Ultraviolet (UV) Treatment Toolkit: Technical Resource for States using EPA's Ultraviolet Disinfection Guidance Manual to Evaluate UV Technology

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ACKNOWLEDGMENTS AND DISCLAIMER

This guidance document is a result of a multi-year collaboration among the United States Environmental Protection Agency (U.S. EPA) [Office of Water, Office of Ground Water and Drinking Water, Standards and Risk Management Division, Technical Support Center (OGWDW/SRMD/TSC) and Office of Research and Development, Center for Environmental Solutions and Emergency Response, Water Infrastructure Division (ORD/CESER/WID)] and the drinking water programs of the states of Ohio, Indiana, and Kentucky.

This work aligns with a memorandum of cooperation (MOC) signed in 2013 by the Ohio Environmental Protection Agency (Ohio EPA), the Indiana Department of Environmental Management (IDEM), the Kentucky Department for Environmental Protection Cabinet (KY DEP), and Confluence (the Water Technology Innovation Cluster of the Ohio River Valley Region, including Dayton, Cincinnati, Northern Kentucky, and Southeast Indiana). The purpose of the MOC is for the parties to collaborate on more consistent approaches to evaluate, and ultimately approve, newer technologies and thereby facilitate their adoption.

As an initial effort under the MOC, a workgroup was created to study ultraviolet (UV) treatment. The workgroup ultimately decided to create a set of information (a "toolkit") that would be useful to state decisionmakers. For purposes of this toolkit, the term "state" refers to states, territories, and tribes with primary enforcement responsibility (primacy) to administer the regulatory program for PWSs under the Safe Drinking Water Act (SDWA).

The workgroup chose its focus because it recognizes that UV treatment and reactor validation is complex and evolving. Therefore, states should benefit by sharing UV experience with one another and having contacts in neighboring states with whom to share questions and concerns. The participants in this project believe the materials in this document provide a foundation for useful collaboration among state drinking water professionals, water system operators, and UV equipment manufacturers.

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INTRODUCTION

Public water systems (PWSs) are increasingly adding ultraviolet (UV) treatment to their drinking water disinfection systems. As such, state approval officials are spending more time reviewing applications for installation of UV treatment systems and developing criteria for ongoing compliance monitoring.

However, many state officials do not have a depth of experience with UV treatment. Therefore, a considerable amount of on-the-job training and continuing education can be required for state officials to effectively judge the technology and allow water systems to use UV treatment. Understandably, states are very mindful of their responsibility to ensure the protection of public health when they consider PWS requests for technology changes.

The Ohio Environmental Protection Agency (Ohio EPA), the Indiana Department of Environmental Management (IDEM), and the Kentucky Department for Environmental Protection Cabinet (KY DEP) welcome the opportunity for newer technologies and recognize that those technologies may benefit consumers of public drinking water. In 2013 they partnered with Confluence, the water technology innovation cluster of the Ohio River Valley region, to collaborate on more consistent approaches to evaluate, and ultimately approve, newer technologies and thereby facilitate their adoption. Under this partnership, interested parties in the Confluence region began to generate ideas for developing more proficiency with UV water treatment technologies.

In 2015, state drinking water officials from OEPA, IDEM, and KYEPC (hereafter, "State UV Workgroup") met with EPA and began a series of workshops on UV treatment to work toward the following goals:

1) Draw from the collective experience of the State UV Workgroup to identify a set of technical priorities and protocols for more consistent review and approval approaches for UV equipment installation and ongoing compliance monitoring among the three states.
2) Develop a set of documents to share these protocols with stakeholders so that water systems, design engineers, and equipment manufacturers have a clearer understanding of the expectations for UV treatment in the Confluence region.
3) Develop checklists and reporting templates for use by other state drinking water programs and stakeholders that may benefit from this information.

These goals have been realized in the attached set of documents, *UV Treatment Toolkit* (hereafter, "UV Toolkit"). This document outlines a protocol for plan review that addresses UV design, validation, operations, and factors for awarding disinfection credit. In addition, the UV Toolkit includes templates that may benefit state officials responsible for review of treatment plans and monthly reports.

The UV Toolkit is not intended to be a complete course in UV drinking water treatment and does not need to be read from start to finish to be helpful. Rather, the State UV workgroup considers it a reference of information and considerations relevant to review of UV treatment plans. As needed, readers can consult the Table of Contents to identify the section they wish to review.

Validation of UV disinfection equipment is a challenging and resource-intensive process. The conditions for treatment created inside each reactor are unique. Therefore, every reactor model should be evaluated independently. To define an acceptable envelope of operation, data should be collected during full-scale operation, under a variety of experimental conditions, while maintaining tight control

on all important variables. Ultimately, the performance of the equipment is determined by the evaluation of a large set of empirical data.

Research on UV disinfection for drinking water is ongoing, and EPA expects significant evolution in UV equipment and methods of operation, design, and validation. No one source of information can address all concerns that may be raised during UV evaluation, but OEPA, IDEM, and KYEPC regard the Ultraviolet Disinfection Guidance Manual (UVDGM) for the Final Long Term 2 Enhanced Surface Water Treatment Rule, published by USEPA (2006) as the single most important source of guidance. Readers will find many references to the UVDGM in the UV Toolkit.

Lastly, the State UV Workgroup would like to make clear that *UV Treatment Toolkit* does not bind any state agency in exercising its authority to establish or enforce water treatment requirements in its state. Rather, this initiative is intended to document OEPA's, IDEM's, and KYEPC's common understanding of the best practices for UV treatment design and operation, which is based on the guidance provided in the UVDGM. The workgroup has sought to identify priority requirements and recommendations for UV treatment that are common to all three states so that interested parties can have a clearer understanding of expectations in the three states. The materials in the UV Toolkit are provided in the hope that other states and stakeholders may benefit from and improve upon them.

SUMMARY OF FEDERAL REQUIREMENTS

Microbial Treatment Requirements

Federal disinfection requirements depend on the characteristics of the public water system (PWS), and have been refined in a series of rules published by EPA, including the Surface Water Treatment Rule (SWTR), the Interim Enhanced Surface Water Treatment Rule (IESWTR), the Long-Term 1 & 2 Enhanced Surface Water Treatment Rule (LT1ESWTR & LT2ESWTR), and the Ground Water Rule (GWR). The surface water rules apply to PWSs using surface water sources or ground water sources under the direct influence of surface water (GWUDI), while the GWR applies only to those PWSs that use ground water sources. All are focused on reducing illnesses caused by pathogens in drinking water. A summary of the minimum treatment requirements for these rules is below, excerpted from the Ultraviolet Disinfection Guidance Manual (UVDGM) published by USEPA (2006), with slight modification to include requirements of the GWR.

Table 1. Microbial Treatment Required by U.S. EPA Drinking Water Treatment Rules[1]

Regulation	***Giardia***	**Virus**	***Cryptosporidium***
GWR	--	4-log removal and/or inactivation[2]	--
SWTR	3-log removal and/or inactivation	4-log removal and/or inactivation	--
IESWTR and LT1ESWTR	No change from SWTR	No change from SWTR	2-log removal
LT2ESWTR	No change from SWTR	No change from SWTR	0- to 2.5-log additional treatment for filtered systems[3] 2- or 3-log inactivation for unfiltered systems[3]

[1] The term "log" means the order of magnitude reduction in concentration; e.g., 2-log removal equals a 99% reduction, 3-log removal equals a 99.9% reduction, and 4-log removal equals a 99.99% reduction.

[2] Applies to ground water PWSs that choose to provide treatment in lieu of triggered source water monitoring or as a corrective action under the GWR.

[3] Specific requirements for each plant depend on source water monitoring results and current treatment practices (40 CFR 141.710 – 141.712).

Table 2. Additional *Cryptosporidium* Treatment Requirements for Filtered PWSs[1,2]

***Cryptosporidium* Concentration (oocysts/L)**	**Bin Classification**	**Conventional Filtration Treatment (includes softening)**	**Direct Filtration**	**Slow Sand or Diatomaceous Earth Filtration**	**Alternative Filtration Technologies**
< 0.075	**1**	No additional treatment	No additional treatment	No additional treatment	No additional treatment
≥ 0.075 and < 1.0	**2**	1 log treatment[3]	1.5 log treatment[3]	1 log treatment[3]	As determined by the state[3,5]
≥ 1.0 and < 3.0	**3**	2 log treatment[4]	2.5 log treatment[4]	2 log treatment[4]	As determined by the state[4,6]
≥ 3.0	**4**	2.5 log treatment[4]	3 log treatment[4]	2.5 log treatment[4]	As determined by the state[4,7]

[1] 40 CFR 141.711

[2] Additional treatment requirements reflect a *Cryptosporidium* removal credit of 3 log for a conventional, slow sand, or diatomaceous earth filtration, and a 2.5-log credit for direct filtration plants.

[3] PWSs may use any technology or combination of technologies from the microbial toolbox.

[4] PWSs must achieve at least 1 log of the required treatment using ozone, chlorine dioxide, UV light, membranes, bag/cartridge filters, or bank filtration.

[5] Total *Cryptosporidium* treatment must be at least 4.0 log.

[6] Total *Cryptosporidium* treatment must be at least 5.0 log.

[7] Total *Cryptosporidium* treatment must be at least 5.5 log.

Table 3. Additional *Cryptosporidium* Treatment Requirements for Unfiltered PWSs

Average *Cryptosporidium* Concentration (oocysts/L)	**Additional *Cryptosporidium* Inactivation Requirements**
≤ 0.01	2 log[1]
> 0.01	3 log[1]

[1] Overall disinfection requirements must be met with a minimum of two disinfectants [40 CFR 141.712(d)].

UV Treatment Requirements

UV treatment can be used by surface water or ground water sources to meet the requirements outlined in Tables 1 - 3. The GWR "allows States to approve and set compliance monitoring and performance parameters for any alternative treatment, including UV light or UV light in combination with another treatment technology, that will ensure that systems continuously meet the 4-log virus treatment requirements" (71 FR 65604). In the GWR, U.S. EPA recognized "there is currently limited information available for States to make determinations regarding performance requirements for UV reactors to ensure that adequate virus inactivation is being achieved," but stated, "EPA believes that testing of full-scale UV reactors is necessary to ensure disinfection performance and a consistent level of public health protection" (71 FR 65605).

The LT2ESWTR was finalized in the same year as the GWR and included UV treatment in the "microbial toolbox" of acceptable techniques for drinking water disinfection (40 CFR 141.711). The LT2ESWTR also established more specific dose and validation testing requirements. Table 4 lists requirements for UV dose with reference to a wavelength of 254 nm as produced by a low-pressure mercury vapor lamp. The values in Table 4 are applicable only to post-filter applications of UV in filtered systems and to unfiltered systems.

Table 4. UV Dose Requirements for Inactivation Credit[1]

Log Credit	*Cryptosporidium* UV Dose (mJ/cm^2)	*Giardia lamblia* UV Dose (mJ/cm^2)	Virus UV Dose (mJ/cm^2)
0.5	1.6	1.5	39
1.0	2.5	2.1	58
1.5	3.9	3.0	79
2.0	5.8	5.2	100
2.5	8.5	7.7	121
3.0	12	11	143
3.5	15	15	163
4.0	22	22	186

[1] 40 CFR 141.720(d)(1)

UV Validation Requirements, 40 CFR 141.720(d)(2)

The LT2ESWTR requires PWSs to use UV reactors that have undergone validation testing to determine the operating conditions under which the reactor delivers the desired dose. The rule states the following:

- Determination of operating conditions must include flow rate, UV intensity as measured by a UV sensor, and UV lamp status.
- Validated operating conditions must account for UV absorbance of the water, lamp fouling and aging, measurement uncertainty of online sensors, UV dose distributions arising from the velocity profiles through the reactor, failure of UV lamps or other critical system components, and inlet and outlet piping or channel configurations of the UV reactor.
- Validation testing must involve full-scale testing of a reactor that conforms uniformly to the UV reactors used by the PWS, and it also must demonstrate inactivation of a test microorganism whose dose-response characteristics have been quantified with a low-pressure mercury vapor lamp.
- The state or primacy agency may approve an alternative approach to validation testing.

UV Monitoring Requirements, 40 CFR 141.720(d)(3)

The LT2ESWTR requires PWSs to monitor their UV reactors to demonstrate that they are operating within the range of conditions that were validated for the required UV dose. Monitoring must include the following:

- PWSs must monitor each reactor for flow rate, lamp status, UV intensity as measured by a UV sensor, and any other parameters required by the state or primacy agency.
- UV absorbance should also be measured when it is used in a dose-monitoring strategy.
- PWSs must verify the calibration of UV sensors and recalibrate sensors in accordance with a protocol the state or primacy agency approves.

- To receive disinfection credit for UV, PWSs must treat at least 95 percent of the water delivered to the public during each month by UV reactors operating within validated conditions for the required UV dose.

UV Reporting Requirements, 40 CFR 141.721(f)(15)

The LT2ESWTR requires PWSs to report the following:

- Validation test results demonstrating operating conditions that achieve the required UV dose.
- Monthly reports summarizing the percentage of water entering the distribution system that was not treated by UV reactors operating within validated conditions for the required dose.

UV Design Review

States generally require each public water system (PWS) that wishes to install UV treatment to submit detailed design plans to their review officials prior to installation. Due to time constraints, PWSs may seek design approval first (i.e., independent of requesting disinfection credit) so the units can be ordered and installed. Later, the PWS can pursue disinfection credit through a separate request. The State UV Workgroup provides the following considerations for plan reviewers to reference as they evaluate the detailed design plan.

UV Facility Planning

☐ UV reactors can generally be characterized based on lamp type, either low-pressure high-output (LPHO) or medium-pressure (MP). Typically, LPHO reactors have a larger footprint than MP reactors because more UV lamps are needed to deliver the same required UV dose. While LPHO reactors usually have more lamps, they require less overall power input than similarly sized MP reactors because LPHO lamps are more efficient in converting power to germicidal UV light for disinfection. The design plan should include complete specifications for the proposed UV equipment, including:

- Type of UV reactor and lamp (i.e., LPHO or MP)
- Manufacturer and model number
- Diameter of each reactor
- Number of reactors proposed
- Number of lamps per reactor
- Ballast type (e.g., electromagnetic)
- Documented compliance with NSF/ANSI 61

☐ The UV dose requirements table (Table 4) published in 40 CFR 141.720(d)(1) applies only to post-filter UV disinfection in filtration plants and to unfiltered systems that meet filtration avoidance criteria. The most important water quality characteristic affecting UV facility design is ultraviolet transmittance (UVT). To maximize UVT, upstream treatment processes should be optimized to remove soluble and particulate material, as well as organics.

☐ The LT2ESWTR requires validation of UV reactors to demonstrate that they achieve the required UV dose [40 CFR 141.720(d)(2)]. Validation testing establishes the conditions under which the UV reactors must be operated to ensure the required UV dose delivery. To receive log inactivation credit, the LT2ESWTR requires that at least 95 percent of the water delivered to the public during each month is treated by UV reactors operating within validated limits [40 CFR 141.720(d)(3)]. In other words, the UV reactors cannot be operated outside of their validated limits for more than 5 percent of the volume of water that is treated each month.

☐ As specified in 40 CFR 141.720(d)(3), the design flow rate of the UV reactor(s) must fall within the flow rate envelope validated for the reactor and should be based on the rated capacity of the treatment facility or the design rate of closely linked unit processes, such as filtration. The UV facility should be designed to accommodate the average, maximum, and minimum expected flow rates through operations strategies such as varying the number of reactors in service, varying the number of lamps in operation, and varying lamp power.

☐ It is important to consider the level of redundancy desired for the UV reactors. A common practice is to install enough capacity to achieve treatment at the design flow rate with the largest UV reactor out of service.

☐ The following practical considerations may reduce the level of effort associated with routine maintenance or intermittent sampling to evaluate treatment performance.

- Assure there is adequate distance between adjacent reactors to afford access for maintenance tasks (e.g., lamp replacement).
- Each UV reactor should be capable of being isolated and locked out for maintenance, both hydraulically and electrically.
- Drain valves or plugs should be located on each reactor lateral, between the two isolation valves. This may not be necessary if the UV manufacturer incorporated a drain into the UV reactor design.
- Sample taps should be installed both upstream and downstream of each UV reactor.

☐ In most situations, some level of chemical disinfection will be used along with UV. As specified in 40 CFR 141.72, surface water systems must maintain a disinfectant residual in the distribution system. Also, chemical disinfectants may be needed to oxidize other constituents present in the water (e.g., iron, manganese, or taste- and odor-causing compounds) or to reduce algal growth in sedimentation basins. The UV doses required to inactivate viruses are higher than those needed to inactivate *Cryptosporidium* and *Giardia*, while chlorine can inactivate most viruses readily. Accordingly, systems may find it cost effective to meet *Cryptosporidium* and *Giardia* inactivation targets with UV, while relying on chemical disinfection for virus inactivation. If using chlorine, the addition point should be downstream of the UV facility to minimize the possibility of chlorine residual reduction. UV disinfection of water having a chlorine residual may also result in sleeve fouling if iron and manganese are present. To reduce this potential for fouling, iron and manganese can be oxidized and removed by adding potassium permanganate upstream of the sedimentation basin.

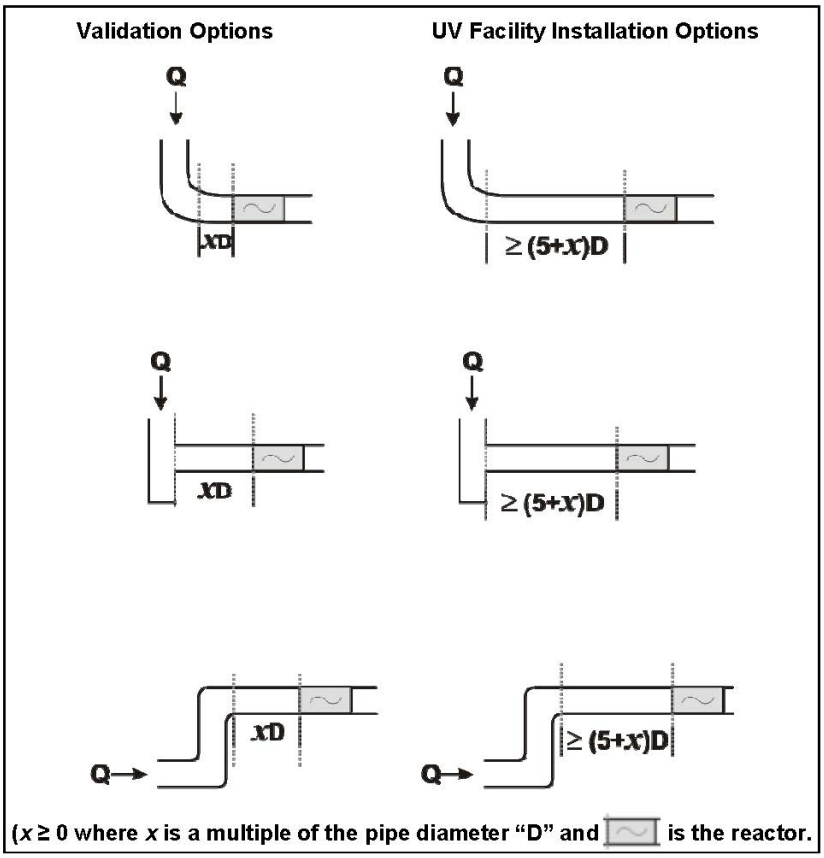
Hydraulics

☐ A hydraulic assessment should be completed (e.g., by calculating the hydraulic grade line) to determine if head loss through the UV facility is manageable or if booster pumping is needed. This analysis should include calculation of maximum and minimum (positive or negative) pressures that could result from a failure event (e.g., downstream valve closing). These pressures should be compared to the strength of the lamp sleeves and UV reactor housing. If the expected range of operating pressures is wide, the UV manufacturer should be consulted to devise an adequate system for pressure control.

