

Environmental Technology Verification Protocol


Drinking Water Systems Center

PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR REMOVAL OF INORGANIC CONSTITUENTS

Prepared by



NSF International

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

ET ✓ ET ✓ ET ✓

**EPA/NSF ETV
PROTOCOL FOR EQUIPMENT VERIFICATION TESTING
OF REMOVAL OF INORGANIC CONSTITUENTS**

Prepared by:
NSF International
789 Dixboro Road
Ann Arbor, MI 48105

Recommended by
The Steering Committee for the Verification of
Drinking Water Systems
On June 18, 1999
Modified on February 25, 2000 and in March 2002

With support from
The U.S. Environmental Protection Agency
Environmental Technology Verification Program

Copyright 2002 NSF International 40CFR35.6450.

Permission is hereby granted to reproduce all or part of this work, subject to the limitation that users may not sell all or any part of the work and may not create any derivative work therefrom. Contact ETV Drinking Water Systems Center Manager at (800) NSF-MARK with any questions regarding authorized or unauthorized uses of this work.

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

NSF International (NSF) is an independent not-for-profit 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. The 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 package 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 International (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 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 removing inorganic constituents, 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 removal of inorganic constituents.

Prior to the verification testing of a drinking water treatment systems, plants and/or equipment, the equipment manufacturer and/or supplier must select an NSF-qualified Field Testing Organization. This designated Field Testing Organization 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 Field Testing Organization 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 state-certified or third party- or EPA-accredited laboratory. For information on a listing of NSF-qualified field testing organizations and state-certified or third party- or EPA-accredited laboratories, contact NSF International.

ACKNOWLEDGMENTS

The USEPA and NSF International 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.

Chapter 1: Requirements for All Studies

Writers: Joe Jacangelo and Anne Braghetta, Montgomery Watson

Technical reviewer: James Taylor, University of Central Florida

Chapter 2: Test Plan for Reverse Osmosis or Nanofiltration

Writer: Joe Jacangelo and Anne Braghetta, Montgomery Watson

Technical reviewer: James Taylor, University of Central Florida

Chapter 3: Test Plan for Electrodialysis and Electrodialysis Reversal

Writer: Mark Thompson, Advanced Membrane Systems

Technical reviewer: Steve Duranceau, Boyle Engineering

Steering Committee Members that voted on Chapters 1 and 2:

Mr. James Bell	Dr. Gary S. Logsdon
Mr. Jerry Biberstine, Chairperson	Mr. David Pearson
Mr. John Dyson	Mr. Dallas Post
Mr. Allen Hammer	Mr. John Trax
Mr. Joseph Harrison	Mr. Victor Wilford
Dr. Joseph G. Jacangelo	

Steering Committee Members that voted on Chapter 3:

Mr. James Bell	Dr. Gary S. Logsdon
Mr. Jerry Biberstine	Mr. David Pearson
Mr. Kevin Brown	Mr. Rene Pelletier
Mr. John Dyson	Mr. Edward Urheim
Mr. Joseph Harrison	Mr. Victor Wilford
Dr. Joseph Jacangelo	

TABLE OF CONTENTS

	<u>Page</u>
Chapter 1: EPA/NSF ETV Protocol for Equipment Verification Testing - Removal of Inorganic Constituents: Requirements for All Studies	1-1
Chapter 2: EPA/NSF ETV Equipment Verification Testing Plan - Removal of Inorganic Chemical Contaminants by Reverse Osmosis or Nanofiltration.....	2-1
Chapter 3: EPA/NSF ETV Equipment Verification Testing Plan – Removal of Inorganic Chemical and Radionuclide Contaminants by Electrodialysis and Electrodialysis Reversal	3-1

CHAPTER 1

EPA/NSF ETV

PROTOCOL FOR EQUIPMENT VERIFICATION TESTING
FOR REMOVAL OF INORGANIC CONSTITUENTS

REQUIREMENTS FOR ALL STUDIES

Prepared by:
NSF International
789 Dixboro Road
Ann Arbor, MI 48105

Copyright 2002 NSF International 40CFR35.6450.

Permission is hereby granted to reproduce all or part of this work, subject to the limitation that users may not sell all or any part of the work and may not create any derivative work therefrom. Contact ETV Drinking Water Systems Center Manager at (800) NSF-MARK with any questions regarding authorized or unauthorized uses of this work.

TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1-4
1.1 Objectives	1-6
1.2 Scope.....	1-6
2.0 EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES	1-7
2.1 Verification Testing Organization and Participants.....	1-7
2.2 Organization.....	1-8
2.3 Verification Testing Site Name and Location.....	1-8
2.4 Site Characteristics.....	1-8
2.5 Responsibilities.....	1-9
3.0 EQUIPMENT CAPABILITIES AND DESCRIPTION	1-9
3.1 Equipment Capabilities	1-9
3.2 Equipment Description	1-11
4.0 EXPERIMENTAL DESIGN	1-12
4.1 Objectives	1-12
4.2 Equipment Characteristics	1-13
4.2.1 Qualitative Factors	1-13
4.2.2 Quantitative Factors	1-14
4.3 Water Quality Considerations	1-14
4.3.1 Feedwater Quality.....	1-15
4.3.2 Treated Water Quality.....	1-15
4.4 Recording Data.....	1-16
4.5 Recording Statistical Uncertainty.....	1-16
4.6 Verification Testing Schedule	1-17
5.0 FIELD OPERATIONS PROCEDURES	1-19
5.1 Equipment Operations and Design	1-19
5.2 Communications, Documentation, Logistics, and Equipment	1-19
5.3 Equipment Operation and Water Quality Sampling for Verification Testing.....	1-20
6.0 QUALITY ASSURANCE PROJECT PLAN (QAPP)	1-21
6.1 Purpose and Scope.....	1-21
6.2 Quality Assurance Responsibilities	1-21

TABLE OF CONTENTS (continued)

	<u>Page</u>
6.3	Data Quality Indicators..... 1-21
6.3.1	Representativeness..... 1-21
6.3.2	Accuracy..... 1-22
6.3.3	Precision..... 1-23
6.3.4	Statistical Uncertainty..... 1-24
6.4	Water Quality and Operational Control Checks..... 1-24
6.4.1	Quality Control for Equipment Operation..... 1-24
6.4.2	Water Quality Data..... 1-24
6.4.2.1	Duplicate Analysis of Selected Water Quality Parameters..... 1-25
6.4.2.2	Method Blanks..... 1-25
6.4.2.3	Spiked Samples..... 1-25
6.4.2.4	Travel Blanks..... 1-25
6.4.2.5	Performance Evaluation Samples for On-Site Water Quality Testing..... 1-25
6.5	Data Reduction, Validation, and Reporting..... 1-25
6.5.1	Data Reduction..... 1-25
6.5.2	Data Validation..... 1-26
6.5.3	Data Reporting..... 1-26
6.6	System Inspections..... 1-26
6.7	Reports..... 1-26
6.7.1	Status Reports..... 1-26
6.7.2	Inspection Reports..... 1-27
6.8	Corrective Action..... 1-27
7.0	DATA MANAGEMENT AND ANALYSIS, AND REPORTING..... 1-28
7.1	Data Management and Analysis..... 1-28
7.2	Report of Equipment Testing..... 1-28
8.0	HEALTH AND SAFETY MEASURES..... 1-29

1.0 INTRODUCTION

This document is the protocol to be used for Verification Testing of equipment designed to achieve removal of inorganic constituents. This protocol may be applicable to various types of water treatment equipment capable removal of inorganic constituents. Equipment testing might be undertaken to verify the inorganic constituent removal capabilities and performance of drinking water treatment equipment employing processes that may include but are not limited to membrane filtration (reverse osmosis), ion exchange, electrodialysis/electrodialysis reversal, alumina adsorption, softening, etc. The specific inorganic constituents to be targeted for removal during Verification Testing shall be clearly identified in the Product-Specific Test Plan (PSTP) prior to the initiation of testing by the Field Testing Organization (FTO). The PSTP may include the testing requirements of more than one Testing Plan; however, the FTO must adhere to the specific minimum requirements of each protocol in developing a 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.

This protocol document is presented in two fonts. The non-italicized font provides the rationale for the requirements and background information that the FTO may find useful in preparation of the PSTP. *The italicized text indicates specific study protocol deliverables that are required of the FTO or of the Manufacturer 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 primary 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 which may be defined as either a package plant or modular system.
- Field Testing Organization (FTO) - An organization qualified to conduct studies and testing of equipment in accordance with protocols and test plans. The role of the FTO is to complete the ETV Testing application on behalf of the Manufacturer, to enter into contracts with NSF, as

discussed herein, to operate or supervise operation of a system during the study testing period and to complete 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 FTO during operation and monitoring of the package plant or modular system in the Verification Testing Program.
- **Modular System** - A package functional assembly of components for use in a drinking water treatment system or package plant, that provides a limited form of treatment of the feed water(s) and which is discharged to another package plant module or in the final step of treatment to the distribution system.
- **NSF** - NSF International, its staff, or other authorized representatives.
- **Package plant** - a complete water treatment system including all components from connection to the raw water(s) through discharge to the distribution system.
- **Plant Operator** - the person working for a small water system who is responsible for operating package 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 period(s).
- **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 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 package plants and/or modular systems 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.
- **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, accuracy, precision, statistical uncertainty, and quality assurance and quality control requirements.

- Verification - to establish the evidence on the range of performance of equipment and/or device 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 dire.
- Water System - The water system that employs water treatment equipment to provide potable water to its customers.

1.1 Objectives

The specific objectives of Verification Testing may be different for each system, depending upon the statement of objectives of the specific equipment to be tested. 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 Program may include but are not limited to the following:

- 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 development of Verification Testing is to describe the procedures that will be used to verify the Statement of Performance Objectives made for water treatment equipment. A Verification Testing plan document 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 be described in detail and provided as part of the PSTP.

1.2 Scope

This protocol outlines the Verification process for equipment designed to achieve removal of inorganic constituents. This protocol can be used in conjunction with a number of different testing plans for drinking water treatment systems designed to achieve removal of inorganic constituents.

An overview of the Verification process and the elements of the PSTP to be developed by the FTO 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 (QA) and quality control (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 chemical hazard, biohazard, electrical, mechanical and other safety codes.

Content of PSTP Regarding Verification Testing Objectives and Scope:

The structure of the PSTP must conform to the outline below: The required components of the Document will be described in greater detail in the sections below.

- *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 TESTING PLAN (described in the section below)*
- *DATA MANAGEMENT AND ANALYSIS (described in the section below)*
- *SAFETY PLAN (described in the section below)*

2.0 EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES

2.1 Verification Testing Organization and Participants

The required content of the PSTP and the responsibilities of participants are listed at the end of each section. In the development of a PSTP, Manufacturers and their designated FTO 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.

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

2.2 Organization

The organizational structure for the Verification Testing showing lines of communication shall be provided by the FTO in its application on behalf of the Manufacturer.

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. Depending upon the Verification Testing requirements stipulated in the Testing Plan employed, testing of the equipment may be recommended under different conditions of feedwater quality (or source water quality) that allow evaluation of system performance over a range of seasonal climate and weather conditions. However, only one, one-month Verification Testing period is required for Equipment Verification Testing.

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, the FTO shall 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. The FTO shall address the issue of whether the operation of the system will be continuous or intermittent. 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 pollution discharge permits needed?

2.5 Responsibilities

The PSTP shall identify the organizations involved in the testing and describes the primary responsibilities of each organization. Multiple Manufacturer testing for removal of inorganic constituents may be conducted concurrently, and be fully in compliance with the ETV Testing Program. The responsibilities of the Manufacturer will vary depending on the type of Verification Testing. However, at a minimum, the Manufacturer shall be responsible for:

- Providing the equipment to be evaluated during Verification Testing. The equipment must be in complete working order at delivery to the test site;
- Providing equipment that explicitly meets all requirements of OSHA, NEMA, UL, NSF and other appropriate agencies in order to ensure operator safety during Verification Testing.

The FTO shall be responsible for:

- Providing needed logistical support, establishing a communication network, and scheduling and coordinating the activities of all Verification Testing participants;
- Advising the Manufacturer on feedwater quality and test site selection, such that the selected test sites have feedwater quality consistent with the objectives of the Verification Testing (The Manufacturer may recommend a site for Verification Testing);
- Managing, evaluating, interpreting, and reporting on data generated by the Verification Testing;
- Evaluating and reporting on the performance of technologies applied to achieved removal of inorganic constituents.

Content of PSTP Regarding Equipment Verification Testing Responsibilities:

The FTO shall be responsible for including the following elements in the PSTP:

- *Definition of the roles and responsibilities of appropriate Verification Testing participants.*
- *A table that includes the name, affiliation and mailing address of each participant, a point of contact, their role, telephone and fax numbers, and e-mail address.*
- *Organization of operational and analytical support.*
- *List of the testing site with name(s) and location(s).*
- *Description of the testing site(s), the site characteristics and location of equipment on testing site.*

Manufacturer Responsibilities:

- *Provision of complete, field-ready equipment for Verification Testing;*
- *Provision of logistical, and technical support, as required; and*
- *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

For this Verification Testing, the Manufacturer and their designated FTO 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. 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. In conjunction with a Statement of Performance Objectives, the FTO shall state the pertinent detection limits for the specific inorganic analytical method. Statements should be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. The FTO on behalf of the Manufacturer shall also provide information as to what advantages the Verification Testing equipment provides over existing equipment. The Statement of Performance Objectives must be specific and verifiable by a statistical analysis of the data. Examples of two statements are:

1. *“This system is capable of achieving 90% fluoride removal during operation at a flux of 30 gallons per square foot per day (gfd) (75% recovery; temperature less than 20 °C) in feedwaters with fluoride concentrations less than 10 mg/L and total dissolved solids concentrations less than 500 mg/L.”*
2. *“This system is capable of producing a product water with less than 4 mg/L fluoride concentration during operation at a flux of 30 gfd (75% recovery; temperature less than 20 °C) in feedwaters with fluoride concentrations less than 20 mg/L and total dissolved solids concentrations less than 500 mg/L.”*

For each Statement of Performance Objectives proposed by the FTO and the Manufacturer in the PSTP, the following information shall be provided: percent removal of the targeted inorganic constituent, rate of treated water production (i.e., flux); product water recovery; feed stream water quality regarding pertinent water quality parameters; temperature; concentration of target inorganic constituent; and other pertinent water quality and operational conditions. During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Objectives. The following equation may be used to determine percent removal of the specific inorganic constituent targeted for removal:

$$\% \text{ constituent removal} = 100 \cdot \left[\frac{C_{\text{feed}} - C_{\text{finished}}}{C_{\text{feed}}} \right]$$

where: C_{feed} is the concentration of the selected inorganic constituent in the feedwater in mg/L; and
 C_{finished} is the concentration of the selected inorganic constituent in the finished water in mg/L.

The FTO on behalf of the Manufacturer shall be responsible for identification of which specific inorganic constituents shall be monitored and recorded for testing under the Statement of Performance Objectives in the PSTP. The analysis of inorganic constituent concentrations in the feed water, treated water and wastewater streams shall be performed by a state-certified or third party or EPA-accredited laboratory using an approved Standard or EPA Method.

The Statement of Performance Objectives prepared by the FTO (in collaboration with the Manufacturer) shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feed water. 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 Program 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.

It should be noted that many of the drinking water treatment systems participating in the Inorganics Removal Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this Inorganics Removal Protocol and the associated Verification Testing Plans are oriented towards removal of inorganic constituents from feedwaters, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters.

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. Equipment size and weight
- f. Shipping requirements and special handling precautions
- g. Equipment maintenance requirements
- h. Serial Number
- i. Warning and Caution statements in legible and easily discernible print size
- j. Capacity or output rate (if applicable)

In addition, the equipment shall be provided by the Manufacturer with all OSHA required safety devices (if applicable).

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 several perspectives;*
- *Brief introduction and discussion of the engineering and scientific concepts on which the inorganics removal capabilities of the water treatment equipment are based;*
- *Description of the system and each process included as a component in the modular system including all relevant schematics of treatment and pretreatment systems;*

- *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 rates of waste (concentrates, residues, waste products, required regeneration frequencies; materials replacement frequencies; 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 removal capabilities of the equipment to be evaluated during Verification Testing, with comparisons to conventional water treatment 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 feed water quality suitable for treatment with the equipment, the upper limits for concentrations of contaminants that can be removed, 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), equipment size and weight, shipping requirements and special handling precautions, equipment maintenance requirements, 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.) for 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 the FTO will use to evaluate the results of the Verification Testing.

4.1 Objectives

The objectives of this Verification Testing are to evaluate equipment in the following areas: 1) performance relative to the Manufacturer's stated range of constituent removal objectives and equipment operation; 2) performance relative to variations in feedwater quality (such as concentrations of the selected inorganic constituent[s], total dissolved solids [TDS], temperature, pH, alkalinity,

turbidity etc.); 3) logistical, human, and economic resources necessary to operate the equipment; and 4) reliability, ruggedness, cost, range of usefulness, safety and ease of operation.

The PSTP provided by the FTO shall include those treatment tests listed in ETV test plans that are most appropriate to challenge the removal capabilities of the equipment for the selected inorganic constituents. For example, if equipment is only intended for removal of fluoride (or another inorganic constituent), there would be no need to conduct testing to evaluate the removal of sulfate, hardness ions or alkalinity, or other inorganic constituents that are not directly applicable. However, it should also be noted that many of the drinking water treatment systems participating in the Inorganics Removal Verification Testing Program will be capable of achieving multiple water treatment objectives. The Verification Testing Program may for example be undertaken to demonstrate equipment removal capabilities for a wide number of inorganic constituents (an example list will be provided later). In addition, the FTO and the Manufacturer may wish to construct the PSTP so that Verification Testing may also demonstrate the treatment system's removal capabilities and treatment operations for additional water quality parameters. The incorporation of additional treatment objectives may also necessitate attention to the other applicable protocol and test plan documents in the development of the PSTP.

4.2 Equipment Characteristics

This section discusses factors that will be considered in the design and implementation of the Equipment Verification Testing Program. The following equipment characteristics will be included in discussion of the Verification Testing Program: 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 of the equipment (footprint), unit processes included in treatment train, chemicals needed, chemical hazards associated with equipment operation, and response of treatment process to intermittent operation.

