inactivation of microbiological contaminants. The equipment Field Testing Organization (FTO) must adhere to the requirements of this protocol in developing a Product-Specific Test Plan (PSTP). The final submission of the PSTP shall:

- include the information requested in this protocol;
- conform to the format identified herein; and
- conform to the specific NSF International (NSF) Equipment Verification Testing Plan or Plans related to the statement or statements of objectives that are to be verified.

The testing of new technologies and materials that are unfamiliar to the NSF/EPA will not be discouraged. It is recommended that resins or membranes or any other material or chemical in the equipment conform to NSF International/American National Standards Institute (NSF/ANSI) Standard 60 and 61.

The PSTP may conform to the requirements of more than one Testing Plan. For example, testing might be undertaken to verify performance of a system employing oxidants or mixed disinfection processes, ultraviolet (UV) radiation (thermal or light irradiation), or other processes for inactivation of microbiological contaminants.

This protocol document is presented in two fonts. The non-italicized font provides the rationale for the requirements and background information that the Field Testing Organization may find useful in preparation of the PSTP. *The italicized text indicates specific study protocol deliverables that are required of the Field Testing Organization and that must be incorporated in the PSTP.*

The following glossary terms are presented here for subsequent reference in this protocol:

- Distribution System - a system of conduits by which a potable water supply is conveyed to consumers, typically by a network of pipelines.

- EPA - The United States Environmental Protection Agency, its staff or authorized representatives.

- Equipment - Testing equipment for use in the Verification Testing Program may be defined as either a package plant or modular system.

- Field Testing Organization (FTO) - An organization qualified to conduct studies and testing of package plants or modular systems in accordance with protocols and test plans. The role of the Field Testing Organization is to complete the application on behalf of the company; to enter into contracts with NSF, as discussed herein, arrange for or conduct the skilled operation of a package plant or modular system during the intense period of testing during the study and the tasks required by the protocol.

- Manufacturer - a business that assembles and/or sells package plant equipment and/or modular systems. The role of the Manufacturer is to provide the package plant and/or modular system and technical support during the Verification Testing Program. The

Manufacturer is also responsible for providing assistance to the third party testing organization during operation and monitoring of the package plant or modular system in the Verification Testing Program.

- Modular System - A functional assembly of components for use in a drinking water treatment system or packaged and/or modular plant, each part of which provides a limited form of treatment of the feedwater(s) and which is discharged to another packaged and/or modular plant module or the final step of treatment.

- NSF - NSF International, its staff, or other authorized representatives.

- Plant Operator - the person working for a small water system who is responsible for operating water treatment equipment to produce treated drinking water. This person may also collect samples, record data and attend to the daily operations of equipment throughout the testing periods.

- Package plant - a complete water treatment system including all components from connection to the feedwater(s) through discharge to the distribution system.

- Product-Specific Test Plan (PSTP) - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the EPA/NSF ETV Protocol(s) and Test Plan(s) that apply to a specific make and model of a package plant/modular system.

- Protocol - A written document that clearly states the objectives, goals, and scope of the study as well as the test plan(s) for the conduct of the study. Protocol will be used for reference during Manufacturer participation in Verification Testing Program.

- Report - A written document that includes data, test results, findings, and any pertinent information collected in accordance with a protocol, analytical methods, procedures, etc., in the assessment of a product whether such information is preliminary, draft or final form.

- Testing Plan - A written document that describes the procedures for conducting a test or study for the application of water treatment technology. At a minimum, the test plan will include detailed instructions for sample and data collection, sample handling and sample preservation, precision, accuracy, and reproducibility goals, and quality assurance and quality control requirements.

- Testing Laboratory - An organization certified by a third-party independent organization, federal agency, or a pertinent state regulatory authority to perform the testing of drinking water samples. The role of the testing laboratory in the verification testing of equipment is to analyze the water samples in accordance with the methods and meet the pertinent quality assurance and quality control requirements described in the protocol, test plan and PSTP.

- Verification - to establish the evidence on the range of performance of equipment and/or devices under specific conditions following a predetermined study protocol.

- Verification Statement - A written document that summarizes a final report reviewed and approved by NSF on behalf of the EPA or directly by the EPA.

- Water System - the water system that operates using water treatment equipment to provide potable water to its customers.

1.1 Objectives

The scope of this protocol is designed to address drinking water systems that use innovative technologies to achieve inactivation of microbiological contaminants. The specific objectives of the verification testing may be different for each system, depending upon the statement of objectives of the specific equipment to be tested. The performance objectives are used to establish data quality objectives (DQOs) in order to develop the experimental design of the verification test. The broader the performance objectives, the more comprehensive the PSTP must become to achieve the DQOs. Verification testing conducted at a single site may not represent every environmental situation which may be acceptable for the equipment tested, but it will provide data of sufficient quality to make a judgment about the application of the equipment under conditions similar to those encountered in the verification testing. The objectives developed by each Manufacturer will be defined and described in detail in the PSTP developed for each piece of equipment. The objectives of the equipment verification testing may include:

- Generation of field data appropriate for verifying the performance of the equipment;
- Evaluation of new advances in equipment and equipment design.

An important aspect in the preparation of verification testing is to describe the procedures that will be used to develop field data, and verify performance, reliability, and costs of the water treatment equipment. The PSTP shall incorporate the Quality Assurance/Quality Control (QA/QC) elements needed to provide data of appropriate quality sufficient to reach a defensible position regarding the equipment performance. A Quality Assurance Project Plan (QAPP) shall describe quality control and assurance procedures in detail and shall be provided by the Field Testing Organization as part of the PSTP.

1.2 Scope

This protocol outlines the verification process for equipment designed to achieve inactivation of microbiological contaminants. The scope of this protocol includes Testing Plans for drinking water treatment systems designed to achieve inactivation of microbiological contaminants. These contaminants include but are not limited to protozoa, bacteria and viruses. Verification of the inactivation of protozoan cyst and oocyst contaminants may be performed but methods for determining the viability of cysts and oocysts are interim and subject to change.

An overview of the verification process and the elements of the PSTP to be developed by the Field Testing Organization are described in this protocol. Specifically, the PSTP shall define the following elements of the verification testing:

- Roles and responsibilities of verification testing participants;
- Procedures governing verification testing activities such as equipment operation and process monitoring; sample collection, preservation, and analysis; and data collection and interpretation;

- Experimental design of the Field Operations Procedures;
- Quality assurance and quality control (QA/QC) procedures for conducting the verification testing and for assessing the quality of the data generated from the verification testing; and,
- Health and safety measures relating to biohazard, chemical hazard, electrical, mechanical and other safety codes.

Content of Product-Specific Test Plan:

The structure of the PSTP *must conform to the outline below. The required components of the PSTP are described in greater detail in the sections following the outline. The required content of the PSTP and the responsibilities of participants are listed at the end of each section.*

- *TITLE PAGE*
- *FOREWORD*
- *TABLE OF CONTENTS - The Table of Contents for the PSTP should include the headings provided in this document although they may be modified as appropriate for a particular type of equipment to be tested.*
- *EXECUTIVE SUMMARY - The Executive Summary describes the contents of the PSTP (not to exceed two pages). A general description of the equipment and the statement of performance objectives which will be verified during testing shall be included, as well as the testing locations, a schedule, and a list of participants.*
- *ABBREVIATIONS AND ACRONYMS - A list of the abbreviations and acronyms used in the PSTP should be provided.*
- *EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES (described in the sections below)*
- *EQUIPMENT CAPABILITIES AND DESCRIPTION (described in the sections below)*
- *EXPERIMENTAL DESIGN (described in the sections below)*
- *FIELD OPERATIONS PROCEDURES (described in the section below)*
- *QUALITY ASSURANCE PROJECT PLAN (described in the section below)*
- *DATA MANAGEMENT AND ANALYSIS (described in the section below)*
- *HEALTH AND SAFETY PLAN (described in the section below)*

2.0 EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES

2.1 Verification Testing Organization and Participants

Manufacturers and their designated Field Testing Organization shall provide a table including the name, affiliation, and mailing address of each participant, a point of contact, description of participant's role, telephone and fax numbers, and e-mail address in the PSTP.

The equipment provided by the Manufacturer shall explicitly meet all the requirements of Occupational Safety and Health Association (OSHA), National Electrical Manufacturers Association (NEMA), Underwriters Laboratory (UL), NSF and other appropriate agencies in order to ensure operator safety during Verification Testing.

2.2 Organization

The Field Testing Organization in its application on behalf of the Manufacturer shall provide the organizational structure for the verification testing showing lines of communication.

2.3 Verification Testing Site Name and Location

This section discusses background information on the verification testing site(s), with emphasis on the quality of the feedwater, which in some cases may be the source water at the site. The PSTP must provide the site names and locations at which the equipment will be tested. In some cases, the equipment will be demonstrated at more than one site. The equipment may be tested under different conditions of feedwater quality (or source water quality) and a range of seasonal climate and weather conditions.

2.4 Site Characteristics

The PSTP must include a description of the test site. This shall include a description of where the equipment will be located. If the feedwater to the equipment is the source water for an existing water treatment plant, describe the raw water intake, the opportunity to obtain raw water without the addition of any chemicals, and the operational pattern of raw water pumping at the full-scale facility (is it continuous or intermittent?). If applicable, the Field Testing Organization shall also describe in the PSTP how the water flow to the test equipment will be separated from the existing treatment facilities with such equipment as backflow preventers, air gaps, break tanks, etc.

The source water characteristics shall be described and documented. The PSTP shall also describe facilities to be used for handling the treated water and wastes (i.e., residuals) produced during the Verification Testing. Can the required water flows and waste flows produced be dealt with in an acceptable way? Are water and air pollution discharge permits needed?

2.5 Responsibilities

This section identifies the organizations involved in the testing and describes the primary responsibilities of each organization. The responsibilities of the Manufacturer will vary depending on the type of verification testing. Multiple Manufacturers testing at one time is also an option.

The Field Testing Organization shall be responsible for:

- Providing needed logistical support, establishing a communication network, and scheduling and coordinating the activities of all verification testing participants;

- Ensuring that locations selected as test sites have feedwater quality consistent with the objectives of the verification testing (Manufacturer may recommend a verification testing site(s));

- Managing, evaluating, interpreting, and reporting on data generated by the verification testing;

- Evaluating and reporting on the performance of the microbiological inactivation technologies.

The manufacturer shall be responsible for provision of the equipment to be evaluated.

Content of PSTP Regarding Equipment Verification Testing Responsibilities:

The Field Testing Organization, shall be responsible for including the following elements in the PSTP:

- *Definition of the roles and responsibilities of appropriate verification testing participants;*
- *A table which includes the name, affiliation, and mailing address of each participant, a point of contact, description of participant's role, telephone and fax numbers, and e-mail address;*
- *Organization of operational and analytical support;*
- *List of the site name(s) and location(s);*
- *Description of the test site(s), the site characteristics and identification of where the equipment will be located.*

Manufacturer Responsibilities:

- *Provision of complete, field-ready equipment for verification testing;*
- *Provision of logistical, and technical support, as required;*
- *Provision of technical assistance to the qualified testing organization during operation and monitoring of the equipment undergoing verification testing.*

3.0 EQUIPMENT CAPABILITIES AND DESCRIPTION

3.1 Equipment Capabilities

The Manufacturer and their designated Field Testing Organization shall identify the water quality objectives to be achieved in the statement of performance objectives of the equipment to be evaluated in the verification testing. The statement of performance objectives shall be clearly stated in the PSTP. The statement of performance objectives must be specific and verifiable by a statistical analysis of the data. An example of a satisfactory statement of performance objectives would be:

> "This system is capable of achieving inactivation of 99.9% (3-log removal) of *Giardia muris* protozoa in feedwaters with total organic carbon concentrations less than 5.0 mg/L and turbidities less than 1 NTU (Nephelometric turbidity units)."

A statement of performance objectives such as: "This system will achieve inactivation of microbiological contaminants in accordance with the requirement of the Surface Water Treatment Rule on a consistent and dependable basis," would not be acceptable.

The Manufacturer shall be responsible for identification of which microbiological contaminants shall be monitored for inactivation under the statement of performance objectives. The statement

of performance objectives prepared by the Field Testing Organization in collaboration with the Manufacturer shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feedwater. Statements of performance objectives that are too easily met may not be of interest to the potential user, while performance objectives that are overstated may not be achievable. The statement of performance objectives forms the basis of the entire equipment verification testing and must be chosen appropriately. Therefore, the design of the PSTP should include a sufficient range of feedwater quality to permit verification of the statement of performance objectives.

Statements should also be made in the PSTP regarding the applications of the equipment, the known limitations of the equipment and what advantages it provides over existing equipment.

3.2 Equipment Description

Description of the equipment for verification testing shall be included in the PSTP. Data plates shall be permanent and securely attached to each production unit. The data plate shall be easy to read in English or the language of the intended user, located on the equipment where it is readily accessible, and contain at least the following information:

a. Equipment Name
b. Model #
c. Manufacturer's name and address
d. Electrical requirements - volts, amps, and Hertz
e. Serial Number
f. Warning and Caution statements in legible and easily discernible print size
g. Capacity or output rate (if applicable)

In addition, the equipment provided by the Manufacturer shall be provided with all OSHA required safety devices (e.g., safety shields or shrouds, emergency shut-off switches, etc.).

Content of PSTP Regarding Equipment Capabilities and Description:

The PSTP shall include the following documents:

- *Description of the equipment to be demonstrated including photographs from relevant angle or perspective;*
- *Brief introduction and discussion of the engineering and scientific concepts on which the microbiological inactivation capabilities of the water treatment equipment are based;*
- *Description of the equipment and each process included as a component in the modular system including all relevant schematics;*
- *Brief description of the physical construction/components of the equipment, including the general environmental requirements and limitations, required consumables, weight, transportability, ruggedness, power and other needed, etc.;*
- *Statement of typical rates of consumption of chemicals, a description of the physical and chemical nature of wastes, and rate of waste generation (concentrates, residues, etc.);*
- *Definition of the performance range of the equipment;*
- *Identification of any special licensing requirements associated with the operation of the equipment;*
- *Description of the applications of the equipment and the inactivation capabilities of the treatment system relative to existing equipment. Comparisons shall be provided in such*

areas as: treatment capabilities, requirements for chemicals and materials, power, labor requirements, suitability for process monitoring and operation from remote locations, ability to be managed by part-time operators;

- *Discussion of the known limitations of the equipment. The following operational details shall be included: the range of feedwater quality suitable for treatment with the equipment, the upper limits for concentrations of microorganisms that can be inactivated to concentrations below the manufacturer-specified level, level of operator skill required to successfully use the equipment.*

Manufacturer Responsibilities:

- *Provision of complete, field-ready equipment with the following information explicitly provided: Equipment Name, Model #, Manufacturer's name and address, Electrical requirements (e.g., volts, amps, and Hertz), Serial Number, Warning and Caution statements in legible and easily discernible print size, Capacity or output rate (if applicable)*
- *Provision of equipment complete with all OSHA required safety devices (e.g., safety shields or shrouds, emergency shut-off switches, etc.) verification testing.*

4.0 EXPERIMENTAL DESIGN

This section discusses the objectives of the verification testing, factors that must be considered to meet the performance objectives, and the statistical analysis and other means that NSF will use to evaluate the results of the verification testing.

4.1 Objectives

The objectives of verification testing are to evaluate equipment in the following areas: 1) performance relative to the manufacturer's stated range of equipment objectives; 2) the impacts of variations in feedwater quality (such as turbidity, particle concentration, background microbial concentration, temperature, pH, alkalinity, iron, manganese and/or other appropriate inorganics, etc.) on equipment performance; 3) the logistical, human, and economic resources necessary to operate the equipment; and 4) the reliability, ruggedness, cost, range of usefulness, and ease of operation.

A PSTP shall include those treatment tests (seeding studies) listed in ETV test plans that are most appropriate. For example, if equipment is only intended for inactivation of viruses, there would be no need to conduct testing to evaluate the inactivation of *Giardia* and *Cryptosporidium.*

The Field Testing Organization must prepare a statistical design of experiments which identifies independent and dependent variables, numbers of experimental runs to be performed, QA/QC of the data, and statistical techniques that will be used to analyze the data and draw meaningful conclusions. This design will be evaluated by NSF staff to insure that it can adequately address the statement of performance objectives stated in the PSTP.

4.2 Equipment Characteristics

This section discusses factors that will be considered in the design and implementation of the equipment verification testing. These factors include ease of operation, degree of operator attention required, response of equipment and treatment process to changes in feedwater quality, electrical requirements, system reliability features including redundancy of components, feed flow requirements, discharge requirements, spatial requirements for the equipment (footprint), unit processes included in treatment train, chemical consumption requirements, and the response of the treatment process and equipment to intermittent operation.

Verification testing procedures must simulate routine conditions. This can be achieved by field testing or by laboratory testing under conditions that simulate field operations as closely as possible.

4.2.1 Qualitative Factors

Some factors, while important, are difficult or impossible to quantify. These are considered qualitative factors. Important factors that cannot easily be quantified are the portability of equipment, the modular nature of the equipment, the safety of the equipment and the logistical requirements necessary for using it.

Typical qualitative factors to be discussed are listed below, and others may be added. The PSTP shall discuss those factors that are appropriate to the test equipment.

- Reliability or susceptibility to environmental conditions
- Equipment safety
- Effect of operator experience on results.

4.2.2 Quantitative Factors

Many factors of the equipment characteristics can be quantified by various means in this Verification Testing Program. Some can be measured while others cannot be controlled. Typical quantitative factors to be discussed are listed below, and others may be added. The PSTP shall discuss those factors that are appropriate to the test equipment.

- Power and consumable supply (such as chemical and materials) requirements
- Cost of operation, expendables, and waste disposal
- Hydrodynamics of equipment
- Length of operating cycle
- Estimated labor hours (and labor classification) for operation and maintenance.

These quantitative factors will be used as an initial benchmark to assess equipment performance.

4.2.3 Evaluation of Reactor Hydrodynamics

Characterization of the reactor hydrodynamics within each system is essential to define the contact time of feedwaters with chemical or physical mechanisms for microbiological inactivation. This characterization shall be accomplished through tracer tests conducted on each component of the inactivation equipment under the flow, temperature, and water quality conditions that shall be employed during microbiological inactivation experiments.

The Manufacturer shall propose a tracer test methodology in the PSTP that shall be used to demonstrate the flow conditions through the microbiological contaminant inactivation equipment. It is recommended that the tracer testing be conducted using a pulse-feed (slug-dose) method, with a known volume of an appropriate tracer material. The goal of tracer testing is to provide a profile of the tracer concentration as a function of time through the reactor. For appropriate tracer test methods, the Manufacturer is referred to the American Water Works Association Research Foundation (AWWARF) study "Experimental Methodologies for the Determination of Disinfection Effectiveness" (Haas et al., 1993) and to Appendix C of the Guidance Manual (GM) for Compliance with the Filtration and Disinfection Requirements of the Surface Water Treatment Rule for Public Water Systems using Surface Water Sources (USEPA, 1989). The latter Appendix document provides a discussion of alternative tracer test methods and indicates the frequency at which samples shall be taken to adequately define the residence time distribution.

The duration of each tracer test shall be based on the expected hydraulic conditions within the reactor. It is difficult to precisely determine the tracer testing duration for a particular reactor *a priori*, because the hydrodynamic characteristics of a particular reactor are not known until tracer testing is conducted. Therefore, tracer studies conducted in this Verification Testing Program shall be performed to include sampling over a minimum time period of three Hydraulic Detention Times (HDTs). Details of each tracer study shall be addressed in individual equipment Testing Plans.

4.3 Water Quality Considerations

The primary treatment goal of the equipment employed in this Verification Testing Program is to achieve inactivation of microbiological contaminants found in feedwaters (or raw waters) such that product waters are of acceptable microbiological quality. The experimental design in the PSTPs shall be developed so the relevant questions about water treatment equipment capabilities can be answered.

Manufacturers should carefully consider the capabilities and limitations of their equipment and assist the Field Testing Organization in preparing PSTPs that sufficiently challenge their equipment. The Manufacturer should adopt an experimental approach to verification testing that would provide a broad market for their products, while recognizing the limitations of the equipment, and not conducting microbiological inactivation testing that would be beyond the capabilities of the equipment. A wide range of contaminants or water quality problems that can be addressed by water treatment equipment varies, and some treatment equipment can address a broader range of problems than other types. Manufacturers shall use ETV Testing Plans as the basis for the specific PSTPs.

4.3.1 Feedwater Quality

One of the key aspects related to demonstration of equipment performance in verification testing is the range of feedwater quality that can be treated successfully. The Manufacturer and Field Testing Organization should consider the influence of feedwater quality on the quality of treated waters produced by the equipment, such that product waters meet the microbiological water quality goals or regulatory requirements. As the range of feedwater quality that can be treated by the equipment becomes broader, the potential applications for treatment equipment with verified performance objectives may also increase.

The specific water quality parameters to be monitored in the Verification Testing Program shall be specified by the Field Testing Organization in the PSTP. The following feedwater quality constituents may be important for treatment equipment intended to inactivate microbiological contaminants:

- density (concentration) of microorganisms (bacteria, viruses and protozoa)
- turbidity, particles
- dissolved organic carbon (DOC), total organic carbon (TOC), or UV-254 absorbance
- biological dissolved organic carbon (BDOC) or assimilable organic carbon (AOC)
- temperature, with temperatures near freezing having potential for the most difficult treatment conditions
- pH and alkalinity
- total Kjeldahl nitrogen (TKN), ammonia nitrogen
- total dissolved solids (TDS), and other individual inorganic parameters
- presence of background microbial populations including algae and other organisms
- iron, manganese, and hardness

4.3.2 Treated Water Quality

Production of treated water of a high quality in terms of microbiological constituents shall be the primary goal of the water treatment systems included in this Equipment Verification Program. The statement of performance objectives provided by the Field Testing Organization shall be related to the inactivation of viruses and bacteria.

In addition, the Field Testing Organization may wish to make a statement about performance objectives of the equipment for removal or inactivation of other contaminants. Other water quality parameters that are useful for assessing equipment performance may be considered in the Field Testing Organization's statement of objectives. These may include:

- particle count or concentration
- total and fecal coliform bacteria
- heterotrophic plate count bacteria (HPC)
- concentrations of disinfectant by-products (i.e., trihalomethanes (THMs) haloacetic acids (HAAs), aldehydes)

- BDOC or AOC
- *Giardia* and *Cryptosporidium* inactivation

Furthermore, some water treatment equipment can be used to meet aesthetic goals. Water quality considerations that may be important for some small systems include:

- color, taste and odor
- total dissolved solids
- iron and manganese
- corrosivity

4.3.3 Analysis of Disinfectant Residuals

In the case that chemical disinfectants are employed in the microbiological contaminant inactivation equipment, measurement of chemical disinfectant residuals shall be performed on the treated waters where appropriate. Methods for water sampling and the analysis of disinfectant residuals (as well as disinfectant by-products) shall be included in the PSTP. At a minimum, measurement of chemical disinfectant residuals shall be performed at times corresponding to the initial, midpoint, and final times for each microbiological inactivation experiment, with testing at additional intermediate times as deemed necessary. Where appropriate, techniques included in *Standard Methods for the Examination of Water and Wastewater* shall be employed for measurement of disinfectant residuals. Analysis of Disinfection By-Products for this Verification Testing Program shall be conducted according to the appropriate Standards Methods or EPA laboratory techniques.

4.4 Microbial Inactivation Challenge Organisms

The general types of microbiological challenge organisms for which the inactivation protocol may be demonstrated are listed below:

- bacteria or bacterial spores
- viruses
- protozoan cysts or oocysts (only interim non-standard methods available)

In the Product-Specific Test Plan, the Field Testing Organization shall indicate which microorganisms will be used as test organisms for the microbiological inactivation challenge studies. *Cryptosporidium* and *Giardia* may be obtained from: Waterborne Inc., 6047 Hurst Street, New Orleans, LA 70118-6129 or equivalent. Bacteria, viruses and phages shall be obtained from: American Type Culture Collection (ATCC), 12301 Parklawn Drive, Rockville, MD 20852 or equivalent. The following criteria are recommended for demonstrating equivalency:

(a) use of the same isolate strain
(b) use of the same host species
(c) use of same processing and cleanup techniques
(d) demonstration of comparable ID_{50} value

Appropriate methodologies for handling and spiking of microorganisms is provided in the section below. The PSTP shall state a standard method for assessing the viability of the

microbiological species (only non-standard methods available for protozoan cysts or oocysts) employed for inactivation challenge experiments prior to initiation of the seeding studies. Requirements for determination of microbial viability are discussed further in Section 6.5 of this Protocol and the notice below. The procedures for evaluation of microbial viability shall be thoroughly described by the Field Testing Organization in the PSTP. Analysis for detection, enumeration and viability of microbiological contaminants shall be performed according to standard or EPA-approved methodologies, at a state-certified or third party- or EPA-accredited laboratory.

A peer-reviewed standard method is not available for protozoan cyst or oocyst inactivation. At present, animal infectivity is considered the gold standard and will be the only method that will be accepted for ETV testing. Use of an alternate method, such as cell culture, will be considered if sufficient data is presented to demonstrate the equivalency of this method to animal infectivity for the intended application. Guidelines for demonstrating method equivalency are available from EPA's Alternative Test Procedure (ATP) protocol.

The animal infectivity protocol used by the FTO must be described in the FOD and must meet the following minimum requirements:

(1) The source of the oocysts and cysts must be fully documented with respect to: (a) inoculum isolate used; (b) breed, strain, age and supplier of host animal; (c) harvesting and cleanup techniques used, age of cyst/oocysts used in the disinfection experiments; (d) how the cysts/oocysts were stored and maintained prior to use. Cysts/oocysts should be no more than four weeks old at the time of the disinfection studies and the viability of the cysts/oocysts used in pilot-scale or full-scale seeding studies must be demonstrated. This demonstration must be performed by verifying that the positive control data obtained by infectivity measurements is at least 80 percent of the hemacytometer count data.

(2) The mechanics of the assay procedure must be fully documented with respect to the breed and strain and age and supplier of the host animals receiving the inoculant, inoculant procedures, the cohort size used for each experimental condition, the date of inoculation and sacrifice of host animals, the portion of the animal and processing used for isolation of cysts/oocysts, and the microscopy technique used to determine presence of cysts/oocysts.

(3) The host infectivity dose-response model must be fully described. Either a linear transformation of a logistic dose-response with model parameter estimation using maximum likelihood (Finch et al., 1994) or a Most Probable Number (MPN) method with MPN calculations made using the Thomas formula approximation or solution of the full MPN equation (Oppenheimer et al., 2000) must be used. For either method, it is imperative that the ID_{50} value required to calculate the concentration of cysts/oocysts is either directly measured for each batch of cysts/oocysts utilized, or that only reduction of infectivity before and after disinfection is reported from the dose-response data. Because this reduction is based on the ID_{50} value appearing in both the numerator and the denominator, it is not necessary to know the actual value, provided that the same batch of cysts/oocysts is used with and without disinfection.

(4) The QA/QC criteria must be fully detailed and all data produced outside of these criteria must be flagged as suspect. The following minimum checks must be performed: (a) each disinfection study must include a positive control; (b) the assay calculated value of

"infectious" cysts/oocysts for the positive control must fall within one log of the hemacytometer counts for total number of cysts/oocysts spiked; (c) hemacytometer counts must be performed for all disinfection samples and these counts should not differ by more than 0.25 log.

NOTICE:
An expert workshop on the state of disinfection research for the control of *Cryptosporidium* in drinking water was convened under the auspices of the U.S. Environmental Protection Agency (EPA) and the AWWA Research Foundation (AWWARF) in Washington, DC, from January 12 to 14, 1998. Information on this workshop can be found on the internet at the web site: http://www.awwarf.com/newprojects/crypwksp/crypwksp.htm

The goals and objectives for this workshop were:

- Discuss the existing data on *Cryptosporidium* inactivation;
- Determine a common frame of reference for the variety of studies;
- Determine what information is missing or controversial.

Among other issues discussed was the definition of viability:

> "For no microorganism, is the definition of viability unambiguous. Different endpoints may yield different results. Hence a procedure for incorporating experimental data obtained using different endpoints would be desired.
>
> "Animal infectivity is a reference method. There is a pressing need for developing a secondary reference method for disinfection testing that is easier to perform and less costly to maintain.
>
> "Interpretation of data taken by alternative (non-reference) methods must be grounded in the development of a quantitative relationship between a reference method and the alternative methods."

4.5 Spiking of Challenge Organisms for Seeding Studies

In the PSTP, the Field Testing Organization shall thoroughly describe the methodology to be used for conducting any microbiological inactivation challenge studies with the equipment. In this section, a general protocol for conducting microbiological contaminant seeding or challenge studies is described below, as based upon the methods developed in the AWWARF study "Experimental Methodologies for the Determination of Disinfection Effectiveness" (Haas et al., 1993).

In spiking of challenge microorganisms to the inactivation equipment, a concentrated mixture of microorganisms shall be prepared and fed to the main water stream at a known feed rate. The dilution of the concentrated microbial suspension is based upon the density of microorganisms in the concentrated mixture, the flow rate of water to the equipment, and the desired concentration of microorganisms in the disinfection reactor. The following equation shall be used by the Field Testing Organization prior to initiation of the seeding studies in order to provide a crude estimation of the appropriate flowrate and concentration of enumerable challenge organisms to be employed during the spiking of challenge microorganisms:

$$Q_m = \left[\frac{D_m}{C_m - D_m}\right]\sum_{i=1}^{n} Q_{wi}$$

where: Q_m is the flow rate of concentrated microbiological contaminant suspension (L/min)

Q_{wi} is the sum of the flow rates of raw water and any other added flows to the equipment (Q_{w1}, Q_{w2},...,Q_{wn}) such as disinfectant solutions (L/min)

D_m is the desired initial steady-state concentration of microorganisms in the disinfection reactor following dilution and prior to any inactivation (infectious units/L)

C_m is the concentration of enumerable microorganisms in the feed suspension (infectious units/L)

The appropriate flowrate and concentration of enumerable microorganisms shall be initially estimated based upon Equation 1; however, the final influent density of microorganisms shall be measured directly from the feedstream to the disinfection system.