☐ PWSs commonly use off-site validation testing to meet the LT2ESWTR requirements. In this case, reviewers should confirm that the inlet and outlet piping to the UV reactor in the UV facility will result in a UV dose delivery that is equal to or greater than the UV dose delivered when the UV reactor was validated. This condition can be met by following ONE of three approaches.

1. **Minimum five (5) pipe diameters of straight pipe upstream of UV reactor:** The length of straight pipe upstream of each UV reactor at the UV facility is the length of straight pipe used in the validation testing plus a minimum of five (5) pipe diameters. To avoid jetting flow, the inlet piping should have no expansions for at least ten (10) pipe diameters upstream of the reactor. During validation testing, the inlet piping to the reactor consists of either a single 90- degree bend, a "T" bend, or an "S" bend, followed by a length of straight pipe if necessary.

Figure 1. Schematic of Hydraulic Option #1



Source: UVDGM (USEPA, 2006)

2. **Identical inlet and outlet conditions:** Inlet and outlet conditions used during validation match those used at the WTP for at least ten (10) pipe diameters upstream and five (5) pipe diameters downstream of the UV reactor.

3. **Velocity profile measurement:** Velocity of the water measured at evenly spaced points through a given cross-section of the flow upstream and downstream of the reactor is within 20 percent of the theoretical velocity in both the validation test stand and the WTP installation. The theoretical velocity is defined as the flow rate divided by the cross-sectional area. To avoid jetting flow, the inlet piping should have no expansions for at least ten (10) pipe diameters upstream of the reactor. Also, any valves located in that length of straight pipe should always be fully open during UV reactor operation. To avoid swirling flow, the validation piping should not include two out-of-plane 90° bends in series.

☐ As specified in 40 CFR 141.720(d)(3), during operation, flow through each UV reactor must conform to the validated operating conditions. Generally, each UV reactor should have a dedicated flowmeter to confirm that the reactor is operating within the validated flow rate. Active flow control and distribution, in which a dedicated flow meter and modulating control valve are installed for each UV reactor, provides the greatest hydraulic control in applications with widely varying flow rates. The second method is passive flow distribution, in which equal flow split (using weirs or orifices) is monitored with flow meters. The state may also approve other methods (e.g., one flow meter coupled with pressure differential measurements).

☐ The UV lamps in the UV reactor should be submerged at all times to prevent overheating and UV equipment damage. This is accomplished by installing the UV reactors at an elevation below the hydraulic grade line elevation. Two common methods for keeping the UV lamps submerged are:

1. Install a flow control structure (e.g., weir or orifice) immediately downstream of the UV reactor or at another location that ensures full pipe conditions through the UV reactors.
2. Use flow control valves to monitor and maintain the hydraulic grade line.

Air release valves, air/vacuum valves, or combination air valves may be necessary to prevent air pockets and negative gauge pressure conditions.

☐ Each UV reactor should be capable of being isolated and removed from service. Isolating or shutting down a UV reactor will require valves, gates, or similar devices upstream and downstream of the UV reactor. Valves are preferred because they provide a tighter seal. If the isolation valves are also used for flow control, the flow control valve should be located downstream of the UV reactor to limit the disturbance of the flow entering the UV reactor.

Design Parameters

☐ It is important to correctly characterize the water quality and desired production at the treatment plant because they define the conditions under which the UV reactors must be validated and then operated [40 CFR 141.720(d)(2)]. The most important water quality characteristic affecting UV facility design is UVT, because the UVT of the water directly influences UV dose delivery. As specified in 40 CFR 141.720(d)(2), during operations, the UV intensity, as measured by UV sensors, must meet or exceed the setpoint(s) to ensure delivery of the validated dose. Quantifying both a design UVT and the full range of UVT expected during operation is essential. For LPHO reactors, the key parameter is UVT at 254 nanometers (nm). If MP lamps are being considered, it is also desirable to measure the UVT at the wavelengths in the germicidal range (UV transmittance scan from 200 – 300 nm).

☐ If UVT data are not already available, weekly UVT measurement is suggested, but the duration of the sampling period depends on the source water quality. For example, a PWS with very stable UVT measurements may need only one or two months of data. A PWS that experiences seasonal changes, however, would need more frequent data collection during seasonal events and over a longer period of time (6 to 12 months or more). The duration and frequency of UVT measurement should capture the range of expected source water quality.

☐ Design data should be collected at a point in the treatment process where UV will be installed. The data collection should capture typical water quality and any water quality variation due to storm events, reservoir turnover, seasonal changes, source water blends, and variations in upstream treatment.

☐ Fouling is typically caused by precipitation of compounds on the lamp sleeve and the UV sensor window (if applicable). To determine the potential for fouling, the water quality parameters listed below should be monitored before the UV facility is designed, unless adequate water quality data are available.

- Calcium
- Alkalinity
- Hardness
- Iron
- Manganese
- pH
- ORP

☐ If the ORP, pH, and inorganic constituent concentrations are low, fouling is not likely to be an issue, and a cleaning system may not be necessary. However, a cleaning system should be considered if iron and manganese are present. Pilot tests of waters with total hardness levels less than 140 mg/L and iron less than 0.1 mg/L found that standard cleaning protocols and wiper frequencies (one sweep every 15 – 60 minutes) addressed the effect of sleeve fouling at the sites tested (For more information, see Section 3.4.4.2 of the UVDGM.

☐ Sleeve fouling, sleeve aging, lamp aging, and UV sensor window fouling (if applicable) affect long-term UV reactor performance. The fouling/aging factor accounts for these issues. The fouling/aging factor is calculated by multiplying the fouling factor by the aging factor and typically ranges from 0.4 to 0.9. The fouling/aging factor is typically used in validation testing to ensure the UV equipment can meet the required dose in a fouled and/or aged condition. When purchasing a pre-validated reactor, the PWS should determine if validation testing was conducted under conditions of reduced lamp output (e.g., 70 percent) that is equal to or less than reduced lamp output expected for fouled/aged conditions at its water treatment plant (e.g., 0.75, or 75 percent).

Operations Approach

☐ The PWS should select and identify a strategy for operating the proposed UV facility. The dose-monitoring strategy establishes the operating parameters used to confirm UV dose delivery. It affects how a reactor is validated, how instrumentation and controls are designed, and how the reactor is operated. UV manufacturers commonly design their reactors to operate using either the UV Intensity Setpoint Approach or the Calculated Dose Approach.

The UV Intensity Setpoint Approach relies upon one or more “setpoints” for UV intensity that are established during validation testing. As specified in 40 CFR 141.720(d)(2), during operations, the UV intensity, as measured by UV sensors, must meet or exceed the setpoint(s) to ensure delivery of the validated dose. Also, 40 CFR 141.720(d)(3) states the reactor must be operated within the validated range of flow rates and lamp statuses (i.e., the “validated operating conditions”). One key characteristic of the UV Intensity Setpoint Approach is that water systems need not monitor UVT during operations to confirm dose delivery. Instead, the approach relies on UV intensity readings by UV sensors to account for changes in UVT.

The Calculated Dose Approach uses a dose-monitoring equation to estimate the UV dose based the parameters measured during reactor operations. The most common operational parameters in dose-monitoring equation are flow rate, UV intensity, and UVT. UV manufacturers may develop a theoretical dose-monitoring equation using numerical models (e.g., computational fluid dynamics [CFD]). Although the theoretical equations can be used as a starting point, Section 3.5.2.2 of the UVDGM strongly recommends that water systems use an empirical dose-monitoring equation developed through validation testing. To generate the empirical dose-monitoring equation, validation tests are performed over a wide range of flow rates, UVT values, and lamp power combinations. Regression analysis is used to fit the observed validation data to an equation.

The principal operating advantage of the UV Intensity Setpoint Approach compared to the Calculated Dose Approach is that UVT monitoring is not needed to confirm dose delivery. Operation is relatively straightforward and simple to control with as few as one operational setpoint and one maximum value for flow rate. In addition, the UV Intensity Setpoint requires fewer validation tests than the Calculated Dose Approach and data analyses are relatively straightforward.

Water systems may favor the Calculated Dose Approach over the UV Intensity Setpoint Approach because it offers significant flexibility to reduce operating costs by manipulating lamp power (e.g., turning off banks of lamps or powering down lamps when the UVT increases and/or the flow rate decreases). This process is also called “dose pacing.” Another potential advantage is that operations are more intuitive because the calculated dose, adjusted for uncertainties and biases, can be directly compared to the EPA-required dose for the target pathogen and log inactivation.

Instrumentation and Controls

☐ UV equipment operation can range from manual to fully automatic, depending on the reactor’s size and complexity. For all operating approaches, the UV reactor should be configured to shut-down under critical alarm conditions. Examples of critical alarms include:

- Lamp/Ballast Failure: multiple simultaneous lamp/ballast failures identified
- Low Liquid Level: liquid level within the UV reactor drops
- High Temperature: Temperature within the UV reactor or ballast exceeds a safe setpoint

☐ The following alarms should also be installed (as applicable) to assist in safe and effective operation of the reactors.

- Lamp Age: Run-time for lamp indicates end of defined operational lamp life
- Calibration Check of UV Sensor: UV sensor requires calibration check based on operating time
- Low UV Validated Dose: validated UV dose (based on UV reactor parameters, i.e., flow rate, UV intensity, and UVT) falls below required UV dose
- Low UV Intensity: Intensity falls below validated conditions
- Low UV Transmittance: UVT falls below validated conditions
- High Flow Rate: Flow rate falls outside of validated range
- Mechanical Wiper Function Failure: Wiper function fails
- Lamp/Ballast Failure: Single lamp/ballast failure identified

☐ At a minimum, the following signals and indications (as applicable) should be specified.
- UV reactor status
- UV lamp status
- UV intensity
- Lamp cleaning cycle and history
- Accumulated run time for individual lamps or banks of lamps
- Influent flow rate

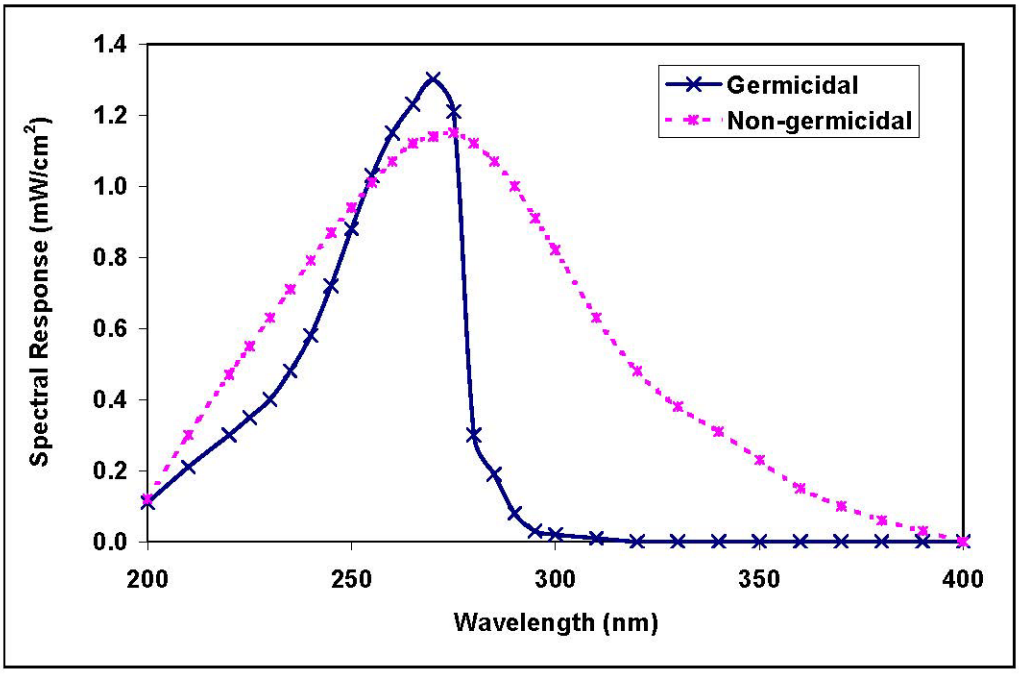
☐ At a minimum, the following UV reactor controls (as applicable) should be specified.
- UV reactor on/off control
- UV dose setpoints, UV intensity setpoints, or UVT setpoints
- UV lamps on/off
- UV reactor manual/auto control
- UV reactor local/remote control
- Manual lamp power level control
- Manual lamp cleaning cycle control
- Automatic lamp cleaning cycle setpoint control

☐ One or more reactor bypass lines may be installed at the UV facility to enable maintenance or to overcome any impediments to emergency use. The PWS should install safeguards to prevent the introduction of inadequately treated water through the bypass line, such as a lockout system.

☐ The design proposal should specify the cleaning system that will be provided, whether manual or automatic, including the time intervals expected and the criteria that will be used to determine initiation of cleaning.

☐ The design proposal should document the spectral response of the UV sensors. Section 5.4.8 of the UVDGM recommends *germicidal* sensors for facilities installing new UV drinking water treatment systems. In some cases, MP lamps with non-germicidal sensors have been installed at water treatment plants. These water systems should apply a correction factor to validation test data to account for polychromatic bias (see Appendix D.4 in the UVDGM). However, it is recommended that facilities installing new UV treatment systems use reactors that are equipped with germicidal sensors. Germicidal sensors are defined as having the following properties:
- A spectral response (i.e., UV intensity measured at various wavelengths) that peaks between 250 and 280 nm.
- Less than 10 percent of its total measurement is due to light above 300 nm when mounted on the UV reactor and viewing the UV lamps through the water that will be treated.

Figure 2. Hypothetical Examples of the Spectral Response of a Germicidal and a Non-Germicidal UV Sensor



Source: UVDGM (USEPA, 2006)

☐ The UV facility should be integrated into the Supervisory Control and Data Acquisition (SCADA) system to control operation and monitor and record the process parameters. The SCADA system should be configured to enable the operator to easily obtain the information needed for monthly operating reports and operations logs, in the event the PWS would like to obtain UV inactivation credit.

Power Supply

☐ UV lamps can turn off if a voltage fluctuation, power quality anomaly, or a power interruption occurs. Power quality tolerances depend on the UV equipment design and vary significantly among UV manufacturers. The UV manufacturer should be contacted to determine the power quality tolerance and the length of time for the equipment to reach full power after a power quality event. In most cases, power quality problems alone will not cause UV reactors to deviate from the requirements (at least 95% of the water delivered each month is treated by UV reactors operating within the validated conditions for the required UV dose [40 CFR 141.720(d)(3)]). Therefore, a power quality assessment is probably necessary only when the installation site is known to have power quality problems (e.g., 30 power interruptions and/or brownouts per month) or is in a remote area and the power quality is unknown.

☐ If the power reliability requirements and, consequently, the disinfection objectives cannot be met by relying solely on the commercial power supply, it may be necessary to use back-up power, power conditioning equipment, or both. A simple backup power supply (e.g., generator) may be sufficient if power quality issues are infrequent. If an existing backup power supply is in place, its load capacity should be assessed to determine whether it can accept the additional load associated with the UV facility.

- ☐ Selection of the UV reactors should be based on a thorough analysis of the potential for the equipment to induce harmonic distortion. Such disturbances can cause electrical system problems, including overheating of some power supply components and can affect other critical systems, such as variable frequency drives (VFDs), programmable logic controllers (PLCs), and computers. The UV facility design and UV equipment should meet the Institute of Electrical and Electronic Engineers (IEEE) 519 Standard that addresses harmonics.

OVERVIEW OF UVDGM VALIDATION PROTOCOL

The purpose of validation testing is to determine the operating conditions under which a UV reactor delivers the **Validated Dose**. The **Validated Dose** must be greater than or equal to the **Required Dose** to receive log inactivation credit for a target pathogen [40 CFR 141.720(d)]. EPA established the **Required Dose** values, for a variety of target pathogens and inactivation levels, in the Long-Term 2 Enhanced Surface Water Treatment Rule [40 CFR 141.720(d)(1)]. Validation testing also establishes the operational setpoints used during reactor operations to confirm delivery of the **Validated Dose**.

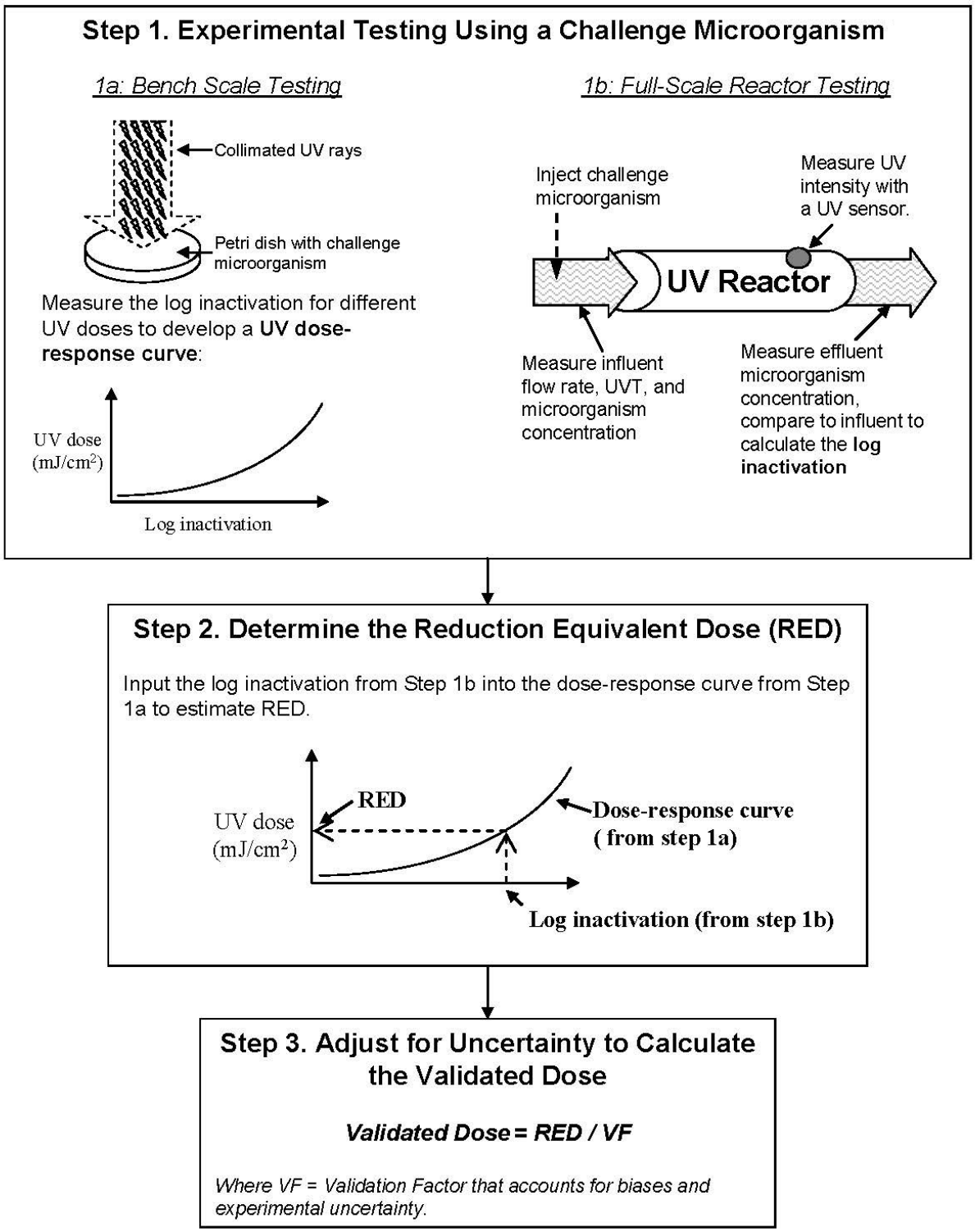
Unlike chemical disinfection, UV light leaves no residual that can be monitored to determine the delivered dose. UV sensors can measure intensity of UV light, but they cannot measure the dose delivered to the microorganisms as they pass through the reactor at different trajectories. Therefore, to receive UV treatment credit for inactivating *Cryptosporidium*, *Giardia*, or viruses, a water system must use UV reactors that have undergone validation testing [40 CFR 141.720(d)(2)]. Section 5.2.3 of the UVDGM recommends that an independent third party provide oversight to ensure that validation testing and data analyses are conducted in a technically sound manner and without bias.

