# Guidelines for Ultraviolet Disinfection of Drinking Water

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### Ministry of Health

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## 1. Objective

To provide guidance on the reduction of pathogenic microorganisms[1] in drinking water using ultraviolet (UV) disinfection and the design, operation, and maintenance of UV equipment for drinking water applications.

## 2. Background and Regulatory Framework

The *Drinking Water Protection Act* (DWPA) (2001) and Drinking Water Protection Regulation (DWPR) (2003) specify water quality standards[2], monitoring schedules and recommended treatment aimed at reducing the risks from pathogens in drinking water. There are three main types of pathogens in drinking water that pose risks to human health: viruses, protozoa, and bacteria. The ingestion of these pathogens can result in short term illness and in some instances, serious long-lasting illnesses or even death.

To ensure the provision of clean, safe, and reliable drinking water in British Columbia, the multi-barrier approach is used. The multi-barrier approach is a system of procedures, processes and tools that collectively prevents or reduces the risk of contamination of drinking water from source-to-tap to reduce risks to human health[3]. Drinking water treatment is one component of the multi-barrier approach. Other components include source protection, operator training, water system maintenance, water quality monitoring and emergency response planning.

Section 5 of the DWPR requires that drinking water from a water supply system must be disinfected if the water originates from surface water, or groundwater that in the opinion of a Drinking Water Officer is at risk of containing pathogens. As "disinfection" is not defined in the DWPA or DWPR, technical guidance on disinfection is provided in this document for UV disinfection, the Design Guidelines for Drinking Water Systems in British Columbia (anticipated release date in 2022), the Guidelines for Pathogen Log Reduction Credit Assignment (2022) and in provincial drinking water treatment objectives.

Provincial drinking water treatment objectives are set out in the following guidance documents which are included in Part B to the Drinking Water Officers' Guide:

- Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia which provides a general overview of microbiological drinking water treatment objectives for surface water supplies; and

[1] Health risks posed from chemical, physical, or radiological parameters are beyond the scope of this document.

[2] Schedule A of the Drinking Water Protection Regulation specifies bacteriological water quality standards for *Escherichia coli* (*E. coli*) and total and fecal coliform bacteria as no detectable bacteria per 100 mL of drinking water. Where more than 1 sample is collected in a 30 day period, the standard for total coliform is at least 90% of samples have no detectable total coliform bacteria per 100 mL and no sample has more than 10 total coliform bacteria per 100 mL.

[3] B.C. Office of the Provincial Health Officer (2019). Clean, Safe, and Reliable Drinking Water.

- Drinking Water Treatment Objectives (Microbiological) for Groundwater Supplies in British Columbia which specifies guidance on the treatment necessary to address microbiological contamination of groundwater sources and the assignment of subsurface filtration treatment credits.

Provincial drinking water treatment objectives for harvested rainwater are set out in the following guidance document which supplements the existing provincial treatment objectives for surface water supplies:

- Guidance for Treatment of Rainwater Harvested for Potable Use in British Columbia which provides a general overview of assessing the risks and treatment of rainwater for potable use.

All surface water supplies require disinfection; however, the requirement to disinfect groundwater supplies only applies to groundwater sources at risk of microbiological contamination. The Guidance Document for Determining Groundwater at Risk of Containing Pathogens (GARP) was developed to assist Health Authorities and water suppliers determine if a particular groundwater source requires disinfection. Risk factors that are discussed in the guideline include well construction, well location, aquifer characteristics and water quality results.

## 3. Purpose and Scope

This guideline provides provincial guidance[4] on the reduction of pathogenic microorganisms in drinking water using UV disinfection. The information in this document should be used by issuing officials during the approvals process, particularly with respect to the issuance of construction permits and operating permits under the *Drinking Water Protection Act* and the Drinking Water Protection Regulation. The information in this document can also be used by water suppliers, designers, and any other person or persons responsible for the planning and design of new water supply systems and when considering changes to existing systems.