Verification testing procedures shall simulate routine conditions as much as possible and in most cases testing may be done in the field. Under such circumstances, simulation of field conditions would not be necessary.

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 modular nature of the equipment, the safety of the equipment, the portability of equipment, the ease of operation of the testing 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
- Effect of operator's technical knowledge on system performance and robustness of operation

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 system
- Length of operating cycle
- Daily labor hours required for operation and maintenance

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

4.3 Water Quality Considerations

The primary treatment goal of the equipment employed for Verification Testing through this protocol is to achieve removal of designated inorganic constituents found in feedwaters (or raw waters) such that product waters are of acceptable water quality. Depending upon the goals of the equipment Manufacturer, the driving force for Verification Testing of inorganic constituent removal may be to demonstrate a certain removal of the designated inorganic constituent under a specific set of operating and feedwater quality conditions. The objectives of Verification Testing may also be to assure production of water with palatable, healthful and consistent water quality. The experimental design and Statement of Performance Objectives 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 prepare PSTPs that sufficiently challenge their equipment. The FTO on behalf of 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. The FTO should not adopt an experimental approach to Verification Testing for removal of inorganic constituents 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 Verification Testing Plans prepared by NSF as the basis for the development of the experimental plan in each specific PSTP.

4.3.1 Feedwater Quality

One of the key aspects related to demonstration of equipment performance in the Verification Testing is the range of feedwater quality that can be treated successfully. The Manufacturer and FTO should consider the influence of feedwater quality on the quality of treated waters produced by the equipment, such that treated waters meet the criteria stipulated by the FTO in the Statement of Performance Objectives. For example, if desired by the Manufacturer the Statement of Performance Objectives may be tailored to demonstrate production of treated waters that reduce contaminants to under a certain concentration. As the range of feedwater quality that can be treated by the equipment broadens, the potential applications for treatment equipment with verified performance objectives will also increase.

The FTO shall provide a list of inorganic constituents in the PSTP that may be pertinent in the Equipment performance for removal of inorganic chemical contaminants. This list may include (but should not be limited to) some of the inorganics evaluated for removal during the Verification Testing Program: barium, cadmium, calcium, chloride, chromium, fluoride, iron, magnesium, manganese, nitrate, nitrite, phosphate, silica, sodium, strontium, sulfate, pH, alkalinity, total dissolved solids (TDS), conductivity, turbidity.

One of the questions often asked by regulatory officials in approval of water treatment equipment is: "Has it been shown to work on the water where you propose to put it?" By covering a large range of water qualities, the Verification Testing is more likely to provide an affirmative answer to that question.

4.3.2 Treated Water Quality

Removal of inorganic constituents shall be the primary goal of the water treatment systems included in this Equipment Verification Testing Program. If a FTO states that water treatment equipment can be used to treat water to meet specified regulatory requirements for a selected inorganic constituent, the Verification Testing must provide data that support such a statement of removal objectives, as appropriate. Where desired by the Manufacturer, the Statement of Performance Objectives provided by the FTO shall be related to percent removal capabilities or to capabilities to reduce contaminants concentrations to a certain level. The FTO on behalf of the Manufacturer shall be responsible for identification of the specific inorganic species that shall be monitored during the Equipment Verification Testing Program. Laboratory analysis for the inorganic constituents stipulated by the FTO shall be performed by a state-certified or third party- or EPA-accredited laboratory.

The FTO may also wish to make a statement about performance objectives for removal of other unregulated contaminants, or regulated contaminants that are not directly related to removal of inorganic constituents. For example, some water treatment equipment can be used

to meet aesthetic and distribution system goals. Removal goals for some of these parameters may also be presented in the PSTP as additional statements of performance objectives.

4.4 Recording Data

For all verification experiments targeted to demonstrate removal of inorganic constituents, water quality data on the following parameters pH, hardness, alkalinity, concentration of the selected inorganic constituent(s), total dissolved solids, and temperature should be monitored for the feedwater, finished water, and wastewater at a minimum. The specific water quality parameters to be monitored and with what frequency shall be stipulated by the FTO in the test plan employed for development of the PSTP prior to initiation of the Verification Testing Program. As appropriate, some water quality parameters (e.g., temperature, pH) may be monitored on-site, as designated by the FTO in the PSTP. At a minimum, the following items of information and operational conditions shall also be maintained for each experiment:

- Water type (raw water, pretreated feedwater, finished water, waste water);
- Experimental run (e.g. 1st run, 2nd run, 3rd run, etc.);
- Type of chemical addition, dose and chemical combination, where applicable;
- Rate of flow through system, volume waste production as percent finished water flow, cumulative flow through system in terms of bed volumes (where applicable);
- Transmembrane pressure, membrane flux and element recovery (for membrane processes, where applicable)
- Chemical cleaning frequency or regeneration frequency (where applicable);
- Voltage requirements, current draw and power consumption at specific operating conditions.

4.5 Recording Statistical Uncertainty

For the analytical data obtained during Verification Testing, 95% confidence intervals shall be calculated by the FTO for concentrations of selected inorganic constituents and for other water quality parameters (e.g., TDS, hardness, alkalinity, dissolved organic carbon) that are stipulated by the test plan employed in which eight or more samples were collected. The FTO shall ensure in the PSTP that sufficient water quality data and operational data are collected to allow estimation of statistical uncertainty. The specific testing plans that may be employed with the Protocol stipulate only a minimum frequency for monitoring of selected inorganic constituents. The FTO shall therefore ensure that sufficient water quality and operational data are collected during Verification Testing for the statistical analysis described herein. The FTO shall specify which water quality parameters shall be subjected to the statistical confidence interval calculations. 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.

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:

$$\text{Confidence Interval} = \bar{X} \pm t_{n-1, 1-\frac{\alpha}{2}} \left(\frac{S}{\sqrt{n}} \right)$$

where: \bar{X} is the sample mean;

S is the sample standard deviation;

n is the number of independent measurements included in the data set; and

t is the Student's t distribution value with $n-1$ degrees of freedom;

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:

$$95\% \text{ Confidence Interval} = \bar{X} \pm t_{n-1, 0.975} \left(\frac{S}{\sqrt{n}} \right)$$

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 second term. 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, flow rate, overflow rate, cleaning efficiency, in-line turbidity or in-line particle counts, etc.) obtained during the equipment Verification Testing Program. However, as specified by the FTO, calculation of confidence intervals may be required for such analytical parameters as concentration of selected inorganic constituents, TDS concentration, hardness, alkalinity, etc. In order to provide sufficient analytical data for statistical analysis, the FTO shall collect discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period. The procedures, sampling requirements and frequency of monitoring shall be provided in detail in the Verification Testing Plan.

4.6 Verification Testing Schedule

Verification testing activities include equipment set-up, initial operation, verification operation, and sampling and analysis. Initial operations shall be conducted so that equipment can be tested and 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 removal of inorganic constituents, an initial period of bench-scale testing of feedwater followed by treatment equipment operation may be needed to determine the appropriate operational parameters for testing equipment. A number of operational parameters may require adjustment to achieve successful functioning of the process train. These parameters may include but are not limited to: process flow rates, recovery rates, feedwater pH, chemical dosages, chemical types (where appropriate), cross-flow velocity and other parameters that may result in successful functioning of the process train.

It is required under this protocol that one, one-month Verification Testing period be conducted under the selected Testing Plan. It is recommended however, that more than one testing period be conducted in order to demonstrate equipment performance over a seasonal range of climatic conditions that may produce substantial variability in feedwater quality. It may also be appropriate to conduct Verification Testing under different feedwater temperature conditions due to the potential impact on equipment performance and removal capabilities from changes in water viscosity and diffusional processes.

Content of PSTP Regarding Experimental Design:

The PSTP shall include the following elements:

- *Identification of qualitative and quantitative measures of equipment operation addressed in the Verification Testing Program.*
- *Identification and discussion of the particular water treatment issues and concentrations of selected inorganic constituents, pH and TDS concentrations 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 removal of selected inorganic constituents. Parameters of significance for treated water quality were listed above in Sections 4.3.2 and 4.3.2. as well as in applicable ETV Testing Plans.*
- *Description of data recording protocol for equipment operation, feedwater quality parameters, and treated water quality parameters.*
- *Description of the confidence interval calculation procedure for selected water quality parameters.*
- *Detailed outline of the Verification Testing schedule, with regard to the timing of the Verification testing period relative to any pertinent annual climatic conditions, (i.e., different temperature conditions, seasonal differences between rainy and dry conditions).*

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 reporting inorganics removal data shall be stated explicitly by the FTO 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 process equipment capable of achieving removal of inorganic constituents.)

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 FTO shall therefore be specified to demonstrate treatment capabilities over a broad range of operational conditions and feedwater qualities.

Initial operations of the inorganics removal equipment will allow FTOs to refine the equipment 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.

5.2 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 qualified FTO 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, orientation, 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 Testing 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 Testing 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 FTO in the PSTP.

5.3 Equipment Operation and Water Quality Sampling for Verification Testing

All field activities shall conform to requirements provided in the PSTP that was developed and NSF-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 FTO in the PSTP. As necessary for Verification analysis, state-certified or third party- or EPA-accredited laboratories certified for analysis of inorganic constituents and other water quality parameters shall be selected to perform analytical services. The analysis of inorganic constituents shall be performed by a state-certified or third party- or EPA-accredited laboratory using an approved Standard Method.

If unanticipated or unusual situations are encountered that may alter the plans for equipment operation, water quality sampling, or data quality, the FTO 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 operation of the testing equipment shall be described by the FTO 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.*

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 are 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 the operating parameters for the testing equipment and for the 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 FTO.

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 Testing, the NSF and EPA require that data quality parameters be established based on the proposed end uses of the data. Data quality parameters include three indicators of data quality: 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 maintaining consistent sample collection procedures, including sample locations, timing of sample collection, sampling procedures, sample preservation, sample packaging, and sample shipping, and by executing random DBP spiking procedures. 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 experimentally determined sample result and the accepted reference value for the sample. Analytical accuracy is a measure of analytical bias due to systematic errors. 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.

In this Verification Testing, the FTO will be responsible for maintaining consistent sample collection procedures, including sample locations, timing of sample collection, sampling procedures, sample preservation, sample packaging, and sample shipping to maintain a high level of accuracy in system monitoring. In addition, analytical accuracy shall be quantified by executing random spiking procedures for the specific inorganic constituents chosen for testing. The FTO 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 equipment operating data, maintaining a high level of accuracy will require collecting a sufficient quantity of data during operation to be able to detect a change in operations. 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 FTO 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:

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

where: SSR = spiked sample result
 SR = sample result
 SA = spike amount added

Recoveries for laboratory control samples are calculated as follows:

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

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:

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

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 the 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 4.5 - 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 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 shall be analyzed for selected water quality parameters at specified intervals in order to determine the precision of analysis. The procedure for determining samples to be analyzed in duplicate shall be provided in each Verification Testing Plan with the required frequency of analysis and the approximate number. The duplicate analysis shall be performed according to the requirements for calculation of 95% confidence intervals, as presented in Section 4.5.

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.

6.4.2.3 Spiked Samples. The use of spiked samples will depend on the testing program, and the contaminants to be removed. For evaluation of analytical accuracy, the FTO must specify the procedure and frequency of spiking, as well as acceptance criteria, and actions if criteria are not met.

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.

6.4.2.5 Performance Evaluation Samples for On-Site Water Quality Testing. Performance evaluation (PE) samples are samples whose composition is unknown to the analyst. Analysis of PE samples shall be conducted for selected water quality parameters before equipment testing is initiated by submission of samples to the analytical laboratory. Control limits for the PE samples will be used to evaluate the sampling method and analytical performance of the equipment testing organization and analytical laboratory, respectively. One kind of PE sample that would be used for on-site QA in most studies done under this protocol would be PE conductivity sample.

A PE sample comes with statistics that 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 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.

6.5.1 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 dependent. The purpose of this step is to provide data that will be used to

verify the Statement of Performance Objectives. These data shall be obtained from logbooks, instrument outputs, and computer outputs as appropriate.

6.5.2 Data Validation

The operator shall verify the 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 of data recording and sampling. Information on data acquisition and analytical QA/QC will be examined by analytical technicians and by the laboratory supervisor. Laboratory and project managers shall verify that all instrument systems are correctly calibrated and that QA/QC objectives for accuracy, precision, and method detection limits have been met.

Analytical outlier data are defined as those QC data lying outside a specific QC objective window for accuracy and precision 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. 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.

6.5.3 Data Reporting

The data reported during the Verification Testing Program shall be explicitly defined by the FTO in the PSTP. At a minimum, the data tabulation shall list the results for feedwater and treated water quality analyses, the results of inorganic constituent removal analyses 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.

6.6 System Inspections

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

6.7 Reports

6.7.1 Status Reports

The FTO shall prepare periodic reports for distribution to pertinent parties, e.g., manufacturer, EPA, the 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 at the beginning of the report to introduce the salient

issues of the testing period. When problems occur, the Manufacturer and FTO 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 in the PSTP.

6.7.2 Inspection Reports

Any QA inspections that take place at the field testing site or at the analytical laboratory during Verification Testing shall be formally reported by the FTO, the Verification entity, and the Manufacturer.

6.8 Corrective Action

Each PSTP must incorporate a corrective action plan. This plan must include the predetermined acceptance limits, 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 reporting of accuracy.*
- *Description of methodology for reporting of precision.*
- *Description of methodology for reporting of statistical uncertainty.*
- *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.*
- *Outline of the procedure for determining samples to be analyzed in triplicate, the frequency and approximate number.*
- *Description of the procedures used to assure that the data are correct.*
- *Listing of techniques and/or equations used to quantify any necessary data quality indicator calculations in the analysis of water quality parameters. These include: accuracy, precision, and statistical uncertainty (e.g., confidence interval calculation).*
- *Outline of the frequency, format, and content of reports in the PSTP.*
- *Development of a corrective action plan in the PSTP.*

Field Testing Organization Responsibilities:

- *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.*

7.0 DATA MANAGEMENT AND ANALYSIS, AND REPORTING

7.1 Data Management and Analysis

The responsibilities of the Field Testing Organization for data management and analysis have been provided in the Responsibilities Summary Sheet, the Project Guidance Manual, and/or the Terms and Conditions cited earlier in this protocol.

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 in the report. The data management section of the PSTP shall describe what types of data and information need to be collected and managed, and 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
- Manufacturer PSTP
- QA/AC 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 need 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
- ventilation of equipment or of trailers or buildings housing equipment, if gases generated by the equipment could present a safety hazard

Content of PSTP Regarding Safety:

The PSTP shall address safety considerations that are appropriate for the equipment being tested and for the chemicals employed in the Verification Testing.

CHAPTER 2

EPA/NSF ETV

EQUIPMENT VERIFICATION TESTING PLAN

FOR THE REMOVAL OF INORGANIC CHEMICAL CONTAMINANTS

BY REVERSE OSMOSIS OR NANOFILTRATION

Prepared by:
NSF International
789 Dixboro Road
Ann Arbor, Michigan 48105

Copyright 2002 NSF International 40CFR35.6450.

Permission is hereby granted to reproduce all or part of this work, subject to the limitation that users may not sell all or any part of the work and may not create any derivative work therefrom. Contact ETV Drinking Water Systems Center Manager at (800) NSF-MARK with any questions regarding authorized or unauthorized uses of this work.

TABLE OF CONTENTS

	<u>Page</u>
1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN	2-4
2.0 INTRODUCTION	2-4
3.0 GENERAL APPROACH	2-5
4.0 DEFINITION OF OPERATIONAL PARAMETERS	2-6
5.0 OVERVIEW OF TASKS	2-10
5.1 Task 1: Membrane Operation	2-10
5.2 Task 2: Cleaning Efficiency.....	2-10
5.3 Task 3: Finished Water Quality.....	2-10
5.4 Task 4: Data Handling Protocol	2-11
5.5 Task 5: Quality Assurance Project Plan	2-11
6.0 TESTING PERIODS	2-12
7.0 TASK 1: MEMBRANE OPERATION	2-13
7.1 Introduction	2-13
7.2 Experimental Objectives	2-13
7.3 Work Plan	2-14
7.4 Analytical Schedule	2-16
7.4.1 Operational Data Collection	2-16
7.4.2 Feedwater Quality Limitations	2-16
7.5 Evaluation Criteria and Minimum Reporting Requirements	2-17
8.0 TASK 2: CLEANING EFFICIENCY	2-17
8.1 Introduction	2-17
8.2 Experimental Objectives	2-17
8.3 Work Plan	2-18
8.4 Analytical Schedule	2-18
8.4.1 Operational Data Collection	2-18
8.4.2 Sampling	2-19
8.5 Evaluation Criteria and Minimum Reporting Requirements	2-19
9.0 TASK 3: FEEDWATER AND TREATED WATER QUALITY MONITORING	2-20
9.1 Introduction	2-20
9.2 Experimental Objectives	2-20

TABLE OF CONTENTS (continued)

		<u>Page</u>
9.3	Work Plan	2-20
9.4	Analytical Schedule	2-21
	9.4.1 Feedwater, Permeate and Concentrate Characterization	2-21
	9.4.2 Water Quality Sample Collection	2-22
9.5	Evaluation Criteria and Minimum Reporting Requirements	2-24
10.0	TASK 4: DATA HANDLING PROTOCOL	2-24
10.1	Introduction	2-24
10.2	Experimental Objectives	2-24
10.3	Work Plan	2-25
11.0	TASK 5: QUALITY ASSURANCE PROJECT PLAN (QA/QC)	2-26
11.1	Introduction	2-26
11.2	Experimental Objectives	2-26
11.3	Work Plan	2-26
	11.3.1 Daily QA/QC Verification	2-26
	11.3.2 Monthly QA/QC Verification	2-26
11.4	Analytical Methods and Sample Collection	2-27
	11.4.1 pH	2-27
	11.4.2 Conductivity	2-27
	11.4.3 Turbidity	2-27
	11.4.4 Analysis of Inorganic Contaminants	2-28
12.0	OPERATION AND MAINTENANCE	2-28
12.1	Maintenance	2-29
12.2	Operation	2-29
12.3	Operability	2-30
13.0	REFERENCES	2-33

TABLES

Table 1.	Summary of Equipment Operational Characteristics to be Evaluated in Each Verification Testing Task	2-11
Table 2.	Task 1 Required Minimum Operating Data	2-15
Table 3.	Minimum Required Water Quality Sampling	2-22
Table 4.	List of Inorganic Chemical Contaminants for Verification Testing	2-23
Table 5.	Membrane Plant Design Criteria Reporting Items	2-31
Table 6.	Membrane Element Characteristics	2-32
Table 7.	Pretreatment Processes Used Prior to Nanofiltration or Reverse Osmosis	2-33

1.0 APPLICATION OF THIS EQUIPMENT VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of reverse osmosis (RO) or nanofiltration (NF) membrane equipment to be used within the structure provided by the ETV document “EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Inorganic Constituents: Requirements For All Studies”. This Testing Plan is to be used as a guide in the development of a Product-Specific Test Plan (PSTP) for testing of RO or NF process equipment to achieve removal of inorganic constituents. It should be noted that this Equipment Verification Plan is only applicable to RO, NF or other high-pressure membrane processes.