A control experiment with the challenge microorganisms in the absence of disinfectant shall be conducted in order to obtain a mass balance on microorganisms through the inactivation equipment, and to evaluate the potential losses of microorganisms through the system. The Field Testing Organization shall provide an SOP as an Appendix ~~in~~ to the PSTP that confirms with the outline provided below.

SOP for Conducting Microbial Challenge Tests

Stated Objective: The stated objective must agree with the statement of performance objectives to be verified provided in the PSTP. It must specify:

(a) the reactor to be tested (manufacturer, model, and scale),
(b) the flowrate(s) to be challenge tested,
(c) the number of lamps and lamp settings to be challenge tested,
(d) the challenge organism,
(e) the targeted level of inactivation.

Description of the Challenge Organism:

(a) Discuss the rationale for utilizing the selected organism,
(b) Safety factors and precautions needed in working with the organism,
(c) Supplier and catalog number or host and harvest and processing protocols,
(d) Proper storage, handling, and disposal techniques,
(f) Methodology of verifying the viability throughout usage.

Description of the Spiking Protocol:

(a) Quantity of organisms or criteria for quantity of organisms required per seeding,
(b) Duration of each seeding experiment and required feed stock volume,
(c) Detailed descriptions of challenge organism feed storage and mixing conditions and injection techniques,
(d) Flow measurement techniques and target flow values for feed stock and influent to achieve steady state conditions,
(e) Requirement for any modifications to influent water quality (i.e. dechlorination, pH adjustment, etc.),
(f) Cleaning protocols for all equipment utilized in challenge study.

Description of the Challenge Protocol:

(a) Number of replicates and sample collection points,
(b) Time and cleaning required between seedings to achieve uncontaminated steady state,
(c) Sample collection techniques and containers,
(d) Chain of custody protocols and handling requirements and holding times,
(e) Name and credentials of laboratory performing analysis,
(f) Citation of analytical methodology,
(g) Total number of replicates and experimental conditions to be tested.

Description of Experimental Quality Control

(a) Required number and type of positive and negative controls (at least one negative control with reactor non-operational, one positive control verifying feed stock concentration, and one trip blank per day's operation is required),
(b) Discussion of schedule and sequence for collection of controls during performance challenge experiments,
(c) Laboratory precision and accuracy acceptance criteria for release of data.

4.6 Recording Data

For all microbiological challenge experiments, data should be maintained on the pH, temperature and other water quality parameters listed in Sections 4.3.1 and 4.3.2 above. The following items of information shall also be maintained for each experiment:

- Disinfectant type and dose. In the case where multiple chemical disinfectants are used, the type of disinfectants must also be specified (e.g. ozone, chlorine, monochloramine, etc.);
- Water type (raw water, pretreated feedwater, product water, waste water);
- Experimental run (e.g. 1st run, 2nd run, 3rd run, etc.);
- Contact time; initial time is considered the time at which microorganisms and disinfectant come into contact with reactor vessel. If reactor vessel is not appropriate terminology, Manufacturer shall explain mechanism of inactivation and design of inactivation chamber;
- UV intensity readings; UV intensity shall be recorded at the time each sample is withdrawn from the reactor for processes that rely on UV irradiation.
- Residual; residual disinfectant concentrations are measured for each sample withdrawn from the reactor vessel. This is only applicable to technologies that use a residual for disinfection. Not applicable for UV irradiation or other non-chemical disinfection techniques;
- Microbiological Contaminant Concentration; this value is a derived quantity equal to the number of organisms divided by the equivalent volume examined;
- Dilution factor; for the microbial analytical techniques the dilution or concentration factor should be expressed as a decimal fraction (0.2 means that one volume of the diluted material is equivalent to 0.2 volumes of original material);
- Analyzed volume of sample actually plated or examined for microorganism counts; this volume of sample is important for accurate reporting of microbial analytical techniques.
- Number of organisms; the counted number of bacterial colonies, plaque forming units or cysts shall be recorded;
- Power input where appropriate for selected microbiological inactivation techniques;

- Power fluctuations (surges, brown outs, etc.) during testing; these power factors are particularly important for determining the inactivation effectiveness of electrotechnologies.

4.7 Recording Statistical Uncertainty for Assorted Water Quality Parameters

For the analytical data obtained during verification testing, 95% confidence intervals shall be calculated by the Field Testing Organization for the log transformation of the inactivation data (i.e., log{N/No}) and also for water quality parameters in which eight or more samples were collected. The specific testing plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. Data quality objectives and the vendor's performance objectives shall be used to assess which water quality parameters are critical and thus require confidence interval statistics.

For the broad range of water quality parameters, the consistency and precision of water quality data can be evaluated with use of the confidence interval. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. The following formula shall be employed for confidence interval calculation:

$$\text{confidence interval} = \overline{X} \pm t_{n-1,1-\frac{a}{2}} \left(S / \sqrt{n} \right) \qquad (2)$$

where: X is the sample mean;
S is the sample standard deviation;
n is the number of independent measurements included in the data set;
t is the Student's t distribution value with n-1 degrees of freedom; and
α is the significance level, defined for 95% confidence as: 1 - 0.95 = 0.05.

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

$$\text{95\% confidence interval} = \overline{X} \pm t_{n-1,0.975} \left(S / \sqrt{n} \right) \qquad (3)$$

With input of the analytical results for pertinent water quality parameters into the 95% confidence interval equation, the output will appear as the sample mean value plus or minus the width of the confidence interval. The results of this statistical calculation may also be presented as a range of values falling within the 95% confidence interval. For example, the results of the confidence interval calculation may provide the following information: 520 +/- 38.4 mg/L, with a 95% confidence interval range described as (481.6, 558.4).

Calculation of confidence intervals shall not be required for equipment performance results (e.g., filter run length, cleaning efficiency, in-line turbidity or in-line particle counts, etc.) obtained during the equipment testing verification program. However, as specified by the Field Testing Organization, calculation of confidence intervals may be required for such analytical parameters as feedwater microbiological contaminant concentration, TOC, DOC, grab samples of turbidity, THMs, HAAs. In order to provide sufficient analytical data for statistical analysis, the Field Testing Organization shall collect three discrete water samples at one set of operational

conditions for each of the specified water quality parameters during a designated testing period. The procedures and sampling requirements shall be provided in detail in the Verification Testing Plan.

4.8 Verification Testing Schedule

Verification testing activities include equipment set-up, initial operation, verification operation, and sampling and analysis. Initial operations are intended to be conducted so that equipment can be tested to be sure it is functioning as intended. If feedwater (or source water) quality influences operation and performance of equipment being tested, the initial operations period serves as the shake-down period for determining appropriate operating parameters. The schedule of testing may also be influenced by coordination requirements with a utility.

For water treatment equipment involving chemical/physical inactivation of microbiological contaminants, an initial period of bench-scale testing of feedwater followed by treatment equipment operation may be needed to determine the appropriate disinfectant dosages, disinfectant type where appropriate, and pH values of feedwater that will result in successful functioning of the process train.

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's objectives, such as in the treatment of surface water where additional testing during each season may assist in verifying an objective. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can challenge the manufacturer's objectives. For example, climatic changes between rainy and dry seasons may produce substantial variability in feedwater turbidity, TOC, and other water quality parameters. Cold weather operations will be an important component of seasonal water quality testing because of the impact of cold temperatures on water viscosity and inactivation efficacy. Cold water temperatures (1°C to 5°C) have been shown to have an adverse affect on some water treatment processes due to the increase in water viscosity and alteration of diffusional processes at cold temperatures. Cold temperature considerations may be particularly important for thermal inactivation processes. Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Content of PSTP Regarding Experimental Design:

The PSTP shall include the following elements:

- *Identification of the qualitative and quantitative factors of equipment operation to be addressed in the Verification Testing Program, including estimated costs of operation and labor.*
- *Detailed development of the statistical design for the Verification Testing with identification of dependent and independent variables, number of experimental runs to be performed, QA/QC of the data and statistical techniques that will be used to analyze the data.*
- *Description of hydrodynamic tracer study to be conducted on the microbial inactivation equipment;*

- *Identification and discussion of the particular water treatment issues and microbiological contaminants that the equipment is designed to address, how the equipment will solve the problem, and who would be the potential users of the equipment;*
- *Identification of the range of key water quality parameters, given in applicable ETV Testing Plans, which the equipment is intended to address and for which the equipment is applicable;*
- *Identification of the key parameters of treated water quality and analytical methods that will be used for evaluation of equipment performance during the inactivation of microbiological contaminants. Parameters of significance for treated water quality were listed above in Sections 4.3.2 and in applicable ETV Testing Plans;*
- *Description of data recording protocol for equipment operation, water quality parameters, and microbial water quality parameters;*
- *Description of the confidence interval calculation procedure for selected water quality parameters;*
- *Detailed description of the methodologies to be used for conducting the microbiological inactivation challenge studies with the equipment.*
- *Detailed outline of the verification testing schedule.*

5.0 FIELD OPERATIONS PROCEDURES

5.1 Equipment Operations and Design

The ETV Testing Plan specifies procedures that shall be used to ensure the accurate documentation of both equipment performance and treated water quality. Careful adherence to these procedures will result in definition of verifiable performance of equipment. The specific reporting techniques, methods of statistical analysis and the QA/QC of microbial data and inactivation procedures shall be stated explicitly by the Field Testing Organization in the PSTP before initiation of the Verification Testing Program. (Note that this protocol may be associated with a number of different ETV Testing Plans for different types of microbiological inactivation process equipment.)

The design aspects of water treatment process equipment often provide a basis for approval by state regulatory officials and can be used to determine if equipment evaluated in the Verification Testing Program can be employed under higher or lower flow rate conditions. The field operations procedures and testing conditions provided by the Field Testing Organization shall therefore be specified in the PSTP to demonstrate treatment capabilities over a broad range of operational conditions and feedwater qualities.

5.2 Communications, Documentation, Logistics, and Equipment

The successful implementation of the verification testing will require detailed coordination and constant communication between all verification testing participants.

All field activities shall be thoroughly documented. Field documentation will include field logbooks, photographs, field data sheets, and chain-of-custody forms. The Field Testing Organization shall be responsible for maintaining all field documentation. Field notes shall be kept in a bound logbook. Each page shall be sequentially numbered and labeled with the project name and number. Field logbooks shall be used to record all water treatment equipment

operating data. Completed pages shall be signed and dated by the individual responsible for the entries. Errors shall have one line drawn through them and this line shall be initialed and dated.

All photographs shall be logged in the field logbook. These entries shall include the time, date, direction, subject of the photograph, and the identity of the photographer. Any deviations from the approved final PSTP shall be thoroughly documented in the field logbook at the time of inspection and in the verification report.

Original field sheets and chain-of-custody forms shall accompany all samples shipped to the analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples shall be provided at the time of the QA/QC inspection and included in the verification report.

As available, electronic data storage and retrieval capabilities shall be employed in order to maximize data collection and minimize labor hours required for monitoring. The guidelines for use of data-loggers, laptop computers, data acquisition systems etc., shall be detailed by the Field Testing Organization in the PSTP.

5.3 Initial Operations

Initial operations of the microbiological inactivation equipment will allow Field Testing Organizations to refine their operating procedures and to make operational adjustments as needed to successfully treat the feedwater. Information generated through this period of operation may be used to revise the PSTP, if necessary. A failure at this point in the verification testing could indicate a lack of capability of the process equipment and the verification testing might be canceled.

5.4 Equipment Operation and Water Quality Sampling for Verification Testing

All field activities shall conform to requirements provided in the PSTP that was developed and approved for the verification testing being conducted. All sampling and sample analysis conducted during the Verification Testing Program shall be performed according to the procedures detailed by the Field Testing Organization in the PSTP.

If unanticipated or unusual situations are encountered that may alter the plans for equipment operation, water quality sampling, or data quality, the Field Testing Organization must discuss the situation and planning modifications with the NSF technical lead. Any deviations from the approved final PSTP shall be thoroughly documented.

During routine operation of water treatment equipment, the total number of hours during which the equipment is operated each day shall be documented. In addition, the number of hours each day during which the operator was working at the treatment plant performing tasks related to water treatment and the operation of the treatment equipment shall be documented. Furthermore, the tasks performed during equipment operation shall be described by the Field Testing Organization, the Water System or the Plant Operator.

Content of PSTP Regarding Field Operations Procedures:

The PSTP shall include the following elements:

- *A table summary of the proposed time schedule for operating and testing,*
- *Field operating procedures for the equipment and performance testing, based upon the ETV Testing Plan with listing of operating parameters, ranges for feedwater quality, and the sampling and analysis strategy.*
- *Provision of detailed sampling and analysis plan for water quality and microbial parameters.*

Manufacturer Responsibilities:

- *Provision of all equipment needed for field work associated with this verification testing;*
- *Provision of a complete list of all equipment to be used in the verification testing. A table format is suggested;*
- *Provision of field operating procedures.*

6.0 QUALITY ASSURANCE PROJECT PLAN (QAPP)

The QAPP for this verification testing specifies procedures that shall be used to ensure data quality and integrity. Careful adherence to these procedures will ensure that data generated from the verification testing will provide sound analytical results that can serve as the basis for performance verification.

6.1 Purpose and Scope

The purpose of this section is to outline steps that shall be taken by operators of the equipment and by the analytical laboratory to ensure that data resulting from this verification testing is of known quality and that a sufficient number of critical measurements are taken.

6.2 Quality Assurance Responsibilities

A number of individuals may be responsible for monitoring equipment operating parameters and for sampling and analysis QA/QC throughout the verification testing. Primary responsibility for ensuring that both equipment operation and sampling and analysis activities comply with the QA/QC requirements of the PSTP (Section 6) shall rest with the Field Testing Organization.

QA/QC activities for the state-certified or third party- or EPA-accredited analytical laboratory that analyzes samples sent off-site shall be the responsibility of that analytical laboratory's supervisor. If problems arise or any data appear unusual, they shall be thoroughly documented and corrective actions shall be implemented as specified in this section. The QA/QC measurements made by the off-site analytical laboratory are dependent on the analytical methods being used.

6.3 Data Quality Indicators

The data obtained during the verification testing must be of sound quality for conclusions to be drawn on the equipment. For all measurement and monitoring activities conducted for

equipment verification, the NSF and EPA require that data quality parameters be established based on the proposed end uses of the data. Data quality parameters include four indicators of data quality: representativeness, accuracy, precision, and statistical uncertainty.

Treatment results generated by the equipment and by the laboratory analyses must be verifiable for the purposes of this program to be fulfilled. High quality, well documented analytical laboratory results are essential for meeting the purpose and objectives of this verification testing. Therefore, the following indicators of data quality shall be closely evaluated to determine the performance of the equipment when measured against data generated by the analytical laboratory.

6.3.1 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the parameter represented by the data. In this verification testing, representativeness will be ensured by executing consistent microbiological challenge spiking procedures and consistent sample collection procedures, including sample locations, timing of sample collection, sampling procedures, sample preservation, sample packaging, and sample shipping. Representativeness also will be ensured by using each method at its optimum capability to provide results that represent the most accurate and precise measurement it is capable of achieving. For equipment operating data, representativeness entails collecting a sufficient quantity of data during operation to be able to detect a change in operations.

6.3.2 Accuracy

For water quality analyses, accuracy refers to the difference between a sample result and the reference or true value for the sample. Loss of accuracy can be caused by such processes as errors in standards preparation, equipment calibrations, loss of target analyte in the extraction process, interferences, and systematic or carryover contamination from one sample to the next. Loss of accuracy for microbial species can be caused by such factors as error in dilution or concentration of microbiological organisms, systematic or carryover contamination from one sample to the next, improper enumeration techniques, etc. The Field Testing Organization shall discuss the applicable ways of determining the accuracy of the chemical and microbiological sampling and analytical techniques in the PSTP.

For equipment operating parameters, accuracy refers to the difference between the reported operating condition and the actual operating condition. For water flow, accuracy may be the difference between the reported flow indicated by a flow meter and the flow as actually measured on the basis of known volumes of water and carefully defined times (bucket and stopwatch technique) as practiced in hydraulics laboratories or water meter calibration shops. For mixing equipment, accuracy is the difference between an electronic readout for equipment RPMs and the actual measurement based on counted revolutions and measured time. Accuracy of head loss measurement can be determined by using measuring tapes to check the calibration of piezometers for gravity filters or by checking the calibration of pressure gauges for pressure filters. Meters and gauges must be checked periodically for accuracy, and when proven to be dependable over time, the time interval between accuracy checks can be increased. In the PSTP, the Field Testing

Organization shall discuss the applicable ways of determining the accuracy of the operational conditions and procedures.

From an analytical perspective, accuracy represents the deviation of the analytical value from the known value. Since true values are never known in the field, accuracy measurements are made on analysis of QC samples analyzed with field samples. QC samples for analysis shall be prepared with laboratory control samples, matrix spikes and spike duplicates. It is recommended for verification testing that the PSTP include laboratory performance of one matrix spike for determination of sample recoveries. Recoveries for spiked samples are calculated in the following manner:

$$\% \text{ Recovery} = \frac{100(SSR - SR)}{SA}$$

where: SSR = spikes sample result
SR = sample result
SA = spike amount added.

Recoveries for laboratory control samples are calculated as follows:

$$\% \text{ Recovery} = \frac{100(\text{found concentration})}{\text{true concentration}}$$

For acceptable analytical accuracy under the verification testing program, the recoveries reported during analysis of the verification testing samples must be within control limits, where control limits are defined as the mean recovery plus or minus three times the standard deviation.

6.3.3 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Analytical precision is a measure of how far an individual measurement may be from the mean of replicate measurements. The standard deviation and the relative standard deviation recorded from sample analyses may be reported as a means to quantify sample precision. The percent relative standard deviation may be calculated in the following manner:

$$\% \text{ Relative Standard Deviation} = \frac{S(100)}{X_{average}}$$

where: S = standard deviation
$X_{average}$ = the arithmetic mean of the recovery values.

Standard Deviation is calculated as follows:

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X)^2}{n-1}}$$

where: X_i = the individual recovery values
X = the arithmetic mean of then recovery values
n = the number of determinations.

For acceptable analytical precision under the verification testing program, the percent relative standard deviation for drinking water samples must be less than 30%.

6.3.4 Statistical Uncertainty

Statistical uncertainty of the water quality parameters analyzed shall be evaluated through calculation of the 95% confidence interval around the sample mean. Description of the confidence interval calculation is provided in Section 4.7 - Recording Statistical Uncertainty.

6.4 Water Quality and Operational Control Checks

This section describes the QC requirements that apply to both the treatment equipment and the on-site measurement of water quality parameters. It also contains a discussion of the corrective action to be taken if the QC parameters fall outside of the evaluation criteria.

The quality control checks provide a means of measuring the quality of data produced. The Manufacturer may not need to use all the ones identified in this section. The selection of the appropriate quality control checks depends on the equipment, the experimental design and the performance goals. The selection of quality control checks will be based on discussions among the Manufacturer and the NSF.

6.4.1 Quality Control for Equipment Operation

This section will explain the methods to be used to check on the accuracy of equipment operating parameters and the frequency with which these quality control checks will be made. If the quality of the equipment operating data cannot be verified, then the water quality analytical results may be of no value. Because water cannot be adequately treated if equipment is not operating within specifications, obtaining valid equipment operating data is a prime concern for verification testing.

An example of the need for QC for equipment operations is an incident of state rejection of test data because the treatment equipment had no flow meter to use for determining engineering and operating parameters related to flow.

6.4.2 Water Quality Data

After treatment equipment is operating within specifications and water is being treated, the results of the treatment are interpreted in terms of water quality. Therefore the quality of water sample analytical results is just as important as the quality of the equipment

operating data. Therefore, the QAPP must emphasize the methods to be employed for sampling and analytical QA. The important aspects of sampling and analytical QA are given below:

6.4.2.1 Duplicate Analysis of Selected Water Quality Parameters. Duplicate samples must be analyzed for selected water quality parameters to determine the precision of analysis. The procedure for determining samples to be analyzed in duplicate shall be provided with the frequency of analysis and the approximate number.

6.4.2.2 Method Blanks. Method blanks are used for selected water quality parameters to evaluate analytical method-induced contamination, which may cause false positive results. Method blanks shall not be employed for microbiological analyses.

6.4.2.3 Spiked Samples. The use of spiked samples will depend on the testing program, and the contaminants to be removed. If spiked samples are to be used specify the procedure, frequency, acceptance criteria, and actions if criteria are not met. Spiked samples shall not be employed for microbiological analyses.

6.4.2.4 Travel Blanks. Travel blanks for selected water quality parameters shall be provided to the analytical laboratory to evaluate travel-related contamination. Travel blanks shall not be employed for microbiological analyses.

6.4.2.5 Microbiological Travel Samples. If analysis is not conducted at the site of verification testing and sampling, the laboratory conducting microbiological analysis shall perform a travel viability and enumeration study at the start of the Verification Testing Program by shipping samples dosed with microbial concentrations to the test site and having the bottles returned after 24 hours on site. At the time of return receipt by the laboratory, the viability of the organisms shall be determined at this time.

6.4.2.6 Performance Evaluation Samples for On-Site Water Quality Testing. Performance evaluation (PE) samples are samples of unknown concentration prepared by an independent PE lab and provided as unknowns to an analyst to evaluate his or her analytical performance. Analysis of PE samples shall be conducted for selected water quality parameters before testing is initiated by submission of samples to the analytical laboratory. The control limits for the PE samples will be used to evaluate the equipment testing organization's and analytical laboratory's method performance. One kind of PE sample that would be used for on-site QA in most studies done under this protocol would be a series of either protozoa, bacteria or virus PE samples.

PE samples come with statistics about each sample which have been derived from the analysis of the sample by a number of laboratories using EPA-approved methods. These statistics include a true value of the PE sample, a mean of the laboratory results obtained from the analysis of the PE sample, and an acceptance range for sample values. The analytical laboratory is expected to provide results from the analysis of the PE samples that meet the performance objectives of the verification testing.

6.5 Microbial Viability

Control experiments for each test organism must be conducted to evaluate the stability of microbiological viability in the absence of any disinfectant. These control experiments shall be conducted in a manner identical to the disinfection experiments except that no disinfectant shall be added to the reactor. The results of the control experiments will allow for quantification of the microbiological viability in the absence of any disinfectant over the time course of the disinfection experiments. Microbial viability testing shall also be performed on microbiological travel samples in order to confirm viability of organisms from point of addition to laboratory analysis.

The Field Testing Organization shall establish procedural controls in terms of the level of acceptable microbial viability for the challenge experiments. Die-away of organisms during shipping is sometimes observed. However, if greater than one log of microbial die-away is observed through the microbiological travel sample study, then the procedures for provision of organisms to the site for seeding studies will be evaluated and corrective action will be taken.

6.6 Data Reduction, Validation, and Reporting

To maintain good data quality, specific procedures shall be followed during data reduction, validation, and reporting. These procedures are detailed below.

6.6.1 Data Reduction

Data reduction refers to the process of converting the raw results from the equipment into concentration or other data in a form to be used in the comparison. The procedures to be used will be equipment and data dependent. The purpose of this step is to provide data which will be used to verify the statement of performance objectives. These data shall be obtained from logbooks, instrument outputs, and computer outputs as appropriate. Microorganism data shall be transformed by taking the $\log_{10}$ of the data unless data analysis demonstrates an alternative distribution than a logarithmic distribution.

6.6.2 Data Validation

The operator shall verify the completeness of the appropriate data forms and the completeness and correctness of data acquisition and reduction. The field team supervisor or another technical person shall review calculations and inspect laboratory logbooks and data sheets to verify accuracy and completeness. Calibration and QC data will be examined by the individual operators and the laboratory supervisor. Laboratory and project managers shall verify that all instrument systems are in control and that QA objectives for accuracy, completeness, and method detection limits have been met.

Analytical outlier data are defined as those QC data lying outside a specific QC objective window for precision and accuracy as determined by the state-certified or third party- or EPA-accredited laboratory for a given analytical method. Should QC data be outside of control limits, the analytical laboratory or field team supervisor will investigate the cause of the problem. If the problem involves an analytical problem, the sample will be reanalyzed or another sample will be collected and analyzed. If the problem can be

attributed to the sample matrix, the result will be flagged with a data qualifier. This data qualifier will be included and explained in the final analytical report.

6.6.3 Data Reporting

The data reported during the Verification Testing Program shall be explicitly defined by the Field Testing Organization in the PSTP. At a minimum, the data tabulation shall list the results for feedwater and treated water quality analyses, the results of microbiological analyses (log_{10} data transformation), microbiological inactivation achieved (log_{10} data transformation) and equipment operating data. All QC information such as calibrations, blanks and reference samples are to be included in an appendix. All raw analytical data shall also be reported in an appendix. All data shall be reported in hardcopy and electronically in a common spreadsheet or database format.

6.7 System Inspections

On-site system inspections for sampling activities, field operations, and laboratories shall be conducted as specified by the ETV Testing Plan. These inspections will be performed by the NSF to determine if the ETV Testing Plan is being implemented as intended. Separate inspections reports will be completed after the inspections and provided to the participating parties.

6.8 Reports

6.8.1 Status Reports

The Field Testing Organization shall prepare periodic reports to pertinent parties, e.g., manufacturer, community. These reports shall discuss project progress, problems and associated corrective actions, and future scheduled activities associated with the verification testing. Each report shall include an executive summary a the beginning of the report to introduce the salient issues of the testing period. When problems occur, the Manufacturer and Field Testing Organization project managers shall discuss them, and estimate the type and degree of impact, and describe the corrective actions taken to mitigate the impact and to prevent a recurrence of the problems. The frequency, format, and content of these reports shall be outlined by the Field Testing Organization in the PSTP.

6.8.2 Inspection Reports

Any QA inspections that take place in the field or at the analytical laboratory while the verification testing is being conducted shall be formally reported by the Field Testing Organization to the Verification entity and Manufacturer.

6.9 Corrective Action

Each PSTP must incorporate a corrective action plan. This plan must include the predetermined acceptance limits of microbial viability and key analytical parameters (to be reviewed by NSF), the corrective action to be initiated whenever such acceptance criteria are not met, and the names of the individuals responsible for implementation.

Routine corrective action may result from common monitoring activities, such as:

- Performance evaluation inspections
- Technical systems inspections

Content of PSTP Regarding Quality Assurance Project Plan:

The PSTP shall include the following elements:

- *Description of methodology for measurement of accuracy;*
- *Description of methodology for measurement of precision;*
- *Description of the methodology for use of blanks, the materials used, the frequency, the criteria for acceptable method blanks and the actions if criteria are not met;*
- *Description of any specific procedures appropriate to the analysis of the PE samples. It has to be clear how these samples are going to be used in the verification testing;*
- *Outline of the procedure for determining samples to be analyzed in duplicate, the frequency and approximate number;*
- *Description of procedures to be used for determination of microbial viability and for the spiking of microorganisms over the equipment during control studies;*
- *Description of the procedures used to assure that the data are correct;*
- *Definition of data to be reported during the Verification Testing Program, in terms of analytical parameter type and frequency;*
- *Listing of techniques and/or equations used to quantify any necessary data quality indicator calculations in the analysis of water quality parameters, microbiological contaminants or operational conditions (e.g., flow rates, mixer speeds, detention times). These include: representativeness, completeness, accuracy, precision (e.g., relative percent deviation, standard deviation);*
- *Outline of the frequency, format, and content of reports in the PSTP;*
- *Development of a corrective action plan in the PSTP.*
- *Provision of all QC information such as calibrations, blanks and reference samples in an appendix. All raw analytical data shall also be reported in an appendix;*
- *Provision of all data in hardcopy and electronic form in a common spreadsheet or database format.*
- *Description of all techniques to establish (where applicable) the representativeness, completeness, accuracy and precision of methods in the analysis of water quality parameters, microbiological contaminants or operational conditions (e.g., flow rates, mixer speeds, detention times).*

7.0 DATA MANAGEMENT AND ANALYSIS, AND REPORTING

7.1 Data Management and Analysis

A variety of data will be generated during a verification testing. Each piece of data or information identified for collection in the ETV Testing Plan will need to be provided. The data management section of the PSTP shall describe what types of data and information needs to be collected and managed. It shall also describe how the data will be reported to the NSF for evaluation.

Laboratory Analyses: The raw data and the validated data must be reported. These data shall be provided in hard copy and in electronic format. As with the data generated by the innovative equipment, the electronic copy of the laboratory data shall be provided in a spreadsheet. In addition to the sample results, all QA/QC summary forms must be provided.

Other items that must be provided include:

- field notebooks;
- photographs, slides and videotapes (copies);
- results from the use of other field analytical methods.

7.2 Report of Equipment Testing

The Field Testing Organization shall prepare a draft report describing the verification testing that was carried out and the results of that testing. This report shall include the following topics:

- Introduction
- Executive Summary
- Description and Identification of Product Tested
- Procedures and Methods Used in Testing
- Results and Discussion
- Conclusions and Recommendations
- References
- Appendices
- PSTP
- QA/QC Results

Content of PSTP Regarding Data Management and Analysis, and Reporting:

The PSTP shall include the following:

- *Description of what types of data and information needs to be collected and managed.*
- *Description of how the data will be reported.*

8.0 HEALTH AND SAFETY MEASURES

The safety procedures shall address safety considerations, including the following as applicable:

- storage, handling, and disposal of hazardous chemicals including acids, caustic and oxidizing agents.
- conformance with electrical code
- chemical hazards and biohazards, if pathogenic microorganisms are used in testing
- ventilation of equipment or of trailers or buildings housing equipment, if gases generated by the equipment could present a safety hazard (one example is ozone).

Content of PSTP Regarding Safety:

The PSTP shall address safety considerations that are appropriate for the equipment being tested and for the challenge organisms, if any, being used in the verification testing.

9.0 REFERENCES

Haas, C. N., J. C. Hornberger, U. Anmangandla, M. Heath, and J. Jacangelo (1993). *Experimental Methodologies for the Determination of Disinfection Effectiveness.* AWWA Research Foundation and American Water Works Association, Denver, CO.

USEPA, Science and Technology Branch, "Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Utilities using Surface Water Sources", October 1989.

