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Environmental Technology Verification Protocol

Water Quality Protection Center

Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications

Prepared by

NSF International

Under a Cooperative Agreement with

U.S. Environmental Protection Agency

ETV ETV ETV

VERIFICATION PROTOCOL FOR SECONDARY EFFLUENT AND WATER REUSE DISINFECTION APPLICATIONS

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FOREWORD

In 1995, the U.S. Environmental Protection Agency (EPA) instituted the Environmental Technology Verification Program (ETV) to verify the performance characteristics of commercial-ready environmental technologies through the evaluation of objective and quality-assured data. Managed by EPA's Office of Research and Development, ETV was created to substantially accelerate the entrance of innovative environmental technologies into the domestic and international marketplaces. The independent technology verifications generated through the ETV Program provide purchasers and permitters of technologies with an independent and credible assessment of the technology they are purchasing or permitting. Participation on the part of technology manufacturers is strictly voluntary.

The goal of the ETV Water Quality Protection Center, one of six ETV Centers that were established to address each of the major environmental media and various categories of environmental technologies, is to verify the performance of technologies used to protect ground and surface waters from contamination. The Center is guided by the expertise of several stakeholder groups. Stakeholder groups consist of representatives of key customer groups for the particular technology sector, including buyers and users of technology, developers and vendors, state and federal regulatory personnel, and consulting engineers. All technology verification activities are based on testing and quality assurance protocols that have been developed with input from the major stakeholder/customer groups.

NSF is the verification partner organization for two centers under EPA's ETV Program: the Drinking Water Systems Center and the Water Quality Protection Center. NSF International is an independent, not-for-profit organization dedicated to public health, safety, and protection of the environment. NSF develops standards, provides educational services, and offers superior third-party conformity assessment services, while representing the interests of all stakeholders. In addition to well-established standards-development and certification programs, NSF specifically responds to and manages research projects, one-time evaluations and special studies.

This *Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications* was developed under the Source Water Protection Pilot, which merged with the Wet Weather Flow Technologies Pilot in 2002 to form the Water Quality Protection Center. Testing conducted under the ETV program using this protocol does not constitute an NSF or EPA certification of the product tested. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

Verification differs from certification in that it employs a broad, public distribution of test reports and does not use pass/fail criteria. In addition, there are differences in policy issues relative to certification versus verification. Certification, unlike verification, requires auditing of manufacturing facilities, periodic retesting, mandatory review of product changes, and use of the NSF Mark. Both processes are similar, however, in regard to having standardized test methods and independent performance evaluations and test result preparation. This protocol is subject to revision; please contact NSF to confirm this revision is current.

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1 INTRODUCTION

This introductory section presents the objectives of the ETV program, a general description of UV disinfection technologies, and the technical approach to be used in the verification of UV equipment and related systems.

1.1 ETV OBJECTIVES

The Environmental Technology Verification (ETV) program was created by the United States Environmental Protection Agency to accelerate the development and commercialization of improved environmental technologies through third-party verification and reporting of performance. The goal of the ETV Program is to verify performance characteristics of commercial-ready environmental technologies through the evaluation of objective and quality assured data so that potential buyers and permitting authorities are provided with an independent and credible assessment of the technology that they are buying or permitting.

There are six "centers" in the ETV Program, one of which is the Water Quality Protection (WQP) Center being administered by NSF International. The goal of the WQP Center is to verify technologies that protect the quality of ground and surface waters by preventing or reducing contamination. The WQP Center addresses several areas of environmental technologies, one of which is disinfection technologies, including UV radiation. A Technology Panel formed through NSF International advises on the design of the protocol and its subsequent implementation.

A generic protocol is being developed through the WQP Center for the verification of disinfection equipment used for treated wastewater from small (less than 0.01 mgd) on-site, or similar systems. These include UV and chemical disinfectants:

> "Verification Protocol for Wastewater Disinfection Technologies for Small Systems" Draft 1.0, prepared by HydroQual, Inc. for USEPA and NSF International, December 2000.

With respect to the use of UV, other protocols have been used and/or proposed in the industry that have very similar objectives to that of the ETV Program. These include a protocol that has been a "standard" for assaying dose-delivery in a secondary effluent application, testing the equipment at 55 and/or 65%T (at 254 nm) and at lamp output in the vicinity of 65 to 75 percent nominal. The National Water Research Institute (NWRI) recently published a second protocol, appended to its document:

> "Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse" NWRI and American Water Works Association Research Foundation, December 2000.

This addressed water reuse applications where the treated wastewaters received final treatment by granular or other media filtration, membrane filtration, or reverse osmosis varying the transmittance

accordingly to 55, 65 and 90 percent (at 254 nm), respectively. It required a default power attenuation factor of 0.5 and that test conditions mimic a quartz-fouling factor (default) of 0.8. Protocols are suggested in the same guidance document for verifying alternate quartz-fouling and/or lamp-power attenuation factors.

In addition to the cited protocols, a verification protocol was also prepared under the ETV Wet-Weather Flow Technologies Pilot to address high-rate disinfection of wet-weather flows with UV radiation:

> "Generic Verification Protocol for High-Rate, Wet-Weather Flow Disinfection Applications" Version 4.1, Prepared by HydroQual, Inc., for USEPA and NSF International, July 2000.

Given the UV disinfection applications that are already covered by the ETV Program, incorporating the secondary effluents and wastewater reuse applications, and related testing, results in comprehensive coverage of the broad spectrum of opportunities available to the UV industry in wastewater treatment. It also brings this myriad of protocols and testing requirements under the single umbrella of the ETV program, a benefit to the industry, allowing prospective owners a single resource from which to gain UV technology information.

The ETV Program and its associated Technology Panel recommended the preparation of this generic protocol for testing UV technologies, as applied to secondary effluents and wastewater reuse. It specifies the objectives and technical approach of the ETV center and the general procedures that shall be followed to meet the specific technology verification objectives. Subsequently reviewed by the Stakeholder Advisory Group (SAG) and approved by the EPA, it is then offered to technology vendors who elect to participate in the testing program. A project or technology-specific Test Plan shall be prepared in which the protocols are refined to meet the technology's configuration and vendor claims, while staying within the framework and objectives of the generic protocol.

1.1.1 Purpose of this Protocol

This Verification Protocol describes the steps that must be followed to ensure that an UV technology verification is carried out in a consistent and objective manner, with appropriate quality control to ensure the integrity of the data.

1.1.2 Verification Process

The verification process under the ETV program consists of three major steps:

1. Planning. The planning phase establishes the procedures to be followed for verification of a specific technology, the testing firm, and the verification program's organization with respect to personnel and oversight. A Verification Test Plan is developed by the

designated testing organization and is submitted for approval to the NSF and EPA. It will include detailed site and equipment specifications, procedures for testing (including documentation for conformity to the generic protocol), and a quality assurance project plan for assuring valid data. Guidelines for this phase of the program are provided in Section 2.

2. Verification Testing. This phase of the project involves the actual assembly, installation, and operation of the test facility, collection of the targeted samples, and completion of all analyses required under the Verification Test Plan. Sections 3, 4 and 5 present the protocols for this testing phase of the UV Disinfection ETV for secondary wastewater and water reuse applications.

3. Data Assessment and Reporting. The final phase of the verification program includes analysis of the data generated during testing, and preparation of a final Verification Report and Verification Statement. Guidelines for this phase of the project are given in Section 6.

1.2 UV TECHNOLOGY DESCRIPTION

Ultraviolet (UV) light radiation is a widely accepted method for accomplishing disinfection of treated wastewaters. Its germicidal effectiveness is generally attributed to its ability to damage links in the DNA molecule of a cell, resulting in the cells' inability to replicate. UV is most effective in the far UV region of the electromagnetic spectrum, between 230 and 290 nm (generally referred to as the UVC range), generally corresponding to the absorbance spectrum of nucleic acids. The optimum germicidal wavelengths appear to be in the vicinity of 255 to 265 nm.

The dominant commercial source of UV light for germicidal applications is the mercury vapor, electric discharge lamp. These are commercially available in "low-pressure" and "medium-pressure" configurations. The conventional low-pressure lamp operates at 0.007 mm Hg, and is typically supplied in long lengths (0.75 to 1.5 m) and with diameters between 1.5 and 2 cm. The major advantages of the low-pressure lamp are that its UV output is nearly monochromatic at a wavelength of 254 nm and it is energy efficient, converting approximately one-third of its input energy to UV light. The overall output of a conventional low-pressure lamp is relatively low, typically about 25 W at 254 nm for a 70 to 75 W, 1.47-m long lamp. More recent developments have produced higher output low-pressure lamps, generally by using an amalgam and/or a higher current discharge and pressures between 0.01 to 0.001 mm of Hg. These are very similar in appearance to the conventional low-pressure lamps, but with outputs 1.5 to 5 times higher, thus reducing the required number of lamps for an application.

The medium-pressure lamps operate at 100 mm of Hg, and can have many times the total UVC output of the conventional low-pressure lamp, depending on the input energy to the lamp. The light is polychromatic in this case, with a conversion of approximately 7 percent of its input energy to germicidal light in the vicinity of 254 nm. However, the sum of all the spectral lines in the UVC region can total three to four times the output at 254 nm. Because of the very high output rates, fewer medium-pressure

lamps are needed, when compared to conventional low-pressure lamps, although they are substantially lower in efficiency.

Other UV sources are being developed and commercialized, including pulsed power lamps and lasers. These are emerging in the disinfection market, and may find a commercial niche in the future. This protocol can be used in large part for such systems, modified as needed in the Verification Test Plan.

The low- and medium-pressure germicidal lamps are sheathed in quartz sleeves and placed directly in the wastewater stream, configured in a geometric array, and oriented horizontally or vertically. The lamp systems are typically modular in design, and assembled in single or multiple channels and/or reactors. Key considerations in the design of the system are directed to efficient delivery of the energy to the wastewater and to the organisms. This is quantified as the "dose," or the product of the intensity of the radiation (I, watts/cm^2) and the time (t, seconds) to which an organism is exposed to the radiation. The intensity of the radiation is a function of the output of the lamps, and of the factors that attenuate the energy as it moves to and through the water. These include simple dilution of the energy as it moves from the source, absorbance of the energy by the quartz sleeve separating the lamp from the liquid, and the chemical absorbance, or demand, of the energy by constituents in the wastewater.

Exposure time is a function of the hydraulic and physical design of the reactor. Ideally, all elements entering the reactor should be exposed to all levels of radiation for the same amount of time; a condition described as turbulent, ideal plug flow. In fact, non-ideal conditions exist; there is a distribution of residence times in the reactor due to advective dispersion and mixing in the reactor. The degree to which the reactor strays from ideal plug flow will directly impact the efficiency of dose-delivery in the system.

1.3 TECHNICAL APPROACH

There are three major UV system operation and performance elements addressed in this Protocol, comprising up to eleven individual verifications. A vendor may choose to conduct verifications covering any one or combination of these test elements:

Dose-Delivery Verification

Quantitative assessment of the ability of the UV equipment to deliver dose at liquid UV transmittances (at 254 nm) that are representative of the desired application(s)

a. Secondary Effluent

- 55% Transmittance
- 65% Transmittance
- 75% Transmittance

b. Reuse Applications (Based on NWRI/AwwaRF Guidelines, December 2000)

- Granular or Fabric Media Filtered Effluent – 55% Transmittance
- Membrane Filtered Effluent – 65% Transmittance
- Reverse Osmosis Effluent – 90% Transmittance

Dose-Delivery Reliability Verification

a. Quartz Surface Maintenance

Assessment of the efficacy of an UV system's automatic cleaning device to consistently maintain the quartz surfaces in a clean state, efficiently transmitting the UV energy to the liquid

b. System Reliability

System response control and a qualitative assessment of UV system monitors, alarms and/or indicators

c. Process Control

The ability of the UV system to automatically monitor and/or adjust UV doses to changing conditions

UV Design Factor Verification

a. Quartz-Fouling Factor Determination

Quantitative determination of the long-term attenuation factor for quartz transmittance losses

b. Lamp-Age Factor Testing

Quantitative determination of the relative UV output after continuous normal operation for the vendor-prescribed effective life

1.3.1 Dose-Delivery

By its nature, UV disinfection performance is dependent on the upstream processes used for pretreatment, particularly for particle removal or reduction, and for oil/grease and organics removal. These conditions are variable, particularly as they apply to alternative levels of treatment provided upstream and from site to site. The design basis typically developed for a specific UV system application incorporates the characteristics of the wastewater to be disinfected, including particulates, the nature and size distributions of the particulates, bacterial levels to be disinfected, flow rates, and the UV transmissibility (or, conversely, the absorbency) of the wastewaters. These are all established to reflect a planned level of treatment, and the expected variability in quality and quantity. Finally, the dose required to meet specific target levels is typically established from direct testing (e.g., collimated-beam, dose-response methods) of the wastewaters or similar wastewaters. Once this "design basis" is established, independent of the UV equipment, the next step is to select equipment that can meet these specific dose requirements under the expected wastewater conditions.

Demonstrating, or verifying, the ability of a specific system to deliver an effective dose meets the ETV's technical objective. This is described as the "delivered dose," which is defined (NWRI/AwwaRF, December 2000) as the dose equivalent to that measured with the collimated beam apparatus for the same degree of inactivation of the target pathogen. Although recent research has been directed to modeling the delivered dose, particularly methods utilizing computational fluid dynamics in conjunction with computed intensity fields, (NWRI/AwwaRF, December 2000), direct biological assay procedures have generally been used to estimate the delivered dose for specific reactor configurations, typically as a function of the hydraulic loading rate. It is a viable and accepted method and has been

used successfully for many years. The results are often applied to qualification requirements in bid documents for wastewater treatment plant applications.

The bioassay procedure uses a known microorganism, which is cultured and harvested in the laboratory and then subjected to a range of discrete UV doses. These doses are provided by a laboratory-scale, collimated-beam apparatus, which can deliver a known accurately measured dose (measured intensity, I, times a controlled time, t). By measuring the response (log survival ratio) to these doses, a dose-response relationship, or calibration curve, is developed for the specific organism. Once calibrated, this same batch of microorganisms is then injected into the field-scale UV test unit, which is operated over a range of hydraulic loadings (thus yielding a range of exposure times). The response of the organism can then be used to infer, from the laboratory-based dose-response relationship, the dose that was delivered by the UV unit. These tests are typically run in a "clean" water matrix (i.e. a particle-free potable water supply), which has been adjusted by chemical means to mimic the transmittances encountered with secondary wastewaters or wastewater reuse applications.

Effective dose delivery is also predicated on the assumption that the hydraulic behavior results in full dose distribution throughout the reactor. This is achieved by approximating plug-flow conditions with low axial dispersion. Methods to assess the hydraulic characteristics of reactors include the development of residence time distributions (RTD) and the measurement of velocities across a representative cross-sectional plane in the up- and down-stream vicinities of the lamp batteries.

The velocity profiles are typically measured with appropriate meters at a pre-set minimum number of points in a cross-section, sufficient to be representative of the entire cross-section. The intent is to determine if there is a constant, or near-constant velocity across the entire cross-section. The RTD tests require continuously injecting a conservative tracer into the wastewater until a new steady-state condition is achieved over background conditions. Once steady state is achieved, the tracer feed is discontinued and the die-off is recorded. The tracer data are analyzed for conformance to industry-accepted guidelines for acceptable plug-flow characteristics. It is acknowledged that for some closed-shell systems, minimal hydraulic detention times preclude the use of these methods. In these cases, the vendor shall propose an alternative test methodology in the final Verification Test Plan.

1.3.2 Dose-Delivery Reliability

While dose delivery is critical in assessing the performance and capacity of a given disinfection system, the ability of the system to reliably maintain delivery of the dose is equally important. Does the system respond adequately to changing conditions to maintain a minimum applied disinfectant dose? This addresses process control (automatic or manual adjustment to dosing), system response to component failures, power interruptions, upstream treatment upsets, intermittent flows, and depletion of disinfectant. Additionally, with respect to UV systems, such operational considerations must address maintenance devices available for cleaning the quartz surfaces.

Certainly, all integral components for any system need to be structurally and functionally reliable,

such as mixers, diffusers, pumps, lamps, ballasts, and controls, etc.; however, individual assessment of such items is not considered under this protocol. Also, ancillary equipment or systems whose express functions are with operator or public health and safety concerns or issues are not covered. The intent of the protocol is not to optimize a particular design; it is to assess the system's overall capability with respect to dose-delivery reliability.

1.3.2.1 Quartz Surface Maintenance

This protocol incorporates an evaluation of the cleaning device provided with a particular commercial UV system. The approach is to operate a unit with a "typical" feed, comprising simulated or actual wastewaters, and to monitor the transparency of the quartz sleeves. The Verification Test Plan for this aspect of a specific ETV will need to address a performance benchmark (i.e., quantify fouling). This will include controlling the wastewater characteristics imposed on the system (with respect to "fouling" agents), establishing the period of operation and assessing the system's ability to "restore" the quartz surface relative to operation without such a device. It is appropriate to conduct this part of the evaluation on small-scale systems, as long as the cleaning device and operating conditions are representative of the full-scale application.

1.3.2.2 System Response or Impact from Failures/Interrupts/Upsets/Maintenance

It is not realistic to expect uninterrupted dose-delivery reliability under all possible circumstances. Upstream process upsets may result in temporary conditions where disinfection efficiency is severely compromised. It must also be recognized that individual system components or part of the overall disinfection system may fail unilaterally. Issues such as impact from power interruptions or atypical "upset conditions" should be addressed in the final installation design.

What generally is important from a dose-delivery reliability standpoint is the capability of a system to either self-adjust or somehow indicate conditions which need attention under "normal" operations. UV systems either have to be equipped with an automatic cleaning system or have the ability to indicate when cleaning is required or when lamps fail.

To verify specific applicable claims under this section, the vendor must provide an Operations and Maintenance Manual for the given application. The O&M manual should include recommended or required maintenance schedules for each piece of operating equipment or subsystem. The manual should also provide recommended procedures for proper operation of all components and modules comprising the entire disinfection system.

The protocol provides generic guidance for assessing operational status indicators or alarms. In the case of automatic lamp shutoffs in cases of no flow, the system will be operated under both conditions and the response assessed qualitatively (e.g. did the lamps shut off). It is not the intent of the protocol to determine long-term reliability or verify the life span of individual components, but simply confirm a vendor's claimed response(s) to a given situation or set of conditions.

1.3.2.3 Process Control

Process control ensures that there is constant disinfection performance despite fluctuations in wastewater quality and/or flow. Process control may be a pretreatment design consideration, such as flow equalization prior to disinfection. In some cases, it would then be possible to maintain the dose at some constant minimum. This is very often the case with UV in that "overdosing" is of no real concern.

In some cases, process control relies on either manual or automatic adjustments to the UV dose in response to some predetermined, quantifiable change in conditions. The NWRI Guidance (NWRI/AwwaRF, December 2000) requires the inclusion and reporting of the "operational dose" on a continuous basis, defined as an operating algorithm that uses water quality and equipment conditions to estimate real-time dose. This must be calibrated to performance data, such as might be obtained from the dose-delivery assays. The verification of this algorithm can be a component of this test element.

Based on the stated vendors' claims, process control reliability can be verified by confirming expected specific system responses to changes in conditions, using prescribed microbial inactivation rates as performance indicators. Testing is conducted in batch mode using an appropriate wastewater matrix (secondary effluent or reuse water). A series of bioassay test runs are undertaken where the transmittance of the water matrix is changed for each test. Between run sets, the system will be manually adjusted (as prescribed by the vendor) or the system will be allowed to change automatically as test conditions change. Samples will be collected to measure microbial inactivation and inferred delivered dose. Qualitative observations will also be recorded, such as status of alarms, flags or other indicators.

1.3.3 UV Design Factor Verification

Two fundamental design factors used for sizing UV systems are the quartz sleeve fouling factor and the end-of-lamp life, or aging factor. While empirical data exist that allow designers to choose appropriate factors, they may sometimes be too conservative for some applications. The previously cited "Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse" by NWRI/AWWARF suggests general protocols to allow vendors to demonstrate design factors that may be ultimately less conservative than those used as default values in the general guidelines.

1.3.3.1 Quartz Sleeve Fouling Factor Verification

To verify a quartz-sleeve fouling factor, the protocol requires that a vendor-supplied UV system be equipped with an automatic cleaning device. The UV equipment, with the cleaning mechanism in operation, will be continuously subjected to a typical secondary effluent for a period of at least six months. Transmittance of the quartz sleeves will be measured every two months and these measurements will be compared to the transmittance of a clean, new quartz sleeve. This evaluation does not have to be conducted on a full-scale module; however, at least four sleeves shall be monitored for the duration of the test. Polychromatic lamps may be used; however, this protocol only provides generic guidelines with respect to the peak wavelengths at which quartz transmittance should be monitored.

1.3.3.2 Lamp Age Factor Verification

To verify a lamp age factor, the protocol requires that a set number of lamps be operated in an environment typical of full-scale operation, covering a specified range of operating water temperatures. Testing may be conducted remotely or in the laboratory. Lamps must also be operated with a prescribed number of on/off cycles and their output shall be measured at intervals of not less than 20 percent of the vendor-prescribed lamp life. The output at the end of the test period will be compared to those measured immediately after the initial 100-hour burn-in period. Polychromatic lamps may also be used; however, this protocol only provides generic guidelines with respect to the peak wavelengths at which lamp output should be monitored.

2 DEVELOPMENT OF A VERIFICATION TEST PLAN

Prior to the start of verification testing of a UV system under the ETV Program, the testing organization (TO) shall prepare a Verification Test Plan that clearly describes how, where, and by whom testing is to be conducted. An adequate Verification Test Plan will help to ensure that testing is conducted and that the results are reported in a manner consistent with the requirements specified in this Protocol. A good Verification Test Plan also ensures that information about a vendor's equipment is available for incorporation into a Verification Report upon the completion of testing. An individual Verification Test Plan shall be developed for each UV System undergoing verification testing.

At a minimum a Verification Test Plan for the verification of a UV System shall include:

- An introduction that briefly describes the objectives of verification testing and an overview of the approach taken to accomplish the verification;
- Roles and responsibilities of participants in the verification testing;
- A complete description of the technology and its intended functions and capabilities;
- A description of the site(s) where verification testing is to take place;
- A description of the experimental design, that includes the specific test procedures to be followed and identifies any necessary deviations from the requirements established in this Protocol;
- A description of the Quality Assurance/Quality Control procedures to be employed to ensure data quality objectives are met;
- A description of how data is to be analyzed, managed, and reported; and
- Health and safety procedures.

Subsections 2.1 through 2.8 of this protocol establish guidelines and requirements for the content and scope of each section required in a Verification Test Plan.

2.1 OBJECTIVES

The objectives of the verification test shall be clearly explained, including those identified by the ETV program itself and those claims identified by the Vendor.

