DRAFT 4.1

GENERIC VERIFICATION PROTOCOL FOR HIGH-RATE, WET-WEATHER FLOW DISINFECTION APPLICATIONS

ETV Wet-Weather Flow Technologies Pilot
High-Rate Disinfection

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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 systems.

1.1 ETV OBJECTIVES

The Environmental Technology Verification (ETV) program was created 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 permitters are provided with an independent and credible assessment of the technology that they are buying or permitting.

High-rate disinfection has been identified as one of five, high-priority technology categories to be verified under the EPA/NSF ETV Wet Weather Flow Technologies Pilot.. The ETV Technology Panel on High Rate Disinfection divided this category into three primary technology groups: (1) Radiation; (2) Chemical; and (3) Mixing.

- Radiation technologies include ultraviolet light, pulsed light, and other emerging electromagnetic processes. At this point, ultraviolet light technologies are established and commercially available, and fall within the mission of the ETV.

- Chemical processes include high-rate chemical disinfection by the use of chlorine, bromine chloride, chlorine dioxide, ozone, peracetic acid, peroxide and others chemical agents that are commercially available.

- Mixing technologies are relevant to high-rate chemical disinfection. These include inductive mixers and diffusers.

The ETV Technology Panel on High-Rate Disinfection recommended that separate Verification Protocols be developed for these three technology groups.

1.1.1 Purpose of this Protocol

This Verification Protocol describes the steps that must be followed to ensure that a UV technology verification is carried out in a consistent and objective manner.

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 Test Plan. Sections 3, 4 and 5 present the protocols for this testing phase of the UV Disinfection ETV.

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 light (UV) radiation is a widely accepted method for accomplishing disinfection of treated wastewaters. Its germicidal effectiveness is derived from 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 (UVC) region of the electromagnetic spectrum, between 230 and 290 nm, 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 a higher current discharge and pressures between 10^{-2} to 10^{-3} mm 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. A low-pressure, high output lamp supplied by one vendor offers a nearly 20-fold increase in output at 254nm.

The medium-pressure lamps operate at 10^2 mm Hg, and can have many times the total UVC output of the conventional low-pressure lamp, depending on the input energy to the lamp. This can range as high as 5 kW in current systems. The light is polychromatic in this case, with a conversion of 7 to 15 percent of its input energy to germicidal light in the vicinity of 254 nm, substantially lower in efficiency than the low-pressure lamp. Because of its higher output, however, fewer lamps are required.

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

The low- and medium-pressure germicidal lamps are sheathed in quartz sleeves and placed directly in the wastewater stream, configured in a symmetrical array, and oriented horizontally or vertically. The lamp systems are typically designed modularly, and assembled in 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.

Consistent maintenance of the quartz surfaces in a clean state, allowing the transmission of the energy to the liquid, is important for the successful operation of a UV reactor. In wet-weather wastewater environments, this is especially critical. Such applications generally require automatic, continuous-operating cleaning devices as an integral part of the system. Although one could suggest that the owner provide manual cleaning between storm events, this would be a burdensome and possibly ineffective maintenance requirement.

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 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

Three major UV system operation and performance elements are addressed by this Verification Protocol:

1. Dose Delivery

The ability of the UV equipment to deliver dose at liquid UV transmittances that are representative of wet weather flows.

2. Quartz Surface Maintenance

The ability of the UV equipment to maintain the quartz surfaces in a clean state, efficiently transmitting the UV energy to the liquid in a low-grade wastewater matrix.

3. Performance in a Particulates-Bearing Matrix

The ability of the UV equipment to disinfect effectively in a wastewater matrix comprised of a relatively high concentration of particulates.

1.3.1 Dose Delivery

By its nature, UV 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 highly variable, particularly as they apply to wet-weather flows and from site to site. The design basis typically developed for a UV system application incorporates the characteristics of the wastewater to be treated, 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 pretreatment, and the expected variability in quality and quantity. Finally, the dose required to meet specific target levels is determined, 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.

The ETV's first technical objective is met by demonstrating, or verifying, the ability of a specific system to deliver an effective dose. This is the "delivered dose", which is the dose actually received by the microbes in the wastewater. Although recent research has been directed to modeling the delivered dose (particularly methods utilizing computational fluid dynamics in conjunction with computed intensity fields, Reference 1), 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, whereby 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 delivered by a laboratory-scale, collimated-beam apparatus, which can deliver a known, accurately measured dose. Measuring the response to these doses (Log survival ratio), a dose-response relationship is developed for the specific organism. A culture of the same organism is then injected into the large-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 would be run in a "clean" water matrix (from a potable water supply) which has been adjusted by chemical means to mimic the transmittances encountered under wet-weather conditions.

1.3.2 Cleaning Device Evaluation

While dose-delivery is critical in assessing the performance and capacity of a given system, the ability of the system to reliably maintain delivery of the dose is equally critical. With respect to wet-weather flows, which are characterized as low-grade and high in particulates, organics and inorganics, and greases and oils, the ability of the UV system to consistently maintain dose-delivery is dependent on the ability of the cleaning mechanism to keep the quartz surfaces clean. Certainly other components must be reliable, such as the lamps, quartz, ballasts, controls, etc., but these are not considered within the venue of the ETV.

A system's quartz sleeves will still likely have to be periodically cleaned manually (by taking the modules out of the reactors and hand-cleaning them. The auto-cleaning devices should greatly extend the lengths of operating times between such activities. This is particularly critical due to the intermittent operating regime for wet-weather applications. The systems will be left either submerged in standing water or left dry for extended periods of time. The unit must always be kept in a clean state in order to bring it on line quickly, and on demand.

This protocol incorporates an evaluation of the cleaning device. The approach is to operate a unit with a "typical" low-grade wastewater feed, and to monitor the transparency of the quartz sleeves. The 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. 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.

This Protocol calls for the operation of two small units, each with the equivalent of a full-scale cleaning device. These would be operated in parallel, both receiving a primary clarifier effluent of known characteristics, one with the cleaning device in operation, the other without. The principal focus will be the condition of the quartz sleeves relative to a known clean quartz and UV source. The objective will be to demonstrate the efficacy of the offered cleaning device relative to the same system without such a device. Analytical testing is limited to chemical and physical characterization of the wastewater being used. The operation of the units is intermittent in order to mimic the on/off operation in an overflow situation.

1.3.3 Performance in a Particle-Bearing Matrix

The third testing element of this Protocol demonstrates the ability of the UV unit to

operate and perform in a representative wastewater that has undergone some degree of pretreatment. In this test phase, the objective is to assess disinfection performance in a wastewater matrix and to quantify disinfection efficiency with respect to both dispersed and aggregated microorganisms. In the first two elements of the protocol, the equipment itself is verified with respect to dose delivery and the efficacy of its cleaning device. This third phase of testing takes the same system and assesses its ability to perform in a wastewater that has the principal characteristic of wet-weather flows: particulates that contain microorganisms and occlude them from exposure to UV.

In general, UV is not wholly effective in treating (inactivating) particle-associated organisms. This is the principal reason one observes a "tailing" in the dose-response relationship developed for a particle-bearing wastewater. As one increases the dose, the dispersed or non-aggregated organisms are inactivated, but the aggregated organisms remain and become the base residual that can be attained by the given UV equipment. Often, this residual can be correlated with the concentration of particulates in the wastewater, typically quantified as suspended solids and/or turbidity (Reference).

In a CSO/SSO wastewater regime, it is recognized that pretreatment for some degree of particulates removal is necessary in order to accomplish reasonable overall disinfection goals in conjunction with the UV system (Reference 2). This may involve removal of gross or large solids via screening or centrifugal separation, or further reduction in the mean particle size by enhanced screening, gravity and/or ballasted sedimentation, or direct filtration. Specific applications will likely provide a total system that includes pretreatment for solids reduction and a downstream UV system (both of which are obviously influenced by the type of wastewater, the disinfection goals for the particular application, and economics).

The objective of this third test element is to assess the particle-based inactivation function of the UV system. Within this framework, a degree of flexibility will be allowed as to the type of pretreatment process used prior to the UV system. The application of primary clarification shall be the default pretreatment process; however a Verification Test Plan developed for a particular UV System may propose the use of alternative pretreatment technologies.

This Protocol calls for testing the UV system with wastewaters that have been pretreated by a selected solids-removal process. The system would be operated on a batch basis in order to effectively quantify and adjust, if appropriate, specific characteristics of the wastewater (transmittance, dilution, etc.). The system will need to be kept at a consistent operating condition, particularly with respect to the condition of the quartz. The intent is to generate performance data under "clean" quartz conditions, separating the disinfection performance evaluation from the cleaning-device evaluation. The protocol does not require an evaluation of the pretreatment process itself, only a rigorous characterization of its effluent, which serves as the feed to the UV system. This will include microbiological and chemical parameters, and a quantification of the particulates, including mean particle size and particle size distribution. Performance will be quantified by the inactivation of selected microbial indicators (such as fecal coliforms) over a

range of flows and within a specific target range of transmittances. Accompanying tests address the dose-response of the selected microbial indicator, differentiation of particle effects with respect to inactivation, and particle size distribution characterization.

2. DEVELOPMENT OF A VERIFICATION TEST PLAN

Prior to the start of verification testing of a UV system under the ETV Program, the field testing organization (FTO) shall prepare a Verification Test Plan that clearly describes how and by whom testing is to be conducted. An adequate 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 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 Test Plan should be developed for each UV System undergoing verification testing.

At a minimum a 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 approach taken in this study;
- 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
- 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 test plan.

2.1 OBJECTIVES

The objectives of the Verification 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 Wet Weather Flow Technologies Pilot. 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 Wet Weather Flow Technologies ETV;
- Coordination of Verification Report peer reviews, including review by the Stakeholder Advisory Group and Technology Panel;
- 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 Field Testing Organization (FTO)

The Field 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. The FTO will serve as the primary consultant for developing, implementing and reporting the verification. The responsibilities of the FTO 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

- Preparation and review of the Draft Verification Report.

2.2.4 UV Technology Vendor

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

- Provide the test unit for verification, and 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 wet weather 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, FTO 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 FTO and shall be identified as part of the Verification Test Plan, along with their roles and responsibilities.

2.2.6 Technology Panel on High-Rate Disinfection

The ETV Technology Panel on High-Rate Disinfection will serve as a technical and professional resource during all phases of the verification, including the review of test plans and the issuance of verification reports.

2.3 CAPABILITIES AND DESCRIPTION OF THE SYSTEM

The Test Plan shall provide details on the UV System to be verified, 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. Sections 3.2, 4.1 and 5.1 of this Protocol provide a general description of the system requirements for the dose assay, cleaning device and wastewater assay elements of the test program, respectively. These requirements must be clearly delineated within the Verification Test Plan.

The 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 taint the verification. The statement of capabilities forms the basis of the equipment verification testing and should be chosen carefully.

2.4 TECHNICAL APPROACH AND FACILITIES

The Test Plan shall summarize the overall conceptual approach to the ETV, including its compliance with this generic protocol. The Test Plan shall clearly describe the testing, test location, and the pretreatment that will be incorporated into the test facility. Any deviations from the generic protocol shall be highlighted and discussed, including justification for the alternative approach.

2.4.1 Test Facility Description

The Test Plan shall include equipment layouts, specifications and operating instructions, as necessary. Sections 3.3, 4.1.2, and 5.2 of this Protocol establish the general requirements for facilities to support the different test elements.

2.5 EXPERIMENTAL DESIGN

The 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 three Test Elements. Hereto, the Test Plan shall follow Sections 3, 4 and 5 of this Protocol for each of the three test elements. Within this framework, the **Sampling, Analysis and Monitoring Plan** must be detailed, 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.

2.6 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. This shall conform to and incorporate the wastewater treatment plant's general plan.

2.7 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
Materials and Methods

This section presents the protocols and materials for the UV equipment verification of dose delivery, the first test element. Test elements 2 and 3 (Cleaning Device and Performance, respectively) can be found in Sections 4 and 5.

The dose delivery capabilities of the system shall be verified by a dose-response assay. This will use an MS2 phage, which will be first cultured and harvested, and then calibrated in the laboratory via a collimated-beam apparatus. This phage culture will then be added to a prepared batch of potable water, which has been adjusted to a targeted transmittance at 254 nm. The water will be passed through the UV reactor over a targeted range of flows and sampled for influent and effluent phage analysis. This will yield a dose-hydraulic loading relationship for the particular system configuration.