In order to participate in the equipment verification process for membrane processes, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the above-referenced ETV Protocol document as guidelines in the development of a PSTP. The FTO shall clearly specify in its PSTP the inorganic constituents targeted for removal and the sampling program that shall be followed during Verification Testing. The PSTP should generally follow the Verification Testing Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task in the PSTP should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing Program is to achieve removal of inorganic chemical constituents present in feedwater supplies. The Manufacturer may wish to establish a Statement of Performance Objectives (see General Approach below) that is based upon removal of target inorganic constituent(s) from feedwaters. For example, the Manufacturer could include in the PSTP a Statement of Performance Objectives that would achieve reduction of specific water quality parameters (such as fluoride, nitrate, nitrite, cadmium, etc). The experimental design of the PSTP shall be developed to address the specific Statement of Performance Objectives established by the Manufacturer. Each PSTP shall include all of the included tasks, Tasks 1 to 5.

2.0 INTRODUCTION

Reverse osmosis, nanofiltration and other demineralization membrane processes are currently in use for a number of water treatment applications ranging from removal of inorganic constituents, total dissolved solids (TDS), total organic carbon (TOC), synthetic organic chemicals (SOCs), and other constituents.

In order to establish appropriate operations conditions such as permeate flux, recovery, cross-flow velocity, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require

a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the Verification Testing. The need of pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

Pretreatment processes ahead of RO or NF systems are generally required to remove particulate material and to ensure provision of high quality water to the membrane systems. For example, RO and NF membranes cannot generally be applied for treatment of surface waters without pretreatment of the feedwater to the membrane system. For surface water applications, appropriate pretreatment primarily for removal of particulate and microbiological species must be applied as specified by the Manufacturer. In the design of the PSTP, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application upstream of the RO or NF membrane process. The stipulated feedwater pretreatment process(es) shall be employed upstream of the membrane process at all times during the Equipment Verification Testing Program. The definition of pretreatment processes shall NOT include scaling control, corrosion control, and treatment for stabilization of RO-treated or NF-treated waters, as these treatments may be considered integral to the operation of the RO or NF systems.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as a part of this Verification Testing Plan will be contracted with a laboratory certified by a state or accredited by a third party organization (i.e., NSF) or the EPA for the appropriate water quality 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. The Statement of Performance Objectives must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. Two examples of Statements of Performance Objectives that may be verified in this testing are:

1. *“This system is capable of achieving 90% fluoride removal during operation at a flux of 30 gallons per square foot per day (gfd) (75% recovery; temperature less than 20 °C) in feedwaters with fluoride concentrations less than 10 mg/L and total dissolved solids concentrations less than 500 mg/L.”*
2. *“This system is capable of producing a product water with less than 4 mg/L fluoride concentration during operation at a flux of 30 gfd (75% recovery; temperature less than 20 °C) in feedwaters with fluoride concentrations less than 20 mg/L and total dissolved solids concentrations less than 500 mg/L.”*

For each Statement of Performance Objectives proposed by the FTO and the Manufacturer in the PSTP, the following information shall be provided: percent removal of the targeted inorganic constituent, rate of treated water production (i.e., flux); recovery; feedwater quality regarding pertinent water quality parameters; temperature; concentration of target inorganic constituent; and other pertinent water quality and operational conditions. During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Objectives.

This ETV Testing Plan is broken down into 5 tasks, as shown in the Overview of Tasks section below. These Tasks shall be performed by any Manufacturer wanting performance verification for their equipment through ETV. The Manufacturer's designated FTO shall provide full detail of the procedures to be followed in each Task in the PSTP. The FTO shall specify the operational conditions to be verified during the Verification Testing Plan. All permeate flux values for Verification Testing shall be reported in terms of temperature-corrected flux values, as either gallons per square foot per day (gfd) at 68 °F or liters per square meter per hour (L/(m²-hr) at 20 °C. Temperature-correction may also be normalized to 25 °C (77 °F) depending upon the recommendation of the equipment Manufacturer.

4.0 DEFINITION OF OPERATIONAL PARAMETERS

Permeate: Water produced by the RO or NF membrane process.

Feedwater: Water introduced to the membrane element.

Permeate Flux: The average permeate flux is the flow of permeate divided by the surface area of the membrane. Permeate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S} \quad (4.1)$$

where: J_t = permeate flux at time t (gfd, L/(h-m²))
 Q_p = permeate flow (gpd, L/h)
 S = membrane surface area (ft², m²)

It should be noted that only gfd and L/(h-m²) shall be considered acceptable units of flux for this testing plan.

Temperature Adjustment for Flux Calculation: Temperature corrections to 20°C (or 25°C) for permeate flux and specific flux shall be made to correct for the variation of water viscosity with temperature. The following empirically-derived equation may be used to provide temperature corrections for specific flux calculations:

$$J_t \text{ (at } 20^\circ \text{ C)} = \frac{Q_p \times e^{-0.0239(T-20)}}{S} \quad (4.2)$$

where: J_t = permeate flux at time t (gfd, L/(h·m²))
 Q_p = permeate flow (gpd, L/h)
 S = membrane surface area (ft², m²)
 T = temperature of the feedwater (°C)

Net Driving Pressure: The Net Driving Pressure is the pressure available to drive water through the membrane, equal to the average feed pressure (average of feed pressure and concentrate pressure) minus the differential osmotic pressure, minus the permeate pressure:

$$\text{NDP} = \left[\frac{(P_f + P_c)}{2} \right] - P_p - \Delta\pi \quad (4.3)$$

where: NDP = net driving pressure for solvent transport across the membrane (psi, bar)
 P_f = feedwater pressure to the feed side of the membrane (psi, bar)
 P_c = concentrate pressure on the concentrate side of the membrane (psi, bar)
 P_p = permeate pressure on the treated water side of the membrane (psi, bar)
 $\Delta\pi$ = osmotic pressure (psi)

Osmotic Pressure Gradient: The term osmotic pressure gradient refers to the difference in osmotic pressure generated across the membrane barrier as a result of different concentrations of dissolved salts. The following equation provides an estimate of the osmotic pressure across the semi-permeable membrane through generic use of the difference in total dissolved solids (TDS) concentrations on either side of the membrane:

$$\Delta p = \left(\left[\frac{(TDS_f + TDS_c)}{2} \right] - TDS_p \right) \cdot \left(\frac{1 \text{ psi}}{100 \frac{\text{mg}}{\text{L}}} \right) \quad (4.4)$$

where: TDS_f = feedwater total dissolved solids (TDS) concentration (mg/L)
 TDS_c = concentrate TDS concentration (mg/L)
 TDS_p = permeate TDS concentration (mg/L)

Note that the different proportions of monovalent and multivalent ions composing the TDS will influence the actual osmotic pressure, with lower unit pressures resulting from multivalent species. The osmotic pressure ratio of 1 psi per 100 mg/L is based upon TDS largely composed of sodium chloride. In contrast, for TDS composed of multivalent ions, the ratio is closer to 0.5 psi per 100 mg/L TDS.

Specific Flux: The term specific flux is used to refer to permeate flux that has been normalized for the net driving pressure. The equation used for calculation of specific flux is given by the formula provided

below. Specific flux is usually discussed with use of flux values that have been temperature-adjusted to 20 °C or 25 °C:

$$J_{im} = \frac{J_t}{NDP} \quad (4.5)$$

where: NDP = net driving pressure for solvent transport across the membrane (psi, bar)
 J_t = permeate flux at time t (gfd, L/(h·m²)). Temperature-corrected flux values should be employed.

Water Recovery: The recovery of feedwater as permeate water is given as the ratio of permeate flow to feedwater flow:

$$\% \text{ System Recovery} = 100 \cdot \left[\frac{Q_p}{Q_f} \right] \quad (4.6)$$

where: Q_f = feedwater flow to the membrane (gpm, L/h)
 Q_p = permeate flow (gpm, L/h)

Recycle Ratio: The recycle ratio represents the ratio of the recycle flow from the membrane concentrate to the total flow of water that is used as feedwater flow to the membrane. This ratio provides an idea of the recirculation pumping that is applied to the membrane system to reduce membrane fouling and specific flux decline.

$$\text{Recycle Ratio} = \left[\frac{Q_r}{Q_f} \right] \quad (4.7)$$

where: Q_f = total feedwater flow to the membrane (gpm, L/h)
 Q_r = recycle hydraulic flow as concentrate to the feed side of the pump (gpm, L/h)

Solute Rejection: Solute rejection is controlled by a number of operational variables that must be reported at the time of water sample collection. Bulk rejection of a targeted inorganic chemical contaminant may be calculated by the following equation:

$$\% \text{ Solute Rejection} = 100 \cdot \left[\frac{C_f - C_p}{C_f} \right] \quad (4.8)$$

where: C_f = feedwater concentration of specific constituent (mg/L)
 C_p = permeate concentration of specific constituent (mg/L)

Solvent and Solute Mass Balance: Calculation of solvent mass balance shall be performed during Task 1 in order to verify the reliability of flow measurements through the membrane. Calculation of

solute mass balance across the membrane system shall be performed as part of Task 3 in order to estimate the concentration of limiting salts at the membrane surface.

$$Q_f = Q_p + Q_c \quad (4.9)$$

$$Q_f C_f = Q_p C_p + Q_c C_c \quad (4.10)$$

where: Q_f = feedwater flow to the membrane (gpm, L/h)
 Q_p = permeate flow (gpm, L/h)
 Q_c = concentrate flow (gpm, L/h)
 C_f = feedwater concentration of specific constituent (mg/L)
 C_p = permeate concentration of specific constituent (mg/L)
 C_c = concentrate concentration of specific constituent (mg/L)

Solubility Product: Calculation of the solubility product of selected sparingly soluble salts will be important exercise for the test plan in order to determine if there are operational limitations caused by the accumulation of limiting salts at the membrane surface. Text book equilibrium values of the solubility product should be compared with solubility values calculated from the results of experimental Verification Testing, as determined from use of the following equation:

$$K_{sp} = g_A^y [A^{y-}]^x g_B^y [B^{x+}]^y \quad (4.11)$$

where: K_{sp} = solubility product for the limiting salt being considered
 γ = free ion activity coefficient for the ion considered (i.e., A or B)
 $[A]$ = molal solution concentration of the anion A for sparingly soluble salt $A_x B_y$
 $[B]$ = solution concentration of the anion B
 x, y = stoichiometric coefficients for the precipitation reaction of A and B

Mean Activity Coefficient: The mean activity coefficients for each of the salt constituents may be estimated for the concentrated solutions as a function of the ionic strength:

$$\log g_{A,B} = -0.509 \cdot Z_A Z_B \sqrt{m} \quad (4.12)$$

where: γ = free ion activity coefficient for the ion considered (i.e., A or B)
 Z_A = ion charge of anion A
 Z_B = ion charge of cation B
 μ = ionic strength

Ionic Strength: A simple approximation of the ionic strength can be calculated based upon the concentration of the total dissolved solids in the feedwater stream:

$$m = (2.5 \cdot 10^{-5}) \cdot (TDS) \quad (4.13)$$

where: μ = ionic strength
TDS = total dissolved solids concentration (mg/L)

5.0 OVERVIEW OF TASKS

The following section provides a brief overview of the tasks that shall be included as components of the Verification Testing Plan and PSTP for removal of inorganic chemical contaminants.

5.1 Task 1: Membrane Operation

The objective of this task is to evaluate RO or NF membrane operation. The system performance shall be evaluated relative to the stated water quality goals and 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 (see Testing Periods section below). Membrane productivity, rate of specific flux decline, and rejection capabilities will be evaluated at one set of operating conditions for the testing period. Membrane operations performance will also be evaluated in relation to feedwater quality and changes in quality resulting from seasonal or climatic changes. The impact of scale formation on specific flux may also be evaluated via addition of different pretreatment chemicals.

5.2 Task 2: Cleaning Efficiency

An important aspect of membrane operation is the restoration of membrane productivity after specific flux decline has occurred. The objective of this task is to evaluate the efficiency of the membrane cleaning procedures recommended by the Manufacturer. At the conclusion of the required one-month testing period, the membrane system will be cleaned chemically according to the Manufacturer's recommended procedures. The fraction of specific flux that is restored following chemical cleaning will be determined and recorded.

5.3 Task 3: Finished Water Quality

The objective of this task is to evaluate the quality of water produced by the membrane system and the removal of inorganic chemical contaminants achieved by the membrane system at the specified operational conditions. Multiple water quality parameters will be monitored during the one-month testing period, as specified by the FTO on behalf of the Manufacturer in the PSTP. At a minimum, monitoring of the water quality parameters shall include the following: pH, feedwater temperature, conductivity, total dissolved solids (TDS), alkalinity, Langlier Saturation Index (LSI), turbidity, total suspended solids (TSS), silica (total & dissolved), total organic carbon (TOC) and silt density index (SDI). Other water quality parameters that may include individual inorganic chemical contaminant concentrations will be selected and included in the PSTP at the discretion of the FTO and the Manufacturer. Water quality produced will be evaluated in relation to feedwater quality and operational conditions. Mass balances for selected inorganic constituents shall be calculated as needed to determine the accumulation of limiting salts on the membrane surface. Post-treatment capabilities of the

equipment shall also be evaluated for pH adjustment, corrosion control, removal of carbon dioxide and hydrogen sulfide (if present) from the permeate stream.

An overview of the equipment operational and production characteristics to be evaluated for each task of the Verification Testing Plan is provided in Table 1.

Table 1: Summary of Equipment Operational Characteristics to be Evaluated in Each Verification Testing Task

Equipment Operational Characteristic to be Evaluated	Task
1. Feedwater flow rate	1
2. Permeate flow rate	1
3. Concentrate flow rate	1
4. Inlet and Outlet pressures to membrane element	1
5. Permeate pressure	1
6. Feedwater temperature	1
7. Recycle Ratio	1
8. Power consumption	1
9. Permeate stream characterization	3
10. Calculation of limiting salt concentrations	3
11. Waste stream characterization and range of waste stream flow rates	1,3

5.4 Task 4: Data Handling Protocol

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 during Verification Testing. Prior to the beginning of field testing, the database or spreadsheet 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 results can be effectively transmitted to NSF for review. Relevant data will be prepared for inclusion in a final report at the conclusion of the Verification Testing Program.

5.5 Task 5: Quality Assurance Project Plan

An important aspect of Verification Testing is the Quality Assurance Project Plan (QAPP) developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during membrane equipment Verification Testing.

6.0 TESTING PERIODS

The required tasks of the ETV Testing Plan (Tasks 1 through 5) are designed to be completed during the one-month testing period, not including mobilization, shakedown and start-up. The Verification Testing Program requires that one testing period be performed for Verification Testing; however, it is recommended that additional testing periods be conducted in order to verify equipment performance under different conditions of feedwater quality and temperature. The schedule for equipment monitoring during the one-month testing period shall be stipulated by the FTO in the PSTP, and shall meet or exceed the minimum monitoring requirements included under Task 1 of this testing plan. The FTO shall ensure in the PSTP that sufficient water quality data and operational data will be collected to allow estimation of statistical uncertainty in the Verification Testing data, as described in the “Protocol for Equipment Verification Testing of for Removal of Inorganic Constituents”, Section 4.5. The FTO shall therefore ensure that sufficient water quality and operational data are collected during Verification Testing for the statistical analysis described herein.

The recommendation for Verification Testing beyond the required one-month testing period is based on evaluation of equipment performance under different feedwater quality conditions that may be experienced annually. For example, climatic changes between rainy and dry seasons may produce substantial variability in feedwater turbidity and TOC for surface water sources. In addition, seasonal changes may also affect groundwater source quality by introducing variability in feedwater pH and variations in concentrations of TDS and specific inorganic chemical constituents. Cold weather operations can be an important component of seasonal water quality testing because of the impact of cold temperatures (1°C to 5°C) on water viscosity, membrane permeability and diffusional processes. In particular, for membrane process treatment equipment, factors that can influence treatment performance include:

- feedwaters with high seasonal concentrations of inorganic constituents and TDS. These conditions may increase finished water concentrations of inorganic chemical contaminants and may promote precipitation of inorganic materials in the membrane;
- feedwaters with variable pH; increases in feedwater pH may increase the tendency for precipitation of sparingly soluble salts in the membrane element and may require variable strategies in anti-scalant addition and pH adjustment;
- cold water, encountered in winter or at high altitude locations;
- high concentrations of natural organic matter (measured as TOC), which may be higher in some waters during different seasons;
- high turbidity, often occurring in spring, as a result of high runoff resulting from heavy rains or snowmelt.

It is highly unlikely that all of the above problems would occur in a water source during a single one-month period. Therefore, additional testing beyond the required one month of testing may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. During each testing period, Tasks 2 and 3 (evaluation of cleaning efficiency and finished water quality) can be performed concurrent with Task 1, the membrane operation testing procedures.

7.0 TASK 1: MEMBRANE OPERATION

7.1 Introduction

Membrane operation will be evaluated in Task 1, with quantification of temperature-corrected rate of specific flux decline and water recoveries. The rates of specific flux decline will be used to demonstrate membrane performance at the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the FTO in terms of a temperature-corrected flux value (e.g., gfd at 68°F or L/[m²-hr] at 20°C) before the initiation of the Verification Testing Program.