2.2 PROJECT ORGANIZATION

The organization of the project shall be explained, including the management and oversight activities of the effort. Organizations and individuals assigned to the project shall be described, including their specific roles. Key individuals must be presented, including a brief description of their relevant experience. General guidelines on the roles and responsibilities for the major parties are summarized in the following discussions.

2.2.1 NSF International

NSF International is the USEPA's verification partner on the Water Quality Protection Center. NSF's responsibilities include:

- Review and approval of the Verification Test Plan;
- Oversight of Quality Assurance, including the performance of technical system and data quality audits, as prescribed in the Quality Management Plan for the ETV Water Quality Protection Center;
- Oversight and audit of the Testing Organization;
- Coordination of Verification Report peer reviews;
- Review and approval of the Verification Report; and
- Preparation and dissemination of the Verification Statement.

2.2.2 U.S. Environmental Protection Agency (EPA)

The EPA will have review and approval responsibilities through the various phases of a Verification project:

- Verification Test Plan;
- Verification Report;
- Verification Statement; and
- Posting the Verification Report and Verification Statement on the EPA Website.

2.2.3 Testing Organization (TO)

The Testing Organization shall have experience in the operation and evaluation of UV systems, the performance of the various procedures comprising the protocol, and the design and performance of pilot studies. In addition, key individuals must have direct relevant experience and training in the operation, investigation and sampling tasks associated with each test element. One of these key individuals in a supervisory or managerial role must also be a registered professional engineer. The TO will serve as the primary consultant for developing, implementing and reporting the verification. The responsibilities of the TO will include, but not be limited to, the following:

- Developing the Verification Test Plan in conformance with the generic protocol, including its revisions in response to comments made during the review period;
- Coordinating the Verification Test Plan with the Vendor and NSF, including documentation of equipment and facility information and specifications for the Verification Test Plan;
- Contracting with sub-consultants and general contractors, as needed, to implement the Test Plan;
- Coordinating and contracting, as needed, with the Host of the test facility, and arranging the necessary logistics for activities at the plant site;
- Managing the communications, documentation, staffing and scheduling activities necessary to successfully and efficiently complete the verification;
- Overseeing and/or performing the verification testing per the approved Verification Test Plan;
- Managing, evaluating, interpreting and reporting the data generated during the verification testing; and
- Preparing and reviewing the Draft Verification Report.

2.2.4 UV Technology Vendor

The Vendor's responsibilities may include, but shall not be limited to the following:

- Provide the test unit for verification, with all ancillary equipment, instrumentation, materials and supplies necessary to operate, monitor, maintain and repair the system;
- Provide documentation and calculations necessary to demonstrate the system's

conformity to commercial systems, hydraulic scalability, and to the requirements of the protocol;

- Provide descriptive details of the system, its operation and maintenance, its capabilities and intended function in the targeted applications;
- Provide technical support for the installation and operation of the UV system, including designation of a staff technical support person and of an on-site technician for training;
- Review and approval of the Verification Test Plan; and
- Review and comment on the Verification Report and Verification Statement.

2.2.5 Support Organizations

The Verification Test Plan may require the support of other organizations, if such activities cannot be provided from the NSF, EPA, TO or Vendor. This may include laboratory microbiological and chemical analyses, instrumentation calibrations, mechanical/construction, and operations. Any contractors brought into the project will be subordinate to the TO and shall be identified as part of the Verification Test Plan, along with their roles and responsibilities.

2.2.6 Technology Panel on Disinfection

Some or all of the WQP Center UV Disinfection Technology Panel will serve as a technical and professional resource during all phases of the verification, including the review of Verification Test Plans and the issuance of verification reports.

2.3 CAPABILITIES AND DESCRIPTION OF THE SYSTEM

2.3.1 System Description

The Verification Test Plan shall provide details of all components comprising the disinfection system to be verified including the purpose of each component, its intended applications and the scale of the test equipment. This must also address the test unit's conformity with full-scale commercial systems offered by the vendor.

A process flow diagram illustrating the testing facility system components should be provided. The diagram should show all components of the test facility, including support equipment, location of sampling points and flow metering. The facility description should clearly delineate the equipment components that are being verified and those that are being provided through the vendor and others to support the test facility. In addition, the following information should be included:

- Detailed dimensional drawings of the equipment showing all components, including;

  - Vendor name, address and telephone number
  - Equipment name, model number and serial number
  - Electrical requirements (voltage, amperage, frequency)
  - Warning and caution statements, as applicable
  - Capacity and output rate, as applicable

- A detailed description of physical characteristics of the equipment including its weight and size;

- A detailed drawing of the equipment layout;

- Utility requirements such as water and electricity;

- Identification of any special permitting requirements associated with the operation of the equipment, if appropriate; and

- The method for effluent disposal and verification that it is a permitted practice for the site.

The vendor must also provide any ancillary equipment necessary for the health and safety of the operator in compliance with Occupational Safety and Health Administration (OSHA) standards (e.g. face shields, emergency shut off switches, etc.).

2.3.2 System Capabilities

The Verification Test Plan shall address the application of the equipment, its limitations and its potential advantages. Statements of capabilities that are too easily met may not be of interest to the potential user, while statements of capabilities that are overstated may not be achievable and may diminish the value of the verification. The statement of capabilities forms the basis of the equipment verification testing and should be chosen carefully. The statement of capabilities should include, but not necessarily be limited to:

- Regulated microbial species or microbial indicators that can be removed or reduced by the tested technology;

- The anticipated dose – delivery levels as a function of the targeted water quality;

- The operating limits in terms of hydraulic loading range;

- The operating envelope in terms of wastewater quality, specifically wastewater transmittance for UV systems;
- Instrumentation and control requirements;
- Equipment installation requirements; and
- Operation and maintenance requirements.

2.4 EXPERIMENTAL DESIGN

The Verification Test Plan shall describe how the objectives and technical approach will be implemented, and shall include the procedures that will be followed for each of the Test Elements chosen for the Verification. Within this framework, a **Sampling, Analysis and Monitoring Plan** must be provided, in support of the Experimental Design. This must address the procedures that will be followed for sampling, and references for all analytical methods. All monitoring equipment and instrumentation shall be described.

2.5 HEALTH AND SAFETY PLAN (HASP)

The Verification Test Plan shall have a HASP, which addresses safety considerations that are appropriate to the test site and the equipment being tested, and the storage, handling, transport and disposal of chemical constituents or wastewaters. If testing is to be conducted at a site covered by a separate HASP, the Verification Test Plan HASP shall conform with and incorporate any other requirements under that facility's general plan.

2.6 QUALITY ASSURANCE PROJECT PLAN (QAPP)

The Verification Test Plan shall include a QAPP that specifies procedures to be used to ensure data quality and integrity. This shall follow the generic outline presented separately in Section 7.

3 TEST ELEMENT 1: DOSE-DELIVERY VERIFICATION

The dose-delivery capabilities of the system, for application to secondary or reuse waters, shall be verified by an MS2 coliphage assay. The challenge MS2 phage shall be calibrated in the laboratory via a collimated-beam apparatus, and then added to a prepared batch of either granular or cloth media-filtered effluent or potable water, which has been adjusted to a targeted transmittance at 254 nm. The seeded water shall be passed through the UV reactor over a targeted range of flows and sampled for influent and effluent phage analysis. This shall yield a dose-hydraulic loading relationship for the particular system configuration. Table 3-1 provides a summary of the laboratory and field tasks in this Test Element.

3.1 DOSE–RESPONSE CALIBRATION

Key elements of the bioassay process are the selection and harvesting of a test organism, and the accurate calibration of its response to UV exposure.

3.1.1 Selection, Culturing and Harvesting of Test Organism

The test organism shall be the F-specific RNA bacteriophage MS2. For a number of reasons, this organism is widely used to assay delivered UV germicidal dose (NWRI/AwaaRF, December 2000):

- The MS2 phage has a relatively high tolerance to ultraviolet light and exhibits dose requirements that are typically higher than what is required by most bacterial and viral organisms to exhibit measurable levels of inactivation. This allows development of a dose-response relationship that encompasses dose levels required for most disinfection applications.

- The response of the bacteriophage is fairly consistent over repeated applications.

- The MS2 phage can be cultivated up to densities of 10^{12} pfu/mL. This permits its practical use for preparing and inoculating the relatively large volumes of water needed to test large-scale reactors.

- This phage is not pathogenic to humans, and is harmless in the aquatic environment. No special safety precautions are required.

- The attachment site is only expressed at temperatures exceeding 35°C. This temperature is much higher than would be present in secondary effluent or reuse applications. Because the attachment site is not present at the applicable temperature, there is no risk of confounding results by infection and subsequent multiplication in the natural environment.

- Standard procedures are available for cultivating and enumerating F-specific RNA bacteriophage.

Table 3-1. Summary of the Experimental Effort for Test Element 1: Dose-Delivery Verification					
TASK	**SUBTASK**	**REF**	**DESCRIPTION**	**FREQUENCY**	**ANALYSES TO BE DONE**
A. Prepare MS2 Phage	1. Harvesting.	3.1.1	Prepare a sufficient quantity of phage in one stock for the full verification.	Prepare one stock for a full verification of a vendor's system.	Periodic titers of the MS2 Phage to estimate density. Once per month.
B. Dose Calibration	1. Intensity Probe and radiometer calibration.	3.1.2.2	In accordance with the vendor's specification.	Once per 4 months of active use.	No analytical.
	2. Measure intensity field across sample surface plane in collimator.	3.1.2.3	Map the intensities across the sample surface plane. This is to assure uniformity.	Once for each stock dose-response calibration. Verify once every four weeks.	No analytical.
	3. Verify Dechlorination and the Effect of Coffee and Thiosulfate on Phage.	3.4.1	Check dechlorination of the stock water. Test each new stock phage with exposure to coffee and thiosulfate to assure that the phage are unaffected.	Once for each stock.	UV transmittance of the control and test samples (approximately 10). Phage titers of each sample (approximately 10). Residual Chlorines (as needed).
	4a. Dose-Response Calibration Runs (Secondary Effluent Applications Only).	3.1.2.3 and 3.1.3	Conduct a collimated beam dose run on the phage to calibrate its response to UV. Each run is comprised of exposure to a minimum of five doses. Seed water shall be the same water source that will be used for the field challenge tests.	Minimum of four runs for each stock phage conducted within 3 weeks before field testing and during the field test period.	1. Five doses plus a minimum of two controls in each run, at a single transmittance. Do this at least four times. 2. Approximately 12 transmittances (each control). 3. Approximately 70 phage analyses (controls, test dose samples, in duplicate).

Table 3-1. Summary of the Experimental Effort for Test Element 1: Dose-Delivery Verification					
TASK	**SUBTASK**	**REF**	**DESCRIPTION**	**FREQUENCY**	**ANALYSES TO BE DONE**
	4b. Dose-Response Calibration Runs (Reuse Applications Only)	3.1.2.3 and 3.1.3	Conduct a collimated beam dose run on the phage to calibrate its response to UV. Each run is comprised of exposure to a minimum of five doses. Seed water shall be the seeded feed water adjusted to the test transmittance used for the field challenge tests.	Each run must be carried out within 24 hours of the field challenge tests.	1. Five doses plus a minimum of two controls in each run, at a single transmittance. Do this four times. 2. Approximately 15 transmittances (each control). 3. Approximately 70 phage analyses (controls and test dose samples, in duplicate).
C1. Test Unit Assay (Secondary Effluent) Application Only	1. System Monitoring	3.4.3.1 3.4.3.2	Monitor the test system for operating variables and test unit conditions	At each hydraulic loading sampling event.	1. Temperature of ambient (influent) water and, at each flow condition sampled. If the test unit uses low-pressure, low-output lamps, measure lamp temperature (2 lamps). 2. Intensity at 100% and test % output. 3. Voltage/Amperage at each Intensity setting, or alternative method to verify lamp operation. 4. Flow rate at every sampling 5. Headloss (via elevation or pressure differentials) at each flow

Table 3-1. Summary of the Experimental Effort for Test Element 1: Dose-Delivery Verification					
TASK	**SUBTASK**	**REF**	**DESCRIPTION**	**FREQUENCY**	**ANALYSES TO BE DONE**
					sampled.
	2. Conduct Dose-Flow Assays	3.4.3.1 and 3.4.2.1	Conduct runs with prepared phage batches. Each run shall comprise five different flow rates (equivalent to five doses). Quartz sleeves are cleaned manually each day or with each run.	Minimum of four runs at each selected target test transmittance.	1. Conduct Influent and Effluent sampling in triplicate at each flow event at the test transmittances [55, 65 and/or 75% at 254nm] 2. Conduct a duplicate flow event at each 10th flow event. 3. Yields a total 30 samples (5 flow events with 3 inf/eff samples each) for phage analyses and 15 transmittances (influents only) for each flow-series run.
	3. Residence Time Distribution (RTD)	3.4.3.3.1	Determine fundamental hydraulic information about the reactor using tracer techniques.	Minimum three runs at the lowest, highest and mid-point of the test flow range.	No analyses unless methodology requires discrete collection of samples and analysis for tracer concentration
C2. Test Unit Assay (Reuse) Application Only	1. Minimum Sensor Level Determination	3.4.2.6	Determine the most conservative means for achieving the combined effect of end-of-lamp life, and minimum water transmittance, loss through sleeve and a fouling factor. The results will be the basis for the dose-flow assays. (1) Combined effect by transmittance altering only.	Minimum of three runs at a single flow rate before the start of dose-flow assay testing.	1. Conduct influent and effluent sampling in triplicate for each test condition. 2. Yields 6 samples for phage analysis for each separate test run.

Table 3-1. Summary of the Experimental Effort for Test Element 1: Dose-Delivery Verification					
TASK	**SUBTASK**	**REF**	**DESCRIPTION**	**FREQUENCY**	**ANALYSES TO BE DONE**
			(2) Combined effluent by direct reduction of lamp output at the minimum water transmittance depending on the application. This comparison shall be done only if the commercial system itself offers power turndown, and only to the extent that this turndown can be applied.		
	2. System Monitoring	3.4.3.1 3.4.3.2 3.4.3.3	Monitor the test system for operating variables and test unit conditions.	At each hydraulic loading sampling event.	1. Power at every dose. 2. Temperature of ambient water and air, at each flow condition sampled. If low-pressure, low-output lamps are used, also measure the lamp temperature (2 lamps). 3. Intensity at 100-percent and 50-percent output. 4. Voltage/Amperage at each Intensity setting. 5. Flow rate at every sampling. 6. Headloss (via elevation or pressure differentials) at each flow sampled.
	3. Conduct Dose-	3.4.3.1	Conduct runs with prepared	Minimum of four runs	1. Conduct Influent and Effluent

Table 3-1. Summary of the Experimental Effort for Test Element 1: Dose-Delivery Verification					
TASK	**SUBTASK**	**REF**	**DESCRIPTION**	**FREQUENCY**	**ANALYSES TO BE DONE**
	Flow Assays	and 3.4.2.1	phage batches. Each run shall comprise five different flow rates (equivalent to five doses). Quartz sleeves are manually cleaned each day or with each run.	at each minimum sensor level.	sampling in triplicate at each flow event, at each minimum sensor level. 2. Conduct a duplicate flow event at each 10^{th} flow event. 3. Yields a total of approximately 30 samples for phage analyses and 15 transmittances for each test run (see C2).
	4. Velocity Profile Measurements	3.4.3.3.2	Establish velocity profile before first reactor and after final reactor.	Minimum of three runs at each hydraulic loading.	No Analytical.

F-specific RNA bacteriophage are bacterial viruses which can infect a specific host strain with F- or sex-pili, producing clear areas, or plaques, within a confluent lawn of grown host strain. The methodology for detection and enumeration of F-specific RNA bacteriophage (ATTC 15597 – B1) is presented in ISO DIS 10705 (Havelaar): Water Quality - Detection and Enumeration of Bacteriophage (see References). Briefly, a sample infected with MS2 phage is mixed with a small volume of semi-solid nutrient medium. A culture of host-strain is added to the sample. The sample is then plated on a solid nutrient medium and then incubated for a period of 16 to 20 hours. After the incubation period, the number of visible plaques is counted on the plate. The results are expressed as the number of plaque forming units (C_{pfu}) per unit volume. The required host strain is *Escherichia coli (E. coli)* ATTC 23631. Alternate methods, as outlined in NWRI/AwwaRF (December 2000), can also be used.

A large enough stock of MS2 shall be cultured and harvested by the methods outlined in Havelaar (ISO, 1995) or NWRI/AwwaRF (December 2000) to meet the needs for a complete field assay of a specific piece of equipment. The amount required shall be demonstrated as part of the Verification Test Plan. The entire stock shall be filtered through a 0.45-micron membrane filter as the final cleanup. This stock shall be stored under refrigerated conditions (or under deep-freeze, if facilities are available), and used to develop a dose-response relationship. Stocks shall be kept separate and calibrated separately. Although evidence suggests that variations from stock to stock are relatively small, greater precision can be obtained for a dose-response calibration within a stock. If the stock is held for a period of months, the response of the phage to UV shall be checked at least once per month to assure that the culture is viable and unchanged.

3.1.2 Dose-Response Calibration of the MS2 Phage

3.1.2.1 Collimated Beam Apparatus

The dose-response calibration assay is conducted using a collimated beam apparatus that consists of a lamp housing and a collimating tube. Figure 3-1 presents an example of a collimating apparatus. The lamp housing is a horizontal tube, constructed of an opaque and a non-reflective material and ventilated continuously via a blower or other device. The collimating tube, also constructed of an opaque non-reflective material, extends downward and perpendicular to the center of the lamp. The purpose of the tube is to select and direct those photons emitted from the lamp into a uniform, or collimated path, perpendicular to the surface of the sample being irradiated. This radiation is imposed on the surface of a mixed sample held in a container immediately below the collimator, which may be suspended by an adjustable drive, as shown, or with a lab jack. The lower, open workspace must be treated as a microbiological work area with respect to cleanup and disinfection procedures. The use of the collimator requires the use of an accurate timing device and radiometer (not shown).

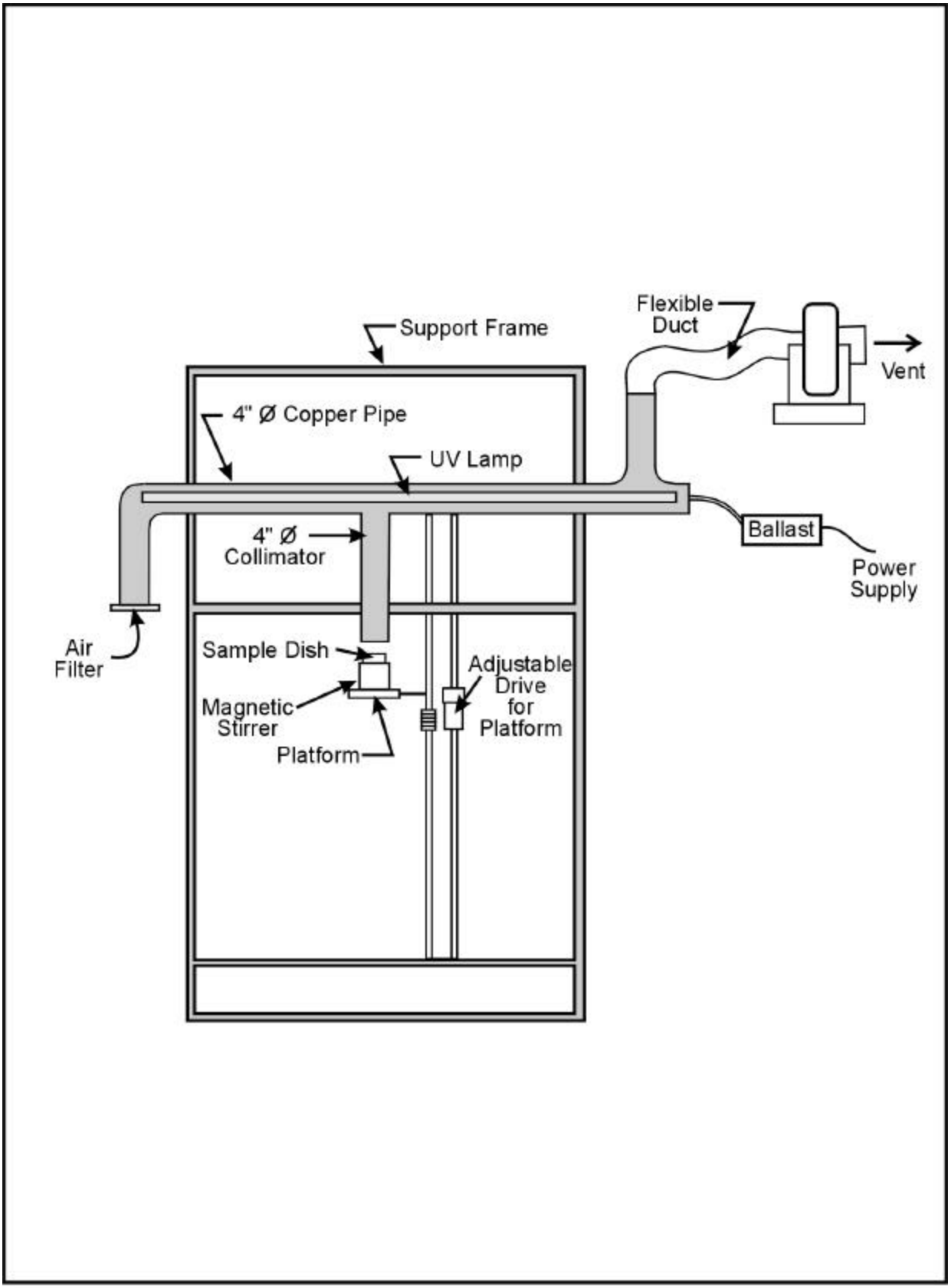

FIGURE 3-1. Example Collimator Apparatus for Dose-Response Test.

Collimators can be constructed rather simply, and the Verification Test Plan shall provide a detailed description of the apparatus, including dimensional drawings. Certain specifications will need to be met:

- The lamp shall be a conventional, monochromatic G64T5 lamp, or equivalent low-pressure lamp. Multiple lamps and lamps of varying length may be used. The collimator shall be equipped with a lamp temperature monitor and shall be designed to minimize lamp temperature fluctuations.

- The ratio of the length of the collimating tube to its diameter shall be at least 4:1 in order to assure a uniform emission from the bottom of the tube.