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CHAPTER 2

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN FOR OZONE AND ADVANCED OXIDATION PROCESSES FOR INACTIVATION OF MICROBIOLOGICAL CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the Environmental Technology Verification (ETV) Plan for evaluation of water treatment equipment utilizing ozone and advanced oxidation for inactivation of microorganisms. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan (PSTP) for testing ozone and advanced oxidation equipment, within the structure provided by the "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies." This ETV plan is applicable only to water treatment systems that rely on ozone and advanced oxidation to inactivate microorganisms. Water treatment systems using ozone oxidation for reasons other than disinfection (i.e. taste and odor control, inorganics oxidation) are not required to conduct the experiments outlined in this ETV plan, as long as adequate disinfection is being achieved by other technologies (e.g., chlorine or chloramines). Ozone is sometimes combined with ultraviolet (UV) light or hydrogen peroxide to improve oxidation. These advanced oxidation processes (AOPs) can also be tested under this plan.

In order to participate in the equipment verification process for microbial inactivation by ozone and advanced oxidation, the equipment Manufacturer and their designated Field Testing Organization shall use the procedures and methods described in this test plan, and in the "Protocol for Equipment Verification Testing for Inactivation of Microbiological Contaminants: Requirements for All Studies" as guidelines for development of the PSTP.

This ETV test plan is applicable to the testing of water treatment equipment utilizing ozone and advanced oxidation for inactivation of microorganisms in drinking water. This plan is applicable to both surface water and ground water supplies.

2.0 INTRODUCTION

Ozone is a powerful oxidant that is applied during water treatment for microbial inactivation as well as oxidation of pesticides, metals, and taste and odor causing compounds. The use of ozone in potable water treatment in the United States has increased substantially in the last 20 years, due to its superior inactivation of microorganisms (e.g., cysts) relative to chlorine, chloramine, and chlorine dioxide.

Ozone is applied to drinking water as a gas, which is generated on-site. The ozone gas is transferred into a dissolved state by either bubbling or injecting ozone gas into the process stream. Ozone can be applied to untreated (raw) or treated (e.g., coagulated/settled or filtered) water.

In this ETV test plan, ozone or AOP equipment performance can be verified in one of two ways: 1) by achieving a certain level of "CT" [concentration, C (in mg/L), of ozone multiplied by contact time, T (in minutes)] during treatment; or 2) by conducting microbial seeding or challenge testing by measuring the microbial inactivation (for a variety of microorganisms) achieved by the ozone or by AOPs.

Ozone CT values have been established by the USEPA for virus and *Giardia* cyst inactivation for use in guiding state regulatory agencies in the implementation of the filtration and disinfection rules. While the USEPA has not yet established CT requirements for *Cryptosporidium* inactivation, CT values can be determined in this ETV plan to establish the level of CT that can be achieved with the ozone or some types of AOP equipment. Thus, many ozone systems will be able to use the CT approach in this ETV plan.

AOPs convert dissolved ozone to hydroxyl radicals, a process which occurs more rapidly as pH is elevated (e.g., varying from a slow reaction at pH 6 and below, to an instantaneous reaction at pH 9 and above). The ability of hydroxyl radicals to inactivate microbes is not well defined, and specific CT values for AOPs have not been developed because (a) the half-life of hydroxyl free radicals is on the order of microseconds and (b) the highest concentration of hydroxyl free radicals that can be developed in aqueous solution is on the order of 10^{-12} Molar. Therefore, the Manufacturers of some AOP systems may choose to conduct microbial seeding or challenge testing to show the level of inactivation that can be achieved for a specific process. Manufacturers of some ozone systems may also choose to conduct microbial inactivation studies for equipment verification.

Labatiuk, Belosevic, and Finch (1994) recommended that ozone disinfection processes should maintain a stable ozone residual for disinfection prior to the addition of hydrogen peroxide for oxidation of other compounds. If water treatment equipment employing an AOP concept provides for detention time in which water can be in contact with dissolved ozone for a significant time before the application of hydrogen peroxide or ultraviolet radiation, evaluation of CT values attained prior to conversion of ozone to hydroxyl radicals may be possible. In this situation, AOP systems could be tested to develop CT information, but the manufacturer's statement of performance regarding disinfection capability would have to be limited to the portion of the treatment process in which a dissolved ozone residual is maintained.

3.0 GENERAL APPROACH

Testing of equipment covered by this ETV plan will be performed by an NSF-qualified Field Testing Organization (FTO) that is selected by the equipment Manufacturer. Water quality and microbiological analytical work to be carried out as part of this ETV plan will be contracted with a state-certified or third party- or EPA-accredited analytical laboratory.

4.0 OVERVIEW OF TASKS

4.1 Initial Operations: Overview

The purpose of these tasks is to provide preliminary information, which will facilitate final test design and data interpretation. Initial Operations Tasks A and B are not mandatory but they are recommended as an aid to successful completion of Verification Testing. Furthermore, if the verification entity conducts a site visit for quality assurance (QA) purposes, the Task B would need to be performed.

4.1.1 Task A: Characterization of Feed Water

The objective of this Initial Operations task is to obtain a chemical and physical characterization of the feed water for those systems using ozone or AOPs for inactivation. The biological quality of the feed water shall be determined for those plants conducting microbiological seeding or challenge testing.

A thorough description of the watershed or aquifer and any pretreatment modules that provide the feed water should also be prepared to aid interpretation of feed water characterization.

4.1.2 Task B: Initial Test Runs

During Initial Operations, the equipment Manufacturer may want to evaluate equipment operation and determine flow rates, hydraulic retention time, contact times (via tracer tests), ozone dosage, number of ozone injection points, pH range, temperature, alkalinity, sequencing or timing of UV light/hydrogen peroxide addition relative to ozonation, or other factors which provide effective treatment of feed water. This is a recommended Initial Operations task.

The equipment Manufacturer may also want to work with the FTO and analytical laboratory to perform blank or preliminary challenges and sampling routines to verify that sampling equipment can perform its required functions including microorganism survivability (if conducting microbiological challenge testing). This is also a recommended Initial Operations Task.

4.2 Verification Operations: Overview

The verification testing objective is to operate the treatment equipment provided by the equipment Manufacturer and to assess its ability to meet stated water quality goals and any other performance characteristics specified by the Manufacturer. Equipment shall be operated for a minimum of one test period to collect data on equipment performance and water quality for purposes of performance verification. The test period(s) selected should represent the worst-case for concentrations of ozone demanding contaminants (e.g., iron, manganese, organics, hydrogen sulfide, pesticides, or turbidity).

4.2.1 Task 1: Verification Testing Runs and Routine Equipment Operation

To characterize the technology in terms of efficiency and reliability, water treatment equipment that includes ozone (or AOPs) shall be operated for Verification Testing purposes with the operational parameters based on the results of the Initial Operations testing (see Task B).

4.2.2 Task 2: Feed Water and Finished Water Quality

During each Verification Testing period, feed water and treated water samples shall be collected and analyzed for those parameters relevant to oxidation performance and microbial inactivation or for those parameters affecting equipment performance, as outlined in Section 10, Table 1.

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

During each Verification Testing run, operating conditions and performance of water treatment equipment shall be documented. This includes ozone feed gas concentration, gas and liquid pressures, gas and liquid temperatures, gas and liquid flow rates, ozone off-gas concentration, applied and transferred ozone dosage, power usage for the ozone generator, ozone transfer equipment, ozone feed-gas and off-gas monitors (if part of the ozone system) and ozone destruct unit, as well as stability of the electrical power supply (surges, brown-outs, etc.).

If ozone (or an AOP) is used following pretreatment (e.g., coagulation/settling), then a complete description of the pretreatment process shall be provided. For AOP systems, the operating conditions and parameters associated with hydrogen peroxide or UV light equipment must also be documented.

4.2.4 Task 4: Microbial Inactivation

The ability of water treatment ozone equipment to achieve microbial inactivation will be demonstrated by maintaining a level of performance criteria (CT value) for ozone systems. Microbial seeding studies to verify microbial inactivation will be allowed in lieu of the performance criteria (CT value) requirement. To evaluate microbial inactivation by hydroxyl radicals in AOP systems (i.e. after addition of hydrogen peroxide or after use of UV light), microbial seeding studies are required.

4.2.5 Task 5: Data Management

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the FTO and NSF for data obtained during the Verification Testing. Prior to the beginning of field testing, the database design must be developed by the FTO and reviewed and approved by NSF. This will ensure that the required data will be collected during the testing, and that it can be effectively transmitted to NSF for review.

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

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operating and water quality parameters during ozone equipment

Verification Testing. Prior to the beginning of field testing, a QA/QC plan must be developed which addresses all aspects of the testing process. Each water quality parameter and operational parameter must have appropriate QA/QC measures in place and documented. For example, the protocol for ozone measurement using a spectrophotometer should describe how the instrument is calibrated, what adjustments are made, and provide a permanent record of all calibrations and maintenance for that instrument.

5.0 TESTING PERIODS

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's performance objectives, such as in the treatment of surface water where additional testing during each season may assist in verifying an objective. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's performance objectives. Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

The required tasks in the Verification Testing Plan (Tasks 1 through 6) are designed to be carried out during each testing period. Each testing period shall provide for at least 200 hours of ozone equipment operation. During this time, the performance and reliability of the equipment shall be documented.

Some systems may operate for less than 24 hours per day. Interruptions in ozone production are allowed but the reason and duration of all interruptions shall be fully described in the Verification Testing report. Any testing conducted at intervals less than 200 hours is considered a test *run*, whereas the entire 200 hours (either continuous or as the sum of individual test runs) of ozone equipment operation is considered the Verification Test *period*. If ozone production is interrupted during a verification test run, that test run shall be considered to have been concluded at the time of interruption of the ozone feed. After restart, all data collected are to be part of a new verification test run.

6.0 DEFINITION OF OPERATIONAL PARAMETERS

Definitions that apply to ozone and AOP processes are given below. Refer to Appendix A of *Ozone in Water Treatment, Application and Engineering*, by the American Water Works Association Research Foundation and Compagnie Générale des Eaux, Lewis Publishers, 1991 for a more detailed description of terms.

6.1 Feed Gas or Ozone Production Concentration (% weight or g/m^3 NTP)

The feed gas or ozone production concentration (Y_1) is the ozone concentration (in gaseous form) being applied to the water being treated. It is expressed in units of g/m^3 normal temperature and pressure (NTP) or as percent by weight. The temperature and pressure values associated with NTP are 0°C and one atmosphere (i.e., 14.696 psi, 760 mm Hg, or 101.325 kPa), respectively.

6.2 Off Gas Concentration (% weight or g/m^3 NTP)

The off gas concentration (Y_2) is the ozone concentration (in gaseous form) of the gas which is being released (i.e., off gas) from the water being treated. This off gas contains ozone, which was not transferred into a dissolved form during treatment. It is expressed in units of g/m^3 NTP or as percent by weight.

6.3 Applied Ozone Dosage (mg/L)

The amount of ozone added to the water being treated is the applied ozone dosage. The equation for calculating the applied ozone dosage is as follows:

$$D = P/(8.34\ L)$$

where:
- D = applied ozone dosage (mg/L)
- P = ozone production (lb/day)
- L = water flow rate (MGD, million U.S. gallons per day)

6.4 Transfer Efficiency (percent)

The transfer efficiency is defined as the percentage of ozone that becomes dissolved into the water being treated. The equation for calculating the transfer efficiency is as follows:

$$TE = [(Y_1 - Y_2)/Y_1]*100$$

where:
- TE = transfer efficiency (percent)
- Y_1 = ozone production concentration (g/m^3 NTP or percent by weight)
- Y_2 = off gas ozone concentration (g/m^3 NTP or percent by weight)

This calculation assumes that the flow of the feed gas is equal to the flow of the off gas. The transfer efficiency calculation can be refined by measuring both gas flow rates or by monitoring the dissolved gas concentration in the liquid phase if the Manufacturer desires.

6.5 Transferred Ozone Dosage (mg/L)

The transferred ozone dosage is the concentration of ozone that becomes dissolved into the water being treated. The equation for calculating the transferred ozone dosage is as follows:

$T = (D * TE)/100$

where: T = transferred ozone dosage (mg/L)
D = applied ozone dosage (mg/L)
TE = transfer efficiency (percent, i.e., 95.0 and not 0.95)

6.6 Dissolved Ozone Concentration (mg/L)

The concentration of ozone in solution is the dissolved ozone concentration. It is measured using an indigo bleaching technique (e.g., HACH AccuVac or *Standard Method* 4500-O_3 B) or by inserting a dissolved ozone probe into the process stream. The procedure for calibration of ozone probes is described in Section 14.4.7. The dissolved ozone concentration is used to calculate CT values.

6.7 CT (mg-minute/L)

The product of the dissolved ozone concentration 'C' in mg/L and the contact time 'T' in minutes is referred to as the CT value. CT is the number produced by multiplying these two values together. Thus, equivalent CT values can be produced by a small C multiplied by a large T or a large C for a small T. For example, if the dissolved ozone concentration after 10 minutes of contact time is 0.5 mg/L, the CT value is 10 * 0.5 = 5 mg-minute/L.

The CT value is used as a surrogate measure of disinfection effectiveness for certain microorganisms by assuming that adequate inactivation has occurred when water is exposed to a given disinfectant concentration for a given contact time. The CT value required for achieving a specific level of disinfection by ozone depends on the temperature and pH of the water being treated.

If an ozone system uses side stream injection for ozone application, none of the sample ports used for collecting samples that will be analyzed for ozone concentration may be located at the ozone side stream. All sample ports used for collecting samples needed for determining CT values shall be located in the main ozone contactor where the bulk flow of water is being disinfected.

The USEPA has outlined a recommended method for calculating CT values for conventional ozone contactors in Appendix O of the *Guidance Manual for the Surface Water Treatment Rule*. Two methods of calculating the total CT of a contactor can be used during Verification Testing: conservative and log integration.

6.7.1 Conservative Method of Determining CT Values

For contactors with multiple sampling ports, the CT value for each sample port (calculated using the measured dissolved ozone concentration and the appropriate contact time represented by the individual sample port) can be summed to calculate the overall CT value for the contactor. The T_{10}/T_{theory} factor (which shall be determined during the hydrodynamic tracer tests described in Chapter 1, Protocol for Equipment Verification

Testing of Microbiological Contaminant Inactivation) is then applied to the summed CT values to account for any short circuiting within the contactor. This method of determining CT value is referred to as the "conservative" approach.

The T_{10} value represents the minimum length of time for which 90 percent of the water will be exposed to the disinfectant within the contactor (as determined using tracer testing) while T_{theory} represents hydraulic detention time of the contactor (calculated by dividing the total volume of the contactor by the water flow rate).

An example using the conservative approach follows: if there are three sample ports, located along the ozone contactor at 2, 4, and 6 minutes of hydraulic detention time, and the dissolved ozone concentrations are 1.0, 0.7, and 0.5 mg/L at each sample port, respectively, the summed CT value for a contactor having a T_{10}/T_{theory} of 0.8 would be calculated as follows:

$$CT = (T_{10}/T_{theory}) * [(C_{port\ 1} * T_{port\ 1}) + (C_{port\ 2} * T_{port\ 2\text{-}port\ 1}) + (C_{port\ 3} * T_{port\ 3\ -\ port\ 2})]$$

$$CT = (0.8) * [(1.0\ mg/L * 2\ min.) + (0.7\ mg/L * 2\ min.) + (0.5\ mg/L * 2\ min.)]$$

$$CT = 3.52\ mg\text{-}minute/L$$

6.7.2 Log Integration Method of Determining CT Value

From the equation for the conservative method of determining CT values, it can be concluded that the addition of more sampling points would result in a more accurate determination of the actual disinfection environment in the ozone contactor. Since it may be impractical to add more sampling ports to an ozone contactor, a log integration approach may be used during Verification Testing.

If the rate of ozone decay follows first order reaction kinetics, the ozone residual at any point in the contactor can be calculated (Coffey and Gramith, 1994). By measuring the ozone residual at two points (the upstream location, which may be the ozone application point, and the downstream location) in the contactor where the detention time between those two points is known, the ozone decay rate, k, can be calculated. With a constant decay rate and a known initial ozone residual, the log integration method can be used to calculate the CT value. The equation used to calculate CT values based on the log integration method is as follows:

$$CT = (T_{10}/T_{theory}) * (C_o) * (e^{(kt)}\text{-}1)/k$$

where: T_{10}/T_{theory} = Short-circuiting factor determined during tracer tests (< 1.0)
C_o = Initial concentration of dissolved ozone at the upstream sampling point, mg/L
k = Decay rate, 1/minute
t = Contact time at the downstream location, minutes

The decay rate, k, is determined using the following equation:

$k = -[\ln C - \ln C_o]/t$

where: C = Dissolved ozone concentration at downstream location, mg/L

Note that the C_o concentration is the measured dissolved ozone concentration at the upstream sampling location and C_o is not the applied ozone dosage.

The log integration method provides a higher, more accurate CT value than the conservative method. The following example illustrates how to calculate the CT values using the log integration method.

If there are two sample ports, located along the ozone contactor at 0 and 6 minutes of hydraulic detention time, and the dissolved ozone concentrations are 1.4 and 0.5 mg/L at each sample port, respectively, the log integrated CT value for a contactor having a T_{10}/T_{theory} of 0.8 would be calculated as follows:

First, calculate the decay rate, k:

$k = -[\ln C - \ln C_o]/t$

$k = -[\ln (0.5) - \ln (1.4)]/6 \text{ min}$

$k = -[(-0.693) - (0.336)]/6$

$k = 0.172/\text{min}$

Next, calculate the CT value:

$CT = (T_{10}/T_{theory}) * (C_o) * (e^{(kt)} - 1)/k$

$CT = (0.8) * (1.4) * (e^{(0.172 * 6)} - 1)/0.172$

CT = 11.8 mg-minutes/L

This comparison shows that the log integration method can give higher CT values than the conservative method.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

This Initial Operations task is performed to determine if the chemical, biological, and physical characteristics of the feed water are appropriate for the water treatment equipment to be tested.

Initial Operations Tasks A and B are not mandatory but they are recommended as an aid to successful completion of Verification Testing.

7.2 Objectives

The objective of this task is to obtain a complete chemical and physical characterization of the source water, or the feed water after pre-treatment that will be entering the treatment system being tested.

7.3 Work Plan

During this Initial Operations task, the following water quality characteristics of the feed water to the ozone system should be measured and recorded for both ground and surface waters: ozone demand, turbidity, temperature, pH, alkalinity, calcium, total hardness, total sulfides, total organic carbon, dissolved organic carbon, ultraviolet absorbance (at 254 nm), color, bromide, iron, and manganese.

Sufficient information shall be obtained to illustrate the variations expected to occur in these parameters that will be measured during the Verification Testing for a typical annual cycle for the water source. This information will be compiled and shared with NSF so NSF and the FTO can determine the adequacy of the data for use as the basis to make decisions on the testing schedule.

A brief description of the watershed or aquifer source shall be provided, to aid in interpretation of feed water characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e., flat, gently rolling, hilly, mountainous) and a description of the kinds of human activity that take place (i.e., mining, manufacturing, cities or towns, farming, wastewater treatment plants) with special attention to potential sources of pollution that might influence feed water quality. The presence of livestock as well as the existence of other wildlife (e.g., beavers) in the watershed shall be reported. The nature of the water source, such as stream, river, lake or man-made reservoir, should be described as well. Aquifer description should include (if available) the above characterization relative to the recharge zone, a description of the hydrogeology of the water bearing stratum(a), well boring data, and any Microscopic Particulate Analysis data indicating whether the groundwater is under the influence of surface waters. Any information pertaining to the nature of the well and aquifer (e.g., shallow well or vulnerable well) should also be included.

Any pretreatment, including oxidation, coagulation, or pH adjustment, of the water upstream of the ozone equipment shall be completely documented and characterized. Any coagulant or other chemical addition shall be identified and the chemical form and dosage shall be fully described.

7.4 Analytical Schedule

There is no recommended analytical schedule for characterization of the feed water. Any existing water quality data should be reviewed to assess the character of the feed or source water

as well as the range of water quality that can be expected during each season. Water quality sampling can be performed if there are data gaps in the existing information.

7.5 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of the equipment performance objectives but should not be beyond the range of water quality suitable for treatment for the equipment in question. The device shall be tested using water of the quality for which the equipment was designed.

8.0 TASK B: INITIAL TEST RUNS

8.1 Introduction

During the Initial Operations, a Manufacturer may choose to evaluate equipment operations and determine flow rates, hydraulic residence time, ozone production, CT results, and power supply requirements, or other factors applicable to the technology and related to effective treatment of the feed water. The Manufacturer may also choose to work with the FTO and the analytical laboratory to perform blank or preliminary challenges (if necessary) and sampling routines to verify that sampling equipment can perform the required functions under normal operating conditions. This information may also indicate operating conditions under which the Manufacturer's stated performance objectives are not met, or whether any CT values cannot be achieved. This is a recommended Initial Operations task. An NSF field inspection of equipment operations and sampling and field analysis procedures may be carried out during the initial test runs, and if this occurs, the Initial Operations Task B must be performed.

The "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies" (Chapter 1) under which this test plan is formulated requires hydraulic tracer testing to demonstrate flow conditions and residence times (i.e., T_{10} times) in the ozone equipment. The equipment Manufacturer may want to conduct such tests during these initial runs.

The hydrodynamic tracer testing may be done at the ETV field test site, or at another location, including the manufacturer’s plant. Testing at a location other than the field test site may be advantageous in terms of using dye tracers, sampling and analysis, etc. The tracer testing must be conducted by the FTO, regardless of the site chosen for this testing. Performing hydrodynamic tracer tests at a location other than the ETV field test site is an option only if the treatment equipment has an ozone contact chamber produced by the manufacturer and if this contact chamber is the standard chamber provided with the treatment equipment.

Additional tracer tests are required if flow rates or hydraulics differ from those demonstrated previously (i.e., other Verification Testing). Procedures for developing a tracer test methodology are described in the Protocol.

8.2 Objectives

The objective of these test runs is to bracket the proper operating parameters for treatment of feed water during Verification Testing. The disinfection ability of an ozone system will vary depending on the quality of the feed water being treated and the season. Therefore, conducting initial test runs is strongly recommended.

8.3 Work Plan

Because Initial Operations test runs are not a requirement of this ETV plan, the Manufacturer and FTO can decide the duration of Initial Operations. Enough time should be available to establish optimal operating conditions and to ensure that the system will be able to meet any performance objectives.

8.4 Analytical Schedule

Because these runs are being conducted to define future operating conditions for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during Verification Testing is recommended, however, so the operator can gain familiarity with the time requirements that will be applicable during Verification Testing. Also during the Initial Operations phase, NSF may conduct an initial on-site inspection of field operations, sampling activities, and on-site analyses. The sampling and analysis schedule to be used during Verification Testing shall be followed during the on-site inspection.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed in a manner, which will meet or exceed the statement of performance objectives. If performance is not as good as claimed in the statement of performance objectives, the Manufacturer may conduct additional Initial Operations or cancel the remainder of the testing program.

9.0 TASK 1: VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

9.1 Introduction

Water treatment equipment that includes ozone or AOPs shall be operated for verification testing purposes with the operational parameters appropriate for the manufacturer's statement of performance objectives.

9.2 Experimental Objectives

The objective of this task is to operate the ozone or AOP equipment and characterize the effectiveness and reliability of the equipment.

9.3 Work Plan

9.3.1 Verification Testing Runs

The Verification Testing Runs in this task consist of an evaluation of the treatment system, using the most successful treatment parameters defined during Initial Operations. Performance and reliability of the equipment shall be tested during one or more Verification Testing periods consisting of at least 200 hours of ozone production at the test site. If only one testing period is used, the time selected should represent the worst-case for concentrations of ozone-demanding contaminants. During each testing period, Tasks 1 through 6 shall be conducted simultaneously.

Operation to treat a range of feed water quality is recommended for equipment treating surface waters because of the differences in water quality that can occur on a seasonal basis, although pre-treatment modules, when present, may dampen these variations. Factors that can influence microbial inactivation include:

- The presence of ozone-demanding substances that may be present in the form of particulate matter, dissolved organic matter, or dissolved inorganic matter; often occurring in the spring, or during reservoir or lake turn-over events, or also encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snow melt. Algae also exert an ozone demand, as do iron, manganese, and cyanide. The presence of ozone-demanding substances will affect the CT value achieved by the system.

- pH: which can vary seasonally, will affect the decay rate of ozone in natural waters, and may also affect the CT values achieved by the system.

- Temperature: the required CT values for *Giardia* and viruses are higher for colder water.

- Other ozone-demanding substances.

9.3.2 Routine Equipment Operation

If the water treatment equipment is being used for production of potable water during the time intervals between verification runs, routine operation of the equipment will occur. In this situation, the operating and water quality data collected and furnished to the Safe Drinking Water Act (SDWA) primacy agency shall be supplied to the NSF-qualified FTO for use in evaluating conditions during verification testing.

For equipment that is being used to treat water for distribution to customers, it is assumed that the State has already issued a permit (if one is necessary) for installation and operation. If verification testing is being conducted to establish the inactivation capabilities of the existing equipment, permission by the State may be required if the system were taken off-line for Verification Testing.

9.4 Schedule

During Verification Testing, water treatment equipment shall be operated for a minimum of 200 hours. The reason and duration of any interruptions in ozone production during Verification Testing shall be fully documented.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for 200 hours during each Verification Testing period. Data shall be provided to substantiate that 200 hours of operation have been completed.

10.0 TASK 2: FEED WATER AND TREATED WATER QUALITY

10.1 Introduction

Water quality data shall be collected during Verification Testing for the feed water and treated water as shown in Table 1. The Field Test Organization, on behalf of the equipment Manufacturer, shall assure the sampling or measuring of the water quality parameters in Table 1. The FTO may use local personnel to assist in collection of samples or measurement of test parameters, but is responsible for their training to assure proper techniques are used at all times.

10.2 Experimental Objectives

The objective of this task is to identify the presence and concentration of water quality characteristics, which might affect the ability of ozone to inactivate microorganisms. This task also may be conducted to provide data on the effect of ozone use on the formation of disinfection by-products such as trihalomethanes (THMs) and haloacetic acids (HAAs) in the test water.

10.3 Work Plan

The Manufacturer or FTO will be responsible for establishing the testing operating parameters, on the basis of the Initial Operations testing. Many of the water quality parameters described in this task will be measured on-site by the NSF-qualified FTO or by local community personnel properly trained by the FTO. Analysis of the remaining water quality parameters will be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurements of water quality parameters in the field are listed in the Analytical Methods section in Table 2. The analytical methods utilized in this study for on-site monitoring of feed water and treated water qualities are described in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference

numbers for water quality parameters are provided for both the field and laboratory analytical procedures. EPA Methods for analysis of the parameters listed in Table 2 also may be used.

Any disinfectant added upstream of the ozone addition point will affect the ozone demand; therefore, an agreement between NSF, the manufacturer, and the FTO must be made to determine whether or not to allow pre-disinfection prior to ozonation during the Verification Testing Period. If a pre-disinfectant is used, testing shall be conducted to verify that no disinfectant residual exists at the influent of the ozone contactor, or if a disinfectant residual does exist, a quenching solution (e.g., sodium bisulfite or hydrogen peroxide) shall be used. The latter option (quenching) is less desirable because the concentration of the quenching agent will have to be carefully monitored during testing to minimize over-feeding of the quenching agent (which would result in an ozone demand).

10.4 Analytical Schedule

Water quality data shall be collected at the intervals specified in Table 1. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection protocol shall be defined by the FTO in the PSTP. Algae sampling is not required for systems using groundwater sources.

For water quality samples that will be shipped to a state-certified or third party- or EPA-accredited laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as needed) prepared by the laboratory. These samples shall be preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times, as specified by the laboratory. Original field sheets and chain-of-custody forms shall accompany all samples shipped to the laboratory. Copies of field sheets and chain-of custody forms for all samples shall be provided to NSF.

10.5 Evaluation Criteria

Evaluation of water quality in this task is related to the manufacturer's statement of performance objectives for plants that employ ozone or AOPs in the treatment process.

11.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

Throughout the Verification Testing period, operating conditions shall be documented. This shall include descriptions of pretreatment chemistry and filtration performance for the system processes, if used, and their operating conditions. The performance of the ozone equipment (including ozone generator(s), air preparation system(s), off-gas destruct unit(s), injection equipment, ozone monitor(s), and contactor(s)) as well as UV light and hydrogen peroxide equipment shall be documented. The total volume of water treated and the total power usage for all equipment associated with the ozone or AOP system shall also be recorded.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions during treatment, and the performance of the equipment. This task is intended to collect data that describe operation of the equipment and information that can be used to develop cost estimates for operation of the equipment.

11.3 Work Plan

During Verification Testing, treatment equipment operating parameters for both pretreatment and ozonation shall be monitored and recorded on a routine basis by the NSF-qualified FTO or by local community personnel properly trained by the FTO.

Table 3 outlines some of the operating parameters that shall be monitored throughout Verification Testing. Operating parameters, in addition to those listed in Table 3, may be needed to adequately assess the operating conditions of the ozone or AOP equipment. These additional parameters shall be identified by the Manufacturer and the FTO and agreed upon by the Manufacturer and NSF.

Examples of operational parameters that shall be monitored are:

- water flow rates
- gas flow rates
- water pressures
- gas pressures
- water temperatures
- gas temperatures
- ozone operating voltage
- ozone production power consumption
- air preparation power consumption or other consumables for air preparation
- oxygen feed rate (if applicable) and other pertinent operation information
- performance of oxygen generation or oxygen feed equipment
- ozone electrical frequency, if variable
- amperage of ozone equipment.

On a daily basis, the operator shall note and record whether any visual effects of ozonation are apparent in the treated water or on piping or vessels that convey or hold treated water. This may include surface scum, precipitation of metals, color changes, etc. At the end of the test period, if an ozone contact chamber is provided with the equipment and if it is accessible, the contact chamber shall be inspected for deposits of scum, precipitation of metals, or color changes, and this information shall be noted in the Verification Testing report.

11.4 Schedule

Table 3 presents the schedule and recording data required for ozone and AOP systems. The length of time (hours) of operation (during Verification Testing) shall be recorded for all of the ozone and AOP equipment.