Table 3-1 provides a summary of the Tasks in this Test Element that are associated with the experimental effort and require chemical and/or microbiological analyses.

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. 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. Approximately 3 per week.
B. Dose Calibration	1. Intensity Probe Calibration	3.1.2.2	In-lab actinometric calibration check for the UV detector used in the collimated beam test	Weekly during the collimated beam testing	Chemical actinometer analysis, approximately 3 per week.
	2. Measure intensity field across sample surface plane in collimator.	3.1.2.1	Map the intensities across the sample surface plane. This is to assure uniformity.	Once for each stock dose-response calibration. Verify once every two weeks.	No analytical.
	3. Verify Effect of Coffee and Thiosulfate on Phage	3.4.1	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 (less than 10) Phage titers of each sample (less than 10)
	4. Collimator Verification	3.1.2.4	Confirm that the collimator and container are consistent over the test transmittance range.	Once for each system verification project.	1. Three doses and two controls at 90%, 40% and 15% transmittance. Run in duplicate. 2. Approximately 6 transmittances and 15 phage analyses with each test run.
	5. Dose-Response Calibration Runs	3.1.2.3	Conduct a collimated beam dose run on the phage in order to calibrate its response to UV. Each run is comprised of exposure to a minimum of five doses.	Minimum of five runs for each stock phage.	1. Five doses plus three controls in each run, at a single transmittance. Do this five times. 2. Approximately 15 transmittances (each control). 3. Approximately 40 phage analyses.

Table 3-1 Continued

TASK	SUBTASK	REF	DESCRIPTION	FREQUENCY	ANALYSES TO BE DONE
	6. Dose-Response Calibration Checks	3.1.3	Conduct periodic checks of the same stock, measuring its response to a given dose.	Weekly	1. Expose a phage sample to a single, pre-selected collimated beam dose. Do this in duplicate, with a control. 2. Will require 2 transmittances and 4 phage analyses.
C. 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. Power at every dose 2. Temperature of water, air and lamp (2 lamps), at each flow condition sampled. 3. Intensity at 100 and 75 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.
	2. Tracer Run	3.4.3.1 (Step 5)	Determine the time needed for a system to reach steady state after a step injection. This will set the time needed before samples can be collected	Once at the test units lowest and highest test flows	1. No analytical. Use in-line radiometer to track plume passage.
	3. Assay No-Dose Controls	3.4.3.1 (Step 6)	Evaluate and quantify any reductions in phage through the system, without the lamps in operation.	Twice at the low and high flow rates.	1. Conduct Influent and Effluent sampling in triplicate at each flow event. 2. Will require 4 transmittances and 24 phage analyses.
	4. Conduct Dose-Flow Assays	3.4.3.1	Conduct runs with prepared phage batches. Each run shall comprise five different flow rates. Quartz are cleaned each day or with each run.	Minimum of four runs at each transmittance.	1. Conduct Influent and Effluent sampling in triplicate at each flow event, at each of two transmittances (15 and 40 percent) 2. Conduct a duplicate flow event at each 10^{th} flow event. 3. Yields a total of approximately 264 phage analyses (influent and effluent) and 132 transmittances (influent only)

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 recommended for use in the bioassay of a UV unit is F-specific RNA bacteriophage MS2. For a number of reasons, this organism is widely used to assay delivered UV germicidal dose:

- The MS2 phage has a relatively high tolerance to ultraviolet light and exhibits dose requirements that are typically higher than required by most bacterial 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 using it to inoculate the relatively large volumes of water needed to test large-scale reactors.

- The MS2 phage can be cultivated and harvested in relatively large quantities by a properly equipped laboratory.

- It is not pathogenic to humans, and is harmless in the aquatic environment. No extraordinary 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 CSO/SSO applications. Because the attachment site is not present at the applicable temperatures, 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.

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 is presented in ISO DIS 10705 (Havelaar): Water Quality - Detection and Enumeration of Bacteriophage (Reference 3). 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 recommended host strain is *Escherichia coli (E. coli)* ATTC **23631**.

A large enough stock of MS2 shall be cultured and harvested by the methods outlined in Havelaar (Reference 3) to meet the needs for a complete assay of a specific piece of equipment. The amount required shall be demonstrated as part of the 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, 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 will be obtained for a dose-response calibration within a stock. Periodically, if the stock is held for a period of months, the response of the phage to UV shall be checked to assure that the culture is viable and unchanged.

3.1.2 Dose 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. The lamp housing is ventilated continuously via a blower or other device The collimating tube, also constructed of an opaque non-reflective material, extends downward from the center of the lamp housing. 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 irradiate. This radiation is imposed on the surface of a mixed sample held in a container immediately below the collimator.

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

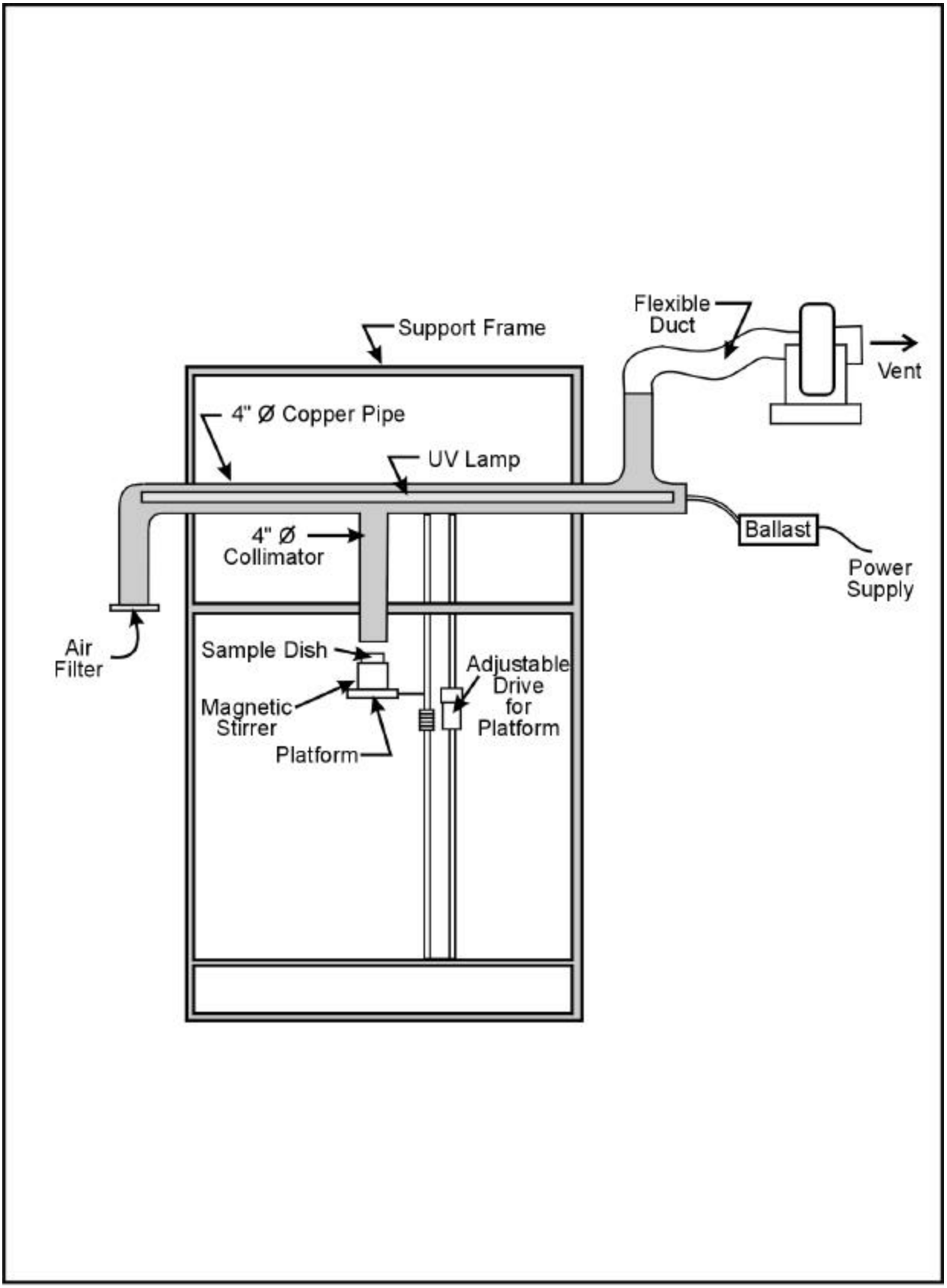

FIGURE 3-1. Example Collimator Apparatus for Dose-Response Test.

- The lamp shall be a conventional, monochromatic G64T5 lamp, or equivalent low-pressure lamp. Multiple lamps and lamps of varying length may be used, but care shall be taken to minimize fluctuations in the temperature in the housing. The unit may be equipped with a temperature monitor to demonstrate this.

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

- The measure of intensity 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 at equal intervals in cross-sectional lines and then averaged. The ratio of any single value to the average shall not exceed 1.25. The grid pattern shall cover the entire surface and shall contain a minimum of 20 equal-area cells. The procedure, as described in the Test Plan, shall ensure minimal variation of intensity across the surface of the sample. This procedure does not have to be done often, assuming that the sample container is always the same and is always in the exact same position relative to the collimator.

- 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.

- Airflow across the lamp surface shall be maintained continuously in order to prevent overheating of the lamps.

- The depth of the sample shall be such that the calculated intensity at the bottom of the container is greater than 50 percent of the intensity at the surface of the sample.

- 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 excessive surface turbulence. The magnetic stirrer shall be insulated such that there is no significant rise in the sample temperature during exposure.

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

For each MS2 phage stock harvested, an assay shall be performed in the laboratory to define its response to a given dose. The assay involves exposing a known concentration of MS2 phage to a known UV intensity from the collimating apparatus over various time intervals and then measuring the effect on the phage. Dose is determined by multiplying the intensity (depth-corrected for the given transmittance) and exposure time. A dose-response relationship is then developed, expressed as log survival (N/No) 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 will be used to conduct the field tests. If the field test is to 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.

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 immediately before an ETV is conducted, and then after completion of the test program. It is advisable to have two detectors available as checks against one another. Additionally, the detectors shall be checked experimentally, via an actinometry test, to assure consistency and accuracy of the dose imposed as part of the collimated beam dose-response test. During the actual dosing procedures, a minimum of three UV intensity readings shall be taken, generally at the beginning, middle and end of a dose-response assay run. The readings shall be within 5 percent of their average.

3.1.2.2 Intensity Calibration for the Collimated Beam and Sensor

The UV sensor shall be calibrated via photochemical actinometry at least once each week of testing with the collimating apparatus. This is to assure that the irradiance measured at the surface of the petri dish sample is accurate, and the consequent dose applied to the sample is accurately calculated. Procedures reported by Hoyer and Nick in DVGW Technical Standard W294 (Reference 4), Appendix A, are suggested, although alternative actinometric approaches will be considered. The Test Plan must detail the procedures to be used.

3.1.2.3 Dose-Response Test with the Collimated Beam Apparatus

To develop a dose-response relationship, the measurement of responses at a minimum of five different doses is recommended, covering and bracketing the expected range of operating doses of the UV test unit. 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 should 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 desired specifications discussed in Section 3.1.2.2. Before starting the dose-response runs, conduct and document the intensity sensor actinometric calibration, and the intensity mapping across the surface of the sample container. This shall be done at least twice, preferably before and after the total dose-response calibration task. If exposure times of less than 10 seconds are needed, than an automatic shutter arrangement is recommended for the collimating apparatus.

The 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 Test Plan:

1. Warm the collimator UV lamp(s) for a minimum period of 1 hour. Record the intensity periodically (e.g., every 5 minutes) at the exact height of the sample surface until a stable reading is obtained.

2. Place a known volume and density of MS2 phage in the irradiation container and add the spinbar. 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 cm. If low transmittances are being tested, the depth shall be adjusted such that the intensity is still more than 50 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)

2 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.

3. Remove the shield and start the timer.

4. After the desired time has elapsed, cover the irradiation vessel with the shield and turn off the stirrer. This sample is plated immediately. Samples are plated in triplicate at three dilutions.

5. Steps 2 through 4 are repeated at different time intervals.

6. Control samples are generated following the same procedure, without exposure to the UV light. Control samples are developed at least at time zero and the maximum exposure time. Intermediate controls can be generated; depending on the overall number of samples being generated in a given run.

7. At 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 recommended at intermediate points to assure consistency of the reading; if desired, one can measure the intensity before and after each dose delivery.