- The irradiance across the cross-sectional plane at the bottom of the collimating tube shall be relatively uniform. The irradiance across the surface plane of the sample dish shall be mapped over the entire plane at sectors of equal area (minimum of 20 cells); the average irradiance shall be determined via numerical integration. Ninety percent of the data points shall have a ratio of single value to the average between 0.9 and 1.1. The mapping procedure, which shall be described in the Verification Test Plan, must ensure minimal variation of intensity across the surface of the sample, and the Verification Test Plan must describe what measures will be taken to restore a collimator not meeting specifications. This mapping procedure should be done at least once every two months for the same setup (sample container is always the same and is always in the exact same position relative to the collimator), and immediately if any change is made to the apparatus.

- The diameter of the sample container shall be less than the diameter of the collimating tube. The outer perimeter of the sample container shall never be outside the diameter of the collimator. The container shall be a petri-type dish, with straight sides and a flat bottom.

- The sample container to be irradiated shall be located immediately below the collimating tube. The distance between the sample surface and the bottom of the collimating tube shall be less than 2.5 cm in order to minimize dispersion of radiation once it leaves the collimator. The sample container must be in the same fixed position relative to the collimator whenever a test is being conducted.

- The depth of the sample shall be such that the calculated intensity at the bottom of the container is greater than 25 percent of the intensity at the surface of the sample (refer to Section 3.1.2.3).

- The sample in the dish must be continuously stirred via a small spinbar and magnetic stirrer. The spinbar size and speed shall be sufficient to maintain a stirred sample, but

shall not cause surface turbulence. Once a workable stirring speed is identified, this speed shall be left undisturbed for the remainder of the assay and the stirrer shall be turned on and off at the preset speed. The magnetic stirrer shall be insulated such that there is no significant (e.g., no more than 2 degrees C) rise in the sample temperature during exposure.

- The apparatus shall allow for positioning a radiometer detector at the exact elevation of the sample surface.

- The venting provided for maintaining a reasonably constant lamp temperature should not be excessive and should be designed to minimize contamination of the air in the vicinity of the collimator. A filter on the intake air is suggested, as shown on Figure 3-1.

3.1.2.2 Intensity Probe and Radiometer Calibration

The UV intensity emitted from the collimating tube is measured with a radiometer (IL 1700, SED 240 detector, International Light, Newburyport, Massachusetts, or equivalent), calibrated using standards traceable to the National Institute of Standards and Technology. Calibrations of the detector and meter shall be certified and performed within six weeks before an ETV test is conducted, and then after completion of the test program, if it occurs more than four months after startup. It is advisable to have two detectors available as checks against one another. Additionally, the detectors may be checked experimentally, via a previously standardized actinometric procedure, to assure consistency and accuracy of the dose imposed as part of the collimated beam dose-response test (Bolton, 1997). Similarly, a reference sensor can be maintained and checked by an actinometric procedure, and factory calibrations. Refer to Section 3.2.1 regarding the general specifications expected for the UV sensors. During the actual collimated-beam dosing activities, a minimum of three UV intensity readings shall be taken, generally at the beginning, middle and end of a dose-response assay run at a single reference point. The readings shall be within 5 percent of their average. If variations occur beyond these limits, the tests shall be repeated. The Verification Test Plan shall detail the readings to be taken.

3.1.2.3 Dose-Response Test with the Collimated Beam Apparatus

A collimated beam dose-response assay shall be performed for each MS2 phage stock. The assay requires exposing a known concentration of MS2 phage to a known UV intensity from the collimating apparatus over various time intervals and then measuring phage survival. Dose is determined by multiplying the intensity (averaged to account for deviations across the exposure plane and depth-corrected for the given transmittance) and exposure time. A dose-response relationship is then developed, expressed as log survival (N/N_0) as a function of the applied dose.

The laboratory assay shall be conducted under controlled, constant conditions. All waters used for dilution (of the phage stock) shall be the same as used for the field tests. For secondary effluent verifications, the tests can be conducted at the ambient source-water transmittance. For reuse verifications, the dose-response test water must be from the field-seeded and transmittance-adjusted waters being directly used for the challenge test. If the field test shall be conducted with a reactor using

an alternate lamp (medium-pressure, or low-pressure/high-output lamps), the dose-response calibration shall still be conducted with the conventional low-pressure, monochromatic G64T5 lamp. The overall intent is to normalize the bioassay results to an equivalent dose at 254 nm.

To develop a dose-response relationship, the measurement of responses at a minimum of five different doses is required, covering and bracketing the expected operating range of UV doses of the UV test unit. At least four runs should be conducted, resulting in at least 20 points to develop a dose-response relationship. Extrapolations shall not be made beyond the minimum and maximum dose levels actually tested. The collimating apparatus shall be set up and adjusted as needed to yield the desired intensity from the collimator to the sample surface. This is typically on the order of 0.1 to 0.5 mW/cm^2, and is generally a function of the setup of the apparatus and the need to have exposure times that are long enough to be practically applied and measured. Generally, exposure times shall be greater than 30 seconds. The intensity can be altered by having one, two or more lamps in operation, or by adjusting the collimator length. The collimator must still stay within the specifications discussed in Section 3.1.2.1. Before starting the dose-response runs, the intensity mapping must be completed across the surface of the sample container. Mapping shall be conducted at least once every four weeks of active testing. If exposure times of less than 10 seconds are needed, an automatic shutter arrangement is recommended for the collimating apparatus.

The Verification Test Plan shall present the methods and materials to be used to conduct the collimated beam dose-response analyses. The following is a general procedure to be followed, unless otherwise specified and approved in the Verification Test Plan:

1. Warm the collimator UV lamp(s) and radiometer for a minimum period of 0.5 hour. Record the intensity periodically (e.g., every 5 minutes) at the exact height of the sample surface until a stable reading is obtained. Begin testing only when there is a variance of 5 percent or less for the last three readings.

2. Place a known volume of MS2 phage solution in the irradiation container and add a sterile spinbar (UV sterilization is adequate). The targeted density should be at least 10^6pfu/mL, reflecting the intent to achieve up to a five-log reduction at the higher dose levels. The volume that is added shall be determined from a calculation/direct measurement, such that the depth is accurately known. This should be on the order of 1 to 2 cm. If low transmittance samples are being tested, the depth shall be adjusted such that the estimated intensity at the bottom of the container is still more than 25 percent of the surface intensity, based on the attenuation of the intensity at the given transmittance:

$$I/I_o = e^{-kd} \qquad (3\text{-}1)$$

Where:

I_o = the incident intensity at the surface of the sample (mW/cm^2)

I = the intensity at the bottom of the sample (mW/cm^2)
k = the absorbance coefficient (base e) (cm^{-1})
d = the depth of the sample (cm)

3 The depth should be constant over the entire area of the sample. Place the vessel onto the magnetic stirrer and allow the sample to thoroughly mix. The sample should be mixed for about 30 seconds before the sample is exposed.

4. Simultaneously remove the shield and start the timer.

5. After the desired time has elapsed, cover the irradiation vessel with the shield and turn off the stirrer. This sample shall be plated immediately. Samples shall be plated in triplicate at three dilutions, according to the requirements of the bacterial or phage enumeration protocol, which shall be included in the verification test plan.

6. Repeat Steps 2 through 4 for different time intervals.

7. Control samples shall be generated following the same procedure for each 5-dose run. Controls are run in the same manner as each test dose sample, except that the lamps are off (or shielded) and there is no exposure to the UV light. As a minimum, control samples are analyzed at time zero and the maximum exposure time for the dosed samples, yielding at least 2 controls for each dose series. Intermediate controls may be generated, depending on the overall number of samples being generated in a given run; if five or more dose levels are run, at least one intermediate control should be sampled.

8. During the middle and end of the dose-response runs (e.g. after the third and fifth dose applications), measure and record the intensity at the elevation of the sample surface. These readings shall not vary by more than 5 percent from the initial reading. Checks are required at intermediate points to assure consistency of the reading; if desired, the intensity may be measured before and after each dose delivery. The Verification Test Plan shall define this.

9. The concentration of the phage solution used for the dosing assays shall be greater than 1×10^6 pfu/mL, and shall be sufficient to yield no less than 20 pfu/mL after exposure (this is relevant at the very high doses, where one can expect nearly 5-logs reduction). The transmittance of the diluted phage stock used for the assays shall be measured with each preparation.

10. Compute the dose as follows:

$$D = I_o t\left[\left(1 - e^{-kd}\right) / kd\right] \qquad (3\text{-}2)$$

Where:

D = UV Dose at 253.7 nm (mW-s/cm^2)
t = Exposure time (seconds)
I_o= Incident intensity at the surface of the sample (mW/cm^2)
k = absorbance coefficient (cm^{-1}) (note that this is base e)
d = Depth of the sample (cm)

The incident intensity shall be corrected for reflectance at the surface of the sample. This is approximately 2.5 percent of the measured incident intensity (Reference 5). Thus the value of I_o should be approximately 0.975 times the measured intensity at the surface of the sample. With respect to the absorbance coefficient, note that this is base e, with units cm^{-1}. Spectrophotometers can report absorbance and/or transmittance. Absorbance units per centimeter (a.u./cm) can be converted to the absorbance coefficient:

$$\text{Absorbance Coefficient, } k = 2.3(\text{a.u./cm}) \qquad (3\text{-}3)$$

Transmittance measurements can also be converted by the relationship:

$$\%T = 100 * 10^{-(\text{a.u./cm})} \qquad (3\text{-}4)$$

3.1.3 Dose-Response Data Analysis

The theoretical UV disinfection model follows first order kinetics according to the following equation:

$$N = N_o\, e^{KIt} \qquad (3\text{-}5)$$

Where:

N = the organism density remaining after exposure to UV, pfu/mL
N_o = the initial organism density, pfu/mL
K = the inactivation rate constant, cm^2/W-s
I = the intensity of UV radiation, W/cm^2
t = the exposure time, seconds

The product (It) is the applied UV dose. The above equation can be expressed as a linear relationship by graphing the logarithm of N/N_o as a function of the applied UV dose. The resulting slope of a linear regression analysis is equal to the inactivation rate constant, K. Note that the intensity in this case is the depth-averaged intensity, as described in equation 3-2, accounting for the transmittance of the sample being tested.

The data generated by a dose-response analysis are N, N_o and the applied UV doses. An example of a dose-response curve is presented on Figure 3-2, displaying data generated from several MS2 stocks. Under ideal conditions, the data from a dose-response analysis should be expected to intercept the origin, and should be linear throughout the full dose range. This is generally not the case. The observed data do not yield a y-intercept at zero, and there is evidence of tailing at the higher dose levels. The deviation of the observed data from the theoretical model results from the non-ideal conditions under which the tests are performed. For the purposes of developing a dose-response curve, it is more appropriate to apply a model that better represents the observed data. Figure 3-2 presents an example of a non-linear regression of dose-response data. Non-linear regression analyses of the dose response data are suggested for the ETV, unless otherwise proposed and approved in the Verification Test Plan.

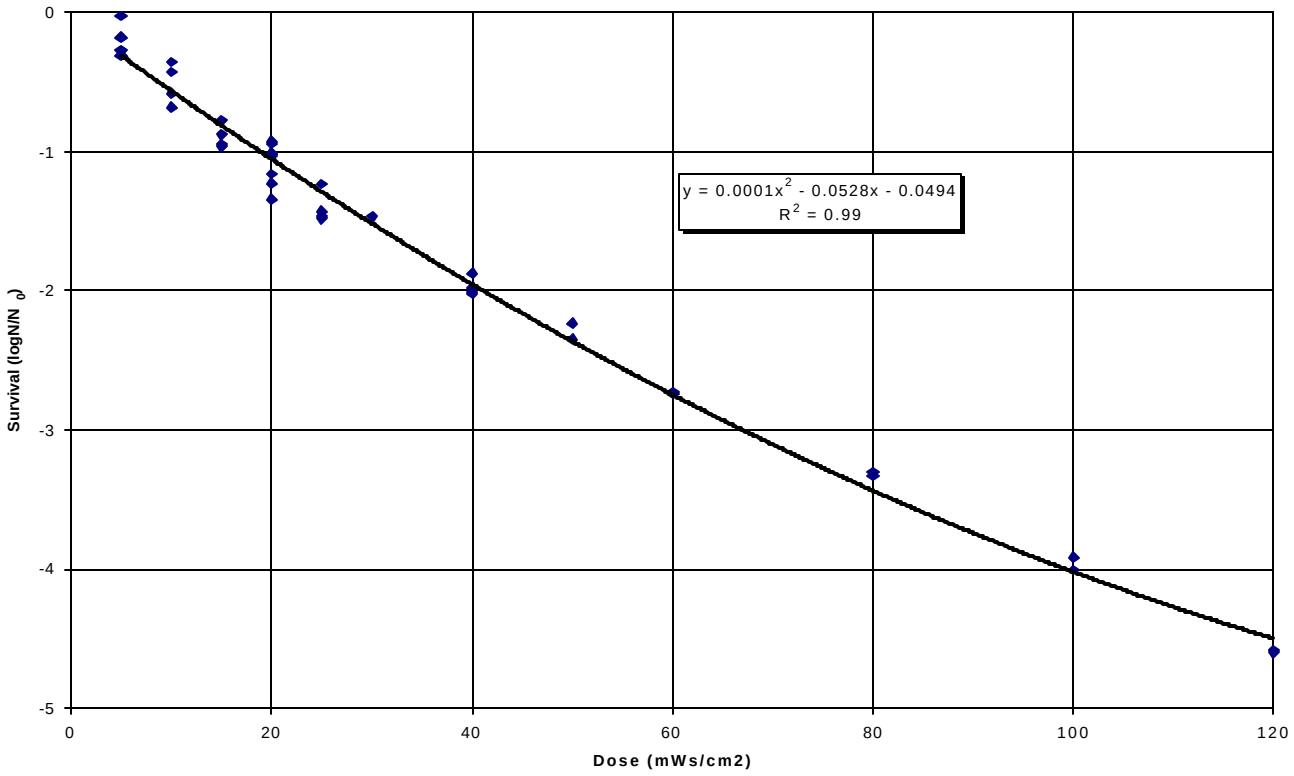

Figure 3-2. Example Dose-Response Calibration for MS2 Coliphage

Dose response data for the MS2 coliphage must be generated in the range of 10 to 100 mJ/cm^2 and these data must fall in the area bounded by the following equations:

$$-\log_{10}(N/N_0) = 0.036*(\text{ UV Dose, mJ/cm}^2) + 0.134$$

$$-\log_{10}(N/N_0) = 0.044*(\text{UV Dose, mJ/cm}^2) + 0.700$$

If the verification test plan requires operating conditions outside the 10 to 100 mJ/cm^2 dose range, data

in this range must still be generated to determine QA compliance of the MS2 coliphage. However, the data and linear relationship developed within this range of 10 to 100 mJ/cm^2 cannot be extrapolated to doses outside this range. If the field tests are to assess doses outside this range, then dose-response data outside this range must also be generated. These additional data shall not be held to the QA defined by the above lines, but must represent an uninterrupted continuation of those data. If, as expected, the outer range are non-linear, then a non-linear regression analysis shall be performed to develop a representative relationship of dose and survival outside the linear range of 10 to 100 mJ/cm^2. The Verification Test Plan shall present a discussion of the methods that will be used to estimate dose delivery if the intent is to verify performance levels outside of the range 10 to 100 mJ/cm^2.

In addition, at least 80 percent of the data points shall lie inside the area defined above; if not, the run is discarded. The remaining data can lie in the region outside the area, but all data points in the appropriate dose range shall be included in the regression analysis. Conformance with this requirement forms the primary QA control for the collimating apparatus and the growth, harvesting and calibration of the MS2 phage.

For secondary effluent applications, a minimum of four dose-response runs, each run comprising 5 doses (two of which bracket the operating range of the proposed test unit), are required for the dose-response calibration of the MS2 stock culture. These can be conducted before the field testing is initiated, or conducted through the term of the field tests. For reuse applications, each dose-response run must be conducted concurrently or within 24 hours of a field challenge test using the same seeded, transmittance-altered waters.

3.2 UV TEST UNIT SPECIFICATIONS

The test unit submitted for evaluation by the ETV protocol must be equivalent in configuration and operation to the commercial unit offered by the vendor. It will be critical to clearly describe both the commercial unit and the test unit as part of the Verification Test Plan.

3.2.1 Size and Component Considerations

The system that is tested shall be a hydraulically scaleable unit. In some cases, given the modular nature of UV systems, the test unit may be a commercially available full-scale module. Note that for secondary effluent verifications, only one reactor (pilot or full scale) is required. A minimum of two independent reactors in series is required for reuse application verifications. A reactor is defined as an independent combination of single or multiple bank(s) in series with a common mode of failure (e.g., electrical, cooling, cleaning system, etc.) (NWRI/AwwaRF, December 2000). The maximum scale-up from the unit used for the verification test shall be 10:1. There shall be no scale-down from the test unit size. The minimum size for scale-up shall be 4 lamps per reactor. Hydraulically scaleable means that the hydraulic behavior and characteristics of the test system are sufficiently similar to that of the full-scale unit, such that direct design sizing assumptions can be made on the basis of the test unit results. Examples for assessing hydraulic similarity include the ratios of flow rate to number of lamps; equivalent

cross-sectional velocities; equivalent ratios of width to depth and length to cross-sectional dimension (e.g. aspect ratio), ratio of wetted perimeter to total quartz perimeter, etc. These would need to be selected on the basis of the type of system (e.g., open channel, closed reactor, etc.). This is best done as part of the Verification Test Plan and serves to justify/qualify a test unit selected for verification. The vendor is required to submit such calculations of hydraulic comparisons between the test unit and the equivalent full-scale, commercial unit. The Verification Organization and Field Test Organization shall be responsible for reviewing and accepting the hydraulic claims provided by the vendor. The information on the hydraulic scaling calculations shall become part of the final Verification Report.

With respect to system components, there are key elements of the test unit that should be identical to that of the full-scale commercial unit. The vendor must provide the following documentation for each UV reactor tested;

- A technical description of the UV reactor that includes dimensions, maximum pressure rating, working flow range, head loss, internal fixtures, spare part specifications, circuit diagram, power consumption, ballast information, and the number and type of UV lamps and sleeves.

- Assembly and installation instructions (with all the necessary information on electrical and mechanical installation).

- An operation and maintenance manual.

- Cleaning procedures and instructions (including any special cleaning equipment).

If they are a part of a commercial system, intensity meters, temperature probes for the lamp and the liquid, voltage and amperage readouts, power meters, lamp indicator lights, ambient air temps and exhaust air temps (in systems that may have cooling or temperature control devices) shall also be provided. The use, calibration and recording of these monitoring and control devices shall be detailed as part of the Verification Test Plan.

UV sensors in the reactor can be useful to the test program to denote operation of the lamps (although these are generally noted by pilot lights on the individual lamps). In addition to the sensors provided with the commercial unit, at least one reference sensor (IL1700 NBS 254, SUD, or equivalent) shall be installed within the reactor in a fixed, non-movable position. Fiber-optic extensions for such sensors are acceptable. The consistency of output on a day-to-day basis shall be monitored during the test period. Readings should not vary significantly (+/- 5% of mean) under both clean water and adjusted water conditions.

The UV reactor must have UV sensors that continuously monitor UV intensity within the reactor. The vendor must specify the number and location of UV sensors within the reactor and must provide the methodology used for selecting the sensor location and monitoring positions in the

Verification Test Plan. The sensors must be set to monitor the UV lamp output away from the lamp electrodes and must account for the UV intensity field geometry, the possible scaling of the lamp sleeve, and the influence of water UV absorbance.

The vendor must provide reference sensors that can be used to verify the accuracy of the reactor sensors. The UV reactor shall be designed with a sensor(s) position that allows reproducible determination of the UV intensity by reference and system sensors. The Verification Test Plan shall describe the sensors and their fixed location setups, and how these conform to commercial system design. During testing, the reactor sensors must be checked by comparison with the reference sensors. If the reading of a reactor sensor deviates from the reference sensor by more than the measurement uncertainty, as specified below, then the cause of the deviation must be identified or the reactor sensors must be recalibrated or replaced.

Documentation must be provided to verify that UV reactor sensors and reference sensors conform to the performance standards as described in "Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse," (NWRI/AwwaRF, December 2000):

- The working range of sensors must correspond to the UV intensity expected at the monitoring position(s) in the UV reactor.

- The measurement uncertainty of reactor sensors must be less than 10 percent of the working range. Uncertainty of reference sensors must be less than 5 percent of the working range.

- The selectivity of the reactor sensors must be greater than 90 percent for the germicidal range (i.e., wavelengths between 200 and 300 nm). The selectivity of reference sensors must be greater than 95 percent.

- The linearity of reactor and reference sensors in the working range must be within 5 percent.

- The stability of sensors must be such that sensitivity does not deviate by more than 5 percent within the specified working temperature range and over a specified operating period of at least 5,000 hours.

- The acceptance angle of all reactor and reference sensors must be uniform.

Temperature probes shall be installed on at least two lamps in the conventional low-pressure, low-output lamp systems. Changes in temperature, if any, shall be reported as a function of flow.

3.2.2 Lamp Output

The vendor must specify the type and manufacturer of the lamps used in the UV reactor. The UV lamps must be subject to a burn-in period (e.g., 100 hours) sufficient to produce nearly constant emission during the test period. For UV lamp sleeves and sensor monitoring windows, the vendor must specify the dimensions, transmission spectrum, and pressure rating. For medium-pressure lamps, the reactor must be equipped against overheating with a safety cut-off switch. Instrumentation must be provided to monitor ballast power. The vendor must also supply all necessary facilities to allow testing at reduced UV output. The reduced UV output testing is intended to simulate old and fouled lamp conditions.

Data on lamp output and the anticipated effects of temperature shall be included in the Verification Test Plan. The lamps that are used in the test unit, and the ballasts used to drive them, must be the same that are used in the commercial systems. This is a critical factor in establishing the acceptability of the test unit as representative of the full-scale commercial systems. The vendor shall verify this information, which shall be incorporated into the Verification Test Plan.

3.2.3 Reactor Configuration

The Verification Test Plan submitted for a specific equipment dose-delivery assay shall be explicit with respect to the layout of the lamp reactors, and conformity with the full-scale design of the system. This shall include the number of lamps, modules and banks; channel design; stilling plates in the case of open-channel gravity flow systems; level control; and inlet and outlet structures. Engineering drawings and equipment specifications will be provided as support documentation for the test unit design. The ETV Verification Organization and Testing Organization must approve the design and conformity to full-scale design practice.

3.3 TEST FACILITY

The ETV protocol anticipates a fairly large-scale equipment configuration, requiring a site capable of supplying sufficient wastewater or potable water and, in the case of the granular, synthetic or cloth-media filtration application for reuse, filtered effluent, on a continuous basis, and with capacity to dispose of the material once it has passed through the system. The protocol assumes that the appropriate location will be a secondary wastewater treatment plant with access to a potable water supply and filtered final effluent.