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance objectives. If no relevant statement of performance objectives exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

12.0 TASK 4: DOCUMENTATION OF EQUIPMENT PERFORMANCE: CALCULATION OF CT AND (OPTIONAL) INACTIVATION OF MICROORGANISMS

12.1 Introduction

Inactivation of microorganisms is one of the primary purposes of ozone in drinking water treatment modules. The ability of ozone and AOP equipment to inactivate certain microorganisms can be assessed by determining the CT values that can be attained by the equipment under carefully defined water quality and operating conditions and/or measuring the inactivation of microorganisms by conducting challenge testing.

The ability of ozone to inactivate virus and *Giardia* is well documented and the USEPA, in its guidance manual to the states, has adopted a CT approach for determining inactivation of these microorganisms by disinfection. The USEPA has not yet adopted CT values for *Cryptosporidium*, because researchers are still carrying out studies on this (March 1999).

Microbial seeding studies can also be performed to determine the inactivation ability of the ozone equipment being tested. This will be necessary for AOPs, the performance of which cannot be estimated by using CT calculations. The measurement of inactivation is a comparison of the percent of viable organisms in the feed stream with the percent of viable organisms in the effluent.

12.2 Experimental Objectives

The objective of this task is to determine the CT capabilities of the equipment (based on data from Tasks 2 and 3), and if microbial challenge testing is performed, to determine the logs of inactivation achieved during these tests.

12.3 Work Plan

The manufacturer shall conduct water quality sampling and calculate CT values attained by the equipment. In some instances, microbial challenge testing will be used to determine the level of log inactivation that can be achieved by the ozone or AOP equipment.

12.3.1 CT Criteria

The CT concept of assessing disinfection is described in detail in Section 6.6. The data that are needed to calculate CT values include: dissolved ozone concentration at

appropriate monitoring points, pH, temperature, and water flow rate and T_{10} contacting time. The CT values necessary to achieve inactivation of viruses, *Giardia*, and *Cryptosporidium* are different from one another and are described in the next two sections.

12.3.1.1 Required CT for Virus and *Giardia.* The EPA-published CT values associated with inactivation of viruses and *Giardia* cysts are shown in Tables 4 and 5, respectively. If the Manufacturer's statement of performance is presented in terms of logs of inactivation of viruses or *Giardia* cysts, the calculated CT values for an ozone system or for an AOP system that provides for dissolved ozone contact in the water being treated before introduction of hydrogen peroxide or UV radiation must exceed the relevant EPA-published CT values shown in Tables 4 and 5. Because CT values for viruses and *Giardia* cysts are temperature dependent, testing should be scheduled to include the extreme range in water temperatures expected to occur during different seasons of the year. The range in water temperatures being treated shall be determined and agreed upon by the FTO and the Manufacturer during the Initial Test Runs conducted prior to Verification Testing.

If a Manufacturer's statement of performance presents log inactivation values that exceed those shown in Tables 4 and 5, or presents log inactivation values for water quality conditions not included in Tables 4 and 5, microbial challenge or seeding studies shall be required to verify the levels of inactivation achieved by the equipment.

If the pH of the feed water to the ozone or AOP system is less than 6 or greater than 9, microbial challenge studies are required for Verification Testing.

12.3.1.2 CT Calculations for *Cryptosporidium.* The USEPA has not developed CT values for estimating the log inactivation of *Cryptosporidium* by disinfection, and as of March 1999 regulatory requirements for *Cryptosporidium* have not been promulgated. During verification testing, the CT value achieved by the equipment shall be determined, regardless of the level of *Cryptosporidium* inactivation that has occurred. However, if a Manufacturer states that the equipment can achieve a certain level of *Cryptosporidium* inactivation, microbial challenge testing must be performed.

12.3.2 Microbial Challenge Tests

Microbial challenge tests, if undertaken, shall be conducted at full scale with commercially available equipment and not with pilot or prototype equipment. The FTO shall conduct the challenge studies in the field, and the FTO shall submit the resulting samples to a state-certified or third party- or EPA-accredited laboratory. Water produced during challenge testing shall not be distributed to the public. Challenge organisms to be tested will be selected by the equipment Manufacturer. Microbial challenge tests shall be performed three times per Verification Test period.

As a QA/QC measure, one additional process control microbial seeding test shall be performed while the ozone equipment is not operating. This seeding test shall be

performed after the three microbial challenge tests have been completed, and the system has been flushed with at least three volumes of water (with ozone equipment in use) to ensure that all seeded organisms have exited the system.

If the Manufacturer's Statement of Performance Objectives is based on microbial inactivation, the FTO shall identify the microbiological contaminant inactivation capabilities in the Statement of Performance Objectives provided in the PSTP. In the Statement of Performance Objectives, the Manufacturer shall identify the specific microbiological contaminants to be monitored during equipment testing and the specific operational conditions under which inactivation testing shall be performed. The Statement of Performance Objectives prepared by the FTO on behalf of the Manufacturer shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feed water. Examples of satisfactory Statements of Performance Objectives based on microbial inactivation were provided below.

> *For Microbial Inactivation:*
> *"This system is capable of achieving 3-log_{10} inactivation of Giardia lamblia at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.5 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L and alkalinity less than 150 mg/L as $CaCO_3$."*
>
> *Microbial Inactivation (Comparative):*
> *"This system is capable of achieving 3-log_{10} inactivation of Giardia lamblia at CTs 20% lower than EPA's published chlorine CTs. This level of Giardia lamblia inactivation will be achieved by the equipment at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.5 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L and alkalinity less than 150 mg/L as $CaCO_3$."*

12.3.2.1 Organisms Employed for Challenge Experiments. Microorganisms that may be used for inactivation studies are listed below. These species represent microorganisms of particular interest and concern to the drinking water industry, and represent a range of resistance to inactivation methods. The specific batches of microorganisms used in inactivation testing must be shown to be initially viable by the laboratory involved in the analytical aspects of the testing.

Protozoan cysts and oocysts: *Giardia muris, Giardia lamblia, Cryptosporidium parvum*
Bacteria: *Bacillus subtilis, Pseudomonas* spp., *Clostridium perfringens,*
Virus: MS2 bacteriophage (surrogate)

12.3.2.2 Spiking Protocols. The total number of organisms required to provide steady-state microbiological populations will depend on the overall volume of the disinfection contactor, the flow rate through the contactor, the detection limits of the analytical methods, the number of surviving microorganisms at the end of the test, and the duration

of the experiments. For viruses, a steady-state final concentration large enough to show 4-log inactivation in the effluent is necessary. For all organisms, the laboratory (ies) supplying the organisms and performing the viability studies shall be experienced in challenge testing and be able to predict initial dosages required to overcome any inherent experimental losses. Microbial challenges shall be conducted either by batch seeding or by feed stream injection.

12.3.2.3 Batch Seeding. A batch feed tank with sufficient volume to provide the required test volume shall be used. The discharge from this tank shall be located so that 100% of the contents can be delivered to the system. The tank shall be filled with feed water that shall be dechlorinated, if necessary. The feed water shall be stirred during dechlorination. Verification of dechlorination shall be performed prior to the introduction of the seed organisms. The feed tank shall be continuously stirred during seeding and throughout the testing period. Prior to microbial seeding of the tank, agitation of the bulk seed container received from the supplier (by vortexing or sonication) shall be employed to assure organisms are not clumped together. A secondary source of feed water (dechlorinated, if necessary) sufficient to provide 3 retention time equivalents (as determined by tracer tests or as defined by system functions) shall be available to add to the tank when the initial contents have been consumed. The purpose of this feed water will be to continue flushing seeded organisms through the ozone contactor to the effluent sample ports.

12.3.2.4 In-line Injection. The microorganism feed suspension will be plumbed into the test unit with a check-valve equipped injection port followed by a mixing chamber. A one liter carboy equipped with a bottom dispensing port will feed this injection port by means of a metering pump (diaphragm or peristaltic or equivalent) via siliconized or Teflon tubing. The pump shall be capable of fluid injection into the pressurized system feed line for the duration of the test, at a measurable and verifiable rate such that the one-liter carboy is depleted coincident with the end of the test.

The carboy with the spiked suspension will contain a magnetic stir bar, will be filled with one liter of system water (dechlorinated if necessary), and will be placed on a stirplate. The stock suspension of microorganisms shall be agitated by methods such as vortexing or sonication prior to being added to the carboy. After the appropriate flow rate has been established through the ozone contactor, the contactor is operating properly, and sample collection systems are readied, the injection pump can be started. During the course of the test run, monitoring of the flow rate through the ozone contactor and the spike injection rate shall be performed at regular intervals. Adjustments to these flow rates will be made to maintain test conditions.

12.3.3 Test Operation and Sample Collection

12.3.3.1 Test Stream Sampling. Sample ports shall be provided for the feed water stream (spiked with concentrations of microbiological contaminants) and the ozone-treated water stream at the contactor effluent. The FTO shall specify the specific ways in which sample collection is performed according to the organisms that will be used for the

proposed microbiological inactivation experiments. Examples of potential sample collection methods for bacterial, viral and protozoan organisms are provided below. The methods described, or any other peer-reviewed method may be used for verification testing. The FTO shall propose in the PSTP the specific methods that are to be used for viability assessment of the selected microorganisms (See Section 12.3.5 below).

For bacterial and/or viral seeding experiments, methods for organism spiking and sample collection shall be consistent with a selected peer-reviewed method. The frequency and number of samples collected for each sampling point will be determined by the length of the test run and shall be specified by the FTO in the PSTP. The volume of each ozone-treated water sample from the disinfection contactor effluent will depend on the concentrations of test organisms spiked, and the requirements of the analytical laboratory.

For protozoan spiking experiments, EPA Method 1622 or any other method that has been evaluated through the peer-reviewed process (e.g., Nieminski and Ongerth, 1995) may be followed for sample collection from the spiked water streams. The sample collection system shall be plumbed to allow installation of housings and filters for capture of sufficient flow for microbiological analysis. The FTO shall provide an indication of the recovery efficiency achievable under the sample collection method selected for use during protozoa seeding studies. The specific capture filter recovery system shall be fully described in the PSTP by the FTO. In addition, the PSTP shall include a plan of study for verification testing with a minimum of three standard recovery efficiency tests from the microbiological laboratory.

The sample tap(s) shall be sanitized with 95% ethanol one minute prior to initiating any bacteria or virus sample collection. Taps shall be flowing at the appropriate sample rate for at least one minute prior to sample collection.

12.3.3.2 Chlorine Residual Analysis. The chlorine concentration of the dilution water used for preparing microorganism spiking solutions shall be measured to ensure that no chlorine residual is present.

12.3.3.3 Post-Test Sample Handling. At completion of the test run, the FTO shall disconnect the capture filter holders from the sample taps. Filters shall then be handled and prepared for delivery to the analytical laboratory as directed by that laboratory. The FTO shall then take steps to contain and/or sanitize any organisms remaining in the system. Depending on the unit (design and materials), sanitization may be done using steam or hot water (80°C for 10 minutes). The QA/QC plan should address how this sanitization procedure is to be done to ensure inactivation of live organisms and subsequent removal of inactivated organisms from the unit. The plan should also address biosafety concerns for both humans and the environment.

12.3.4 Experimental Quality Control

Two QA/QC samples shall be included in the microbial challenge tests: 1) process control; and, 2) trip control. The requirements associated with these QA/QC samples are discussed in Task 6, Section 14.5.

12.3.5 Viability Analysis

Methods for assessing the viability of the selected bacteria and viruses shall be specified by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA for the appropriate microbial analyses. Selected viability methods shall be specified by the FTO in the PSTP.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying objectives that an ozone treatment system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), Slifko et al. (1997) and others (see Section 16.0 References in this Test Plan). Interim, non-standard methods for assessing the viability of cyst and oocyst (e.g., excystation, DAPI/PI) may be used for verification of inactivation after exposure to disinfectants. However, any interim organism viability method is subject to review by experts of cyst and oocyst viability and subsequent method change. Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity. Microbial viability analyses are further discussed in Section 4.4 of the "Protocol For Equipment Verification Testing of Microbiological Contaminant Inactivation."

Prior to microbial challenge testing, an adequate method of determining viability should be selected to provide meaningful results for the study. For example, the experimental set-up for viability analyses should be able to adequately show the range of log inactivation capabilities of the ozone system being tested.

12.4 Analytical Schedule

For CT value determinations, during the 200 hours of ozone production for Verification Testing, the dissolved ozone residual shall be measured at specified sampling locations and at regular intervals. These intervals shall be three times per day (3/d) if ozone production is continuous over the 200 hour testing period or three times per staffed shift (3/shift) if ozone production is to be periodically interrupted or terminated during Verification Testing such that the periods of ozone production are less than 24 hours. For example, if a system operates for only 8 hours each day, Verification Testing will be conducted over a total of 25 days. Each day, dissolved ozone measurements shall be collected at three different times. The pH, temperature, and water flow rate also need to be measured concurrently with the dissolved ozone concentration so the CT values can be calculated accurately.

Microbial challenge testing shall be performed three times during the Verification Test period. The operating conditions shall be the same for each of the three required challenge tests. These challenge tests shall be conducted during the 200 hours of Verification Testing. A recommended schedule for microbial testing would be to begin the challenge testing at 50, 100, and 150 hours of continuous operation. If additional time is needed beyond the 200 hours for Verification Testing, the schedule of testing for all water quality parameters and operational conditions of Tasks 1, 2, and 3 shall be continued until the microbial challenge tests are completed.

12.5 Evaluation Criteria

The CT values measured in this task will be compared to the Manufacturer's statement of performance for the ozone or AOP equipment. These field-measured CT values will be compared to the EPA-published CT values for the level of inactivation of virus and *Giardia* (Tables 4 and 5) achieved by the ozone or AOP system. If microbial challenge testing is performed, the measured log inactivations of microorganisms will be compared to the ozone CT/inactivation relationships established by the USEPA.

The total CT values for the ozone or AOP system will be calculated for each individual sampling time (i.e., three sampling events per day or per shift), therefore each Verification Test period will produce a minimum of 25 individual CT values. The minimum, maximum, and average CT value for each Verification Test shall also be reported.

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the Verification Testing program shall involve the use of computer spreadsheet software and manual recording of the operational parameters for the water treatment equipment on a daily basis.

13.2 Experimental Objectives

The objectives of this task are: 1) to establish a viable structure for the recording and transmission of field testing data so the FTO will provide sufficient and reliable operational data for verification purposes, and 2) to provide the information needed for a statistical analysis of the data, as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies."

13.3 Work Plan

The following protocol has been developed for data handling and data verification by the FTO. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These

specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form the data will be manipulated into a convenient framework to allow analysis of water treatment equipment operation. Backup of the computer databases to diskette should be performed on a monthly basis at a minimum. When SCADA systems are not available, direct instrument feed to data loggers and laptop computers shall be used when appropriate.

For parameters for which electronic data acquisition is not possible, field testing operators will record data and calculations by hand in laboratory notebooks (daily measurements will be recorded on specially-prepared data log sheets as appropriate). Each notebook must be permanently bound with consecutively numbered pages. Each notebook must indicate the starting and ending dates that apply to entries in the logbook. All pages will have appropriate headings to avoid entry omissions. All logbook entries must be made in black water insoluble ink. All corrections in any notebook shall be made by placing one line through the erroneous information. Products such as "correction fluids" are never to be utilized for making corrections to notebook entries. Operating logs shall include a description of the water treatment equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items. The original notebooks will be stored on-site; photocopies will be forwarded to the project engineer of the FTO at an agreed upon schedule. This protocol will not only ease referencing the original data, but will also offer protection of the original record of results.

The database for the project will be set up in custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each of the monitored water quality and operational parameters from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheets. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will by initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each challenge test run or verification run) will be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited laboratories, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.4 Statistical Analysis

Water quality developed from grab samples collected during test runs according to the Analytical Schedule in Task 2 of this Test Plan shall be analyzed for statistical uncertainty. The FTO shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as

described in "Protocol for Equipment Verification Testing of Microbiological Contaminant Inactivation" (Chapter 1). Statistical analysis could be carried out for a large variety of testing conditions.

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Information on the differences in feed water quality variations for entire test runs versus the quality produced during the optimized portions of the runs would be useful in evaluating appropriate operating procedures.

14.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL

14.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the water treatment equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during testing. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals shall be documented and recorded on a routine basis. Daily routine walk-throughs during testing shall be used to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment, such as flow meters, will be checked to verify that the readout matches with the actual measurement (i.e., flow rate) and that the signal being recorded is correct. The items listed below are in addition to any specified checks outlined in the analytical methods.

14.3.1 Daily QA/QC Verifications

These verifications shall be conducted daily:

- In-line turbidimeter flow rates (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench-top model

14.3.2 QA/QC Verifications Performed Every Two Weeks

These verifications shall be conducted every two weeks:

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).
- In-line turbidimeters, if any, (clean out reservoirs and re-calibrate, if employed)

14.3.3 QA/QC Verifications For Each Testing Period

This verification shall be conducted before testing begins:

- Tubing: Verify that all tubing and connections are in good condition and replace if necessary. For surface water systems, microbial growth could occur between verification test runs, so replacement of tubing prior to each verification test may be necessary.

14.4 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and disinfected water quality are described in the following section. Use of either bench-top or in-line field analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it reduces the introduction of error and the variability to analytical results generated by inconsistent sampling techniques.

14.4.1 pH

Analysis for pH will be performed according to *Standard Method* 4500-H^+ or EPA Method 150.1/150.2. A three-point calibration of any pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.4.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Methods* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1^{o}C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1^{o}C to +51^{o}C, subdivided in 0.1^o increments, would be appropriate for this work.)

14.4.3 True Color

True color shall be measured with a spectrophotometer at 455 nm, using an adaptation of the *Standard Methods* 2120 procedure. Samples shall be collected in clean plastic or glass bottles and analyzed as soon after collection as possible. If samples cannot be

analyzed immediately they shall be stored at 4°C for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C shall be used, and results should be expressed in terms of PtCo color units.

14.4.4 Dissolved Oxygen

Analysis for dissolved oxygen shall be performed according to *Standard Method* 4500-O using an iodometric method or the membrane electrode method. The techniques described for sample collection must be followed very carefully to avoid causing changes in dissolved oxygen during the sampling event. Sampling for dissolved oxygen does not need to be coordinated with sampling for other water quality parameters, so dissolved oxygen samples should be taken at times when immediate analysis is going to be possible. This will eliminate problems that may be associated with holding samples for a period of time before the determination is made.

If the sampling probe is not mounted such that the probe is continuously exposed to the process stream, then care must be taken when measuring the dissolved oxygen concentration. For best results, collect the dissolved oxygen sample with minimal agitation and measure the dissolved oxygen concentration immediately. If possible, measure the dissolved oxygen under a continuous stream of sample by placing the tip of the probe in the sample container, allowing the sample to overflow the container while the probe reaches equilibrium (usually less than 5 minutes).

14.4.5 Total Sulfides

Total sulfide samples should also be collected with minimal agitation and analyzed immediately after sample collection. If possible, the sample container should be filled using a piece of flexible Tygon tubing attached to the sampling port. The end of the tubing should be placed at the bottom of the sampling container, and the container filled to overflowing before removing the tubing and tightly capping the container.

14.4.6 Turbidity Analysis (Optional)

Turbidity analyses shall be performed according to *Standard Methods* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top turbidimeter may be used for measurement of the feedwater

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

14.4.6.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, the vial must be allowed to warm up by partial submersion into a warm water bath for approximately 30 seconds.

14.4.6.2 In-line Turbidimeters. In-line turbidimeters are required for filtered water monitoring during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow rate should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.4.7 Dissolved Ozone

The dissolved ozone concentration can be measured using an indigo bleaching technique, such as *Standard Method* 4500-O_3 B or the HACH Indigo AccuVac method. When sampling for dissolved ozone, it is important to minimize sample agitation and transfer from one container to another. One good sampling technique is to collect the sample directly from the sample tap. If HACH AccuVac vials are used, the tip of the AccuVac can be placed directly into the tap opening where the water is flowing. Apply pressure and snap the tip while it is inside the sample tap opening. The vacuum in the AccuVac

vial will draw the water sample into the AccuVac. Once the AccuVac is filled, remove the AccuVac from the sample tap and analyze according the HACH instructions. If necessary, a short piece (i.e., less than 2 feet) of Tygon tubing can be attached to the sample tap for dissolved ozone sampling. If HACH AccuVac vials are not used, use of tubing attached to the sample port for sample collection is recommended to minimize sample agitation and mixing. This tubing should be Tygon and should be no longer than 2 feet in length.

Another method for measuring dissolved ozone is a dissolved ozone probe. These probes can be placed in the process stream to provide continuous measurements of ozone residuals. Check the probe tip daily to ensure that the membrane has been installed properly and that there are no air bubbles underneath the membrane. Also, check that the pressure and flow rate within the contactor are within the appropriate range for the probe being used. The performance of the probe shall be verified on a daily basis by measuring the dissolved ozone concentration with one of the indigo bleaching methods to ensure that the probe is functioning properly.

A third method for measuring dissolved ozone concentrations is an on-line analyzer which uses UV spectrophotometry to measure the gas-phase concentration of ozone which has been stripped from a liquid sample. These analyzers then correlate the gas-phase ozone concentration to the dissolved ozone concentration. These analyzers are calibrated at the factory.

14.4.8 Gas Phase Ozone

Gas phase ozone concentrations can be measured using either UV absorbance ozone monitors or a wet-chemistry test. Ozone monitors are calibrated at the factory and provide a continuous measure of the ozone concentration in gas phase. The wet-chemistry test method of measuring the ozone concentration of a gas stream involves bubbling ozone through a potassium iodide solution, acidification with sulfuric acid, and titration with sodium thiosulfate. This method is described in detail in Rakness *et al*. (1996). During each Verification Test, a wet-chemistry measurement of the ozone feed gas shall be conducted to independently check that the ozone monitor is functioning properly. If ozone monitors are not available, wet-chemistry tests shall be performed three times per day or three times per shift to measure the ozone concentration in the feed gas and off gas.

14.4.9 Hydrogen Peroxide

The concentration of hydrogen peroxide can be measured using one of two spectrophotometric methods: 1) cobalt-bicarbonate and 2) peroxidase. The cobalt-bicarbonate method, described in Masschelein *et al.* (1977), can be used to measure up to 2 mg/L hydrogen peroxide at 260 nm, whereas the peroxidase method, described in Bader *et al*. (1988), can be used to measure up to 1.7 mg/L hydrogen peroxide at 551 nm.

At low pH, ozone and peroxide can be in solution at the same time, because the reaction rate is slow. The presence of ozone interferes with any hydrogen peroxide analysis; therefore, to measure the amount of hydrogen peroxide in the AOP system, ozone production shall be temporarily terminated while hydrogen peroxide samples are being collected and analyzed.

To ensure the proper feed rate of hydrogen peroxide to the AOP system, use a stopwatch to measure the time required to collect a specified volume of hydrogen peroxide stock solution from the feed system. This requires that the hydrogen peroxide feed line to the contactor be temporarily disconnected so that the pumping rate of the stock hydrogen peroxide solution can be measured. Typically, a graduated cylinder is used to collect the pumped hydrogen peroxide sample and the size of the graduated cylinder is such that the length of collection time exceeds 10 seconds.

The strength of the peroxide feed solution can also be determined from the peroxide supplier's shipping information, as long as the peroxide being used for testing has not been: 1) diluted by the user; 2) exposed to contamination (which would affect its strength); 3) stored for longer than one year; or, 4) stored at temperatures greater than 77 °F.

14.5 Chemical and Biological Samples Shipped Off-Site for Analyses

The analytical methods that shall be used during testing for chemical and biological samples that are shipped off-site for analyses are described in this section.

14.5.1 Organic Samples

Samples for analysis of total organic carbon (TOC), dissolved organic carbon (DOC), and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held and shipped in accordance with *Standard Method* 5010 B. Storage time before analysis shall be minimized, according to *Standard Methods*.

Assimilable organic carbon (AOC) samples shall be collected in sampling containers supplied by the state-certified or third party- or EPA-accredited laboratory. Sample collection, preservation, and storage requirements are outlined in *Standard Methods* 9060A and 9060B.

14.5.2 Microbial Parameters: Viruses, Bacteria, Protozoa, and Algae

Samples for analysis of any microbial parameter shall be collected in bottles supplied by the analytical laboratory. Microbial samples shall be refrigerated at approximately 2 to 8°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately 2 to 8°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory

within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8°C until initiation of processing. TC densities shall be reported as most probable number per 100 ml (MPN/100 mL) and HPC densities shall be reported as colony forming units per mL (cfu/mL).

Methods for assessing the viability of the selected bacteria and viruses shall be specified by the laboratory(ies) performing the analysis and shall be specified in the PSTP. The FTO may select a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA for analysis of microbial contaminants in water samples.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying objectives that an ozone system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), and Slifko et al. (1997). Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity.

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 2 to 8°C, and held at that temperature range until counted.

14.5.3 Inorganic Samples

Inorganic chemical samples, including alkalinity, shall be collected and preserved in accordance with *Standard Method* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Method*s 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

14.5.4 Bromate

Samples for the analysis of bromate samples shall be collected in sampling containers supplied by the state-certified or third party- or EPA-accredited laboratory. Sample collection and storage requirements are outlined in EPA Method 300.1 or shall be provided by the laboratory conducting the analysis.

14.6 Microbial Challenge Testing

The quality control requirement for microbiological testing was specified in Task 4, Section 12.3.4.

14.6.1 Process Control

A second round of testing shall be carried out using procedures described in Section 12.3, Task 4, but without operating the ozone equipment. The purpose of this testing is to evaluate any cumulative effects produced by the equipment, the spiking and sampling procedures, and the sample handling procedures on organism viability. This testing shall not occur until sanitizing agents and inactivated target organisms, whose presence could affect subsequent tests of the unit (*Giardia* and *Cryptosporidium*), have been eliminated from the contactor. The process control samples should show minimal inactivation of the target organism(s) relative to the trip control sample. Significant inactivation of the organisms in the process control sample indicates that some aspect of the process other than ozone disinfection contributes to inactivation of the test organism(s). Repeat testing is required when this is shown to occur.

14.6.2 Trip Control

For tests utilizing spike challenges, a replicate or subsample of the spiking suspension shall accompany the actual spiking suspension from the analytical laboratory. This replicate sample shall undergo all of the processes used on the actual suspension including dose preparation pre-enumeration, shipping, preparation for spiking, and return to the laboratory for enumeration and viability baseline assessment. The trip control samples should show minimal inactivation of the target organism(s). Significant inactivation of the trip control sample indicates that some step in handling the suspension contributed to inactivation of the test organism(s). The seeding tests must be repeated when significant inactivation of the trip control sample is observed.

15.0 OPERATION AND MAINTENANCE

The following are recommendations for criteria for Operation and Maintenance (O&M) Manuals for drinking water treatment equipment employing ozone treatment.

15.1 Maintenance

The Manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment including, but not limited to, the following, where applicable:

- ozone generator (dielectric replacement)
- ozone diffusers or injection port, control valves
- ozone destruct unit (catalyst replacement)
- gas phase ozone monitors (for feed gas and off gas)
- dissolved ozone monitoring equipment
- cooling water equipment
- air preparation unit or oxygen feed system for ozone generation
- gas and liquid rotameters

- UV lamps and other relevant equipment
- peroxide feed equipment
- other equipment such as pumps and valves

The Manufacturer shall also provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment, including but not limited to, the following, where applicable:

- piping
- contactor chamber

15.2 Operation

The Manufacturer shall provide readily understood recommendations for procedures related to proper operation of all equipment. Among the operating aspects that should be addressed in the O&M manual are:

Ozone Generator
- air preparation or oxygen feed requirements (moisture content, filtration requirements, flow rate)
- cooling water requirements (flow)
- range of variable voltage for adjusting ozone output
- proper sequence of operation for start-up and shut-down
- proper sequence of operation for initial start-up or for re-start after maintenance

Ozone Monitors (Gas Phase)
- temperature and pressure compensation
- zeroing and calibration procedures
- proper sequence of operation for start-up and shut-down

Ozone Destruct Units
- heater and/or blower requirements
- catalyst requirements
- proper sequence of operation for start-up and shut-down

Air Preparation or Oxygen Feed Systems
- desiccant requirements and replacement procedures
- filters (maintenance and replacement schedule)
- proper sequence of operation for start-up and shut-down
- supplemental gas (air or nitrogen) flow rate, pressure, and temperature.