8. The titer of the phage solution used for the dosing assays shall be greater than 1 $x10^6$ pfu/mL, and shall be sufficient to yield no less than 50 pfu/mL after exposure (this is relevant at the very high doses, where one can expect nearly 5-logs reduction). Measure the transmittance of the diluted phage stock used for the assays. Generally, one should expect that the transmittance at 254 nm is greater than 95 percent. Lower transmittances can be observed because of a lower grade dilution water (or, for example) if the water had to be dechlorinated with thiosulfate). The transmittance shall be measured with a spectrophotometer equipped with an integrating sphere. Although it is not critical to account for scattered light in the matrix used for the dose-response analysis, it will be important in the other test elements. As such, it is appropriate to impose a consistent measurement protocol for this parameter.

9. Compute the dose as follows:

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

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 will measure absorbance units per centimeter (a.u./cm); this is converted to the absorbance coefficient:

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

Transmittance measurements can also be converted by the relationship:

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

3.1.2.4 Collimator Verification

The latter part of the dose calculation (Equation 3-2) expression comprises a depth-correction for the incident intensity, such that the dose is computed with the average intensity in the sample. This assumes that the depth is not too deep, and all other facets of the collimator are correct. The Test Plan shall describe how these assumptions will be verified; such as by conducting dose-response runs over a range of transmittances, from the higher level that represents the source water, to the adjusted levels that will be tested in the field. In all cases the maximum depth should conform to the specification that the bottom intensity in the sample dish is greater than 50 percent of the surface intensity. At least three doses shall be tested, each in duplicate and at a minimum of three transmittances. The test runs shall be conducted in duplicate. This entire procedure shall be conducted at least once within the period of a full system verification, and repeated if the collimator configuration is changed. The collimator procedures shall be validated by ensuring that the dose required to achieve a given response at each of the three transmittances is within 10 percent of the average dose. Otherwise, the procedures shall be modified and revalidated.

3.1.3 Dose-Response Data Analysis

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

$$N = N_o e^{KIt}$$

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, $cm^2/W\text{-}s$
I = the intensity of UV radiation, mW/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.

The data generated by a dose-response analysis are N, N_o and the applied UV doses. These data are analyzed using the above equation to yield a log survival-dose response curve for the organism. 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 a non-linear regression of the example dose-response data. Non-linear regression analyses of the dose response data are suggested for the ETV, unless otherwise proposed and approved in the Test Plan.

A minimum of five 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 theMS2 stock culture. These can be conducted before the field testing is initiated, or conducted through the term of the field tests. The multiple runs are required because of the inherent variability with this type of analysis. Confidence limits around the dose-response curve can also be constructed. The correlation coefficient for the dose-response analysis shall be greater than 0.9. If is it less, then additional runs shall be made.

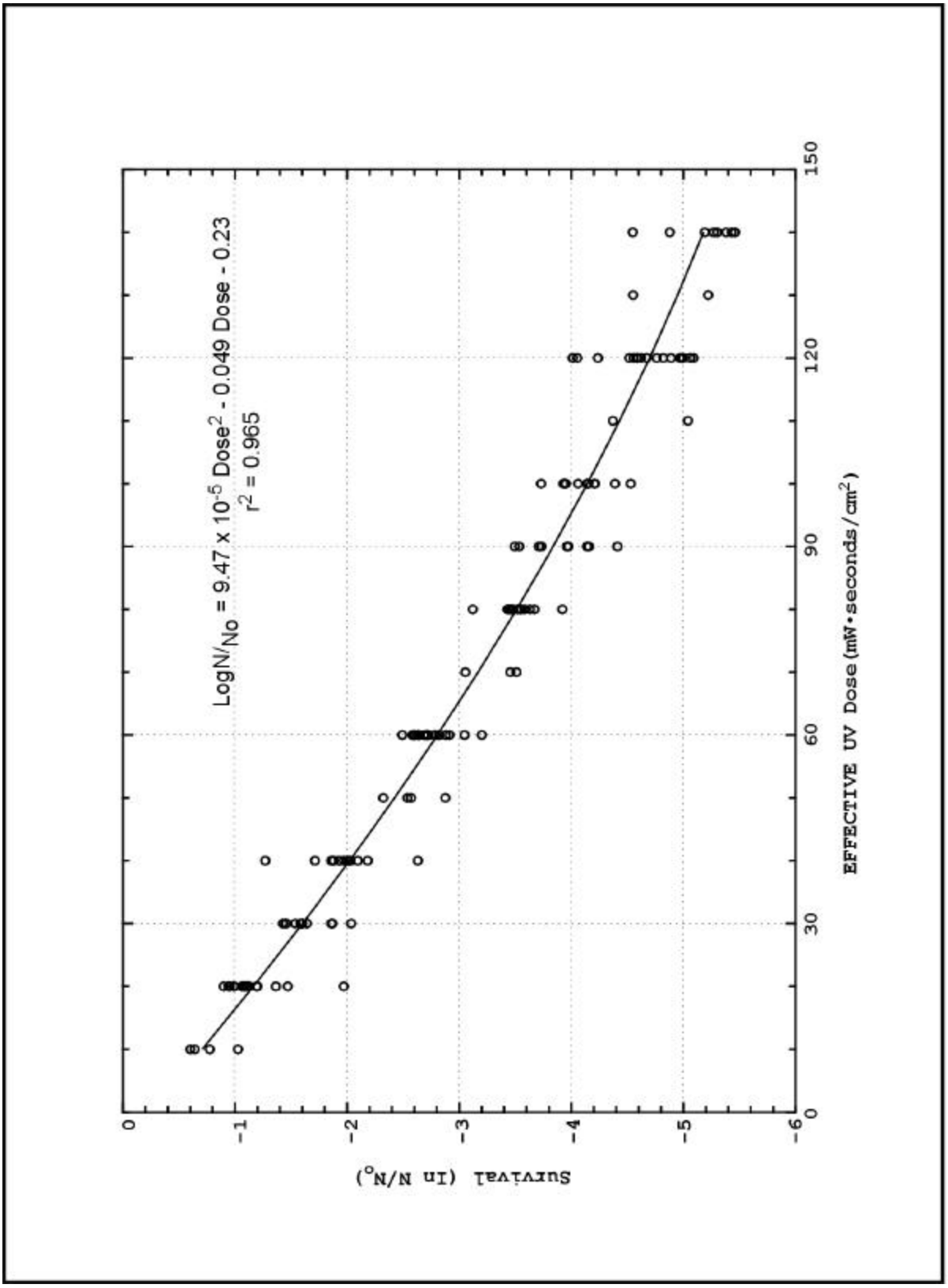

FIGURE 3-2. Example MS2 Dose-Response Correlation.

Once the dose-response curve is generated, a calibration check shall be performed weekly. This involves exposing a single MS2 phage sample to a known UV dose and comparing the observed and predicted survival rates. The results are acceptable if they fall within the 95 percent confidence limits. If the results fall outside the confidence limits, additional calibration checks shall be performed. If the calibration checks repeatedly fail, then a new dose-response curve shall be developed, or the stock phage shall be discarded.

3.2 UV TEST UNIT SPECIFICATIONS

The test unit submitted for evaluation by the ETV protocol must be or must closely simulate 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 test plan, including any dissimilarity between the two.

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. 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 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 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. These include the lamp, ballast, quartz sleeve, and the automatic cleaning device. Although the assay portion of this verification is not concerned with the effectiveness of the cleaning device, the device should be included in the test unit, since its operation will likely influence the flow patterns within the reactor. If there are other fixed or moving devices (baffles, support bars, sensors, etc.) in the commercial unit that can affect the local flow patterns within the system, then these shall also be provided in the test unit.

This Protocol does not address the verification of operating monitors such as 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). These monitors may be useful during testing and should be provided if offered as part of the commercial system. Some of these monitors will be specific to the lamp/ballast configuration of the reactor under test. The use, calibration and recording of these monitoring and control devices should be detailed as part of the Test Plan.

Intensity monitors 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 under both clean water and adjusted water conditions.

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

3.2.2 Lamp Output

Data on lamp output and the anticipated effects of temperature shall be included in the 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 certify this information and the certification will be incorporated into the Test Plan.

3.2.4 Reactor Configuration

The 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 Pilot Coordinator 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 and water on a continuous basis, and with capacity to dispose of the material once it is passed through the system. The protocol assumes that the appropriate location will be a wastewater treatment plant with access to primary wastewaters and a

potable water supply.

3.3.1 Test Facility Equipment

This protocol gives direction to the setup at a test site. Figure 3-3 presents an example schematic flow diagram for conducting a large-scale dose-delivery bioassay. The 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 Test Plan. At a minimum the Test Plans shall describe the following site equipment, as suggested in Figure 3-3:

- **Batch Tank**. A sufficiently large tank will be needed for preparation of the batch water to feed the UV system. The size of the tank 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. Pump specifications and curves shall be submitted with the Test Plan, demonstrating how the five equivalent dose flows will be accomplished.

- **Generator**. Experience has shown that different systems require different service with respect to power. A diesel-powered generator may be appropriate to run the system 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.

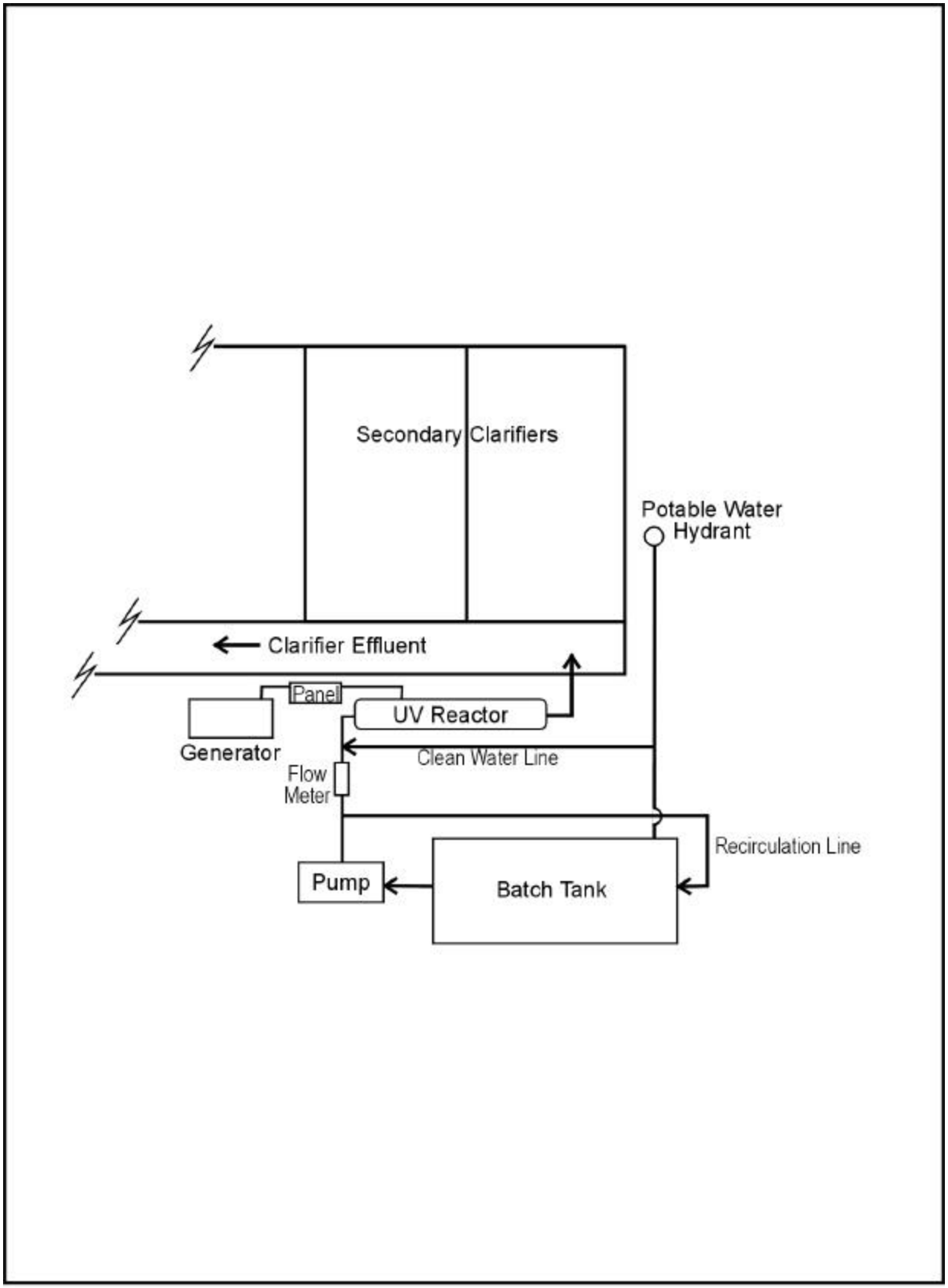

FIGURE 3-3. Example Test Facility Layout for Phage Dose-Delivery Assays.