3.3.1 Test Facility Equipment

This protocol gives direction to the setup at a test site. Figure 3-3 presents an example test facility layout for conducting a large-scale dose-delivery bioassay. The Verification Test Plan shall provide more detail in its layout of the test facility. This protocol is based on a batch-testing approach, drawing from a batch of test water that has been adjusted to specified characteristics. The batch

approach offers good control and consistency and is established as the default method within this protocol. Alternate methods, such as those that may use a continuous flow stream with direct injection may be proposed in the Verification Test Plan. In the case of tests that are conducted by continuous injection of seed and transmittance-adjustment chemicals, the facility should be equipped with continuous transmittance monitors, or semi-continuous sampling shall be conducted to assure that a consistent %T adjustment is made throughout the exposure period (influent/effluent sampling event). At a minimum the Test Plans shall describe the following site equipment, as suggested in Figure 3-3:

- **Batch Tank**. One or more sufficiently large tanks will be needed for preparation of the batch water to feed the UV system. The size of the tank(s) required will depend on the system requirements. These should have access ladders and sufficiently sized ports for intake and discharge. If they are steel tanks, they should be lined to avoid metal corrosion in an aggressive water condition.

- **Pump**. One or two pumps are suggested. Hereto, the size of the pump or pumps will be dependent on the system needs. It is important that the piping and intakes are well sealed to avoid air induction and discharge to the UV system. Fine bubbles dispersed in the water can affect the transfer of energy to the liquid and will impact the performance of the UV system. This same observation applies to pumps that may be used for batch water mixing or recirculation. Pump specifications and curves shall be submitted with the Verification Test Plan, demonstrating how the five equivalent dose flows will be accomplished.

- **Electrical Source**. Experience has shown that different systems require different service with respect to power. A diesel-powered generator may be appropriate to run the system or direct feed may be used depending on local power availability and conditioning.

- **Flow meter**. A magnetic flow meter is recommended, with a digital readout. The calibration and flow ranges shall be verified.

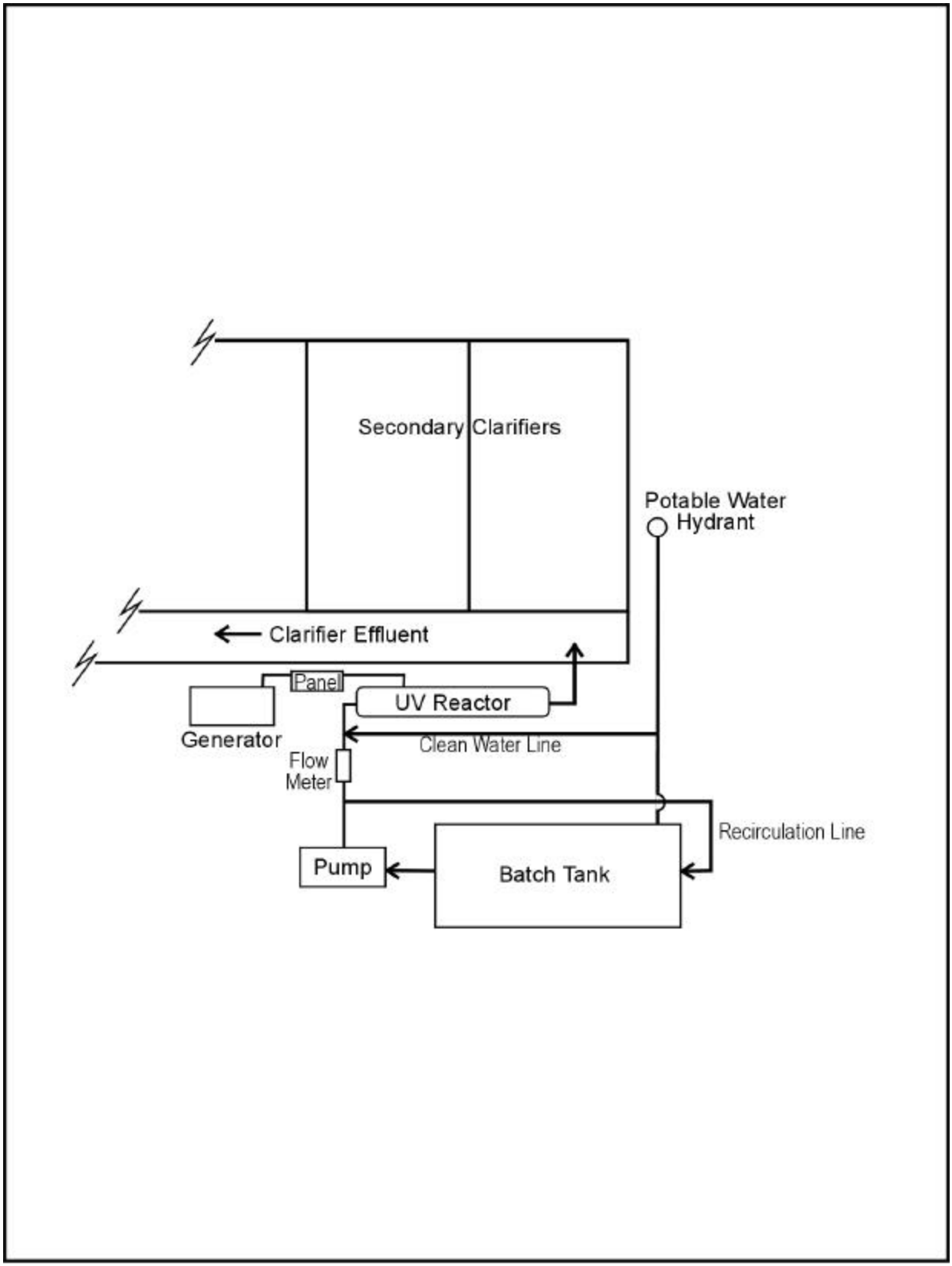

FIGURE 3-3. Example Test Facility Layout for Phage Dose-Delivery Assays.

- **Discharge**. The discharge during this Test Element is relatively clean, consisting of potable water that has had an absorber and phage seed added. It does not require treatment. The discharge from larger systems, however, can be significant and can affect the receiver. Depending on the size of the test system, a location that can accept short-term, high-volume inputs is required. An appropriate location would be a large capacity wastewater treatment plant.

- **Piping**. Generally, Schedule 40 PVC is sufficient. However, in higher-pressure systems, such as closed-vessel reactors, Schedule 80 PVC shall be used.

- **Water Source**. Clean, potable quality water is recommended for the dose-delivery bioassays for the Secondary Effluents and the Reuse applications with pretreatment by microfiltration and RO Treatment. This may be conveniently tapped off an existing hydrant at a candidate treatment plant location. In this case, backflow preventers will be required. A water meter is generally placed in-line to monitor water use. For reuse verifications for granular, synthetic or cloth-filtered water, a granular media filtered reclaimed water (1 ntu minimum turbidity) is required.

The TO will be required to prepare and submit with the Verification Test Plan appropriate Piping and Instrumentation Diagrams, equipment layouts, and schematics of the test facility, showing all components of the test equipment and accessory installations, and all sampling and monitoring locations.

3.4 DOSE-FLOW ASSAY

3.4.1 Test Batch Preparation

Batch preparation is an effective method for preparing test water of consistent quality with respect to UV transmittance, dechlorination and phage seeding. In this method, a sufficient volume of test water to conduct a number of dose-flow assay samplings is prepared in a large vessel. The tank is equipped with a mixing or recirculation system to adequately and efficiently mix the tank contents. Once the batch is prepared, the test water can be delivered to the UV system under controlled conditions.

The UV transmittance of the test water shall be adjusted to the transmittances required for this test, as specified in 3.4.2.2. The transmittance of the test water shall be adjusted by adding a substance that will absorb the UV energy at 253.7 nm, but will not interfere with the test (e.g., cause toxicity to the phage). Instant coffee has been found to be very effective at reducing the UV transmittance at 253.7 nm and testing has shown that it does not have an effect on MS2 phage at the levels routinely used for adjustment of the transmittance. It also exhibits a relatively flat spectral line across the UVC wavelength range. To determine the amount of coffee needed to adjust the transmittance to the target level, a relationship of percent UV transmittance at 253.7 nm, versus the amount of coffee added to the test water shall be developed. This can be accomplished in the laboratory and then scaled-up to determine quantities needed for the test batch preparation. An example of this relationship developed for a

potable water source where the UV transmittance was targeted between 50 and 80 percent is shown in Figure 3-4. The relationship was found to be linear, with a correlation coefficient of 0.941. This relationship can be used as a guidance tool for estimating the amount of coffee needed, although a similar relationship should be generated using the specific test water, since both the UV transmittance of the test water and the particular brand/type of instant coffee used will effect the results. If polychromatic lamp systems are being tested, full UVC spectral scans shall be performed in order to determine the impact of the UV absorbent.

If the test water contains chlorine, such as the residual in a potable water supply, the water shall be dechlorinated before it is used in the assay. Dechlorination may be accomplished by adding sodium thiosulfate directly into the batching vessel. The stoichiometry between sodium thiosulfate and free chlorine (as HOCl) is such that one mole of sodium thiosulfate reacts with 4 moles of free chlorine. To remove 1 mg/L of residual chlorine (as Cl), approximately 1.1 mg/L of sodium thiosulfate is needed. An excess of sodium thiosulfate is generally added to assure quick removal of the chlorine. This should be 4–times the stoichiometric amount. This is a critical step in the preparation of a test batch; even modest chlorine residuals (0.5 to 1.0 mg/L) can affect the phage. The Verification Test Plan shall describe the procedure for measuring and recording the chlorine residual before and after dechlorination. The use of the batch water shall proceed only after it is confirmed that there is non-detectable residual chlorine. If an on-site chlorine test kit is used, it shall have a minimum detection limit of 0.05 mg/L. The impact of the thiosulfate on polychromatic absorbance shall be measured and documented at this point.

The addition of thiosulfate for dechlorination may affect the pH in poorly buffered waters. The pH should be measured after the addition of thiosulfate and dechlorination is complete. If the pH is within 0.5 s.u. of the initial pH, the batch is acceptable. Consider buffering the water if the pH falls outside these acceptable limits. The Verification Test Plan shall discuss and present reagents that will be use for buffering.

The stock MS2 phage suspension shall be added directly into the batching vessel in sufficient quantity to achieve a density between 10^6 and 10^7 pfu/mL. As an example, if the MS2 phage stock has a concentration of 10^{11} pfu/mL and the batch size is 10,000 gallons, approximately 400 mL of stock phage solution would be required. The phage shall be added after the test water is dechlorinated and after the UV transmittance has been adjusted to the target level. The transmittance of the batch shall be checked again once the phage has been added, and adjusted, if necessary. The phage stock solution shall be kept on ice and out of direct sunlight until it is needed. Temperatures shall not exceed 10 degrees C, and the stock shall be stored under such temporary conditions for no more than 8 hours.

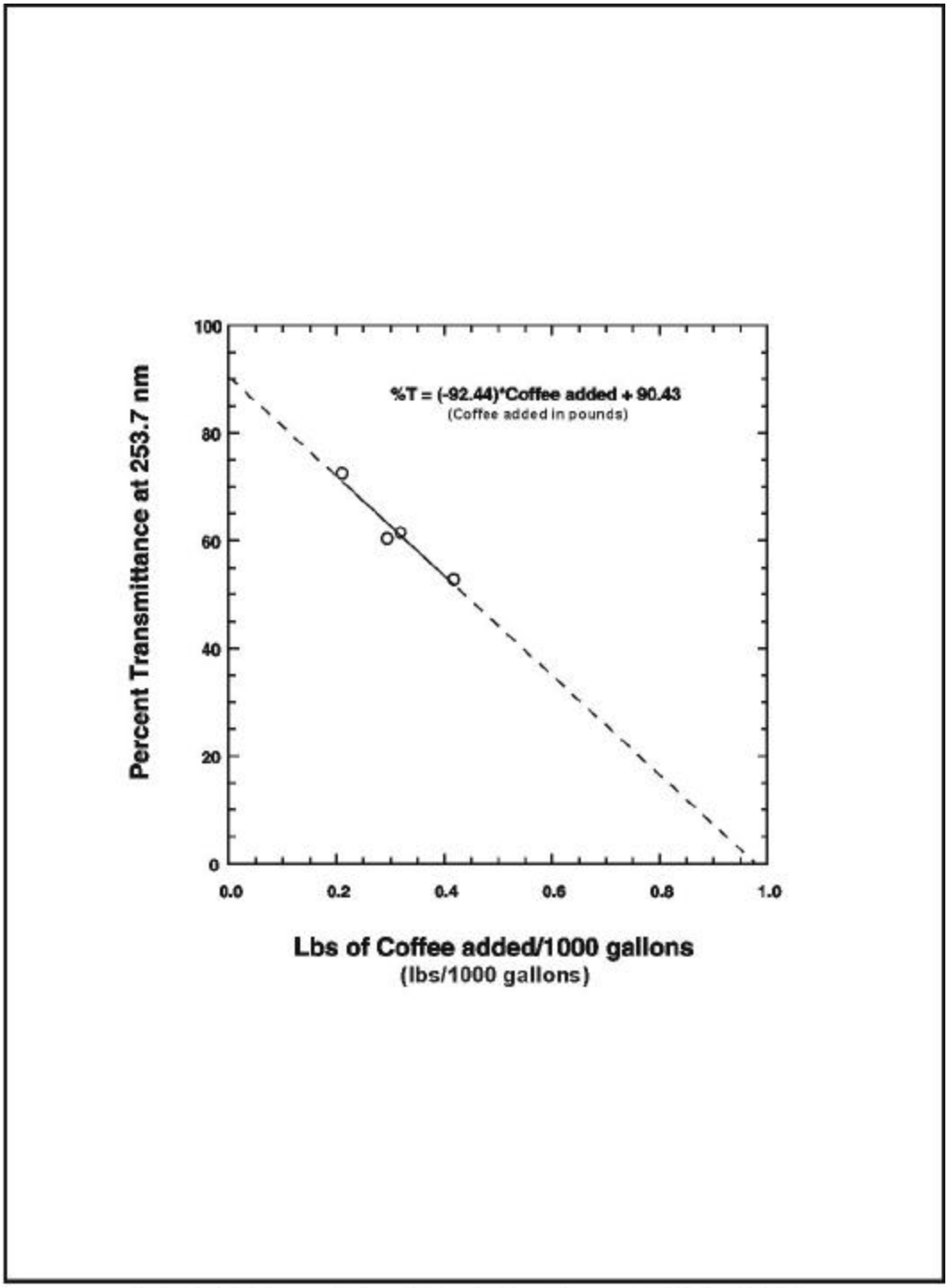

FIGURE 3-4. Example Correlation of Transmittance with Coffee Addition.

The following is a default protocol to prepare batches of test water for field testing. The Verification Test Plan shall detail the proposed procedure (or alternate, non-batch, continuous procedure) for preparing the test water:

1. Fill the batching tank with the source water.

2. Check the residual chlorine in the waters and compute the amount of thiosulfate to be added.

3. When the batching vessel is approximately half full, add the appropriate amounts of both sodium thiosulfate and instant coffee. The recirculation pump or tank mixers shall be operating at this time.

4. After the batching vessel reaches capacity, the contents shall continue to be mixed for an additional amount of time sufficient to achieve a homogenous solution. Sampling and analyzing the transmittance of the sample can verify this. Mixing is complete once there is minimal variation in the reading (less than 2 percent change).

5. Collect a sample and measure the residual chlorine. The residual chlorine shall be non-detect. If not, add sufficient thiosulfate to exceed the measured residual's stoichiometric requirement by a factor of three. Allow the contents to continue mixing and resample to confirm complete dechlorination.

6. Once the tank contents have been dechlorinated, collect a sample and measure the UV transmittance at 253.7nm. The percent transmittance shall be within +/- 2 percentage units of the target level. If the measured percent transmittance is below the target level, replace some of the test water with clean water until the target transmittance is achieved (confirm dechlorination once again). If the measured percent transmittance is above the target level, add an additional amount of coffee (as determined from the relationship of transmittance versus coffee addition) until the target level is achieved.

7. Add the appropriate volume of MS2 phage stock solution to the test water, making certain to rinse the container with a small amount of chlorine-free water. Add the rinse waters to the test water to assure that all organisms are added to the test water.

8. Mix the contents of the batching vessel. While mixing, take a sample for final percent transmittance reading before testing begins. If necessary, adjust accordingly by the procedure in (6).

3.4.2 Test Conditions

A dose-flow assay is conducted to establish a relationship between delivered UV dose and flow rate through a scaleable UV test reactor under specific test conditions. To develop this relationship, a minimum of five flow rates shall be tested at conditions best simulating actual full-scale conditions. Test conditions that need to be defined are the condition of the quartz surfaces, UV transmittance of the test water, indicator organism densities, lamp output, temperature, flow rates and headloss:

3.4.2.1 Quartz Surface Condition

The objective of the assay portion of this test is to assess the performance of the system with respect to dose delivery, when the quartz surfaces are clean. It is recommended that the test unit's quartz sleeves be manually cleaned before each "batch run" or, at a minimum, once each day before startup of the unit. This is done by physically removing each lamp module from the unit, spraying/wiping the quartz with a cleaner (e.g. Lime-Away), rinsing the surface with clean water and then reinserting the module in the reactor. The vendor can offer alternative methods.

3.4.2.2 UV Transmittance of the Test Water

For verifications under secondary effluent applications, dose-flow assays shall be conducted at 75%, 65% and/or 55% transmittances. For verification under reuse applications, the dose-flow assays shall be conducted at the following transmittances:

Upstream Process Application	Test Transmittance
Media Filtration	55%
Membrane Filtration	65%
Reverse Osmosis (R/O)	90%

The transmittance of the test water shall be adjusted as described in Section 3.4.1. Note that the vendor may choose to have different distances between the lamps in the unit as a function of the targeted transmittance. This is acceptable as long as this option is offered commercially, and it is fully described and justified in the Verification Test Plan. Transmittance shall be measured using a UV spectrophotometer or photometer. In the case of polychromatic lamp applications, a transmittance scan of the prepared water shall be made over the operating UVC spectra of the lamp, and specifically between 230 and 280 nm. The distance of the light path and cuvette used shall be reported. This information shall be included in the final Verification Report. In all cases, deionized water shall be used as a reference and matched quartz cuvettes shall be used to hold the samples and reference water. A photometer uses only a single cuvette, which must be properly cleaned.

3.4.2.3 Turbidity

The finished, or potable, waters used for preparation of the coliphage challenge batches shall conform to local drinking water regulations with respect to turbidity levels. In the case of the test condition for granular, synthetic or cloth-filtered reuse waters, a filtered secondary effluent shall be used,

which has a turbidity of at least 1 NTU. This conforms to NWRI/AwwaRF guidance (December 2000).

3.4.2.4 MS2 Phage Densities

The density of the MS2 phage in the test water shall be high enough to yield a measurable density after treatment at the highest applied dose. The target initial (influent) density shall be between 10^6 to 10^7 pfu/mL. The minimum exposed effluent density shall be 50 pfu/mL.

3.4.2.5 Lamp Output

With operating time, both low- and medium-pressure lamps will diminish in their output of UVC light. The low-pressure lamp's rating, or nominal output, is generally cited as that output after 100 hrs of operation, while output near the end of a lamp's operating life is cited as 50 to 75 percent of nominal (this varies among different lamp types and manufacturers). In the case of medium pressure lamps, there is no need to burn-in the lamps, but, to be consistent, the burn-in shall be done, regardless of the lamp type. The end-of-life factor of a medium-pressure lamp is variable, depending on the watt density (watt/cm of bulb), the power level during operation of the lamp, the hours of operation and the number of on/off cycles. The end-of-life output of a medium-pressure lamp is suggested to be between 50 and 80 percent of nominal, depending on the above factors.

Standard practice for assays is to adjust the output of the lamps to reflect the end of their guaranteed UV output, since design sizing would necessarily have to account for the actual output of the lamps over the course of their operation.

The lamps that are installed in the Test Unit shall be new and shall then be "burned-in" for a period of 100 hours. This shall occur regardless of the type of lamp and ballast configuration, and should be accomplished as part of the test set-up.

3.4.2.6 Reduced Lamp Output

The assays shall be conducted under conditions that simulate a prescribed lamp-aging factor. This can be done by turning down the input power to the lamps or by further reducing the transmittance of the water. The testing shall be conducted at 75 percent of the UV intensity of the submerged lamps for secondary effluent applications, and at 50 percent of the nominal intensity for reuse applications. If the vendor chooses an alternate equivalent lamp-aging factor, it must be explained fully and technically justified in the final Verification Test Plan. The Verification Test Plan shall describe how both the 100 percent (of nominal) and reduced (75 percent output or 50 percent output) electrical conditions are verified (e.g., direct voltage and amperage readings). Installing a UV sensor in a fixed position in the water and measuring a reduction in intensity equivalent to the target percent of the intensity observed when the lamps are at 100 percent output shall verify the intensity reduction. Note, for reuse applications, a reduction factor higher than 50 percent may be used if an alternate lamp-age factor has been established through an appropriate verification (see Section 5.2). The Verification Test Plan shall describe how the stability of the lamp output shall be verified. For example, a determination must be made of the time for lamps to warm up and to respond to adjustments in power changes. The

verification test plan shall also describe how the output stability of the system is verified during test runs; power or intensity measurements may be used to verify that there are no major excursions in unit performance during flow tests. Continuous recordings are recommended to monitor the selected variable, such as intensity, which shall not vary more than +/- 5% of the mean reading.

Note that for certain commercial systems the lamp-ballast configuration precludes direct electrical manipulation to achieve a reduced UV output. Recognizing this, an alternate method for simulating end-of-life output via UV transmittance adjustment may be used:

1. Using an approved point-source summation algorithm (USEPA/HydroQual UVDIS 3.1, or equivalent), the theoretical nominal intensity is calculated for water transmittances between 15% and 90% (every 0.5%). Note that this calculation must be consistent in its treatment of boundary conditions in the calculation of the average reactor intensity.

2. Starting with the targeted flow-dose test water transmittance (e.g. 65%), calculate the target test intensity level by direct ratio of the test water transmittance and the prescribed test output reduction factor (e.g. 0.50), loss through sleeve factor 0.9, and fouling factor, 0.8. From the theoretical intensity vs. transmittance relationship developed in step 1, determine the transmittance necessary to achieve the "new" reduced intensity (+/- 5%). This is the actual transmittance that will be used for the flow-dose runs.

   Note that the default values for the test output reduction factor and fouling factor can be changed if alternate values are verified previously (refer to Section 5).