Monitoring in Task 1 shall be focused on determination of the operational characteristics such as those indicated in Table 2 (e.g.: flux, temperature-corrected specific flux, recovery, etc.). The actual operational parameters monitored will depend upon the type of Statement of Performance Objectives made in the PSTP, or other factors applicable to the technology which provide effective treatment of the feedwater. The FTO shall establish the testing conditions to be evaluated for Task 1 in the PSTP. An NSF field inspection of equipment operations and sampling and field analysis procedures may be carried out during the initial test runs in Task 1.

Rate of temperature-corrected specific flux decline is a function of water quality and operational strategy. Many additional factors may influence specific flux decline with RO or NF membranes including membrane compaction, inorganic scaling, particulate or organic fouling, biofouling, and other factors. In this task, specific flux decline shall be monitored to evaluate operational trends. Chemical characterization of the feedwaters and permeate water stream with calculation of membrane rejection capabilities will be performed as part of Task 3. In addition, calculation of the operational limitations caused by limiting salt concentrations will be performed in Task 3. The testing runs conducted under Task 1 shall be performed in conjunction with Tasks 2 and 3. With the exception of the additional testing periods conducted at the FTO's discretion, no additional membrane test runs are required for performance of Tasks 2 and 3.

Any pretreatment included in an RO, NF or other treatment system designed for inorganic contaminant removal shall be considered to be an integral part of the membrane treatment system and shall not be tested independently. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for optional evaluation purposes. The definition of pretreatment processes shall NOT include scaling control, corrosion control, and treatment for stabilization of RO-treated or NF-treated waters, as these treatments may be considered integral to the operation of the RO or NF systems.

7.2 Experimental Objectives

The objectives of Task 1 are to demonstrate the following: 1) the appropriate operational conditions for the membrane equipment; 2) the feedwater recovery achieved by the membrane equipment at the designated operational conditions; and 3) the rate of specific flux decline observed over extended membrane filtration operation during the one-month testing period. This task is also intended to provide in operational power consumption information that can be used to develop cost estimates for operation

and maintenance of the equipment. Complete chemical and physical characterization of the feedwaters and treated waters produced by the system, with calculation of limiting salt concentrations, will be performed as part of Task 3.

It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the FTO, as pertains to permeate flux and transmembrane pressure. Verification of membrane operation under the conditions specified in the Statement of Performance Objectives shall also apply to conditions that are considered less challenging to the RO or NF system. Examples of conditions considered less challenging may include lower permeate fluxes, lower system recoveries and higher cross-flow velocities.

7.3 Work Plan

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

After set-up and shakedown of the membrane equipment, RO or NF operation should be established at the operational conditions established by the Statement of Performance Objectives. The membrane system shall be operated as shown schematically in Figure 1 for a minimum of one month. A summary of the operational parameters to be recorded during Task 1 and the minimum frequency of monitoring are presented in Table 2. The FTO shall provide in the PSTP the necessary methods for monitoring of the operational parameters presented in Table 2. Additional monitoring of feedwater chemistry shall be performed during Verification Testing, as described below in Table 2.

Determination of optimal membrane operating conditions for a particular water could potentially require as long as one year of operation. For Task 1 however, each set of operating conditions shall be maintained for the one-month testing period (continuous 24-hour operation). At a minimum, the membrane shall be chemically cleaned according to Manufacturer's specifications at the conclusion of the one-month testing period. At this time, the cleaning efficiency shall be determined per the requirements outlined in Task 2.

If substantial specific flux decline occurs at the specified operating conditions before the one-month operating period is complete, adjustments to the operational strategy shall be made (such as a decrease in nominal flux or recovery). Decisions on which adjustments should be made shall be based upon the Manufacturer's experience and consultation with the FTO conducting the study. Adjustments in chemical addition (such as anti-scalant addition and pH adjustment) shall not be considered to constitute changes in the overall operational strategy, as mentioned above. The FTO shall also specify the run termination criteria for the particular RO or NF membrane equipment being tested under the Verification Testing Program. For example, the termination criteria may be defined as a 10% or 20% decline in specific flux, a drop in the percent solute rejection, or an increase in transmembrane pressure to a specific value. In the case that fouling and specific flux decline occurs in a shorter time than the one-

month testing period, the membrane shall be chemically cleaned and the operating or pretreatment conditions shall be adjusted. After these conditions are changed, the system would be operated until the completion of the one-month testing period. Because only one testing period shall be required in this Verification Testing Plan, the FTO shall specify the primary permeate flux at which the equipment is to be verified.

Table 2: Task 1 Required Minimum Operating Data

Operational Parameter	Action, Monitoring Frequency
Feedwater, permeate and concentrate flow rates (for each stage of the RO or NF system)	Check and record twice daily. Adjust when 10% above or below target. Record both before and after adjustment.
Membrane Element Inlet and Outlet Pressures (for each stage of the RO or NF system)	Check and record twice daily.
Permeate Pressure (for each stage of the RO or NF system)	Check and record twice daily
Recovery (for each stage of the RO or NF system)	Check and record twice daily. Adjust when 10% above or below target.
Recycle Ratio	Check and record twice daily. Adjust when 10% above or below target.
Total Dissolved Solids Concentration in Feedwater, Concentrate, Permeate (for each stage of the RO or NF system)	Calculation of osmotic pressure gradient on daily basis. (Calculation per Eqn. 4.4, Section 4).
Feedwater Temperature	Record twice daily
Horsepower and efficiency of motors, and consumed amperage for RO or NF treatment (at each set of operational conditions)	Provide record of pumping requirements, current draw to motors on cumulative basis, power factor.
Concentrate composition for disposal	Sample waste stream once during the minimum one-month testing period.
Concentrate flow rate for disposal	Check and record waste flow streams (if applicable) twice daily.

Concentrate streams and other waste streams generated by the membrane equipment 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 RO or NF membrane treatment system in the PSTP, including pH, temperature, conductivity, TDS, alkalinity, turbidity, TSS, TOC and disinfectant residual. The FTO shall also discuss the applicable potential waste stream disposal issues in the PSTP, including disposal to the sewer or receiving waters.

Testing of additional operational conditions may be included in the Verification Testing Program at the discretion of the Manufacturer and their designated FTO. Testing of alternate operational conditions shall be performed by including additional one-month testing period beyond the one-month testing period required by the Verification Testing Program. Additional testing periods may be included to

demonstrate membrane performance at different operational conditions or under different feedwater quality conditions. The FTO on behalf of the Manufacturer shall perform testing with as many different water quality conditions as desired for verification status.

This Membrane ETV Testing Plan has been written with the aim to balance the costs of verification with the benefits of testing the RO or NF process over a wide range of operating conditions. Given that it may take more than one month to observe a significant specific flux decline in high-pressure membrane systems as RO or NF, examination under a wide range of operating conditions would be prohibitively expensive for the membrane Manufacturer. Therefore, this Verification Testing Plan requires that one set of operating conditions be tested during the one-month testing period. It shall be furthermore understood that beyond the single set of verification operating conditions, membrane operation that occurs at a lower flux, a lower recovery, or a higher cross-flow velocity shall also constitute a verifiable condition.

7.4 Analytical Schedule

7.4.1 Operational Data Collection

Measurement of membrane performance parameters shall be monitored a minimum of 2 times per day, as indicated in Table 2. Monitoring shall be performed for each stage in the RO or NF system. Temperature measurements shall be made on a daily basis in order to provide data for temperature correction of specific flux and for reporting of solute rejection (addressed in Task 3).

In an attempt to calculate costs for operation of membrane equipment, power costs for operation of the membrane equipment shall also be closely monitored and recorded by the FTO during the one-month testing period, as indicated in Table 2. Furthermore, the costs of chemical addition shall be estimated by measurement of chemical usage through recording the day tank concentration, daily volume consumption and unit cost of chemicals.

7.4.2 Feedwater Quality Limitations

The characteristics of feedwaters used during the one-month testing period (and any additional testing periods) shall be explicitly reported with the compiled results from membrane flux, specific flux and recovery monitoring. Accurate reporting of such feedwater characteristics as pH, temperature, conductivity, TDS, alkalinity, turbidity, TSS, silica, TOC concentration and SDI is critical for the Verification Testing Program, as these parameters may substantially influence the range of achievable membrane performance and treated water quality under variable raw water quality conditions. The TDS concentrations in the feedwater, permeate and concentrate streams shall be used to calculate the osmotic pressure gradient (Equation 4.4) across the membrane on a daily basis. Osmotic pressure gradient value shall then be used for calculation of net driving pressure and specific flux on a daily basis. Specific monitoring requirements for feedwater quality shall be stipulated in Task 3.

7.5 Evaluation Criteria and Minimum Reporting Requirements

- General operational performance
 - ⇒ Graph of specific flux normalized to 20°C or 25°C (Equation 4.5) vs. time over the one-month testing period. Graphs showing time-dependent change of experimental parameters will be defined as temporal profiles. One temporal profile graph of specific flux shall be provided for each set of operational conditions and/or water qualities evaluated during Verification Testing.
 - ⇒ Temporal profile of net driving pressure normalized to 20°C or 25°C (Equation 4.3) over the one-month testing period. One temporal profile graph shall be provided for each set of operational conditions and/or water qualities evaluated during Verification Testing.
 - ⇒ Temporal profile of water recovery (Equation 4.6) over the one-month testing period. One temporal profile graph shall be provided for each set of operational conditions and/or water qualities evaluated.
 - ⇒ Temporal profile of the concentrate flow and other waste stream flows produced during the one-month testing period.
- Power consumption
 - ⇒ Provide table of horsepower requirements, motor efficiency and consumed amperage for the testing period(s), as measured for each set of operational conditions.
- Concentrate stream characterization
 - ⇒ Provide table of concentrate stream quality parameters measured during the one-month testing period.

8.0 TASK 2: CLEANING EFFICIENCY

8.1 Introduction

During and following the test runs of Task 1, the membrane equipment may require chemical cleaning to restore membrane productivity. At a minimum, one cleaning shall be performed at the conclusion of the one-month period of required testing. In the case that the membrane does not fully reach termination criteria as specified by the Manufacturer in Task 1, chemical cleaning shall be performed after the one-month testing period. Measurement of membrane performance parameters at one set of operational conditions shall be made before and after cleaning.

8.2 Experimental Objectives

The objective of this task is to evaluate the effectiveness of chemical cleaning for restoring the specific flux of the membrane system. Evaluation of the chemical cleaning procedure will be useful in confirming that standard Manufacturer-recommended cleaning practices are sufficient to restore membrane productivity. Furthermore, such testing may determine if the chemical cleaning procedure degrades the membrane in terms of its rejection capabilities for inorganic chemical contaminants. Cleaning chemicals and cleaning routines shall be adopted from the recommendations of the Manufacturer; this task is considered a "proof of concept" effort, not an optimization effort. It should be noted that selection of a chemical cleaning procedure is typically dependent upon the specific feedwater quality. The testing plan

should permit evaluation of cleaning solutions that are considered optimal for the selected feedwaters. If the Manufacturer determines that a pre-selected cleaning formulation is not effective, the testing plan should allow the Manufacturer to modify it.

8.3 Work Plan

The membrane systems may experience specific flux decline during the membrane test runs conducted for Task 1. At the conclusion of the one-month testing period, these membranes shall be utilized for the cleaning assessments. No additional experiments shall be required to produce specific flux decline such that chemical cleaning evaluations will be performed. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the Manufacturer. After each chemical cleaning of the membranes, the system shall be restarted and the initial conditions of specific flux, recovery and inorganics rejection capabilities shall be tested.

The Manufacturer and their designated FTO shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- cleaning chemicals
- quantities and costs of cleaning chemicals
- hydraulic conditions of cleaning
- time duration of each cleaning step
- initial and final temperatures of chemical cleaning solution
- quantity and characteristics of residual waste volume to be disposed
- recommended methods and considerations for disposal of residual cleaning waste

In addition, detailed procedures describing the methods for pH neutralization of the used acid or alkaline cleaning solutions should be provided along with information on the proper disposal method for regulated chemicals. A description of all cleaning equipment and its operation shall be included in the PSTP prepared by the FTO.

8.4 Analytical Schedule

8.4.1 Operational Data Collection

Flow rates, pressures, recovery, and temperature data shall be collected during the cleaning procedure if possible and shall be recorded immediately preceding system shutdown. At the conclusion of each chemical cleaning event and immediately upon return to membrane operation, the initial operating conditions of net driving pressure, flow rate, recovery, and temperature shall be recorded and the specific flux calculated.

The efficacy of chemical cleaning shall be evaluated by the recovery of temperature-adjusted specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficacy achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow evaluation of the potential for irreversible loss of specific flux and projections for

usable membrane life. Analysis of feedwater and permeate quality in subsequent runs shall also be used to evaluate any loss in membrane rejection capabilities caused by chemical cleaning.

Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in this task:

1) The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux value of the current filtration run (J_{tmf}) and the initial specific flux (J_{tmi}) measured for the subsequent filtration run:

$$\% \text{ Recovery of Specific Flux} = 100 \cdot \left[1 - \frac{J_{tmf}}{J_{tmi}} \right] \quad (8.1)$$

where: J_{tmf} = Final Specific flux (gfd/psi, L/(h-m²)/bar) at end of the previous run
 J_{tmi} = Initial Specific flux (gfd/psi, L/(h-m²)/bar) at the beginning of the current run.

2) The loss of specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run (J_{tmi}) divided by the original specific flux measured at the initiation of operation for the first filtration run in a series (J_{tmo}):

$$\% \text{ Loss of Original Specific Flux} = 100 \cdot \left[1 - \frac{J_{tmi}}{J_{tmo}} \right] \quad (8.2)$$

where: J_{tmo} = Original Specific flux (gfd/psi, L/(h-m²)/bar) measured at the initiation of membrane testing.

8.4.2 Sampling

The temperature, pH, conductivity, TDS, TOC and turbidity of each cleaning solution shall be measured and recorded during various periods of the chemical cleaning procedure. In addition, in the case that the cleaning solution employs an oxidant, such as chlorine, the concentration of the oxidant both before and at the end of the cleaning should be measured. Notes recording the visual observations (color, degree of suspended matter present) shall also be provided by the FTO. No other water quality sampling shall be required.

8.5 Evaluation Criteria and Minimum Reporting Requirements

The minimum reporting requirements shall include presentation of the following results:

- Specific flux recovery
- ⇒ Provide table of post cleaning specific flux recoveries during the one-month period of operation
- Cleaning efficiency

- ⇒ Provide table of cleaning efficiency indicators described above for chemical cleaning procedures performed during the one-month period of operation
- Assessment of irreversible loss of specific flux and estimation of usable membrane life for costing purposes.

9.0 TASK 3: FEEDWATER AND TREATED WATER QUALITY MONITORING

9.1 Introduction

The water quality data for the feedwater, the membrane permeate and concentrate streams shall be collected during the membrane test runs conducted as part of Task 1. No additional test runs shall be performed for Task 3 to acquire data on feedwater and treated water quality. The requirements for monitoring of water quality parameters in the feedwater, permeate and concentrate streams shall be clearly specified by the FTO in the PSTP according to the objectives of the Verification Testing program and the Statement of Performance Objectives. The specific water quality goals and the target removal goals for the membrane equipment shall also be recorded in the PSTP. A list of the minimum number of water quality parameters to be monitored during equipment Verification Testing in this Testing Plan is provided in Table 3 in the Analytical Schedule section below. A list of the potential water quality parameters for additional monitoring is provided in Table 4 for the feedwater, the membrane permeate and concentrate streams. The actual water quality parameters selected for testing and monitoring during equipment Verification Testing shall be explicitly stipulated by the FTO in the PSTP.

9.2 Experimental Objectives

The objective of this task is to assess the ability of the membrane equipment to demonstrate the treatment and/or rejection capabilities indicated in the PSTP Statement of Performance Objectives. Mass balances shall be performed as part of Task 3 in order to evaluate the concentration of rejected species at the membrane surface during membrane operation. Calculation of the recovery limitation caused by limiting salts will be performed to determine the impact of feedwater quality on membrane operation. Statistical analysis, as described in the “EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Inorganic Constituents: Requirements For All Studies” (Section 4.5: Recording Statistical Uncertainty) is only required for those water quality parameters that shall be monitored on a weekly basis during each Verification Testing period.

9.3 Work Plan

The Manufacturer through their designated FTO shall identify the equipment rejection capabilities for selected inorganic chemical contaminants in the Statement of Performance Objectives provided in the PSTP. The Statement of Performance Objectives shall clearly establish the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. For each Statement of Performance Objectives proposed by the FTO, the following information shall be provided: percent removal of the targeted inorganic constituent, rate of treated

water production (i.e., flux); recovery; feedwater quality regarding pertinent water quality parameters; temperature; concentration of target inorganic constituent; and other pertinent water quality and operational conditions. Two examples of acceptable Statements of Performance Objectives are provided in Section 3.0. The Statement of Performance Objectives prepared by the Manufacturer and their designated FTO shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feedwater, as indicated by examples in Section 3.0.

Monitoring of water quality parameters in the feedwater, permeate and concentrate water streams shall allow calculation of percent rejection of the measured parameters and targeted inorganic chemical contaminants for the specific operational conditions evaluated. Estimation of the percent rejection of selected inorganic water quality parameters shall be based upon the equation for solute rejection provided in the section titled Definition of Operational Parameters, Equation 4.8.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. Analysis of the remaining water quality parameters shall be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurement of water quality parameters are identified in Tables 3 and 4. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures. A number of the analytical methods utilized in this study for on-site monitoring of feedwater and permeate water qualities are further described in Task 5, Quality Assurance Project Plan.

For the water quality parameters requiring analysis at a state-certified or third party- or EPA-accredited laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the state-certified or third party- or EPA-accredited laboratory. These samples shall be preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

It should be noted that the membrane equipment participating in the Verification Testing Program for inorganics removal may be capable of achieving multiple water treatment objectives. Although this Testing Plan is oriented towards removal of inorganic chemical contaminants, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters.

9.4 Analytical Schedule

9.4.1 Feedwater, Permeate and Concentrate Characterization

During the one-month testing period, the feedwater, permeate and concentrate water streams shall be characterized at a single set of operating conditions indicated in the Statement of Performance Objectives. The minimum water quality monitoring requirements for this Verification Testing plan are provided in Table 3.