- **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, except in higher-pressure systems, as may be experienced with closed-vessel reactors.

- **Water Source**. Clean, potable quality water is recommended for the dose-delivery bioassays. 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.

The FTO will be required to prepare and submit with the Test Plan appropriate P and IDs, 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 mixed 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 (Reference 6). In order 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 type of instant coffee used will effect the results.

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 in order 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 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 kits used, it shall have a minimum detection limit of 0.05 mg/L.

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.

With each new stock of phage, tests shall be conducted to confirm that the phage are unaffected by the addition of thiosulfate and coffee at levels required for the full--scale tests. The Test Plan shall describe this procedure, typically encompassing running dose-response tests (at a selected dose level) with and without the thiosulfate and/or coffee in solution.

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

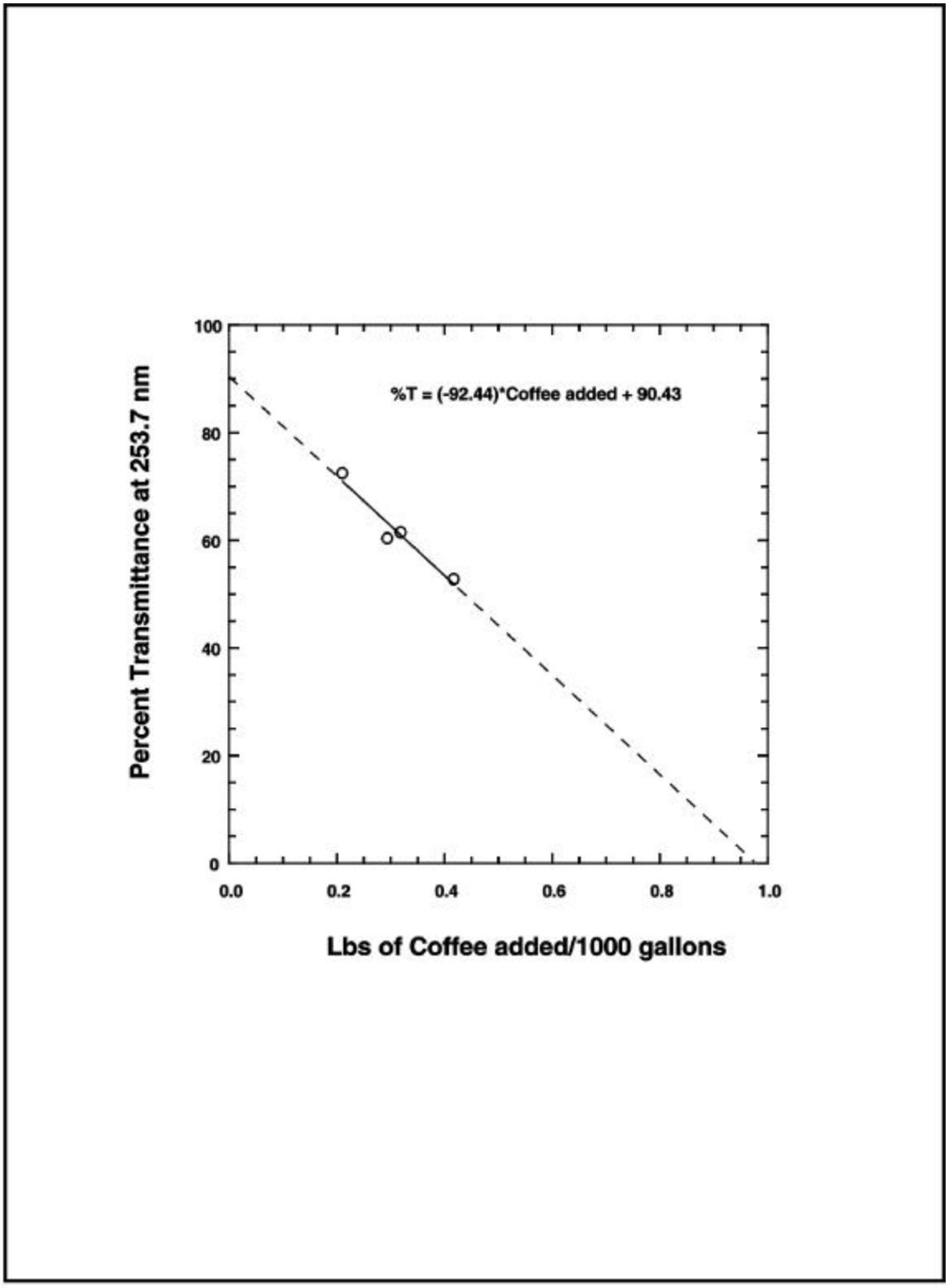

FIGURE 3-4. Example Correlation of Transmittance with Coffee Addition.

1. The batching vessel is filled with the source water.

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

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. This can be verified by sampling and analyzing the transmittance of the sample. 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. If the percent transmittance is within +/- 1 percentage unit of the target level, then proceed to the next step. 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 and add the rinse waters to the test water.

8. Mix the contents of the batching vessel. While mixing, take a sample for percent transmittance. 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. Descriptions of how these test conditions are set follows.

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. A separate evaluation will assess the ability of the system to consistently maintain clean surfaces. As such, it is recommended that the test unit's quartz sleeves be manually cleaned before each "batch run" or, at 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

The dose–flow assay shall be conducted with at least two test waters of different UV transmittances representative of the range of UV transmittances observed with wet weather flows. Typically, these waters are low-grade, high in particulates, have fairly low transmissibility of UVC. The UV transmittance of these waters will vary from site to site. The dose-flow assay shall be conducted using test waters having a UV transmittances of 15% and 40%.

The transmittance of the test water shall be adjusted as described in Section 3.4.1. Transmittance shall be measured using a UV spectrophotometer equipped with an integrating sphere, or equivalent, which corrects for light scattering. Although this is not critical in the non-particle matrix used for this Test Element (dose-delivery efficiency), it will be for the test element that treats actual wastewaters. As such, it is appropriate to use consistent measurement techniques. In the case of polychromatic lamp applications, a transmittance scan of the prepared water shall be made over the operating spectral range of the lamp, and specifically between 230 and 280 nm. This information shall be included in the final Verification Report. In all cases, distilled water shall be used as a reference and matched quartz cuvettes shall be used to hold the samples and reference water.

3.4.2.3 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 density shall be between 10^6 to 10^7 pfu/mL. The minimum effluent density shall be approximately 50 pfu/mL.

3.4.2.4 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 60 to 70 percent of nominal (this varies among different lamp-types). In the case of medium pressure lamps, there is no need to burn-in the lamps and the end-of-life output is generally near 80 percent.

Standard practice for assays is to adjust the output of the lamps to reflect such extended operation conditions, 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 unit to be tested shall be new and shall then be "burned-in" for a period of 200 hours. This shall occur regardless of the type of lamp and ballast configuration, and should be accomplished as part of the test set-up. The testing shall then be conducted at 75 percent of the UV intensity from the submerged lamps. The test plan shall describe how both the 100 percent and 75 percent output electrical conditions are verified (e.g., direct voltage, amperage and frequency readings). The intensity reduction shall be verified by installing a UV sensor in a fixed position in the water and measuring a reduction in intensity equivalent to 75 percent of the intensity observed when the lamp was at 100 percent output.

3.4.2.5 Reduced Lamp Output

When verifying a system that has automatic "dimming" capabilities, the Test Plan shall include the procedures to be used to quantify the outputs and dose delivery efficiency at these "adjusted" outputs. If it is not possible to quantify the outputs and dose-delivery efficiency at the reduced lamp outputs then the Verification Report shall explicitly state the conditions (e.g., 75 percent output) under which the system was tested, and that the system's capacity at the alternative outputs was not verified.

Such verification testing can be done at the discretion of the vendor. The Test Plan shall specify how this would be done. At minimum, the test unit shall be operated at selected output settings (for example 100, 75 and 50 percent), and at one or two hydraulic loading conditions. Dose delivered information is then collected via the bioassay procedure for each of the transmittance levels. In this way, at a given flow and transmittance level, one will have a relationship of dose and output. As with the bioassay approach as a whole, this shall be done in quadruplicate, at minimum.

3.4.2.6 Temperature

Lamp output will vary with temperature in the 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 Test Plan. This information shall also be included in the Verification Report. If possible, field testing should be conducted within a specific liquid temperature operating range, targeting 17ºC to 20 ºC, with an overall acceptable range of 14

ºC to 23 ºC.

3.4.2.7 Hydraulic Loading Rates

A minimum of five hydraulic loading rates shall be tested in quadruplicate. The hydraulic loading rate (HLR)(is defined as the flow (Lpm) divided by the number of lamps. Alternatively, the HLR can be defined as the flow per Total Input Watts or nominal UV Watts in the system. 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 should be measured accurately. An in-line magnetic flow meter is recommended. The flow meter calibration should be verified periodically by comparing the flow meter reading to flows that are computed using the change in volume (in the preparation vessel) over a given time. 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.

3.4.2.8 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 lamp battery. In closed reactors, pressure differential measurements shall be taken at the inlet and outlets of the reactor at each test flow rate. The Test Plan shall specify the method and instrumentation used to measure headlosses, and include appropriate specifications.

3.4.2.9 Power Utilization

A recording watt-meter 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 related solely to the test. This will allow for an estimate of the total power draw for the system, which can then be normalized to the number of lamps. The Test Plan will specify the wattmeter, and the method for measuring total power draw per lamp.

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 Test Plan must clearly define the procedure to be used for a particular ETV:

1. The UV system is 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 is 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. 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 is prepared in the batching vessel, as outlined in Section 3.4.1, Test Water 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 is then "turned-down" until the intensity observed by the sensor is 75 percent of the initial setting. The system shall be allowed time to stabilize to this reading, and the electrical characteristics shall be measured and recorded.

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

   The time required to achieve steady-state conditions shall be determined at the minimum and maximum flows to be tested. This may be done via a tracer injection to the influent of the system and monitoring the time (and equivalent volumes) required to reach a steady state reading at the system effluent. These data should then be used to establish the minimum number of volume changes that should be incurred before sampling. The Test Plan shall describe the procedure used to establish this.

6. Influent and effluent samples are collected in triplicate. Note that this comprises a sampling event. A sample of the influent is also collected to measure UV transmittance. The influent and effluent samples shall be collected in an alternating sequence. The influent sample may be taken directly from the batch tank or from a continuously flowing tap off the feed pipe. The effluent sample shall be taken from the reactor outflow and shall represent the total water stream.

   The Test Plan shall include a procedure to verify that the influent sampling location is appropriate and that there are no "non-UV" factors that influence the phage as it passes through the reactor. To do this, sample the inlet and outlet of the reactor with the lamps off and verify that the phage densities are the same statistically (at 95 percent confidence, by comparison of the means). The procedure shall be conducted at least once during the test period.

7. Once sampling is completed, the flow rate shall be adjusted to the next target flow rate. Steps 5 and 6 are repeated. (It is not necessary to repeat the influent sampling verification; this needs to be done only once.)

8. After all flow rates have been tested for a single batch run (i.e., the contents of the batch tank have been nearly depleted), the flow rate shall be adjusted to the baseline flow rate (note that the 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 shall be obtained and recorded.

Sampling locations are equipment specific and shall be clearly defined in the Test Plan. Samples shall be collected in pre-labeled sterile sampling containers. 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. 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 and 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 At a minimum, three replicates of each sample shall be plated. Each replicate shall be plated at three dilutions with each dilution plated in duplicate. Samples collected for the determination of percent transmittance samples shall be kept at 4 ºC and analyzed within 96 hours of collection.

3.4.3.2 System Monitoring

Several operating parameters may provide information about how a UV system is operating. The Test Plan shall identify parameters that are important to the performance of a specific UV system to be tested. These parameters may include, but are not limited to lamp output, 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 Test Plan shall describe how the parameters are to be monitored.