For the secondary effluent application, either direct electrical turn down or transmittance adjustment is acceptable. For reuse applications, screening challenge runs must be conducted to first determine which method (electrical turndown or transmittance altering) provides the most conservative approach. This value is referred to as the "minimum sensor level" as described in the NWRI/AwwaRF guidance (NWRI/AwwaRF, December 2000). This shall comprise influent/effluent phage analyses in triplicate at a single flow under each turndown method. Whichever method yields the lower dose shall be used for the verification testing. Other methodologies may be suggested by the vendor and must be technically justified in the final Verification Test Plan.

3.4.2.7 Temperature

Lamp output will vary with temperature in the conventional, low-pressure lamp systems. Testing on different systems at different locations could lead to some bias in the results if the operating temperatures are significantly different. As stated earlier, the anticipated impact of liquid temperature on lamp output shall be addressed in the Verification Test Plan. The impact of liquid temperature on lamp output shall be specified by the vendor. This will allow an estimation of the intensity reduction occurring at less-than-optimum temperatures. Tests shall be performed within a liquid temperature range of 10°C

to 30°C for most applications. A significant deviation outside this temperature range must be justified in the VTP; for example, stormwater runoff disinfection in cold climates may involve lower operating temperatures.

3.4.2.8 Hydraulic Loading Rates

A minimum of five hydraulic loading rates shall be tested in quadruplicate. The hydraulic loading rate (HLR) shall be defined as the flow (Lpm) divided by the number of lamps. Alternatively, the HLR can be defined as the flow per total input watts (Lpm/W). One can express the rate in terms of nominal UV Watts in the system, but this can only be a secondary expression, since there is no direct verification of UV output. In either case the flow is the primary variable. These flow rates should represent the expected operating condition for the targeted application and should bracket the peak design flow rate of the test unit.

Flow rate shall be measured accurately. An in-line magnetic flow meter is recommended. The flow meter calibration should be verified at the beginning and end of the hydraulic tests by comparing the flow meter reading to flows that are computed using the change in volume (in the preparation vessel) over a given time or by inferring flow in an open-channel by collecting velocity profile measurements. Specific procedures for flow meter calibration shall be included in the Quality Assurance Project Plan. The flow meter shall have the same operating range as the proposed testing, and shall have a precision at least within 5 percent of the actual flow.

3.4.2.9 Headloss Measurement

Although not a direct factor in the performance of a system, as defined by its dose delivery, headloss is a key factor in determining a system's design application. Headloss measurements through the lamped portion of open channel, gravity flow reactors, shall be recorded for each test flow rate. This can be done by measuring depth differentials (from a constant elevation datum) between the approach and exit ends of the reactors. In closed reactors, pressure differential measurements shall be taken at the inlet and outlets of the reactor at each test flow rate. The Verification Test Plan shall specify the method and instrumentation used to measure headlosses, and include appropriate specifications and calibrations.

3.4.2.10 Power Utilization

Power Utilization must be determined as part of all test plans. The purpose of power measurements is to 1) Determine the power requirements of the system; and 2) Monitor the electrical stability of the system during the flow tests. Some of these measurements (for 100% intensity) need to be made before and/or after the actual flow tests if lower lamp output intensity is achieved by reducing power to the unit. On-going measurement of power (voltage, amperage) or lamp intensity is needed during the actual flow tests in order to verify that power fluctuations are not inducing changes during the actual flow test.

A recording wattmeter shall be installed on the power input to the UV system, inclusive of the power panel and the lamp banks, but exclusive of any major device that is solely related to the test and

is not part of the normally installed system. This recording unit will allow for monitoring the total power draw for the system under various conditions (e.g. warm-up, full lamp intensity, lower lamp intensity during flow tests). Data collected during periods of 100% intensity will show power draw during "normal system operation." Data collected during flow tests under "turn down" conditions (lower lamp intensity) will provide information on conditions during the actual test. Power data collected during warm up and "turn down/up" periods can be used to show the relationship of lamp intensity to power draw or panel current. The Verification Test Plan will specify the wattmeter (5 percent accuracy) and the method for calibration and measuring total power draw for the system and estimating the draw per lamp.

The Verification Test Plan shall also describe how power measurements to each lamp unit (e. g. ballast control or lamp group) exclusive of other power consuming components will be achieved. These measurements must be made for a system that is operating under 100% lamp output. This direct measurement of power draw by lamp group will provide data for scaling the power requirements for systems with different numbers of lamps and/or different control panel configurations.

3.4.3 Test Procedures, Sampling, System Monitoring

3.4.3.1 Test Procedure

Each dose-flow assay shall be conducted using the same batch preparation procedure, thereby insuring similar test water characteristics with respect to organism density and UV transmittance. A minimum of four runs shall be conducted, each comprising five different doses. The following presents the general procedure for conducting a dose-flow assay. It is provided as the default protocol and can be modified to meet the needs of the specific test set-up. The Verification Test Plan must clearly define the procedures to be used for a particular ETV, and shall include sample sizes, sample collection sites, sampling procedures, handling and storage as well as inclusion of or reference to microbiological protocols:

1. The UV system shall be turned on and allowed to operate for at least one hour prior to testing to ensure a stable output from the lamps. This is determined by monitoring the lamp intensity. The stable lamp intensity shall be established as the 100 percent output (nominal) operating condition for the system with respect to current and voltage. This warm-up and stabilization period must be done with a continuous flow of water, independent of the batch tank, which is likely being prepared at the same time. This flow can be set to an arbitrary baseline rate whereby the initial (100 percent) settings can be checked. The water shall be from a clean source, (i.e., potable water) and the flow rate should be low to conserve water. However, it must be sufficient to avoid any water temperature change (greater than 0.5 degrees C) due to the heat from the lamps. The Verification Test Plan shall detail this operation, including the minimum flow rate. All sensors and recording meters shall be checked for stable and accurate operation at this time.

2. While the lamp battery is stabilizing, a batch of test water shall be prepared in the

batching vessel, as outlined in Section 3.4.1, Test Batch Preparation.

3. After the lamp intensity has stabilized, the UV intensity shall be measured and recorded using a radiometer detector that is set in a fixed position within the lamp battery (e.g., on the downstream side of the end bank, pointing into the lamp battery). It shall be separate and independent from any sensor device supplied with the system. The detector shall be kept in this fixed position throughout the test period in order to obtain consistent and comparable results. The system shall then be turned-downed electronically, if possible, or the batch shall be prepared at an alternate transmittance as described in Section 3.4.1.

4. Once the system is stabilized and the batch test water has been prepared and checked, the water source to the test unit is changed from the clean source to the prepared test water, still maintaining a relatively low flow. Lamp intensity is again monitored and recorded until a stable reading is obtained. The flow through the system is then changed from the baseline flow rate to a desired flow rate. The flow rate is monitored via the magnetic flow meter until a stable reading is obtained.

5. The system shall be operated under these conditions for a time interval sufficient to accomplish a minimum of five volume changes in the entire UV system, inclusive of the approach and exit reactor, thereby ensuring steady-state conditions. The lamp intensity shall be recorded. At this time, additional parameters, as defined by the vendor, shall also be recorded, specific to the test unit.

   Note that the time required to achieve steady-state conditions shall be determined by direct calculation of the total void volume between the tank outlet and the channel effluent point and at the flows to be tested. These data should then be used to establish the minimum number of volume changes that should be incurred before sampling. As stated earlier, at least five volumes shall pass before sampling can proceed. The Verification Test Plan shall describe the procedure used to establish this or an alternate approach, if desired.

6. Sampling locations are equipment specific and shall be clearly defined in the Verification Test Plan. Samples shall be collected in pre-labeled sterile sampling containers.

7. Influent and effluent samples shall be collected in triplicate. Note that this comprises a sampling event.

8. After a sample is collected, it shall be capped, placed in a cooler and the cooler lid closed to prevent any exposure to sunlight. Samples shall be held under refrigerated storage for no more than 48 hours. If possible the samples should be plated within 6 hours after collection, although time studies have shown that the samples can be held

under refrigerated conditions for an extended period of time (up to 48 hours). At a minimum, three replicates of each sample shall be plated. Each replicate shall be plated at two dilutions with each dilution plated in triplicate.

9. One duplicate sampling event shall be conducted (a second set of triplicate influent and effluent samples at the given flow condition) with every 10th sampling event collected.

10. A separate sample of the influent shall also be collected to measure UV transmittance. Samples collected for the determination of percent transmittance samples shall be kept at 4ºC and analyzed within 96 hours of collection.

11. The influent and effluent samples shall be collected in an alternating sequence, and at times that approximate the time of travel. The influent sample may be taken directly from the batch tank, from a continuously flowing tap off the feed pipe or directly from the channel. The effluent sample shall be taken from the reactor outflow, directly in channel over an effluent weir or from a continuously flowing sample tap. In all cases, the influent and effluent samples must be representative of the total water stream.

12. Once sampling is completed, the flow rate shall be adjusted to the next target flow rate. Steps 5 and 6 are repeated.

13. After all flow rates have been tested for a single batch run (i.e., the contents of the batch tank have been depleted), the feed shall be switched to the alternate water source and the flow rate shall be adjusted to the baseline flow rate, as in Step 1 (note that the Verification Test Plan should define this). The intensity shall be recorded. The water source shall be changed to clean water at the baseline flow rate. A stable intensity (+/- 5% of mean) shall be obtained and recorded.

3.4.3.2 System Monitoring

Several operating parameters may provide information about how an UV system is operating. The Verification Test Plan shall identify parameters that are important to the performance of a specific UV system to be tested. These parameters shall include, but are not limited to lamp output, lamp amperage/voltage (to verify operation), power conditioning, ambient air temperature, and water temperature. The selected parameters should be monitored under the different flow conditions, at the beginning and ending of each flow test. The Verification Test Plan shall describe how the parameters are to be monitored.

3.4.3.3 Hydraulic Testing

Depending on the verification undertaken, additional hydraulic characterization of the system will be required.

3.4.3.3.1 Residence Time Distribution

For verifications conducted for secondary effluent applications, residence time distributions will be developed at a minimum of three flow conditions, equivalent to the lowest, highest and mid-point of the dose-flow series. Protocols are established for the step-response method in the U.S. EPA Design Manual for Municipal Wastewater Disinfection (EPA/625/1-86-921, 1986). The procedure is summarized as follows:

1. A concentrated coffee solution is continuously injected at a constant rate into the upstream end of the reactor.

2. Coffee injection is continued until a new "steady-state" UV intensity is reached from background.

3. The coffee solution is shut-off and the return of UV intensity to background conditions is traced on a chart recorder.

4. Chart recordings are then digitized and used to develop residence time distribution curves.

Alternate protocols are acceptable but must be described in the final Verification Test Plan. Note that for some reactors, the step-response method may not be appropriate. In that case the vendor and TO may prescribe an alternate methodology, which must be fully described and technically justified in the final Verification Test Plan.

3.4.3.3.2 Velocity Profiles

Velocity profiles shall be established for system verification for reuse applications. The profile shall be measured at a cross-section within 0.3 m (11.8 inch) upstream of the first reactor and 0.3 m (11.8 inch) downstream of the final reactor. The velocity measurement shall be conducted at equally spaced points in a grid layout covering the entire cross-section of the UV reactor. The velocity measurement points shall be 6 to 12 centimeters (cm) (2.4 to 4.7 inches) apart. For reactors smaller than 25-cm (9.8-inch) wide or 25-cm (9.8-inch) in diameter, velocity measurements shall be conducted at a minimum of four points (two-by-two grid). For larger reactors, a minimum of nine points (three-by-three grid) shall be used for establishing the velocity profile. For widths less than 100 cm, the spacing between the velocity measurement points shall not exceed 12 cm (4.7 inch). For widths greater than 100 cm, the velocity measurement points shall not exceed 15 cm. The grid layout shall be specified in the Verification Test Plan.

For each flow rate used in the reactor validation test, three velocity measurements shall be conducted at each point using sonic, vector oriented meters, or similar. The Verification Test Plan shall specify the velocity meters that will be used for testing, including calibration methods. For the reactor tested, the mean measured velocity at any measured cross-sectional point

(excluding momentum boundaries [i.e., stationary surfaces such as reactor wall]) shall not vary by more than 20 percent from the theoretical average velocity (i.e., flow divided by the cross-sectional area), unless an alternate velocity field can be measured and demonstrated to provide satisfactory performance.

Note that for closed-shell or pressure reactors, the vendor or TO must propose a test methodology and protocol for assessing the hydraulic behavior of the unit. This may or may not be based on velocity profiles; however, the approach and considerations must be fully explained and technically justified in the final Verification Test Plan.

3.4.3.3.3 Headlosses

The headloss through the lamp reactor portions of the system shall be measured at each of the flow rates tested under the dose-flow studies. The Verification Test Plan shall describe the method to be used for such measurements.

3.5 DATA COMPILATION AND ANALYSIS

All data generated from the ETV dose-delivery test element will be compiled, analyzed and presented in the Verification Report. These data specifically address the components related to dose-response calibration and the dose-flow evaluation of the test unit.

3.5.1 Dose-Response Calibration

The dose-response calibration method was described in Section 3.1.2, and the analysis of the data in Section 3.1.3. The Verification Test Plan should include the design of the collimator used, calibration of the intensity probe, as well as contingency planning in the event a stock fails to meet the required acceptance criteria (e.g., preparation of a new stock, repeating the dose-response tests, and/or acceptance of the stock after verifying its dose-response by the repeated tests).

3.5.2 Dose-Flow Relationships

The influent and effluent phage data from the test unit evaluation shall be compiled, along with the associated flow and transmittance data. The log survival ratio, or response, shall be used to determine the delivered dose, by comparing it to the dose-response relationship developed by the collimated beam method. This equivalent dose is then computed and plotted against the flow rate for each of the transmittances tested. For reuse applications, the 75-percent confidence interval for inactivation results shall be established using the two-tail Students-t distribution. This is also the default statistical procedure to be applied for secondary effluent applications unless another method is detailed in the Verification Test Plan.

A non-linear regression analysis shall be conducted to develop a dose-flow relationship. This should relate the dose as a function of the inverse flow.

The flow shall be expressed as a hydraulic loading as follows:

1. Flow per lamp (Lpm/Lamp)
2. Flow per Total Watt Input (Lpm/W)

A graphical representation of the log survival ratio as a function of hydraulic loading shall also be included.

Note that if similar dose data are collected at reduced power levels, as discussed in Section 3.4.2.5, relationships shall be developed for dose as a function of the equivalent Lpm/Total Watt Input for the given flow and transmittance. Figure 3-5 presents an example of a dose-hydraulic loading (expressed as Lpm/Lamp) relationship.

Other relevant data collected as part of the test program shall be compiled and presented, including:

- Power consumed per unit lamp
- Intensity readings at the different flow settings and calibration steps
- Temperatures recorded for ambient air and water, and relevant system temperatures
- Other measurements and relevant to the specific ETV.

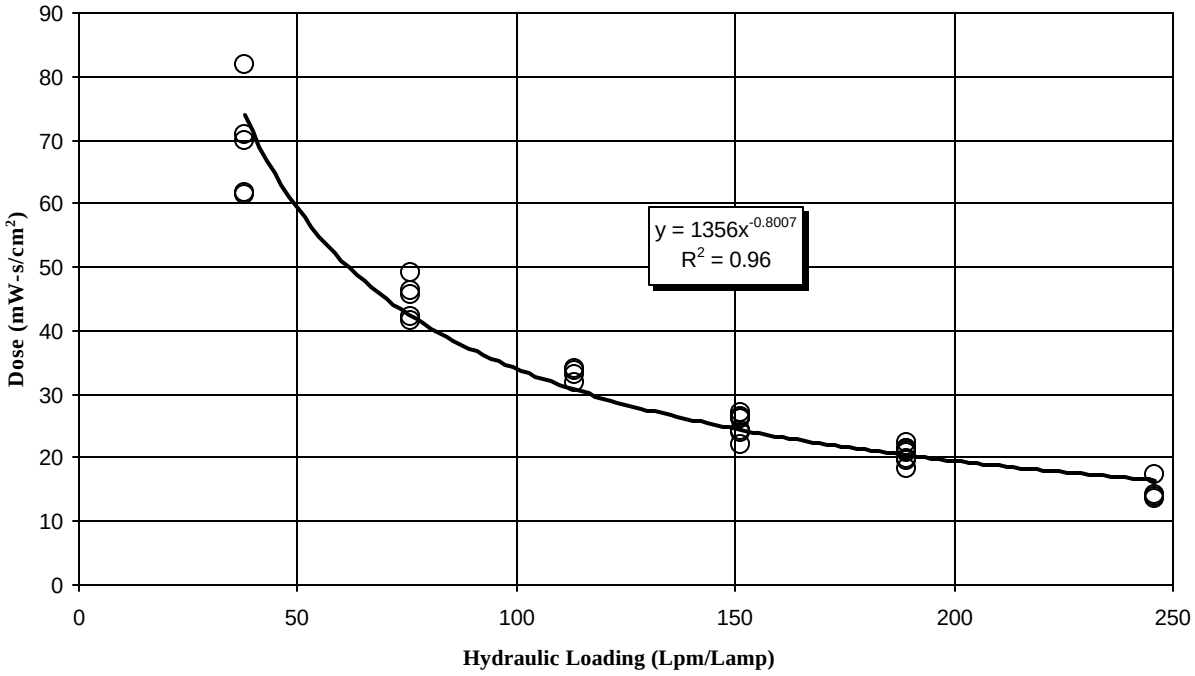

FIGURE 3-5. Example Relationship of Dose (mW-s/cm2) as a Function of Hydraulic Loading (Lpm/Lamp)

3.5.3 Hydraulic Characterization Results

RTD curves developed for the test unit shall be presented in the verification report. There shall be a digitized tracer recording for each test. The first derivative of the tracing will be calculated showing the slope of the curve as a function of time. Lastly, the cumulative area under the residence time curve as a function of time, effectively showing the distribution of residence times in the system, will be generated.

Key quantitative parameters derived from these RTD analyses shall be tabulated. The flow rates and equivalent velocities through the lamp battery shall be given. The theoretical detention time shall be computed as the volume (less the quartz/lamp assembly) divided by flow (V/Q), while the mean residence time (θ) is computed as the first moment of the residence time curve.

Several dimensionless ratios will be derived from the RTD analysis, which are useful in evaluating hydraulic characteristics. Guidance is also given as to expected values for such indices, although an acceptable unit does not have to conform to these indices:

θ/T The ratio of the mean residence time to the theoretical residence time. This should fall between 0.8 and 1.2.

t_p/θ The ratio of the time at which the peak tracer level occurs to the mean residence time. This should be greater than 0.9, indicating absence of any skew in the residence time due to back mixing, dead spaces or eddying effects.

t_{50}/θ The ratio of the time for 50 percent of the tracer to pass to the mean residence time is also a measure of the skew and should be greater than 0.9 for effective plug flow.

t_i/θ The ratio of the time the tracer first appears to the mean residence time is a measure of short-circuiting, and should be greater than 0.5.

t_{90}/t_{10} The ratio of the time for 90 percent of the tracer to pass to the time for 10 percent of the tracer to pass. Also known as the Morrill Dispersion Index, it is a measure of the spread of the residence time distribution curve; a value of 1.0 would indicate ideal plug flow, and 21.9 for ideal complete mix. A value of 2.0 or less is generally required for UV systems.

The dispersion coefficient, E, shall also be computed from the RTD analysis. E can vary from zero to infinity, approaching zero under ideal plug flow conditions. An E less than 100 cm^2/sec is generally targeted for UV disinfection reactors. An additional parameter, the dimensionless dispersion number, d, is derived from this testing and should fall below 0.05 for plug-flow conditions.

Headloss and velocity data shall be presented as tabular summaries.

4 TEST ELEMENT 2: DOSE-DELIVERY RELIABILITY VERIFICATIONS

This test element includes protocols for verifying dose-delivery reliability through three means: quartz surface maintenance, general system reliability and/or process controls. Not all sub-elements may be appropriate for a given technology. The Verification Test Plan shall describe in detail which of the test sub-elements will be verified.

4.1 TEST ELEMENT 2A: UV QUARTZ SURFACE MAINTENANCE

This section presents the methods and materials associated with evaluating the UV device for cleaning the quartz sleeves. Maintenance of the quartz surfaces is a critical operation for an UV system to ensure continued effective performance. The protocol calls for operating two parallel units, each with a full-scale equivalent of the cleaning mechanism. Both units receive the source effluent on an intermittent basis; one unit has the cleaning device activated while the second does not. The testing focuses on the condition of the quartz, and compares the rates at which the surfaces foul and lose their required UV transmissibility.

Table 4-1 provides a summary of the Tasks in Test Element 2A.

4.1.1 Test System Specifications

4.1.1.1 Size and Component Considerations

The objective of this test element is to evaluate the effectiveness of a full-scale cleaning device that is commercially offered as a component of a UV disinfection system. Typically, these are comprised of devices that wipe the surface of the quartz, with mechanical or pneumatic drives. In some cases, a cleaning solution such as acid is a component of the wiping device. Operating variables tend to be limited to the number of strokes that the device makes over the quartz surface. Other cleaning mechanisms may include ultrasonic and/or in-situ chemical scouring. Note that this protocol is limited to in-situ devices.

From a practical verification standpoint, the vendor shall provide a system size, based on fabrication requirements, that reflects the modularization of the cleaning mechanism. Thus, a multiple lamp unit shall be provided if it represents the smallest commercial module for a full-scale cleaning device. In the Verification Test Plan, the vendor shall clearly state the specifications of the test units and their conformity to full-scale specifications. The reactor enclosure itself does not necessarily have to mimic a full-scale configuration; thus one can provide a closed shell, pressure vessel, even if the normal design is open channel, gravity flow. In all cases, the units shall be provided with ports to quickly drain the wastewaters when they are shutdown.

Table 4-1. Summary of the Experimental Effort for Test Element 2A: UV Quartz Cleaning Device Verification					
TASK	**SUBTASK**	**REF**	**DESCRIPTION**	**FREQUENCY**	**ANALYSES TO BE DONE**
A. Initial Analysis	1. Sampling and Analysis of WW	4.1.1.2.1	The wastewater to be used as the matrix for challenging the wiper is sampled and analyzed for a target list of compounds.	Two samples collected from the proposed feed water.	Analyze each for TSS, Turbidity, Grease and Oil (G/O), COD, BOD5, Fe, Hardness, TDS, Calcium, Magnesium, Total Phosphates, pH, Settleable solids, %T at 254nm (T and F),* and Langlier Index.
B. Cleaning Evaluation	1. Wastewater sampling	4.1.2.3 (Step 3)	During operations, collect samples of the feed to the units, characterize the wastewater quality.	Once per 3-day operating period (three consecutive test days)	1. Sample the common influent. These will comprise time-composites, and single grabs, depending on the analytical need. 2. Analyze each sample for %T (T and F), COD, G/O, Fe, Hardness, TSS, Temperature, pH, Ca, Mg, Total Phosphates, Langlier Index, BOD5.
	2. Monitor and Test Quartz Transparency	4.1.2	The quartz sleeves from each test unit shall be measured for their transparency at the end of every third test day. The quartz will be cleaned if their transparency falls below a pre-set level.	The evaluation shall proceed until the measured quartz transmittance reaches 50% of its initial transmittance, at which point the quartz sleeves will be cleaned. Run for three cycles or 21 days, whichever is longer.	1. Each quartz sleeve is tested at the end of every third test day. 2. If one considers 4 quartz per unit(or 8 test quartz) and 3 control quartz sleeves, eleven sleeves will require transparency testing every three test days. 3. If the quartz sleeves are cleaned, their transparency has to be measured before re-installing in the test unit. This represents a "cycle."
	3. Monitor the operation and condition of the test units.	4.1.2.3 (Steps 4,6 and 10)	Throughout the testing period, observe the unit with respect to fouling of surfaces, accumulation of debris, etc.	Every test day.	1. Observations shall be recorded with respect to flow rates, cumulative volumes treated, intensity (if test unit is equipped with monitors), cleaning mechanism stroke rate, and appearance of the quartz surfaces and of the cleaning mechanism.