Table 3: Minimum Required Water Quality Sampling

Parameter	Sampling Frequency	Test Stream to be Sampled	Standard Method	EPA Method
pH	1/Day	Feed, Perm.	4500- H+ B	150.1 150.2
Temperature	2/Day	Feed	2550	
Conductivity	2/Day	Feed, Perm., Conc.	2510 B	120.1
TDS	1/Day	Feed, Perm., Conc.	2540 C	
Alkalinity	1/Month	Feed, Perm., Conc.	2320 B	
Langlier Saturation Index (LSI)	1/Month	Feed, Perm., Conc.		
Turbidity	1/Month	Feed, Perm., Conc.	2130 B Method 2	180.1
TSS	1/Month	Feed, Perm., Conc.	4500-NH ₃ G 2540 D	
Silica (total and dissolved)	1/Month	Feed, Perm., Conc.	3500 Si 4500-Si D 4500-Si E 4500-Si F 3120 B	200.7
TOC	1/Month	Feed, Perm., Conc.	5310 C	
Silt Density Index (SDI)	1/Month	Feed	ASTM D4189-95	
Selected Inorganic Constituents (see Table 4)	1/Week	Feed, Perm., Conc.		

In addition, the FTO (on behalf of the Manufacturer) shall indicate in the PSTP the specific target inorganic chemical contaminants that shall be monitored in the Verification Testing Program per the Statement of Performance Objectives. A list of the potential inorganic chemical contaminants that may be included in this Verification Testing program is included in Table 4. The recommended monitoring frequency for these inorganic chemical contaminants shall be a minimum of once per week.

9.4.2 Water Quality Sample Collection

Water quality data shall be collected at the specified intervals during each testing period. The minimum monitoring frequency for the minimum required water quality parameters is provided in Table 3. A minimum monitoring frequency of once per week shall be adopted for additional inorganic chemical contaminants to be included in the Verification Testing Program. At the discretion of the Manufacturer and the designated FTO, the water quality sampling program may be expanded to include any number of water quality parameters and an increased frequency of water quality parameter sampling. Sample collection frequency and protocol shall be defined explicitly by the FTO in the PSTP. To the extent possible, analyses for inorganic water quality parameters shall be performed on water sample aliquots obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

Table 4: List of Inorganic Chemical Contaminants for Verification Testing

Parameter	Standard Method	EPA Method
Aluminum	3500 Al	200.7, 200.8, 200.9
Barium	3500 Ba	200.7, 200.8
Cadmium	3500 Cd	200.7, 200.8, 200.9
Calcium	3500 Ca	200.7
Chloride	4500 Cl	300.0
Chromium	3500 Cr	200.7, 200.8, 200.9
Fluoride	4500 F ⁻	300.0
Iron	3500 Fe	200.7, 200.9
Manganese	3500 Mn	200.7, 200.8, 200.9
Magnesium	3500 Mg	200.7
Nitrate	4500 NO ₃ ⁻²	300.0, 353.2
Nitrite	4500 NO ₂ ⁻²	300.0, 353.2
Ortho-Phosphate		365.1, 300.0
Sodium	3500 Na B	200.7
Strontium	3500 Sr	200.7
Sulfate	4500 SO ₄ ⁻²	300.0, 375.2
Other Inorganic Chemical Contaminants	TBD*	
Optional:		
UV absorbance	5910 B	
Total Trihalomethanes		502.2, 524.2, 551
Haloacetic Acids		552.1
Total Coliform Bacteria	9221 B or Colilert	300.0 B
Heterotrophic Plate Count Bacteria	9215 B	300.0 B

* TBD - to be determined

The TDS concentrations in the feedwater, permeate and concentrate streams shall be used to calculate the ionic strength of the feedwater and concentrate streams, as well as osmotic pressure gradient across the membrane on a daily basis. Osmotic pressure gradient value shall then be used for calculation of net driving pressure and specific flux on a daily basis. Mass balances for specified water quality parameters shall also be calculated at a frequency (minimum of once weekly) designated by the FTO. Calculation of the potential for recovery limitation based upon limiting salt concentrations shall also be performed at a frequency (minimum of once weekly) designated by the FTO.

9.5 Evaluation Criteria and Minimum Reporting Requirements

- Percent removal of inorganic chemical constituents
 - ⇒ Provide temporal plot of concentrations of target inorganic constituents and TDS in the feedwater, permeate and concentrate water streams over the one-month period of operation. Relevant inorganic constituents for monitoring shall be specified by the FTO on behalf of the Manufacturer in the PSTP.
 - ⇒ Provide table with weekly values of percent removal of target inorganic constituents and other pertinent water quality parameters for the one-month period of operation. The equation shown in the section titled Definition of Operational Parameters shall be used to determine percent removal of all pertinent water quality parameters for Verification Testing by the FTO and Manufacturer.
 - ⇒ Conduct mass balances through the membrane testing system for specific water quality constituents (minimum of once weekly) as identified by the FTO in the PSTP. The mass balance equation presented in the section titled Definition of Operational Parameters shall be used to the mass of concentration of inorganic constituents in different water streams.
 - ⇒ Calculate limiting salt concentrations (via solubility product calculation Equation 4.11) for specific water quality constituents (minimum of once weekly) as identified by the FTO in the PSTP. The equation for solubility product calculation as presented in the section titled Definition of Operational Parameters (Equation 4.11) shall be used to compare with standard Solubility Product values to determine if the salt concentration is posing a limitation to operational system recovery.
- Individual water quality and removal goals specified by the Manufacturer
 - ⇒ Provide feed, permeate and concentrate concentrations of any measured water quality parameters in tabular form for the one-month period of operation.
- Removal of Total Suspended Solids and Turbidity
 - ⇒ Plot temporal graph of feedwater and permeate measurements for total suspended solids during the one-month period of operation.
 - ⇒ Plot temporal graph of feedwater and permeate turbidity measurements during the one-month period of operation.

10.0 TASK 4: DATA HANDLING PROTOCOL

10.1 Introduction

The data management system used in the Verification Testing program shall involve the use of computer spreadsheets and manual (or on-line) recording of operational parameters for the membrane equipment on a daily basis.

10.2 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 to NSF for verification

purposes, and 2) to develop a statistical analysis of the data, as described in the document “EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Inorganic Constituents: Requirements For All Studies.”

10.3 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 membrane equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

In the case when a SCADA system is not available, 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.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the FTO at least once per week during the one-month testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the membrane 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 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 spreadsheet. 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 membrane test run) shall 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 state-certified or third party- or EPA-accredited laboratories, the data shall be tracked by use of the same system of run numbers. 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.

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, lap-top computers, data acquisition systems etc., shall be detailed by the FTO in the PSTP.

11.0 TASK 5: QUALITY ASSURANCE PROJECT PLAN (QA/QC)

11.1 Introduction

Quality assurance and quality control of the operation of the membrane equipment and the measured water quality parameters shall be maintained during the Verification Testing program. A Quality Assurance Project Plan detailing the QA/QC procedures to be followed during Verification Testing shall be provided by the FTO as part of the PSTP.

11.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. 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.

11.3 Work Plan

Equipment flowrates and associated signals should 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. Particular care shall be taken to confirm that any chemicals are being fed at the defined flowrate into a flowstream that is operating at the expected flowrate, such that the chemical concentrations are correct. In-line monitoring equipment such as flowmeters, etc. shall be checked to confirm that the readout matches with the actual measurement (i.e. flowrate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

11.3.1 Daily QA/QC Verifications:

- Chemical feed pump flowrates (verified volumetrically over a specific time period)
- Flow rates to on-line analytical equipment (e.g., pH meter, conductivity meter, turbidimeter), if any (verified volumetrically over a specific time period).

11.3.2 Monthly QA/QC Verifications:

- In-line flowmeters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings);
- On-line pH meters, conductivity meters, turbidimeters etc. (clean out reservoirs and recalibrate, if employed)

- 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)

11.4 Analytical Methods and Sample Collection

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

11.4.1 pH

Analyses for pH shall be performed according to Standard Method 4500-H⁺. A three-point calibration of the 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.

11.4.2 Conductivity

Analyses for conductivity shall be performed according to Standard Method 2510 B. A three-point calibration of the conductivity meter used in Verification Testing shall be performed once per day when the instrument is in use. Certified conductivity solutions in the expected range shall be used. The probe shall be stored in the appropriate solution defined in the instrument manual.

11.4.3 Turbidity

Turbidity analyses shall be performed according to Standard Method 2130 with either an on-line or bench-top turbidimeter. During each testing period, the on-line and bench-top turbidimeters shall be left on continuously. Once each turbidity measurement is complete, the unit shall be switched back to its lowest setting. All glassware used for turbidity measurements shall be cleaned and handled using lint-free tissues to prevent scratching. Sample vials shall be stored inverted to prevent deposits from forming on the bottom surface of the cell.

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

On-line Turbidimeters: On-line turbidimeters may be used for measurement of turbidity during Verification Testing, and must be calibrated as specified in the instrument manufacturer's operation and maintenance manual. It will be necessary to periodically verify the on-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 the comparison suggest inaccurate readings, then all on-line turbidimeters should be re-calibrated. 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 shall also be performed using a volumetric measurement. Instrument bulbs shall be replaced on an as-needed basis. It should also be verified that the LED read-out matches the data recorded by the data acquisition system, if the latter is employed.

Bench-Top Turbidimeters: Grab samples of feedwater and oxidized/disinfected water may be analyzed using a bench-top turbidimeter. Readings from this instrument shall 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 5.0 Nephelometric Turbidity Units (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 re-calibrate when more than one turbidity range is used.

The method for collecting grab samples shall be performed according to the following protocol: 1) running a slow, steady stream from the sample tap, 2) triple-rinsing a dedicated sample beaker in this stream, 3) allowing the sample to flow down the side of the beaker to minimize bubble entrainment, 4) double-rinsing the sample vial with the sample, 5) carefully pouring from the beaker down the side of the sample vial, 6) wiping the sample vial clean, 7) inserting the sample vial into the turbidimeter, and 8) 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 in a warm water bath for approximately 30 seconds.

11.4.4 Analysis for Inorganic Chemical Contaminants

Methods to be employed for analysis of specific analytical parameters shall be explicitly identified by the FTO in the PSTP. The methods selected for analysis of all inorganic constituents shall comply with those described in the most recent edition of Standard Methods or should be considered a comparable EPA Method.

12.0 OPERATION AND MAINTENANCE

The following are recommendations for criteria to be included in Operation and Maintenance (O&M) Manuals for RO/NF membrane systems that are designed to achieve removal of inorganic chemical constituents. Descriptions of the membrane equipment unit process shall be developed by the FTO on behalf of the Manufacturer and included in the PSTP. Appropriate parameters for system description shall include but not be limited to the following elements: standard design criteria, membrane element and process characteristics, pre-treatment requirements and post-treatment concerns. An overview of

the pertinent membrane plant design information that may be required for the PSTP is provided in Table 5. A list of relevant membrane element characteristics is provided in Table 6. Table 7 provides an overview of the chemical addition details that are pertinent to operation and design of pretreatment systems ahead of RO/NF. The following sections provide lists of maintenance and operations criteria that may be helpful for development of O & M Manuals for RO membrane systems.

12.1 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, including detailed information on the valve configuration for cross-flow operation
- pressure gauges
- flow meters
- air compressors
- chemical feeder systems
- mixers
- motors
- instruments, such as streaming current monitors or turbidimeters
- water meters, if provided

The Manufacturer shall 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

12.2 Operation

The Manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are the following issues:

Membrane Filtration:

- control of feed flow to the membrane system and individual stages
- measurement of inlet/outlet pressures and permeate flows
- measurement of transmembrane pressure changes during membrane test run
- feed flow control in response to temperature changes
- measurement/calculation of cross-flow velocity

Chemical cleaning:

- selection of proper chemical washing sequence
- proper procedures for dilution of chemicals
- monitoring of pH through chemical cleaning cycle

- rinsing of membrane system following chemical clean
- return of membrane system to service

Chemical feeders (in the case that chemical pretreatment is applied):

- calibration check on flow meters and dosing pumps
- settings and adjustments -- how they should be made
- dilution of chemicals -- proper procedures

Intermittent Operation:

- proper procedures for system shut-down and start-up
- safety checks of chemical concentrations prior to system shut-down
- safety checks of potential contaminant concentrations prior to system shut-down and start-up
- proper procedures for rinsing and disinfection of system following shut-down

Monitoring and Sampling Procedures:

- observation of feedwater or pretreated water turbidity
- observation of transmembrane pressure increase
- proper monitoring procedures for measurement of permeate conductivity
- proper safety procedures

The Manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- no raw water (feedwater) flow to plant
- can't control rate of flow of water through equipment
- poor permeate quality
- failed test for membrane integrity
- low pressure at feedwater pump
- automatic operation (if provided) not functioning
- transmembrane pressure builds up excessively rapidly
- reduced permeate flux
- reduced percent solute rejection
- 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 for pH adjustment
- no antiscalant addition

12.3 Operability

The following are recommendations regarding operability aspects of systems that are designed to achieve removal of inorganic chemical 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 and pressures through membrane unit -- the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- presence of devices to aid the operator with flow control adjustment and chemical dosage selection:
 - ⇒ are continuous turbidimeters provided for monitoring of feedwater and permeate turbidity?
- continuous particle counter provided for monitoring of membrane permeate?
- does plant have multiple feed points for chemicals:
 - ⇒ for pH adjustment?
 - ⇒ for antiscalant addition?
- is transmembrane pressure measurement provided?
- is rate of flow of raw water measured?
- are chemical feeds paced with raw water flow?

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 should be dealt with in the portion of the reports that are written in response to Tasks 1 & 2 of the Verification Testing Plan.

Table 5: Membrane Plant Design Criteria Reporting Items

Parameter	Value
Number of Stages	
Number Pressure Vessels in Stage 1	
Number Pressure Vessels in Stage 2	
Number Membrane Elements per Pressure Vessel	
Recovery per Stage (%)	
Recovery for System (%)	
Design Flux (gfd)	
Initial Specific Flux (gfd/psi) at 20 °C or at 25 °C	
Maximum Flow Rate to an Element (gpm)	
Minimum Flow Rate to an Element (gpm)	
Pressure Loss per Element (psi)	
Pressure Loss in Stage Entrance and Exit (psi)	
Feed Stream TDS (mg/L)	
TDS Rejection (%)	
Rejection of Specific Inorganic Constituent (%)	

Table 6: Membrane Element Characteristics

Parameter	Value
Membrane Manufacturer	
Membrane Element Model Number	
Size of Element Used in Study (e.g., 4"x40")	
Active Membrane Surface Area per Element (ft ² , m ²)	
Active Surface Area of Equivalent 8"x40" Element (ft ² , m ²)	
Sales Price for an Equivalent 8"x40" Element (\$)	
Molecular Weight Cut-Off (Daltons)	
Membrane Material Construction	
Membrane Hydrophobicity	Hydrophilic/Hydrophobic
Reported Membrane Charge	Negative/Neutral/Positive
Spacer Thickness (ft)	
Scroll Width (ft)	
Design Pressure (psi)	
Design Flux at Design Pressure (gfd)	
Variability of Design Flux (%)	
Design Specific Flux (gfd/psi) at 20 °C at 25 °C	
Standard Testing Recovery (%)	
Standard Testing pH	
Standard Testing Temperature (°C)	
Design Cross-Flow Velocity (ft/s)	
Maximum Flow Rate to an Element (gpm)	
Minimum Flow Rate to an Element (gpm)	
Required Feed Flow to Permeate Flow Ratio	
Maximum Element Recovery (%)	
Rejection of Reference Solute and Conditions of Test (e.g., Solute type and concentration)	
Variability of Rejection of Reference Solute (%)	
Acceptable Range of Operating Pressures (psi, bar)	
Acceptable Range of Operating pH Values	
Typical Pressure Drop across a Single Element (psi)	
Maximum Permissible SDI	
Maximum Permissible Turbidity	
Chlorine/Oxidant Tolerance	
Suggested Cleaning Procedures	

Table 7: Pretreatment Processes Used Ahead of Reverse Osmosis or Nanofiltration

Parameter	Value
Pre-Filter Exclusion Size (μm)	
Type of Acid used	
Acid Concentration	
Volume Acid added (mL) per L of Feedwater	
Type of Scale Inhibitor Used	
Scale Inhibitor Concentration	
Volume Scale Inhibitor added (mL) per L of Feedwater	
Type of Coagulant used	
Coagulant Dose (mg/L)	
Type of Polymer used during Coagulation	
Polymer Dose (mg/L)	

13.0 REFERENCES

Standard Methods for the Examination of Water and Wastewater. 1999. 20th edition. APHA, AWWA, and WEF, Washington, D.C.

Streeter, V.L. and E.B. Wiley. 1985. *Fluid Mechanics*, 8th ed. New York, McGraw Hill Book Company.

USEPA, 1989. Guidance Manual for Compliance with Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources, Cincinnati, OH. Science and Technology Branch.

USEPA, 1990. Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Waters. American Water Works Association, Washington, D.C.

USEPA, 1996. ICR Manual for Bench- and Pilot-Scale Treatment Studies. Office of Ground Water and Drinking Water, Cincinnati, OH. Technical Support Division.

CHAPTER 3

EPA/NSF ETV

EQUIPMENT VERIFICATION TESTING PLAN

FOR THE REMOVAL OF INORGANIC CHEMICAL AND RADIONUCLIDE

CONTAMINANTS BY ELECTRODIALYSIS AND

ELECTRODIALYSIS REVERSAL

Prepared by:
NSF International
789 Dixboro Road
Ann Arbor, Michigan 48105

Copyright 2002 NSF International 40CFR35.6450.

Permission is hereby granted to reproduce all or part of this work, subject to the limitation that users may not sell all or any part of the work and may not create any derivative work therefrom. Contact ETV Drinking Water Systems Center Manager at (800) NSF-MARK with any questions regarding authorized or unauthorized uses of this work.