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 on 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. For each stock culture harvested for the specific ETV, the controls and exposed residual phage, transmittance (absorbency), and exposure time data shall be compiled and tabulated, and the resultant dose and log survival ratio (log N/No) computed and tabulated. The log survival ratio shall be plotted against the dose, and a non-linear correlation expression developed for each relevant stock. An example is presented in Figure 3-2. The correlation coefficient for this relationship should be greater than 0.90. This relationship shall be compared against the relationship and 90 percent confidence limits developed for the composite of other stocks developed within the same laboratory. The 90 percent confidence limits of the individual stock being used should fall within the 90 percent confidence limits of the composited data from the multiple stocks. If it falls outside the limits of the composite data, the Verification Report shall discuss the actions taken. Such actions may include the 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. This verification should include testing of the collimating apparatus itself (see Section 3.1.2.4), and direct calibration of the intensity probe (see Section 3.1.2.2).

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 use 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. 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

A dose relationship shall be developed for both of these parameters, in addition to the dose-flow relationship. 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 certifications relevant to the specific ETV

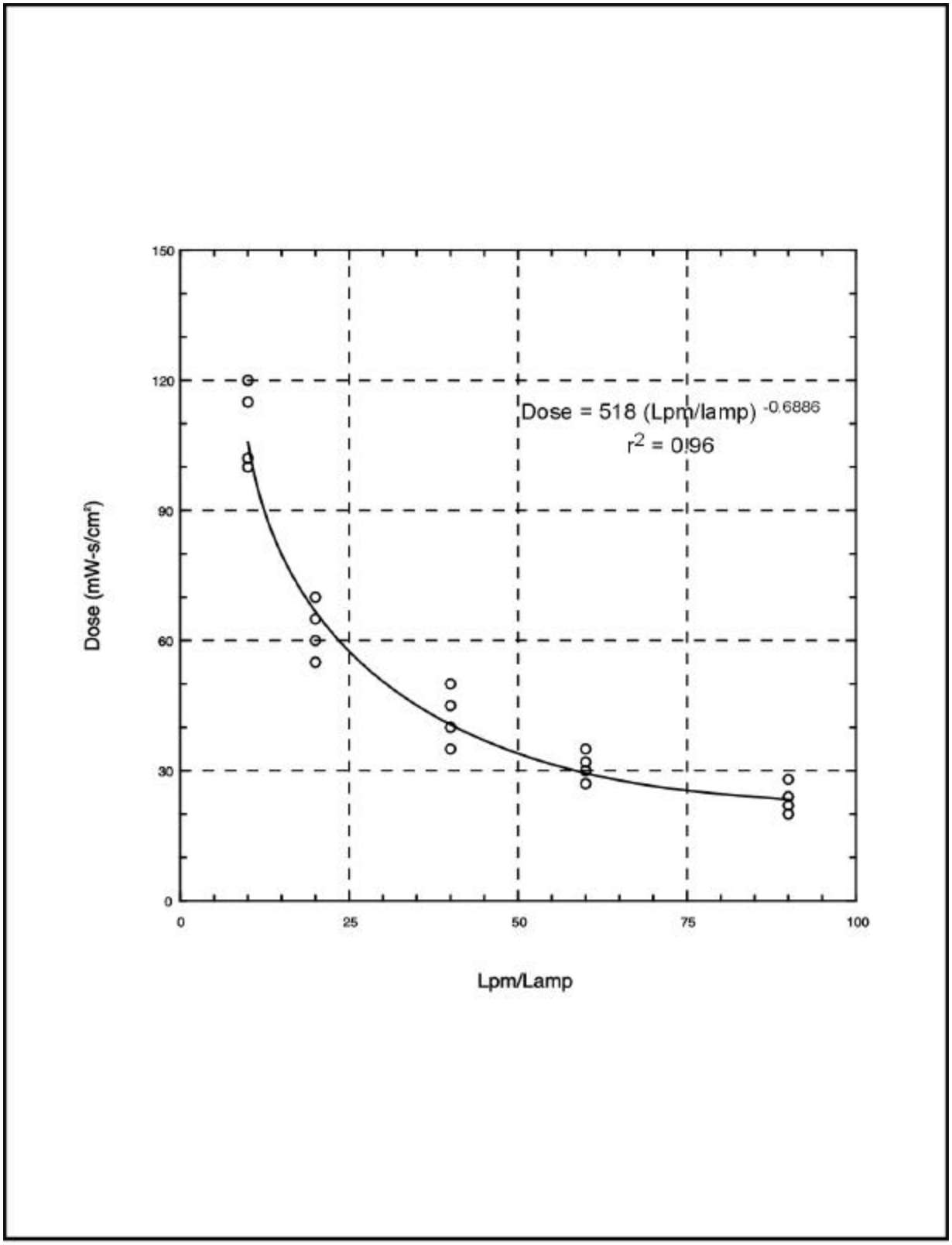

FIGURE 3-5. Example Relationship of Dose (mW-s/cm^2) as a function of Hydraulic Loading (Lpm/lamp).

4. TEST ELEMENT 2: UV QUARTZ CLEANING DEVICE VERIFICATION
Methods and Materials

This section presents the methods and materials associated with evaluating the UV system cleaning device. Maintenance of the quartz surfaces is a critical operation for a UV system in a wet-weather wastewater matrix. The protocol calls for operating two parallel units, each with a full-scale equivalent of the cleaning mechanism. Both units receive the same primary 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 2 that require chemical or biological testing. This represents the experimental effort associated with the Test Element.

4.1 TEST SYSTEM SPECIFICATIONS

Two identical units shall be setup at the test facility. These shall be plumbed and wired to operate in parallel.

4.1.1 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 verification standpoint, it is necessary only to simulate one quartz sleeve, and the cleaning device associated with this sleeve. From a practical standpoint, the vendor may need to offer a larger system, based on fabrication requirements, and the degree of modularization of the cleaning mechanism. Thus, a multiple lamp unit may be provided because it represents the smallest module for a full-scale cleaning device. In the test plan, the vendor shall clearly state the specifications of the test units and their conformity to full-scale specifications. The reactor 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 2: UV Quartz Cleaning Device Verification

TASK	SUBTASK	REF	DESCRIPTION	FREQUENCY	ANALYSES TO BE DONE
A. Initial Analysis	1. Sampling and Analysis of WW	4.1.2.1	The wastewater to be used as the matrix for challenging the wiper is sampled and analyzed for a target list of compounds	This shall be done on three samples collected from the primary effluent (Default) one to two days apart.	1. Three samples: Analyze each for TSS, Turbidity, PSD, G/O, COD, Fe, Hardness, TDS, Calcium, Magnesium, Total Phosphates, pH, Settleable solids, %T at 254nm (T and F)
B. Dose Assay of Test Units	1. Initial Dose Calibration of Test Units	4.1.2.3	The test units are calibrated to dose as a function of flow at two transmittances	This shall be done once at the beginning of Test Element 2.	1. Each Unit at 4 doses, at each of 2 transmittances (15 and 40 percent). 2. Each sampling event in triplicate; yields 48 phage and 24 %T samples. 3. Reference Task C-6 in Table 3-1, for phage dose calibration checks.
	2. Dose Checks on Operating Units	4.2.3 (Step 9)	A dose check is run on each test unit after shutting them down and draining them. This is to estimate dose reduction in a “dirty” or used state.	Every two weeks, or every second cycle for the unit with the wiper in operation. Three dose checks (total operating period of 6 weeks) shall be performed.	1. At the same operating flow and wiper rate, with phage-seeded clean water feed adjusted to the average wastewater transmittance. Single dose, each unit sampled in triplicate. 2. With two units, yields 12 phage and 2 transmittance samples every two weeks; this is done three times (total 36 phage and 6 transmittance tests).
C. Cleaning Evaluation	1. Wastewater sampling	4.2.3 (Step 2)	Collect samples of the feed to the units, characterize the wastewater quality	Every operating day. This is four days per week for up to 6 weeks.	1. Sample the common influent to each 6-hour “On” period. These will comprise 6-hour 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. Total of 24 samples. 3. Analyze every fourth sample for Ca, Mg, Total Phosphate, Particle Size Distribution, Settleable Solids (in addition to the analyses in No.2); total of 6 samples.

Table 4-1. Continued

TASK	SUBTASK	REF	DESCRIPTION	FREQUENCY	ANALYSES TO BE DONE
	2. Monitor and Test Quartz Transparency	4.2.3 and 4.2.2	The quartz sleeves from each test unit shall be measured for their transparency at the end of each "on" cycle. The quartz will be cleaned if their transparency falls below a pre-set level.	The evaluation shall proceed for 6 cycles, which comprises the manual cleaning of the unit that has the cleaning device in operation	1. Each quartz sleeve is tested at the end of each "on" cycle. 2. Assuming 4 quartz per unit, 8 test quartz and 3 control quartz will require transparency testing each of four days per week, for up to six weeks. 44 transparency tests per week. 3. If the quartz sleeves are cleaned, their transparency has to be measured before re-installing in the test unit. Assume this occurs each day for the non-operating unit and once per week for the operating unit. 20 transparency tests per week (total of 64 with No. 2 included.
	3. Monitor the operation and condition of the test units.	4.2.3 (Step 8)	Throughout the testing period, observe the unit with respect to fouling of surfaces, accumulation of debris, etc.	This is done after every "on" period.	1. Observations shall be recorded with respect to flow rates, cumulative volumes treated, intensity (if test unit is equipped with monitors), cleaning rate, and appearance of the quartz surfaces and of the cleaning mechanism.

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. The reactor design should be such that there is easy access to the quartz 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 cleaning effectiveness. As such, UV intensity detectors shall be installed in the two test systems. One shall be in a fixed position for each of the quartz/lamp assemblies. These may be fiber-optic strands, feeding back to the radiometer. These 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 Test Plan shall include drawings and sensor specifications, including details on the positions of the sensors in the reactors. The Test Plan may offer alternative strategies to monitor the output through the quartz sleeves with detectors that are themselves non-fouling.

4.1.2 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.

4.1.2.1 Feed Formulation/Characterization

Selecting an appropriate feed water to use for the cleaning evaluations is important. Options include:

- drawing wastes directly from a municipal wastewater plant;
- capturing SSO or CSO wastewaters; or
- synthesizing mixtures (e.g., primary wastewaters diluted with plant effluent) to simulate wet-weather conditions.

The third option is recommended because the water quality characteristics can be better controlled and specific fouling agents can be added to the mixture, if desired (examples might include hardness, iron, calcium and magnesium, oils, fats and greases). The wastewater shall be biologically active. Pretreated wastewater (e.g., secondary effluent, primary effluent, or a mixture of both) that can be spiked with specific components should be considered.

The water quality characteristics of the feed water should be representative of wet weather flows. The same wastewater used in the cleaning evaluation may be used in the third test element (see Section 5). This will allow for a unified wastewater characterization. At a minimum, the following feed-water parameters shall be monitored as part of the cleaning device evaluation:

Total Suspended Solids (TSS)
Turbidity
Particle Size Distribution (PSD)
Grease and Oils (G/O)
Chemical Oxygen Demand (COD)
Iron
Hardness
Total Dissolved Solids (TDS)
Fecal Coliforms
Calcium
Magnesium
Total Phosphates
pH
Settleable solids
Transmittance at 254nm (filtered and unfiltered)

The 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 feed water. Primary effluent from a wastewater treatment plant may be diluted with the same plant's secondary effluent, if necessary, to achieve the water quality characteristics required for Test Element 3 (see section 5.3). 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 regularly in order to clearly document the wastewater conditions during the operation of the units. The Test Plan shall provide characterization data from the proposed test site and shall detail any anticipated adjustments to the wastewater. The 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.

4.1.2.2 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 primary clarification system, and discharged to a constant head tank. Additives, including chemicals and/or process water for dilution may be added to the constant head tank equipped with a low-speed mixer. The Test Plan may propose alternative configurations provided they conform to the requirements of Protocol.

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.