Cooling Water System
- maintenance of proper temperature
- monitoring cooling water flow
- pump maintenance

- proper sequence of operation for start-up and shut-down
- maintenance of recirculation equipment, if cooling water is recirculated

Ozone Contactor Systems
- maintenance schedule and procedures
- replacement procedures

UV lamps
- hours of operation (verification procedures)
- UV irradiance (calibration and verification procedures)
- maintenance schedule and procedures
- replacement procedures
- proper sequence of operation for start-up and shut-down

Hydrogen Peroxide Feed System
- procedures for variable speed adjustments to pump
- information about proper tubing type and size
- anticipated schedule for tubing replacement
- storage information (i.e., safety, container type, container material, temperature, length of storage time) for stock hydrogen peroxide solutions
- proper sequence of operation for start-up and shut-down

Control Valves
- open/close indication
- sequence of operations

The Manufacturer shall provide a troubleshooting guide; a simple checklist of what to do for a variety of problems, including but not limited to:
- no flow to unit
- sudden change in flow to unit
- no electric power
- automatic operation (if provided) not functioning
- valve stuck or will not operate

16.0 REFERENCES

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Table 1. Water Quality Sampling and Measurement Schedule

Parameter	Sampling Location	Mandatory (M) or Optional (O)	Frequency*	
			Surface Water Systems	Ground Water Systems
Temperature (°C)	Feed Water Treated Water	M	3/d or 3/shift	3/d or 3/shift
Dissolved Ozone Residual (mg/L)	Treated Water†	M	3/d or 3/shift	3/d or 3/shift
pH	Feed Water	M	3/d or 3/shift	3/d or 3/shift
Total Alkalinity (mg/L as $CaCO_3$)	Feed Water	O	1/d	1/d
Total Organic Carbon (mg/L)	Feed Water	O	1/d	1/50 hours of ozone production
Dissolved Organic Carbon (mg/L)	Feed Water	O	1/d	1/50 hours of ozone production
UV absorbance at 254 nm (1/m)	Feed Water Treated Water	O	1/d	1/50 hours of ozone production
Color (Pt-Co)	Feed Water Treated Water	O	1/d	1/50 hours of ozone production
Turbidity (NTU)	Feed Water Treated Water	O	3/d or 3/shift	3/d or 3/shift
Bromide (mg/L)	Feed Water Treated Water	O	1/50 hours of ozone production	1/50 hours of ozone production
Bromate (µg/L)	Feed Water Treated Water	O	1/50 hours of ozone production	1/50 hours of ozone production

Table 1. Water Quality Sampling and Measurement Schedule, continued

Parameter	Sampling Location	Mandatory (M) or Optional (O)	Frequency*	
			Surface Water Systems	Ground Water Systems
Bacteria and Viruses	Feed Water Treated Water	M**	A minimum of three triplicate samples per Verification Testing period.	A minimum of three triplicate samples per Verification Testing period.
Protozoa	Feed Water Treated Water	M**	A minimum of three samples per Verification Testing period.	A minimum of three samples per Verification Testing period.
AOC (ug acetate/L)	Treated Water	M	1 per 200 hours	1 per 200 hours
Quenching Solution (mg/L) (e.g., hydrogen peroxide)	Feed Water	M	1/d	1/d
Hydrogen Peroxide (mg/L)	Stock Solution Treated Water	M††	1 per 50 hours 1 per Verification test period	1 per 50 hours 1 per Verification test period.
Total THMs (µg/L) (chloroform, bromoform, bromodichloromethane, dibromochloromethane)	Treated Water	O	1/50 hours of ozone production	1/50 hours of ozone production
HAAs (µg/L) (monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, dibromoacetic acid)	Treated Water	O	1/50 hours of ozone production	1/50 hours of ozone production

Table 1. Water Quality Sampling and Measurement Schedule, continued

Parameter	Sampling Location	Mandatory (M) or Optional (O)	Frequency*	
			Surface Water Systems	Ground Water Systems
Iron (µg/L)	Feed Water	O	1/50 hours of ozone production	1/50 hours of ozone production
Total Manganese (µg/L)	Feed Water Treated Water	O	1/50 hours of ozone production	1/50 hours of ozone production
Dissolved Manganese (µg/L) (Manganese concentration passing through 0.2 µm filter)	Feed Water Treated Water	O	1/50 hours of ozone production	1/50 hours of ozone production
Total Sulfides	Feed Water	O	1/d	1/d
Dissolved Oxygen	Feed Water Treated Water	O	1/50 hours of ozone production	1/50 hours of ozone production
Algal enumeration and speciation	Feed Water	O	1 per Verification Test Period	Not Required
Calcium (mg/L as $CaCO_3$)	Feed Water	O	1/50 hours of ozone production	1/50 hours of ozone production
Total Hardness (mg/L as $CaCO_3$)	Feed Water	O	1/50 hours of ozone production	1/50 hours of ozone production

* 3/d or 3/shift means that the water quality parameter shall be measured either 3 times per day if ozone production is continuous over the 200 hours of Verification Testing, or 3 times per staffed shift if ozone production is periodically terminated or interrupted, and the length of time of ozone production is less than 24 hours. 1/50 hours of ozone production means that the water quality parameter shall be measured once per each 50 hours of ozone production, regardless of interruptions in ozone production.

† The dissolved ozone concentration should be measured at sampling ports within the ozone contactor or immediately at the outlet of the ozone contactor. Multiple sampling ports may need to be sampled to calculate CT values.

** Mandatory if microbial challenge testing is being conducted. If CT calculations are used, these methods are not required.

†† The peroxide concentration of the stock solution shall be checked at the prescribed frequency. The peroxide concentration within the contactor shall be checked once during or immediately prior to the verification testing period, while the ozone equipment is not operating. Peroxide monitoring within the contactor will require that samples be withdrawn at appropriate sampling ports at the end or outlet of the contactor.

Table 2. Analytical Methods

Parameter	Facility	*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total organic carbon	Lab	5310 C	
Turbidity	On-Site	2130 B / Method 2	180.1
Dissolved Ozone Residual	On-Site	4500 O_3 B; HACH Indigo Blue Method*	
Iron	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
UV_{254} absorbance	Lab	5910 B	
Calcium Hardness	Lab	3500-Ca D	
Dissolved Manganese (manganese passing through 0.2 µm filter)	Lab	3500-Mn	200.0 / 243.2 / 243.3
Bromide	Lab	4500-Br^-	300.0
Total THMs	Lab	6232B	502.2, 524.2, 551
Haloacetic Acids (HAAs)	Lab	6251 B	552.1
Dissolved Organic Carbon	Lab	5310 C	
Color (Pt-Co)	Lab	2120 C	110.2
Total Sulfides	Lab or On-Site	4500-S^{2-} D, E	
Dissolved Oxygen	Lab or On-Site	4500-O	
AOC	Lab	9217	
Bromate	Lab		300.1
Hydrogen Peroxide (mg/L)	Lab or On-site	HACH Method HYP-1 or Masschelein, W., *et al*., (1977) or Bader *et al*. (1988)	
Algal enumeration and speciation	Lab	Part 10000, Biological Examination†	

* Dissolved ozone residual measurements can also be from a properly calibrated and installed dissolved ozone monitor.

† *Standard Methods* does not contain a method for enumeration and speciation of algae. It does, however, contain methods for laboratory techniques, which may need to be performed for proper enumeration and speciation of the algae. Only an experienced and qualified laboratory analyst shall conduct algal enumeration and speciation.

Table 3. Equipment Operating Data

Operational Parameter		Frequency
Water Flow (gpm)	Feed Water	3/d or 3/shift
	Side Stream (if applicable)	3/d or 3/shift
	Cooling Water	3/d or 3/shift
Water Pressure (psig)	Inlet to Ozone System	3/d or 3/shift
	Outlet of Ozone System	3/d or 3/shift
	Side Stream (if applicable)	3/d or 3/shift
	Cooling Water	3/d or 3/shift
Water Temperature (°C)	Inlet to Ozone System	3/d or 3/shift
	Outlet to Ozone System	3/d or 3/shift
	Side Stream (if applicable)	3/d or 3/shift
Gas Phase Ozone Concentration (% wt)	Feed Gas	3/d or 3/shift
	Off Gas	3/d or 3/shift
Power Usage (kw/hr)	Ozone Generator	3/d or 3/shift
	Air Preparation System or Oxygen System	3/d or 3/shift
	Gas Phase Ozone Feed and Off Gas Monitors	3/d or 3/shift
	Cooling Water System	3/d or 3/shift
	Destruct Units	3/d or 3/shift
	Other pumps or motors	3/d or 3/shift
Ozone Feed Gas Temperature (°C)		3/d or 3/shift
Ozone Feed Gas Pressure (psig)		3/d or 3/shift
Ozone Feed Gas Flow (scfm)		3/d or 3/shift
Atmospheric Pressure (psia)		1/d or 1/shift
Dew Point (if using air feed system)		1/d or 1/shift
Ozone Production (lb/d)		1/d or 1/shift
If applicable: Purity of oxygen supply (%) Supplemental nitrogen flow rate (scfm), pressure (psig), and temperature (°C) Supplemental air flow rate (scfm), pressure (psig), and temperature (°C)		 1/d or 1/shift 1/d or 1/shift 1/d or 1/shift
If applicable: Peroxide feed concentration (mg/L) Peroxide feed rate (mL/min) Peroxide to Ozone ratio (by weight)		1/d or 1/shift
If applicable: Operating parameters for UV-light systems (see ETV Testing Plan for Microorganism Contaminant Inactivation by Ultraviolet Based Technology – Chapter 4)		3/d or 3/shift

Table 4. CT Values for Inactivation of *Giardia* Cysts by Ozone at pH 6 to 9

	Temperature (°C)					
Inactivation	0.5	5	10	15	20	25
0.5 log	0.48	0.32	0.23	0.16	0.12	0.08
1.0 log	0.97	0.63	0.48	0.32	0.24	0.16
1.5 logs	1.5	0.95	0.72	0.48	0.36	0.24
2.0 logs	1.9	1.3	0.95	0.63	0.48	0.32
2.5 logs	2.4	1.6	1.2	0.79	0.60	0.40
3.0 logs	2.9	1.9	1.4	0.95	0.72	0.48

Source: Appendix O to the Guidance Manual For Compliance With the Filtration and Disinfection Requirements For Public Water Systems Using Surface Water Sources.

Table 5. CT Values for Inactivation of Viruses by Ozone

	Temperature (°C)					
Inactivation	0.5	5	10	15	20	25
2.0 logs	0.9	0.6	0.5	0.3	0.25	0.15
3.0 logs	1.4	0.9	0.8	0.5	0.4	0.25
4.0 logs	1.8	1.2	1.0	0.6	0.5	0.3

Source: Appendix O to the Guidance Manual For Compliance With the Filtration and Disinfection Requirements For Public Water Systems Using Surface Water Sources.

CHAPTER 3

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN FOR ON-SITE GENERATION OF HALOGEN DISINFECTANTS FOR INACTIVATION OF MICROBIOLOGICAL CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing on-site generation of halogen disinfectants used in drinking water treatment systems for small public or private water supplies. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan (PSTP) for testing of microbiological inactivation equipment using on-site generation of halogen disinfectants, within the structure provided by the Protocol entitled "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies".

Various types of treatment equipment employ on-site generation of halogen disinfectants to meet water treatment objectives such as microbiological inactivation and oxidation. This Equipment Verification Testing Plan is applicable only to treatment systems that rely on equipment for on-site generation of halogen disinfectants to effectively inactivate microorganisms in drinking water treatment systems. Systems may incorporate innovative techniques for generation of halogen disinfectants, such as the electrolysis of brine to produce chlorine and multiple oxidants.

In order to participate in this equipment verification process for microbiological inactivation via on-site generation of halogen disinfectants, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol as guidelines for the development of the PSTP. The Field Testing Organization (FTO) shall clearly specify in its PSTP the methods that shall be used for spiking of microorganisms, sampling of water streams and determination of microorganism viability, as well as any methods to be used for measurement of disinfectant concentrations in treated water streams. Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying objectives that an on-site halogen generation system inactivates protozoan cysts and oocysts if the method has undergone peer review. Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity.

2.0 INTRODUCTION

This ETV Testing Plan is applicable to any system that is used for on-site generation of halogen disinfectants for drinking water treatment applications, such as primary disinfection, residual disinfection, and process chemistry enhancement. This Testing Plan is also applicable to treatment systems that used in response to emergency scenarios. Typical systems in this category for on-site generation of halogen disinfectants may include but are not limited to: salt brine electrolysis generators, mixed oxidant systems, systems that include on-site generation of chlorine dioxide, systems providing iodination technologies, and other systems employing on-site generation of halogens. Based upon the goals of the Verification Testing Program, there are four primary aspects to the equipment evaluation process: 1) demonstration of equipment operation and generation capabilities; 2) measurement of halogen concentration and speciation; 3) inactivation of microbiological contaminants in feed waters to the system; and 4) measurement of the formation of disinfection by-products (DBPs) and other water quality parameters in treated waters.

To be applicable for this verification program, the on-site halogen generation systems must have the primary goal of halogen production for use in drinking water treatment applications. Additional goals of the on-site halogen generation systems may be to inactivate microbial

contaminants (primary disinfection), to provide a residual disinfectant in the distribution system (residual disinfection), to reduce formation of disinfection by-products (DBPs), or to provide oxidation of dissolved and particulate matter (organic or inorganic) in the source water.

On-site halogen generation systems that reduce the reliance on chlorine for disinfection hold promise for small utilities. Small on-site generators may be easier to operate than chlorine gas systems, and may provide effective oxidation of dissolved water constituents. In addition, the use of on-site generation systems such as salt brine electrolysis generators, mixed oxidant systems and chlorine dioxide generators may also allow for reduced formation of disinfection by-products. Further, on-site systems, such as iodine generators, may have applications in emergency situations.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by a NSF-qualified FTO that is selected by the equipment Manufacturer. The analytical work will be contracted with a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the U.S. Environmental Protection Agency (EPA) for the appropriate water quality or microbiological parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Objectives the specific performance criteria to be verified and the specific operational conditions under which the verification testing shall be performed. There are several types of Statements of Performance Objectives that may be verified in this testing. Examples of Statements of Performance Objectives are included in Table 1.

Table 1.
Types of Statements of Performance Objectives for On-Site Halogen Generation Systems

Type of Statement of Performance Objectives	Example of Statement of Performance Objectives
Halogen Production	*"This system is capable of producing a halogen concentration of 1,000 mg/L (0.1%) as ClO_2 in the concentrated halogen stream at a generation system output of 80%."*
CT	*"This system is capable of producing a chlorine concentration of 10 mg/L for a 10-minute contact time that will meet or exceed EPA published CTs for 1.0 log_{10} inactivation of Giardia at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.0 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L, alkalinity less than 150 mg/L as $CaCO_3$ and water temperatures greater than 5°C."*
CT (Comparative)	*"This system is capable of producing halogen concentrations that will meet EPA published CTs for 4-log_{10} inactivation of virus and 3- log_{10} inactivation of Giardia at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.5 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L and alkalinity less than 150 mg/L as $CaCO_3$, while producing DBP concentrations 75% less than those produced by free chlorine at identical CTs."*
Microbial Inactivation	*"This system is capable of achieving 3-log_{10} inactivation of Giardia lamblia at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.5 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L and alkalinity less than 150 mg/L as $CaCO_3$."*
Microbial Inactivation (Comparative)	*"This system is capable of achieving 3-log_{10} inactivation of Giardia lamblia at CTs 20% lower than EPA's published chlorine CTs. This level of Giardia lamblia inactivation will be achieved by the equipment at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.5 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L and alkalinity less than 150 mg/L as $CaCO_3$."*

The tasks required to complete the Verification Testing depend on the type of Statement of Performance Objectives made by the Manufacturer. The following tasks are included in this Verification Testing program:

- Task 1: Equipment Operation and Disinfectant Production Capabilities
- Task 2: Microbiological Contaminant Inactivation (Optional)
- Task 3: Treated Water Quality
- Task 4: Data Management
- Task 5: Quality Assurance/Quality Control (QA/QC)

For each of the above-mentioned tasks and Statements of Performance Objectives, there are a number of different operational and system characteristics that would require evaluation during Verification Testing. Table 2 provides an overview of the equipment operational characteristics to be evaluated in tasks 1 through 3 of the Verification Testing Plan. Tasks 4 and 5 shall be performed for all Statements of Performance Objectives.

Table 2.
Summary of Equipment Operational Characteristics
To be Evaluated in Each Verification Testing Task

Type of Statement of Performance Objectives (See Table 1)	Equipment Operational Characteristic to be Evaluated	Task*
Halogen Production	1. Range of feed water flow rates	1
	2. Range of halogen concentrations produced under a variable range of percent generator output	1
	3. Speciation of halogens produced	1
	4. DBP formation	3
	5. Power consumption	1
	6. Characteristics and costs of initial constituent materials for halogen generation	1
	7. Waste stream characterization and range of waste stream flow rates	1
CT	Characteristics 1 through 7, and:	
	8. Hydraulic tracer testing	1
	9. Range of hydraulic residence times of feed waters (disinfectant contact times) through the system	1
Microbial Inactivation	Characteristics 1 through 9, and:	
	10. Microbial inactivation	2

*Note: Tasks 4 and 5 shall be performed for all Statements of Performance Objectives

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be components of the Verification Testing Plan and PSTP for on-site generation of halogen disinfectants used in drinking water treatment systems for small public or private water supplies.

4.1 Task 1: Equipment Operation and Disinfectant Production Capabilities

The objective of this task is to operate the treatment equipment provided by the Manufacturer and to assess its ability to produce on-site generation of halogen disinfectants for microbial contaminant inactivation. The system performance shall be evaluated relative to the stated water quality goals and any other performance characteristics specified by the Manufacturer. For Verification Testing purposes, the equipment shall be operated for a minimum of one, one-month testing period for each operational condition for which verification is desired. It is recommended that Verification Testing be performed under the poorest conditions of feed water quality for which the Manufacturer wishes to make a Statement of Performance Objectives. The FTO must provide statements in the PSTP as to what would constitute the worst-case feed water quality for the specific on-site halogen generation system. Examples of such worst-case feed water quality may include cold temperatures and/or high concentrations of suspended solids, organic carbon or oxidizable materials. Additional one-month testing periods shall be performed for other feed

water qualities or other operating conditions for which the Manufacturer wishes to make a Statement of Performance Objectives.

For all types of Statements of Performance Objectives, the FTO shall evaluate the following operational parameters: range of flow rates for which system is designed, concentration of disinfectants generated by the system (under a range of operational conditions and a range of percent disinfectant output), the speciation of the disinfectants produced by the on-site generation system, and production of DBPs. For Statements of Performance Objectives based on CT or inactivation, the FTO shall also determine hydraulic retention times. For Statements of Performance Objectives based on inactivation, the FTO shall determine contact times between the disinfectant and microbiological contaminants. Inactivation of microbiological contaminants will be addressed in Task 2. Formation of DBPs and other water quality impacts in treated waters will be addressed in Task 3.

4.2 Task 2: Microbiological Contaminant Inactivation (Optional)

This task shall be performed if the Statement of Performance Objectives is based on inactivation. This task may be waived if the Statement of Performance Objectives is based only on halogen production or CT. The objective of this task is to measure the performance of the on-site halogen generation drinking water treatment equipment for inactivation of selected bacterial, viral or protozoan contaminants that may include: *Clostridium perfringens*, *Klebsiella*, *Pseudomonas aeruginosa* (if there high HPC counts are present in feed waters), MS2 bacteriophage, *Giardia lamblia*, and/or *Cryptosporidium parvum*.

4.3 Task 3: Treated Water Quality

The objective of this task is to evaluate the quality of treated water. Multiple water quality parameters will be monitored during each testing period. The mandatory water quality monitoring parameters for all testing periods shall include: pH, temperature, turbidity, disinfectant residual, hydrogen sulfide, alkalinity, total dissolved solids (TDS), ammonia nitrogen, total organic carbon (TOC), UV absorbance at 254 nm (UVA), true color, iron, manganese, chloride, bromide, sodium, total coliforms, and heterotrophic plate count (HPC) bacteria. Monitoring of free available chlorine (FAC) and total available chlorine (TAC) shall be required for all Verification Testing of on-site halogen generation systems, whether or not chlorine is considered the primary agent of inactivation. Formation of instantaneous and/or DBP formation testing of organic DBPs in the treated water shall also be monitored by the FTO, as applicable. Inorganic by-products of treatment with the on-site halogen generation system shall be monitored as applicable, including but not limited to chlorite, chlorate and bromate. Water quality produced shall be evaluated in relation to feed water quality and operational conditions.

4.4 Task 4: Data Management

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the FTO and NSF for data obtained during the Verification Testing. Prior to the beginning of field testing, the database design must be developed by the FTO and reviewed and approved by NSF. This will insure that the required data will be collected during the testing, and that it can be effectively transmitted to NSF for review.

4.5 Task 5: Quality Assurance/Quality Control (QA/QC)

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during Verification Testing of the on-site halogen generation equipment. Prior to the beginning of field testing, a QA/QC plan must be developed which addresses all aspects of the testing process. Each water quality parameter and operational parameter must have appropriate QA and QC measures in place and documented. For example, the protocol for pH measurement should describe how the pH meter is calibrated (frequency, pH values), what adjustments are made, and provide a permanent record of all calibrations and maintenance for that instrument.

5.0 TESTING PERIODS

For Verification Testing purposes, the equipment shall be operated for a minimum of one, one-month testing period at each set of operational conditions and/or feed water qualities for which verification is desired (i.e., conditions of testing that will support the Statement of Performance Objectives). For example, separate one-month testing periods shall be performed for different operating conditions of the halogen generation equipment, such as different output levels of the halogen generator (e.g., separate one-month testing periods for 80%, 50% and 20% generator output). Examples of some of the different operational conditions that might be included as separate testing periods in the Verification Testing program are listed in Table 3.

Table 3.
Examples of Potential Operating Conditions for Verification Testing

Potential Operating Conditions	Required Testing Period	Required Tasks per Testing Period	Optional Tasks per Testing Period
80% generator output	one month	1, 3, 4, 5	2
50% generator output	one month	1, 3, 4, 5	2
20% generator output	one month	1, 3, 4, 5	2

It is recommended that one-month of Verification Testing shall be performed under the poorest feed water quality for which the Manufacturer wishes to verify the Statement of Performance Objectives. The FTO must provide statements in the PSTP as to what would constitute the worst-case feed water quality for the specific on-site halogen generation system. Examples of some of the different water quality conditions that might be included as separate testing periods in the Verification Testing program are listed in Table 4.

Table 4.
Examples of Potential Feed water Types for Evaluation in Distinct Testing Periods

Potential Testing Conditions	Required Testing Period	Required Tasks per Testing Period	Optional Task in Testing Period
Poor Water Quality	one-month	1, 3, 4, 5	2
Spring Run-Off Event	one-month	1, 3, 4, 5	2
Summer Algae Bloom	one-month	1, 3, 4, 5	2
Cold Temperature	one-month	1, 3, 4, 5	2
Untreated Surface Water	one-month	1, 3, 4, 5	2
Treated Surface Water	one-month	1, 3, 4, 5	2
Groundwater	one-month	1, 3, 4, 5	2
Groundwater Under the Influence	one-month	1, 3, 4, 5	2

Examples of poor feed water quality may include high concentrations of suspended solids, organic carbon or other materials that can exert an oxidant demand. These worst-case feed water quality characteristics may not occur simultaneously. For example, the Manufacturer may wish to conduct an additional one-month testing period during a spring run-off event in order to demonstrate equipment performance on a water quality characterized by elevated turbidity and organic material. The Manufacturer may wish to conduct testing in another one-month testing period during a summer algae bloom for demonstration of performance under conditions of elevated levels of organic material. Additionally, the Manufacturer may wish to conduct testing in a third one-month testing period during the coldest water temperatures of the winter.

The Manufacturer may also wish to demonstrate the Statement of Performance Objectives using water supplies from both surface water sources (treated and untreated) and groundwater sources (e.g., untreated and/or under the influence of surface water). In this case, the FTO must provide statements in the PSTP as to what constitutes the worst-case feed water quality for each supply and schedule the testing periods accordingly.

Prior to the initiation of Verification Testing, sufficient information shall be provided to illustrate the variations expected to occur in feed water quality for a typical annual cycle for the water source. Any pretreatment chemical additions that may impact the feed water to the on-site halogen generation system shall be fully described by the FTO in the PSTP. For example, any coagulant or other chemical additions shall be identified. Predicted effects on feed water turbidity, suspended solids and total organic carbon concentration shall also be discussed in the PSTP prepared by the FTO. Failure to adequately characterize the feed water could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

The required tasks (Task 1 and Tasks 3 through 5) and optional task (Task 2) in the Verification Testing Plan are designed to be completed during each one-month testing period performed for the Verification Testing. One month is the minimum duration of each testing period; longer testing periods may be employed at the discretion of the Manufacturer or as necessary to complete the required (and optional, if applicable) tasks. The required one-month duration of each testing period does not include the time required for mobilization or start-up, nor does it include the time required to achieve steady-state operation.

6.0 TASK 1: EQUIPMENT OPERATION AND DISINFECTANT PRODUCTION CAPABILITIES

6.1 Introduction

During Task 1, the FTO shall evaluate equipment operations and determine the rates of feed water flow and halogen production concentration for which the on-site generation system is designed. The on-site halogen generation equipment shall be operated for Verification Testing purposes within the operational range presented in the Manufacturer's Statement of Performance Objectives, as described above in Section 3.0. Monitoring in Task 1 shall be focused on determination of the operational characteristics summarized above in Table 2, depending on the type of Statement of Performance Objectives made in the PSTP, or other factors applicable to the technology that provide effective treatment of the feed water. The FTO shall establish the testing conditions to be evaluated for Task 1 in the PSTP.

Before the initiation of Verification Testing in Task 1, the FTO on behalf of the Manufacturer shall make known the limitations of the equipment and any existing equipment incompatibilities with treatment processes or chemical additions. To this end, a listing shall be provided by the Manufacturer describing the potentially incompatible treatment processes or chemical additions (i.e., oxidants, coagulants, anti-scalants, chemicals for pH adjustment) that would adversely impact the equipment materials or the treatment process. In addition, the FTO shall report any incompatibilities between equipment and treatment processes or chemical additions that are observed during the course of the Verification Testing Program.

The FTO (with input from the equipment Manufacturer) may want to conduct preliminary studies in Task 1 to determine the range of operational capabilities during initial runs with the on-site halogen generation equipment. For Statements of Performance Objectives based on CT or microbial inactivation, the FTO shall describe in the PSTP the type of disinfectant contacting system that will be employed during Verification Testing of the on-site halogen generation system. The FTO shall also propose and fully describe in the PSTP the method of hydraulic tracer testing that will be performed to demonstrate flow conditions and residence duration (exposure time). Procedures for developing a tracer test methodology are described in the General Requirements section of the Protocol for Equipment Verification Testing of Microbiological Contaminant Inactivation.

This testing plan applies to halogen generation systems that are designed for either continuous flow or for intermittent flow through the generation equipment. If the Statement of Performance Objectives applies to intermittent flow applications, this should be specifically stated in the Statement of Performance Objectives and the work plan should include a designated shutdown period each day in which the on-site halogen generation equipment is turned off.

6.2 Objectives

The objectives of Task 1 are to determine the appropriate range for equipment operation and to determine the range of disinfectant concentrations (as well as speciation) generated under different conditions of percent system generation output. The performance of on-site halogen generation systems may be different for feed waters from different test sites or for the feed water from the same site during different seasonal water quality episodes. Therefore, it will be necessary to fully document the feed water conditions under which Verification Testing is

performed. Complete chemical, biological and physical characterization of the feed waters and treated waters produced by the system will be performed as part of Task 3. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

6.3 Work Plan

Mobilization and start-up of equipment shall be performed prior to the initiation of Task 1 testing. Furthermore, the on-site halogen generation system shall have achieved a condition of steady-state operation before the start of Task 1 testing. The FTO shall clearly describe in the PSTP the protocol for start-up of the on-site halogen generation system, as well as operations and maintenance issues that may arise during mobilization and start-up.

During each day of Verification Testing in Task 1 (minimum one-month testing period at one set of operational conditions and/or one set of water quality characteristics), treatment equipment operating parameters for the on-site halogen generation will be monitored and operating data will be recorded. Operating parameters for monitoring shall include: rate of feed water and treated water flow; generated halogen concentration and speciation (dilution of concentrated halogen stream may be required); rate and quality of feed stock (i.e., salt) consumption, and other equipment characteristics as specified for measurement by the FTO in the PSTP. In addition, the aggregate horsepower of all motors and mechanical efficiencies of all motors/devices supplied with the equipment shall be determined and used to develop an estimate of the maximum power requirements and routine power consumption during operation. A summary of the operational parameters to be recorded during Task 1 and the minimum frequency of monitoring is presented in Table 5. The FTO shall provide the necessary methods information for monitoring of the operational parameters presented in Table 5. Additional monitoring of feed water chemistry shall be performed during Verification Testing, as described below in Task 3 (Section 8.0).

If any waste streams are generated by the on-site halogen generation system, these streams must be fully characterized during Task 1 testing. The FTO shall fully describe and provide general characterization of the waste streams that are generated by the on-site halogen generation system in the PSTP, including pH, total dissolved solids (TDS), alkalinity, disinfectant residual, and temperature. In the case that water softening of the feedwater is required prior to halogenation, the characteristics of the waste streams produced by the water softener shall also be described. The FTO shall also discuss the applicable potential waste stream disposal issues in the PSTP, including disposal to the sewer or receiving water.

Table 5.
Task 1 - Required Minimum Operating Data for On-Site Halogen Generation Systems

Operational Parameter	Action, Monitoring Frequency
Feed water flow rate	Check and record twice daily. Adjust when 10% above or below target. Record both before and after adjustment.
Rate of feed stock consumption	Check and record consumption twice daily. Adjust when 10% above or below target. (Quality of feed stock required by equipment shall also be recorded.)
Halogen concentration and speciation (at each set of operational conditions)	Sample the following and record twice daily: 1. Concentrated halogen stream (generator product) 2. Halogen-treated water at disinfection contactor influent (if applicable) 3. Halogen-treated water at disinfection contactor effluent (if applicable)
Horsepower and efficiency of motors, and consumed amperage for on-site generation (at each set of operational conditions)	Provide record of current draw to motors on cumulative basis. Provide information on start-up amperage and horsepower requirements.
Waste stream composition (Testing recommended for each batch of constituent chemicals)	Sample once each one-month testing period for: pH, NaOH, TDS, heavy metal scan (only those technologies producing definable waste). Water softeners may require monitoring of additional parameters.
Waste stream flow rate	Check and record waste flow streams (if applicable) twice daily.
For Statements of Performance Objectives based on CT or microbial inactivation: Hydraulic detention time in disinfectant contacting system (at selected flow rate)	Provide correlation to measured value on daily basis.

6.4 Schedule

During Verification Testing, water treatment equipment shall be operated continuously for a minimum of one month at one set of operational conditions (e.g., percent generator output – Table 3) and/or one feed water quality (examples given Table 4). Interruptions in operation may be allowed during the one-month testing period as needed for system maintenance. Necessary details of the system shutdown procedure shall be specified by the FTO in the PSTP.

6.5 Evaluation Criteria

- General operational performance
  - ⇒ Temporal profile of feed water flow rate over each one-month testing period. One temporal profile graph (at daily resolution) shall be provided for each set of operational conditions and/or water qualities evaluated during Verification Testing.

⇒ Temporal profile of waste stream flow rate measured during each one-month testing period.

⇒ Table of disinfectant concentrations generated for each disinfectant species in the halogenated water and treated water streams during each one-month testing period.

- Rate of consumption of feed material for halogen generation and for feedwater conditioning. Quality of feedstock material required for halogen generation shall also be reported.
- Power consumption
  ⇒ Table of horsepower requirements, motor efficiency and consumed amperage for the testing period(s), as measured for each set of operational conditions.
- Waste stream characterization
  ⇒ Table of waste stream quality parameters measured during each one-month testing period.
- Contact time (only for Statements of Performance Objectives based on CT or microbial inactivation)
  ⇒ Table of calculated or estimated hydraulic detention time in disinfectant contacting system for each set of operational conditions evaluated during the testing period(s).