TABLE OF CONTENTS

	<u>Page</u>
1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN	3-4
2.0 INTRODUCTION	3-4
3.0 GENERAL APPROACH	3-5
4.0 DEFINITION OF OPERATIONAL PARAMETERS	3-6
5.0 OVERVIEW OF TASKS	3-9
5.1 Task 1: Membrane Operation	3-9
5.2 Task 2: Cleaning Efficiency.....	3-9
5.3 Task 3: Finished Water Quality.....	3-11
5.4 Task 4: Data Handling Protocol	3-11
5.5 Task 5: Quality Assurance Project Plan	3-11
6.0 TESTING PERIODS	3-11
7.0 TASK 1: MEMBRANE OPERATION	3-12
7.1 Introduction	3-12
7.2 Experimental Objectives	3-13
7.3 Work Plan	3-13
7.4 Analytical Schedule	3-15
7.4.1 Operational Data Collection	3-15
7.4.2 Feedwater Quality Limitations	3-16
7.5 Evaluation Criteria and Minimum Reporting Requirements	3-16
8.0 TASK 2: CLEANING EFFICIENCY	3-17
8.1 Introduction	3-17
8.2 Experimental Objectives	3-17
8.3 Work Plan	3-17
8.4 Analytical Schedule	3-18
8.4.1 Operational Data Collection	3-18
8.4.2 Sampling	3-19
8.5 Evaluation Criteria and Minimum Reporting Requirements	3-19
9.0 TASK 3: FEEDWATER AND TREATED WATER QUALITY MONITORING	3-19
9.1 Introduction	3-19
9.2 Experimental Objectives	3-20

TABLE OF CONTENTS (continued)

		<u>Page</u>
9.3	Work Plan	3-20
9.4	Analytical Schedule	3-21
	9.4.1 Feedwater, Product and Concentrate Characterization	3-21
	9.4.2 Water Quality Sample Collection	3-22
9.5	Evaluation Criteria and Minimum Reporting Requirements	3-23
10.0	TASK 4: DATA HANDLING PROTOCOL	3-24
10.1	Introduction	3-24
10.2	Experimental Objectives	3-24
10.3	Work Plan	3-24
11.0	TASK 5: QUALITY ASSURANCE PROJECT PLAN	3-25
11.1	Introduction	3-25
11.2	Experimental Objectives	3-25
11.3	Work Plan	3-26
	11.3.1 Daily QA/QC Verifications	3-26
	11.3.2 Monthly QA/QC Verifications	3-26
11.4	Analytical Methods and Sample Collection	3-26
	11.4.1 pH	3-26
	11.4.2 Conductivity	3-26
	11.4.3 Turbidity	3-27
	11.4.4 Analysis of Inorganic Contaminants.....	3-28
12.0	OPERATION AND MAINTENANCE	3-28
12.1	Maintenance	3-29
12.2	Operation	3-30
12.3	Operability	3-31
13.0	REFERENCES	3-32

TABLES

Table 1.	Summary of Equipment Operational Characteristics to be Evaluated in Each Verification Testing Task	3-10
Table 2.	Task 1 Required Minimum Operating Data	3-14
Table 3.	Minimum Required Water Quality Sampling	3-21
Table 4.	List of Inorganic Chemical Contaminants for Verification Testing	3-22
Table 5.	Membrane Plant Design Criteria Reporting Items	3-28
Table 6.	Membrane Element Characteristics	3-29

1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for electrodialysis and electrodialysis reversal (ED/EDR). It should be noted that this Equipment Verification Plan is only applicable to electrically driven membrane processes.

In order to participate in the equipment verification process for ED/EDR, the Field Testing Organization (FTO) must adhere to the procedures and methods described in this study protocol and in the referenced ETV Protocol Document as guidelines for the development of a Product-Specific Test Plan (PSTP). The Procedures should generally follow those Tasks outlined herein, with changes and modifications made for adaptations to specific ED/EDR equipment. At a minimum, the format of the procedures written for each Task in the PSTP should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing Program is to achieve removal of inorganic or radioactive chemical constituents present in feedwater supplies. The Manufacturer may wish to establish a Statement of Performance Objectives (see General Approach below) that is based upon removal of target inorganic constituent(s) from feedwaters. The experimental design of the PSTP shall be developed to address that specific Statement of Performance Objectives established by the Manufacturer. Each PSTP shall include all of the included tasks, Tasks 1 to 5 as outlined below.

2.0 INTRODUCTION

Electrodialysis (ED) and Electrodialysis Reversal (EDR) are electrically driven membrane processes that are used for a broad number of water treatment applications ranging from sea water desalting processing, brackish water desalting, ultrapure water production and other specialized industrial applications. The most common application of ED/EDR is the production of potable water or demineralized industrial process water from brackish water sources. ED and EDR reduce the total dissolved solids in brackish water by electrically removing contaminants that exceed acceptable levels for drinking or process water.

ED/EDR is an electrochemical separation process in which ions are transferred through membranes from a diluting stream to a more concentrated solution as a result of direct electric current flow. Water flows through flow spacers between cation and anion selective membranes with the direct current between the anode and cathode serving as the driving force for the migration of ions. The membranes are “stacked”, alternating the cation and anion permeable membranes thus allowing the ions to be

removed or concentrated in the alternate water passages depending on the selectivity of the membrane. Cations are attracted to the negative electrode (cathode) and anions to the positive electrode (anode).

In order to establish appropriate operating conditions, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established prior to Verification Testing. The need of pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as part of this Verification Testing Plan will be contracted with a laboratory certified by a state or accredited by a third party organization (i.e. NSF) or the US Environmental Protection Agency (USEPA) for the appropriate water quality 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. The Statement of Performance Objectives must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or under perform. There are different types of Statements of Performance Objectives that may be verified in this testing. Examples of two statements are:

1. *“This system is capable of achieving 90% fluoride removal during the operation using three electrical and three hydraulic stages at 90% water recovery in feedwater where fluoride levels are less than 10 mg/L and total hardness is less than 100 mg/L as CaCO₃ for water temperature ranging between 10° and 45°C.”*
2. *“This system is capable of producing a product water with less than 4 mg/L fluoride concentration during operation at recovery of 90 % (3-stage EDR) in feedwater with fluoride concentrations less than 10 mg/L and total hardness levels less than 100 mg/L as CaCO₃ for water temperature ranging between 10° and 45°C.”*

For each Statement of Performance Objectives proposed by the FTO and the Manufacturer in the PSTP, the following information shall be provided: percent removal of the targeted inorganic constituent; rate of treated water production; recovery; feedwater quality regarding pertinent water quality parameters; temperature; concentration of target inorganic constituent; and other pertinent water quality and operational conditions. During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Objectives. A mass balance using feed, product and waste stream concentrations must be used to confirm that steady state has been obtained and that none of the contaminant being removed is retained by the ED/EDR membrane stack(s).

This ETV Testing Plan is broken down into eight tasks, as shown in the Overview of Tasks section below. As noted above, Tasks 1 to 5 shall be performed by any manufacturer wanting to achieve verification of their equipment by NSF. The manufacturer shall provide full detail of the procedures to be followed in each Task in the PSTP. The Manufacturer shall specify the operational conditions to be verified during the Verification Testing Plan and provide water quality and performance data as needed to verify performance.

4.0 DEFINITION OF OPERATIONAL PARAMETERS

Faraday’s Law (Equation 4.1): The passage of 96,500 amperes of electric current for one second will transfer one gram equivalent of salt. The quantity of 96,500 amperes-seconds is called a Faraday. Faraday’s law is the basis for calculating the amount of electric current needed in a ED/EDR system for transferring a specific quantity of salts.

$$I = \frac{F^* \times Q_d \times \Delta N}{e \times n} \quad (\text{Equation 4.1})$$

where: I = Direct electric current in amperes
 F* = Faraday’s constant (96,500 ampere-seconds/equivalent)
 Q_d = Flow rate of the demineralized stream through the membrane stack (L/sec).
 ΔN = Change in normality of demineralized stream between the inlet and outlet of membrane stack (equivalents/L)
 e = Current efficiency
 n = Number of cell pairs

Ohm’s Law (Equation 4.2): Ohm’s Law states that the potential (E) of an electrical system is equal to the product of current (I) and the system resistance (R).

$$E = I \times R \quad (\text{Equation 4.2})$$

Resistance in Series Model (Equation 4.3): Several components make-up the resistance in an ED/EDR system in order to use Ohm’s Law. The following resistance components must be included in calculating the system resistance using the applied voltage and amperage as shown in Equation 4.2 for a given salt removal and temperature condition.

$$R_{cp} = R_{cm} + R_{am} + R_c + R_{di} \quad (\text{Equation 4.3})$$

where: R_{cp} = resistance per unit area of one cell (ohm/cm²)
 R_{cm} = resistance per unit area of cation membrane (ohm/cm²)
 R_{am} = resistance per unit area of anion membrane (ohm/cm²)
 R_c = resistance per unit area of concentrate stream (ohm/cm²)
 R_{di} = resistance per unit area of demineralized stream (ohm/cm²)

Electrical Resistance (Equation 4.4): The electrical resistance of an ED/EDR system is done using the initial resistance calculated using Equation 4.3. This is based on the initial water quality conditions, percent salt removals and water temperature. During operation of the ED/EDR system, the total stack electrical resistance is calculated using Equation 4.3 and normalized for feed water quality conditions, salt removals and temperature according to the manufacturer's normalization criteria. The change in electrical resistance during the demonstration program will be presented as follows and plotted against time:

$$R_d = R_t \div R_i \quad \text{(Equation 4.4)}$$

where:

- R_d = resistance change per unit ED/EDR stack (ohm/cm²)
- R_t = resistance of ED/EDR stack at time "t" (ohm/cm²)
- R_i = resistance of ED/EDR stack at start-up (ohm/cm²)

Current Efficiency (Equation 4.5): The efficiency of the current being used to transfer salts across the membrane can be calculated using the following equation:

$$e = \frac{F^* \times Q_d \times \Delta N \times 100}{I \times n} \quad \text{(Equation 4.5)}$$

- where:
- I = Direct electric current (amperes)
 - F^* = Faraday's constant (96,500 ampere-sec./equivalent)
 - Q_d = Flow rate of the demineralized stream through the membrane stack (L/sec).
 - ΔN = Change in normality of demineralized stream between the inlet and outlet of membrane stack (equivalent/L)
 - e = Current efficiency
 - n = Number of cell pairs

Feed stream: This is the water quality that is fed into the membrane stack. Most of the feed stream is fed into the dilute stream (the stream that the salts are being removed from) and a lesser amount into the concentrate stream.

Dilute stream: Stream in the membrane stack that the salts are being removed from and eventually becomes the product water from the ED/EDR process.

Concentrate stream: Stream in membrane stack into which ions are transferred into and concentrated. This is also referred to as the brine stream. A portion of the concentrate stream is typically re-circulated through the membrane stack to maintain crossflow velocities through the membrane stack and increase water recovery.

Water Recovery (Equation 4.6): Total amount of water produced from the total amount of water used. Recovery can be calculated from the following equation:

$$\text{Recovery} = \frac{Q_{\text{feed}} - Q_{\text{product}}}{Q_{\text{feed}}} \times 100\% \quad (\text{Equation 4.6})$$

Solute Rejection (Equation 4.7): Solute rejection is controlled by a number of operational variables that must be reported at the time of water sample collection. Bulk rejection of a targeted inorganic chemical contaminant may be calculated by the following equation.

$$\% \text{ Solute Rejection} = 100 \cdot \left[\frac{C_f - C_p}{C_f} \right] \quad (\text{Equation 4.7})$$

where: C_f = feedwater concentration of specific constituent (mg/L)
 C_p = product concentration of specific constituent (mg/L)

Water and Solute Mass Balance (Equation 4.8): Calculation of solvent (water) mass balance shall be performed during Task 1 in order to verify the reliability of flow measurements through the membrane. Calculation of solute mass balance across the membrane system shall be performed as part of Task 3 in order to estimate the concentration of limiting salts at the membrane surface.

$$\begin{aligned} Q_f &= Q_p + Q_c \\ Q_f C_f &= Q_p C_p + Q_c C_c \end{aligned} \quad (\text{Equation 4.8})$$

where: Q_f = feedwater flow to the membrane (gpm, L/h)
 Q_p = product flow (gpm, L/h)
 Q_c = concentrate flow (gpm, L/h)
 C_f = feedwater concentration of specific constituent (mg/L)
 C_p = product concentration of specific constituent (mg/L)
 C_c = concentrate concentration of specific constituent (mg/L)

Solubility Product (Equation 4.9): Calculation of the solubility product of selected sparingly soluble salts will be required for the test plan in order to determine operational limitations caused by the accumulation of limiting salts at the membrane surface. Text book equilibrium values of the solubility product should be compared with solubility values calculated from the results of experimental Verification Testing, as determined from use of the following equation:

$$K_{sp} = \gamma_A^x [A^{y-}]^x \gamma_B^y [B^{x+}]^y \quad (\text{Equation 4.9})$$

where: K_{sp} = solubility product for the limiting salt being considered
 γ = free ion activity coefficient for the ion considered (i.e., A or B)
[A] = molal solution concentration of the anion A for sparingly soluble salt $A_x B_y$
[B] = molal solution concentration of the anion B for sparingly soluble salt $A_x B_y$
x, y = stoichiometric coefficients for the precipitation reaction of A and B

Mean Activity Coefficient (Equation 4.10): The mean activity coefficients for each of the salt constituents may be estimated for the concentrated solutions as a function of the ionic strength:

$$\log g_{A,B} = -0.509 \cdot Z_A Z_B \sqrt{m} \quad (\text{Equation 4.10})$$

where: g = free ion activity coefficient for the ion considered (i.e., A or B)
 Z_A = ion charge of anion A
 Z_B = ion charge of cation B
 m = ionic strength (cm²/sec-volt-equivalent)

Ionic Strength (Equation 4.11): A simple approximation of the ionic strength can be calculated based upon the concentration of the total dissolved solids in the feedwater stream:

$$m = (2.5 \cdot 10^{-5}) \cdot (TDS) \quad (\text{Equation 4.11})$$

where: μ = ionic strength (cm²/sec-volt-equivalent)
TDS = total dissolved solids concentration (mg/L)

5.0 OVERVIEW OF TASKS

The following section provides a brief overview of the tasks that shall be included as components of the Verification Testing Plan and PSTP for the removal of inorganic and radionuclide contaminants.

5.1 Task 1: Membrane Operation

The objective of this task is to evaluate ED/EDR membrane operation. The system performance shall be evaluated relative to the stated water quality goals and other performance characteristics specified by the Manufacturer. For Verification Testing purposes, the equipment shall be operated for a minimum of one, two-month testing period (see Testing Periods section below). Membrane productivity, rate of performance decline, and rejection capabilities will be evaluated at one set of operating conditions for the testing period. Membrane operations performance will also be evaluated in relation to feedwater quality and changes in quality resulting from seasonal or climatic changes. The impact of scale formation may also be addressed via addition of different pretreatment chemicals.

5.2 Task 2: Cleaning Efficiency

Materials are deposited on the membrane's surface and can create "hot spots" and cause loss of performance. Changes in feed water quality can cause increased fouling as well as operational changes. Chemical cleaning is used to recover the ED/EDR systems performance and remove foulants from the membrane's surface. The efficiency of the clean-in-place process determines how well the foulants are removed from the membranes and the long term performance of the system.

5.3 Task 3: Finished Water Quality

The objective of this task is to evaluate the quality of water produced by the membrane system and the removal of inorganic chemical contaminants achieved by the membrane system at the specified operational conditions. Multiple water quality parameters will be monitored during the two-month testing period, as specified by the FTO on behalf of the Manufacturer in the PSTP. At a minimum, monitoring of the water quality parameters shall include the following: pH, feedwater temperature, conductivity, total dissolved solids (TDS), alkalinity, Langlier Saturation Index (LSI), turbidity, total suspended solids (TSS), sulfate, sulfide, hardness, calcium, iron, manganese, aluminum, total organic carbon (TOC) and UV-254. Other water quality parameters that may include individual inorganic chemical or radionuclide contaminant concentrations will be selected and included in the PSTP at the discretion of the FTO and the Manufacturer. Water quality produced will be evaluated in relation to feedwater quality and operational conditions. Mass balances for selected inorganic constituents shall be calculated as needed to determine the accumulation of limiting salts on the membrane surface. Post-treatment capabilities of the equipment shall also be evaluated for pH adjustment and corrosion control in the product stream.

An overview of the equipment operational and production characteristics to be evaluated for each task of the Verification Testing Plan is provided in Table 1.

Table 1: Summary of Equipment Operational Characteristics to be Evaluated in Each Verification Testing Task

Equipment Operational Characteristic to be Evaluated	Task
1. Feedwater flow rate	1
2. Dilute stream flow rate	1
3. Concentrate flow rate	1
4. Off-Spec operational period	1
5. Inlet and Outlet pressures to membrane stack	1
6. Applied Stack Voltage	1
7. Applied Stack Amperage	1
8. Feedwater temperature	1
9. Electrode flush flow rate	1
10. Feed Water Conductivity	1
11. Feed Stream characterization	1
12. Product Water Conductivity	1
13. Power consumption	1
14. Current efficiency	1
15. Dilute stream characterization	3
16. Calculation of limiting salt concentrations	3
17. Waste stream characterization and range of waste stream flow rates	1,3

5.4 Task 4: Data Handling Protocol

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 the NSF during Verification Testing. Prior to the beginning of field testing, the database or spreadsheet 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 results can be effectively transmitted to NSF for review. Relevant data will be prepared for inclusion in a final report at the conclusion of the Verification Testing Program.

5.5 Task 5: Quality Assurance Project Plan

An important aspect of Verification Testing is the Quality Assurance Project Plan (QAPP) developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during membrane equipment Verification Testing.

6.0 TESTING PERIODS

The required tasks of the ETV Plan (Tasks 1 through 5) are designed to be completed during the two-month testing period, not including mobilization, shakedown and start-up. The Verification Testing Program requires that one testing period be performed for Verification Testing; however, it is recommended that additional testing periods be conducted in order to verify equipment performance under different conditions of feedwater quality and temperature. The schedule for equipment monitoring during the two-month testing period shall be stipulated by the FTO in the PSTP, and shall meet or exceed the minimum monitoring requirements included under Task 1 of this testing plan. The FTO shall ensure in the PSTP that sufficient water quality data and operational data will be collected to allow estimation of statistical uncertainty in the Verification Testing data, as described in the “EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Inorganic Constituents: Requirements For All Studies”, Section 4.5. The FTO shall therefore ensure that sufficient water quality and operational data are collected during Verification Testing for the statistical analysis described herein.