This guideline is intended to supplement and not replace industry standards, guidelines, and best practices for UV disinfection of drinking water. More detailed information on the design and operation of drinking water systems can be found in the Design Guidelines for Drinking Water Systems in British Columbia.

## 4. Drinking Water Pathogens

The primary goal of drinking water disinfection is to reduce the presence of pathogens (disease-causing organisms) and associated health risks to an acceptable or tolerable level. The three main types of pathogens in drinking water that pose risks to human health are discussed below.

[4] The guidance in this document is not legally binding. In the event of an inconsistency between the guidance in this document and the DWPA, DWPR, a drinking water operating permit or construction permit, or any direction of a Drinking Water Officer, the guidance in this document gives way to legally binding requirements.

## 4.1 Viruses

Viruses are submicroscopic infectious agents that replicate only inside the living cells of host organisms. UV disinfection can be used to reduce viruses in water, but the effectiveness of UV disinfection varies significantly depending upon the type of virus. For example, double-stranded DNA viruses, such as adenoviruses, are more resistant to UV than single-stranded RNA viruses, such as hepatitis A (Meng and Gerba, 1996; cited in Health Canada, 2011). Adenoviruses are excreted in large numbers by humans and are commonly found in untreated sewage and many surface water sources. Because some adenoviruses can cause illness, particularly in children and immunocompromised adults, adenovirus is sometimes used to establish UV disinfection requirements for viruses.

Other pathogenic viruses which pose risks to drinking water sources have also been studied for their UV disinfection requirements. Studies show that hepatitis A, poliovirus type 1, and various strains of coxsackievirus and rotavirus require a UV dose[5] ranging from 16 – 61 mJ/cm$^2$ from low pressure UV lamps for 4-log virus inactivation (see the Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Enteric Viruses); of the viruses studied, rotavirus was the most resistant to UV disinfection after adenovirus.

Due to the high UV dosages required to reduce the concentration of enteric viruses in water, chemical disinfection (e.g. chlorination) is often the most appropriate treatment process for virus reduction.

## 4.2 Protozoa

Protozoa such as *Cryptosporidium* and *Giardia* are relatively large pathogenic single-celled microorganisms that, like enteric viruses, multiply only in the gastrointestinal tract of humans and other animals. *Cryptosporidium* oocysts and *Giardia* cysts[6] cannot multiply in the environment but can survive in water longer than intestinal bacteria. UV disinfection is the most effective means of oocyst and cyst inactivation.

## 4.3 Bacteria

Bacteria are single-celled microorganisms that can exist either as independent (free-living) organisms or as parasites (dependent on another organism for survival). Bacteria exhibit a range of UV sensitivity: many types are inactivated at low UV doses, while others (especially spore-forming bacteria) are considerably more resistant to UV disinfection than *Cryptosporidium* oocysts and *Giardia* cysts[7]. Bacterial reduction is normally sufficient if disinfection systems are designed to target virus reduction and as such, bacteria are not typically treated separately.

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[5] See Section 5 – UV Disinfection for more information on UV dose.

[6] Oocysts and cysts are the infective spore-like life stages of protozoa which are environmentally hardy and are shed by infected individuals in feces (CDC, 2020).

[7] USEPA (2006). Ultraviolet Disinfection Guidance Manual for The Final Long Term 2 Enhanced Surface Water Treatment Rule. Also refer to Masjoudi *et al.* (2021), Sensitivity of Bacteria, Protozoa, Viruses, and Other Microorganisms to Ultraviolet Radiation.

## 5. UV Disinfection

UV light inactivates pathogens by damaging their nucleic acids (DNA and RNA) so that they cannot replicate and infect humans. The degree of pathogen inactivation depends upon the UV dose that is applied. For practical purposes, UV dose is expressed as the product of UV intensity, expressed in milliwatts per square centimeter of exposed area ($mW/cm^2$) and the amount of time that a microorganism is exposed to UV light in a reactor vessel (measured in seconds). The units of UV dose are expressed as millijoules per square centimeter ($mJ/cm^2$) which is equivalent to milliwatt seconds per square centimeter ($mW{\cdot}s/cm^2$).