Outline of Validation Protocol

The validation protocol recommended in Chapter 5 of the UVDGM uses *biodosimetry*. Under this approach, the log inactivation of a challenge microorganism is measured during full-scale reactor testing for specific operating conditions of flow rate, UV transmittance (UVT), and UV intensity. The dose-response equation for the challenge microorganism (relating UV dose to log inactivation) is determined using independent, bench-scale testing. Log inactivation values from full-scale testing are input into the laboratory-derived UV dose-response relationship to estimate the **Reduction Equivalent Dose (RED)**. The **RED** value is adjusted for uncertainties and biases to produce the **Validated Dose** of the reactor for the specific operating conditions tested. The **Validated Dose** is compared to the **Required Dose** for compliance purposes.

The key steps of the validation protocol are shown in the diagram below and are described thereafter.

Figure 3. Validation Steps



Source: UVDGM (USEPA, 2006)

Step 1: Conduct Experimental Tests Using a Challenge Microorganism

Because handling of the target pathogen during validation testing is neither practical nor in the best interest of public health, Section 5.2.1 of the UVDGM recommends that a challenge microorganism whose sensitivity to UV light is similar to the target pathogen be used in all experiments. Using a challenge microorganism instead of the target pathogen, however, introduces uncertainty into the testing results. This uncertainty is accounted for by applying a **Validation Factor**.

1a. Bench-scale testing using a collimated beam apparatus

To account for possible dose-response variability that can be influenced by numerous variables, Section 5.7.3 of the UVDGM recommends that at least one collimated beam test be conducted for each day of full-scale reactor testing. In these experiments, UV light is directed down a collimating tube to dose a sample of challenge microorganisms of a known concentration. After a specified exposure time, the sample is analyzed to determine the log inactivation (where log inactivation in this situation equals the log concentration prior to UV light exposure minus the log concentration after UV light exposure) as a function of UV dose. The UV dose delivered to the microorganisms is calculated based on the UV intensity, exposure time, and other experimental factors.

Collimated beam tests are performed at a range of doses to generate a UV dose-response curve for the specific challenge microorganism. The functional forms of the equations for UV dose-response curves can vary depending on the results but are often quadratic.

1b. Full-scale reactor testing

In these experiments, the challenge microorganisms are injected upstream of the UV reactor. Samples are analyzed to determine the log inactivation (where log inactivation in this situation equals log influent concentration minus log effluent concentration) for test conditions of flow rate, UVT, lamp status, and UV intensity as measured by UV sensors.

Step 2: Estimate the Reduction Equivalent Dose (RED)

In this step, the results from the previous steps are combined. The log inactivation of the challenge microorganism measured during the full-scale testing is entered into the UV dose-response equation to calculate the **RED** of the reactor. **RED** values are always specific to the following:

- The challenge microorganism used during experimental testing.
- The validation test conditions during full-scale reactor tests (flow rate, UVT, lamp status, and UV intensity as measured by the UV sensor).

Step 3: Calculate the Validated Dose

In this step, the **RED** is divided by a **Validation Factor** to produce the **Validated Dose**. The **Validation Factor** accounts for biases associated with using a challenge microorganism instead of the target pathogen, and for experimental uncertainty. The **Validated Dose** is associated with the validation test conditions of flow rate, lamp status, UV intensity as measured by a UV sensor, and in some cases, UVT. As noted previously, the **Validated Dose** is compared to the **Required Dose** to determine the inactivation credit for the target pathogen.

Experimental Accuracy and Quality Control

Section 5.5 of the UVDGM recommends that, during validation testing, all equipment be carefully selected and calibrated to minimize uncertainty. Tests verifying equipment accuracy (particularly UV

sensor checks) should be documented in the Validation Report. The UVDGM recommends the following targets for measurement uncertainty.

- Flow Meters: 5 percent or less (Section 5.5.1 of the UVDGM)
- UV Spectrophotometers: 10 percent or less (Section 5.5.2 of the UVDGM)
- UV Sensors: 10 percent or less (Section 5.5.4 of the UVDGM)

Section 5.6.4 of the UVDGM recommends the following quality control samples for full-scale reactor testing.

- Reactor Controls: influent and effluent water samples taken with the UV lamps (in the reactor) turned off. The change in log concentration from influent to effluent should correspond to a change in **RED** (from the UV dose-response curve) that is within the measurement error of the minimum **RED** measured during validation (typically 3 percent or less).
- Reactor Blanks: influent and effluent water samples taken with no addition of challenge microorganism to the flow passing through the reactor. Blanks should be collected at least once on each day of testing and the concentration of challenge microorganisms should be negligible.
- Trip Controls: one sample bottle of challenge microorganism stock solution should travel with the stock solution used for validation testing from the microbiological laboratory to the location of reactor testing and back to the laboratory. The change in the log concentration of the challenge microorganism in the trip control should be within the measurement error. (i.e., the change in concentration over the test run should be negligible). This is typically on the order of 3 to 5 percent.
- Method Blanks: sample bottle of sterilized reagent grade water that undergoes the challenge microorganism assay procedure. The concentration of challenge microorganism with the method blank should be non-detectable.
- Stability Samples: influent and effluent samples collected at low and high UVT that are used to assess the stability of the challenge microorganism concentration and its UV dose-response over the time period from sample collection to completion of challenge microorganism assay. The challenge microorganism concentrations in the stability samples should be within 5 percent of each other.

As stated in Section 5.7.3 of the UVDGM:

- If the full-scale reactor testing lasts for more than one day, at least one collimated beam test should be conducted for each day of testing.
- A minimum total of two collimated beam tests should be conducted, one each at the highest and lowest UVT values evaluated during full-scale reactor resting.

Identifying Test Conditions

Numerous combinations of experimental tests can be performed to validate a UV reactor. The number of tests could range from a few tests to a complex matrix spanning a range of UV dose, flow rate, UVT, ballast power, and lamp status combinations. The most intensive case is the validation of a new UV reactor over a wide range of operating conditions to develop a dose-monitoring equation. The target pathogen and target log inactivation for the water system define the **Required Dose** that is desired for validation testing. The full range of operating conditions expected by the water system for flow rate and UVT dictate the flow rate and UVT conditions used during validation testing.

Validation testing of UV reactors produces the following types of data for each experimental test:

- Concentration of the challenge microorganism in the influent and effluent sample [e.g., plaque forming units per milliliter (pfu/mL) for MS2 phage]
- UVT of water (percent)
- Flow rate [gallon per minute (gpm) or mgd]
- UV intensity as measured by the UV sensor (mW/cm^2)
- Lamp power [watt (W) or kilowatt (kW)]
- Status (on/off) for each lamp

Section 5.8 of the UVDGM states that all experimental data should be documented, preferably in tabular format, and included in the Validation Report.

Selecting the Challenge Microorganism

As stated in Section 5.3 of the UVDGM, the ideal challenge microorganism has the same sensitivity to UV light (i.e., the same microbial dose-response) as the target pathogen. Section 5.3 further states that, if medium pressure (MP) lamps are used, the challenge organism should display a similar action spectrum, which is the relative sensitivity of the organism at other wavelengths compared to its sensitivity at 254 nm.

Male-specific-2 bacteriophage (MS2) phage has historically been used for validation testing but its UV resistance is significantly greater than *Cryptosporidium* and *Giardia*. More sensitive microorganisms, such as T1 and T7 phage are, therefore, commonly used. To demonstrate 3- or 4-log inactivation for viruses, validation testing would need to demonstrate greater than 6-log inactivation of MS2 phage. Such a demonstration requires an extremely high concentration in the reactor influent to allow for enumeration of the organisms in the effluent samples. Because of the need for serial dilutions, these high concentrations are difficult to measure and can introduce error into the experiment. Research to find alternative challenge microorganisms for demonstrating virus inactivation is ongoing. Some recent validations have included *B. pumilus* spores, *A. brasiliensis,* and Adenovirus type-2 as high resistant test microorganisms for virus UV inactivation applications, but there are differing practices for applying these test microbes in validation testing and differing acceptance criteria are often encountered in validation reports.

Table 5 summarizes the UV sensitivity of some commonly used and some candidate bioassay microorganisms. The UV sensitivity of the target microorganisms *Cryptosporidium*, *Giardia*, and viruses can be defined by the EPA-required UV doses presented earlier in the UV Toolkit.

Table 5. UV Sensitivity of Challenge Microorganisms

Microorganism	Reported Delivered UV Dose (mJ/cm^2) to Achieve Indicated Log Inactivation				Reference
	1-log	2-log	3-log	4-log	
Bacillus subtilis	28	39	50	62	Sommer et al. 1998
MS2 phage	16	34	52	71	Wilson et al. 1992
Qß phage	10.9	22.5	34.6	47.6	Mackey et al. 2006
PRD-1 phage	9.9	17	24	30	Meng and Gerba 1996
B40-8 phage	12	18	23	28	Sommer et al. 1998
ϕx174 phage	2.2	5.3	7.3	11	Sommer et al. 1998
E. coli	3.0	4.8	6.7	8.4	Chang et al. 1985
T7	3.6	7.5	11.8	16.6	Mackey et al. 2006
T1	~5	~10	~15	~20	Wright 2006

Source: UVDGM (USEPA, 2006)

A portion of the **Validation Factor** accounts for the difference in microbial response between the challenge microorganism and target pathogen. Using a challenge organism with significantly higher UV resistance than the pathogen of interest (e.g., using MS2 to earn *Cryptosporidium* inactivation credit) may result in a high **Validation Factor**. To provide a better estimate of the UV dose that a UV reactor can deliver to a target pathogen, a challenge microorganism with similar UV sensitivity to the target pathogen can be used (UVDGM, Section 5.3). Alternatively, two challenge microorganisms whose UV sensitivities bracket that of the target pathogen (i.e., one challenge microorganism is less resistant and the other is more resistant than the target pathogen) can be selected (UVDGM, Section 5.3).

One advantage to this second approach is that the factor used to account for the difference between the microbial response of the challenge microorganism and target pathogen (the RED Bias Factor) can be set to 1.0. A drawback of this test microbe bracketing procedure is that there is no established standard protocol for preparing the experimental design, analyzing the results, and assessing the validated range, particularly for reactors employing multiple lamps and banks. A variety of validation practices have been employed for bracketing applications by testing organizations over the years, and differing approaches and criteria are often encountered in validation reports.

A recent EPA-ORD report titled, **Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems**, (USEPA 2020) describes additional validation approaches primarily emphasizing the use of MS2 and T1 test microbes. The new methodologies employ a "Combined Variable" approach when applying UV disinfection for the inactivation of *Cryptosporidium*, *Giardia*, and virus. These approaches also benefit from determining true RED bias and, therefore, the RED Bias Factor can be set to 1.0. In addition, the four alternative calculated dose procedures presented do not require the use of B. pumilus spores, A. brasiliensis, and Adenovirus type-2 which often have higher observed dose response variability and no established QA/QC dose-response-bounds criteria. Instead, they employ the use of MS2 and T1 with historically tighter and established QA/QC bounds as provided in the report. The approaches address both LP and MP reactors that include multiple lamps configured in rows/banks, including applications for low wavelength monitoring of polychromatic systems. The USEPA 2020 report may be downloaded from: https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=349759&Lab=CESER

Calculating the Reduction Equivalent Dose (RED)

As described in Section 5.8.1 of the UVDGM, the **RED** should be calculated for all full-scale reactor test conditions, individually for each replicate, using one of the following two methods.

Tests Conducted with **One** Challenge Microorganism

1. For each test condition replicate (i.e., influent and effluent sample pairs), calculate the log inactivation (log I).

   $$\log I = \log\left({}^{N_0}/_{N}\right)$$

   where:

   N_0 = Challenge microorganism concentration in influent sample (pfu/mL or cfu/mL)

   N = Challenge microorganism concentration in corresponding effluent sample (pfu/mL or cfu/mL)

2. Determine the **RED** (in mJ/cm^2) for each test condition replicate pair using the measured log inactivation (log I) and the UV dose-response curve developed through collimated beam testing. If individual UV dose-response curves cannot be combined, the curve for a given day of testing should be used to determine the **RED** for full-scale reactor testing data collected that day. If individual dose-response curves developed on the same day of testing cannot be combined, the curve resulting in the most conservative (lowest) **RED** values should be used.

Example 5.2 in Chapter 5 of the UVDGM demonstrates the **RED** calculation process.

Tests Conducted with **Two** Challenge Microorganism

If validation testing is done with two challenge microorganisms whose UV sensitivities bracket the UV sensitivity of the target pathogen (i.e., one microorganism is more resistant and one is less resistant), the following approach can be used to estimate the **RED** of the target pathogen for each test condition:

1. For each test condition, calculate the UV sensitivity (mJ/cm^2 per log I) of the challenge microorganism using the following equation:

   $$\text{UV sensitivity} = {}^{RED}/_{\log I}$$

   where:

   RED = The RED for the test replicate as derived by inputting log I into the UV dose-response equation

   Log I = log inactivation for the test replicate (calculated previously)

2. Create a graph with UV sensitivity on the x-axis and **RED** (mJ/cm^2) on the y-axis for each test condition.
3. For each challenge microorganism, plot paired UV sensitivity and **RED** values on the graph (2 values).
4. Draw a straight line between the two points.
5. Determine the UV sensitivity for the target pathogen by selecting the UV dose from EPA's **Required Dose** table (Table 4) for 1 log inactivation (log I = 1)

6. Using the straight line in the graph created in Step 4, read the corresponding **RED** value for the UV sensitivity of the target pathogen (as determined in Step 5).

Example 5.3 in Chapter 5 of the UVDGM demonstrates the calculation of **RED** with two challenge microorganisms.

If the UV reactor being validated uses MP lamps, Section 5.3 of the UVDGM recommends an Action Spectra Correction Factor (ASCF) be applied to the test results to account for differences in action spectra between the challenge microorganism and the target pathogen. Section D.4.1 of the UVDGM describes this application, but these issues are more thoroughly addressed in the final report for the WRF Project 4376 (Linden *et al.,* 2015). Linden *et al.* (2015) provides wavelength response data from 200 to 300 nm for six challenge microorganisms, including MS2 and T1UV phage, and wavelength response data for *Cryptosporidium*, *Giardia*, and adenovirus. Linden *et al.* (2015) also provides tables of validation-specific ASCFs that could be broadly applied to MP reactors regardless of their configuration, and guidance for calculating validation- and site-specific ASCF values for a UV reactor using CFD-based UV dose models.

Deriving the Validation Factor (VF)

Several considerations are involved in using experimental testing to define a **Validated Dose** and validated operating conditions. For example, a challenge microorganism may have a different UV sensitivity than the target pathogen. To determine the **Validated Dose**, the **RED** is divided by the **Validation Factor (VF)** to quantitatively account for key areas of uncertainty. The equation for the **VF** is shown below.

$$VF = B_{RED} \times \left(1 + {}^{U_{Val}}/_{100}\right)$$

where:

VF = Validation Factor
B_{RED} = RED Bias Factor
U_{Val} = Uncertainty of Validation expressed as a percentage

In addition to the B_{RED}, Section 5.9 of the UVDGM states that a bias factor to account for the influence of nongermicidal light on UV sensor readings (referred to as the "polychromatic bias factor") should be included in the **VF** for MP reactors that meet either of the following criteria:

- The MP reactor is equipped with a non-germicidal sensor.
- The MP reactor is equipped with a germicidal sensor, but the sensor is mounted further than 10 cm from the lamp and the water to be treated has a low UVT (< 80%).

Derivation of the polychromatic bias factor and its inclusion in the **VF** calculation are addressed in Section D.4.3 of the UVDGM.

RED Bias Factor (B_{RED})

The B_{RED} is a correction factor that accounts for the difference between the UV sensitivity of the target pathogen and the UV sensitivity of the challenge microorganism. If validation testing is performed using two challenge microorganisms whose UV sensitivities bracket those of the target pathogen (i.e., one challenge microorganism is less resistant than the target pathogen and the other is more resistant than the target pathogen), the B_{RED} is equal to 1.0. The B_{RED} is also equal to 1.0 if testing employs the "Combined Variable" approach (USEPA 2020).

Section 5.9.1 of the UVDGM describes the procedure for determining the B_{RED}. It recommends calculating one B_{RED} for the UV facility, based on the site-specific application (i.e., minimum operating UVT and target pathogen log inactivation desired), which results in a constant **VF** for all conditions. As an alternative, the B_{RED} can be defined as a function of UVT. This alternative may be advantageous for the Calculated Dose Approach, where UVT is continually monitored during operations, which means that the VF and the **Validated Dose** would vary along with UVT. The disadvantage of using a variable **VF** is that the UV reactor control system would need to be designed and programmed to do these calculations and that the VF reported to the state will vary, making operations and reporting more complex.

Uncertainty in Validation (U_{Val})

The U_{Val}, also referred to as the experimental uncertainty, has between 1 and 3 input variables based on how well validation testing adhered to the recommended QA/QC limits in the UVDGM. Section 5.9.2 of the UVDGM provides two decision trees for selecting the appropriate equation for calculating U_{Val}, one for the UV Intensity Setpoint Approach and another for the Calculated Dose Approach.

As described in 5.9.2, at least one input variable, which depends on the dose-monitoring strategy of the UV reactor, should be used in all cases. The Uncertainty of the Setpoint value (U_{SP}) is always calculated for the UV Intensity Setpoint Approach, and the Uncertainty of Interpolation value (U_{IN}) is always calculated for the Calculated Dose Approach. U_S is the Uncertainty of UV Sensor measurements, expressed as a fraction (e.g., 15 percent, or 0.15). U_{DR} is the Uncertainty of the Dose-Response fit at a 95-percent confidence level. Note that if individual UV dose-response curves cannot be combined and there is more than one U_{DR} value, the maximum value should be used in the decision tree, as described in Section 5.9.2 of the UVDGM.

A complete description of the procedure for calculating the U_{Val} and its components is provided in Section 5.9.2 of the UVDGM. The EPA-ORD UV report (USEPA 2020) provides additional details regarding VF application procedures.

Developing the Algorithm for UV Reactor Operation

To develop a final algorithm for operation of the UV reactor, the calculated **RED** values should be evaluated over the entire spectrum of conditions tested at full scale (described in Section 5.8.1 of the UVDGM). In addition, the algorithm should account for uncertainties and biases that may arise during experimental testing, by integrating the **VF** (described in Section 5.9 of the UVDGM). The form of the operational algorithm is dictated by the dose-monitoring strategy. The two most common dose-monitoring strategies are the UV Intensity Setpoint Approach and the Calculated Dose Approach.

UV Intensity Setpoint Approach

For the UV Intensity Setpoint Approach, the purpose of validation testing is to determine the **Validated Dose** corresponding to the UV intensity setpoint for a reactor at a particular flow rate. Typically, the manufacturer determines the UV intensity setpoint for their reactor based on the desired disinfection credit for the application. Section 5.6.1 of the UVDGM recommends that the water system work with the manufacturer to ensure that the setpoint is defined conservatively low enough to account for combined onsite conditions of minimum UVT and maximum fouling/aging.

The UVDGM describes the UV Intensity Setpoint Approach requiring two validation test conditions. The first involves reducing UVT until UV intensity measured by the UV sensor is equal to the UV intensity

setpoint. The second involves testing at high UVT but reducing power until the UV intensity measured by the sensor is equal to the UV intensity setpoint. If the UV sensor is in the ideal location (i.e., a location that gives UV dose delivery proportional to the UV sensor reading), the two test conditions are expected to yield the same **RED**. Selecting the minimum **RED** from these two test conditions accounts for UV reactor designs where the sensor is not in the ideal location.

As described in Section 5.8.2 of the UVDGM, several replicate tests (typically 3 – 5) with the same stock solution of challenge microorganisms should be performed for each test condition. Replicate **RED** values are then averaged to produce one **RED** for each test condition. From these average values, the minimum **RED** should be selected and used in the **Validated Dose** calculation.