The recommendation for Verification Testing beyond the required two-month testing period is based on evaluation of equipment performance under different feedwater quality conditions that may be experienced annually. For example, climatic changes between rainy and dry seasons may produce substantial variability in feedwater turbidity and TOC for surface water sources. In addition, seasonal changes may also affect groundwater source quality by introducing variability in feedwater pH and variations in concentrations of TDS and specific inorganic chemical constituents. Cold weather operations can be an important component of seasonal water quality testing because of the impact of cold temperatures (1°C to 5°C) on water viscosity, membrane selectivity and salt diffusion process. In particular, for membrane process treatment equipment, factors that can influence treatment performance include:

- feedwaters with high seasonal concentrations of inorganic constituents and TDS. These conditions may increase finished water concentrations of inorganic chemical contaminants and may promote precipitation of inorganic materials in the membrane;
- feedwaters with variable pH; increases in feedwater pH may increase the tendency for precipitation of sparingly soluble salts in the membrane element and may require variable operational strategies.
- excessive levels of hydrogen sulfide, iron, manganese and aluminum must be removed prior to the ED/EDR unit;
- cold water, encountered in winter or at high altitude locations;
- high concentrations of natural organic matter (measured as TOC), which may be higher in some waters during different seasons;
- high turbidity, often occurring in spring, as a result of high runoff resulting from heavy rains or snowmelt.

It is highly unlikely that all of the above problems would occur in a water source during a single two-month period. Therefore, additional testing beyond the required two months of testing may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. During each testing period, Tasks 2 and 3 (evaluation of cleaning efficiency and finished water quality) can be performed concurrent with Task 1, the membrane operation testing procedures.

7.0 TASK 1: MEMBRANE OPERATION

7.1 Introduction

Membrane operation will be evaluated in Task 1, with quantification of electrical resistance, current efficiency and differential pressure. The rate of electrical resistance increase will be used to demonstrate membrane performance at the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the FTO in terms of a temperature and salt removal corrected electrical resistance value (e.g., electrical resistance for % salt rejection at 20 °C per number of cell pairs) before the initiation of the Verification Testing Program.

Monitoring in Task 1 shall be focused on determining the operational characteristics such as those indicated in Table 2 (e.g.: current efficiency, electrical resistance, recovery, etc.). The actual operational parameters monitored will depend upon the type of Statement of Performance Objectives made in the PSTP, or other factors applicable to the technology that provide effective treatment of the feedwater. The FTO shall establish the testing conditions to be evaluated for Task 1 in the PSTP. An NSF field inspection of equipment operations and sampling and field analysis procedures may be carried out during the initial test runs in Task 1.

The rate of the electrical resistance increase is a function of water quality and operational strategy. Many factors may influence performance decline with ED/EDR membranes including inorganic scaling, particulate or organic fouling, biofouling, and other factors. In Task 1, electrical resistance increase shall be monitored to evaluate operational trends. Chemical characterization of the feedwater and dilute water stream with calculation of membrane rejection capabilities will be performed as part of Task 3. In addition, calculation of the operational limitations caused by limiting salt concentrations will be performed in Task 3. The testing runs conducted under Task 1 shall be performed in conjunction with Tasks 2 and 3. With the exception of the additional testing periods conducted at the FTO's discretion, no additional membrane test runs are required for performance of Tasks 2 and 3.

Any pretreatment included in an ED/EDR or other treatment system designed for inorganic contaminant removal shall be considered to be an integral part of the membrane treatment system and shall not be tested independently. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for optional evaluation purposes. The definition of pretreatment processes shall NOT include scaling control, corrosion control, and treatment for stabilization of ED/EDR-treated waters, as these treatments may be considered integral to the operation of the ED/EDR system.

7.2 Experimental Objectives

The objectives of Task 1 are to demonstrate the following: 1) the appropriate operational conditions for the membrane equipment; 2) the feedwater recovery achieved by the membrane equipment at the designated operational conditions; and 3) the rate of electrical resistance increase observed over extended ED/EDR membrane system operation during the two-month testing period. Task 1 is also intended to provide in operational power consumption information that can be used to develop cost estimates for operation and maintenance of the equipment. Complete chemical and physical characterization of the feedwater, concentrate stream and treated waters produced by the system, with calculation of limiting salt concentrations will be performed as part of Task 3.

It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the FTO, as pertains to power consumption and salt removals per stage. Verification of membrane operation under the conditions specified in the Statement of Performance Objectives shall also apply to conditions that are considered less challenging to the ED/EDR system. Examples of conditions considered less challenging may include lower salt rejections and lower system recoveries.

7.3 Work Plan

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

After set-up and shakedown of the membrane equipment, ED/EDR operation should be established at the operational conditions established by the Statement of Performance Objectives. The membrane system shall be operated for a minimum of two months. A summary of the operational parameters to be recorded during Task 1 and the minimum frequency of monitoring are presented in Table 2. The FTO shall provide in the PSTP the necessary methods for monitoring of the operational parameters presented in Table 2. Additional monitoring of feedwater chemistry shall be performed during Verification Testing, as described below in Table 2.

Table 2: Task 1 Required Minimum Operating Data

Operational Parameter	Action, Monitoring Frequency
Dilute-in, electrode flush and concentrate make-up flow rates	Check and record twice daily. Adjust when 5% above or below target. Record both before and after adjustment.
Membrane Stack Inlet and Outlet Pressures (for each ED/EDR system)	Check and record twice daily.
Voltage and Amperage for + and - operational (for each electrical stage of the ED/EDR system)	Check and record twice daily
Voltage drop per inch of stack	Check and record weekly.
Recycle Ratio to obtain target Recovery	Check and record twice daily. Adjust when 2% above or below target.
Total Dissolved Solids Concentration in Feedwater, Concentrate, Product (for each stack of the ED/EDR system)	Calculation of salt normality gradient on daily basis. (Calculation per Equation 4.4, Section 4).
Feedwater Temperature	Record twice daily
Concentrate composition for disposal	Sample waste stream once during the minimum two-month testing period.
Concentrate and product flow rate	Check and record flow streams twice daily.

Determination of optimal membrane operating conditions for a particular water could potentially require as long as one year of operation. For Task 1 however, each set of operating conditions shall be maintained for the two-month testing period (continuous 24-hour operation). At a minimum, the membrane shall be chemically cleaned according to Manufacturer's specifications at the conclusion of the two-month testing period. At this time, the cleaning efficiency shall be determined per the requirements outlined in Task 2.

If substantial electrical resistance increase occurs at the specified operating conditions before the two-month operating period is complete, adjustments to the operational strategy shall be made. Decisions on which adjustments should be made shall be based upon the Manufacturer's experience and consultation with the FTO conducting the study. Adjustments in chemical addition (such as pH adjustment) shall not be considered to constitute changes in the overall operational strategy, as mentioned above. The FTO shall also specify the run termination criteria for the particular ED/EDR membrane equipment being tested under the Verification Testing Program. For example, the termination criteria may be defined as a 5% or 10% increase in electrical resistance, a drop in the percent solute rejection, or an increase in stack differential pressure to a specific value. In the case that

fouling and electrical resistance increase occurs in a shorter time than the two-month testing period, the membrane shall be chemically cleaned and the operating or pretreatment conditions shall be adjusted. After these conditions are changed, the system would be operated until the completion of the two-month testing period. Because only one testing period shall be required in this Verification Testing Plan, the FTO shall specify the primary salt rejection levels at which the equipment is to be verified.

Concentrate streams and other waste streams generated by the membrane equipment must be completely characterized during Task 1 testing. The FTO shall completely describe and provide general characterization of the waste streams that are generated by the ED/EDR membrane treatment system in the PSTP, including pH, temperature, calcium, sulfate, TDS, alkalinity, TSS, disinfectant residual and any other parameter regulated in the waste stream. The FTO shall also discuss the applicable potential waste stream disposal issues in the PSTP, including disposal to the sewer or receiving waters.

Testing of additional operational conditions may be included in the Verification Testing Program at the discretion of the Manufacturer and their designated FTO. Testing of alternate operational conditions shall be performed by including one or more one-month testing period beyond the two-month testing periods required by the Verification Testing Program. Additional testing periods may be included to demonstrate membrane performance at different operational conditions or under different feedwater quality conditions. The FTO on behalf of the Manufacturer shall perform testing with as many different water quality conditions as desired for verification status.

This Membrane ETV Testing Plan has been written with the aim to balance the costs of verification with the benefits of testing the ED/EDR process over a wide range of operating conditions. Given that it may take more than one month to observe a significant electrical resistance increase in ED/EDR systems, examination under a wide range of operating conditions would be prohibitively expensive for the membrane Manufacturer. Therefore, this Verification Testing Plan requires that one set of operating conditions be tested during the two-month testing period. It shall be furthermore understood that beyond the single set of verification operating conditions, membrane operation that occurs at lower salt rejections or a lower recovery shall also constitute a verifiable condition.

7.4 Analytical Schedule

7.4.1 Operational Data Collection

Measurement of membrane performance parameters shall be monitored a minimum of 2 times per day, as indicated in Table 2. Monitoring shall be performed for each stage in the ED/EDR system. Temperature measurements shall be made on a daily basis in order to provide data for temperature correction of electrical resistance and for reporting of solute rejection (addressed in Task 3).

In an attempt to calculate costs for operation of membrane equipment, power costs for operation of the membrane equipment shall also be monitored and recorded by the FTO a minimum of 2 times per day, as indicated in Table 2. Furthermore, the costs of chemical

addition shall be estimated by measurement of chemical usage through recording the day tank concentration, daily volume consumption and unit cost of chemicals.

7.4.2 Feedwater Quality Limitations

The characteristics of feedwater used during the two-month testing period (and any additional testing periods) shall be explicitly reported with the compiled results from electrical resistance, stack pressure drop and recovery monitoring. Accurate reporting of such feedwater characteristics as pH, temperature, conductivity, TDS, alkalinity, turbidity, sulfide, sulfate, iron manganese, aluminum calcium, hardness, TSS, and TOC concentration is critical for the Verification Testing Program, as these parameters may substantially influence the range of achievable membrane performance and treated water quality under variable raw water quality conditions. The TDS concentrations in the feedwater, product and concentrate streams shall be used to calculate the salt (Equation 4.4) removals through the membranes on a daily basis. Salt removal value shall then be used for calculation of current efficiency on a daily basis. Specific monitoring requirements for feedwater quality shall be stipulated in Task 3.

7.5 Evaluation Criteria and Minimum Reporting Requirements

- General operational performance
 - ⇒ Graph of change in electrical resistance (Equation 4.4) normalized to 20°C or 25°C and corrected for salt removals vs. time over the two-month testing period. Graphs showing time-dependent change of experimental parameters will be defined as temporal profiles. One temporal profile graph of electrical resistance shall be provided for each set of operational conditions and/or water qualities evaluated during Verification Testing.
 - ⇒ Temporal profile of differential pressure across each membrane stack over the two-month testing period. One temporal profile graph shall be provided for each set of operational conditions and/or water qualities evaluated during Verification Testing.
 - ⇒ Temporal profile of water recovery (Equation 4.6) over the two-month testing period. One temporal profile graph shall be provided for each set of operational conditions and/or water qualities evaluated.
- Power consumption
 - ⇒ Provide table of energy requirements, DC current efficiency, motor efficiency and consumed amperage for the testing period(s), as measured for each set of operational conditions.
- Concentrate stream characterization
 - ⇒ Provide table of concentrate stream quality parameters measured during the two-month testing period.

8.0 TASK 2: CLEANING EFFICIENCY

8.1 Introduction

During and following the test runs of Task 1, the membrane equipment may require chemical cleaning to restore membrane productivity. At a minimum, one cleaning shall be performed at the conclusion of the two-month period of required testing. In the case that the membrane does not fully reach termination criteria as specified by the Manufacturer in Task 1, chemical cleaning shall be performed after the two-month testing period. Measurement of membrane performance parameters at one set of operational conditions shall be made before and after cleaning.

8.2 Experimental Objectives

The objective of Task 2 is to evaluate the effectiveness of chemical cleaning for restoring the electrical resistance of the membrane system. Evaluation of the chemical cleaning procedure will be useful in confirming that standard Manufacturer-recommended cleaning practices are sufficient to restore membrane productivity. Furthermore, such testing may determine if the chemical cleaning procedure degrades the process in terms of its rejection capabilities for inorganic and radionuclide chemical contaminants. Cleaning chemicals and cleaning routines shall be adopted from the recommendations of the Manufacturer; this task is considered a "proof of concept" effort, not an optimization effort. It should be noted that selection of a chemical cleaning procedure is typically dependent upon the specific feedwater quality. The testing plan should permit evaluation of cleaning solutions that are considered optimal for the selected feedwaters. If the Manufacturer determines that a pre-selected cleaning formulation is not effective, the testing plan should allow the Manufacturer to modify it.

8.3 Work Plan

The membrane systems may experience electrical resistance increase during the membrane test runs conducted for Task 1. At the conclusion of the two-month testing period, the equipment shall be utilized for the cleaning assessments. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the Manufacturer. After each chemical cleaning of the equipment, the system shall be restarted and the initial conditions of operation, electrical resistance, salt rejection percentage, recovery and specific inorganic and radionuclide contaminant rejection capabilities shall be tested.

The Manufacturer and their designated FTO shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- cleaning chemicals
- quantities and costs of cleaning chemicals
- hydraulic conditions of cleaning
- time duration of each cleaning step
- initial and final temperatures of chemical cleaning solution
- quantity and characteristics of residual waste volume to be disposed
- recommended methods and considerations for disposal of residual cleaning waste

- procedure for tearing down and rebuilding ED/EDR membrane stack

In addition, detailed procedures describing the methods for pH neutralization of the used acid or alkaline cleaning solutions should be provided along with information on the proper disposal method for regulated chemicals. A description of all cleaning equipment and its operation shall be included in the PSTP prepared by the FTO.

8.4 Analytical Schedule

8.4.1 Operational Data Collection

Flow rates, pressures, voltage, amperage, recovery, and temperature data shall be collected during the cleaning procedure if possible and shall be recorded immediately preceding system shutdown. At the conclusion of each chemical cleaning event and immediately upon return to membrane operation, the initial operating conditions of salt rejection, electrical power, flow rate, recovery, ED/EDR stack voltage probe readings, and temperature shall be recorded and the electrical resistance calculated.

The efficacy of chemical cleaning shall be evaluated by the recovery of temperature-adjusted electrical resistance after chemical cleaning as noted below, with comparison drawn from the cleaning efficacy achieved during previous cleaning evaluations (if available). Comparison between chemical cleanings shall allow evaluation of the potential for irreversible loss of performance. Analysis of feedwater and dilute stream quality in subsequent runs shall also be used to evaluate any loss in membrane rejection capabilities caused by chemical cleaning.

Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in Task 2. These are conditional on the temperature and ionic strength remaining constant or appropriately adjusted for changes in these two parameters.

- 1) The immediate recovery of membrane performance, as expressed by the ratio between the final electrical resistance value (R_f) and the initial electrical resistance (R_i) measured for the subsequent operational run:

$$\% \text{ Increase of Original Electrical Resistance} = 100 * [1 - (R_i \div R_f)]$$

where: R_f = resistance of ED/EDR stack at prior to cleaning (ohm/cm²)
 R_i = resistance of ED/EDR stack at start-up (ohm/cm²)

- 2) The reduction in differential pressure across the membrane stack(s), as expressed by the ratio between the initial differential pressure for any given run (dP_i) divided by the final differential pressure measured at the initiation of operation for the final run in a series (dP_f):

$$\% \text{ Increase of Original Differential Pressure} = 100 * [1 - (dP_i \div dP_f)]$$

where: dP_f = differential pressure of ED/EDR stack at prior to cleaning (psid)

dP_i = differential pressure of ED/EDR stack at start-up (psid)

8.4.2 Sampling

The temperature, pH, conductivity, TDS, TOC, aluminum, calcium, sulfate, iron, manganese, and turbidity of each cleaning solution shall be measured and recorded during various periods of the chemical cleaning procedure. In addition, in the case that the cleaning solution employs an oxidant, such as chlorine, the concentration of the oxidant both before and at the end of the cleaning should be measured. Notes recording the visual observations (color, degree of suspended matter present) shall also be provided by the FTO.

8.5 Evaluation Criteria and Minimum Reporting Requirements

The minimum reporting requirements shall include presentation of the following results:

- Electrical Resistance recovery
⇒ Provide table of post cleaning electrical resistance recoveries during the two-month period of operation
- Differential Pressure recovery
⇒ Provide table of differential pressure recovery described above for chemical cleaning procedures performed during the two-month period of operation
- Assessment of irreversible increase of electrical resistance and estimation of usable membrane life for costing purposes.

9.0 TASK 3: FEEDWATER AND TREATED WATER QUALITY MONITORING

9.1 Introduction

Water quality data for the feedwater, the membrane product and concentrate streams shall be collected during the membrane test runs conducted as part of Task 1. No additional test runs shall be performed for Task 3 to acquire data on feedwater and treated water quality. The requirements for monitoring of water quality parameters in the feedwater, product and concentrate streams shall be clearly specified by the FTO in the PSTP according to the objectives of the Verification Testing program and the Statement of Performance Objectives. The specific water quality goals and the target removal goals for the membrane equipment shall also be recorded in the PSTP. A list of the minimum number of water quality parameters to be monitored during equipment Verification Testing in this Testing Plan is provided in Table 3. A list of the potential water quality parameters for additional monitoring is provided in Table 4 for the feedwater, the membrane product and concentrate streams. The actual water quality parameters selected for testing and monitoring during equipment Verification Testing shall be explicitly stipulated by the FTO in the PSTP.

9.2 Experimental Objectives

The objective of this task is to assess the ability of the membrane equipment to demonstrate the treatment and/or rejection capabilities indicated in the PSTP Statement of Performance Objectives. Mass balances shall be performed as part of Task 3 in order to evaluate the concentration of removed species during membrane system operation. Calculation of the recovery limitation caused by limiting salts will be performed to determine the impact of feedwater quality on membrane operation. Statistical analysis, as described in the “EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Inorganic Constituents: Requirements For All Studies” (Section 4.5: Recording Statistical Uncertainty) is only required for those water quality parameters that shall be monitored on a weekly basis during each Verification Testing period.