UV dose delivery is influenced by the:

a) UV reactor design;
b) flow rate and fluid dynamics of water passing through the UV reactor;
c) UV transmittance (UVT) of the water being treated; and
d) UV intensity field within the reactor, which can be impacted by lamp sleeve transmittance and sleeve fouling, as well as lamp output, position, and aging.

Low pressure (LP) UV lamps (including low-pressure high-output lamps, LPHO) produce UV light at a single wavelength of 254 nm, which is an effective wavelength for the germicidal inactivation of pathogens. Medium pressure (MP) UV lamps produce polychromatic UV light which spans many wavelengths over the germicidal range (200 nm to 300 nm). Selection of lamp technology requires consideration of the reactor size, power demand and cost. Lamp and reactor selection (including dose monitoring strategy) should also consider monitoring and O&M requirements with respect to the water supplier's operational capacity. Refer to Section 11 – Monitoring Parameters and Section 12 – Equipment Verification and Calibration for more details.

The high efficacy and reliability of UV disinfection technology is well established within the drinking water sector. One of the advantages of using UV light for drinking water disinfection is that the disinfection by-products typically associated with the use of chemical disinfectants are not formed. However, unlike chlorine which can be used for both primary and residual disinfection, UV disinfection can only be used for primary disinfection because it does not have any residual disinfection capability.

UV dose requirements for the inactivation of *Cryptosporidium*, *Giardia,* and viruses, as developed by the U.S. EPA, are set out in Table 1. Note that due to the potential for particulate matter to interfere with UV disinfection, these dose requirements apply to post-filter applications of UV disinfection in filtered systems and to unfiltered systems that meet U.S. EPA filter avoidance criteria[8]. Particles in unfiltered water can interfere with UV disinfection in two ways: by decreasing the UVT, and by associating with microorganisms (including pathogens) and shielding them from UV light[9]. While the first effect can generally be captured by UVT monitoring, particle association with microorganisms can

[8] 40 CFR 141.71.

[9] USEPA (2006). Ultraviolet Disinfection Guidance Manual for The Final Long Term 2 Enhanced Surface Water Treatment Rule.

affect UV dose-response and cannot be predicted through monitoring. Particles larger than approximately 7–10 µm are able to enmesh and protect coliform bacteria from UV light, and smaller particles can shield viruses from UV exposure, reducing disinfection efficiency[10].

Due to this potential for interference by particles, pathogen log reduction credit assignment for drinking water systems in British Columbia should be based on:

- post-filter applications of UV equipment, or
- application of UV equipment to drinking water systems that use
    - a groundwater source at low risk of containing pathogens,
    - a 'GARP-viruses only' water source, or
    - a water source that has been granted a filtration exemption by a Drinking Water Officer.

For unfiltered systems that meet filtration exemption criteria, special consideration should be given to UVT and particle data when UV disinfection is being considered as part of the treatment process. Particle count analysis can be used to determine the level and type of pre- and post-treatment that should be provided; for example, if a source water experiences turbidity excursions with high counts of particles larger than 7 µm, at a minimum, cartridge filtration pre-treatment should be considered (i.e. cartridge filters with adequate pore size for particle removal).

The UV dose requirements in Table 1 account for the UV dose-response relationships of the target pathogens but do not address other significant sources of uncertainty in full-scale UV reactor applications due to the hydraulic effects of the UV installation, the UV equipment, and the monitoring approach. Due to these factors, UV reactors undergo validation testing to determine the operating conditions under which the reactors deliver the required UV dose for pathogen log reduction credit[11]. Reactor validation is discussed in Section 6.

[10] Templeton et al. (2008). Particle-associated viruses in water: Impacts on disinfection processes. Critical Reviews in Environmental Science and Technology, 38:3, 137-164.