Section 5.8.2 of the UVDGM recommends additional test conditions if the water system will be using variable setpoint operations (e.g., each of the first two test conditions should be repeated at different flow rates). In this case, the minimum **RED** value should be identified for each flow rate range.

The last step in developing the algorithm is to adjust the **RED** results by the **VF** to determine the **Validated Dose** for the reactor using the following equation.

$$\text{Validated Dose} = {}^{RED}/_{VF}$$

where:

RED = the minimum RED for the UV intensity setpoint.
VF = the Validation Factor

For the UV Intensity Setpoint Approach, one **Validated Dose** is calculated for a given UV intensity setpoint corresponding to the minimum **RED**. When the UV reactor is operating at a UV intensity level above the setpoint, the true UV dose delivered to microorganisms passing through the reactor is always equal to or greater than the **Validated Dose**.

The inactivation credit for the target pathogen is determined by comparing the **Validated Dose** to the **Required Dose** [40 CFR 141.720(d)]. Validated operating conditions are as follows:

- The UV intensity measured by UV sensors is greater than the UV intensity setpoint.
- The flow rate is less than or equal to the flow rate evaluated during validation testing.
- The lamp status for each lamp (i.e., on/off setting) is equivalent to the settings used during validation testing.

The validation approach described above produces a UV intensity setpoint and **Validated Dose** that are independent of UVT. Thus, UVT is not typically monitored during reactor operations. An underlying assumption of the UV intensity setpoint approach is that the **RED** delivered at intermediate UVTs with the reactor operating at the setpoint will lie between the two measured UVTs. Recent UV reactor operations experience and research (USEPA 2020) shows that the log inactivation and associated **RED** delivered at intermediate UVTs can be lower than the **REDs** measured with the two validation test conditions. Therefore, the State UV Workgroup believes the UV intensity setpoint approach should include test points measured at intermediate UVTs with the ballast power lowered until the UV sensor reads at the setpoint value.

The German Deutscher Verein des Gas- und Wasserfaches (DVGW) and the Austrian Osterreichisches Normungsinstitut (ÖNORM) protocols validate UV systems for a *B. subtilis* **RED** of 40 mJ/cm^2 using the UV intensity setpoint approach. Many of those validations have used two test conditions as described above. Section 5.2.2 of the UVDGM states that UV reactors certified by DVGW and ÖNORM for a *B. subtilis* **RED** of 40 mJ/cm^2 should be granted 3-log *Cryptosporidium* and 3-log *Giardia* inactivation credit. Wright (2007) provides analysis of the expected validated dose for *Cryptosporidium* and *Giardia* inactivation credit with a *B. subtilis* **RED** of 40 mJ/cm^2 after applying a validation factor calculated per the UVDGM. The analysis shows that a *B. subtilis* **RED** of 40 mJ/cm^2 conservatively achieves 3-log inactivation credit with *Cryptosporidium* and *Giardia* for UVTs ranging from 70 to 98 percent. Based on this analysis, a UV system designed and operated to deliver a *B. subitlis* or MS2 **RED** of 40 mJ/cm^2, based on the UV intensity setpoint approach per the UVDGM, can still be considered to achieve 3-log inactivation credit with *Cryptosporidium* and *Giardia*. However, the State UV Workgroup believes that UV systems designed and operated to deliver *B. subtilis* or MS2 **REDs** that are lower than 40 mJ/cm^2, based on the UV intensity setpoint per the UVDGM, should be evaluated for disinfection credit on a case-by-case basis by the validation facility.

Calculated Dose Approach

For the Calculated Dose Approach, the purpose of validation testing is to develop a dose-monitoring equation relating **RED** to operating parameters such as flow rate, UVT, lamp power, and (in some cases) lamp status and number of multiple-lamps or banks. For each operating parameter used in the equation, Section 5.6.2 of the UVDGM recommends that at least three conditions be evaluated during validation testing. Three data points are needed for interpolation of results because the relationship between **RED** and operating parameters such as flow rate and UVT is typically non-linear.

Section 5.6.2 of the UVDGM recommends that the maximum and minimum flow rate and UVT be selected as test conditions, along with at least one intermediate value for each. During validation, a UV-absorbing chemical (such as lignin sulfonic acid or humic acid) is typically injected into the flow to produce UVT values that span the desired range. Test conditions for lamp power should be the maximum, minimum, and one intermediate level. The minimum power condition should include reduction in lamp output caused by fouling and aging. The magnitude of the power reduction (or power turn-down) is determined by calculating the relative sensor intensity, which is defined as follows:

$$\text{Relative sensor intensity} = S/S_0$$

where:

S_0 = UV intensity measured at 100 percent lamp power

S = UV intensity measured at reduced lamp power

In many cases, three operating parameters (UVT, flow rate, and lamp power) are used in the dose-monitoring equation, resulting in a minimum of 27 test conditions (3 × 3 × 3). Fewer test conditions are needed when the dose-monitoring equation is based on fewer than three parameters, such as when a minimum UVT is assumed for all operating conditions. More than 27 test conditions may be needed when the water system plans to vary lamp status during operations (e.g., UVT, flow rate, and lamp power are used in the dose-monitoring equation and individual banks of lamps will be turned off and on to conserve power).

Section 5.6.2 of the UVDGM recommends that at least three replicate tests with the same stock solution of challenge microorganisms be performed for each test condition, with each test requiring both

influent and effluent sampling. If there are 27 test conditions established, the number of expected sample results is 162 (27 × 3 × 2).

After testing is complete, the data are fitted to an equation using a technique such as multivariate linear regression. The variables in the dose-monitoring equation are typically flow rate, UVT, UV intensity, or some subset thereof. The number of operating banks of lamps is also a possible variable for the equation for those water systems that use multiple banks. As described in Section 5.8.3 of the UVDGM, the equation should pass through the origin (0,0) if the **RED** is calculated as a function of measured UV intensity or inverse flow rate. A non-zero intercept would introduce a bias.

Section 5.8.3 of the UVDGM recommends that the goodness-of-fit of the equation be determined by calculating the p-statistics for the model coefficients. For the fit to be acceptable, the p-statistic for each model coefficient should be 0.05 or less.

The **VF** should be used to determine the **Validated Dose** for the reactor, as follows:

$$\text{Validated Dose} = {}^{RED}/_{VF}$$

where:

RED = the calculated dose from the dose-monitoring equation
VF = the Validation Factor

A key advantage of the Calculated Dose Approach is that water systems can reduce power when UVT is high and/or the flow rate is low. To receive treatment credit, the reactor must be operated so as to maintain a **Validated Dose** that is greater than or equal to the **Required Dose** for the target pathogen and target log inactivation level [40 CFR 141.720(d)]. Validated operating conditions for the Calculated Dose Approach are as follows:

- The operating UVT is equal to or greater than the minimum UVT evaluated during validation testing.
- The operating flow rate is less than or equal to the flow rate evaluated during validation testing.

Additional details regarding the application of the Calculated Dose Approach are presented in the EPA-ORD UV report (USEPA 2020). These approaches and procedures include:

- Microbial methods and dose-response QA/QC bounds for commonly used microbial surrogates in UV reactor validation.
- Approaches for the development of calculated UV dose-monitoring algorithms with improved accuracy that eliminate the need for RED bias factors.
- Approaches for the development of UV dose-monitoring algorithms that do not require an online UVT monitor for simplified UV system operations.
- Implementation of “low wavelength” UV sensors and approaches for the development of medium pressure UV dose-monitoring algorithms that account for the disinfection associated with wavelengths below 240 nm.
- Criteria for the development of a robust validation test matrix, monitoring algorithm goodness of fit and QA/QC requirements, and standardized approaches for defining the validated range of UV reactors.

- Target UV doses for 4.5, 5.0, 5.5 and 6.0 log inactivation of *Cryptosporidium*, *Giardia* and virus for UV applications requiring higher levels of disinfection than the maximum 4.0 log provided by the UVDGM.
- General validation and data analysis procedures that are commonly implemented in UV reactor validation but are not explicitly documented in the UVDGM.
- Updated equipment operating procedures to improve the accuracy of UV dose-monitoring with the water treatment application.

UV VALIDATION REPORT CONTENTS

The Long-Term 2 Enhanced Surface Water Treatment Rule requires PWSs to use UV reactors that have undergone validation testing to determine the operating conditions under which the reactor delivers the desired dose. The regulation includes the following statement:

> Validation testing must involve full-scale testing of a reactor that conforms uniformly to the UV reactors used by the PWS, and it also must demonstrate inactivation of a test microorganism whose dose-response characteristics have been quantified with a low-pressure mercury vapor lamp [40 CFR 141.720(d)(2)].

States (and other primacy agencies) have significant flexibility to establish a process for water systems to seek and obtain approval for UV treatment in their state. The regulation simply requires water systems to submit the following:

> Validation test results demonstrating operating conditions that achieve the required UV dose [40 CFR 141.721(f)(15)].

EPA created the Ultraviolet Disinfection Guidance Manual (UVDGM) for the Final Long Term 2 Enhanced Surface Water Treatment Rule (USEPA, 2006) to aid states and water systems in establishing criteria for evaluating UV treatment. The State UV Workgroup chooses, in large part, to use the recommendations in the UVDGM to instruct water systems on the contents that should be included in UV validation reports submitted for state review. The State UV Workgroup believes it is important that all deviations from the UVDGM be justified in the validation report (and in follow-up questions, if need be) to the satisfaction of the reviewer.

In general, The State UV Workgroup believes a validation report should include sections addressing: Executive Summary, Description of the UV Reactor, UV Validation Test Facility, Methods, Analysis, Validation Factors, Compliance to the UVDGM Checklists, and Appendices with all data, calibration certificates, and supporting information. The State UV Workgroup believes the technical contents should include UV sensor equations, the UV dose equation, validated range, and target REDs for disinfection credit.

UV research and development has continued to evolve since the UVDGM was published. The recent EPA-ORD UV report (USEPA 2020) addresses additional content for consideration in validation reports that are specific to methods using the Calculated Dose Approach employing Combined Variable analysis, including the assessment of systems not using an online UVT monitor, and medium pressure (MP) UV systems incorporating both low and high wavelength UV sensors.

Calculated Dose Approach Using UVT Monitor

Outline of State UV Workgroup Suggested Validation Report Contents

1. Executive Summary: includes the UV sensor and UV dose-monitoring equations, validated range, validation factors and required REDs for disinfection credit, and adherence to the UVDGM checklists.
2. UV Reactor Documentation: describes the wetted dimensions of the reactor and optical properties of the lamps, sleeves, UV sensors, and UV sensor ports that impact UV dose delivery and monitoring. These descriptions allow the installed reactor to be compared to the validated reactor, to ensure they are the same.
3. Validation Methods:
    a. Description of the test train.
    b. UV reactor inlet and outlet piping with dimensions.
    c. Challenge microorganism stock solution preparation.
    d. Challenge microorganism enumeration.
    e. Third party oversight.
    f. Water quality measurement methods (UVT, chlorine, etc.).
    g. Functional test methods (headloss, power, UV sensor reference checks, UV sensor equation development).
    h. Biodosimetry methods.
    i. QA/QC (Accuracy of instrumentation, microbial, lamp output, mixing, etc.).
4. Validation Results:
    a. Water quality measurements.
    b. Headloss vs. flow curves.
    c. Lamp output ranking and positioning if the number of UV sensors are less than the number of lamps.
    d. Power consumption vs. power setting curves.
    e. Results of duty sensor checks using reference sensors.
    f. Analysis describing development of UV sensor equations with tabulated coefficients and plots of measured vs. predicted UV sensor readings.
    g. Challenge microorganism UV dose response curves with fits and QA/QC bounds.
    h. Analysis describing development of UV dose-monitoring algorithm with tabulated coefficients and plots of measured vs. predicted log inactivation and RED.
    i. Analysis showing MS2 predicts T1UV and vice versa as a proof of rigorous assessment, if Combined Variable analysis is used (USEPA 2020).
    j. Validated range.
    k. Example calculations using UV dose-monitoring algorithms.
5. Validation Factor Analysis:
    a. RED bias.
    b. Polychromatic bias if applicable.
    c. Uncertainty of validation.
    d. Tables showing validation factors and required REDs for disinfection credit.
6. Discussion of the UVDGM Checklists describing whether or not validation equipment and testing adhere to the UVDGM Checklists. All deviations from the UVDGM Checklists should be explained in detail.

7. Appendices:
    a. Functional and biodosimetric data.
    b. QA/QC results (microbial, UVT monitors, mixing, etc.).
    c. Calibration certificates for UV sensors, UVT monitors, flowmeters, radiometers, and power meters.
    d. Microbial methods.

UV DISINFECTION CREDIT

Drinking water treatment rules reflect a multibarrier approach for treatment of pathogens. The total microbial reduction requirements for treatment of surface water are well defined by the Surface Water Treatment Rule, the Interim Enhanced Surface Water Treatment Rule, the Long Term 1 Enhanced Surface Water Treatment Rule, and the Long Term 2 Enhanced Surface Water Treatment Rule.

The rules for filtered water systems require all the following:

1. Total of 4-log removal and/or inactivation of viruses.
2. Total of 3-log removal and/or inactivation of *Giardia*.
3. 2-log removal of *Cryptosporidium*.
4. Up to an additional 2.5-log removal and/or inactivation of *Cryptosporidium* (for surface water systems which are classified in Bin 2, 3, or 4 based on source water monitoring of *Cryptosporidium*.)

States and primacy agencies have authority to establish the criteria that must be met for PWSs to earn disinfection credit for UV treatment [40 CFR 141.720(d)(2)(iii)]. Ultimately, each installed UV reactor is operated using an algorithm based on the UV Intensity Setpoint Approach or the Calculated Dose Approach. In either case, there are many operating parameters that are developed and used to calculate the treatment capability of the UV reactor during validation testing. It is helpful for reviewers to track these validation parameters according to the surrogate that was used during testing.

The following tables are a useful way to document the validation parameters of a reactor and the resulting treatment credit. Tables 6 and 7 are included to provide examples and explanation of the parameters they document. Tables 8 - 11 are provided for use by reviewers. Throughout, references are made to the UVDGM.

UV Disinfection Credit Tables

Table 6. Validated Conditions

UV Reactor Name and Number:_____

Parameter	**Value**
Validated Water	{e.g., Portland Blue Lake Aquifer with SuperHume, Portland Sand and Gravel Aquifer with SuperHume, New York Water with LSA}
Validated Sleeve	{e.g., Type 214, Type 219, synthetic}
Validated Flow Range	{e.g., 55 gpm to 700 gpm}
Validated UVT Range	{e.g., 79.2 to 97.3%}
Validated Power Condition	{Range of power validated condition: i.e. 40 to 100%}

Table 7. (*Cryptosporidium*/*Giardia*/Virus) Validation Parameters

Inactivation Credit:**_____Log**

Validation Surrogate	**(e.g., MS2, T1, QB}**		
Validated Range of Reduction Equivalent Dose (RED)	{From Validation Report, e.g., 20.76 to 79.42 mJ/cm^2} *(See Section 5.8.1 of the UVDGM)*		
Validation Factor (VF)	{Variable based on parameters below, or fixed to a conservative value} *(See Section 5.9 of the UVDGM)*		
RED Bias (B_{RED})	{Accounts for the difference between the UV sensitivity of the target pathogen and the UV sensitivity of the challenge microorganism} *(See Section 5.9.1 of the UVDGM)*		
Polychromatic Bias Factor (B_{POLY})	{Relevant for *some* medium pressure reactors} *(See Section 5.9 of the UVDGM)*		
Uncertainty of Sensor Value (U_S)	{Value; or eliminated based on meeting quality assurance guidance} *(See Section 5.5.4 of the UVDGM)*		
Uncertainty of Fit of Dose-Response Curve (U_{DR})	{Value; or eliminated based on meeting specific uncertainty bounds} *(See Section 5.9.2 of the UVDGM)*		
Uncertainty of Interpolation (U_{IN})	{Calculated value is used in the algorithm based on observed UVT} *(See Section 5.9.2.2 of the UVDGM)*		
Action Spectra Correction Factor for *Cryptosporidium* (ASCF)	*(See WRF Project 4376—Linden et al., 2015*)		

Table 8. Validated Conditions

Parameter	**Value**
Validated Water	
Validated Sleeve	
Validated Flow Range	
Validated UVT Range	
Validated Power Condition	

Table 9. *Cryptosporidium* Validation Parameters

Inactivation Credit:**_____Log**

Validation Surrogate			
Validated Range of Reduction Equivalent Dose (RED)			
Validation Factor (VF)			
RED Bias (B_{RED})			
Polychromatic Bias Factor (B_{POLY})			
Uncertainty of Sensor Value (U_S)			
Uncertainty of Fit of Dose-Response Curve (U_{DR})			
Uncertainty of Interpolation (U_{IN})			
Action Spectra Correction Factor for *Cryptosporidium* (ASCF)			

Table 10. *Giardia* Validation Parameters

Inactivation Credit:_____**Log Credit**

Validation Surrogate			
Validated Range of Reduction Equivalent Dose (RED)			
Validation Factor (VF)			
RED Bias (B_{RED})			
Polychromatic Bias Factor (B_{POLY})			
Uncertainty of Sensor Value (U_S)			
Uncertainty of Fit of Dose-Response Curve (U_{DR})			
Uncertainty of Interpolation (U_{IN})			
Action Spectra Correction Factor for *Cryptosporidium* (ASCF)			

Table 11. Virus Validation Parameters

Inactivation Credit:_____**Log Credit**

Validation Surrogate			
Validated Range of Reduction Equivalent Dose (RED)			
Validation Factor (VF)			
RED Bias (B_{RED})			
Polychromatic Bias Factor (B_{POLY})			
Uncertainty of Sensor Value (U_S)			
Uncertainty of Fit of Dose-Response Curve (U_{DR})			
Uncertainty of Interpolation (U_{IN})			
Action Spectra Correction Factor for *Cryptosporidium* (ASCF)			

UV VALIDATION CHECKLISTS

A series of checklists appear in Section 5.11 of the UVDGM that identifies key elements in each phase of the UV validation process, including documentation of the UV reactor equipment, development of the validation test plan, drafting of the validation report, documentation of quality assurance/quality control (QA/QC), and third-party review of the validation report. The State UV Workgroup believes that, at the completion of testing, all the elements identified in the checklists should be incorporated into a validation report.

Each of the five checklists from the UVDGM are presented in this section of the UV Toolkit, along with some perspective provided to aid the regulatory reviewer. Wherever section numbers are provided, they refer to the UVDGM. Some elements listed in the checklists may be more helpful to those conducting the validation testing, while other elements are more helpful to equipment operators and regulatory reviewers. In some instances, reviewers may find aspects of a particular validation test that did not strictly follow the UVDGM protocol. This may be reasonable, since there may be alternative procedures, still consistent with the intent of the UVDGM, that have evolved since its publication. However, EPA and the State UV Workgroup believes it is important that all deviations from the recommended protocol be justified in the validation report (and in follow-up questions, if need be) to the satisfaction of the reviewer. This will inevitably require some professional judgment on the part of the reviewer, which will be enhanced by experience. Reviewers are encouraged to share questions and concerns with regulators from neighboring states that have installed similar equipment, as well as manufacturers and design engineers.

As stated in Chapter 3 of the UVDGM, "…this manual was written with the understanding that UV technology will continue to expand and evolve…" Indeed, it has. Accordingly, the recent EPA-ORD UV report (USEPA 2020) describes the application of alternative calculated-dose UV validation approaches. The report addresses:

- Microbial methods and dose-response QA/QC bounds for commonly used microbial surrogates in UV reactor validation.
- Approaches for the development of calculated UV dose-monitoring algorithms with improved accuracy that eliminate the need for RED bias factors.
- Approaches for the development of UV dose-monitoring algorithms that do not require an online UVT monitor for simplified UV system operations.
- Implementation of "low wavelength" UV sensors and approaches for the development of Medium Pressure UV dose-monitoring algorithms that account for the disinfection associated with wavelengths below 240 nm.
- Criteria for the development of a robust validation test matrix, monitoring algorithm goodness of fit and QA/QC requirements, and standardized approaches for defining the validated range of UV reactors.
- Criteria for assessing UV validation reports and revised checklists.
- Target UV doses for 4.5, 5.0, 5.5 and 6.0 log inactivation of *Cryptosporidium*, *Giardia* and virus for UV applications requiring higher levels of disinfection than the maximum 4.0 log provided by the UVDGM.
- General validation and data analysis procedures that are commonly implemented in UV reactor validation but are not explicitly documented in the UVDGM.
- Updated equipment operating procedures to improve the accuracy of UV dose-monitoring with the water treatment application.