7.0 TASK 2: MICROBIOLOGICAL CONTAMINANT INACTIVATION (OPTIONAL)

7.1 Introduction

If the Statement of Performance Objectives is based on microbial inactivation, the effectiveness of the on-site generation equipment for inactivation of microorganisms such as bacteria, viruses, or protozoa (or a combination thereof) introduced in the feed water to the system will be evaluated in this task. The measurement of inactivation for this study will be based upon a comparison of the percent of viable organisms in the feed water stream and the percent of viable organisms in the halogen-treated water stream at the disinfection contactor effluent. In the case that the FTO can demonstrate that the feed waters contain a naturally occurring and consistent concentration of microorganisms approved by this inactivation test plan that is sufficient to demonstrate the manufacturer's Statement of Performance Objectives, no spiking of organisms will be necessary for the inactivation experiments.

7.2 Objectives

The objective of this task is to characterize the on-site halogen generation technology in terms of efficacy for inactivation of selected microbiological contaminants. Microorganisms for inactivation testing will be selected by the FTO and specifically identified in the PSTP.

7.3 Work Plan

If the Manufacturer’s Statement of Performance Objectives is based on microbial inactivation, the FTO shall identify the microbiological contaminant inactivation capabilities in the Statement of Performance Objectives provided in the PSTP. In the Statement of Performance Objectives, the Manufacturer shall identify the specific microbiological contaminants to be monitored during equipment testing and the specific operational conditions under which inactivation testing shall be performed. The Statement of Performance Objectives prepared by the FTO on behalf of the Manufacturer shall also indicate the range of water quality under which the equipment can be

challenged while successfully treating the feed water. Examples of satisfactory Statements of Performance Objectives based on microbial inactivation were provided in Table 1.

7.3.1 Organisms Employed for Inactivation Experiments

The FTO on behalf of the Manufacturer shall specify which organisms shall be employed in Verification Testing for demonstration of the inactivation efficacy of the on-site halogen generation system. Examples of organisms for potential use in this task are listed below in Table 6. These species represent microorganisms of particular interest and concern to the drinking water industry, and represent a range of resistance to inactivation methods. The specific batches of microorganisms used must be shown to be viable by the laboratory involved in the analytical aspects of the testing. The FTO shall specify in their PSTP, which of the approved organisms will be employed for Verification Testing. The FTO shall also specify the specific methods that shall be used for analysis of the count and the viability of the test organisms.

Table 6.
Example Microorganisms for Task 2 Inactivation Experiments

Type of Spiking Organism	Example Microorganisms for Inactivation Experiments
Bacteria	*Clostridium perfringens* *Klebsiella* *Pseudomonas aeruginosa* (if high HPC counts are present) Total Coliform Bacteria
Virus	MS2 Bacteriophage Enteric virus species
Protozoan (oo)cysts	*Giardia lamblia* *Cryptosporidium parvum*

Microbial inactivation experiments with the on-site generation system shall be performed as three replicate studies done consecutively at one set of selected operational conditions and/or a range of influent water qualities, as required in Task 1. Microbiological inactivation experiments may be conducted during the minimum one-month Verification Testing period that is required for a single set of operating conditions and/or influent water quality in Task 1. Only one process control test shall be performed in which the on-site halogen generation system is turned off. The FTO shall fully describe the spiking and sampling methods to be used during the microbial inactivation testing in Task 2. A description of some possible spiking and sampling methods is provided below in the Analytical Methods portion of this Section 7.0.

7.4 Analytical Methods

7.4.1 Spiking Protocols

The total number of each type of test organism required for spiking will depend on the reactor volume, the water flow rate, and the desired steady-state concentration of microbiological contaminants in the reactor. The total number of organisms required to provide these steady-state microbiological populations will depend on the overall volume

of the disinfection contactor, the detection limits of the sampling and analytical methods and the duration of experiments. For all organisms, the laboratory(ies) supplying the organisms and performing the viability studies shall be experienced in challenge testing and be able to predict initial dosages required to overcome any inherent experimental losses. The FTO shall fully describe in the PSTP the spiking methodology to be employed during the microbiological inactivation testing. An example of a spiking protocol for microbiological inactivation studies is provided below.

The feed water stream to the on-site halogen generation test unit will be plumbed with a check-valve to prevent back-flow of waters spiked with concentrations of microbiological contaminants. Consistent dosing of the spiking stock suspension will be controlled by means of a metering pump (diaphragm or peristaltic or equivalent) via siliconized or Teflon tubing. The pump shall be capable of fluid injection into the pressurized system feed line for the duration of the test, at a measurable and verifiable rate such that the dosing of the spiking stock suspension is consistent throughout the duration of the test run. Once appropriate flow has been initiated through the test system, the test unit must be demonstrated to operate in a steady-state condition. The spiking shall continue for a period of time that allows a minimum of three retention time-equivalents through the on-site generation and contacting system (as determined by tracer tests or as defined by system functions) prior to sample collection. During the course of the experiment, monitoring of the system flow rate and spike injection rate shall be performed and adjustments made to maintain test design.

7.4.2 Sample Collection

7.4.2.1 Test Stream Sampling. Sample ports shall be provided for the feed water stream (spiked with concentrations of microbiological contaminants) and the halogen-treated water stream at the contactor effluent. The FTO shall specify the specific ways in which sample collection is performed according to the organisms that will be used for the proposed microbiological inactivation experiments. Examples of potential sample collection methods for bacterial, viral and protozoan organisms are provided below. The methods described, or any other peer-reviewed method may be used for verification testing. The FTO shall propose in the PSTP the specific methods that are to be used for viability assessment of the selected microorganisms (See Section 7.5 below).

For bacterial and/or viral seeding experiments, methods for organism spiking and sample collection shall be consistent with a selected peer-reviewed method. The frequency and number of samples collected for each sampling point will be determined by the length of the test run and shall be specified by the FTO in the PSTP. The volume of each halogen-treated water sample from the disinfection contactor effluent will depend on the concentrations of test organisms spiked, and the requirements of the analytical laboratory.

For protozoan spiking experiments, EPA Method 1622 or any other method that has been evaluated through the peer-reviewed process (e.g., Nieminski and Ongerth, 1995) may be followed for sample collection from the spiked water streams. The sample collection system shall be plumbed to allow installation of housings and filters for capture of sufficient flow for microbiological analysis. The FTO shall provide an indication of the recovery efficiency achievable under the sample collection method selected for use during protozoa seeding studies. The specific capture filter recovery system shall be fully

described in the PSTP by the FTO. In addition, the PSTP shall include a plan of study for verification testing with a minimum of three standard recovery efficiency tests from the microbiological laboratory.

7.4.2.2 Post-Test Sample Handling. The FTO shall take steps to sanitize the system following microbial spiking experiments to inactivate any organisms remaining in the system. Depending on the unit (design and materials), sanitization may be done using steam or hot water (80°C for 10 min) or other acceptable disinfectant. The FTO shall specify in the QA/QC plan of the PSTP how this sanitization procedure is to be done to ensure inactivation of live organisms and subsequent removal of inactivated organisms from the unit. Biosafety concerns for humans and the environment that are associated with the disinfection of live organisms shall be outlined in the Safety Plan that is developed as part of the QA/QC plan in the PSTP. (Refer to section 10.5 of this test plan for more detail on the Health and Safety Measures to be detailed in the QA/QC Safety Plan.)

7.4.2.3 Process Control. A control round of testing shall also be carried out identical to the procedure identified by the FTO in the PSTP, with the on-site halogen generation system turned off. The purpose of this testing is to evaluate any cumulative effects of the equipment stream, spiking and sampling processes, and sample handling on organism viability. This testing shall not occur until elimination of sanitizing agents and inactivated target organisms, whose presence could affect the inactivation capabilities of the unit. The process control samples should show minimal inactivation of the target organism(s) relative to the trip control sample. If significant inactivation of the process control sample is measured in control testing, some aspect of the process other than on-site halogen generation system may have contributed to inactivation of the test organisms. Under such a scenario, re-testing of the on-site halogen generation system for microbiological inactivation would be required.

7.4.2.4 Trip Control. For tests utilizing spike challenges, a replicate or sub-sample of the spike dose shall accompany the actual spike dose from the analytical laboratory, including all preliminary processes of dose preparation pre-enumeration, shipping, and preparation for spiking, through return to the laboratory for enumeration and viability baseline assessment. The trip control samples should show minimal inactivation of the target organism(s). Significant inactivation of the trip control sample would indicate that some aspect of the handling, from preparation to testing, contributed to inactivation of the test organism(s). Evidence of greater than 90% inactivation of trip control samples will require re-testing.

7.4.2.5 Comparison Control. If the Statement of Performance Objectives involves comparison of microbial inactivation by the on-site halogen generation system to microbial inactivation by another disinfectant (i.e., chlorine), then a control experiment shall be conducted using the comparison disinfectant. In this experiment, all spiking, contacting, sampling and analysis must be identical to that employed for the inactivation testing with the on-site halogen generation system, with the exception that free chlorine shall be used to meet CT rather than the halogens generated on site.

7.5 Microbiological Viability Analysis

Methods for assessing the viability of the selected bacteria and viruses (see Table 6) shall be specified by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the EPA for the appropriate microbial analyses. Selected viability methods shall be specified by the FTO in the PSTP.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying objectives that an on-site halogen generation system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), Slifko et al. (1997) and others (see Section 12.0 References in this Test Plan). Interim, non-standard methods for assessing the viability of cyst and oocyst (e.g., excystation, DAPI/PI) may be used for verification of inactivation after exposure to halogen disinfectants. However, any interim organism viability method is subject to review by experts of cyst and oocyst viability and subsequent method change. Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity.

7.6 Evaluation Criteria and Minimum Reporting Requirements

- Concentrations of microbiological contaminants in the feed water and halogen-treated water at the disinfection contactor effluent
  - ⇒ Table of feed water and treated water concentrations of the NSF-approved spiked microorganisms (Table 6) for challenge experiments (three replicate runs), process control experiment, and comparison control experiment (if applicable)
  - ⇒ Trip control results
  - ⇒ Bar graph of $\log_{10}$ inactivation results for three replicate test runs and all control test runs
  - ⇒ The variability of the results from microbial inactivation tests should be presented with the bar graphs as 95% confidence intervals.

8.0 TASK 3: TREATED WATER QUALITY

8.1 Introduction

Water quality data shall be collected for the feed water and halogen-treated water as shown in the sampling schedule in Table 7. These data shall be collected during the equipment operation test runs of Task 1 and the microbiological contaminant inactivation test runs of Task 2 (if applicable). No additional test runs need to be performed for Task 3, other than those performed for Tasks 1 and 2.

8.2 Experimental Objectives

The objective of this task is to assess the impact on water quality of treatment with the on-site halogen generation system. Specific water quality analyses and sampling frequencies are detailed in Table 7.

8.3 Work Plan

A list of the minimum number of water quality parameters is provided in Table 7 for monitoring of the feed water, concentrated halogen stream, and halogen-treated water at the disinfection contactor influent and effluent during Equipment Verification Testing. The actual water quality parameters selected for testing and monitoring shall be stipulated by the FTO in the PSTP.

Table 7.
Water Quality Sampling Schedule (Minimum Required for Each Testing Period)

Parameter	Sampling Frequency	Test Stream to be Sampled	Standard Method	EPA Method
On-Site Analyses				
pH	1/Day	Feed, Treated[1], Waste	4500 H+	150.1/ 150.2
Temperature	1/Day	Feed, Treated, Waste	2550 B	
Turbidity	1/Day	Feed, Treated	2130 B	180.1
Disinfectant Residual: Chlorine (FAC, TAC) Iodine Chlorine Dioxide Bromine	2/Day	Feed[2], Concentrated Halogen Stream[3], Halogen-Treated Water at Contactor Influent[4] and Effluent[1], Waste	 4500-Cl F[5] 4500-I B[5] 4500-ClO_2 D[5]	 300.0 300.0
Hydrogen sulfide	1/Day	Feed	4500-S^{2-}	
Laboratory Analyses				
Alkalinity	1/Week	Feed, Treated, Waste	2320 B	
TDS	1/Testing Period	Feed, Treated, Waste	2540 C	
Ammonia Nitrogen	1/Week	Feed, Treated	4500-NH_3 G	
TOC	1/Testing Period	Feed, Treated	5310 C	
UVA	1/Week	Feed, Treated	5910 B	
True Color	1/Week	Feed, Treated	2120 B	
Iron	1/Testing Period	Feed, Treated	3500-Fe C	200.7/ 200.8/ 200.9
Manganese	1/Testing Period	Feed, Treated	3500-Mn C	200.7/ 200.8/ 200.9
Chloride	1/Testing Period	Feed, Treated	4500-Cl^- F	300.0
Bromide	1/Testing Period	Feed, Treated	4500-Br^- C	300.0
Sodium	1/Testing Period	Feed, Treated	3500-Na B	200.7
Total Coliform Bacteria	5/Week	Feed, Treated	9221 / 9222 / 9223	
HPC Bacteria	5/Week	Feed, Treated	9215 B	
TTHMs	1/Testing Period	Feed[2], Treated		524.2
HAAs	1/Testing Period	Feed[2], Treated		552.1

Table 7. (continued)
Water Quality Sampling Schedule (Minimum Required for Each Testing Period)

Parameter	Sampling Frequency	Test Stream to be Sampled	Standard Method	EPA Method
Optional DBPs[6]:				
Haloacetonitriles	1/Testing Period	Feed[2], Treated		551
(HANs)	1/Testing Period	Feed[2], Treated		551
Chloropicrin	1/Testing Period	Feed[2], Treated		551
Chloral Hydrate	1/Testing Period	Feed[2], Treated		524.2
Cyanogen Chloride				
Chlorite, Chlorate (if applicable)	1/Testing Period	Feed[2], Treated		300.0 B
Bromate (if applicable)	1/Testing Period	Feed[2], Treated		300.0 B
DBP Formation Testing[7]				
TTHMs	1/Testing Period	Treated		524.2
HAAs	1/Testing Period	Treated		552.1
Optional DBPs[6]:				
HANs	1/Testing Period	Treated		551
Chloropicrin	1/Testing Period	Treated		551
Chloral Hydrate	1/Testing Period	Treated		551
Cyanogen Chloride	1/Testing Period	Treated		524.2
Bromate (if applicable)	1/Testing Period	Treated		300.0 B
Chlorite, Chlorate (if applicable)	1/Testing Period	Treated		300.0 B

[1] For purposes of Table 7, "treated" water indicates the halogen-treated water at the disinfection contactor effluent. If the equipment being tested does not include a disinfection contactor (i.e., includes only feed water and concentrated halogen stream sampling points), then only the feed water sample shall be collected.

[2] Feed water sampling for these parameters shall be performed once during the Verification Testing to verify that no addition of disinfectants or oxidants and no formation of DBPs occurs upstream of the feed water sampling point.

[3] The "concentrated halogen stream" is the generator product stream.

[4] The "halogen-treated water at contactor influent" indicates the feed water to the equipment immediately after dosing with the concentrated halogen stream.

[5] The stated Standard Method shall be used if the halogen generator produces only one of the listed disinfectants (e.g., chlorine) and no other disinfectant. If the halogen generator produces more than one of the listed disinfectants, or if the halogen generator produces bromine, then the method described in White (1992) and Palin (1974) shall be used for disinfectant residual measurement.

[6] Optional DBPs shall be measured if applicable.

[7] DBP formation testing shall be conducted if on-site halogen generation equipment is used to provide both primary disinfection and residual disinfection. Conditions for DBP formation testing preparation shall follow the UFC proposed in the Information Collection Rule (see section 8.4.4 of this test plan).

If the on-site halogen generation system is used only for primary disinfection, with residual disinfection provided by another process, then sampling for organic (Total Trihalomethanes (TTHMs), haloacetic acids (HAAs) and optional DBPs) and inorganic (bromate, chlorite, chlorate) DBPs shall be performed on an instantaneous basis after the specified disinfection contact time. Both instantaneous sampling and simulated distribution system testing for organic and inorganic DBPs shall be performed if the on-site halogen generation system is used for both primary disinfection and residual disinfection. Water samples collected for DBP analysis should be collected simultaneously with samples collected for other analyses such as pH, alkalinity, TOC, UVA, turbidity, ammonia, and other pertinent water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the FTO. Analysis of the remaining water quality parameters shall be performed by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the EPA for the appropriate water quality parameters. The methods to be used for measurement of all water quality parameters in the field and in the off-site analytical laboratory are specified in Table 7 and are described in detail in Task 5, Quality Assurance/Quality Control (QA/QC). Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided in Table 7 for both the field and laboratory analytical procedures.

For the case of off-site shipment, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the off-site analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory. Samples shall be shipped to a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the EPA. Original field sheets and chain-of-custody forms shall accompany all samples shipped to the off-site analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples shall be provided to NSF.

8.4 Analytical Schedule

8.4.1 Characterization of Feed Water, Concentrated Halogen Stream and Halogen-Treated Water at the Disinfection Contactor Influent and Effluent.

The water quality characteristics of the feed water, the concentrated halogen stream and the halogen-treated waters at the influent and effluent to the disinfection contactor shall be characterized by measurement of the parameters listed in Table 7. Sampling shall be performed during steady-state operation of the on-site halogen generation equipment in Task 1 and Task 2 (if applicable).

8.4.2 Water Quality Sample Collection

Water quality data for Task 3 will be collected at regular intervals during test runs conducted for Tasks 1 and 2, as indicated by the sampling frequency in Table 7. No additional test runs shall be required for Task 3 other than those already described in Tasks 1 and 2. The minimum monitoring frequency for the required water quality parameters is provided in Table 7. At the discretion of the Manufacturer and the designated FTO, the water quality sampling program may be expanded to include a

greater number of water quality parameters and to require more frequent sampling. Sample collection frequency and protocol shall be defined by the FTO in the PSTP.

8.4.3 Feed Water Quality Limitations

The characteristics of feed water encountered during each testing period shall be explicitly stated in reporting the data from Tasks 1 and 2. Accurate reporting of such feed water characteristics as turbidity, temperature, pH, ammonia nitrogen and total organic carbon is critical for the Verification Testing, as these parameters can substantially influence the disinfection performance of the on-site halogen generation equipment.

8.4.4 Disinfection By-Product Formation Testing

DBP formation testing shall be performed if the on-site halogen generation equipment is used for residual disinfection in addition to primary disinfection. DBP formation testing shall be performed on the treated water once each testing period (at a minimum) during steady-state operation of the on-site halogen generation equipment for Task 1 or Task 2. DBP formation testing will be used to estimate by-product formation in the distribution system, including TTHMs, the six measured HAA compounds, and (if applicable) HANs, chloropicrin, chloral hydrate, cyanogen chloride, bromate, chlorite and chlorate.

If no additional dosing of halogens is used for residual disinfection subsequent to primary disinfection, the DBP formation testing method shall be performed by collecting a sample of the halogen-treated water at the disinfection contactor effluent and holding the sample in the dark at the uniform formation conditions (UFC) specified in the Information Collection Rule (ICR) Manual for Bench- and Pilot-Scale Treatment Studies. If additional dosing of the halogens is used for residual disinfection subsequent to primary disinfection, the DBP formation testing method shall be performed by collecting a sample of the halogen-treated water at the disinfection contactor effluent, spiking it with an additional dose of disinfectant, and holding the sample in the dark at the UFC. (Refer to the DBP formation testing protocol in Task 5, QA/QC, of this Verification Testing Plan for further details.)

The following UFC will be used for DBP formation testing:

- Incubation period of 24 ± 1 hours
- Incubation temperature of 20 ± 1.0°C
- Buffered pH of 8.0 ± 0.2
- 24-hour chlorine residual of 1.0 ± 0.4 mg/L.

8.4.5 Comparison DBP Testing

If the Statement of Performance Objectives involves comparison of DBP formation by the on-site halogen generation system to DBP formation by another disinfectant (i.e., chlorine), then comparison DBP testing (and DBP formation testing, if applicable) shall be conducted using the comparison disinfectant. For these comparisons, identical procedures for sampling, testing and analysis shall be performed for the DBP sampling with the on-site halogen generation system and alternative disinfectants.

8.5 Evaluation Criteria and Minimum Reporting Requirements

In the items below, "treated water" refers to the halogen-treated water sampled at the disinfection contactor effluent.

- General water quality
  - ⇒ Table of daily feed water and treated water levels of pH, temperature and turbidity during each testing period
  - ⇒ Table of weekly feed water and treated water levels of alkalinity and ammonia nitrogen during each testing period
  - ⇒ Table of feed water and treated water levels of TDS, iron, manganese, chloride, bromide and sodium during each testing period
  - ⇒ Table of twice daily disinfectant residuals during each testing period
- Organic water quality
  - ⇒ Table of weekly feed water and treated water levels of UVA and true color during each testing period
  - ⇒ Table of feed water and treated water levels of TOC during each testing period
- DBPs
  - ⇒ Table of instantaneous, and DBP formation testing if applicable (for treated water only), feed water (one sample) and treated water concentrations of TTHMs and HAAs monitored during each testing period, and other optional DBPs, such as HANs, chloropicrin, chloral hydrate and cyanogen chloride (if applicable)
  - ⇒ Table of instantaneous, and DBP formation testing if applicable (for treated water only), feed water (one sample) and treated water concentrations of bromate, chlorite and chlorate (if applicable) during each testing period
  - ⇒ If applicable, table comparing instantaneous (and DBP formation testing, if applicable) DBP concentrations of TTHMs and HAAs, and if applicable, other DBPs (e.g., HANs, chloropicrin, chloral hydrate and cyanogen chloride) produced in the treated water by the on-site halogen generation system and a comparison disinfectant (i.e., chlorine)
- Indigenous bacteria (Total Coliform and HPC)
  - ⇒ Table of feed water and treated water levels of Total Coliform bacteria (TC) and HPC bacteria during each testing period
  - ⇒ Table of TC and HPC $\log_{10}$ inactivation during each testing period

9.0 TASK 4: DATA MANAGEMENT

9.1 Introduction

The data management system used in the Verification Testing shall involve the use of computer spreadsheet software and manual (or on-line) recording of operational parameters for the on-site halogen generation equipment on a daily basis.

9.2 Experimental Objectives

The objectives of this task are: 1) to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable data for

verification purposes, and 2) to develop a statistical analysis of the data, as described in the "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies".

9.3 Work Plan

The following protocol has been developed for data handling and data verification by the FTO. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma-delimited file. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of water treatment equipment operation. Back-up of the computer databases to diskette should be performed following each testing period at a minimum. When SCADA systems are not available, direct instrument feed to data loggers and laptop computers shall be used when appropriate.

For parameters for which electronic data acquisition is not possible, field testing operators shall record data and calculations by hand in laboratory notebooks. Daily measurements shall be recorded on specially-prepared data log sheets as appropriate. Each notebook must be permanently bound with consecutively numbered pages. Each notebook must indicate the starting and ending dates that apply to entries in the logbook. All pages shall have appropriate headings to avoid entry omissions. All logbook entries must be made in black water-insoluble ink. All corrections in any notebook shall be made by placing one line through the erroneous information. Products such as "correction fluids" are never to be utilized for making corrections to notebook entries. Operating logs shall include a description of the water treatment equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items. The original notebooks shall be stored on site. This protocol will not only ease referencing the original data, but offer protection of the original record of results.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheets. Data entry shall be conducted on site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g., each test run) shall be assigned a run number that shall then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to the chosen laboratory(ies), the data shall be tracked by use of the same system of run numbers. The FTO may send samples to a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the EPA for analysis of water quality parameters. Data from the outside laboratories shall be received and reviewed by the field

testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

9.4 Statistical Analysis

Water quality developed from grab samples collected during test runs according to the Water Quality Sampling Schedule (Table 7) in Task 3 shall be analyzed for statistical uncertainty. For example, the FTO shall calculate the mean values, standard deviations and 95% confidence intervals for grab sample data obtained during the Verification Testing as described in the "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies" (Chapter 1). The mean values with 95% confidence intervals can then be used to compare the water quality results from tests conducted under different conditions of equipment operation or feed water quality. For comparisons between data from more than two testing periods, construction of an analysis of variance (ANOVA) table may be helpful in determining the statistical significance of differences between operational, microbial inactivation and treated water quality results. Statistical analysis such as that described above could be carried out for water quality data obtained under a large variety of testing conditions. The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals.

10.0 TASK 5: QUALITY ASSURANCE/QUALITY CONTROL

10.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the on-site halogen generation equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

10.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during testing. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

10.3 Work Plan

Equipment flow rates and associated signals shall be documented and recorded on a routine basis. A routine daily walk-through during testing shall be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters shall be checked to verify that the read-out matches with the actual measurement (i.e., flow rate) and that the signal being recorded is correct. The items listed below are in addition to any specified checks outlined in the analytical methods.

10.3.1 Daily QA/QC Verifications

These QA/QC verifications shall be conducted daily during testing:

- Chemical feed pump flow rates (verified volumetrically over a specific time period)
- Flow rates to in-line analytical equipment (e.g., pH meter, turbidimeter), if any (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench-top model.

10.3.2 QA/QC Verifications Performed Every Two Weeks

These verifications shall be conducted every two weeks:

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).
- In-line turbidimeters, if any, (clean out reservoirs and re-calibrate, if employed)

10.3.3 QA/QC Verifications To Be Performed For Each Testing Period

This verification shall be conducted before each testing period begins:

- Tubing (verify good condition of all tubing and connections; replace if necessary)

10.4 Analytical Methods and Sample Collection

The analytical methods utilized in this study for on-site monitoring, sample collection and testing of the quality of the feed water, concentrated halogen stream and halogen-treated water at the disinfection contactor influent and effluent are described below. Use of either bench-top or in-line analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it reduces the introduction of error and the variability to analytical results generated by inconsistent sampling techniques.

10.4.1 pH

Analyses for pH shall be performed according to *Standard Method* 4500-H+ or EPA Method 150.1/150.2. A three-point calibration of the pH meter used in this study shall be performed once a day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution, as defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

10.4.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Methods* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every $0.1^{o}C$, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of $-1^{o}C$ to $+51^{o}C$, subdivided in 0.1^{o} increments, would be appropriate for this work.)

10.4.3 True Color

True color shall be measured with a spectrophotometer at 455 nm, using an adaptation of the *Standard Methods* 2120 procedure. Samples shall be collected in clean plastic or glass bottles and analyzed as soon after collection as possible. If samples cannot be analyzed immediately they shall be stored at 4^{o}C for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C shall be used, and results should be expressed in terms of PtCo color units.

10.4.4 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Methods* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top turbidimeter may be used for measurement of the feedwater

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

10.4.4.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, the vial shall be allowed to warm up by partial submersion into a warm water bath for approximately 30 seconds.

10.4.4.2 In-line Turbidimeters. In-line turbidimeters are required for treated water monitoring during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow rate should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

10.4.5 Chlorine Residual

Because free chlorine in aqueous solutions is unstable, the free chlorine concentration in treated water samples will decrease rapidly. Exposure to sunlight or other strong light, or agitation, will accelerate free chlorine loss. Therefore, analysis of free and total chlorine samples shall begin immediately after sampling, and excessive light and agitation shall be avoided. Samples to be analyzed for free or total chlorine shall not be stored prior to analysis.

Glassware to be used for chlorine analyses shall be chlorine demand free. Chlorine demand free glassware will be prepared by soaking glassware in a 50 mg/L chlorine bath for a period of 24 hours. At the end of this time, all glassware will be rinsed three times with organic-free water that has a TOC concentration of less than 0.2 mg/L. Glassware will then be dried at room temperature for a period of 24 hours. During the drying process, bottle openings will be covered with aluminum foil to prevent contamination.

The method for collecting samples for chlorine analyses shall consist of the following procedure: running a slow, steady stream from the sample tap, triple-rinsing a chlorine demand free sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize agitation, performing the free and total chlorine analyses, and recording the measured chlorine concentrations.

10.4.6 Iodine Residual

Because iodine provides a more stable residual than chlorine and is less affected by environmental factors, glassware used for sampling is not required to be iodine demand free. Analysis of iodine samples shall begin as soon as possible after sampling. Samples to be analyzed for iodine shall not be stored prior to analysis. The method for collecting samples for iodine analysis shall be the same as that described above for chlorine residual, with the exceptions noted herein.

10.4.7 Chlorine Dioxide Residual

Similar to chlorine, chlorine dioxide in aqueous solutions is unstable. Exposure to sunlight or other strong light, or agitation, will accelerate chlorine dioxide loss. Therefore, analysis of chlorine dioxide samples shall begin immediately after sampling,

and excessive light and agitation shall be avoided. Samples to be analyzed for chlorine dioxide shall not be stored prior to analysis. Glassware for chlorine dioxide analyses shall be chlorine demand free, as described above in Section 10.4.5. The method for collecting samples for chlorine dioxide residual shall be identical to that described above for chlorine residual.

10.4.8 Bromine Residual

Bromine in aqueous solutions is even more unstable than chlorine. Exposure to sunlight or other strong light, or agitation, will accelerate bromine loss. Therefore, analysis of bromine samples shall begin immediately after sampling, and excessive light and agitation shall be avoided. Samples to be analyzed for bromine shall not be stored prior to analysis. Glassware for bromine analyses shall be chlorine demand free, as described above in Section 10.4.5. The method for collecting samples for bromine residual shall be identical to that described above for chlorine residual.

10.5 Chemical and Biological Samples Shipped Off-Site for Analyses

The analytical methods that shall be used during testing for chemical and biological samples that are shipped off-site for analyses are described in this section.

10.5.1 Organic Samples

Samples for analysis of total organic carbon (TOC) and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held and shipped in accordance with *Standard Method* 5010 B. Storage time before analysis shall be minimized, according to *Standard Methods*.

10.5.2 Microbial Samples: TC and HPC Bacteria, Other Bacteria, Viruses and Protozoa

Samples for analysis of any microbial parameter shall be collected in bottles supplied by the analytical laboratory. Microbiological samples shall be refrigerated at approximately 2 to 8°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately 2°C to 8°C during shipment. Samples shall be processed for analysis by the selected laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 2°C to 8°C until initiation of processing. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities shall be reported as colony forming units per mL (cfu/mL).