[11] USEPA (2006). Ultraviolet Disinfection Guidance Manual for The Final Long Term 2 Enhanced Surface Water Treatment Rule.

### Table 1: UV Dose Requirements (mJ/cm$^2$) for the Inactivation of *Cryptosporidium*, *Giardia* and Viruses[12]

| Target Pathogen | Log Inactivation [a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **0.5** | **1.0** | **1.5** | **2.0** | **2.5** | **3.0** | **3.5** | **4.0** |
| *Cryptosporidium* | 1.6 | 2.5 | 3.9 | 5.8 | 8.5 | 12 | 15 | 22 |
| *Giardia* | 1.5 | 2.1 | 3.0 | 5.2 | 7.7 | 11 | 15 | 22 |
| Viruses (based on adenovirus) [b] | 39 | 58 | 79 | 100 | 121 | 143 | 163 | 186 |

[a] In the U.S., the UV dose values in Table 1 are applicable to post-filter applications of UV in filtered systems and to unfiltered systems that meet filter avoidance criteria under Title 40 of the U.S. Code of Federal Regulations (40 CFR 141.71). In B.C., the UV dose values in Table 1 are recommended for post-filter application of UV, or application of UV equipment to drinking water systems that use a groundwater source at low risk of containing pathogens, a 'GARP-viruses only' water source, or a water source that has been granted a filtration exemption by a Drinking Water Officer.

[b] Typically, chemical disinfection is used for virus inactivation due to the high UV dosages required.

### Adenovirus and Rotavirus

The UV dose requirements for virus inactivation in Table 1 are based on the log inactivation of adenovirus, which is used by some jurisdictions as a target pathogen for establishing UV virus inactivation requirements. In British Columbia, depending upon the results of a source water assessment from the water supplier or other studies conducted by the water supplier, a Drinking Water Officer has the discretion to base virus log inactivation requirements on either adenovirus or rotavirus.

For drinking water sources that are considered to be vulnerable to human fecal contamination[13] and based on the UV dose requirements set out in Table 1, a 40 mJ/cm$^2$ UV dose would provide 0.5-log inactivation of viruses based on adenovirus. Under such circumstances, two or more forms of treatment (e.g. chemical disinfection and UV disinfection), would be necessary to provide additional virus inactivation.

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[12] 40 CFR 141.720(d)(1) and USEPA (2006), Ultraviolet Disinfection Guidance Manual for The Final Long Term 2 Enhanced Surface Water Treatment Rule.

[13] The DWO may use their discretion to determine whether a drinking water source is at risk of fecal contamination. Key considerations could include hydraulic connection to a known human wastewater source (including onsite sewage) and elevated presence of fecal indicators (e.g. *E. coli* > 20 colony forming units/100 mL).

For drinking water sources that are considered to be at low risk from human fecal contamination, a Drinking Water Officer may decide that rotavirus is a more appropriate pathogen upon which to base virus inactivation requirements.

Unlike for adenovirus, standardized UV dose requirements have not been established for different levels of rotavirus inactivation. Some studies[14] have reported that 3 and 4-log rotavirus inactivation require UV doses greater than 40 mJ/cm$^2$. Until the UV dose response requirements for rotavirus are formally developed using modern testing protocols (Bolton *et al.*, 2015), a 40 mJ/cm$^2$ UV dose has been conservatively assigned a 2-log virus inactivation credit in British Columbia based on rotavirus inactivation.

## 6. Reactor Validation

UV reactors for medium and large water systems undergo validation testing to determine the operating conditions required to deliver a validated UV dose. Validation testing is based on reactor type/model and is typically conducted by a recognized third party at a facility specifically designed for reactor validation. There are no requirements for the periodic revalidation of a reactor once it has been validated.