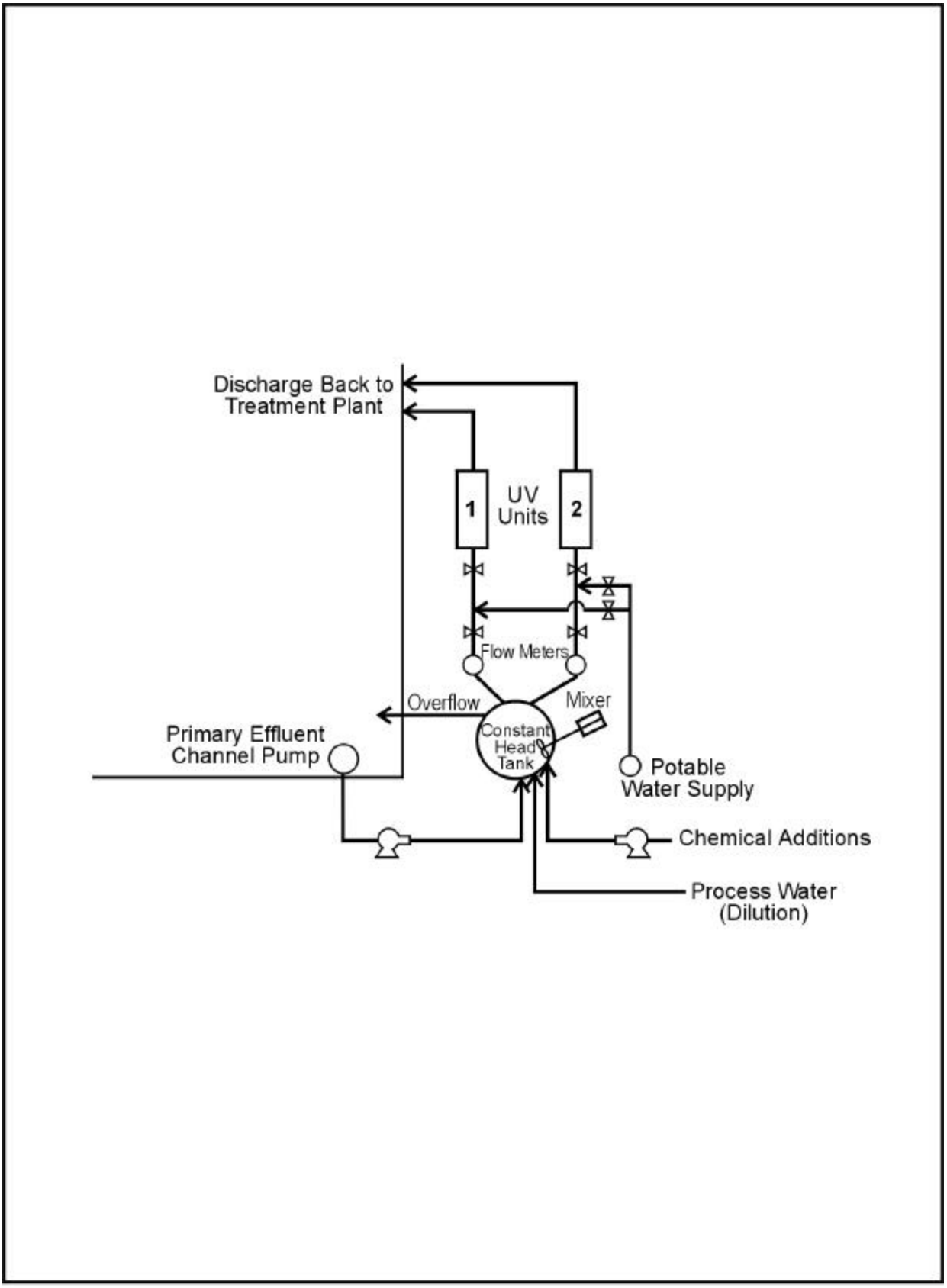

FIGURE 4-1. Schematic Layout of Cleaning Evaluation Test Facility.

A separate, clean-water line should be available for rinsing the units with clean water in accordance with the vendors recommended cleaning procedures.

The 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.

4.1.2.3 Biodosimetry Calibration of the Test Units

The two units to be used for the cleaning evaluation shall be calibrated as to their dose delivery by conducting biodosimetry assays in accordance with Test Element 1 (Section 3) of this Protocol. A clean water supply shall be used, with the water adjusted to transmittances 15 and 40 percent at 254 nm. At least four doses shall be tested (e.g. 10, 20, 40 and 60 mW-s/cm^2) in triplicate at each of the two transmittances. The Test Plan shall clearly present the procedures that will be used for conducting these biodosimetry tests.

4.2 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.

4.2.1 Operating Conditions

The fouling studies shall be conducted at a single, constant flow rate over a sufficient number of "cycles," as described below. The selected flow rate shall be equivalent to a dose of 40 mW-sec/cm^2, with clean quartz, based on the MS2 phage biodosimetry measurements conducted under Section 4.1.2.3.

The units shall be operated intermittently to simulate treatment of wet-weather overflows. A 6-hour-on/18-hour-off sequence is suggested for four days per week for both systems, with the systems off the remaining three days. When the units are "on", there shall be flow through both units and the lamps shall be operated at full power. When the units are "off", there shall be no flow, the units shall be drained and all lamps shall be off. The cleaning device shall be activated during the on-cycle of one unit and inactivated on the second unit.

4.2.2 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 3-1). 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. Multiple low-pressure UV lamps of different lengths and different size Teflon rings may be necessary to accommodate the various lengths and diameters of the quartz sleeves that may be used in a single UV system.

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 test plan should describe the apparatus proposed for such testing and clearly indicate the type of data that will be generated. The Test Plan should, at minimum, measure transparency along the length of the sleeve and about its circumference.

4.2.3 Fouling and Cleaning Procedures

The Test Plan shall describe the procedures for the evaluation of the cleaning mechanism. 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 Test Plan.

1. At time zero, the two units shall be thoroughly cleaned. The Test Plan shall identify and describe the composition of the cleaning fluid. The quartz from each

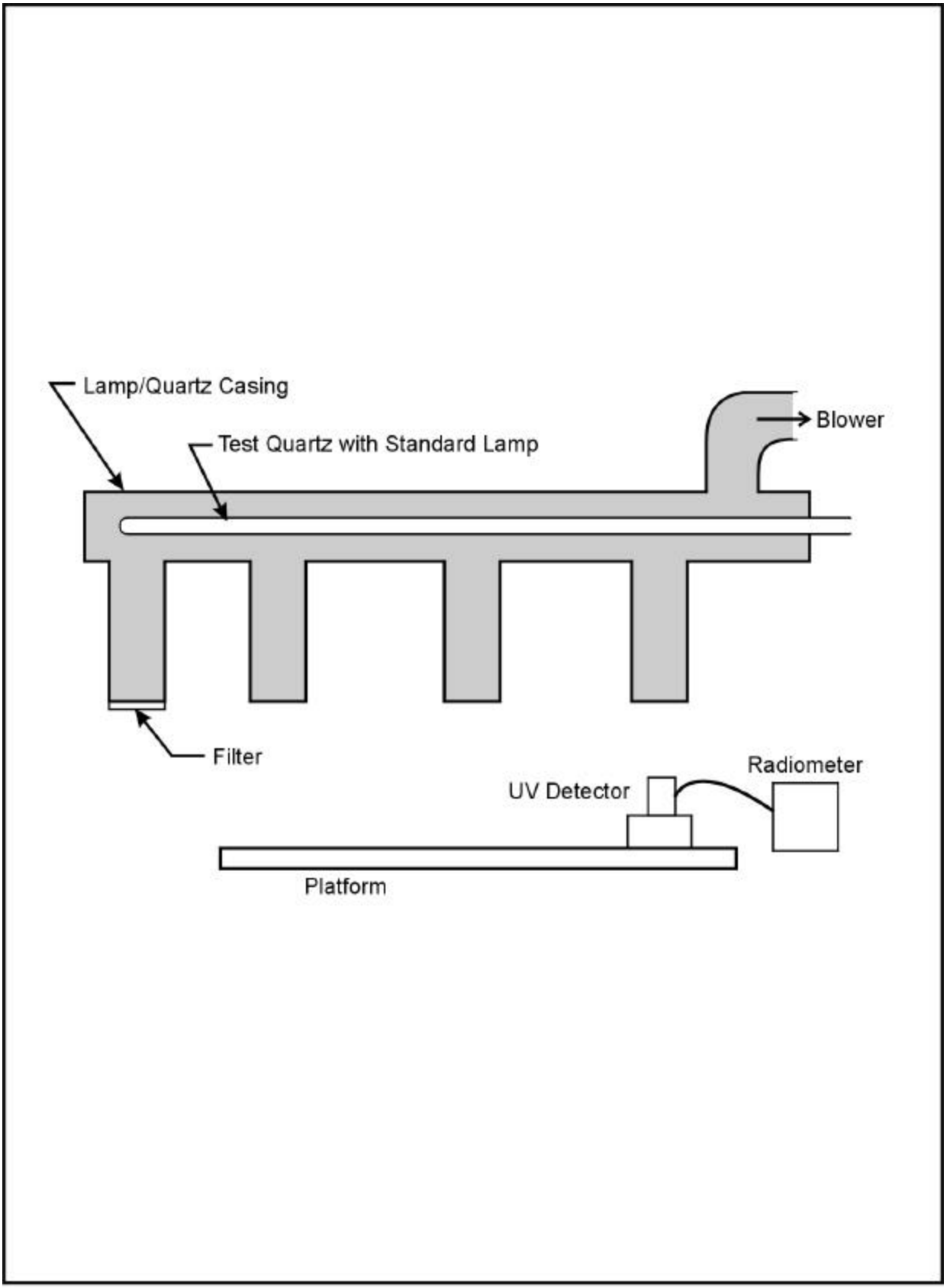

FIGURE 4-2. Quartz Transparency Test Unit.

will be removed (note that each quartz must be properly and permanently labeled) and tested for transparency to UV at 254 nm. The quartz sleeves are then returned to the units.

2. Begin flow to both units at the prescribed rate (see Section 4.2.1). The wastewater feed shall be from the head tank, adjusted by chemical addition and dilution, as needed, and as defined by the Test Plan. The wiper shall be activated at a prescribed operating rate in one unit, and left dormant in the second. A Composite sample shall be taken from the common influent (e.g., the equalization tank) over the 6-hour "on" period. 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 approximately 3 hours for those analytes requiring grab samples only. Every influent sample taken through the term of the study shall be analyzed for:

   Transmittance at 254nm (filtered and unfiltered)
   COD
   G/O
   Iron
   Hardness
   TSS
   Temperature
   pH

   Every 4th Influent sample shall also be analyzed for:

   Calcium
   Magnesium
   Phosphates
   PSD
   Settleable Solids

3. Operate the two units at the constant flow rate for a period of 6 hours. If the units are equipped with intensity sensors, record the intensities periodically through the six-hour period. Record the following at intervals of 30 minutes or less: (1) the flows to the two units (3) the chemical metering inputs; and (3) the process dilution waters flows, if applicable.

4. At the end of the six-hour period, shutdown and 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. If the vendor's operating instructions call for rinsing the system with clean water before shutdown, then this procedure should be incorporated into the Test Plan The wiper operation should

continue through this rinse step, with the lamps off.

5. Once the units have 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 in accordance with Section 4.2.2. 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.

6. 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 vendors operating instructions. After manual cleaning, the transparency of the quartz shall be measured in accordance with Section 4.2.2. The operation from one manual cleaning to the next is considered one "cycle."

7. The operating cleaning device shall be run through 6 cleaning cycles, or 42days (6 weeks), whichever occurs first. Throughout this period, the flow to the unit shall be kept constant. The wiper (or other cleaning device) operation can be modified, if appropriate, during this six-week period. The test plan shall discuss this and justify alternate operating conditions within the prescribed period.

8. 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.

9. The reduction in dose delivered at a given hydraulic loading rate due to fouling shall be quantified. To determine this, both test units shall be assayed with the MS2 biodosimetry procedure contained in Section 3 of this Protocol at least three times during the six-week evaluation session. These are in addition to the initial assays of the units discussed in Section 4.1.2.3. The assays shall be conducted at one dose (equivalent to the operating flow condition) with clean water, adjusted to the average transmittance of the wastewaters used for the cleaning assessment. The influent and the two effluents will be sampled in triplicate, equivalent to a sampling "event". The assays shall be conducted at or near the end of weeks 2, 4 and 6, and shall be done after the units have been drained and shutdown according to the specific operating protocol. Alternatively, the assays may be conducted before a manual "cleaning cycle" is initiated for the units. The units can then be started with the batch biodosimetry test water (seeded and adjusted to the desired transmittance) and sampled at the prescribed operating conditions. The dose

delivered after fouling shall be compared to the dose measured at the start of the testing. The Test Plan shall define the procedures to be used for this protocol element.

4.2.4 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 28-day period).