The USEPA 2020 report complements the guidance presented in the UVDGM.

UVDGM Checklist 5.1: UV Reactor Documentation

Checklist 5.1 concerns the identification of the components of the UV treatment system and their operational characteristics. Below is the State UV Workgroup's description of the elements of Checklist 5.1, based on the information provided in Section 5.11.1 and earlier sections of the UVDGM.

General

- The first element asks for a description of the reactor's dose-monitoring strategy. Broadly speaking, dose-monitoring strategies can be categorized as either the UV Intensity Setpoint Approach or the Calculated Dose Approach. However, as described in Section 5.11.1 of the UVDGM, the report should include operation details specific to the reactor that was tested and its intended application.
- The next two elements ask for dimensions and placement of components within the reactor. This information is important to testers and operators who are assembling and using the equipment.
- UV sensors are among the most important components of the UV system. As stated in Section D.2.1 of the UVDGM, it is to the manufacturer's advantage to go through the process of optimizing the relative position of the UV sensor(s) in the reactor for accuracy and efficiency. For background, Sections D.2.1 and D.2.2 discuss the impact of UV sensor positioning for the UV Intensity Setpoint Approach and Calculated Dose Approach, respectively.

Lamp Specifications

- This element asks for complete identification of all lamp characteristics that are important to their use and performance. The most common types of lamps are low-pressure mercury vapor (LP), low-pressure high-output mercury vapor (LPHO), and medium-pressure mercury vapor (MP). All lamps degrade as they age but the effects vary greatly from lamp to lamp. Section 2.4.2 provides a detailed description of lamp varieties and their characteristics, including discussion of lamp output, sensitivity to power quality, and components such as lamp envelope, electrodes, and mercury fill.

Lamp Sleeve Specifications

- This element asks for identification and description of characteristics of the lamp sleeves that are important to their use and performance. Section 2.4.4 provides details on lamp sleeve design and performance.

Specifications for the Reference and the Duty UV Sensors

- This element asks for identification and description of the UV sensors being employed, as well as data on measurement uncertainty. In any UV treatment system, the reliability of the UV sensor(s) is key because they are one of the tools used to monitor compliance with operating requirements. For background, Section D.3 describes the properties of UV sensors, how those properties impact the sensor's measurement uncertainty, and how that measurement uncertainty can be determined.

Sensor Measurement Properties

- The elements listed in this part of the checklist are defined and discussed in Sections D.3.1 and D.3.2 of the UVDGM. The purpose of this information is to indicate the ability of the manufacturer to quantify the uncertainty for important sensor properties and to demonstrate whether the sensor can meet the purchaser's needs.

Installation and Operation Documentation

- This element is valuable for those involved in testing and operating the reactor. The State UV Workgroup believes this information should always be available at locations where the reactor is being used.

UVDGM Checklist 5.2: Key Elements of the Validation Test Plan

Checklist 5.2 lists the key elements of the UV validation test plan. These are important elements for manufactures and testing engineers to consider during the planning phase of validation testing. Many reviewers will be considering approval for reactors that have already been validated, in which case this list serves as a double-check on the completeness of the test plan. Below is the State UV Workgroup's summary of the elements of Checklist 5.2, based on the information provided in Section 5.11.2 and earlier sections of the UVDGM.

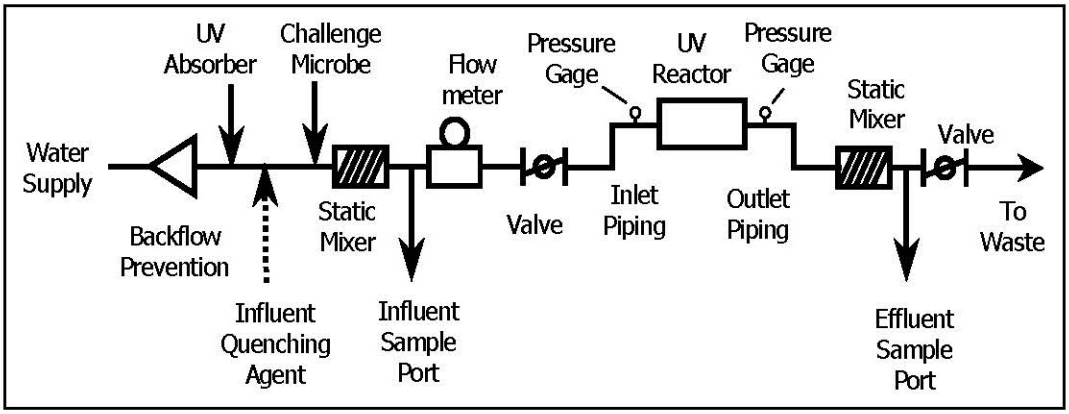
General

- The first five elements of the checklist are key considerations during the planing phase of validation testing. Planners should identify the target pathogen(s), the desired level of treatment (log inactivation), and the operations approach, to establish the appropriate test conditions. Roles and responsibilities should be made clear and logistics should be confirmed (schedule, location, required facilities). Careful consideration should be given to selecting the challenge microorganism(s) to ensure suitability and prepare for laboratory handling and analysis. Lastly, if state regulators are engaged in the validation testing process, their participation should be anticipated.

Design of the Biodosimetry Test Stand/On-Site Testing Facilities

- Offsite reactor validation is conducted using a Biodosimetry Test Stand, depicted in the schematic below. This part of the checklist lists key elements of the test stand, each of which are described in the UVDGM sections provided below.
    - Inlet/outlet piping should be properly configured, as described in Sections 3.6.2 and 3.6.3 of the UVDGM.
    - Adequate mixing of additives and challenge microorganisms should be tested and confirmed at multiple locations in the test stand prior to testing. This process is described in Section 5.4.3 of the UVDGM.
    - Sample ports should be properly located, as described in Section 5.4.4 of the UVDGM.
    - Injection pumps should be identified, confirmed to be appropriate to handle the additives at their anticipated flow rates, and calibrated to minimize uncertainty.

Figure 4. Diagram of a Typical Biodosimetry Test Stand for Full-Scale Reactor Validation



Source: UVDGM (USEPA, 2006)

Collimated Beam Testing Apparatus

- As described in Section 5.7.3 of the UVDGM, at least one collimated beam test should be conducted for each day of full-scale validation testing. If testing is conducted at multiple UVTs, the UVDGM recommends a minimum of two collimated beam tests—one each at the highest and lowest UVT values evaluated. The components of the test apparatus should be identified in the validation report. A full description of the design and operation of a typical test apparatus is in Section C.2.1 of the UVDGM.

Monitoring Equipment Specifications and Verification of Equipment Accuracy

- During validation testing, all equipment should be carefully selected and calibrated to minimize uncertainty. Section 5.5 of the UVDGM provides recommendations for verifying measurement uncertainty during validation testing. Those accuracy targets are as follows:
    - The uncertainty of flow rate measurements should be 5% or less.
    - The measurement uncertainty of the spectrophotometer should be 10% or less.
    - If on-line UVT analyzers are used, they should be periodically checked using grab samples to verify they agree with a properly calibrated bench-top spectrophotometer to within ±2%.
    - Voltmeters, ammeters, and power meters should bear evidence of being in calibration (e.g., have a tag showing that it was calibrated within the specified time period).
    - Duty UV sensor measurements should be within 10% of the average of two or more reference sensor measurements. Note that this error range is smaller than that recommended for treatment operations (i.e., within 20% of the average of two or more reference sensors). The UVDGM states that a 10% error is easily attainable during validation testing and will help ensure good data quality for developing operational setpoints.
    - Radiometers should come from the manufacturer with a calibration certificate indicating that UV intensity is measured with an uncertainty of 8% or less at a 95% confidence level. The UVDGM recommends that calibration be checked using the procedure described in Section C.2.2. In addition, the USEPA 2020 report describes an approach that uses at least three radiometers, including at least one from a different manufacturer.

Experimental Test Conditions

- The validation test plan should describe the test conditions, including the number of tests and the UVT, flow rate, lamp power, lamp status, and influent concentration of challenge microorganisms for each test condition. The plan should also indicate whether new or aged lamps were used, along with the lamp fouling factor.
- Section 5.6 of the UVDGM describes the factors that should be considered during validation test design. That section indicates the use of 2 test conditions per flow condition for validations using the UV Intensity Setpoint Approach, and 27 test conditions for validation using the Calculated Dose Approach with three operating parameters (e.g., UVT, flow rate, and lamp power). Validation practice has evolved since the publication of the UVDGM. The recent EPA-ORD UV report (USEPA 2020) describes alternative approaches for UV validation test designs. For the Intensity Setpoint Approach, intermediate test conditions are recommended along with the classic 2 lamp output/UVT conditions. Test matrix design considerations for the Calculated Dose Approach emphasize a rigorous test design for desired validated ranges. The approaches in the USEPA 2020 report complement, not supersede, the test design considerations presented in the UVDGM.
- The UVDGM recommends a QA/QC plan that involves collection of quality control samples during validation. The recommended samples are listed below and further described in Section 5.6.4.
    - Reactor controls
    - Reactor blanks
    - Trip controls
    - Method blanks
    - Stability samples

UVDGM Checklist 5.3: Key Elements of the Validation Report

Below is the State UV Workgroup's summary of the elements of Checklist 5.3, based on the information provided in Section 5.11.3 and earlier sections of the UVDGM. The validation report should provide detailed documentation of all validation testing results. The UVDGM recommends that the report begin with an executive summary providing key information that can be used by states to assess inactivation credit for the target pathogen(s). Further contents of the validation report are listed in Checklist 5.3.

General

- The first two elements of the checklist ask for documentation of all information included in the first two checklists: Checklist 5.1 UV Reactor Documentation and Checklist 5.2 Key Elements of the Validation Test Plan. These two sets of information, along with the test data and resulting calculations, make up the validation report.
- It is important for the report to describe and explain any deviations to the original test plan that were made during full-scale testing. Deviations aren't uncommon but should be discussed in the report, otherwise a reviewer can be expected to contact the validator to request an explanation.

Full-Scale Reactor Testing Results, with Detailed Results for Each Test Condition Evaluated

- All measured data from full-scale reactor testing should be provided, preferably in tabular form. Examples of tabularized results are provided in Section B.1.2 and B.2.2 of the UVDGM for the UV Intensity Setpoint Approach and the Calculated Dose Approach, respectively.

Collimated Beam Testing Results, Including Detailed Results for Each Collimated Beam Test Used to Create the UV Dose-Response Equation

- Appendix C of the UVDGM describes the use of collimated beam testing to develop a UV dose-response curve and provides a description of each of the items listed in this part of the checklist. As described in Section 5.7.3 of the UVDGM, at least one collimated beam test should be conducted for each day of full-scale validation testing. If testing is conducted at multiple UVTs, the UVDGM recommends a minimum of two collimated beam tests—one each at the highest and lowest UVT values evaluated.
- Using the process described in Sections C.2.3 and C.2.4 of the UVDGM, collimated beam tests produce the following types of experimental data:
    - UV Dose in units of mJ/cm^2
    - Concentration of microorganisms in the petri dish prior to UV exposure (N_o) in units of pfu/mL
    - Concentration of microorganisms in the petri dish after UV exposure (N) in units of pfu/mL
- Test data are ultimately used to calculate log inactivation (log I) and plot it against UV dose (for details, see Section C.3 of the UVDGM). The UVDGM recommends using regression analysis to derive an equation that best fits the data, forcing the fit through the origin. The equation will have different forms depending on the data.
- The resulting equation should not be used for extrapolation outside of the measured range of UV dose.

QA/QC Checks

- Measurement uncertainty and QA/QC checks were covered by Checklists 5.1 and 5.2 but are presented again here for emphasis.

Calculation of the Validated Dose, Log Inactivation Credit, and Validated Operating Conditions

- Section 5.8.1 of the UVDGM describes the process of calculating log inactivation (log I) and the Reduction Equivalent Dose (RED) using one or two challenge microorganisms. For each test condition replicate (i.e., influent and effluent sample pair), log I is calculated. The RED is calculated by plugging the resulting log I into the UV dose-response curve developed through collimated beam testing.
- The Validation Factor (VF) should be determined in order to account for key areas of uncertainty involved in experimental testing. The process of calculating the VF is presented in detail in Section 5.9 of the UVDGM.
- If the reactor is validated using the UV Intensity Setpoint Approach, one or more RED values should be selected as operational setpoints. This process is described in Section 5.8.2 of the UVDGM.
- If the reactor is validated using the Calculated Dose Approach, all the RED data is used to fit an equation for RED as a function of the operating parameters of interest (e.g., flow rate, UVT, UV intensity). This process is described in Section 5.8.3 of the UVDGM. The RED equation should incorporate the on/off status of reactor lamps or lamp banks (if the lamps have a bank configuration).
- The validated dose and validated operating conditions are explained in Section 5.10 of the UVDGM. The validated dose is calculated by dividing the RED by the VF. The inactivation credit for the target pathogen is determined by comparing the validated dose to the EPA-required

dose. To receive treatment credit, the validated dose must be greater than or equal to the required dose for the target pathogen and target log inactivation level [40 CFR 141.720(d)].

- In order to meet the requirements of 40 CFR 141.720(d), the validated operating conditions for the UV Intensity Setpoint Approach are as follows:
    - The UV intensity measured by UV sensors must be greater than the UV intensity setpoint.
    - The flow rate must be equal to or less than the flow rate tested.
    - The lamp status for each lamp (i.e., on/off setting) must be equivalent to the settings used during validation testing.
- In order to meet the requirements of 40 CFR 141.720(d), the validated operating conditions for the Calculated Dose Approach are as follows:
    - The operating UVT must be equal to or greater than the minimum UVT evaluated during validation testing.
    - The operating flow rate must not exceed the flow rate evaluated during validation testing.

Checklist 5.1 UV Reactor Documentation (Page 1 of 2)

Does UV reactor documentation contain the following elements?

Yes	No	
		General
☐	☐	Technical description of the reactor's UV dose-monitoring strategy, including the use of sensors, signal processing, and calculations (if applicable).
☐	☐	Dimensions and placement of all wetted components (e.g., lamps, sleeves, UV sensors, baffles, and cleaning mechanisms) within the UV reactor.
☐	☐	A technical description of lamp placement within the sleeve.
☐	☐	Specifications for the UV sensor port indicating all dimensions and tolerances that impact the positioning of the sensor relative to the lamps. If the UV sensor port contains a monitoring window separate from the sensor, specifications giving the window material, thickness, and UV transmittance should be provided.
		Lamp specifications
☐	☐	Technical description
☐	☐	Lamp manufacturer and product number
☐	☐	Electrical power rating
☐	☐	Electrode-to-electrode length
☐	☐	Spectral output of new and aged lamps (specified for 5 nm intervals or less over a wavelength range that includes the germicidal range of 250 – 280 nm and the response range of the UV sensors)
☐	☐	Mercury content
☐	☐	Envelope diameter
		Lamp sleeve specifications
☐	☐	Technical description including sleeve dimensions
☐	☐	Material
☐	☐	UV transmittance (at 254 nm for LP and LPHO lamps, and at 200 – 300 nm for MP lamps with germicidal sensors)
		Specifications for the reference and the duty UV sensors
☐	☐	Manufacturer and product number
☐	☐	Technical description including external dimensions
☐	☐	Data and calculations showing how the total measurement uncertainty of the UV sensor is derived from the individual sensor properties. (See Table D.1 for an example of the calculation of UV sensor measurement uncertainty from the uncertainty that arises due to each UV sensor property.)

Checklist 5.1 UV Reactor Documentation (Page 2 of 2)

Does UV reactor documentation contain the following elements?

Yes	No	
		Sensor measurement properties
☐	☐	Working range
☐	☐	Spectral and angular response
☐	☐	Linearity
☐	☐	Calibration factor
☐	☐	Temperature stability
☐	☐	Long-term stability
		Installation and operation documentation:
☐	☐	Flow rate, head loss, and pressure rating of the reactor
☐	☐	Assembly and installation instructions
☐	☐	Electrical requirements, including required line frequency, voltage, amperage, and power
☐	☐	Operation and maintenance manuals that include cleaning procedures, required spare parts, and safety requirements. Safety requirements should include information on electrical lockouts, eye and skin protection from UV light, safe handling of lamps, and mercury cleanup recommendations in the event of lamp breakage.

Source: UVDGM (USEPA, 2006)

Checklist 5.2 Key Elements of the Validation Test Plan (Page 1 of 1)

Does the validation test plan contain the following elements?

Yes	No	
☐	☐	Purpose of Validation Testing. General description of why the tests are being done and how the data will be used.
☐	☐	Roles and Responsibilities. Key personnel overseeing and performing the full-scale reactor testing and collimated beam testing, including their qualifications. This section should include contact names and telephone numbers.
☐	☐	Locations and Schedule. Location for conducting full-scale reactor testing and collimated beam testing. Planned schedule for conducting the tests and performing the data analyses.
☐	☐	Challenge Microorganism Specifications. Specifications for the challenge microorganism to be used during validation that include the protocols required for growth and enumeration, the expected UV dose-response, and suitability for use in validation testing.
☐	☐	Plan for state review (if applicable).

Design of the Biodosimetry Test Stand/On-site Testing Facilities

☐	☐	Inlet/outlet piping design, including backflow prevention
☐	☐	Mixing
☐	☐	Sample ports
☐	☐	Pumps
☐	☐	Additives (Material Safety Data Sheets for UV-adsorbing chemical, quenching agent)

Collimated Beam Testing Apparatus

☐	☐	Lamp type
☐	☐	Collimating tube aperture
☐	☐	Distance from light source to sample surface
☐	☐	Radiometer make and model

Monitoring Equipment Specifications and Verification of Equipment Accuracy for the following:

☐	☐	Flow meters
☐	☐	UVT analyzers (if used)
☐	☐	UV Spectrophotometers
☐	☐	Power measurement
☐	☐	UV sensors
☐	☐	Radiometer make, model, and calibration certificates

Experimental Test Conditions including, but not limited to:

☐	☐	Number of tests, UVT, flow rate, lamp power, and lamp status for each test condition
☐	☐	Lamp fouling factor, use of new or aged lamps
☐	☐	Influent concentration of challenge microorganisms for each test condition
☐	☐	QA/QC Plan

Source: UVDGM (USEPA, 2006)

Checklist 5.3 Key Elements of the Validation Report (Page 1 of 1)

Does your validation report contain the following elements?

Yes No

General

☐ ☐ Detailed reactor documentation (see Checklist 5.1), including drawings and serial numbers, and procedures used to verify reactor properties.