T = unfiltered, F= filtered

The two units provided to the test shall be identical. All components, including the lamps, ballasts, quartz sleeves, cleaning devices, cleaning device drives, should be the same as used on a full-scale system. If differences between the test unit and a full-scale system are unavoidable, then the differences shall be fully explained and justified in the Verification Test Plan. The reactor design should be such that there is easy access to the quartz sleeve assemblies. The protocol calls for repeated removal, testing, and reinstallation of the lamp/quartz assemblies, and any design consideration that allows for efficient handling of these elements (without compromising conformity to the full-scale design) is a benefit to the test.

The transparency of the quartz will be the primary indicator of cleaning effectiveness. As such, UV intensity detectors may be installed in the two test systems. These may be fiber-optic strands, feeding back to the radiometer. These are optional and are not meant to be the direct measures of quartz-cleanliness; rather, they will provide a qualitative indication of the quartz surface condition between the times that the quartz will be removed for direct bench-scale measurements. The Verification Test Plan shall include drawings and sensor specifications, including details on the positions of the sensors in the reactors. The Verification Test Plan may offer alternative strategies to monitor the output through the quartz sleeves with detectors that are themselves non-fouling.

4.1.1.2 Test Facility Setup

Important components of the field setup include the wastewater source, pumps, UV units and meters. The discharge should be routed back to the wastewater plant.

4.1.1.2.1 Feed Formulation/Characterization

Depending on the application, the vendor can recommend the type of wastewater for use in these cleaning device efficacy tests. As an example, a primary effluent is used for the same purpose for verification under the ETV Wet-Weather program. Similarly, a secondary effluent can be used as the challenge water for these verifications. The key is to use water that has the ability to foul a quartz surface under normal operating conditions. If one uses water that does not even foul the surfaces of the quartz without the cleaning device, then the verification has little meaning. One can consider using an altered wastewater; for example a blend of secondary and primary effluents, or a secondary effluent that is spiked with known fouling agents (examples might include hardness, iron, calcium and magnesium, oils, fats and greases). This approach is recommended and used as the default method within the context of this protocol.

The wastewater shall be biologically active. Pretreated wastewater (e.g., secondary effluent or filtered secondary effluent) that can be spiked with specific components should be considered if the vendor determines that the system offered is commercially available only for the secondary effluent and/or reuse applications. At minimum, the feedwater shall be characteristic of the application, and shall have a positive Langlier Index. In developing a Verification Test Plan for the verification, the analyses listed in Section 4.1.2.3 shall be conducted and reported for the wastewater or mix of wastewaters to be used for the evaluation. This should be done for two, separately collected samples, at minimum.

The Verification Test Plan shall define the methods to be used for feed-water sampling and analysis. Standard Methods (20th Ed.) and/or USEPA approved methods, if available shall be used for analyses of the feed water. Primary effluent from a wastewater treatment plant may be diluted with the same plant's secondary effluent, if necessary. Addition of known fouling agents such as iron and/or magnesium is acceptable, assuming proper quantification and tracking. The characteristics of the feed shall be monitored weekly in order to document wastewater conditions during operation of the units. The Verification Test Plan shall provide characterization data from the proposed test site and shall detail any anticipated adjustments to the wastewater. The Verification Test Plan shall also specify the methods to be used to dose the wastewaters with chemical additives, how they will be mixed and the procedures for monitoring the specific constituents.

4.1.1.2.2 Test Facility Equipment/Assembly

Figure 4-1 presents a schematic process flow diagram for an example test setup. This is used as the default setup for this protocol. In the example test setup, wastewater in this case is pumped from the effluent of a plant's secondary or filtered secondary discharge trough and discharged to a constant head tank. Additives, including chemical and/or process water for dilution may be added to the constant head tank equipped with a low-speed mixer. The Verification Test Plan may propose alternative configurations provided they conform to the requirements of the Protocol.

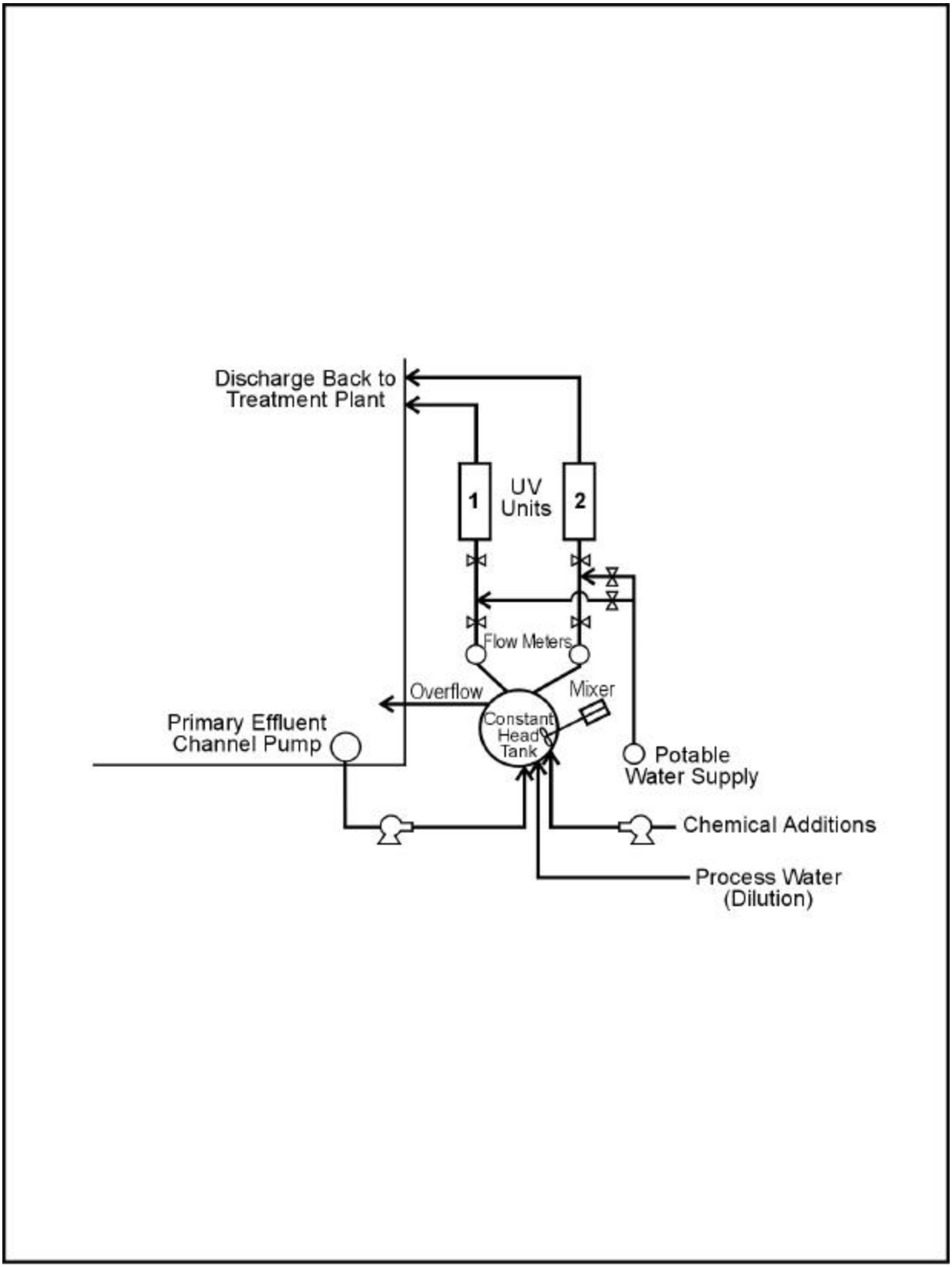

FIGURE 4-1. Schematic Layout of Cleaning Evaluation Test Facility.

In-line valves should be used to set the flow rates, which should be measured by in-line magnetic flow meters for each unit. Discharge from the UV units is back to the WWTP. A separate, clean-water line should be available for rinsing the units with clean water in accordance with the vendor's recommended cleaning procedures.

The Verification Test Plan shall include detailed drawings of the facility setup, including all piping and tankage, and specifications on the UV test units and all accessory instrumentation, electrical and mechanical elements of the test assembly.

4.1.2 Fouling/Cleaning Evaluation

The objective of this test element is to determine the efficacy of a system's cleaning mechanism in maintaining the quartz surfaces while the system is operated intermittently. This will be assessed relative to an identical system that does not activate its cleaning mechanism, and will be quantified by the loss in transparency of the quartz sleeves.

4.1.2.1 Operating Conditions

The fouling studies shall be conducted at a single, constant flow rate over a sufficient time period as described below. There shall be intermittent down periods when the units are not receiving flow and the lamps are off. The selected flow rate to each unit shall be equivalent to a dose and average hydraulic loading per lamp prescribed by the vendor and technically justified in the final Verification Test Plan. The cleaning device shall always be activated on one unit, while the second unit's device will be inactivated for the entire test period. The lamps will be operated at full power in both units when there is flow.

The test period shall encompass a minimum of three "cycles," wherein a cycle is defined as the period between manual quartz cleanings for the unit without the cleaning device, or for a minimum of 21 days, if more than three cycles are experienced during the 21 days. The quartz in this case is cleaned when the average quartz transparency falls below a prescribed set point relative to clean quartz. Within the context of this protocol, a set point of 50% is established, unless otherwise proposed and explained in the Verification Test Plan.

The two units shall have an intermittent operation to simulate down times. Unless otherwise proposed in the Verification Test Plan, the units shall be operated for a period of 20 hours on and 4 hours off. When off, the units shall be in a drained condition, unless the vendor states that the commercial systems are held in effluent during dormant periods. Additionally, the vendor shall state if the unit cleaning devices are operated during shut down and draining. At the end of every third 20-hour on period, the transparency of the quartz from both units shall be measured.

4.1.2.2 Quartz Transparency Measurement

The effectiveness of the cleaning mechanism shall be determined by its relative effect on the transparency of the quartz sleeves to light at 253.7 nm. A standard, monochromatic low-pressure lamp with a standard electronic ballast shall be used as the UV source. Figure 4-2 provides a schematic of an example bench-top testing apparatus.

The quartz sleeves being tested shall be slipped over the standard UV lamp. The quartz/lamp assembly shall be placed in a ventilated housing similar to the collimating apparatus discussed in Section 3 (Figure 4-2). Care shall be taken to assure that the lamp is positioned along the center axis of the quartz, and does not touch the quartz at any point along its arc length. Teflon spacers may be used for this purpose.

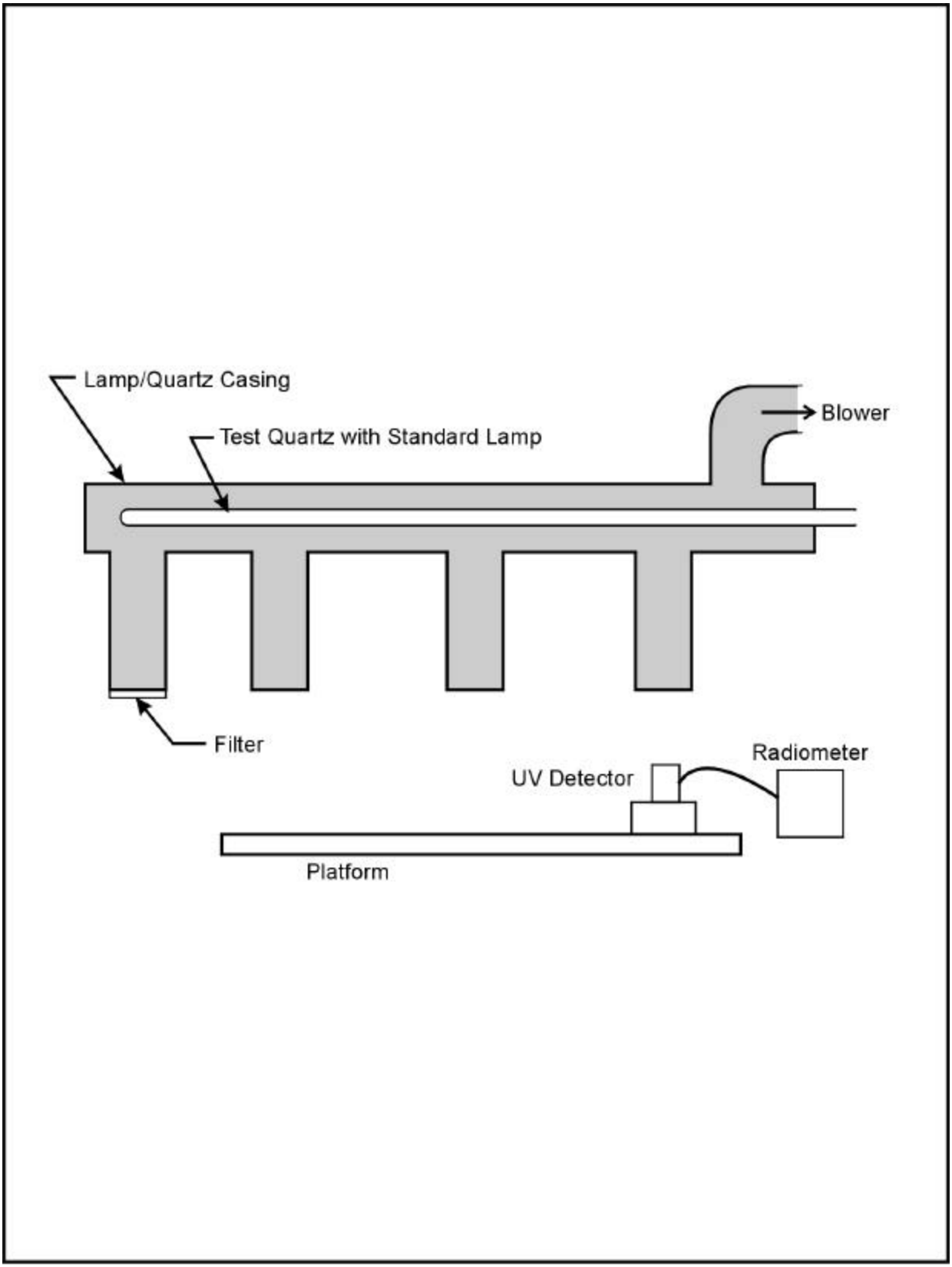

FIGURE 4-2. Quartz Transparency Test Unit.

Collimator sections shall be positioned at the one-third, one-half and two-thirds points along the length of the quartz. The lamp shall be turned on and a stable reading established. Using a narrow-band 254 UV detector, record the intensity at the bottom of each collimator from a fixed position run-to-run. The intensity shall be recorded at quarter-points around the perimeter of the quartz sleeve. In this manner, 12 readings are taken for each quartz sleeve, which are then averaged to give an "average transparency at 253.7 nm." This procedure shall be conducted for each quartz sleeve from the two test units.

In addition, three quartz sleeves, identical to ones used in the test units, but kept in a clean, unused condition, should be tested in the same manner. This should be done at least 20 percent of the number of times the procedure is followed for the test unit quartz sleeves. These will serve as the controls for the test units' fouling evaluations. The QAPP shall address the generation of these data and their analysis.

Note that the apparatus shown on Figure 4-2 is provided as an example. Given the variations of quartz sleeves, there is flexibility with respect to the test apparatus. The Verification Test Plan shall describe the apparatus proposed for such testing and clearly indicate the type of data that will be generated. The Verification Test Plan should, at minimum, measure transparency along the length of the sleeve and about its circumference.

4.1.2.3 Operating Sequence and Procedures

The following procedures shall be used when evaluating UV systems that use a wiping mechanism to clean the quartz surfaces. Planned deviations shall be fully described and justified in the Verification Test Plan.

1. At time zero, the two units shall be thoroughly cleaned. The Verification Test Plan shall identify and describe the composition of the cleaning fluid. The quartz from each will be removed (note that each quartz must be properly and permanently labeled) and tested for transparency to UV at 254 nm, as described in Section 4.1.2.2. The quartz sleeves shall then be returned to the units.

2. Begin flow to both units at the prescribed rate. The wastewater feed shall be from the head tank, adjusted by chemical addition and dilution, as needed, and as defined by the Verification Test Plan. The wiper shall be activated at a prescribed operating rate in one unit, and left dormant in the second.

3. A composite sample shall be taken from the common influent (e.g., the equalization tank) over a minimum 6-hour period once each operating week. This can be a time-composite of grabs taken every 30 minutes manually or via an automatic sampler. Grab samples shall also be taken at the end of the compositing period for those analytes requiring grab samples only. The weekly samples shall be analyzed for the following:

Transmittance at 254nm (filtered and unfiltered)
COD (filtered and unfiltered)
BOD5 (filtered and unfiltered)
G/O
Iron
Hardness
Total Dissolved Solids (TDS)
Temperature
pH
Calcium
Magnesium
Phosphates
Turbidity
Langlier Index
Total Suspended Solids (TSS)

4. If the units are equipped with intensity sensors, record the intensities periodically (at a minimum, daily). Record the following daily: (1) the flows to the two units (2) the chemical metering inputs; and (3) the process dilution water flows, if applicable.

5. After approximately 20 hours continuous operation, shutdown and, if required by the vendor for its commercial systems, drain both units. This draining step should be quick and thorough. The wiper operation should be maintained in accordance with vendor's operating procedures during the draining step. The lamps should be turned off before the units are drained. The quartz shall not be rinsed.

6. At the end of every third 20-hour operating period, turn off the lamps and wipers and drain the units. Once drained and fully shut down, the quartz shall be removed. The condition of the quartz sleeves shall be observed visually and recorded. Each quartz sleeve shall then be tested for transparency at 254 nm in accordance with Section 4.1.2.2. The quartz shall be exposed to air and allowed to drain any excess water. They shall not be wiped in any way nor handled such that the surface condition is disturbed before testing for transparency.

7. If the average transparency of the quartz in either unit has been reduced to less than 50 percent of the average "clean" quartz transparency (an alternate level can be proposed), then the quartz sleeves for that unit should be cleaned manually in accordance with the vendor's operating instructions. After manual cleaning, the transparency of each quartz sleeve shall be measured again. The operation from one manual cleaning to the next of either unit is considered one "cycle". If the transparency is greater than 50 percent, the quartz will not be manually cleaned, and will be returned to its respective unit. Once installed, the flow will be initiated.

8. The units shall be run through 21 days, or through a minimum of three cleaning cycles for the

system without the cleaning device. Throughout this period, the flow to the units shall be kept constant. The wiper (or other cleaning device) operation can be modified, if appropriate, only after three cleaning cycles have been experienced for the non-operating unit during this period. The Verification Test Plan shall discuss this and justify alternate operating conditions within the prescribed period.

9. The Verification Test Plan shall describe any additional testing that is to be conducted on the cleaning devices (such as with different stroke rates for a wiper) as part of this verification, beyond the minimum default program described in steps 1 through 6.

10. Throughout the testing, observations shall be made on the condition of the wiping mechanism. Required maintenance, repair and operational procedures shall be recorded. The nature of material accumulating on the quartz and on the wiping mechanism itself should also be observed and recorded (e.g., organic, inorganic or biological, debris, algal fibers). The materials best suited to chemically remove it shall be noted.

4.1.3 Data Compilation and Analysis

The data and field observations generated during the evaluation of the cleaning device shall be compiled and presented in tabular and graphical formats. To show the effectiveness of the cleaning device the average transparency of the quartz sleeves shall be plotted as a function of operating time and cumulative volume of water treated. This should be done for both systems to allow for comparison between the units with and without the cleaning device in operation. Thus, one should expect relatively frequent manual cleanings of the unit without the device, and extended periods between manual cleanings for the unit with the device (the unit with the cleaning device may not have required manual cleaning within the selected period).

The water quality data (suspended solids, UV transmittance, iron, etc.) should be reported and evaluated with respect to the quality of the wastewater during testing and the impact that specific constituents may have on fouling.

4.2 TEST ELEMENT 2B: GENERAL SYSTEM RELIABILITY

The operational data and observations recorded under Verification test runs for dose delivery capability will be used as a qualitative indicator of the system's overall operational reliability.

Table 4-2 provides a summary of the tasks in Test Element 2B.

4.2.1 System Monitoring

During each day of Verification Testing, operating parameters will be monitored and recorded on a routine basis on Standardized Field forms. This shall include UV irradiance as measured by the

vendor's UV irradiance sensor, lamp hours, cleaning mechanism cycles, and electrical energy consumed by the UV equipment and parts replacement, if necessary. Other parameters may be monitored and must be described in the final Verification Test Plan.

An automatic device for monitoring UV irradiance is strongly suggested with any UV system and is mandatory for systems undergoing verification for reuse applications. The Verification Test Plan should include a determination of the minimum irradiance below which the flow and equipment shutoff should occur to assure adequate disinfection at all times. When the irradiance drops below this value, flow can be shut off or a signal given to the operator indicating the need for cleaning or lamp replacement. The functionality will be assessed qualitatively.

4.2.2 Additional Reliability Claims

The final Verification Test Plan shall include vendors' claims with respect to how the tested system can consistently deliver a verified dose under changing conditions and/or with time. Therefore the TO shall obtain the vendor-supplied O & M manual to evaluate the instructions, procedures, recommendations and/or claims for their applicability under this verification.

4.2.2.1 Monitor Alarms and/or Indicators Verification

Only alarms/indicators that relate to overall system operability, and which react through audible or visual means to situations where disinfection effectiveness may be compromised will be subject to verification claims under this protocol. Those that deal with internal mechanism/component protection or for health and safety alerts are not considered.

4.2.2.2 Example Conditions

At a minimum, the system should have an audible or visual alarm to indicate the following conditions:

(a) Shut off UV lamps if the flow of water to the reactor is stopped or drops below a minimum required level, or if a reactor is physically removed from channel.
(b) Lamp/Ballast Failure Indicator
(c) Startup times from cold start, or delays from shutoff to new start.