The biodosimetry data collected in accordance with 4.1.2.3 shall be reported to determine the impact of fouling on dose delivery and the efficacy of the cleaning device in maintaining the dose-delivery capabilities of the unit. 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.

5. TEST ELEMENT 3: PERFORMANCE IN A PARTICLE-BEARING WET-WEATHER FLOW MATRIX
Methods and Materials

This section establishes requirements for evaluating the performance of a UV system in a wet-weather flow matrix. The objective is to demonstrate the performance capabilities of the UV test system on wastewaters that are characteristic of wet weather flows, particularly with respect to particle-associated microbial inactivation.

Table 5-1 provides a summary of the Tasks within this Test Element that are associated with the experimental effort and require chemical and microbiological analyses.

5.1 TEST UNIT SPECIFICATIONS

The UV system evaluated under this test element shall be identical to the system evaluated under Test Element 1 of this Protocol (see Section 3.2, UV Test Unit Specifications)

5.2 TEST FACILITY REQUIREMENTS

5.2.1 Facility Design

The Test Facility Requirements established for Test Element 1 in Section 3.3 of this Protocol are also applicable to this test element. This protocol assumes that the test facility is located at a wastewater treatment plant, sufficiently large enough to handle the discharges from the test unit without any significant impact on plant operations or performance. In addition, a wastewater treatment plant to be used as a test facility should conform to the following requirements:

- The plant experiences wet-weather related impacts on wastewater quality. The plant can service either sanitary or combined systems.

- The plant should primarily treat residential wastewater with limited input from industrial sources.

- The plant is of sufficient size, and is capable of providing the necessary volumes needed for large-scale testing, and would not experience deleterious effects from operation of one or two systems on an intermittent basis.

There is a capability at the plant for providing dilution of the wastewaters as required in this Protocol. This may be for situations where the transmittance

- has to be adjusted (by dilution), or the wastewaters are too concentrated and are outside targeted ranges for specific parameters (e.g., TSS, BOD, etc.). Preferably, dilution will be with final effluent that is similar to the wastewater matrix with respect to dissolved inorganic constituents. This can often be obtained through a plant's process water system, which typically uses filtered final effluent.

- The primary clarifiers are effective and remove TSS within the desired efficiency range.

- The primary clarification system layout should allow for maintaining a targeted overflow rate in a portion of the clarifiers (by increasing or decreasing the flow to other clarifiers). A plant with several operational primary clarifiers and piping and valving flexibility will help ensure consistent primary clarifier performance during the test period.

- The clarifiers (one or more, as needed) should be operated at a predetermined overflow rate (e.g., within a targeted range, such as 800 to 1200 gpd/ft^2) by adjusting the flow split among the clarifiers. The targeted range should be set based on a review of historical data representing TSS removal rates as a function of overflow rate.

Table 5-1. Summary of the Experimental Effort for Test Element 3: Performance in a Particle-Bearing Wet-Weather Flow Matrix

TASK	SUBTASK	REF	DESCRIPTION	FREQUENCY	ANALYSES TO BE DONE
A. Initial Analysis (Test Plan)	1. Provide Characteristics of Primary Effluent	5.3.1.3	These data, along with historical plant data, will provide information on the primary effluent and conformity with targeted ranges, and establish dose requirements.	3 samples taken 2 to 3 days apart.	1. Analyze each for Hardness, Alkalinity, pH, BOD (T and F), COD, Ammonia, Iron (T and F), Fecal and Total Coliforms, Transmittance Scan (230 to 290 nm) (T and F), TSS, Particle Size Distribution. 2. Conduct collimated beam dose tests at 5 doses, with two controls, for fecal coliform. Do this for all three samples, blended and unblended (see subtask A-2). This will yield approximately 42 FC samples, 12 transmittance samples and 6 TSS samples.
	2. Establish Blending Procedure	5.3.1.3	The UV-exposed samples are to be macerated in a blender to reduce particle size and improve fecal coliform recovery.	Same 3 samples used in Task A-1.	1. Conduct blended and unblended fecal coliform analyses of the three samples exposed to 40 mW-s/cm2. Do this at different "blending" speeds and times to determine maximum recovery of fecal coliforms. Estimate approximately 40 FC analyses.
B. Initial Analysis (Test Element)	1. Establish Characterization	5.3.2.1	Verify characteristics of primary effluent to be used for testing.	3 samples, taken on three days in one week.	1. Analyze each for TSS, COD, PSD, pH, Hardness, Alkalinity, Iron (T and F), G/O, transmittance, settleable solids, total and fecal coliforms.
	2. Dose-Response Assays on Fractionated Samples	5.3.2.2	Establish dose-response of the fecal coliforms and the impact of particulates on dose requirements. Samples are fractionated to ranges of particle sizes.	Same 3 samples as used in Task B-2.	1. Conduct four-dose and two-control runs on each unfiltered sample. Total of 18 FC analyses. Doses should be approximately 10, 20, 40 and 80 mW-s/cm2 (depth-averaged). 2. Filter each sample serially through 50, 10 and 1 micron filters, and analyze filtrates for TSS, %T (T and F), and PSD. Total of 9 samples. 3. Conduct 4-dose and 2-control runs on each of the nine filtrates. Total of 54 FC analyses. Doses should be the same as in No. 1.

Table 5-1. Continued

TASK	SUBTASK	REF	DESCRIPTION	FREQUENCY	ANALYSES TO BE DONE
C. System Runs	1. Conduct Dose-Flow Runs	5.2.3.2	Establish the ability of the system to disinfect in a particle-bearing matrix. Sample influent and effluent at various flows.	A total of five runs shall be conducted, each run comprising four doses, sampled in triplicate.	1. Collect triplicate influent and effluent samples at each of four flow rates through the system, equivalent to 20, 30 50 and 80 mW-s/cm2 (from Test Element 1). 2. Analyze each influent for %T (T and F), TSS, and FC. Total of 12 samples with each run. Analyze each effluent sample for Fecal coliforms, these should be done only after they are "blended". Total of 12 FC. 3. Filter each of the 12 unblended effluent samples through 50, 10 and 1 micron filters (serially), then blend and analyze each filtrate (a total of 36) for Fecal coliform, %T and TSS.
	2. Conduct Dose Fractionation Analysis	5.2.3.2	Conduct filtrations on composite influents and dose response assays on the filtrates. This will demonstrate the dose decrement due to particulates	A composite of the influent from each of the five runs in Task C-1.	1. Composite the influent samples to a single sample and analyze it for Fecal Coliform, TSS, Transmittance, and Particle Size Distribution (PSD). 2. Filter the composite through 50, 10 and 1-micron filters, and measure each filtrate (3 samples) for TSS, Transmittance and PSD. 3. Conduct a 4-dose (10, 20, 40 and 80 mW-s/cm2) and 2-control assay on each of the three filtrates and on the unfiltered sample. Blend the exposed samples and analyze for FC. This yields a total of 24 samples.

5.2.2 Test Facility Equipment

The equipment layout required for this test is similar to that required for the dose assay protocol described in Section 3. The major items include batch tanks, pumps, piping, flow meters, generator (or fixed power source), and a discharge point back to the plant. A pump or pumps are required for drawing wastes from the WWTP, and possibly from the secondary effluent. Additionally, a clean water supply shall be available for rinsing and cleaning of equipment.

As discussed in the Technical Approach in Section 1, the feed to the UV system will likely require some degree of pretreatment for particulate removal or reduction. The type of pretreatment provided (e.g., screens, vortex separators, ballasted sedimentation, filtration, and gravity separation)shall be consistent with the vendors recommended operating instructions. The Test Plan shall clearly describe the pretreatment system and its layout. The evaluation of the processes used for pretreatment are not a part of the ETV. The Test Plan shall include detailed drawings and specifications for the test facility, showing how the pretreated water is generated, brought to the test units and discharged back to the WWTP.

5.3 TESTING REQUIREMENTS

The Test Plan shall describe the procedures for wastewater formulation and characterization, operating and sampling procedures, and data analysis.

5.3.1 Wastewater Formulation and Characterization

The testing shall be conducted on a batch basis, using pretreated wastewaters as the feed. The intent is to operate the UV system on real-time wastewaters from a wastewater treatment plant, while maintaining the ability to control and adjust the characteristics of the wastewater feed. The wastewater feed used in this test should be the same as used Test Element #2.

5.3.1.1 Primary Effluent

It is recommended that primary clarifier effluent, diluted, as needed, with secondary effluent, serve as the wastewater feed for this test. Using primary effluent as a surrogate for CSO- and SSO-type wastewaters is an accepted practice that has been used in past and current studies of technology applications to wet-weather flows (Reference 7,8). Its advantages lie with its similarity to a CSO-type wastewater that has undergone some degree of pretreatment to remove larger particles.

Locating the work at a WWTP that is at least generally influenced by wet weather inflows

(a combined collection system or a sanitary system with a relatively high I/I) is suggested. Alternatively, a dilution water source (e.g. treated final effluent, with the same "background" dissolved solids content) may be provided to adjust the wastewater to one that simulates the more dilute characteristics of a pretreated CSO. The level of dilution should be set to yield concentration levels within an established range.

5.3.1.3 Preliminary Data Requirements

The Test Plan shall show the ability to deliver a wastewater feed with the characteristics within the following ranges:

BOD:	50 to 100 mg/L
TSS:	30 to 60 mg/L
G/O:	5 to 15 mg/L
Iron	1 to 5 mg/L (dissolved greater than 0.5 mg/L)
Hardness	150 to 400 mg/L (as $CaCO_3$)
TDS	200 to 1000 mg/L

Dilution may be required to achieve these characteristics. These water quality characteristics are typical of primary clarifier effluent. If an wastewater feed other than primary clarifier effluent is proposed, alternate ranges may be proposed in the Test Plan. The Test Plan shall include a review of existing plant data that characterizes the primary effluent (or other proposed feed) and demonstrates its suitability for use in testing. In addition, the Test Plan shall include new analytical data from at least three samples collected on three different days for the following parameters:

- Hardness
- Alkalinity
- pH
- BOD (T and F)
- COD
- Ammonia
- Iron (T and F)
- Calcium (T and F)
- Fecal Coliform
- Total Coliform
- % Transmittance at 254nm (T and F)
- % Transmittance Scan (230 through 290 nm)(T and F)

- TSS
- Particle Size Distribution

T and F refer to unfiltered and filtered samples, respectively. Filtration, in this case, should be with a 0.7 u (absolute) filter. The transmittance scan is required when verifying UV systems that use polychromatic lamps. An electronic particle counter may be used to determine the Particle Size Other analyses shall be conducted using Standard Methods (20th Ed.) and USEPA approved analytical methods.

The following preliminary tests should be conducted to determine the suitability of the wastewater feed with respect to presence of particulates and the sensitivity of fecal coliforms contained in the feed:

- Conduct a screening dose-response assay for fecal coliforms on at least three primary effluent samples (the same samples collected for the chemical analyses). This should be at 5 dose levels ranging from 10 through 50 mW-sec/cm^2. This information is useful in establishing the sensitivity of the in-situ microbiology to UV and to understanding the impact of particulates. The assay will yield an estimate of the "tailing" effect, whereby there is a baseline residual coliform level that is reached, and no further reduction is possible because of occlusion in the particulates.

- Dose will be based on exposure at a selected surface intensity (at 254 nm), and corrected to the average intensity in the sample based on the measured transmittance in the sample at 254nm. The unfiltered, corrected transmittance shall be used to compute this. The transmittance of the sample should be first adjusted to a target level (e.g., 40 percent) by dilution (with final effluent) or by the addition of an absorber (e.g., coffee).

- Conventional analyses of transmittance in "dirty" waters, especially those that have significant turbidity, can sometimes be inaccurate and variable in accounting for scattering. Techniques proposed in the Test Plan for analysis of transmittance must be capable of differentiating scattering effects due to particulates in the wastewaters. A spectrophotometer used in sample analysis shall have an integrating sphere attachment for correction due to scattering in the transmittance analysis.

- This protocol assumes that the occlusion/shadowing effects of the particulates will

be relatively consistent for the site over the duration of testing a UV System. Particle Size Distribution (PSD) analyses should also be done on the same samples.

- The Test Plan shall describe the procedures to be followed for the blending or homogenization of the samples. This procedure is followed for primary wastewaters that have large particles, breaking them to smaller particles and improving recovery of coliform that may have occluded in the particles. Procedures have been established, and reside in the literature and with the EPA for setting the blending requirements (References 8, 9). All UV exposed samples that are collected must undergo this blending procedure before coliform enumeration.