☐ ☐ Validation test plan (either a summary of key elements, or the test plan can be attached to the validation report along with documentation of any deviations to the original test plan)

Full-scale reactor testing results, with detailed results for each test condition evaluated. Data should include, but are not limited to:

☐ ☐ Flow rate

☐ ☐ Measured UV intensity

☐ ☐ UVT

☐ ☐ Lamp power

☐ ☐ Lamp statuses

☐ ☐ Inlet and outlet concentrations of the challenge microorganism

Collimated beam testing results, including detailed results for each collimated beam test used to create the UV dose-response equation:

☐ ☐ Volume and depth of microbial suspension

☐ ☐ UV Absorption of the microbial suspension

☐ ☐ Irradiance measurement before and after each irradiation

☐ ☐ Petri factor calculations and results

☐ ☐ Calculations for UV dose

☐ ☐ Derivation of the UV dose-response equation, including statistical methods and confidence intervals (i.e., calculation of U_{DR})

QA/QC Checks:

☐ ☐ Challenge microorganism QA/QC, including blanks, controls, and stability analyses

☐ ☐ Measurement uncertainty of the radiometer, date of most recent calibration, results of reference checks

☐ ☐ Measurement uncertainty of UV sensors and results of reference checks

☐ ☐ Measurement uncertainty of the flow meter, UV spectrophotometer, and any other measurement equipment used during full-scale testing

Calculation of the validated dose, log inactivation credit, and validated operating conditions:

☐ ☐ RED for each test condition

☐ ☐ Calculation of the VF

☐ ☐ Setpoints if the reactor uses the UV Intensity Setpoint Approach

☐ ☐ Dose-monitoring equation if the reactor uses the Calculated Dose Approach

☐ ☐ Log inactivation credit for target pathogens (e.g., *Cryptosporidium*, *Giardia*, and viruses)

☐ ☐ Validated operating conditions (e.g., flow rate, lamp status, UVT)

Source: UVDGM (USEPA, 2006)

UVDGM Checklist 5.4: Review for Quality Assurance/Quality Control

The final two checklists were created to aid evaluation of pre-validated reactors and are, therefore, the primary checklists for state reviewers. The information covered is similar to earlier checklists concerning validation planning and testing design. Checklist 5.4 summarizes the QA/QC recommendations of the UVDGM. Below is the State UV Workgroup's summary of the elements of Checklist 5.4, based on the information provided in Section 5.12 and earlier sections of the UVDGM.

Uncertainty in Measurement Equipment

- Section 5.5 of the UVDGM describes procedures to check measurement uncertainty for flow meters, UV spectrophotometers, and UV sensors. Section C.2.2 of the UVDGM describes a process for checking the accuracy of radiometers.

QA/QC of Microbial Samples

- The UVDGM recommends a QA/QC plan that involves collection of quality control samples during validation. The recommended samples are described in this part of the checklist, based on information presented in Section 5.6.4 of the UVDGM.

Uncertainty in Collimated Beam Testing Data

- The terms listed in this part of the checklist are measurements derived from the setup and operation of the collimated beam apparatus. Sections C.2.3 and C.2.4 of the UVDGM describe the process in detail. Section C.2.2 describes and accuracy check for radiometers, which are used in collimated beam testing to measure irradiance. The uncertainty of the remaining terms on this list should be estimated by laboratory personnel.
- U_{DR} is the uncertainty of the UV dose-response fit of the collimated beam data at a 95% confidence level. Section C.4 of the UVDGM describes the calculation and evaluation of this parameter. If U_{DR} is more than 30% it should be incorporated into the validation factor (VF), which represents the total uncertainty of validation, as described in Section 5.9.2 of the UVDGM.

UVDGM Checklist 5.5: Review for Key Validation Report Elements

Checklist 5.5 contains key elements that should be verified by state personnel when reviewing validation reports. The State UV Workgroup believes states should keep documentation that these key validation criteria were met. Below is the State UV Workgroup's summary of the elements of Checklist 5.5, based on the information provided in Section 5.12 and earlier sections of the UVDGM.

General

- The first element of the checklist is a reminder to review the report against the QA/QC criteria covered in Checklist 5.4.
- Adequate mixing of additives and challenge microorganisms should be tested and confirmed at multiple locations in the test stand prior to testing, as described in Section 5.4.3 of the UVDGM. Sample ports should be properly located, as described in Section 5.4.4.
- Inlet/outlet piping should be properly configured, as described in Sections 3.6.2 and 3.6.3 of the UVDGM.
- Collimated beam tests and full-scale reactor tests should be performed on the same day for a given test condition, using the same stock solution of challenge microorganisms. Full guidelines for conducting experimental validation tests are presented in Section 5.7 of the UVDGM.

- The UV sensitivity of the challenge microorganism and the overall shape of the UV dose-response curve should be consistent with the expected inactivation behavior for that challenge microorganism. Appendix A of the UVDGM presents published UV dose-response curves for MS2 and B. subtilis. The EPA-ORD UV report (USEPA 2020) presents updated dose-response QA/QC bounds for microbial surrogates commonly used in UV reactor validation, based on the accumulated history of the practice.
- The validation test design should account for lamp fouling and aging, minimum UVT, and maximum flow rate expected to occur at the water treatment plant. Section 5.6 of the UVDGM provides a detailed description of the factors to be considered in validation test design.

For UV Reactors Using MP Lamps

- Medium-pressure UV reactors that do not use a germicidal sensor should have a validation factor (VF) that incorporates a polychromatic bias factor. Section D.4.3 of the UVDGM describes the process for determining the polychromatic bias factor. New reactors should have germicidal sensors, thereby avoiding the need to incorporate the polychromatic bias factor.
- When testing of a medium-pressure UV reactor is conducted with a challenge microorganism, an action spectra correction factor should be applied when calculating the validated dose for pathogen inactivation. This concept is discussed in Section D.4.1 of the UVDGM. However, the State UV Workgroup prefers the updated correction process described in the WRF Project 4376 (Linden *et al.,* 2015) and EPA-ORD UV report (USEPA 2020).

For UV Reactors Using the UV Intensity Setpoint Approach

- Section 5.6 of the UVDGM describes the factors that should be considered during validation test design. In that section, EPA specifies a minimum of 2 test conditions for validations using the UV Intensity Setpoint Approach. The EPA-ORD UV report (USEPA 2020) identifies additional intermediate test conditions and describes their implications.
- The UV intensity setpoint should be low enough to account for combined conditions of minimum UVT and maximum lamp fouling/aging at the water treatment plant. Section 5.6.1 of the UVDGM describes a procedure for selecting the UV intensity setpoint.
- After the reduction equivalent dose (RED) is determined for each test condition, the minimum RED should be selected for calculating the validated dose. Section 5.8.2 of the UVDGM describes the process of selecting the minimum RED for the UV Intensity Setpoint Approach.
- The VF calculation incorporates both the RED bias factor (B_{RED}) and the uncertainty of validation (U_{Val}). The U_{Val} should include the uncertainty of setpoint (U_{SP}). Section 5.9 of the UVDGM describes the calculation of the VF. Section 5.9.1 provides the procedure for determining the B_{RED}. Section 5.9.2.1 describes the calculation of the U_{SP} for the UV Intensity Setpoint Approach.
- Additional factors should be incorporated into the U_{Val} if they exceed QA/QC thresholds, as described in Figure 5.4 of the UVDGM. If the uncertainty of sensor value (U_S) exceeds 10%, it should be included in the U_{Val}. Section 5.5.4 of the UVDGM provides guidance on determining U_S. If the uncertainty of the fit of the dose-response curve (U_{DR}) exceeds 30%, it should be included in the U_{Val}. Section C.4 of the UVDGM describes the calculation and evaluation of U_{DR}.
- To receive treatment credit, the validated dose must be greater than or equal to the EPA-required dose for the target pathogen and target log inactivation level, under all validated operating conditions [40 CFR 141.720(d)].

For UV Reactors Using the Calculated Dose Approach

- Section 5.6 of the UVDGM describes the factors that should be considered during validation test design. In that section, the UVDGM recommends a minimum of 27 test conditions for validation using the Calculated Dose Approach with three operating parameters (e.g., UVT, flow rate, and lamp power). The EPA-ORD UV report (USEPA 2020) presents additional approaches and procedures that complement the test design considerations presented in the UVDGM.
- Section 5.8.3 of the UVDGM describes a process for developing the dose-monitoring equation for the Calculated Dose Approach. The UVDGM recommends using multivariate linear regression to fit an equation to the validation test data. The validator should also perform an analysis of goodness of fit and bias for the dose-monitoring equation. For the fit to be acceptable, the p-statistic for each model coefficient should be no greater than 0.05.
- The VF calculation incorporates both the B_{RED} and the U_{Val}. The U_{Val} should include the uncertainty of interpolation (U_{IN}). Section 5.9 of the UVDGM describes the calculation of the VF. Section 5.9.1 provides the procedure for determining the B_{RED}. Section 5.9.2.2 describes the calculation of the U_{IN} for the Calculated Dose Approach.
- Additional factors should be incorporated into the U_{Val} if they exceed QA/QC thresholds, as described in Figure 5.5 of the UVDGM. If the U_S exceeds 10%, it should be included in the U_{Val}. Section 5.5.4 of the UVDGM provides guidance on determining U_S. If the U_{DR} exceeds 30%, it should be included in the U_{Val}. Section C.4 of the UVDGM describes the calculation and evaluation of U_{DR}.
- To receive treatment credit, the validated dose must be greater than or equal to the EPA-required dose for the target pathogen and target log inactivation level, under all validated operating conditions [40 CFR 141.720(d)].

Checklist 5.4 Review for Quality Assurance/Quality Control (Page 1 of 1)

Yes No

Uncertainty in Measurement Equipment (See Section 5.5 and C.2.2 for more information)

☐ ☐ **Flow Meter:** Is the measurement uncertainty < 5 percent?

☐ ☐ **UV Spectrophotometer:** Is the measurement uncertainty ≤ 10 percent?

☐ ☐ **UV Sensors:** Did duty sensors operate within 10 percent of the average of two or more reference sensors? If not, was uncertainty in sensor measurement incorporated into the VF?

☐ ☐ **Radiometer:** (for collimated beam testing only). Do lamp output measurements vary by no more than 5 percent over exposure time? Was the accuracy of the radiometer verified with another radiometer?

QA/QC of Microbial Samples (See Section 5.6.4 for more information)

☐ ☐ **Reactor controls:** For influent/effluent samples taken with the UV reactor lamps turned off, does the change in log concentration correspond to a change in RED that is within the measurement error of the minimum RED measured during validation (typically ≤ 3 %)?

☐ ☐ **Reactor blanks:** For DAILY influent/effluent samples taken with NO challenge microorganisms injected, are the measured concentrations of the challenge microorganism negligible?

☐ ☐ **Trip Controls:** For an UNTESTED sample bottle of challenge microorganism stock solution that travels with tested samples between the laboratory and the reactor, is the change in the log concentration of the challenge microorganism within the measurement error. (I.e., the change in concentration over the test run should be negligible. This is typically on the order of 3 to 5%.)

☐ ☐ **Method Blanks:** For sterilized reagent grade put through the challenge microorganism assay procedure, is the challenge microorganism concentration non-detectable?

☐ ☐ **Stability Samples**: For influent/effluent samples at low and high UVT, are the challenge microorganism concentrations within 5 percent of each other?

Uncertainty in Collimated Beam Testing Data (See Appendix C for more information)

☐ ☐ Do the uncertainties in the terms in the UV dose calculation meet the following criteria:

- Depth of suspension (d) ≤ 10 percent
- Incidence irradiance (E_s) ≤ 8 percent
- Petri factor (P_f) ≤ 5 percent
- L/(d + L) ≤ 1 percent
- Time (t) ≤ 5 percent
- $(1 - 10^{-ad})/ad$ ≤ 5 percent

☐ ☐ Is the **uncertainty in dose-response** (U_{DR}), as calculated using equation C.6, less than or equal to 30 percent? If not, was U_{DR} incorporated into the VF?

Source: UVDGM (USEPA, 2006)

Checklist 5.5 Review for Key Validation Report Elements (Page 1 of 2)

Yes	No	
☐	☐	Does the validation testing meet QA/QC criteria (see Checklist 5.4)?
☐	☐	For full-scale testing, does the mixing and location of sample ports follow recommendations provided in Sections 5.4.3 and 5.4.4, respectively?
☐	☐	If the reactor was validated off-site, do inlet/outlet piping conditions at the water treatment plant result in a UV dose-delivery that is **the same or greater than** the UV dose delivery at the off-site testing facility? (See Section 3.6 for recommended inlet/outlet piping configurations and Section D.6 for considerations for CFD modeling.)
☐	☐	Were collimated beam tests and full-scale reactor tests performed on the same day for a given test condition and using the same stock solution of challenge microorganisms? (See Section 5.7 for experimental testing guidelines.)
☐	☐	Is the UV sensitivity of the challenge microorganism and the overall shape of the UV dose-response curve consistent with the expected inactivation behavior for that challenge microorganism? See Appendix A of this manual for published UV dose-response curves for MS2 and *B. subtilis*.
☐	☐	Does the validation test design account for lamp fouling and aging, minimum UVT, and maximum flow rate expected to occur at the water treatment plant? (See Section 5.6 for recommended test design.)
For UV Reactors Using MP Lamps		
☐	☐	Is the UV reactor equipped with a germicidal sensor? New UV reactors should have germicidal sensors. If an installed reactor uses an MP lamp and a non-germicidal sensor, is a polychromatic bias factor incorporated into the derivation of the VF? (See Section D.4.3 for guidance on the polychromatic bias factor.)
☐	☐	Was validation testing conducted using a challenge microorganism other than MS2 or *B. Subtilis*? If yes, was the need for a correction factor assessed and was that factor applied based on the outcome? (See Sections 5.3 and D.4.1 for more information)
For UV Reactors Using the UV Intensity Setpoint Approach		
☐	☐	Were the minimum test conditions performed as specified in Section 5.6.1?
☐	☐	Is the UV intensity setpoint low enough to account for combined conditions of minimum UVT and maximum lamp fouling/aging at the water treatment plant (See Section 5.6.1 for guidance)
☐	☐	Was the **minimum RED** selected for calculating the validated dose? (See Section 5.8.1 for additional guidance.)
☐	☐	Does the VF calculation include both the B_{RED} and U_{SP}? (See Section 5.9 for additional guidance.)

Checklist 5.5 Review for Key Validation Report Elements (Page 2 of 2)

Yes	No	
For UV Reactors Using the UV Intensity Setpoint Approach (continued)		
☐	☐	If U_S and/or U_{DR} did not meet the QA/QC criteria, were they also included in the VF calculation?
☐	☐	Is the validated dose greater than or equal to the required dose for the water system's target pathogen and log inactivation level?
For UV Reactors Using the Calculated Dose Approach		
☐	☐	Was the minimum number of test conditions evaluated as specified in Section 5.6.2?
☐	☐	Was the empirical equation developed using standard statistical methods (e.g., multivariate linear regression)? (See Section 5.8.2 for additional guidance.)
☐	☐	Does the validation report include an analysis of goodness of fit and bias for the dose-monitoring equation? (See 5.8.2 for additional guidance.)
☐	☐	Does the VF calculation include both the B_{RED} and U_{IN}? (See 5.9.)
☐	☐	If U_S and/or U_{DR} did not meet the QA/QC criteria, were they also included in the VF calculation?
☐	☐	For the range of UVT values and flow rates expected to occur at the water system, is the validated dose greater than or equal to the required dose for the system's target pathogen and log inactivation?

Source: UVDGM (USEPA, 2006)

UV PLAN REVIEW APPROVAL LETTER

Below is an example of a state's plan approval report written for the hypothetical situation of a system installing UV for Cryptosporidium credit, based on a validation study conducted using MS2. It is useful to draft such a report to record approval, to clearly communicate the determination of the state, and to have it available for use by SDWA primacy agency oversight personnel and water treatment plant officials. The summary could also include annotated copies of the review tables that are presented in earlier sections of the UV Toolkit.

The required UV doses for achieving log inactivation of the target pathogen (i.e., Cryptosporidium) were published in the Federal Register on January 5, 2006. The required dose is the dose needed to achieve the target log inactivation for the target pathogen. To achieve compliance, the validated dose must be greater than or equal to the required dose [40 CFR 141.720(d)]. To determine the validated dose, a calculated dose will be divided by a validation factor (VF). The VF is a safety factor to account for various uncertainties. The UV reactor to be installed has undergone validation testing, which has been described in a validation report. The validation report includes equations to determine the calculated dose, the validation factor, and the resulting validated dose. These equations have been programmed into a reactor local control panel (LCP). The control panels will then be monitored by the SCADA system.

The calculated dose equation was formulated during the validation study and it relates the measured UV dose from a collimated beam test (ideal conditions) to the actual dose needed in a full-scale unit (actual conditions) to achieve the same inactivation result. The calculated dose equation is a function of flow rate, UV transmittance (UVT), average UV sensitivity of the challenge microorganism (i.e., MS2), and S/S_0 (intensity at reduced lamp power from fouling/aging versus intensity at 100 percent lamp power). The VF equation takes into account the reduction equivalent dose (RED) bias and the uncertainty of validation (U_{VAL}). The uncertainty of validation is the sum of the uncertainty of sensor values (U_S), the uncertainty of the fit of the dose-response curve (U_{DR}), and the uncertainty of interpolation (U_{IN}). The RED bias (B_{RED}) is a correction factor that accounts for the difference between the UV sensitivity of the target pathogen (i.e., Cryptosporidium) and the UV sensitivity of the challenge microorganism (i.e., MS2).

The REDs observed during validation ranged from 20.76 to 79.42 mJ/cm^2 for the challenge microorganism (i.e., MS2). Therefore, the control system can calculate validated doses based on MS2 data when the REDs are in the range of 20.76 to 79.42 mJ/cm^2.

The challenge microorganism (i.e., MS2) was used as a surrogate for the target pathogen (i.e., Cryptosporidium) during collimated beam testing and validation testing for the units installed at {PWS name}. Recent data shows that at UV wavelengths below 240 nm (which occur with medium pressure lamps), the amount of {Cryptosporidium} inactivation calculated using {MS2} as a surrogate may have been overestimated based on the difference in the action spectra of {Cryptosporidium and MS2}. Although {Cryptosporidium} inactivation may not be as effective at wavelengths lower than 240 nm, these lower wavelengths are effective in inactivating {MS2}. Since the validation studies used {MS2} data to develop formulas for inactivating {Cryptosporidium}, the resulting formulas may overestimate the amount of {Cryptosporidium} inactivation provided at wavelengths below 240 nm. UV stakeholders researched the behavior (action spectra) of {MS2} at lower wavelengths and have provided a guidance document to determine a correction factor for validation. UVT is also a factor,

as the lower wavelengths may not penetrate through water with a low UVT as they would through water with a high UVT. The UV reactors at {PWS Name} will be programmed to include a fixed action spectra correction factor of {1.30} to account for overestimation of inactivation during validation.

The control system that operates the UV facility is a very complex program that continuously compares expected values, calculated values, and measured values and uses them to ensure that an adequate UV dose is being provided and to ensure the system is operating with efficiency. The control system allows the user to treat for {Cryptosporidium based on MS2 data}. Alarms will be provided for the parameters which are required to be monitored (i.e., flow rate, UVT, lamp status, and off-specification events), in addition to many other alarms. Off-specification events will be monitored for duration and volume treated, in order to determine compliance with the off-specification requirements. If the unit operates outside of the validated range, below the required dose, or if data on a measured parameter is not provided due to equipment failure, the PLC will be used to track data during this time so it can be recorded as an off-specification event.

UV OPERATION REQUIREMENTS

To receive disinfection credit from the state, the Long-Term 2 Enhanced Surface Water Treatment Rule requires PWSs to monitor their UV reactors to demonstrate that they are operating within the range of conditions that were validated for the required UV dose. As per 40 CFR 141.720(d)(3), monitoring must include the following:

- PWSs must monitor each reactor for flow rate, lamp status, UV intensity as measured by a UV sensor, and any other parameters required by the state or primacy agency.
- UV absorbance should also be measured when it is used in a dose-monitoring strategy.
- PWSs must verify the calibration of UV sensors and recalibrate sensors in accordance with a protocol the state or primacy agency approves.
- To receive disinfection credit for UV, PWSs must treat at least 95 percent of the water delivered to the public during each month by UV reactors operating within validated conditions for the required UV dose.

The State UV Workgroup believes it is important for the water system to confirm that the UV reactor units will be programmed to conform to the monitoring algorithms devised from validation testing. Further, the workgroup believes that they should be programmed to notate off-specification operation when the reactors are operating outside the validated envelope provided in the validation report. Conformance to these criteria should be field-verified before startup of the UV facility.

Monitoring of Duty UV Sensor Calibration

Manufacturers will calibrate the UV sensors prior to installation. However, over time the UV sensors will drift out of calibration. If a UV reactor is turned on and the calibration of the UV sensors has not been verified, the UV reactor may be operating outside of validated conditions.