Other conditions can be included, based on the vendor's O & M Manual, and can be incorporated into the Verification Test Plan.

Table 4-2. Summary of the Experimental Effort for Test Element 2B: General System Reliability Verification					
TASK	**SUBTASK**	**REF**	**DESCRIPTION**	**FREQUENCY**	**ANALYSES TO BE DONE**
A. Initial Analysis	1. System Monitoring	4.2.1	Record and review operating data/parameters from Test Element 1 Verification	Refer to Section 3.4.3.1, 3.4.3.2 Test Element 1.	No Analytical
B. Monitors, Alarms and/or Indicators Verifications	1. Identify critical monitors, alarms and/or indicators and mechanisms.	4.2.2.1 – 4.2.3	Qualitatively check response of each monitor, alarm and/or indicator when trip mechanism activated.	Three times for each condition	No Analytical

4.2.3 General Test Protocol

(1) Determine the mechanism that triggers a shutdown response (e.g. flow sensor, level monitor)
(2) Artificially create an upset condition (e.g. stop flow to contactor, interrupt power supply)
(3) Verify expected system response (e.g. visual or audible alarm)
(4) Repeat three times for each alarm/indicator test.

4.2.4 Data Compilation and Analysis

The data and field observations generated during this test element shall be compiled and presented in tabular format. A qualitative assessment shall be made regarding the consistency of operational and monitoring data compared to field calibration tests or observations. Qualitative statements shall be included with respect to the basic functionality and response of monitors, alarms and/or indicators

4.3 TEST ELEMENT 2C: PROCESS SYSTEM CONTROL VERIFICATION

This section presents the general test protocol for conducting a verification of an UV system's process control system. A process control system's primary objective is to automatically adjust operating variables to respond to changes in ambient conditions. For most cases, systems are designed for worst-case conditions. This may result in a significant amount of time where the system's deliverable UV dose is much higher than would be necessary for average conditions. Some systems are equipped with automatic lamp controls that can vary the UV output to optimize dose delivery, minimize operating costs and minimize electrical consumption. This test protocol allows a vendor to verify claims for such operations. The objective is not to verify that lamps are capable of being dimmed or that changes encountered by a UV or flow sensor will affect the lamp output (these types of PLC qualitative verifications would be considered under Test Element 2B). The objective of this Test Element would be to demonstrate that a minimum dose could be delivered and maintained under differing hydraulic conditions.

Verification under this test element shall be demonstrated through the use of a dose-delivery assay conducted at different test conditions while allowing the UV system to automatically adjust as needed to meet the vendor's dose-delivery claims. The assay shall be conducted in a clean-water matrix with MS2 phage (same as for Test Element 1).

It is strongly recommended that if a vendor intends to verify process control claims, it is best that the testing be completed concurrently with the standard dose delivery capability verification(s) as described in Section 3. The additional tests required under this test element are summarized in Table 4-3.

Table 4-3. Additional Tasks Required for Test Element 2C: Process Control System Verification					
TASK	**SUBTASK**	**REF**	**DESCRIPTION**	**FREQUENCY**	**ANALYSES TO BE COND**
A. Test Unit Assay	1. System Monitoring	3.4.3.1 3.4.3.2	Monitor the test system for operating variables and test unit conditions	At each hydraulic loading sampling event.	1. Temperature of water, air and lamp (2 lamps), at each flow condition sampled. 2. Intensity at 100 and test output. (Set automatically by P.L.C. or manually at set points prescribed by the vendor) 3. Voltage/Amperage at each Intensity setting.
	2. Conduct Dose-Flow Assays	3.4.3.1	Conduct runs with prepared phage batches. Each run shall comprise four different flow rates. Quartz are cleaned manually each day or with each run.	Minimum of three runs.	1. Conduct Influent and Effluent sampling in triplicate at each flow event at the two test transmittances [55 and 65] 2. Conduct a duplicate flow event at each 10^{th} flow event. 3. Yields a total 24 samples for phage analyses and 12 transmittances (influent only) for each run at each transmittance.

4.3.1 UV Test Unit Specifications

The test unit submitted for evaluation by the ETV protocol must be equivalent to the commercial unit offered by the vendor. It will be critical to clearly describe both the commercial unit and the test unit as part of the Verification Test Plan. This should be in conformance with Section 3.2 et seq.

4.3.2 Test Facility

The test facility for verification under this protocol shall be in conformance with Section 3.3 et seq.

4.3.3 Dose-Flow Assay

Under this verification protocol, flow-dose assays are conducted at different hydraulic loadings and water transmittances to demonstrate the capability of UV systems to automatically respond to changing conditions and maintain a targeted delivered dose. Test conditions set for the dose-delivery assays (Section 3) such as quartz sleeve surface conditions, indicator organism densities and temperature shall be the same as for dose-delivery verifications (refer to Sections 3.4.2.1, 3.4.2.3, 3.4.2.6). The Verification Test Plan shall specifically describe the challenges imposed on the test unit with respect to changes in transmittance, flow and operating power.

4.3.4 Data Compilation and Analysis

All data generated from the ETV process control system verification will be compiled, analyzed and presented in a Verification Report. These data specifically address the components related to dose-response calibration and the dose-flow evaluation on the test unit. The specific analyses and relationships shall be in accordance with Section 3.5.1 et seq.

5 TEST ELEMENT 3: UV DESIGN FACTORS VERIFICATIONS

This section presents test methods and protocols to verify two key design factors: quartz sleeve fouling factor and lamp age factor. Default values for these factors are commonly used in design and often form the basis for test conditions for performance tests (i.e., bioassays). In the case of the secondary effluent UV performance test, the lamp age factor has typically been set at between 0.65 and 0.75, and the quartz sleeves were maintained in a clean state for the tests, equivalent to a fouling factor of 1.0. The NWRI/AWWARF guidance requires a fouling factor of 0.8 and a lamp age factor of 0.5 for design, and as test conditions when verifying dose delivery via biodosimetry. If a vendor wishes to claim a different factor(s), the guidance further states that direct testing must be conducted to verify such alternate factors. The verifications conducted under this protocol will allow a vendor to demonstrate alternative factors. This will then allow for these factors to be used for design/life cycle estimates, as well as conduct dose verification for reuse applications at the alternate verified factors.

5.1 TEST ELEMENT 3A: FOULING FACTOR DETERMINATION

This section presents the general test protocol for conducting an ETV verification of a vendor-prescribed fouling factor. The fouling factor represents the minimum quartz sleeve transmittance achievable in a fouling-inducing matrix in conjunction with a continuously operating cleaning mechanism. The fouling factor can be used as a design criterion for the vendor or other interested parties. In addition, verification under this protocol will allow a vendor to use the derived fouling factor to set the test conditions for dose-delivery verification for reuse applications in lieu of the default values.

While seemingly similar to Test Element 2A, Quartz Cleaning Device Verification, this test element differs in its objective and final product. The goal is to establish an estimate of the long-term deterioration in quartz transmittance due to continuous operation in a fouling environment and with the continuous operation of a cleaning device integral to the commercial system. As such, the test period is longer, and one is not concerned with a comparison to quartz conditions without the cleaning device in operation. A comparison of the two verification protocols is presented on Table 5-1.

Table 5-2 presents a summary of tasks in Test Element 3A.

5.1.1 Test System Specifications

One test unit shall be setup at the test facility. From a verification standpoint, it is necessary only to simulate a minimum of four quartz sleeves or the smallest cleaning mechanism assembly, whichever is greater. In the Verification Test Plan, the vendor shall clearly state the specifications of the test unit and their conformity to full-scale specifications. In all cases, the unit shall be provided with ports to quickly drain the wastewaters when they are shutdown.

Table 5-1. Comparison of Test Element 2A and Test Element 3A		
	Quartz Surface Maintenance	**Fouling Factor Verification**
Objective	Quantitative comparison of fouling with cleaning mechanism vs. no cleaning. Test periods are discrete and not necessarily continuous.	Quantitative determination of relative fouling of system at the end of a continuous six-month (minimum) test period.
No. Units	▪ 2 identical reactors. ▪ 1 with cleaning mechanism on-line ▪ 1 with cleaning mechanism off-line or; ▪ 1 unit with 2 separate lamp banks.	1 reactor with minimum 4 sleeves or smallest mechanism assembly.
Feed Waters	Can vary depending on vendor claims.	Non-disinfected filtered (non-membrane) effluent with a positive Langlier saturation index.
Operating Condition	▪ Single flow rate. ▪ Quartz transparency measurement after approximately 3 days continuous operation. ▪ Short Shutdown period every day ▪ Continue test until transparency is 50%	▪ Single flow rate. ▪ Continuous 6-month operation (minimum). ▪ Quartz transparency measurement every 2 months. ▪ Wiper rate and assembly cannot be modified during the test period.
Monitoring	▪ Influent characterization 1 time per week of continuous operation. ▪ Daily record of system operation conditions.	▪ Lamp power continuous ▪ Daily record of mechanism cycle ▪ Weekly influent characterization
Polychromatic Systems Considerations	Transparency of different wavelengths depends on vendor claims.	Monitor at least 5 wavelengths in the UVC band.

Table 5-2. Summary of the Experimental Effort for Test Element 3A: Fouling Factor Determination					
TASK	**SUBTASK**	**REF**	**DESCRIPTION**	**FREQUENCY**	**ANALYSES TO BE DONE**
A. Initial Analysis	1. Sampling and Analysis of feed water.	5.1.2.1	The feed water to be used is sampled and analyzed for a target list of compounds.	Two samples collected from the filtered effluent one to two days apart.	Analyze each for Turbidity, Fe, Hardness, TDS, Calcium, Magnesium, pH, Temperature, %T at 254nm (T and F), Alkalinity, Langlier Index
B. Fouling Factor Determination	1. Feed water sampling	5.1.6 (Step 3)	Collect samples of the feed to the units, characterize the water quality	Once each week.	1. Sample the influent. These will comprise time-composites, and single grabs, depending on the analytical need. 2. Analyze each sample for %T (T and F), Fe, Hardness, Temperature, pH, Ca, Mg, Langlier Index, Alkalinity, TDS.
	2. Monitor and Test Quartz Transparency	5.1.3 to 5.1.7 and (4.1.2.2)	The quartz sleeves from the test unit shall be measured for their transparency every 2 months.	The evaluation shall proceed for at least six months.	1. Each quartz sleeve is tested at the end of each 2-month period. 2. Assuming 4 quartz per unit, 4 test quartz and 3 control quartz will require transparency testing.
	3. Monitor the operation and condition of the test unit.	5.1.6 (Steps 3 and 7)	Throughout the testing period, observe the unit with respect to fouling of surfaces, accumulation of debris, etc.	This is done at least weekly.	1. Observations shall be recorded with respect to flow rates, intensity (if the test unit is equipped with monitors), cleaning mechanism stroke rate, appearance of the quartz surfaces and of the cleaning mechanism, and lamp input/output power.

All components, including the lamps, ballasts, quartz sleeves, cleaning devices, and cleaning device drives, shall be the same as used on a full-scale system. The vendor shall prescribe in detail, the operating conditions including number passes/stroke intervals, etc. that will be recommended for a full-scale commercial system.

As in test element 2A, the transparency of the quartz will be the primary indicator of fouling. As such, one or more UV intensity detectors may be installed in the test system, but are not meant to be the direct measures of quartz-cleanliness; rather, they will provide a qualitative indication of the quartz surface condition between the times that the quartz will be removed for direct bench-scale measurements. The Verification Test Plan shall include drawings and sensor specifications, including details on the positions of the sensors in the reactors. The Verification Test Plan may offer alternative strategies to monitor the output through the quartz sleeves with detectors that are themselves non-fouling.

5.1.2 Test Facility Setup

Important components of the field setup include the wastewater source, pumps, UV units and meters. The discharge should be routed back to the wastewater plant.

5.1.2.1 Source Water and Characterization

The source water used for this evaluation shall be a non-disinfected filtered (non-membrane) secondary effluent with a positive Langlier saturation index. Additionally, the effluent fed to the unit shall have an average iron concentration of at least 1 mg/L, and a minimum hardness of 100 mg/L as $CaCO_3$. Direct chemical addition can be made in order to meet these minimum targets.

In addition, the source water shall also be characterized for the following parameters:

Turbidity
Iron
Hardness
Calcium
Magnesium
pH
Total Dissolved Solids
Transmittance @ 254 nm (filtered and unfiltered), and other wavelengths desired.
Temperature
Alkalinity
Langlier Index

The initial characterization should be conducted on 3 discrete samples collected one to two days apart within 2 weeks of anticipated startup. The characteristics of the feed water shall be

monitored periodically (at least once per week) throughout the duration of the test. The final Verification Test Plan shall define the methods to be used for feed water sampling and analysis (Standard Methods, 20th Ed. and/or USEPA approved methods.)

5.1.2.2 Test Facility Equipment/Assembly

Figure 5-1 presents a schematic process flow diagram for an example test setup. This is used as the default setup for this protocol. In the example test setup, wastewater is pumped from the effluent of a plant's filtered secondary discharge trough directly through the test reactor. The Verification Test Plan may propose alternative configurations provided they conform to the requirements of Protocol.

In-line valves should be used to set the flow rate, which should be measured by in-line magnetic flow meters. Discharge from the UV unit is back to the WWTP. The Verification Test Plan shall include detailed drawings of the facility setup, including all piping and tankage, and specifications on the UV test units and all accessory instrumentation, electrical and mechanical elements of the test assembly.

5.1.3 Fouling/Cleaning Evaluation

The objective of this test element is to quantitatively determine the transmittance of a system's quartz sleeve, relative to new quartz, after being subjected to the long-term (6 months) conditions in a representative flowing effluent and with the system's cleaning device in continuous operation.

5.1.4 Operating Conditions

The fouling studies shall be conducted at a single, constant flow rate for at least 6 months, as described below. The selected flow rate shall be that needed to achieve an equivalent theoretical average dose level of 50 mWs/cm^2 with the lamps fully powered and the quartz in a clean state, or as otherwise prescribed by the vendor. This must be technically justified in the Verification Test Plan.

The unit shall be operated continuously and the lamps shall be operated at full power or at its highest power set point for a minimum of six months. The cleaning device shall be activated continuously. The mechanism's operating cycle, cleaning solution change-out frequency and/or cleaning sleeve replacement interval (if appropriate) shall conform to the vendors' recommendation for a full-scale commercially available system.

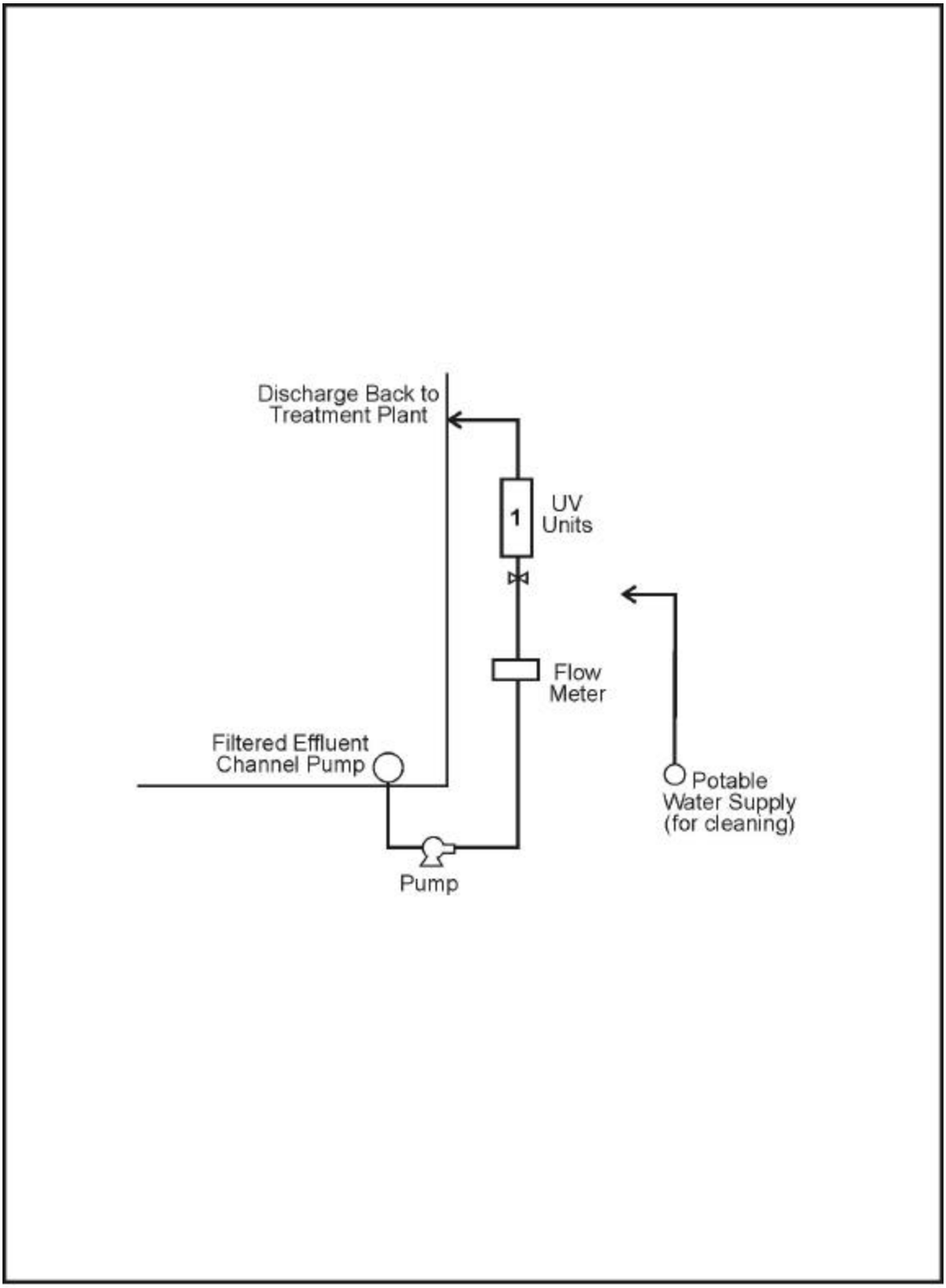

FIGURE 5-1. Schematic Layout of Fouling Factor Verification Test Facility.

5.1.5 Quartz Transparency Measurement

The condition of the quartz sleeve surface shall be quantified by the measured transparency of the quartz sleeves to light at 253.7 nm. This procedure is the same as described for Test Element 2A (refer to Section 4.1.2.2).

5.1.6 Fouling and Cleaning Procedures

The Verification Test Plan shall describe the procedures for the determination of the system-fouling factor. The following procedures shall be used when evaluating UV systems that use a wiping mechanism to clean the quartz surfaces. Planned deviations from these procedures shall be fully described and justified in the Verification Test Plan.

1. At time zero, the unit shall be thoroughly cleaned. The Verification Test Plan shall identify and describe the composition of the cleaning fluid. The quartz from each shall be removed (note that each quartz must be properly and permanently labeled) and tested for transparency to UV at 254 nm or in the case of polychromatic lamps, alternate wavelengths if desired. The quartz sleeves are then returned to the unit.

2. Begin flow to the unit at the prescribed rate. The feed shall be from the filtered (non-membrane) secondary effluent, and the wiper shall be activated at a prescribed operating rate, which shall be recorded, and the lamps operated on full power or at the highest power set point.

3. Operate the unit at the constant flow rate continuously. If the unit is equipped with an intensity sensor, record the intensity and flow rate periodically (minimum of once per business day). Lamp input/output power and water temperature should also be monitored daily. The feed water shall be sampled at least once per week (Section 5.1.2.1). Lamp temperature should be monitored, if the unit uses conventional low-pressure lamps.

4. At the end of two months of continuous operation, shutdown and drain the unit. This draining step should be quick and thorough. The wiper operation should be maintained in accordance with vendor's operating procedures during the draining step. The lamps should be turned off before the unit is drained. The quartz shall not be rinsed.

5. Once the unit has been drained and fully shut down, the quartz shall be removed. The condition of the quartz sleeves shall be observed visually and recorded. Each quartz sleeve shall then be tested for transparency at 254 nm or other wavelength in accordance with Section 5.1.5. The quartz sleeves shall be exposed to air and allowed to drain any excess water. They shall not be wiped in any way nor handled such that the surface condition is disturbed before testing for transparency. The three control quartz sleeves, which are

separate from the four test sleeves, shall also be measured.

6. The quartz sleeves shall then be returned to the unit and the system returned to its prior operating conditions. Quartz transparency measurements shall be conducted at least every two months, for a minimum elapsed period of six months.

7. Throughout the testing, observations shall be made on the condition of the wiping mechanism. Required maintenance, repair and operational procedures shall be recorded. The nature of material accumulating on the quartz and on the wiping mechanism itself should also be observed and recorded (e.g., organic, inorganic or biological, debris, algal fibers).

5.1.7 Data Compilation and Analysis

The data and field observations generated during the six-month operating period shall be compiled and presented in tabular and graphical formats. The ratio of the transparency of the quartz sleeves at each two-month "measurement event" interval to the average transparency of the control quartz sleeve shall be plotted as a function of operating time and cumulative volume of water treated. A trend line through the data set will be used to determine the decay function over the test interval. The lowest ratio observed over the test interval will be the verified "fouling factor" for the commercial system.

The water quality data (e.g. Langlier saturation index, temperature, transmittance, etc) should be reported and evaluated with respect to the quality of the wastewaters during testing. A statement of verification regarding the cleaning mechanism operation and confirmation of full lamp output operation during the test period shall also be included.

5.2 TEST ELEMENT 3B: LAMP AGE FACTOR VERIFICATION

This section presents the general test protocol for conducting an ETV verification of a vendor prescribed lamp age factor. The lamp-age factor can be used as a design criterion for the vendor or other interested parties. In addition, verification under this protocol allows use of the derived lamp-age factor to set the test conditions for dose delivery verification for reuse applications in lieu of the default values.

5.2.1 Minimum System Requirements

Lamp age factor testing must be conducted using a minimum of 10 lamps selected from two different lamp batches for conventional low-pressure lamps and low-pressure, high output lamps. A minimum of ten lamps from two batches is also the default requirement for polychromatic lamp verifications. Note that these quantities represent those that shall have been successfully carried through the entire period. It is recommended that additional lamps be included to allow for breakage.

A vendor may propose testing fewer lamps than the default requirement of ten lamps from two

batches if sufficient historical QA/QC documentation, and previous lamp aging or similar data, is provided by the vendor and/or lamp vendor. The vendor, before the start of a testing program using less than the default number of lamps, should review the supporting documentation and Verification Test Plan with the appropriate regulating authority(ies).