- The dose-response collimated beam tests discussed earlier shall be conducted on the sample as is (unblended) and blended. The blending (or solids homogenization) procedure developed specifically for the site shall be used

5.3.2 Operating and Sampling Requirements

5.3.2.1 Pre-Test Sampling and Analysis

Prior to the start of testing, the required operating conditions shall be established (e.g. a medium pressure system with a maximum flow requirement of approximately 1800 gpm). To ensure the proper feed water characteristics are established prior to the start of testing, the wastewater feed (primary effluent) shall be sampled on three alternating days (e.g., Monday, Wednesday and Friday The sample shall be a composite of grab samples from selected clarifiers collected over a one hour period). At the time of sample collection, the flow through the primary clarifier being sampled shall be recorded. The overflow rate for each clarifier (or set of clarifiers) should be within the targeted operating range specified in the Test Plan.

The primary effluent samples shall be analyzed for the chemical parameters of concern (TSS, COD, PSD, pH, hardness, alkalinity, total and dissolved iron, G/O, percent transmittance, settleable solids, etc.) and microbiological targets (fecal and/or total coliform and others as may be warranted for the specific test).

5.3.2.2 Dose-Response Assays on Fractionated Samples

To establish the dose-response for the field assays and the effect of particulates, the three primary effluent samples shall also be subjected to a dose-response series for fecal (or total) coliforms. The dose-response assays shall be conducted in accordance with Section 3 of this Protocol on the total, unfiltered sample, and on the filtrates from filtrations through 50, 10 and 1

micron filters (alternative sequences can be proposed based on the level of pretreatment being provided to the sample). Suspended solids, transmittances and PSD analyses shall be conducted on the unfiltered sample and the filtrates. The dose response runs shall include at least four dose levels (e.g., 10, 30, 50 and 80 mW-s/cm^2, depth-averaged), and should be run in duplicate, and plated in triplicate. They should also be run at each transmittance in the case of multiple transmittance levels for the field tests. The dose-response assays would be run during the week prior to starting the field tests. The water quality data will serve as an immediate characterization of the wastewaters, and assure their acceptability for testing, particularly if the wastewaters required adjustment.

5.3.2.3 System Performance Testing

The tests shall be conducted on a batch basis. Testing shall be conducted at two selected transmittance levels: 15 and 40 percent at 253.7 nm. The operations shall be set for each test day and sampling shall then be conducted on the influent and effluent from the system. Testing shall focus on performance and the impact of particulates present in the wastewater.

5.3.2.3.1 Batch Preparation of Feed Wastewater. The Test Plan shall describe the procedures to be followed for the preparation of feed wastewater. Recommended batch preparation procedures are described below. Alternate procedures may be proposed in the Test Plan provided they conform to the general requirements established here.

1. Fill the batch tank with primary effluent. Mix the tank contents with a recirculation pump or a mixer. If necessary, dilute the wastes with secondary effluent to bring the wastes within the specified parameter ranges. The dilution should be estimated from known information, built upon previous characterization data developed at the plant.

2. Adjust the transmittance of the feed water in the tank to the target level by adding more dilution water (to raise the transmittance) or a UV absorber such as coffee (to lower transmittance).

3. Mix the tank to assure homogeneity of the wastewater before it is fed to the UV system.

5.3.2.3.2 UV System Operation and Sampling. The Test Plan shall establish procedures for conducting test runs to determine the effect of the UV System on coliform bacteria in the wastewater feed. A single test run shall involve collecting samples of the influent to and effluent from the UV system under a minimum of four different hydraulic loadings using flows

from a single batch of wastewater feed. A separate test run should be conducted each day.

At least five runs should be conducted at each of the specified wastewater feed transmittance levels (15% and 40%). The results generated during this testing phase should provide relationships of dose as a function of flow and transmittance in a primary effluent matrix. Data should also be generated with fecal coliform (or an alternate, indigenous microorganism), showing dose as a function of flow, and demonstrating the impact of particles on dose requirements to achieve a specific inactivation level. The dose delivery quantified on the basis of the dose-hydraulic loadings determined in Test Element 1 shall be compared to dose-response data generated on the fecal coliforms. Differences in applied UV radiation as may affect the level of particulate influence should be discernible from such data.

The hydraulic loadings selected for a single run shall include at least two that are relatively low, representing high dose levels. The intent is to assess the ability of the UV systems to accomplish fecal coliform reductions beyond that associated with non-aggregated microbes, focusing on aggregated and/or particle-associated coliforms. The impact on particles can be observed only at higher dose levels, wherein dispersed coliform have been inactivated and most residual coliforms are those occluded by particles. The dose levels should be selected on the basis of the preliminary dose-response information generated in accordance with Section 5.3.2.2.

The following are recommended procedures for conducting a single test run:

1. Prior to the start of a test run, manually clean the UV system's quartz sleeves in accordance with the vendor's instructions. Throughout the test run, the UV system's automatic cleaning device shall be operated at maximum capacity to achieve maximum transmittance through the quartz. If the system is not equipped with an automatic cleaning device, manually clean the quartz sleeves in accordance with the vendor's instructions after each change in hydraulic loading.

2. Once cleaned, run clean water through the UV System at a low flow to allow for the lamp intensity to stabilize. Monitor the system to confirm that the intensity, temperature, and power conditions are at the desired levels or within the range recommended the vendor.

3. Terminate the flow of clean water and initiate flow of the feed wastewater (from the batch prepared in accordance with 5.2.3.2.1) to the UV system and establish the desired flow rate. Continue wastewater flow for at least five volume changes in the UV unit to ensure steady state conditions have been achieved before initiating sampling. The minimum number of volume changes necessary to assure steady state conditions shall be determined in accordance with 3.1.4.1 of this Protocol.

4 Collect samples in triplicate from the influent and effluent of the UV System.

5 Adjust the flow of feed wastewater to the next desired flow rate and repeat steps 3 and 4. This shall be repeated for a minimum total of four hydraulic loadings.

5.3.2.3.3 Sample analysis. Each influent samples collected in accordance with 5.3.2.3.2 shall be analyzed for percent transmittance (T and F), TSS, PSD and fecal coliform. All exposed fecal coliform samples should be subjected to "blending" or homogenization before plating. The purpose is to disperse aggregated coliform and obtain a truer count of coliforms in the wastewater. The actual procedure shall be developed from preliminary testing and incorporated into the Test Plan.

Each effluent sample should be analyzed for fecal coliform. The effluent samples collected at each of the hydraulic loadings shall also be subjected to filtrations at 50, 10 and 1 micron. The filtrates shall be analyzed for fecal coliform.

A composite shall also be made from the influent samples, and analyzed for the same parameters (fecal coliform, TSS and Percent Transmittance and PSD). The single composite sample from each run shall then be used to conduct a collimated beam, dose-response assay for fractionated samples, including the unfiltered sample, and samples filtered at 50, 10 and 1 micron. The filtrates shall also be analyzed for transmittance, suspended solids and PSD. The dose-response assays shall be conducted at a minimum of four dose levels (e.g., 15, 30, 50 and 80 mW-s/cm^2, depth corrected). Hereto, pre-blending shall be part of the analytical procedure, and shall be defined in the Test Plan.

5.4 DATA COMPILATION AND ANALYSIS

The data and field observations generated as part of Test Element 3 shall be compiled in tabular and graphical form. The principal data components shall include:

- Wastewater characterization data demonstrating conformity with targeted parameter ranges.
- Dose-Response relationships developed for the in-situ fecal coliform shall be displayed as residual coliform and log survival ratio as a function of the delivered collimated beam dose.
- Dose-Response relationships for fecal coliform samples in the same wastewater, but filtered to progressively remove particulates above targeted particle sizes.
- Inactivation data from the full-scale test system should be correlated with the hydraulic loading.
- Dose requirements to achieve targeted log survival ratios should be determined as

function of the particulates extant in a sample.

The data should be analyzed to determine the UV system's dose delivery capabilities in the selected wastewater matrix, and the impact of particles and particle-removal on the dose requirement. The ability of the system to inactivate particle-associated coliform shall be quantified. A suggested approach is to compare the relationship of residual fecal coliform to the residual suspended solids at the high dose levels practiced in the testing.

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 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 wet-weather flows. This should specifically encompass the three Test Elements 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:

- Introduction
- Executive Summary
- Description and Identification of the System Tested
- Procedures and Materials Used in Testing
- Results and Discussion
- References
- Appendices, which may including 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 following discussions offer examples; the test plan should describe how the results of the verification tests would be presented in the Verification Report.

6.2.1 Dose-Delivery Verification

1. Dose-Response Calibration of MS2 Phage, presented as a graphical relationship of the log survival ratio for MS2 phage as a function of the collimated-beam, delivered dose estimate. This should be characterized by a non-linear function within targeted confidence limits and compared to previous calibrations in the same laboratory.

2. Dose-Flow Rate Calibration for the UV Test Unit, expressed graphically as the delivered dose as a function of the flow rate through the unit. This should be done for each water transmittance level (at 253.7 nm) tested. A regression analysis should be shown, with associated correlation coefficients and 95-percent confidence limits.

3. Dose-Hydraulic Loading Relationships for the UV Test Unit, expressed graphically as the delivered dose as a function of: Flow per Lamp (Lpm/Lamp); and, Flow per total input watt (Lpm/Watt). As in No. 2, these should include regression equations and correlation coefficients and should be done at each transmittance tested.

6.2.2 Cleaning Device Performance

1. Average Quartz Transparency with Operating Time. This should be expressed graphically as a chronological record of operating time, and should be developed separately for the units with and without a cleaning device. It should overlay the operating record with respect to manual cleanings. The record should extend for the entire operating time for each flow setting. If different flows are evaluated, separate graphics can be developed.

2. Dose-Delivery Impacts from Quartz Fouling. Tabulate the dose data generated from the MS2 Phage assays, comparing the results from the units with and without cleaning devices, and relative to an initially clean system.

3. Chronological Records of Water Quality Data. These should be for the entire term of the cleaning evaluation and should be done for percent transmittance, suspended solids, grease and oil, COD, iron and others that were incorporated into the test plan. These should be in both graphical and tabular form.

4. Tabular and/or Graphical Display of the Effectiveness of the Cleaning Device Relative to No Device. This can take different forms, depending on the type of device and the test plan. It should clearly exhibit any benefit of the device, and quantify this benefit to the extent possible. An example is the ratio of cleaning cycles for the unit without the device to the unit with the cleaning device.

6.2.3 Performance in a Particle-Bearing Wastewater Matrix

1. Chronological records (graphical and tabular) of the wastewater quality data. These should also display the bounds targeted for the study, and clearly indicate the conformity of the observed data with these targets.

2. Dose-Response Relationships for Fecal Coliform after Pretreatment. These are a compilation of the tests conducted on the influent to the test unit, and reflect whatever degree of pretreatment had been applied to the wastewater. These relationships should be presented graphically as the log survival ratio as a function of the delivered dose (collimated beam). Relevant PSD, TSS and Transmittance data should be reported on each of these.

3. Dose-Response Relationships for Fecal Coliform in Fractionated Samples. These should be the data generated from filtrates of progressive filtrations, with plots of log survival ratios as a function of dose. PSD, TSS and transmittance data should be reported on each of these, and they should be compared directly (possibly with additional graphical displays of the composite data) to the "unfiltered" test results.

4. Dose-Hydraulic Loading Relationships Based on Fecal Coliform and MS2 Phage. These should be presented for each transmittance level tested. The phage dose estimates are based on the results from Test Element 1.

5. Fecal Coliform – Suspended Solids Relationship. These relate the residual coliform achieved at very high doses to the particles present in the wastewater, quantified as suspended solids, and mean particle size and distribution. This presentation should include the fractionated effluent analyses to demonstrate the particle sizes impacted by UV.

7. QUALITY ASSURANCE AND QUALITY CONTROL

A Quality Assurance Project Plan (QAPP) shall be prepared as part of the Test P1lan for evaluating ultraviolet light (UV) disinfection technologies for wet weather flows. The generic format for such QAAPs is outlined in this section.

7.1 PROJECT DESCRIPTI0NS, 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 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 At a minimum, the QAPP shall include quantitative acceptance criteria for QA objectives associated with accuracy, precision, and detection limits for critical measurements (as applicable), for each matrix.

7.5.2 Any additional project-specific QA objectives shall be presented in the QAPP. This includes items such as comparability and representativeness.

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

7.5.4 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

(To be Completed)

9. REFERENCES

(To be Completed)