9.3 Work Plan

The Manufacturer through their designated FTO shall identify the equipment rejection capabilities for selected inorganic chemical and radionuclide contaminants in the Statement of Performance Objectives provided in the PSTP. The Statement of Performance Objectives shall clearly establish the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. For each Statement of Performance Objectives proposed by the FTO, the following information shall be provided: percent removal of the targeted inorganic constituent per stage, rate of treated water production; recovery; feedwater quality regarding pertinent water quality parameters; temperature; concentration of target inorganic or radionuclide constituent; and other pertinent water quality and operational conditions. Two examples of acceptable Statements of Performance Objectives are provided in Section 3.0. The Statement of Performance Objectives prepared by the Manufacturer and their designated FTO shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feedwater, as indicated by examples in Section 3.0.

Monitoring of water quality parameters in the feedwater, product and concentrate water streams shall allow calculation of percent rejection of the measured parameters and targeted inorganic chemical or radionuclide contaminants for the specific operational conditions evaluated. Estimation of the percent rejection of selected inorganic water quality parameters shall be based upon the equation for solute rejection provided in the section titled Definition of Operational Parameters, Equation 4.7.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. Analysis of the remaining water quality parameters shall be performed by a state-certified or third party- or EPA- accredited, analytical laboratory. The methods to be used for measurement of water quality parameters are identified in Tables 3 and 4. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures. A number of the analytical methods utilized in this study for on-site monitoring of feedwater and product water qualities are further described in Task 5, Quality Assurance Project Plan.

For the water quality parameters requiring analysis at a state-certified or third party- or EPA-accredited laboratory, water samples shall be collected in appropriate containers (containing necessary 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 lab. Required information will be included on the “chain-of-custody” provided by the laboratory for all samples.

It should be noted that the membrane equipment participating in the Verification Testing Program for inorganic or radionuclide contaminant removal may be capable of achieving multiple water treatment objectives. Although this Testing Plan is oriented towards removal of inorganic and radionuclide contaminants, the Manufacturer may want to look at the treatment system’s removal capabilities for additional water quality parameters.

9.4 Analytical Schedule

9.4.1 Feedwater, Product and Concentrate Characterization

During the two-month testing period, the feedwater, product and concentrate water streams shall be characterized at a single set of operating conditions indicated in the Statement of Performance Objectives. The minimum water quality monitoring requirements for this Verification Testing plan are provided in Table 3.

Table 3: Minimum Required Water Quality Sampling

Parameter	Sampling Frequency	Test Stream to be Sampled	Standard Method	EPA Method
pH	1/Day	Feed, Product	4500 H ₊	150.1/150.2
Temperature	2/Day	Feed	2550 B	
Conductivity	2/Day	Feed, Prod., Conc.	2510 B	
TDS	1/Week	Feed, Prod., Conc.	2540 C	
Alkalinity	1/Month	Feed, Prod., Conc.	2320 B	
Langlier Saturation Index (LSI)	1/Month	Feed, Prod., Conc.	calculated	
Turbidity	1/Month	Feed, Prod., Conc.	2130 B	180.1
TSS	1/Month	Feed, Prod., Conc.	4500-NH ₃ G	
TOC	1/Month	Feed, Prod., Conc.	5310 C	
Selected Inorganic Constituents (see Table 4)	3/Week	Feed, Prod., Conc.		

In addition, the FTO (on behalf of the Manufacturer) shall indicate in the PSTP the specific target inorganic chemical contaminants that shall be monitored in the Verification Testing Program per the Statement of Performance Objectives. A list of the potential inorganic

chemical contaminants that may be included in this Verification Testing program is included in Table 4. The recommended monitoring frequency for these inorganic chemical contaminants shall be a minimum of three times per week distributed evenly through the week period.

Table 4: List of Inorganic Chemical Contaminants for Verification Testing

Parameter	Standard Method	EPA Method
Aluminum	3500 Al	202.2
Barium	3500 Ba	208.1
Cadmium	3500 Cd	213.2
Calcium	3500 Ca	215.2
Chloride	4500 Cl	325.1
Chromium	3500 Cr	218.2
Fluoride	4500 F ⁻	340.1
Iron	3500 Fe	236.1
Manganese	3500 Mn	243.1
Magnesium	3500 Mg	242.1
Nitrate	4500 NO ₃ ⁻²	352.1
Nitrite	4500 NO ₂ ⁻²	354.1
Sodium	3500 Na B	273.1
Strontium	3500 Sr	200.7
Sulfate	4500 SO ₄ ⁻²	375.4
Sulfide	4500 S ²	376.1
Other Inorganic Chemical Contaminants	TBD*	TBD
Optional:		
UV absorbance	5910 B	-
Total Trihalomethanes	5710	524.2
Haloacetic Acids	5710	552.1

* TBD - to be determined

9.4.2 Water Quality Sample Collection

Water quality data shall be collected at the specified intervals during each testing period. The minimum monitoring frequency for the minimum required water quality parameters is provided in Table 3. A minimum monitoring frequency of three per week shall be adopted for additional inorganic chemical contaminants to be included in the Verification Testing Program. At the discretion of the Manufacturer and the designated FTO, the water quality sampling program may be expanded to include any number of water quality parameters and an increased frequency of water quality parameter sampling. Sample collection frequency and protocol shall be defined explicitly by the FTO in the PSTP. To the extent possible, analyses for inorganic water quality parameters shall be performed on water sample aliquots obtained simultaneously

from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

The TDS concentrations in the feedwater, product and concentrate streams shall be used to calculate the ionic strength of the feedwater and concentrate streams, as well as salt rejections by the membrane stack on a daily basis. Salt rejection gradient value shall then be used for calculation of electrical resistance and current efficiency on a daily basis. Mass balances for specified water quality parameters shall also be calculated at a frequency (minimum of once weekly) designated by the FTO. Calculation of the potential for recovery limitation based upon limiting salt concentrations shall also be performed at a frequency (minimum of once weekly) designated by the FTO.

9.5 Evaluation Criteria and Minimum Reporting Requirements

- Percent removal of inorganic chemical constituents
 - ⇒ Provide temporal plot of concentrations of target inorganic constituents and TDS in the feedwater, product and concentrate water streams over the two-month period of operation. Relevant inorganic constituents for monitoring shall be specified by the FTO on behalf of the Manufacturer in the PSTP.
 - ⇒ Provide table with weekly values of percent removal of target inorganic constituents and other pertinent water quality parameters for the two-month period of operation. The equation shown in the section titled Definition of Operational Parameters shall be used to determine percent removal of all pertinent water quality parameters for Verification Testing by the FTO and Manufacturer.
 - ⇒ Conduct mass balances through the membrane testing system for specific water quality constituents (minimum of once weekly) as identified by the FTO in the PSTP. The mass balance equation presented in the section titled Definition of Operational Parameters shall be used to the mass of concentration of inorganic constituents in different water streams.
 - ⇒ Calculate limiting salt concentrations (via solubility product calculation Equation 4.9) for specific water quality constituents (minimum of once weekly) as identified by the FTO in the PSTP. The equation for solubility product calculation as presented in the section titled Definition of Operational Parameters (Equation 4.9) shall be used to compare with standard Solubility Product values to determine if the salt concentration is posing a limitation to operational system recovery.
 - ⇒ Provide voltage readings obtained from ED/EDR stack probing in Table form.
 - ⇒ Provide temporal plot of polarity readings for amps and volts applied to each stage over the two-month period.
 - ⇒ Develop and provide power consumption plotted in kWhr/1,000 gallons produced versus time for the two-month testing period.
 - ⇒ Provide chemical usage and other ED/EDR stack parts replacement costs over the two-month period.
- Individual water quality and removal goals specified by the Manufacturer
 - ⇒ Provide feed, product and concentrate concentrations of any measured water quality parameters in tabular form for the two-month period of operation.

10.0 TASK 4: DATA HANDLING PROTOCOL

10.1 Introduction

The data management system used in the Verification Testing program shall involve the use of computer spreadsheets and manual (or on-line) recording of operational parameters for the membrane equipment on a daily basis.

10.2 Experimental Objectives

The objectives of Task 4 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 to NSF for verification purposes, and 2) to develop a statistical analysis of the data, as described in the document "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Inorganic Constituents: Requirements For All Studies."

10.3 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 membrane equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

In the case when a SCADA system is not available, 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.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the FTO at least once per week during the one-month testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the membrane 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 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 spreadsheet. 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 membrane test run) shall 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 state-certified or third party- or EPA- accredited laboratories, the data shall be tracked by use of the same system of run numbers using chain-of-custody forms. 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.

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 FTO in the PSTP.

11.0 TASK 5: QUALITY ASSURANCE PROJECT PLAN

11.1 Introduction

Quality assurance and quality control of the operation of the membrane equipment and the measured water quality parameters shall be maintained during the Verification Testing program. A Quality Assurance Project Plan detailing the quality assurance/quality control (QA/QC) procedures to be followed during Verification Testing shall be provided by the FTO as part of the PSTP.

11.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. 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.

11.3 Work Plan

Equipment flowrates and associated signals should 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. Particular care shall be taken to confirm that any chemicals are being fed at the defined flowrate into a flowstream that is operating at the expected flowrate, such that the chemical concentrations are correct.

In-line monitoring equipment such as flowmeters, etc. shall be checked to confirm that the readout matches with the actual measurement (i.e. flowrate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods and include volt and amperage reading equipment.

11.3.1 Daily QA/QC Verifications:

- Chemical feed pump flowrates (verified volumetrically over a specific time period)
- Flow rates to on-line analytical equipment (e.g., pH meter, conductivity meter, turbidimeter), if any (verified volumetrically over a specific time period).

11.3.2 Monthly QA/QC Verifications:

- In-line flowmeters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings);
- On-line pH meters, conductivity meters, turbidimeters etc. (clean out reservoirs and recalibrate, if employed)
- 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)
- Volt and amperage meters (verify gauge readings and signal using calibrated hand-held meters).

11.4 Analytical Methods and Sample Collection

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

11.4.1 pH

Analyses for pH shall be performed according to Standard Method 4500-H⁺ and include temperature compensation. A three-point calibration of the 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.

11.4.2 Conductivity

Analyses for conductivity shall be performed according to Standard Method 2510 B. A three-point calibration of the conductivity meter used in Verification Testing shall be performed once per day when the instrument is in use. Certified conductivity solutions in the expected range shall be used. The probe shall be stored in the appropriate solution defined in the instrument manual.

11.4.3 Turbidity

Turbidity analyses shall be performed according to Standard Method 2130 with either an on-line or bench-top turbidimeter. During each testing period, the on-line and bench-top turbidimeters shall be left on continuously. Once each turbidity measurement is complete, the unit shall be switched back to its lowest setting. All glassware used for turbidity measurements shall be cleaned and handled using lint-free tissues to prevent scratching. Sample vials shall be stored inverted to prevent deposits from forming on the bottom surface of the cell.

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

On-line Turbidimeters: On-line turbidimeters may be used for measurement of turbidity during Verification Testing, and must be calibrated as specified in the instrument manufacturer's operation and maintenance manual. It will be necessary to periodically verify the on-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 the comparison suggest inaccurate readings, then all on-line turbidimeters should be re-calibrated. 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 shall also be performed using a volumetric measurement. Instrument bulbs shall be replaced on an as-needed basis. It should also be verified that the LED read-out matches the data recorded by the data acquisition system, if the latter is employed.

Bench-Top Turbidimeters: Grab samples of feedwater and oxidized/disinfected water may be analyzed using a bench-top turbidimeter. Readings from this instrument shall 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 5.0 Nephelometric Turbidity Units (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 re-calibrate when more than one turbidity range is used.

The method for collecting grab samples shall be performed according to the following protocol: 1) running a slow, steady stream from the sample tap, 2) triple-rinsing a dedicated sample beaker in this stream, 3) allowing the sample to flow down the side of the beaker to minimize bubble entrainment, 4) double-rinsing the sample vial with the sample, 5) carefully pouring from the beaker down the side of the sample vial, 6) wiping the sample vial clean, 7) inserting the sample vial into the turbidimeter, and 8) 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 in a warm water bath for approximately 30 seconds.

11.4.4 Analysis for Inorganic Chemical Contaminants

Methods to be employed for analysis of specific analytical parameters shall be explicitly identified by the FTO in the PSTP. The methods selected for analysis of all inorganic constituents shall comply with those described in the most recent edition of Standard Methods or should be considered a comparable EPA Method.

12.0 OPERATION AND MAINTENANCE

The following are recommendations for criteria to be included in Operation and Maintenance (O&M) Manuals for ED/EDR membrane systems that are designed to achieve removal of inorganic chemical constituents. Descriptions of the membrane equipment unit process shall be developed by the FTO on behalf of the Manufacturer and included in the PSTP. Appropriate parameters for system description shall include but not be limited to the following elements: standard design criteria, membrane process characteristics, pre-treatment requirements and post-treatment concerns. An overview of the pertinent membrane plant design information that may be required for the PSTP is provided in Table 5. A list of relevant membrane element characteristics is provided in Table 6. The following sections provide lists of maintenance and operations criteria that may be helpful for development of O&M Manuals for ED/EDR membrane systems.

Table 5: Membrane Plant Design Criteria Reporting Items

Parameter	Value
Number of Membrane Stacks	
Number Electrical Stages per Stack	
Number Hydraulic Stages per Stack	
Number Membrane Cell Pairs per Hydraulic Stage	
Recovery per Stack (%)	
Recovery for System (%)	
Design Product Flow (gpm)	
Initial Electrical Resistance (ohms) at 20 °C	
Maximum Flow Rate to a Stack (gpm)	
Minimum Flow Rate to a Stack (gpm)	
Pressure Loss per Stack (psi)	
Feed Stream TDS (mg/L)	
TDS Rejection (%)	
Rejection of Specific Inorganic Constituent (%)	

Table 6: Membrane Element Characteristics

Parameter	Value
Membrane Manufacturer	
Membrane Element Model Numbers (anion & cation)	
Size of Element Used in Study (e.g., 18"x40")	
Sales Price for 18"x40" cation membrane (\$)	
Sales Price for 18"x40" anion membrane (\$)	
Membrane Material of Construction (cation)	
Membrane Material of Construction (anion)	
Spacer Thickness (in)	
Sales Price for Electrode (\$)	
Electrode Material of Construction	
Electrode Thickness (in)	
Design differential Pressure (psi)	
Design Salt Rejections per Stage (%)	
Variability of Design Salt Rejections (%)	
Design Electrical Resistance at 20 °C	
Design Recovery (%)	
Design Stack Feed Flow Velocity (ft/s)	
Maximum Flow Rate to Stack (gpm)	
Minimum Flow Rate to a Stack (gpm)	
Required Feed Flow to Electrode Flush Stream (gpm)	
Maximum System Recovery (%)	
Rejection of Reference Solute and Conditions of Test (e.g., Solute type and concentration)	
Variability of Rejection of Reference Solute (%)	
Acceptable Range of Operating Pressures (psi, bar)	
Acceptable Range of Operating pH Values	
Typical Pressure Drop across a Single Stack (psi)	
Maximum Permissible Turbidity	
Chlorine/Oxidant Tolerance	
Average voltage drop for new cell	
Suggested Cleaning Procedures	

12.1 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, including detailed information on the valve configuration for cross-flow operation
- pressure gauges
- flow meters
- air compressors
- chemical feeder systems
- mixers
- motors
- instruments, such as streaming current monitors or turbidimeters
- water meters, if provided
- electrodes

The Manufacturer shall 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

12.2 Operation

The Manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are the following issues:

ED/EDR System:

- control of feed flow and recycle flows to the membrane system and individual stages
- measurement of inlet/outlet pressures and product flows
- measurement of power usage for + and – polarity operation
- measurement of voltage probing in membrane stacks
- measurement/calculation of power and water flow operational parameters
- maintenance of proper stack weeping

Chemical cleaning:

- selection of proper chemical washing sequence
- proper procedures for dilution of chemicals
- monitoring of pH through chemical cleaning cycle
- rinsing of membrane system following chemical clean
- return of membrane system to service

Chemical feeders

- calibration check on flow meters and dosing pumps
- settings and adjustments -- how they should be made
- dilution of chemicals -- proper procedures
- proper dosage and control for ECIP and brine re-circulation feeds (if used)

Intermittent Operation:

- proper procedures for system shut-down and start-up
- safety checks of chemical concentrations prior to system shut-down
- safety checks of potential contaminant concentrations prior to system shut-down and start-up
- proper procedures for rinsing and disinfection of system following shut-down

Monitoring and Sampling Procedures:

- observation of feedwater or pretreated water salt rejection
- observation of power use increase
- proper monitoring procedures for measurement of product conductivity
- proper safety procedures

The Manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- no raw water (feedwater) flow to plant
- can't control rate of flow of water through equipment
- poor product quality
- identification of "hot spots" in membrane stack
- automatic operation (if provided) not functioning
- reduced percent solute rejection
- 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 for ECIP or brine re-circulation
- membrane flow spacer plugged

12.3 Operability

The following are recommendations regarding operability aspects of systems that are designed to achieve removal of inorganic chemical and radionuclide 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 and pressures through membrane unit - the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- fluctuation of applied electrical volts and amps applied to each stage.
- presence of devices to aid the operator with flow control adjustment and chemical dosage selection:
 - ⇒ are continuous flow meters provided for monitoring of feedwater, product and concentrate re-circulation flows?
- Conductivity provided for monitoring of ED/EDR System product?
- does plant have multiple feed points for chemicals:

- ⇒ for ECIP
- ⇒ for concentrate recycle
- are electrical current measurements provided?
- is rate of flow of raw water measured?
- are chemical feeds paced with water flow?

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 should be dealt with in the portion of the reports that are written in response to Tasks 1 & 2 of the Verification Testing Plan.

13.0 REFERENCES

Electrodialysis and Electrodialysis Reversal, American Water Works Association, AWWA M38, Denver, CO, 1995.

Electrodialysis – Electrodialysis Reversal Technology, Ionics Incorporated, Watertown, MA, 1984.

Standard Methods for the Examination of Water and Wastewater. 1999. 20th edition. APHA, AWWA, and WEF, Washington, D.C.

Water Treatment – Membrane Processes, American Water Works Association Research Foundation, Denver, CO 1996.