Section 6.4.1.1 of the UVDGM recommends that calibration of UV sensors be verified with a reference UV sensor at least monthly. Reference UV sensors are off-line UV sensors that should be at least as accurate as the duty UV sensors and should be constructed identically (with any exceptions to make them more accurate). A complete protocol for evaluating and calibrating UV sensor is provided in Section 6.4.1.1 of the UVDGM.

Use of UV Sensor Correction Factor

As stated in Section 6.4.1.1 of the UVDGM, a failed duty UV sensor should be replaced with a calibrated duty UV sensor or the UV reactor is off-specification (if operated). However, replacement may not be an option if multiple UV sensors fail and/or no additional UV sensors are immediately available. PWSs that cannot immediately replace a duty UV sensor that failed the UV sensor calibration criterion should implement a UV sensor correction factor (CF). In this approach, a CF is selected and applied to either the intensity setpoint or required dose (depending on the dose-monitoring strategy) for the affected UV reactor. Operating with a CF is not energy efficient; however, this method enables the UV facility to remain in operation while the UV sensor problem is resolved. A complete protocol for developing and applying a UV sensor CF is provided in Section 6.4.1.1 of the UVDGM. Additional information is provided in USEPA 2020.

Monitoring of UVT Analyzer Calibration

As stated in Section 6.4.1.2 of the UVDGM, compliance monitoring of UVT analyzer calibration is required only when UVT is an integral part of the dose-monitoring strategy, such as with the Calculated Dose Approach. If the UV Intensity Setpoint Approach is used, UVT analyzer calibration checks are not required unless used for other purposes because UVT is not used to verify UV dose delivery.

Section 6.4.1.2 of the UVDGM recommends that on-line UVT analyzers be evaluated at least weekly by comparing the on-line UVT measurements to UVT measurements using a bench-top spectrophotometer. The bench-top spectrophotometer should be maintained and calibrated at the frequency required by the manufacturer. The calibration monitoring frequency may be decreased or increased based on the performance demonstrated over a one-year period, if approved by the state. For example, the frequency could be reduced to once per month if the UVT analyzer is consistently within the allowable calibration error for more than a month during the first year of monitoring. A complete protocol for monitoring UVT analyzer calibration is provided in Section 6.4.1.1 of the UVDGM. Additional information is provided in USEPA 2020.

Off-Specification Events (Operating Outside of Validated Conditions)

Off-specification operation occurs when the UV facility operates outside of the validated conditions, a UV sensor is not in calibration, the UVT analyzer is not in calibration (and it is part of the dose-monitoring strategy), or UV equipment is not equivalent or better than the equipment validated. These situations are explained in further detail below.

Validated Conditions

As specified in 40 CFR 141.720(d)(3), PWSs must monitor each reactor to determine whether it is operating within validated conditions. The validated parameters to monitor depend on the dose-monitoring strategy used and the validation results. Table 12 (from Section 6.4.1.3 of the UVDGM) presents the monitoring parameters for two monitoring approaches, along with examples of off-specification triggers.

Table 12. Off-Specification Examples for Each Monitoring Approach

Dose-monitoring strategy	Parameters Monitored	Off-specification Examples
UV Intensity Setpoint Approach	UV intensity, flow rate, lamp status	1. UV intensity below minimum value 2. Flow rate above validated limit
Calculated Dose Approach	calculated dose, VF, validated dose, flow rate, UVT, lamp status	1. Validated dose below D_{Req} 2. Flow rate above validated limit 3. UVT below minimum value

VF = Validation factor
D_{Req} = Required UV dose

Source: UVDGM (USEPA, 2006)

UV Sensor Calibration

A UV reactor is producing off-specification water if all three of the following conditions occur.

1. Any of the duty UV sensors did not meet the calibration criteria in the state-approved protocol.
2. The duty UV sensors were not replaced with calibrated duty UV sensors.
3. UV sensor correction factor was not applied.

UVT Analyzer Calibration

Similarly, the UV facility may be operating off-specification if the UVT analyzer is found to be out of calibration and remedial actions are not completed.

UV Equipment Components

The LT2ESWTR requires that water systems use reactors that have undergone validation testing [40 CFR 141.720(d)(2)]. It follows, therefore, that installed and replaced components should be equal to or better than the components used during validation testing. If not, the UV facility may be operating off-specification unless the UV equipment is re-validated.

Monitoring and Recording Frequency of Required Parameters

Section 6.4.1.4 of the UVDGM recommends that the required dose-monitoring parameters (flow rate, UV intensity, number of banks on, etc.) be continuously monitored (i.e., at least every 5 minutes) for each UV reactor, and these values recorded at least once every 4 hours. Very small systems (e.g., systems serving fewer than 500 people) that cannot record reactor status every 4 hours (e.g., manual recording is practiced) could consider a reduced recording frequency; however, the UVDGM recommends that the frequency be no less than once per day and should be discussed with the state or primacy agency.

Section 6.4.1.4 of the UVDGM further recommends that all water systems record off-specification alarms at a minimum of 5-minute intervals until the alarm condition has been corrected. Measurement of off-specification volume should start as soon as treatment conditions are found to be outside of the validated range. The measurement of off-specification volume should stop as soon as treatment conditions are shown to be within the validated limits.

Example Reporting Forms

Example monitoring and reporting forms have been included in the UV Toolkit for use by reviewing officials. They are based on those provided in Section 6.5.2 of the UVDGM. Some of them are calculation worksheets for use by the PWS that do not need to be submitted to the state on a regular basis. However, the State UV Workgroup believes PWSs should be prepared to make them available upon request and during on-site surveys.

In addition, the UV Toolkit includes detailed instructions for each form provided. The State UV Workgroup developed these instructions using the information provided in Chapter 6 of the UVDGM, along with information presented in earlier sections of this UV toolkit. Any suggestions contained in these instructions are those of the State UV Workgroup, unless otherwise cited. These forms and instructions are available electronically, to enable states to make changes to suit their needs. Example forms and instructions are provided for each of the following:

- **Monthly Operating Report**: Each month, PWSs must submit a monthly operating report (MOR) [40 CFR 141.721(f)(15)]. One of the most useful planning steps that PWSs can make during UV installation is to design SCADA to allow the operator to complete the MOR easily. The information in the UV Toolkit is intended to serve as a template to aid in that process.
- **Daily Operating Log for Calculated Dose/UV Intensity Setpoint Approach**: To be completed daily for each reactor. Used to record the operating status of the UV equipment and to record the volume of off-specification water produced during operation each day.

- **Off-Specification Calculation Worksheet**: This worksheet can assist PWSs with calculating the percentage of off-specification water produced.
- **UV Sensor Calibration Worksheet**: To be completed whenever UV sensor calibration checks are performed.
- **UV Sensor Correction Factor (CF) Calculation Worksheet**: This worksheet can help PWSs determine the appropriate UV sensor CF when the PWS needs to use this approach to stay in compliance.
- **Monthly UVT Analyzer Calibration Log**: This log would be used only by those PWSs that have included on-line UVT analyzers as part of their dose-monitoring strategies. To be completed whenever UVT analyzer calibration checks are performed.

The State UV Workgroup recommends that the logs and worksheets listed above be filed by PWSs so they are readily available for inspection during on-site audits (e.g., sanitary surveys). In particular, the auditor may want to inspect forms that are not routinely submitted, including daily operating logs and calibration check logs.

INSTRUCTIONS FOR COMPLETING THE UVDGM MONTHLY OPERATING REPORT (MOR)

As specified in 40 CFR 141.721 (f)(15), to receive UV disinfection credit, a water system must complete and submit a monthly report summarizing the percentage of water entering the distribution system that was not treated by UV reactors operating within validated conditions for the required dose.

Public Water System Information

PWS Name: Print or type name of public water system (PWS).
Facility Name: Print or type name of facility.
PWSID: Enter the PWS ID number.
Facility ID: Enter the facility ID number.

Header Rows

Reporting Period: Enter month and year in which data was collected.
Target Pathogen: Enter the name of the target pathogen (i.e., *Giardia*, *Cryptosporidium*, and/or Viruses). The target pathogen should be identified in the plan approval for the UV facility. (Example: If treating for *Cryptosporidium* or, *Cryptosporidium* and *Giardia*, enter "*Cryptosporidium*" as the target pathogen and use only data related to inactivation of *Cryptosporidium* on the form. If treating ONLY for *Giardia*, enter "*Giardia*" as the target pathogen and use only data related to inactivation of *Giardia* on the form.)
Surrogate: Enter the surrogate (or surrogates) the PLC is using to determine the calculated dose for the target pathogen. (Example: MS2, T1UV.) The surrogate(s) used should be the same surrogate(s) used in the validation study and documented in the plan approval.
Target Log Inactivation: Enter the log inactivation credit the system is requesting. This should be at least as high as the inactivation that the system is required to provide and should be lower than or equal to the eligible credit indicated in the plan approval for the UV facility. (Note: The off-specification events for which information is provided on the MOR should be determined by using the target log inactivation.)

Table Columns

The table is designed to capture one full month of operations data for all reactors operated at the UV facility during the reporting period. One row of data should be entered for each reactor.

Reactor Number: Enter the identifying number of the UV reactor. Report information for each reactor that was operated during the reporting period.
Total Reactor Production: Enter the total amount (million gallons) of water treated by the UV reactor and sent to the distribution system during the reporting period.

Off-Specification Data

Number of Off-Specification Events: Enter the number of events in which a reactor was operated off-specification for five minutes or greater. Off-specification operation occurs when the UV facility operates outside of the validated conditions, a UV sensor is not in

calibration, the UVT analyzer is not in calibration (and it is part of the dose-monitoring strategy), or UV equipment is not equivalent or better than the equipment validated.

Total Off-Specification Volume: Enter the total volume (million gallons) of water produced by the reactor during each off-specification event. This number should be determined by completing the Off-Specification Worksheet.

Total Volume Produced (parameter [A] on the report): Add the numbers in the column titled "Total Reactor Production," and enter the total at the bottom of the column. This is the total amount of water produced by the UV facility during the reporting period, including both on-specification and off-specification water.

Total Off-Specification Volume (parameter [B] on the report): Add the numbers in the column titled "Total Off-Specification Volume," and enter the total at the bottom of the column. This is the total amount of off-specification water produced by the UV facility during the reporting period.

Compliance Certification

Total Volume of Off-Specification Water Produced: Enter the total amount of off-specification water (million gallons) produced by the UV facility ([B]).

Total Volume of Water Produced: Enter the total volume of water (million gallons) produced by the UV facility ([A]).

Total Off-Specification Water Produced: Divide [B] by [A] then multiply the result by 100. This is the total percentage of off-specification water produced.

Facility Meets Off-Specification Requirement: Enter "Yes" if the total percentage of off-specification water produced is less than or equal to 5%. Otherwise, enter "No."

Total Number of Duty Sensors Used at this Facility: Enter the total number of sensors.

Total Number of Duty Sensors Checked for Calibration this Month: Enter the total number of sensors that were checked for calibration during the reporting period.

Total Number of Checked Sensors Within Acceptable Range of Tolerance: Enter the total number of sensors that were found to be acceptable, using the UV Sensor Calibration Worksheet.

Reactor that had a Sensor Correction Factor

Complete this box if there were one or more reactors that used a duty sensor with a sensor correction factor applied during this reporting period. The correction factor should be determined using the UV Sensor Correction Factor (CF) Worksheet.

Reactor Number: Enter the number of the reactor that used a sensor with a correction factor.

Sensor Correction Factor: Enter the sensor correction factor.

At the bottom of the report, print the name and certification number of the Operator of Record. The Responsible Official should sign the report and enter the date it was completed.

State Logo

PWS Name: _____
Facility Name: _____
PWSID: _____
Facility ID: _____
Reporting Period: _____

UV Treatment
Monthly Operating Report (MOR)

Target Pathogen: _____ Surrogate: _____ Target Log Inactivation: _____

Reactor Number	Total Reactor Production (MG)	Off-Specification Data	
		Number of Off-Specification Events	Total Off-Specification Volume (MG)
Total Volume Produced: [A]		**Total Off-Specification Volume: [B]**	

Compliance Certification

Total Volume of Off-Specification Water Produced (MG): [B] _____
Total Volume of Water Produced (MG): [A] _____
Total Off-Specification Water Produced (% of Volume of Water Produced): [B] / [A] x 100 _____
Facility Meets Off-Specification Requirement (< 5% of Volume on a Monthly Basis)? (Yes/No) _____

Total Number of Duty Sensors Used at This Facility: _____
Total Number of Duty Sensors Checked for Calibration This Month: _____
Total Number of Checked Sensors Within the Acceptable Range of Tolerance: _____

Reactors that had a Sensor Correction Factor

Reactor Number	Sensor Correction Factor

I certify that I have personally examined and am familiar with the data submitted in this MOR and that it is true and accurate to the best of my knowledge.

Name & Number of Certified Operator	Signature of Responsible Official	Date

INSTRUCTIONS FOR COMPLETING THE UVDGM DAILY OPERATING LOG FOR THE CALCULATED DOSE APPROACH

This log is designed for use with one UV reactor. A separate log should be maintained for each reactor, each day the UV facilities are in operation. The logs should be made available for review upon request.

Public Water System Information

PWS Name: Print or type name of public water system (PWS).
Facility Name: Print or type name of facility.
PWSID: Enter the PWS ID number.
Facility ID: Enter the facility ID number.

Header Rows

Reporting Period: Enter month and year in which data was collected.
UV Reactor Number: Enter the identifying number of the UV reactor.
Maximum Validated Flow Rate: Enter the maximum flow rate which was validated and approved as part of the plan approval for the UV facility. This will remain the same every month.
Minimum Validated UVT: Enter the minimum UVT which was validated and approved as part of the plan approval for the UV facilities. This will remain the same every month.
Target Log Inactivation: Enter the log inactivation credit the system is requesting. This should be at least as high as the inactivation that the system is required to provide and should be lower than or equal to the eligible credit indicated in the plan approval for the UV facility. (Note: The off-specification events for which information is provided on the MOR should be determined by using the target log inactivation.)
Target Pathogen: Enter the name of the target pathogen (i.e., *Giardia*, *Cryptosporidium*, and/or Viruses). The target pathogen should be identified in the plan approval for the UV facility. (Example: If treating for *Cryptosporidium* or, *Cryptosporidium* and *Giardia*, enter "*Cryptosporidium*" as the target pathogen and use only data related to inactivation of *Cryptosporidium* on the form. If treating ONLY for *Giardia*, enter "*Giardia*" as the target pathogen and use only data related to inactivation of *Giardia* on the form.)
Surrogate: Enter the surrogate (or surrogates) the PLC is using to determine the calculated dose for the target pathogen. (Example: MS2, T1UV.) The surrogate(s) used should be the same surrogate(s) used in the validation study and documented in the plan approval.
Dose Required for Target Log Inactivation: Enter the required dose from the UV dose table for the target log inactivation indicated. The required UV doses are published in 40 CFR 141.720(d)(1) and shown in Table 4 of this toolkit.

Table Columns

The table is designed to capture one full month of operations data for a single reactor. One row of data should be entered for each day of operation.

Operations Data

Run Time: Enter the total amount of time (hours) the UV reactor was operated during the day.

Total Reactor Production: Enter the total amount (million gallons) of water treated by the UV reactor and sent to the distribution system.

ASCF (parameter [A] on the log): For systems using medium pressure UV lamps, an action spectra correction factor is necessary to compensate for the difference in inactivation of target pathogen relative to the surrogate used in validation.
(Note: The validation factor should include an Action Spectra Correction Factor (ASCF) for medium pressure UV reactors as determined during the validation study or as determined by the industry as more information becomes available.)
Validation Factor (parameter [B] on the log): Enter the validation factor, as calculated by the validated PLC algorithm for the UV reactor.

Data Observed at Daily Minimum Validated Dose

The PLC should indicate the minimum validated dose provided by the reactor for the day. Once that validated dose is determined, its corresponding operational parameters should be entered in the six columns under the category "Data Observed at Daily Minimum Validated Dose."

UV Sensor Correction Factor (parameter [C] on the log): If a sensor correction factor was needed, enter the sensor correction factor which was calculated using the UV Sensor Correction Factor (CF) Worksheet. If a sensor correction factor was not needed, enter "1."
(Note: A sensor correction factor is only necessary if the UV duty sensor fails the calibration criterion and cannot be replaced immediately. This is not for long term operation and the duty sensor should be replaced as quickly as possible.)
Calculated Dose (parameter [D] on the log): Enter the dose (mJ/cm^2) that is calculated by the validated PLC algorithm for the UV reactor.
Daily Minimum Validated Dose (parameter [E] on the log): Enter the minimum validated dose provided by the reactor for the day ([D]/[A]/[B]/[C]).
Flow Rate: Enter the flow rate (MGD) that occurred at the time the minimum validated dose was produced by the UV reactor during the day.
UVT: Enter the UVT (%) that was measured at the time the minimum validated dose was produced by the UV reactor during the day.
Validated Dose > $D_{req'd}$?: If the validated dose ([E]) is greater than the dose required for target log inactivation, enter "Y." Otherwise, enter "N."

Total Off-Specification Volume: Enter the total off-specification volume (million gallons) for this reactor for the day. This number should be determined by completing the Off-Specification Worksheet.

State Logo

$$Validated\ Dose = \frac{Calculated\ Dose}{VF \times CF \times ASCF\ (if\ applicable)}$$

where:
Calculated Dose is the dose calculated by the validated PLC algorithm.
VF is the validation factor.
CF is the UV intensity sensor correction factor.
The CF is only applied if sensors do not meet recommended criteria.
Note: a CF will not be needed in most cases.
ASCF is the action spectra correction factor (for medium pressure lamps).

UV Treatment Daily Operating Log (Calculated Dose Approach)

PWS Name: _____
Facility Name: _____
PWSID: _____
Facility ID: _____
Reporting Period: _____

UV Reactor Number: _____
Maximum Validated Flow Rate: _____
Minimum Validated UVT: _____
Target Log Inactivation: _____
Target Pathogen: _____ Surrogate: _____
Dose Required[1] for Target Log Inactivation: _____

Operations Data					Data Observed at Daily Minimum Validated Dose						
Day	Run Time (hrs)	Total Reactor Production (MG)	ASCF [A]	Validation Factor (mJ/cm^2) [B]	UV Sensor Correction Factor[2] [C]	Calculated Dose[3] (mJ/cm^2) [D]	Daily Minimum Validated Dose[4] [D]/[A]/[B]/[C] (mJ/cm^2) [E]	Flow Rate (MGD)	UVT (%)	Validated Dose > $D_{req'd}$? ([E] > $D_{req'd}$?) (Y/N)	Total Off-Specification Volume[5] (MG)
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											
26											
27											
28											
29											
30											
31											
Min											
Max											
Total											

[1] $D_{N,M}$ is the dose required for the target log inactivation without a VF or Sensor CF applied.

[2] Sensor CF will be 1 if no CF is used.

[3] Calculated dose is calculated using the dose algorithm in the PLC.

[4] The Validated Dose is the dose based on the calculated dose normalized on the Validation Factor and Correction Factor.

[5] Off-specification worksheet should be used to calculate any daily off-specification volume. If UVT, flowrate, and/or Validated Dose off-specification occur simultaneously, the off-specification time should only be counted once.

INSTRUCTIONS FOR COMPLETING THE UVDGM DAILY OPERATING LOG FOR THE INTENSITY SETPOINT APPROACH

This log is designed for use with one UV reactor. A separate log should be maintained for each reactor, each day the UV facilities are in operation. The logs should be made available for review upon request.

Public Water System Information

PWS Name: Print or type name of public water system (PWS).
Facility Name: Print or type name of facility.
PWSID: Enter the PWS ID number.
Facility ID: Enter the facility ID number.