Methods for assessing the viability of the selected bacteria and viruses (see Table 6) shall be specified by the laboratory(ies) performing the analysis and shall be specified in the PSTP. The FTO may select a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA for analysis of microbial contaminants in water samples.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying objectives that an on-site halogen generation system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), Slifko et al. (1997) and others (see Section 12.0 References in this Test Plan). Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity.

10.5.3 Inorganic Samples

Inorganic chemical samples, including alkalinity, iron, sodium, and manganese, shall be collected and preserved in accordance with *Standard Method* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Methods* 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

10.5.4 Bromate

Samples for the analysis of bromate shall be collected in sampling containers supplied by the state-certified or third party- or EPA-accredited laboratory. Sample collection and storage requirements are outlined in EPA Method 300.1 or shall be provided by the laboratory conducting the analysis.

10.6 DBP Formation Test Protocol

The DBP formation test simulates full-scale disinfection by spiking a water sample with a disinfectant and holding the spiked sample in the dark at a designated temperature and contact time. The spiked water sample may be held at the uniform formation conditions (UFC) specified by the ICR Manual for Bench- and Pilot-Scale Treatment Studies as follows:

- Incubation period of 24 ± 1 hours
- Incubation temperature of 20 ± 1.0°C
- Buffered pH of 8.0 ± 0.2
- 24-hour chlorine residual of 1.0 ± 0.4 mg/L.

For this testing, one of two approaches may be employed, whichever is applicable:

1. If no additional dosing of halogens is used for residual disinfection subsequent to primary disinfection, the DBP formation test method shall be performed by collecting a sample of the treated water and holding the sample in the dark at the UFC.
2. If additional dosing of halogens is used for residual disinfection subsequent to primary disinfection, the DBP formation test method shall be performed by collecting a treated water sample, spiking it with an additional dose of disinfectant, and holding the sample in the dark at the UFC.

For either of the above approaches, as an alternative to utilizing the UFC, the conditions selected for DBP formation testing may be those that most closely approximate the residence time,

disinfectant type and disinfectant residual found in the distribution system at the location of the Verification Testing. These conditions shall be specified in the PSTP for approval by NSF.

For each DBP formation sample, three incubation bottles shall be set up. At the end of the incubation period, each sample shall be analyzed for the final disinfectant residual and the sample with the residual closest to the 1.0 ± 0.4 mg/L range shall be used for the specified DBP analyses.

All glassware used for preparation of the samples and reagents shall be chlorine demand free, as described above in Section 10.4.3.

The preparation of reagents and measurement of samples shall proceed as follows:

Preparation of Chlorine Stock Solution: The stock solution shall be prepared by adding an estimated volume of 6% reagent-grade NaOCl into a 500-mL, chlorine demand free bottle containing an estimated amount of organic-free water. To minimize the dilution error, the chlorine stock solution shall be at least 50 times stronger than the chlorine dose required.

Preparation of Other Halogen Disinfectant Stock Solution: For a halogen disinfectant other than chlorine, stock solution preparation shall be similar to that described above for chlorine stock solution. Organic free water shall be used for dilution and the stock solution shall be at least 50 times stronger than the halogen dose required.

Preparation of Additional Chemicals: Refer to *Standard Method* 4500-Cl F for the preparation method of DPD indicator, FAS standard and buffer solution.

Sample Collection and Incubation: The samples shall be collected in one liter amber bottles with Teflon lined caps. These bottles shall be stored in a temperature-controlled incubator at the specified temperature. Samples shall be adjusted to pH 8.0 ± 0.2 using 1 M HCl or NaOH and shall then be dosed with the appropriate dosage of chlorine (or other halogen disinfectant) to yield a chlorine (or other halogen disinfectant) residual of 1.0 ± 0.4 mg/L after the specified 24-hour storage period. The samples shall be capped head-space free and stored for 24 hours in the dark at the appropriate incubation temperature.

10.7 Health and Safety Measures

The FTO shall include in the PSTP specific instructions and description of the procedures that shall be used to ensure safe start-up, operation, sanitization and cleaning of the on-site halogen generation equipment during Verification Testing. In addition, the PSTP shall include information appropriate for inclusion in a Safety Plan. For example, a safety plan addressing health and safety measures shall address required actions in the event of equipment leaks, recommended organism handling procedures, requirements for protective personal equipment and bio-hazard signs etc. In summary, the following safety concerns shall be addressed by the FTO in the QA/QC plan applicable for the on-site generation equipment and verification testing procedures:

- Storage, handling and disposal of hazardous waste stream and chemicals including acids, bases, brine solutions, and oxidizing agents
- Storage, handling and disposal of biological waste streams

- Conformance with electrical code
- Chemical hazards and biohazards
- Need for spark-proof wires and/or National Electrical Code explosion-proof wiring
- Potential presence of explosive gases
- Ventilation of equipment, trailers (as applicable), or buildings (as applicable) if gases or chemicals generated by the equipment could present a safety hazard
- Emergency response procedures in case of equipment leaks or spillage of biological materials
- Requirement for personal protective equipment and emergency safety equipment.

11.0 OPERATION AND MAINTENANCE

The field testing organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria to be included in Operation and Maintenance (O&M) Manuals for equipment for on-site generation of halogen disinfectants for inactivation of microbiological contaminants. The FTO will report on the applicability of the manual in the development of a final report of the Verification Testing period.

11.1 Maintenance

The Manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves
- pressure gauges
- flow meters
- air compressors
- gas pressure vessels
- chemical feeder systems
- mixers
- motors
- instruments, such as turbidimeters, pH meters, halogen residual monitors
- water meters, if provided

The Manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- tanks and basins
- in-line static mixers
- tubing and hoses

11.2 Operation

The Manufacturer should provide readily interpretable recommendations for procedures related to proper operation of the equipment. In addition, the Manufacturer shall provide a schematic diagram that indicates the flow path of raw water, wastewater and disinfectant chemicals. Among the operating aspects that should be discussed are the following issues:

Disinfectant/Halogen Generation:
- control of feed flow to the on-site halogen generation system
- measurement of halogen concentration generated at a selected percent system output
- measurement of gas pressures (where applicable) generated during halogen generation during on-site system operation
- change in feed flow and halogen generation in response to temperature changes

Disinfectant Contact Time:
- control of feed flow to disinfectant contact basin
- adjustment of hydraulic detention time (i.e., volume if appropriate) in the contact basin
- control of halogen concentration dosed to the contact basin

Chemical Feeders (in the case that chemical pretreatment is applied):
- chemical feed pumps calibration check
- settings and adjustments -- how they should be made
- proper procedures for dilution of chemicals

Intermittent Operation:
- proper procedures for system shut-down and start-up of on-site generation system
- safety checks of halogen and gas concentrations prior to system shut-down
- safety checks of potential microbiological contaminant concentrations prior to system shut-down and start-up
- proper procedures for rinsing and disinfection of system following shut-down
- proper procedures for disinfection of system following spiking of microbiological contaminants

Monitoring and Sampling Procedures:
- observation of feed water quality or pretreated water turbidity
- observation of halogen generation efficiency as a function of feed water quality, flow rates and generation system output
- proper sampling procedures for spiking of microbiological contaminants
- proper safety and disinfection procedures following spiking with microbiological contaminants

The Manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:
- no raw water (feed water) flow to plant
- lack of feed water flow control through equipment
- valving configuration for direct feed flow and pretreated feed flow to system
- poor filtrate quality
- failed halogen generation safety test
- low pump feed pressure
- automatic operation (if provided) not functioning
- reduced rate of halogen generation at same percent system output
- machine will not start and “Power On” indicator off
- machine will not start and “Power On” indicator on
- pump cavitation

- valve stuck or won't operate
- no electric power
- no chemical feed
- no chemical feed to halogen generation system

11.3 Operability

The following are recommendations regarding operability aspects of systems that are designed to achieve inactivation of microbiological contaminants. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program.

During Verification Testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. Among the factors that should be considered are:

- Fluctuation of flow rates, halogen generation and pressures through unit, as well as the time interval at which flow control and adjustment of halogen production is needed
  - ⇒ Does on-site generation system (and any contact tanks provided) provide for variable hydraulic detention time and contact with disinfectant?
  - ⇒ How long can feed pumps and halogen generation equipment maintain target flow and contact time values?
  - ⇒ Is rate of feed water flow to on-site generation system measured?
  - ⇒ Does plant have facilities for pretreatment of feed water in the form of the following: pH adjustment, coagulant chemical feed, other?
  - ⇒ Can pretreatment chemical dosing (if applicable) be adjusted with changes in feed water flow?
- Presence of devices to aid the operator with adjustment of flow control, halogen generation, chemical dosage selection and system safety
  - ⇒ does rate of primary chemical feed change with flow of feed water or change in feed water quality (e.g., halogen demand)?
  - ⇒ are on-line halogen concentration monitors provided with on-site generation system?
  - ⇒ does remote notification to operator occur when a failure of on-site generation system occurs?
- Provision of on-line water quality monitors for feed water, concentrated halogen stream and halogen-treated water streams at the disinfection contactor influent and effluent
  - ⇒ are on-line turbidimeters provided on feed water stream?
  - ⇒ are on-line halogen residual monitors (e.g., chlorine monitors) provided on the halogen-treated water streams?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability and production should be dealt with in the portion of the reports that are written in response to Task 1 of the Verification Testing Plan.

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CHAPTER 4

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN FOR ULTRAVIOLET RADIATION TECHNOLOGIES FOR INACTIVATION OF MICROBIOLOGICAL CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing ultraviolet (UV) light for inactivation of microorganisms. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan (PSTP) for testing UV equipment, within the structure provided by the ETV Protocol entitled "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies". This Environmental Technology Verification (ETV) Testing Plan is applicable only to treatment systems that rely on UV light to effectively inactivate microorganisms. Systems may incorporate unique strategies for enhancing the effect of UV light on target organisms, such as by applying innovative lamp technologies. All UV technologies including their UV lamps. Reactors and Irradiance sensors may be tested under this plan.

In order to participate in the equipment verification process for inactivation by UV, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol as guidelines for the development of the Manufacturer's Product-Specific Test Plan (PSTP). Interim, non-standard methods for assessing the viability of cyst and oocyst after UV treatment may be used for verification. However, any interim method (see Appendix A) is subject to change and must have been reviewed by experts of cyst and oocyst viability.

Various types of water treatment equipment employ UV light for several water purification objectives, including removal of trace organic contaminants through advanced oxidation processes and microbiological disinfection (inactivation). This Test Plan is applicable to the testing of water treatment equipment utilizing UV light for inactivation of microorganisms in drinking water. Because particles and other dissolved UV light absorbing contaminants can interfere with UV light and reduce its disinfecting efficiency, this plan is applicable to the use of UV technology for treating high quality water (<10 Nephlometric Turbidity Units (NTU) turbidity and >70% transmittance at 1 cm are the minimum qualities recommended) sources, including

- treated surface water supplies of consistent high quality;
- groundwater supplies that are high in percent transmittance of filtered and unfiltered water or have been pre-treated to produce water of consistent high quality.

The performance of UV reactors can be impacted by several water quality parameters, such as turbidity, UV transmittance, hardness, alkalinity, iron, manganese, organics, and pH. Many of these parameters result in a loss of UV transmittance due to fouling of the quartz sleeves surrounding the lamps and therefore mainly impact long-term reactor performance and maintenance. Some of these parameters also impact UV transmittance, but there is no need to monitor the UV absorbance of individual compounds. Only the UV transmittance and turbidity of the water may directly impact inactivation performance during a microbial challenge study. Therefore, testing of the system should be performed using the worst conditions of UV transmittance and turbidity anticipated for the installation site.

2.0 INTRODUCTION

UV light currently is being used in place of chlorine for secondary wastewater disinfection in the eastern United States, and is gaining increased attention as a disinfectant for water reuse projects in California. UV technology also is used for drinking water applications in Europe for several reasons:

- It is a physical process that does not involve the addition of chemicals.
- It has been demonstrated to be a highly effective germicide.
- It employs very short contact time (seconds) in pressurized reactors making capital costs low and maintaining existing hydraulic gradients without the need for re-pumping.
- In numerous studies to date it has been shown to produce no disinfection by-products.

The typical sources of UV light are low pressure, mercury vapor arc lamps. These lamps produce approximately 90 percent of their total energy output at the germicidal wavelength of 253.7 nanometers (nm). Low pressure UV technology has been employed in wastewater treatment and some drinking water treatment applications for inactivation of certain bacteria and viruses. Conventional low pressure UV systems have not been found to be effective at killing cysts and oocysts of protozoa such as *Giardia* and *Cryptosporidium* at cost effective dosages. Other UV technologies (including medium pressure, high intensity, advanced, and pulsed) are being developed for the inactivation of more resistant microorganisms, such as protozoan cysts and oocysts. Little is known about which wavelength(s) result in the inactivation of the protozoan cysts and oocysts by high pressure, advanced and pulsed UV technologies. Nonetheless, this ETV Testing Plan is applicable to any UV technology.

3.0 GENERAL APPROACH

Testing of equipment covered by this Test Plan will be conducted by an NSF-qualified Field Testing Organization that is selected by the equipment Manufacturer. Water quality and microbiological analytical work to be carried out as a part of this Test Plan will be contracted with a laboratory certified by a state or accredited by a third party organization (i.e., NSF) or the U.S. Environmental Protection Agency (U.S. EPA) for the appropriate water quality parameters.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the required and optional tasks to be included in any UV inactivation Test Plan.

4.1 Initial Operations: Overview

The purpose of these tasks is to provide preliminary information that will facilitate final test design and data interpretation.

4.1.1 Task A: Characterization Of Feed Water

The objective of this recommended Initial Operations task is to obtain a chemical, biological and physical characterization of the feed water. A brief description of the watershed or aquifer and any pretreatment modules that provide the feed water shall be prepared, to aid in interpretation of feed water characterization.

4.1.2 Task B: Initial Tests Runs

During Initial Operations, the equipment Manufacturer may want to evaluate equipment operation and determine flow rates, hydraulic retention time, contact times (via tracer tests when technically feasible as many advanced UV systems have theoretically short retention times of 2 to 20 seconds), number of UV lamps, the spectral distribution of wavelength from the UV lamp or other factors which provide effective treatment of high quality water. This is a recommended Initial Operations task. The equipment Manufacturer may also want to work with the Testing Organization and analytical laboratory to perform blank or preliminary challenges and sampling routines to verify that sampling equipment can perform its required functions including laboratory studies of UV irradiance and microorganism viability. This is also a recommended Initial Operations Task.

4.2 Verification Operations: Overview

The objective of this task is to operate the treatment equipment provided by the equipment Manufacturer and to assess its ability to meet stated water quality goals and any other performance characteristics specified by the Manufacturer. A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's objectives, such as in the treatment of surface water where additional testing during each season may assist in verifying an objective. The time period selected for testing should represent the worst-case for concentrations of contaminants e.g., dissolved solids which interfere with UV, or potentially can foul a UV lamp or sensor e.g., iron, nitrates.

4.2.1 Task 1: Verification Testing Runs and Routine Equipment Operation

To characterize the technology in terms of efficiency and reliability, water treatment equipment that includes UV lamp, reactor and sensor for measuring UV Irradiance shall be operated for Verification Testing purposes with the operational parameters based on the results of the Initial Operations testing.

4.2.2 Task 2: Feed Water and Finished Water Quality

During each day of Verification Testing, feed water and treated water samples shall be collected, and analyzed for parameters relevant to microbial enumeration or those affecting equipment performance, as outlined in Section 10.0, Table 1.

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

During each day of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. This includes UV Irradiance, lamp and sensor fouling and cleaning applied and frequency, water flow (rate [g.p.m.] and total flow), power usage, stability of power supply (surges, brown-outs, etc.).

4.2.4 Task 4: Microbial Inactivation

The objective of this task is to measure the performance of the UV drinking water treatment equipment that includes the UV lamp and reactor, in inactivating microbiological contaminants during Verification Testing.

4.2.5 Task 5: Data Management

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the Field Testing Organization (FTO) and the NSF for data obtained during the Verification Testing. Prior to the beginning of field testing, the database design must be developed by the Field Testing Organization and reviewed and approved by NSF. This will insure that the required data will be collected during the testing, and that it can be effectively transmitted to NSF for review.

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

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during UV radiation equipment Verification Testing. Prior to the beginning of field testing, a QA/QC plan must be developed which addresses all aspects of the testing process. Each water quality parameter and operational parameter must have appropriate QA and QC measures in place and documented. For example, the protocol for pH measurement should describe how the pH meter is calibrated (frequency, pH values), what adjustments are made, and provide a permanent record of all calibrations and maintenance for that instrument.

5.0 TESTING PERIODS

The required tasks in the Verification Testing Plan (Tasks 1 through 6 except Task 4 when water treatment equipment is being used to deliver potable water at the test site; see section 9 Routine Equipment Operation) are designed to be carried out for a minimum of one verification testing period. Additional verification testing periods may be necessary to verify the manufacturer's objectives, such as in the treatment of surface water where additional testing during each season may assist in verifying a performance objective. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment (<10 NTU turbidity and >70% transmittance), one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants

which can verify the manufacturer's objectives. For example dissolved solids which interfere with UV, or potentially can foul a UV lamp or sensor (e.g., iron, nitrates). Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during Verification Testing periods of a minimum of 320 hours (13 full days plus one 8-hour shift). Only Task 3 shall be conducted during a 27-day period. The purpose of the 27 day test period is to assess operation and maintenance items associated with the equipment, such as the build up of potential scale or other contaminants on the surface of UV lamps and UV irradiance sensors.

6.0 DEFINITION OF OPERATIONAL PARAMETERS

Definitions that apply to UV processes are given below:

6.1 UV Output

The amount of power (in the wavelength range of 200-300 nm) delivered from the lamp to the water and described in terms of watts (W) per lamp. The absolute free-standing UV power of the lamp is decreased by end losses and by transmission losses through the quartz sleeve. The UV output can be reduced because of lamp aging, water temperature, and lamp fouling (as defined in Section 6.7).

6.2 UV Irradiance

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 ($\mu W/cm^2$) or milliwatts per square centimeter (mW/cm^2).

6.3 UV Dose

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

Dose (μW sec/cm^2) = UV Irradiance ($\mu W/cm^2$) x Time (seconds) or
Dose (mW sec/cm^2) = UV Irradiance (mW/cm^2) x Time (seconds) or
Dose (mJ/cm^2) = UV Irradiance (mW/cm^2) x Time (seconds)

6.4 UV Transmittance

The ability of the 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_0) 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: $\%T = 100 \times 10^{-(A/L)}$. Many naturally occurring organic and inorganic constituents (e.g., natural organic matter, iron, nitrate) will absorb energy in the UV

wavelengths, thus reducing the transmittance of the water. This reduced transmittance often interferes with the disinfection efficiency of a UV disinfection system.

6.5 Low Pressure Lamps

Low pressure lamps operate at a temperature between 38 and 49°C (100 and 120°F) to produce a near monochromatic radiation at 253.7 nm. These lamps typically have a linear power density of about 0.3 W/cm.

6.6 Medium Pressure Lamps

Medium pressure lamps produce a high intensity broad spectrum of UV light (extending over the 200-300 nm range of microbiological sensitivity with a maximum output at about 255 nm) with a higher Irradiance and operating at a much higher operating temperature (surface temperatures >500°C) than do low pressure Hg lamps. The linear power density is also much higher (typically 100-300 W/cm).

6.7 Lamp Fouling

If the lamps are submerged in the feedwater, lamp fouling may occur. Lamp fouling is the reduction in UV Irradiance caused by the presence of certain organic and inorganic ions in the water that can result in the accumulation of mineral deposits or biofilm on the quartz sleeves covering the lamps. Chemical or mechanical cleaning is needed to restore the UV Irradiance to design conditions.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

This Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the water treatment equipment to be tested.

7.2 Objectives

The objective of this task is to obtain a complete chemical, biological and physical characterization of the source water or the feed water as pre-treated that will be entering the treatment system being tested.

7.3 Work Plan

The specific parameters needed to characterize the water will depend on the equipment being tested and the source water feeding the UV drinking water treatment equipment. During this Initial Operations task, the feed water to the UV drinking water treatment systems, the following characteristics should be measured and recorded:

- Water Temperature, Turbidity, UV_{254} absorbance and filtered and unfiltered transmittance (and/or absorbance measurements at other wavelengths that are appropriate to the UV

disinfection system being tested), Free and Total Chlorine, Total Organic Carbon, and Color.
- Total Coliform (for a treated water source) or Heterotrophic Plate Count (HPC) (for an untreated water source)
- Aerobic spores, and Algae.
- Total Alkalinity, pH, Calcium, Hardness, Nitrate, aluminum and Iron.

Section 9 of this document provides a list of characteristics that shall be measured and recorded depending on the source of feed water to the UV equipment and should be used as a guideline for Initial Operations.

Sufficient information shall be obtained to illustrate the variations expected to occur in these parameters that will be measured during the Verification Testing for a typical annual cycle for the water source. This information will be compiled and shared with NSF so NSF and the Testing Organization can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

A brief description of the watershed or aquifer source shall be provided, to aid in interpretation of feed water characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activity that take place (i.e. mining, manufacturing, cities or towns, farming) with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source, such as stream, river, lake or man-made reservoir, should be described as well. Aquifer description should include the above characterization relative to the recharge zone, a description of the hydrogeology of the water bearing stratum(a), well-boring data, and any Microscopic Particulate Analysis data indicating whether the groundwater is under the influence of surface waters.

Any pretreatment modules impacting the source water shall be characterized. Any coagulant or other chemical additions shall be identified. Predicted effects on turbidity and particle load by pre-filtration shall be discussed.

7.4 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of the equipment performance objectives but should not be beyond the range of water quality suitable for treatment for the equipment in question. If the device is to be used for treating high quality ground waters or those surface water sources that have already received full or partial treatment, it should be tested on waters of that quality.

8.0 TASK B: INITIAL OPERATIONS

8.1 Introduction

During Initial Operations, a Manufacturer may want to evaluate equipment operations and determine the flow rates, hydraulic residence time, pulse rates, exposure times, number and/or Irradiance of UV lamps, the spectral distribution of wavelength from the UV lamp, degree of power supply/line conditioning required, or other factors applicable to the technology which provide effective treatment of the feed water. The Manufacturer may also want to work with the Testing Organization and the analytical laboratory to perform blank or preliminary challenges and sampling routines to verify that sampling equipment can perform their required functions under normal operating conditions. This information may also indicate operating conditions under which the Manufacturer's stated performance objectives are not met, or whether any threshold UV dose level can be determined. This is a recommended Initial Operations task. An NSF field inspection of equipment operations and sampling and field analysis procedures may be carried out during the initial test runs.

The "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies" (Chapter 1) under which this test plan is formulated requires hydraulic testing to demonstrate flow conditions and residence duration (exposure time). The equipment Manufacturer may want to conduct such tests during these initial runs. Additional tracer tests are required if a system is hydraulically dissimilar to that tested for the Protocol is utilized, or if testing is to proceed at flow rates and conditions other than those demonstrated previously. Procedures for developing a tracer test methodology are described in the Protocol.

8.2 Objectives

The objective of these test runs is to bracket the proper operating parameters for treatment of the feed water during Verification Testing. UV performance may be different for feed waters from different test sites or for the feed water from the same site during different seasons. Therefore, conducting initial test runs is strongly recommended.

8.3 Work Plan

Conducting UV exposure tests on small batches (cuvettes) of feed water containing test organism can be a rapid method of roughly evaluating equipment performance and of bracketing effective UV dosages. Where batch testing cannot be applied to a particular system, scaled back or full-scale initial tests may be designed. Follow-up confirmation of initial batch testing by preliminary scaled back continuous flow tests is recommended. Continuous flow testing is required during verification testing unless the manufacturer's performance objectives also specifies use during intermittent flow or use as typical for very small community systems (<500 persons). The work plan should then include a shut down period of 12 hours each day where the UV equipment is turned off.

8.4 Analytical Schedule

Because these runs are being conducted to define operating conditions for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during Verification Testing would be wise, however, so the operator can gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the Initial Operations phase, the verification organization may conduct an initial on-site inspection of field operations, sampling activities and on-site analysis. The sampling and analysis schedule for Verification Testing shall be followed during the on-site inspection.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance objectives. If the performance was not as good as the statement of performance objectives, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program.

9.0 TASK 1: VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

9.1 Introduction

Water treatment equipment that includes UV lamp, reactor and sensor for measuring the UV light Irradiance shall be operated for Verification Testing purposes with the operational parameters based on the manufacturer's statement of performance objectives.

9.2 Experimental Objectives

The objective of this task is to characterize the technology in terms of efficiency and reliability while operating under the conditions established during the Initial Operations testing. These conditions must represent the operating conditions for which the unit was designed. For example, if the unit is designed to operate at several hundred g.p.m., the testing must be done using flow rates which approximate these conditions. However, if the unit has a family of similar units that differ only in size and the Manufacturer demonstrates with tracer data, calculations, computation, fluid dynamic models, etc., that a smaller unit has the same hydraulic behavior and irradiance distribution as the larger unit, then testing may proceed with the smallest size unit. The experimental protocol must be designed so as to assess the unit adequately when operating under its design conditions.

9.3 Work Plan

9.3.1 Verification Testing Runs

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial

Operations. Performance and reliability of the equipment shall be tested during Verification Testing periods of a minimum of 320 hours (13 full days plus one 8-hour shift). Only Task 3 shall be conducted during a 27 day period. The purpose of the 27 day test period is to assess the build up of potential scale or other contaminants on the surface of UV lamps and UV Irradiance sensors. During each testing run, Tasks 1 through 5 shall be conducted simultaneously.

Seasonal testing may be required for equipment treating surface waters because of the differences in water quality that occur on a seasonal basis, although pre-treatment modules, when present, may damp these variations. For UV treatment equipment, factors that can influence treatment performance include:

- High turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snow melt. Particulate load may absorb or interfere with UV radiation.
- Algae, which may exhibit bloom on a seasonal basis. Algae absorb and interfere with UV radiation.
- Natural organic matter, which may be higher in some waters in the fall. Organic matter may absorb UV radiation, and may contribute to fouling of the lamp surfaces.
- Iron, nitrate, pH, alkalinity and hardness, which may vary seasonally for some waters. These parameters may cause or contribute to fouling of the lamp surfaces or may absorb UV radiation.
- Aluminum from alum coagulation treatment of surface water, hardness from lime softening, may contribute to fouling of the lamp surfaces.

It is unlikely that all of the above problems would occur in surface water during a single season, and this may result in testing during each season of the year and possibly at different test sites. The testing should be designed to test the UV unit when the water quality to that unit changes, either because the unit is operated without pre-treatment or because the pre-treatment produces a different quality water which is presented to the UV unit.

9.3.2 Routine Equipment Operation

If the water treatment equipment is being used for production of potable water, in the time intervals between verification runs, routine operation for water production is anticipated. In this situation, the operating and water quality data collected and furnished to the Safe Drinking Water Act (SDWA) primacy agency shall be supplied to the NSF-qualified testing organization.

9.4 Schedule

During Verification Testing, water treatment equipment shall be operated continuously for a minimum of 320 hours (13 full days plus one 8-hour work shift) with interruptions in operation as needed for system maintenance.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for the 320 hour period, including time for lamp changing and other necessary operating activities, during Verification Testing. Data shall be provided to substantiate the operation for 320 hours or more.

10.0 TASK 2: TEST RUNS FOR FEED WATER AND FINISHED WATER QUALITY

10.1 Introduction

Water quality data shall be collected for the feed water and treated water as shown in Table 1 depending upon the source of feed water (see 10.1.1- 10.1.3), during each day of Verification Testing. The Field Test Organization on behalf of the equipment Manufacturer shall assure the sampling or measuring of the water quality parameters in Table 1 depending upon the source of feed water (see 10.1.1-10.1.3). A Field Testing Organization may use local personnel to assist in collection of samples or measurement of test parameters, but is responsible for their training to assure proper technique. Water quality goals and target inactivation goals for the water treatment equipment shall be recorded in the Product-Specific Test Plan in the statement of objectives.

10.1.1 Untreated Surface Water as Feed Water:

For UV drinking water treatment systems that treat raw or filtered only surface water, the parameters in Table 1 shall be measured and recorded, except free and total chlorine and aluminum as these parameters will not likely occur in raw water (they will likely occur or be added during chemical treatment).

10.1.2 Treated Surface Water as Feed Water:

For UV drinking water treatment systems that treat feed water from consistently and previously treated (lime softening, chemical coagulation etc. but not solely filtration) surface water, the parameters in Table 1 shall be measured and recorded, except algae, total coliform and endospores as previous treatment will likely have removed these contaminants.

10.1.3 Ground Water as Feed Water

For UV drinking water treatment systems that treat ground water, the parameters in Table 1 shall be measured and recorded, except color, algae and endospores as they will not likely occur in ground water, and free and total chlorine and aluminum which are not typically added during chemical treatment of ground water. HPC is also not required for a ground water source.

Table 1. Water Quality Sampling and Measurement Schedule

Parameter:	**Frequency:**
Temperature	Daily
pH	Daily
Total Alkalinity	Semi-weekly
Hardness	Semi-weekly
Total Organic Carbon	Semi-weekly
UV Absorbance (254 and/or other nm)	Semi-weekly
Turbidity	Daily at bench to check continuous Turbidimeters
Algae, number and species	Semi-weekly if no algae bloom. Daily if algae bloom occurs.
True Color	Semi-weekly
Nitrate	Semi-weekly
Iron, Manganese and Aluminum	Semi-weekly
Bacteria and viruses	Daily specified in objectives statement and Total Coliform or HPC or *Bacillus* spores
Free and Total Chlorine	Daily

10.2 Experimental Objectives

For verification testing of inactivation of naturally existing microorganisms this task will allow determination of mean concentrations of organisms and their variability in the feed water. A list of a minimum number of additional water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 1. The actual water quality parameters selected for testing shall be stipulated by the Manufacturer in the Product-Specific Test Plan and shall include all those necessary to permit verification of the statement of performance objectives.