The lamps do not have to be housed in a commercial reactor, but the identical quartz sleeve, lamp and ballast configuration as a commercial system must be used. The vendor claims must include a statement as to the expected lamp life or minimum replacement interval.

The test system shall have the ability to cycle the lamps on/off. The vendor claims must specify the maximum number of on/off cycles and intervals that the lamps shall be operated. There shall be at least four on/off cycles per day for low-pressure systems. For polychromatic systems, lamps are generally not on/off cycled as often, but rather, operated at different power set points. In this case, the vendor claims must address how the minimum power set point is determined and specify the methodology used to adjust set points over the course of the test period. The vendor must address the power and on/off cycling to be imposed for the test period and explain how this conforms to the commercial system.

5.2.2 Test Facility

The only requirements for a test facility are the ability to provide a source of water covering a temperature range of 10 to 25 degrees (as stated by the NWRI/AwwaRF guidance) centigrade and a suitable setup to measure lamp output. As such, testing under this protocol can be conducted at a water or wastewater treatment plant or in a laboratory setting, provided all the basic test requirements are met. Note that the NWRI/AwwaRF (December 2000) guidance states the range as 10 to 25 degrees C. This may not be practical, possibly requiring testing at both a warm and cold climate plant to capture the full temperature range. The modified range required by this protocol is responsive to the intent of the test, and is one that can be found in a single facility.

5.2.3 Test Facility Equipment

This protocol gives general direction to the setup of a test site. The Verification Test Plan shall provide details of the test facility.

5.2.3.1 Test Reactor(s)

Test reactors are the housing in which the lamps will be held as they age. A reactor may hold a single lamp or multiple lamps. The reactor shall be designed so that heat transfer conditions (between the lamps and surrounding water) are similar to full-scale operation. In lieu of constructed reactors, a commercial UV reactor can be used. In this case, the reactors may be placed in a temporary or full-scale channel under appropriate flow conditions.

5.2.3.2 Lamp Output Measurement Reactor

The lamp output measurement reactor is a separate reactor designed to allow for the measurement of output from a single lamp. A series of such reactors can also serve as the aging reactors.

5.2.3.3 Electrical Source

An uninterruptible power supply should power the lamps during testing. This may be from an existing feed line or from a portable generator conditioned to meet the vendor's specifications for their control panel.

5.2.3.4 Water Source

The water source selected for the verification shall be discussed in detail in the final Verification Test Plan. In laboratory test facilities, potable tap or deionized water may be used. Secondary, process, tertiary or potable waters may be used at a treatment plant setup for aging. However, it is also recommended that potable water or DI water be used in the lamp output measurement reactor when recording irradiance. The effect(s), if any, the water source may have on the overall test program shall be discussed in the Verification Test Plan.

5.2.3.5 Water Temperature Variability

The lamps shall be subjected to water temperature variations between 10 and 25 degrees centigrade. If a plant effluent is to be used, historical temperature data shall be included in the Verification Test Plan, if available. Potable sources will not likely be subject to the required variation. Therefore, artificial means for heating and/or chilling the water must be provided. The equipment and methodology to adjust source water temperature during the test period shall be discussed in detail in the Verification Test Plan.

The Verification Test Plan must also address how the temperature variation will be distributed over the course of testing. This distribution should mimic seasonal variations in water temperature.

5.2.3.6 UV Output Monitoring

UV output monitoring during the test period can be measured in-situ, if provided for in the design of the reactor and approved by the TO. A separate test reactor can also be used and is preferred. The minimum requirements for either condition are that UV output readings are not influenced from adjacent lamps and that all readings are conducted under heat transfer conditions representative of full-scale operation.

For low-pressure systems, all UV output measurements shall be at a wavelength of 254 nm. For polychromatic lamps, a minimum of six wavelengths shall be monitored; such as it is 240, 250, 254, 260, 280 and 300 nm. The selection of wavelengths and the methodology/instrumentation for measurement shall be fully described in the Verification Test Plan.

For all measurements, an appropriate UV sensor with necessary diffusers and/or narrow band

filters and radiometer shall be used. The UV sensor assembly shall be calibrated no more than one month before the start of the testing according to the vendor's recommendations. An independent party shall check the calibration at least once every six months of continuous testing.

The TO will be required to prepare and submit with the Verification Test Plan appropriate Piping and Instrumentation Diagrams, equipment layouts, and schematics of the test facility, showing all components of the test equipment and accessory installations and all monitoring locations. A schematic of an example laboratory-based installation using a re-circulation flow loop is presented in Figure 5-2.

5.2.4 General Test Protocol

The following general protocol is provided as a default for testing the output for the individual test lamps with time. It assumes that the full set of lamps are aged in a separate "aging" reactor, and that the individual lamps are then removed and installed in a "measurement" reactor for actual output/irradiance measurements.

1. The lamps shall be burned-in for a minimum of 100 hours before the baseline UV output measurements are taken.

2. All quartz surfaces in the lamp output measurement reactor shall be cleaned according to the vendor's recommendations; this includes the sleeves as well as any quartz windows associated with monitoring ports. The test lamp is then installed in the measurement reactor.

3. Water shall be continuously circulated through the measurement reactor and its temperature adjusted, as necessary, to average ambient conditions (i.e. 20 degrees centigrade +/- 1 degree). Once the water temperature is set, UV output at the selected wavelength(s) shall be measured using an International Light radiometer with the appropriate UV sensors/diffuser/filters (or equivalent). Readings will be taken through water. Water temperature and electrical readings shall be recorded at the time of each measurement. A sample of the source water shall also be collected and measured for UV absorbance at the wavelength(s) measured. The Verification Test Plan should describe in detail how system stabilization/equalization (lamp output with regard to water temperature and flow through) shall be determined and verified.

4. After baseline conditions are established, the lamps are returned to the aging reactor and operated at full power under continuous flow conditions and at the temperature variations prescribed by the Verification Test Plan. The system shall be monitored for flow, lamp-hours elapsed, ballast and lamp power (as appropriate to the specific lamp), and on/off cycling events. Monitoring may be continuous or at discrete time intervals (e.g., daily). The Verification Test Plan shall provide details of the monitoring protocols during the lamp aging periods, and shall describe and justify how continuous operation

of the lamps at full power will be verified.

5. This monitoring and measurement period shall extend for the period claimed by the vendor.

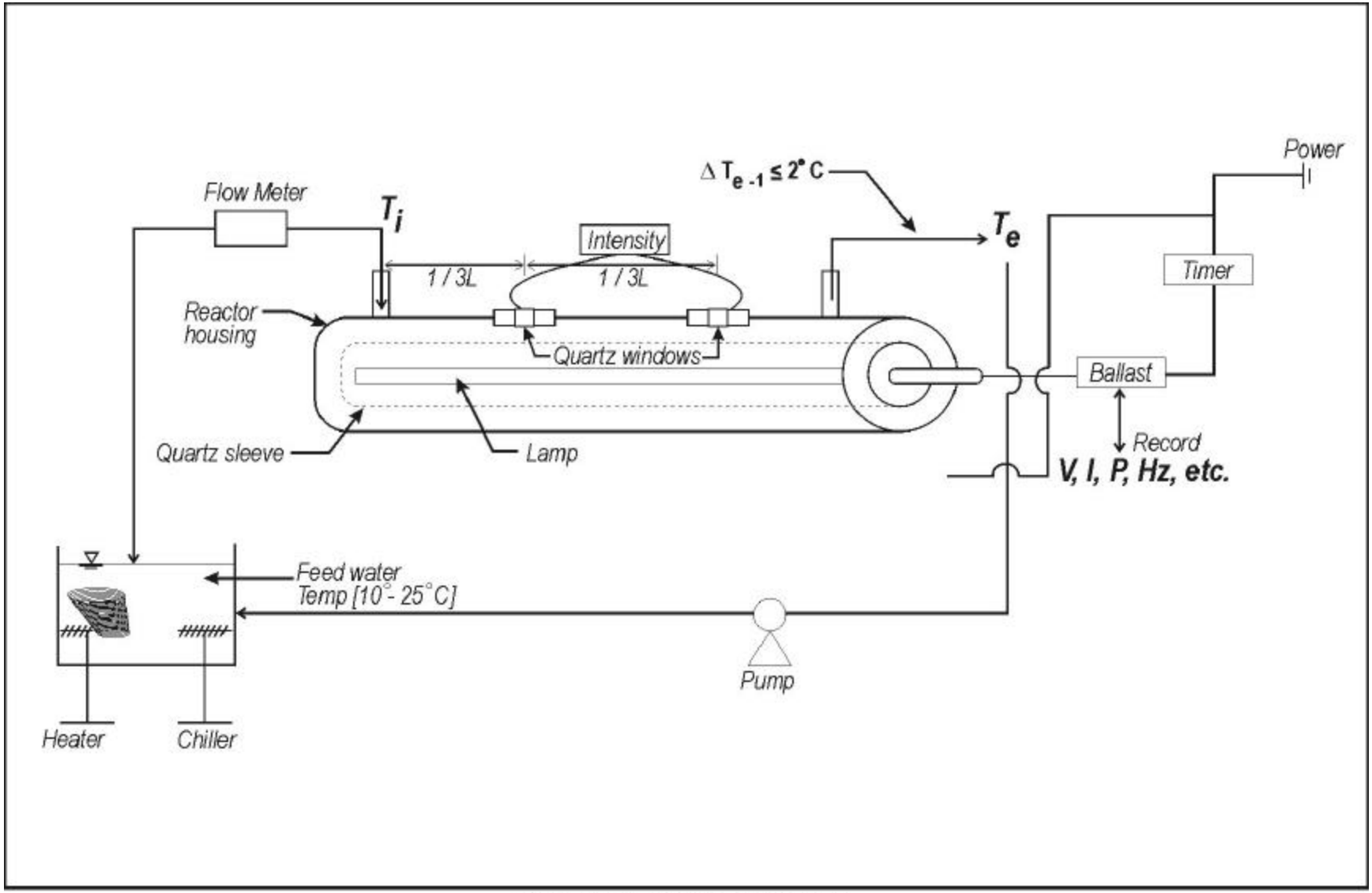

FIGURE 5-2. Test set-up schematic.

UV output measurements shall be repeated following the same methodology at intervals of no more than 20 percent of the specified lamp life or change-out interval. Note, all subsequent UV output measurements must be taken at the same source water temperature at which the baseline conditions were established. Monitoring is necessary only for the water temperature. It is recommended that the lamp temperature be monitored for low-pressure, low-output lamps.

The Verification Test Plan shall provide a plan to ensure that the required water temperature fluctuation is achieved over the course of the test period. The temperature profile does not have to necessarily follow seasonally. At a minimum, 80 percent of the operating period shall be conducted at a source water temperature between 15 and 20 degrees centigrade. Ten percent of the interval shall be conducted with the temperature varying between 10 and 15 degrees and the remaining ten percent shall be conducted at water temperatures between 20 and 25 degrees. Other temperature profiles may be considered, but must be fully described and technically justified in the Verification Test Plan.

There may be some instances where a vendor may choose to conduct the lamp aging and associated measurements at its facility, remote from the TO's location. This is an appropriate set-up; however, the Verification Test Plan must include a detailed plan to ensure that the TO can confidently and independently verify that all conditions regarding lamp-aging conditions are met. This may include continuous data loggers; control panel lockouts or other means.

5.2.5 Data Compilation and Analysis

All data generated from the ETV lamp age factor verification element shall be compiled and presented in the verification report.

Monitoring data shall be tabulated chronologically and all instrumentation calibration certificates and/or in-field checks shall be included in the report. A summary of operational history, including lamp output measurement events, field observations and deviations from the test protocol shall be fully described.

A lamp age factor shall be calculated for each lamp tested by plotting each lamp's output, relative to its baseline, as a function of elapsed lamp-hours. A trend line through the aggregate data set will be used to determine an average UV output decay function over the test interval. The average ratio from the aggregate data set at the end of the test interval shall be reported as the "lamp age factor," unless an alternate approach is discussed in the final Verification Test Plan.

6 DOCUMENTATION AND REPORTING

Documentation and compilation of data generated by the verification testing will be critical tasks. Several documents will also be generated as part of the ETV, including the Verification Test Plan and the final report. A summary Verification Statement will also be prepared, presenting the important results of the ETV.

6.1 DATA MANAGEMENT AND DOCUMENTATION

A variety of data will be generated during the verification testing. All data identified for collection in the verification test should be included in the Verification Report. The data handling section of the Verification Test Plan shall describe the types of data that are to be collected and managed and how they will be subsequently reported. The use of field notebooks, photographs, slides and videotapes, and compiled observations from field tests shall be described. All data shall be available in hard copy and in electronic format.

6.2 VERIFICATION REPORT

The ETV report will follow an establish format, based on NSF and EPA protocols for report preparation. A key element will be the presentation of the results of the ETV. This must be done in a manner that is consistent with the objectives of the ETV, and clearly articulates verification of the capabilities and performance of the UV system to the appropriate applications. This should specifically encompass whichever of the three Test Elements that were performed separately and then summarize the overall effectiveness and application of the system, within the bounds set by the ETV.

The Verification Report shall include the following items:

- Executive Summary
- Introduction and Background
- Description and Identification of the System Tested
- Experimental Design
- Procedures and Materials Used in Testing
- Results and Discussion
- References
- Appendices, which may include Verification Test Plan, O and M Manual(s), QA/QC

Procedures and Test Data

The data shall be compiled, analyzed and presented in the Verification Report in a manner that clearly addresses the objectives of the verification and the individual test elements. The Verification Test Plan should describe how the results of the verification tests would be presented in the Verification Report.

7 QUALITY ASSURANCE AND QUALITY CONTROL

A Quality Assurance Project Plan (QAPP) shall be prepared as part of the Verification Test Plan for evaluating UV disinfection technologies for secondary effluent and water reuse applications. The generic format for such QAPPs is outlined in this section.

7.1 PROJECT DESCRIPTIONS, OBJECTIVES AND ORGANIZATION

7.1.1 The purpose of the study shall be clearly stated.

7.1.2 The processes to be evaluated will be described.

7.1.3 The facility, apparatus and pilot-plant set-up will be fully described.

7.1.4 Project objectives shall be clearly stated and identified as being primary or non-primary.

7.1.5 Responsibilities of all project participants shall be identified. Key personnel and their organizations shall be identified, along with the designation of responsibilities for planning, coordination, sample collection, measurements (i.e., analytical, physical, and process), data reduction, data validation (independent of data generation), data analysis, report preparation, and quality assurance.

7.2 EXPERIMENTAL APPROACH

7.2.1 Pilot-plant installation and shakedown procedures will be identified.

7.2.2 Pilot-plant startup procedures will be identified. Startup will comprise a number of tasks to implement and check operating and sampling protocols. Tasks will include establishing feed makeup and performing flow meter calibration checks, identifying sampling and monitoring points and identifying the types of samples to be collected.

7.2.3 The Verification Test Plan will be outlined for each test unit. This will include developing dose-response curves in the laboratory, performing hydraulic checks on the pilot unit and performing dose-flow bioassays on pilot unit.

7.2.4 Physical, analytical or chemical measurements to be taken during the study will be provided. Examples include total suspended solids, transmittance, grease and oil, pH, temperature, flow, pressure, headloss, relative intensity, lamp hours, particle size distribution, etc.

7.2.5 Sampling and monitoring points for each test unit and the type of sample to be collected (grab or composite) will be identified.

7.2.6 The frequency of sampling and monitoring as well as the number of samples required will be provided. This includes the number of samples needed to meet QA/QC objectives.

7.2.7 Planned approach for evaluation objectives (data analysis). This will include formulas, units, and definition of terms and statistical analyses to be performed in the analysis of the data. Example graphical relationships will be provided.

7.2.8 Demobilization of the pilot units, including scheduling and site restoration requirements, will be described.

7.3 SAMPLING PROCEDURES

7.3.1 Whenever applicable or necessary to achieve project objectives, the method used to establish steady-state conditions shall be described.

7.3.2 Each sampling/monitoring procedure to be used shall be described in detail or referenced. If compositing or splitting samples, those procedures shall be described.

7.3.3 Sampling/monitoring procedures shall be appropriate for the matrix/analyte being tested.

7.3.4 If sampling/monitoring equipment is used to collect critical measurement data (e.g., used to calculate the final concentration of a critical parameter), the QAPP shall describe how the sampling equipment is calibrated.

7.3.5 If sampling/monitoring equipment is used to collect critical measurement data, the QAPP shall describe how cross-contamination between samples is avoided.

7.3.6 When representativeness is essential for meeting a primary project objective, the QAPP shall include a discussion of the procedures to be used to assure that representative samples are collected.

7.3.7 A list of sample quantities to be collected, and the sample amount required for each analysis, including QC sample analysis, shall be specified in the QAPP.

7.3.8 Containers used for sample collection for each sample type shall be described in the QAPP.

7.3.9 Sample preservation methods (e.g., refrigeration, acidification, etc.) and holding times shall be described in the QAPP.

7.4 TESTING AND MEASUREMENT PROTOCOLS

7.4.1 Each measurement method to be used shall be described in detail or referenced in the QAPP.

Modifications to EPA-approved or similarly validated methods shall be specified.

7.4.2 For unproven methods, the QAPP shall provide evidence that the proposed method is capable of achieving the desired performance.

7.4.3 For measurements that require a calibrated system, the QAPP shall include specific calibration procedures, and the procedures for verifying both initial and continuing calibrations (including frequency and acceptance criteria, and corrective actions to be performed if acceptance criteria are not met).

7.5 QA/QC CHECKS

7.5.1 Data Quality Indicators

Statistical analyses shall be carried out on data obtained for all performance measurements. As part of the assessment of data quality, six data quality indicators (DQIs) can be used to interpret the degree of acceptability or utility of the data. At a minimum, the QAPP shall include a protocol for assessing the following DQIs, and acceptable limits and criteria for each of these indicators: representativeness, accuracy, precision, bias, comparability, and completeness.

The TO shall determine acceptable values or qualitative descriptors for all DQIs in advance of verification testing as part of the experimental design. The assessment of data quality will require specific field and laboratory procedures to determine the data quality indicators. All details of DQI selection and values shall be documented in the QAPP.

7.5.1.1 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 testing, representativeness will be ensured by executing consistent verification procedures. Representativeness will also 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.

7.5.1.2 Accuracy

For water quality analyses, accuracy refers to the difference between a sample result and the reference or true value for the sample. Loss of accuracy can be caused by such processes as errors in standards preparation, equipment calibrations, loss of target analyte in the extraction process, interferences, and systematic or carryover contamination from one sample to the next. Loss of accuracy for microbial species can be caused by such factors as error in dilution or concentration of

microbiological organisms, systematic or carryover contamination from one sample to the next, improper enumeration techniques, etc. The TO shall discuss the applicable ways of determining the accuracy of the chemical and microbiological sampling and analytical techniques in the Verification Test Plan.

For equipment operating parameters, accuracy refers to the difference between the reported operating condition and the actual operating condition. For water flow, accuracy may be the difference between the reported flow indicated by a flow meter and the flow as actually measured on the basis of known volumes of water and carefully defined times. Meters and gauges must be checked periodically for accuracy, and when proven dependable over time, the time interval between accuracy checks can be increased. In the Verification Test Plan, the TO 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 the 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 Verification Test Plan include laboratory performance of one matrix spike for determination of sample recoveries. Recoveries for spiked samples are calculated in the following manner:

$$\% \text{ Recovery} = \frac{100(SSR - SR)}{SA} \qquad (7\text{-}1)$$

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

Recoveries for laboratory control samples are calculated as follows:

$$\% \text{ Recovery} = \frac{100(\ found concentration)}{true concentration} \qquad (7\text{-}2)$$

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.

7.5.1.3 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Analytical precision is a measure of how far an individual measurement

may be from the mean of replicate measurements. The standard deviation and the relative standard deviation recorded from sample analyses may be reported as a means to quantify sample precision. The percent relative standard deviation may be calculated in the following manner:

$$\% \text{ Relative Standard Deviation} = \frac{S(100)}{X_{average}} \quad (7\text{-}3)$$

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

Standard Deviation is calculated as follows:

$$\text{Standard Deviation} = \sqrt{\frac{(X_i - X)^2}{n-1}} \quad (7\text{-}4)$$

where: Xi = 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%.

7.5.2 The QAPP shall list and define all other QC checks and/or procedures (e.g., detection limits determination, blanks, surrogates, controls, etc.) used for the project.

7.5.3 For each specified QC check or procedure, required frequencies, associated acceptance criteria, and corrective actions to be performed if acceptance criteria are not met shall be included in the QAPP.

7.6 DATA REPORTING, DATA REDUCTION, AND DATA VALIDATION

7.6.1 The reporting requirements (e.g., units) for each measurement and matrix shall be identified in the QAPP.

7.6.2 Data reduction procedures specific to the project shall be described, including calculations and equations.

7.6.3 The data validation procedures used to ensure the reporting of accurate project data to internal and external clients should be described.

7.6.4 The expected product document that will be prepared shall be specified.

7.7 ASSESSMENTS

7.7.1 Whenever applicable, the QAPP shall identify all audits (i.e., both technical system audits [TSAs] and performance evaluations [PEs]) to be performed, who will perform these audits, and who will receive the audit reports.

7.8 REFERENCES

7.8.1 References shall be provided in the QAPP in the body of the text as appropriate.

8 GLOSSARY

Terms and acronyms used in this Protocol that have special meaning are defined here:

Accuracy - A measure of the closeness of an individual measurement or the average of a number of measurements to the true value and includes random error and systematic error.

Bias - the systematic or persistent distortion of a measurement process that causes errors in one direction.

Comparability – a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

Completeness – a qualitative term that expresses confidence that all necessary data have been included.

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

Generic Verification Protocol - A written document that clearly states the objectives, goals, and scope of the testing under the ETV Program and that establishes the minimum requirements for verification testing and for the development of a verification test plan. A protocol shall be used for reference during vendor participation in the verification testing program.

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

Precision - A measure of the agreement between replicate measurements of the same property made under similar conditions.

Quality Assurance Project Plan (QAPP) - A written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project. The QAPP is a required component of a Verification Test Plan.

Representativeness - A measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point or for a process condition or environmental condition.

Standard Operating Procedure - A written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

Testing Organization - An organization qualified to conduct studies and testing of UV disinfection equipment in accordance with the Verification Protocol.

Vendor - A business that assembles or sells UV Disinfection Technology.

Verification - To establish the evidence on the range of performance of equipment and/or device under specific conditions following an established protocol(s) and verification test plan(s).

Verification Test Plan (VTP) - A written document that establishes the detailed test procedures for verifying the performance of a specific technology. It also defines the roles of the specific parties involved in the testing and contains instructions for sample and data collection, sample handling and preservation, and quality assurance and quality control requirements relevant to a given test site.

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

9 REFERENCES

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