Header Rows

Reporting Period: Enter month and year in which data was collected.
UV Reactor Number: Enter the identifying number of the UV reactor.
Maximum Validated Flow Rate: Enter the maximum flow rate which was validated and approved as part of the plan approval for the UV facility. This will remain the same every month.
Minimum Validated UVT: Enter the minimum UVT which was validated and approved as part of the plan approval for the UV facilities. This will remain the same every month.
Target Log Inactivation: Enter the log inactivation credit the system is requesting. This should be at least as high as the inactivation that the system is required to provide and should be lower than or equal to the eligible credit indicated in the plan approval for the UV facility. (Note: The off-specification events for which information is provided on the MOR should be determined by using the target log inactivation.)
Target Pathogen: Enter the name of the target pathogen (i.e., *Giardia*, *Cryptosporidium*, and/or Viruses). The target pathogen should be identified in the plan approval for the UV facility. (Example: If treating for *Cryptosporidium* or, *Cryptosporidium* and *Giardia*, enter "*Cryptosporidium*" as the target pathogen and use only data related to inactivation of *Cryptosporidium* on the form. If treating ONLY for *Giardia*, enter "*Giardia*" as the target pathogen and use only data related to inactivation of *Giardia* on the form.)
Surrogate: Enter the surrogate (or surrogates) the PLC is using to determine the calculated dose for the target pathogen. (Example: MS2, T1UV.) The surrogate(s) used should be the same surrogate(s) used in the validation study and documented in the plan approval.
Intensity Setpoint Required for Target Log Inactivation: Enter the intensity setpoint which, from the validation study, corresponds to compliance with the required dose from the UV dose table for the target log inactivation indicated. The required UV doses are published in 40 CFR 141.720(d)(1) and shown in Table 4 of this toolkit.

Table Columns

The table is designed to capture one full month of operations data for a single reactor. One row of data should be entered for each day of operation.

Operations Data

Run Time: Enter the total amount of time (hours) the UV reactor was operated during the day.

Total Reactor Production: Enter the total amount (million gallons) of water treated by the UV reactor and sent to the distribution system.

Minimum Flow Rate: Enter the minimum flow rate (MGD) that was observed for the UV reactor during treatment that day.

Average Flow Rate: Enter the average flow rate (MGD) that was observed for the UV reactor during treatment that day.

Maximum Flow Rate: Enter the maximum flow rate (MGD) that was observed for the UV reactor during treatment that day.

Minimum UVT: Enter the minimum UVT (%) which was measured for the reactor that day.

Intensity Requirements

Intensity Setpoint (parameter [A] on the log): Enter the required intensity setpoint (W/m^2), without correction factors. This is the setpoint value from the validation study which corresponds to the required dose for the given target log inactivation.

ASCF (parameter [A] on the log): For systems using medium pressure UV lamps, an action spectra correction factor is necessary to compensate for the difference in inactivation of target pathogen relative to the surrogate used in validation.
(Note: The validation factor should include an Action Spectra Correction Factor (ASCF) for medium pressure UV reactors as determined during the validation study or as determined by the industry as more information becomes available.)

UV Sensor Correction Factor (parameter [C] on the log): If a sensor correction factor was needed, enter the sensor correction factor which was calculated using the UV Sensor Correction Factor (CF) Worksheet. If a sensor correction factor was not needed, enter "1."
(Note: A sensor correction factor is only necessary if the UV duty sensor fails the calibration criterion and cannot be replaced immediately. This is not for long term operation and the duty sensor should be replaced as quickly as possible.)

Adjusted Intensity Setpoint: This is the required intensity (W/m^2) that should be met to achieve the target log inactivation of the target pathogen ([A] × [B] × [C]).

Daily Minimum Intensity (parameter [E] on the log): Enter the minimum intensity (W/m^2) provided by the reactor during treatment for the day.

Minimum Intensity > Adjusted Intensity Setpoint?: If the daily minimum intensity ([E]) is greater than the adjusted intensity setpoint ([D]), enter "Y." Otherwise, enter "N."

Total Off-Specification Volume: Enter the total off-specification volume (million gallons) for this reactor for the day. This number should be determined by completing the Off-Specification Worksheet.

State Logo

UV Treatment
Daily Operating Log
(Intensity Setpoint Approach)

PWS Name: _____
Facility Name: _____
PWSID: _____
Facility ID: _____
Reporting Period: _____

UV Reactor Number: _____
Maximum Validated Flow Rate: _____
Minimum Validated UVT: _____
Target Log Inactivation: _____
Target Pathogen: _____ Surrogate: _____
Intensity Setpoint Required for Target Log Inactivation: _____

Day	Operations Data					Minimum UVT[1]	Intensity Requirements						Total Off-Specification Volume[4]
	Run Time (hrs)	Total Reactor Production (MG)	Minimum Flow Rate (MGD)	Average Flow Rate (MGD)	Maximum Flow Rate (MGD)	(%)	Intensity Setpoint (W/m^2) [A]	ASCF[2] [B]	UV Sensor Correction Factor[3] [C]	Adjusted Intensity Setpoint [A]x[B]x[C] (W/m^2) [D]	Daily Minimum Intensity (W/m^2) [E]	Minimum Intensity > Adjusted Intensity Setpoint? ([E] > [D]?) (Y/N)	(MG)
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													

11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													
Min													
Max													
Total													

[1] UVT measurements are not required but could be useful in addressing operational issues.

[2] An Action Spectra Correction Factor (ASCF) may be required for medium pressure lamps.

[3] Sensor CF will be 1 if no CF is used.

[4] Off-specification worksheet should be used to calculate any daily off-specification volume. If UVT, flowrate, and/or Validated Dose off-specification occur simultaneously, the off-specification time should only be counted once.

INSTRUCTIONS FOR COMPLETING THE UVDGM OFF-SPECIFICATION CALCULATION WORKSHEET

This worksheet should be completed when an off-specification event occurs at the UV facility and should be made available for review upon request. Each UV reactor should be equipped with an alarm to indicate when it is operating outside of the validated conditions. As described in Section 6.4.1.4 of the UVDGM, the required dose-monitoring parameters (e.g., flow rate, UV intensity) should be monitored at least every 5 minutes to send data to the alarm. The off-specification alarm should be recorded at a minimum of 5-minute intervals until the alarm condition has been corrected.

Public Water System Information

PWS Name: Print or type name of public water system (PWS).
Facility Name: Print or type name of facility.
PWSID: Enter the PWS ID number.
Facility ID: Enter the facility ID number.

Header Rows

Reporting Period: Enter month and year in which data was collected.
Target Pathogen: Enter the name of the target pathogen (i.e., *Giardia*, *Cryptosporidium*, and/or Viruses). The target pathogen should be identified in the plan approval for the UV facility. (Example: If treating for *Cryptosporidium* or, *Cryptosporidium* and *Giardia*, enter "*Cryptosporidium*" as the target pathogen and use only data related to inactivation of *Cryptosporidium* on the form. If treating ONLY for *Giardia*, enter "*Giardia*" as the target pathogen and use only data related to inactivation of *Giardia* on the form.)
Surrogate: Enter the surrogate (or surrogates) the PLC is using to determine the calculated dose for the target pathogen. (Example: MS2, T1UV.) The surrogate(s) used should be the same surrogate(s) used in the validation study and documented in the plan approval.
Target Log Inactivation: Enter the log inactivation credit the system is requesting. This should be at least as high as the inactivation that the system is required to provide and should be lower than or equal to the eligible credit indicated in the plan approval for the UV facility. (Note: The off-specification events for which information is provided on the MOR should be determined by using the target log inactivation.)

Table Columns

The table is designed to capture one full month of operations data for all reactors operated at the UV facility during the reporting period. One row of data should be entered for each off-specification event for each reactor.

Date: Enter the date of the off-specification event.
Reactor Number: Enter the identifying number of the UV reactor that had an off-specification event.
Off-Specification Event Description: Describe the parameter(s) that resulted in an off-specification event. Off-specification operation occurs when the UV facility operates outside of the validated conditions, a UV sensor is not in calibration, the UVT analyzer is not in calibration (and it is part of the dose-monitoring strategy), or UV equipment is not equivalent or better than the equipment validated.
Duration: Enter the amount of time (minutes) the reactor produced off-specification water for the day.
Total Off-Specification Volume: Enter the total volume (gallons) of water produced by the reactor during the off-specification event.
Total Off-Specification Volume for the Month: Add the numbers in the column titled "Total Off-Specification Volume," and enter the total at the bottom of the column. This is the total amount of off-specification water produced by the UV facility during the reporting period. This value should be transferred to the Monthly Operating Report (MOR).

State Logo

PWS Name: _____

Facility Name: _____

PWSID: _____

Facility ID: _____

Reporting Period: _____

UV Treatment
Off-Specification Calculation Worksheet

Target Pathogen: _____ Surrogate: _____ Target Log Inactivation: _____

Date[1]	Reactor Number	Off-Specification Event Description	Duration (min)	Total Off-Specification Volume (gal)
			Total Off-Specification Volume for the Month[2]:	

[1] For each off-specification event, data should be entered in one or more rows. All off-specification events in a day can be included in one row if it is the same reactor.

[2] The total off-specification volume for each reactor should be transferred to the Monthly Operating Report (MOR).

INSTRUCTIONS FOR COMPLETING THE UVDGM UV SENSOR CALIBRATION WORKSHEET

Section 6.4.1.1 of the UVDGM recommends that each of the duty sensors installed in every UV reactor be verified with a reference UV sensor at least monthly. Reference UV sensors are off-line UV sensors that should be at least as accurate as the duty UV sensors and should be constructed identically (with any exceptions to make them more accurate). This worksheet is used to document verification or calibration of UV sensors, and should be made available for review upon request.

Public Water System Information

PWS Name: Print or type name of public water system (PWS).
Facility Name: Print or type name of facility.
PWSID: Enter the PWS ID number.
Facility ID: Enter the facility ID number.

Header Rows

Reporting Period: Enter month and year in which data was collected.

Table Columns

The table is designed to record sensor verification or calibration as needed. One row of data should be entered for each sensor checked.

Date: Enter the date the sensor was checked.
Reactor Number: Enter the identifying number of the UV reactor that contains the sensor.
Duty Sensor Number: Enter the duty sensor number.
Duty Sensor Operating Time: Enter the length of time (hours) the sensor has been in operation since its last verification or calibration.
Reference Sensor Serial Number: Enter the serial number of the reference sensor being used to check the duty sensor.
Duty Sensor Reading (parameter [A] on the worksheet): Measure and record the UV intensity measured by the duty sensor.
Reference Sensor Reading (parameter [B] on the worksheet): Replace the duty sensor with the reference sensor. Measure and record the UV intensity measured by the reference sensor.
Calibration Ratio (parameter [C] on the worksheet): Divide the intensity measured by the duty sensor ([A]) by the intensity measured by the reference sensor in ([B]). This is the calibration ratio.
Calibration Ratio ≤ 1.2?: If the calibration ratio ([C]) is less than or equal to 1.2, enter "Y." Otherwise, enter "N."
Sensor Correction Factor Used: If the calibration ratio is greater than 1.2, then a sensor correction factor should be selected using the UV Sensor Correction Factor (CF) Worksheet. [Note: If a CF is needed, the operating algorithm for the UV reactor will need to be adjusted in the PLC for proper reactor operation. Multiply the UV intensity setpoint or the required dose (depending on the dose-monitoring strategy) by the CF to determine the corrected setpoint or required dose.]

If CF is used, [C] - 0.2 ≤ CF?: If the calibration ratio ([C]) minus 0.2 is less than or equal to 1.2, enter "Y." Otherwise, enter "N."

Footer Rows

Number of UV sensors checked: Enter the total number of UV sensors that were checked during the reporting period.

Number of UV sensors out of calibration: Enter the total number of UV sensors found to be out of calibration during the reporting period.

Number of UV sensors sent to manufacturer for recalibration, as documented below: Enter the number of UV sensors sent to the manufacturer for recalibration.

UV Intensity Sensors Sent to Manufacturer for Calibration

Sensor Serial Number: Enter the serial number of the sensor that was sent to the manufacturer.

Date Sent: Enter the date the sensor was sent to the manufacturer.

Date Received: Enter the date the recalibrated sensor was received from the manufacturer.

State Logo

UV Treatment
UV Sensor Calibration Worksheet

PWS Name: _____

Facility Name: _____

PWSID: _____

Facility ID: _____

Reporting Period: _____

$$Calibration\ Ratio = {S_{Duty}}/{S_{Ref}}$$

$$Sensor\ Correction\ Factor = {S_{Duty}}/{S_{Ref}} - 0.2$$

where:
S_{Duty} is the duty UV sensor reading
S_{Ref} is the reference UV sensor reading

Date	Reactor Number	Duty Sensor Number	Duty Sensor Operating Time (hr)	Reference Sensor Serial Number	Duty Sensor Reading[1] [A]	Reference Sensor Reading[1] [B]	Calibration Ratio ([A]/[B]) [C]	Calibration Ratio ≤ 1.2? ([C] ≤ 1.2?) (Y/N)	Sensor Correction Factor Used	If CF is used, [C] - 0.2 ≤ CF? (Y/N)

[1] If three duty sensor and reference sensor readings are taken, the mean of the readings can be used.

Number of UV sensors checked: _____

Number of UV sensors out of calibration: _____

Number of UV sensors sent to manufacturer to be recalibrated, as documented below: _____

UV Intensity Sensors Sent to Manufacturer for Calibration

Sensor Serial Number	Date Sent	Date Received

INSTRUCTIONS FOR COMPLETING THE UVDGM UV SENSOR CORRECTION FACTOR WORKSHEET

This worksheet is used to develop a correction factor (CF) for a UV reactor that has one or more sensors that are out of calibration, and should be made available for review upon request. This worksheet should be used for only one reactor, as the CF applied is reactor specific. Operating with a CF is not energy efficient; however, this method enables the UV facility to remain in operation while the UV sensor problem is resolved. The selected CF should not be changed until the failed UV sensors are replaced with factory calibrated UV sensors. This approach is not recommended for long-term operation, and the UV sensor problem should be resolved as quickly as possible.

Public Water System Information

PWS Name: Print or type name of public water system (PWS).
Facility Name: Print or type name of facility.
PWSID: Enter the PWS ID number.
Facility ID: Enter the facility ID number.

Header Rows

Reporting Period: Enter month and year in which data was collected.
Reactor Number: Enter the identifying number of the UV reactor that contains the sensor.

Table Columns

The table is designed to determine correction factors for failed UV sensors in a single reactor. One row of data should be entered for each sensor evaluated.

Date: Enter the date the duty sensor failed.
Duty Sensor Number: Enter the duty sensor number.
Duty Sensor Operating Time: Enter the length of time (hours) the sensor has been in operation since its last verification or calibration.
Reference Sensor Serial Number: Enter the serial number of the reference sensor being used to check the duty sensor.
Duty Sensor Reading (parameter [A] on the worksheet): Measure and record the UV intensity measured by the duty sensor.
Reference Sensor Reading (parameter [B] on the worksheet): Replace the duty sensor with the reference sensor. Measure and record the UV intensity measured by the reference sensor.
Sensor Correction Factor: Divide the intensity measured by the duty sensor ([A]) by the intensity measured by the reference sensor in ([B]) and subtract 0.2 from the result. This is the sensor correction factor (CF).
Selected UV Sensor Correction Factor: Enter the largest sensor CF calculated for the failed sensors in this reactor. [Note: If a CF is needed, the operating algorithm for the UV reactor will need to be adjusted in the PLC for proper reactor operation. Multiply the UV intensity setpoint or the required dose (depending on the dose-monitoring strategy) by the CF to determine the corrected setpoint or required dose.]

State Logo

UV Treatment

UV Sensor Correction Factor (CF) Worksheet

PWS Name: _____

Facility Name: _____

PWSID: _____

Facility ID: _____

Reporting Period: _____

Reactor Number: _____

$$Calibration\ Ratio = {S_{Duty}}/{S_{Ref}}$$

$$Sensor\ Correction\ Factor = {S_{Duty}}/{S_{Ref}} - 0.2$$

where:

S_{Duty} is the duty UV sensor reading

S_{Ref} is the reference UV sensor reading

Date	Duty Sensor Number	Duty Sensor Operating Time (hr)	Reference Sensor Serial Number	Duty Sensor Reading[1] [A]	Reference Sensor Reading[1] [B]	Sensor Correction Factor ([A]/[B]-0.2)

Selected UV Sensor CF[2]: _____

[1]If three duty sensor and reference sensor readings are taken, the mean of the readings can be used.

[2]UV Sensor CF should be based on the calibration ratios for the failed sensors and should use the maximum ratio. The CF is reactor specific.

INSTRUCTIONS FOR COMPLETING THE UVDGM MONTHLY UVT ANALYZER CALIBRATION LOG

Section 6.4.1.2 of the UVDGM recommends that on-line UVT analyzers used at the UV facility be checked at least weekly, using a certified bench-top spectrophotometer. This log should be completed for each UVT analyzer for each month, and should be available for review upon request.

Public Water System Information

PWS Name: Print or type name of public water system (PWS).
Facility Name: Print or type name of facility.
PWSID: Enter the PWS ID number.
Facility ID: Enter the facility ID number.

Header Rows

Reporting Period: Enter month and year in which data was collected.
UVT Analyzer Number: Enter the identifying number of the UVT analyzer.

Table Columns

The table is designed to record one month of accuracy data for a single UVT analyzer. One row of data should be entered for each weekly check.

Date: Enter the date the UVT analyzer was checked.
On-Line UVT Reading (parameter [A] on the worksheet): Record the reading (%) of the on-line UVT analyzer.
Grab Sample UVT Result (parameter [B] on the worksheet): Record the result (%) of a UVT grab sample from a location close to the on-line UVT analyzer sampling point.
Difference (parameter [C] on the worksheet): Record the absolute value of the difference between the on-line UVT reading ([A]) and the grab sample UVT result ([B]).
[C] ≤ 2%?: If the UVT difference ([C]) is less than or equal to 2%, enter "Y." Otherwise, enter "N."

Footer Rows

All calibration checks were within the acceptable tolerance during this month: Check this box if all calibration checks were within the acceptable tolerance during this month.
Recalibration was required and is documented below: Check this box if the UVT analyzer was required to be recalibrated.

UVT Analyzer Calibration

Manufacturer or On-Site Recalibration?: Enter either “manufacturer” or “on-site” to indicate where the UVT analyzer was calibrated.

Manufacturer Recalibration

Date Sent: Enter the date the UVT analyzer was sent to the manufacturer.

Date Received: Enter the date the recalibrated UVT analyzer was received from the manufacturer.

On-Site Recalibration

Date Recalibration Performed: Enter the date the UVT analyzer was recalibrated.

Recalibration Successful?: Enter “Y” or “N” to indicate whether or not the recalibration was successful.

Initials: The person who recalibrated the UVT analyzer should enter their initials.

State Logo

UV Treatment
Monthly UVT Analyzer Calibration Log

PWS Name: _____

Facility Name: _____

PWSID: _____

Facility ID: _____

Reporting Period: _____

UVT Analyzer Number: _____

$$|UVT_{on-line}(\%) - UVT_{bench}(\%)| \leq 2\% \, UVT$$

Week No.	Dates	On-Line UVT Reading (%) [A]	Grab Sample UVT Value (%) [B]	Difference (|[A]-[B]|) (%) [C]	[C] ≤ 2% UVT? (Y/N)
1					
2					
3					
4					
5					

All calibration checks were within the acceptable tolerance during this month ☐

Recalibration was required and is documented below ☐

UVT Analyzer Calibration

Manufacturer or On-Site Recalibration?	Manufacturer Recalibration		On-Site Recalibration		
	Date Sent	Date Received	Date Recalibration Performed	Recalibration Successful? (Y/N)	Initials

REFERENCES

Linden, K.G., H.B. Wright, J. Collins, C. Cotton, and S.E. Beck. 2015. *Guidance for Implementing Action Spectra Correction with Medium Pressure UV Disinfection*. Final Report Project #4376. Water Research Foundation, USEPA, and American Water Works Association. Denver, CO.

USEPA. 2006. *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule*. EPA 815-R-06-007, U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA. 2020. *Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems.* EPA/600/R-20/094, U.S. Environmental Protection Agency, Office of Research and Development, Center for Environmental Solutions and Emergency Response (CESER), Cincinnati, Ohio.