10.3 Work Plan

The manufacturer will be responsible for establishing the plant testing operating parameters, on the basis of the Initial Operations testing. Many of the water quality parameters described in this task will be measured on-site by the NSF-qualified Field Testing Organization or by local community personnel properly trained by the Field Testing Organization (refer to Table 2). Analysis of the remaining water quality parameters will be performed by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e., NSF), or the U.S. EPA. The methods to be used for measurement of water quality parameters in the field are listed in the Analytical Methods section below in Table 2. The analytical methods utilized in this study for on-site monitoring of feed water and filtered water qualities are described in Task 6, Quality

Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

Table 2: Analytical Methods

Parameter	**Facility**	***Standard Methods* and Other Method References**	**EPA Methods**
Temperature	On-site	2550 B	
pH	On-site	4500 H+ B	150.1/150.2
Total Alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total Organic Carbon	Lab	5310 C	
UV Absorbance (254 and/or other nm)	Lab	5910 B	
Turbidity	On-site	2130 B	180.1
Algae, number species	Lab	10200 and 10900	
True Color	Lab or On-site	2120 B (Hach Co. modification of *SM* 2120 measured at 455 nm)	
Total Coliform	Lab	9221 / 9222 / 9223	
Heterotrophic Plate Count	Lab	9215 B	
E. coli	Lab	9225 or Colilert	
Micrococcus luteus	Lab	AWWARF Surrogate Report by CSU	
Bacillus spores	Lab	Rice et al. 1996	
MS2 Virus	Lab	EPA ICR Method for Coliphage Assay, 1996 or 9224 F	
Algae	Lab	AWWARF Surrogate Report by CSU	
Giardia and *Cryptosporidium*	Lab	EPA Draft 1622, (enumeration only)	
Iron	Lab	3120 B, 3111 B, 3113 B	200.7, 200.9
Manganese	Lab	3120 B, 3111 B, 3113 B	200.7, 200.8, 200.9
Aluminum	Lab	3120 B, 3111 D, 3113 B	200.7, 200.8, 200.9
Nitrate	Lab	4110 B, 4500-No_3-F, 4500-No_3-D, 4500-No_3-E	300.0, 353.2
Free and Total Chlorine	On-site	Hach modification of *SM* 4500 CL:G	

10.4 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of testing, as noted in this section. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined by the Field Testing Organization in the Product-Specific Test Plan.

In the case of water quality samples that will be shipped to the off-site laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory. Original field sheets and chain-of-custody forms shall accompany all samples shipped to the analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples shall be provided to NSF.

10.5 Analytical Schedule

During Verification Testing of UV treatment equipment, the feed water and treated water quality shall be characterized by measurement of the water quality parameters listed above in the Table with the exceptions allowed under sections 10.1.1 - 10.1.3. These parameters are listed to provide verification report readers with background data on the quality of the feed water being treated and the quality of the treated water. These data are to be collected to enhance the acceptability to the Verification Testing data to a wide range of drinking water regulatory agencies.

10.6 Evaluation Criteria

Evaluation of water quality in this task is related to general water quality capabilities indicated by the Manufacturer.

11.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

Task 3 shall be conducted over a minimum 27 day period. During each day of the testing period operating conditions shall be documented. This shall include descriptions of pretreatment chemistry and filtration for the equipment processes used, if any, and their operating conditions. The performance of the UV disinfection equipment shall be documented, including total water throughput and total power usage, UV Irradiance as measured by the manufacturer's UV irradiance sensor, hours of lamp operation, lamp sensor output and its decrease in output over time, frequency of pulsing or length of cycles, if applicable, lamp fouling rates, frequency and type of mechanical cleaning and performance of automatic mechanical wipers or ultrasonic cleaners, if present. In addition, the power supply shall be tracked and spikes and brownout events shall be noted.

The measurement of true UV dose will not be measured as part of the equipment operating performance. The hydraulics and UV irradiance distribution vary greatly and would confound the UV dose calculation. UV irradiance measurements shall be measured for low pressure UV lamp equipment. For equipment using other UV technology, the operating conditions and equipment performance shall be monitored using the sensor provided with the UV system (lamp, sensor and reactor). Any change in reactor design, source of lamp or UV irradiance sensor constitutes a change in the UV system and repeat testing shall be required.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

11.3 Work Plan

During each day of Verification Testing, treatment equipment operating parameters for both pretreatment and UV radiation will be monitored and recorded on a routine basis. This shall include a complete description of pretreatment chemistry; rate of flow and total flow; and UV irradiance as measured by the manufacturer's UV irradiance sensor. Calibration of lamp irradiance sensors shall be demonstrated and recorded. Electrical energy consumed by the UV treatment equipment shall be measured and recorded. In addition, the aggregate horsepower of all motors and mechanical efficiencies of all motor/devices supplied with the equipment shall be determined and used to develop an estimate of the maximum power requirements and routine power consumption during operation. A complete description of each process shall be given, with data on volume and detention time of each process stream at rated flow.

An automatic device for monitoring UV irradiance is strongly suggested with any UV system. The testing plan should include a determination of the minimum irradiance below which equipment shutoff should occur to assure adequate disinfection at all times. 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.

11.4 Schedule

Table 3 presents the schedule for observing and recording UV equipment operating and performance data.

Table 3: Equipment Operating Data

OPERATIONS PARAMETER	ACTION
Flow Rate	Check and record each 2 hours. Adjust when 10% above or below target. Record both before and after adjustment.
Exposure Time*	Record retention or cycle times when applicable. If variable, record degree of variation.
UV Irradiance	Check and record each 2 hours.
UV Sensor	Record out put from in-line monitor. Record changes in lamp irradiance following each cleaning
Lamp Fouling/Cleaning system	Record frequency of sleeve cleaning, if applicable
Lamp Hours	Record Daily
Electric Power	Record meter reading daily
Lamp Cycles	Record frequency of lamp on/off cycles
* Recording of exposure time is required for systems where exposure is independent of hydraulics or UV pulse rate. For others, exposure time will have been determined in preliminary tracer testing by other means for UV systems which have short hydraulic retention times and will not vary during operation.	

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance objectives. If no relevant statement of performance objectives exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

12.0 TASK 4: DOCUMENTATION OF EQUIPMENT PERFORMANCE INACTIVATION OF MICROORGANISMS

12.1 Introduction

Inactivation of microorganisms is the primary purpose of UV drinking water treatment modules. Consequently, the effectiveness of the equipment at inactivating microorganisms introduced by seeding the feed water with bacteria, viruses or protozoa or with a combination of those or other approved types of microorganisms will be evaluated in this task. When the naturally occurring concentration of the microorganism in the feed water at a test site or where an UV water treatment is delivering potable water, is sufficient to challenge the manufacturer's performance objectives, no challenge test or seeding study is necessary. The measurement of inactivation is a comparison of the percent of viable organisms in the feed stream with the percent of viable organisms in the effluent.

12.2 Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer and to characterize the technology in terms of efficacy at inactivation of microbial organisms. Challenge organisms to be tested will be selected by the equipment Manufacturer.

12.3 Work Plan

12.3.1 Microbial Challenge Tests

Microbial challenge experiments shall be conducted at full scale and not with pilot or prototype equipment. The Field Testing Organization shall conduct the challenge studies in the field, and the Field Testing Organization shall submit the resulting samples to a laboratory that is certified, accredited or approved by a State, a third-party organization, or the U.S. EPA.

For cysts and oocysts only, the microbial challenge testing of each operating condition must be performed a minimum of three times in order to achieve a statistical measure of the precision of the performance. A minimum of three conditions are to be tested (i.e. system off – no organisms, system off – seeded organisms added, and system on at optimal setting – seeded organisms added) requiring a total of nine challenge tests corresponding to three replicate challenge experiments at each of the three test conditions. The optimal setting can be specified by the manufacturer and should be supported by the results from the Initial Operations (Section 5). A fourth condition representing a sub-optimal UV dose setting can also be performed, but it is not required. This sub-optimal UV dose condition may be achieved by increasing the flow through the reactor to decrease hydraulic retention time or decreasing the power to the UV lamp, resulting in reduced irradiance of the water.

12.3.1.1 Organisms Employed for Challenge Experiments. Microorganisms which may be used for inactivation studies are listed below. These species represent microorganisms of particular interest and concern to the drinking water industry, and represent a range of resistance to inactivation methods. The specific batch(es) used must be shown to be viable by the laboratory involved in the analytical aspects of the testing.

Bacteria	*Bacillus subtilis*	*Pseudomonas* spp.
	Clostridium perfringens	*E. coli*
Virus	MS2 bacteriophage (surrogate)	

12.3.1.2 Spiking Protocols. The total number of each type of test organism required for spiking will depend on the reactor volume, the water flow rate, and the desired steady-state concentration of microbiological contaminants in the reactor. For viruses, a steady-state final concentration adequate to show 4-log removal against the effluent analyses detection limit is necessary. The total number of organisms required to provide these steady-state microbiological populations will depend on the overall volume of the disinfection contractor, the detection limits of the sampling and analytical methods and the duration of experiments. For all organisms, the laboratory(ies) supplying the

organisms and performing the viability studies shall be experienced in challenge testing and be able to predict initial dosages required to overcome any inherent experimental losses. Microbial challenges shall be conducted either by batch seeding or by feed stream injection. For evaluation of inactivation of *Giardia*, bacteria species, virus, or any other organisms negatively affected by chlorine, dechlorination will be required. Any system based on synergistic effects of chlorine and UV will not require dechlorination. Evaluation of *Cryptosporidium* inactivation will not require removal of chlorine when present in concentrations typical of drinking water (<5 mg/L).

12.3.1.3 Batch Seeding. A batch feed tank with sufficient volume to provide the proposed test volume shall be used. The discharge of the tank shall be situated so that 100% of the contents can be delivered to the system. The tank shall be filled with feed water which shall be dechlorinated, if necessary. Stirring of the feed water shall accompany dechlorination. Verification of dechlorination shall precede introduction of the seed organisms. Stirring of the feed tank shall precede seeding and continue throughout testing. Prior to microbial seeding of the tank, agitation procedures of the bulk seed container (as received from the supplier) such as vortexing and sonication shall be employed to assure organisms are not clumped together. A secondary source of feed water (dechlorinated, if necessary) sufficient to provide 3 retention time-equivalents (as determined by tracer tests or as defined by system functions) shall be available to add to the tank on its depletion. The purpose of this feed water will be to continue flushing seeded organisms through the system to the effluent sample ports.

12.3.1.4 In-line Injection. The feed to the test unit will be plumbed with a check-valve equipped injection port. If the feed stream is divided to parallel treatment units, mixing chamber shall be plumbed downstream of the injection port. A one Liter carboy equipped with a bottom dispensing port will feed this injection port by means of a metering pump (diaphragm or peristaltic or equivalent) via siliconized or Teflon tubing. The pump shall be capable of fluid injection into the pressurized system feed line for the duration of the test, at a measurable and verifiable rate such that the one liter carboy is depleted coincident with the end of the test run. If dechlorination is necessary (see discussion, section 12.3.2.2), a chemical injection pump feeding a port and adequate contact mixing will be required upstream of the microorganism injection port. This pump will meter in a solution of sodium thiosulfate adequate to dechlorinate the feed water over the course of the test run.

The spike carboy will contain a magnetic stir bar and will be filled with one Liter of system water (dechlorinated if necessary) and placed on a stir plate. The prepared batch of spike organisms shall be agitated by methods such as vortexing and sonication and added to the stirring carboy. Once appropriate flow has been initiated through the test system, the test unit is operating properly, sample collection systems are readied, and complete dechlorination (<0.05 mg/L) has been verified at both the influent and effluent sample sites, the injection pump can be started. During the course of the test run, monitoring of the system flow rate and spike injection rate shall be performed and adjustments made to maintain test design.

12.3.2 Test Operation and Sample Collection

12.3.2.1 Test Stream Sampling. Sample ports shall be provided for the feed water stream (spiked with concentrations of microbiological contaminants) and the UV-treated water stream at the contactor effluent. The FTO shall specify the specific ways in which sample collection is performed according to the organisms that will be used for the proposed microbiological inactivation experiments. Examples of potential sample collection methods for bacterial, viral and protozoan organisms are provided below. The methods described, or any other peer-reviewed method may be used for verification testing. The FTO shall propose in the PSTP the specific methods that are to be used for viability assessment of the selected microorganisms (See Section 12.4 below).

For bacterial and/or viral seeding experiments, methods for organism spiking and sample collection shall be consistent with a selected peer-reviewed method. The frequency and number of samples collected for each sampling point will be determined by the length of the test run and shall be specified by the FTO in the PSTP. The volume of each UV-treated water sample from the disinfection contactor effluent will depend on the concentrations of test organisms spiked, and the requirements of the analytical laboratory.

For protozoan spiking experiments, EPA Method 1622 or any other method that has been evaluated through the peer-reviewed process (e.g., Nieminski and Ongerth, 1995) may be followed for sample collection from the spiked water streams. The sample collection system shall be plumbed to allow installation of housings and filters for capture of sufficient flow for microbiological analysis. The FTO shall provide an indication of the recovery efficiency achievable under the sample collection method selected for use during protozoa seeding studies. The specific capture filter recovery system shall be fully described in the PSTP by the FTO. In addition, the PSTP shall include a plan of study for verification testing with a minimum of three standard recovery efficiency tests from the microbiological laboratory.

The sample tap(s) shall be sanitized with 95% ethanol one minute prior to initiating any bacteria or virus sample collection. Taps shall be flowing at the appropriate sample rate for at least one minute prior to sample collection.

12.3.2.2 Chlorine Residual Analysis. When dechlorinating, residual samples of the feed water shall be collected immediately after the grab samples or at regular intervals throughout the test run. These samples shall be analyzed for chlorine residual immediately. In *Giardia*, bacteria and virus inactivation tests where chlorine would affect test organisms and synergistic UV/chlorine effects are not being evaluated, any sample showing >0.05 mg/L residual will void the entire spike test.

12.3.2.3 Post-Test Sample Handling.. Filters shall then be handled and prepared for delivery to the analytical laboratory as directed by that laboratory. The Testing Organization shall then take steps to contain and/or sanitize any organisms remaining in the system. Depending on the unit (design and materials), sanitization may be done using steam or hot water (80ºC for 10 min). The QA/QC plan should address how this sanitization procedure is to be done to insure inactivation of live organisms and

subsequent removal of inactivated organisms from the unit, and biosafety concerns for both humans and the environment.

12.3.3 Experimental Quality Control

12.3.3.1 Process Control. Positive control samples will be obtained by performing a second round of testing identical to the above (12.3.1-12.3.2.3), with the UV lights turned off. The purpose of this testing is to evaluate any cumulative effects of the equipment stream, spiking and sampling processes, and sample handling on organism viability. This testing shall not occur until elimination of sanitizing agents and inactivated target organisms, whose presence could affect subsequent tests of the unit, has been demonstrated (12.3.2.4). The positive process control samples should show minimal inactivation of the target organism(s) relative to the trip control sample. Significant inactivation of the process control sample indicates that some aspect of the process other than UV contributes to inactivation of the test organism(s), and re-testing is required. Negative control samples must also be obtained by performing a third round of testing identical to the above (12.3.1-12.3.2.3), without addition of microorganisms and with the UV lights turned off. The purpose of this testing is to evaluate whether there is any natural background occurrence of the test organism and that steady-state conditions have been achieved and there is insignificant carry-over from one test sample to the next.

Trip Control. For tests utilizing spike challenges, a replicate or subsample of the spike dose shall accompany the actual spike dose from the analytical laboratory, including all preliminary processes of dose preparation pre-enumeration, shipping, and preparation for spiking, through return to the laboratory for collimated beam UV dose-response assessment. The trip control samples should show minimal inactivation of the target organism(s). Significant inactivation of the trip control sample indicates that some aspect of the handling, from preparation to testing, contributed to inactivation of the test organism(s). Significant inactivation of trip control samples will require re-testing.

12.4 Microbiological Viability Analysis

Methods for assessing the viability of the selected bacteria and viruses (see Section 12.3.1.1) shall be specified by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA for the appropriate microbial analyses. Selected viability methods shall be specified by the FTO in the PSTP.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying claims that an UV system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), Slifko et al. (1997) and others (see Section 16.0 References in this Test Plan). Interim, non-standard methods for assessing the viability of cyst and oocyst (e.g., excystation, DAPI/PI) may be used for verification of inactivation after exposure to UV. However, any interim organism viability method is subject to review by experts of cyst and oocyst viability and subsequent method change. Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity. Microbial viability analyses are further discussed in

Section 4.4 of the "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation of Microbiological Contaminants: Requirements For All Studies."

12.4.2 Assessment of Microbial Inactivation

Many different sources of variability can impact the estimation of the log inactivation achieved during microorganism challenge studies. To minimize the impact of these sources, it is imperative that all components of the challenge tests be performed on the same day with one batch of seeding organisms and that all collected samples be shipped and analyzed as a single batch. This will then eliminate the need to propagate sources of error arising from seed stock variability, changes in shift personnel, differences in shipping conditions, or assay techniques. Maintaining this type of control over microbial sources of error coupled with careful flow control during the seeding process will eliminate the need for a detailed propagation of error analysis. Instead, the average log inactivation measured for the reactor during the seeding process only needs to be adjusted for any microbial inactivation observed for the positive control or the trip blank as a simple subtraction.

Specific details of the quality control steps to take to insure the integrity of the seeding studies is described below:

(1)Verification Seed Stock Integrity:

To demonstrate that significant inactivation of the seed stock sample has not occurred during the challenge study, a t-test should be performed to compare the averages of the concentration of the stock solution retained in the laboratory with the stock solution comprising the trip blank. The assays for the two stocks should be performed as a single experiment to eliminate uncontrollable sources of experimental variability. The t-test should demonstrate no difference in the average value of the two samples at a 90% confidence level.

(2) Challenge Study Negative and Positive Controls

The negative and positive controls should be shipped and analyzed concurrently with the challenge study samples to minimize the impact of experimental variability on the calculation of log inactivation achieved by the UV reactor. The measured log inactivation obtained for the challenge studies must be adjusted by the log inactivation results obtained for the negative and positive controls in the following manner:

$$\log\left[\frac{N}{No}\right] = \log\left[\frac{N_{(m)} - N_{(NC)}}{No_{(m)} - No_{(NC)}}\right] - \log\left[\frac{N_{(PC)}}{No_{(PC)}}\right]$$

where

$N_{(m)}$ = the measured effluent concentration of organisms for the bioassay

$No_{(m)}$ = the measured influent concentration of organisms for the bioassay

$N_{(NC)}$ = the measured effluent concentration of organisms in the negative control

$No_{(NC)}$ = the measured influent concentration of organisms in the negative control

$N_{(PC)}$= the measured effluent concentration of organisms in the positive control

$No_{(PC)}$=the measured influent concentration of organisms in the positive control

12.6 Translating Microbial Challenge Test Data to Operational Dose

The log inactivation determined from the full-scale microbial challenge experiments of the treatment equipment must be translated to an operational dose value using bench-scale collimated beam data. The collimated beam data must be obtained using the same batch of water and seeding organisms used in the field challenge experiments. In this manner, the microbial log inactivation determined in the field can be translated to an operational dose value using the dose-response data obtained for the bench-scale collimated beam experiment.

12.6.1 Collimated Beam Apparatus

A collimated beam apparatus can be obtained directly from UV equipment manufacturers or fabricated in accordance with the minimum design criteria specified below. Additional descriptions of the collimated beam unit can be found in the "Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications," (NSF International, 2002). The collimated beam apparatus must consist of the following components:

(a) a monochromatic low-pressure UV lamp
(b) a suitable ballast for powering the UV lamp
(c) appropriate lamp housing with an adequate lamp cooling/venting system
(d) a collimating tube with a sufficient length to diameter ratio to result in a uniform irradiance across the cross-sectional plane at the bottom of the tube
(e) a rapid shutter system (i.e. pneumatic) for the collimating tube if exposure times of less than 10 seconds will be used or a controlled means of changing the collimating tube length in order to vary the applied dose
(f) a stable platform system that can support a suitable sample container in a fixed position immediately below the collimating tube
(g) a suitable sample container (i.e. petri dish) that is sufficiently shallow such that the intensity at the bottom of the container is at least 25 percent of the intensity at the surface of the sample while still providing sufficient volume to support a small spin bar
(h) a magnetic stirrer that is insulated to prevent a rise in temperature of the sample during testing and can adjusted to control the speed of the spin bar to provide adequate mixing without perturbation of the sample surface
(i) a radiometer (IL 1700, SED 240 detector, International Light, Newburyport, Massachusetts, or equivalent)

12.6.2 Calibration of the Collimated Beam Apparatus

The intensity field delivered to the sample from the collimating tube must be measured with a calibrated radiometer. The radiometer must be factory calibrated with standards traceable to the National Institute of Standards and Technology within one month of an ETV test and every 6 months thereafter. Use of alternative calibration procedures may be

considered, but they must be described in detail in the PSTP and approved prior to their use. Replicate intensity readings taken at single sample grid locations must fall within five percent of their average for the radiometer readings to be considered valid.

A properly functioning collimated beam apparatus should generate MS2 bacteriophage dose-response data that falls within pre-established acceptance criteria for the organism. The acceptance criteria specified in the "Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse," (NWRI/AWWARF, 2000) have been revised to reflect additional data sets and have been released in the "Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications," (NSF International, 2002). The FTO must provide seeded MS2 dose-response data for their collimated beam unit prior to its approved use as part of the full-scale microbial challenge experiments.

12.6.3 Dose-Response Test with the Collimated Beam Apparatus

Running a collimated beam dose-response assay serves two purposes:

(1) To verify the integrity of the MS2 phage stock used to seed the field reactor, and
(2) To translate the MS2 phage inactivation observed for the field reactor test to an operational dose equivalent.

To achieve these objectives, the collimated beam dose-response must be performed with each batch of MS2 phage stock utilized and each water quality condition tested.

The FTO test plan must present the methods and materials to be used to conduct the collimated beam dose-response analyses as part of the PSTP. Each collimated beam test must consist of at least five equally spread dose conditions which cover the range of operating doses to be evaluated for the UV field test unit. Each of the five dose conditions must be tested in triplicate and each collimated beam test must also include analysis of a positive control to verify that there is no appreciable inactivation of phage in the collimated beam unit when the UV lamp is not activated. It is recommended that a monochromatic low-pressure UV lamp be used for the collimated beam tests, regardless of the UV lamp type employed in the field reactor. This will enable the operational dose performance of different reactors to be directly compared on the basis of a normalized monochromatic dose response.

The specific items to be provided in the PSTP when describing the collimated beam testing are to include the following:

(1) A detailed schematic of the collimated beam apparatus with labeled dimensions
(2) The organization responsible for building the unit
(3) The lamp make, model number, and age
(4) A description of the accuracy of the shutter controlling lamp exposure time
(5) The dimensions of the sample container and volume and depth of the water sample within the container
(6) The characteristics of the MS2 phage stock (host, phage growth conditions, and enumeration)

(7) The device for measuring incident intensity and the device calibration protocol and frequency
(8) The instrumentation used to measure the UV absorbance of the seeded sample
(9) The algorithm and acceptance criteria used to determine the average intensity applied to the sample container

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software and manual recording operational parameters for the water treatment equipment on a daily basis.

13.2 Experimental Objectives

The objectives of this task are 1) to establish a viable structure for the recording and transmission of field testing data such that the Field Testing Organization provides sufficient and reliable operational data for the NSF for verification purposes, and 2) to develop a statistical analysis of the data, as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies".

13.3 Work Plan

The following protocol has been developed for data handling and data verification by the Field Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of water treatment equipment operation. Backup of the computer databases to diskette should be performed on a monthly basis at a minimum. When SCADA systems are not available, direct instrument feed to data loggers and laptop computers shall be used when appropriate.

For parameters for which electronic data acquisition is not possible, field testing operators will record data and calculations by hand in laboratory notebooks (daily measurements will be recorded on specially-prepared data log sheets as appropriate). Each notebook must be permanently bound with consecutively numbered pages. Each notebook must indicate the starting and ending dates that apply to entries in the logbook. All pages will have appropriate headings to avoid entry omissions. All logbooks entries must be made in black water insoluble ink. All corrections in any notebook shall be made by placing one line through the erroneous information. Products such as "correction fluids" are never to be utilized for making corrections to notebook entries. Operating logs shall include a description of the water treatment equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items. The

original notebooks will be stored on-site; photocopies will be forwarded to the project engineer of the Field Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheets. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each challenge test run) will be assigned a run number that will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to a laboratory that is certified, accredited or approved by a State, a third-party organization, or the EPA, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.4 Statistical Analysis

Water quality developed from grab samples collected during test runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Field Testing Organization shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies" (Chapter 1). Statistical analysis could be carried out for a large variety of testing conditions.

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Information on the differences in feed water quality variations for entire test runs versus the quality produced during the optimized portions of the runs would be useful in evaluating appropriate operating procedures.

14.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL

14.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the water treatment equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during testing. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals shall be documented and recorded on a routine basis. A routine daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters shall be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed below are in addition to any specified checks outlined in the analytical methods.

14.3.1 Daily QA/QC Verifications:

These verifications shall be conducted daily:

- In-line turbidimeters flow rates (verified volumetrically over a specific time period).
- In-line turbidimeter readings checked against a properly calibrated bench-top model.

14.3.2 QA/QC Verifications Performed Every Two Weeks:

These verifications shall be conducted every two weeks:

- In-line turbidimeters (clean out reservoirs and recalibrate).
- In- line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

14.3.3 QA/QC Verifications for Each Testing Period:

This verification shall be conducted before each testing period begins:

- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter).
- Tubing (verify good condition of all tubing and connections, replace if necessary).

14.4 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and finished water quality are described in the section below. Use of either bench-top or in-line field analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it reduces the introduction of error and the variability to analytical results generated by inconsistent sampling techniques.

14.4.1 pH

Analysis for pH shall be performed according to *Standard Methods* 4500-H^+ or EPA Method 150.1/150.2. A three-point calibration of any pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.4.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Method* 2550. Raw water temperatures should be obtained at least once daily. The thermometer shall have a scale marked for every 0.1°C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1° increments, would be appropriate for this work.)

14.4.3 True Color

True color shall be measured with a spectrophotometer at 455 nm, using a Hach Company adaptation of the *Standard Methods* 2120 procedure. Samples should be collected in clean plastic or glass bottles and analyzed as soon after collection as possible. If samples cannot be analyzed immediately they should be stored at 4°C for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C should be used, and results should be expressed in terms of PtCo color units.

14.4.4 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Method* 2130 or EPA Method 180.1 with either a bench-top and in-line turbidimeter.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to the monitoring instruments.

14.4.4.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter; readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected

range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5 and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

When cold water samples cause the vial to fog and prevent accurate readings, the vial must be allowed to warm up by partial submersion into a warm water bath for approximately 30 seconds.

14.4.4.2 In-line Turbidimeters. In-line turbidimeters may be used during verification testing and must be calibrated as specified in the manufacturer's operation and maintenance manual. It will be necessary to periodically verify the in-line readings using a bench-top turbidimeter; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.5 Chemical and Biological Samples Shipped off-Site for Analyses

The analytical methods that shall be used during testing for chemical and biological samples that are shipped off-site for analyses are described in the section below.

14.5.1 Organic Parameters: Total Organic Carbon and UV_{254} Absorbance

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with *Standard Methods* 5010 B. Storage time before analysis shall be minimized, according to *Standard Methods*.

14.5.2 Microbial Parameters: Viruses, Bacteria, Protozoa, and Algae

Samples for analysis of any microbiological parameter shall be collected in bottles supplied by the analytical laboratory. Microbiological samples shall be refrigerated at approximately 2 to 8°C immediately upon collection. Such samples shall be shipped in a

cooler and maintained at a temperature of approximately 2 to 8°C during shipment. Samples shall be processed for analysis by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the US EPA within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8°C until initiation of processing. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) or as total coliform densities per 100 mL and HPC densities shall be reported as colony forming units per mL (cfu/mL). TC and HPC are optional sampling parameters.

Methods for assessing the viability of the selected bacteria and viruses shall be specified by the laboratory(ies) performing the analysis and shall be specified in the PSTP. The FTO may select a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA for analysis of microbial contaminants in water samples.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying claims that an on-site halogen generation system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), Slifko et al. (1997) and others (see Section 12.0 References in this Test Plan). Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity.

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 2 to 8°C, and held at that temperature range until counted.

14.5.3 Inorganic Samples

Inorganic chemical samples, including alkalinity, hardness, aluminum, iron, and manganese, shall be collected and preserved in accordance with *Standard Method* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Method* 3010C. The samples shall be refrigerated at approximately 4°C. Samples shall be processed for analysis by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the US EPA within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

15.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied Operation and Maintenance (O&M) manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for drinking water treatment equipment employing UV technology.

15.1 Maintenance

The Manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment including, but not limited to, the following, where applicable:

- lamps
- control valves
- cooling fans
- quartz sleeves or tubes
- instruments, such as turbidimeters, UV sensors
- water meters
- electrical equipment
- mechanical wipers

The Manufacturer shall also provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment, including but not limited to, the following, where applicable:

- screens
- piping
- treatment chamber

15.2 Operation

The Manufacturer shall provide readily understood recommendations for procedures related to proper operation of the equipment. Among the operating aspects that should be addressed in the O&M manual are:

UV Lamps:

- Hours of operation - how should this be checked
- UV irradiance - how check and/or calibrate
- cleaning - how and when to clean
- changing - how to determine need to change

Screens (where applicable):

- cleaning - when is it needed
- measurement of head loss during operation
- integrity - how to gauge it

Control Valves:

- open/close indication
- sequence of operations

Exposure Time:

- correlation of flowrate and exposure time
- maintenance/calibration of flow meter

Cooling Water System:

- monitoring/maintenance of proper water temperature
- monitoring cooling water flow
- recirculation pumps

The Manufacturer shall provide a troubleshooting guide; a simple checklist of what to do for a variety of problems, including but not limited to:

- no flow to unit
- sudden change in flow to unit
- no electric power
- excessive headloss across screens
- loss of cooling water flow
- filtered water turbidity too high
- sudden reduction in UV irradiance
- automatic operation (if provided) not functioning
- valve stuck or will not operate

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