Note: UV reactors for small water systems are typically certified based on a recognized certification standard. Reactor certification is not the same as reactor validation as the certification and validation processes are not equal (e.g. the factors associated with experimental uncertainty – including UV lamp fouling/aging and the differences in UV sensitivity between challenge organisms and target pathogens – are not accounted for in reactor certification). Reactor certification is discussed in Section 7.

There are several different protocols that are used to validate UV reactors. The following validation protocols are recognized by the Province of British Columbia:

- The German guideline DVGW W294;
- The Austrian standard ÖNORM M 5873; and
- The U.S. EPA UVDGM.

These protocols validate a UV reactor for a reduction equivalent dose (RED; also called the reduction equivalent fluence or REF) based on biodosimetry testing under variable flowrate, UVT and UV intensity settings. Biodosimetry testing is described in Section 6.1.

Validation testing should account for:

a) UVT or absorbance of the water;

[14] Health Canada (2019). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Enteric Viruses.

b) Lamp fouling and aging factors[15];
c) Measurement uncertainty of online sensors;
d) UV dose distributions arising from the velocity profiles through the reactor;
e) Failure of UV lamps or other critical components;
f) Inlet and outlet piping or channel configurations of the UV reactor;
g) RED bias (applicable to UVDGM-validated reactors); and
h) Action spectra bias (applicable to UVDGM-validated reactors).

## 6.1 Biodosimetry Testing

Biodosimetry testing is used to determine the reduction equivalent dose (RED) of a UV reactor by measuring the inactivation of a challenge microorganism after exposure to UV light in the reactor and comparing the results to the dose-response curve of the challenge microorganism determined by bench-scale collimated beam testing. Challenge microorganisms are described in more detail in Section 6.2.

Biodosimetry testing is necessary because it is difficult to predict full-scale reactor disinfection performance based on modeling or bench-scale testing. Biodosimetry testing includes the following steps:

1. **Collimated Beam Testing** – A collimated beam apparatus which produces a precise, uniform UV light output at a wavelength of 254 nm is used to determine the UV dose-response curve of a challenge microorganism. Water samples containing the challenge microorganism are irradiated in a bench-scale laboratory test and the concentrations of viable microorganisms are measured before and after exposure to various doses of UV light. A dose-response curve is graphed by plotting the log inactivation of the challenge microorganism versus the applied dose. The applied dose is calculated based on measured UV intensity, the UV absorbance of water, the depth of the water and the exposure time of the challenge microorganism to the collimated beam. The UV dose-response curve is a measurement of the sensitivity of the challenge microorganism to UV light and is unique to the microorganism. Note that the collimated beam apparatus uses a low-pressure (LP) lamp, and correction factors must be used to adapt the dose-response curves for use with medium pressure (MP) lamps (see Section 6.3)

2. **Full-Scale Reactor Testing** – Log inactivation data are collected from full-scale reactor testing for specific operating conditions (i.e. flow rate, UVT and UV intensity) using the same challenge microorganism as in the collimated beam tests.

3. **Reduction Equivalent Dose** – A reduction equivalent dose (RED) is estimated by interpolating the log inactivation results from full-scale reactor testing onto the UV dose-response curve

[15] Note: If the source water at the proposed installation site has elevated inorganic constituents (iron, manganese, hardness) and pH, lamp fouling and aging factors may need to be determined during on-site commissioning. This may impact cleaning frequencies and overall project cost. Refer to Sections 9.2 and 9.23.

from collimated beam testing. RED values are specific to the challenge microorganism used for collimated beam testing and the validation test conditions for full-scale reactor testing.

4. **Pathogen Specific Validated Dose** (applicable to UVDGM only) – The RED value is adjusted for experimental uncertainties and biases using a pathogen-specific validation factor (VF) to produce a pathogen-specific validated dose:

**Validated Dose = Reduction Equivalent Dose (RED) / Validation Factor (VF)**

Further information on biodosimetry testing can be found in the Section 5.2 of the U.S. EPA UVDGM.

## 6.2 Challenge Microorganisms

Depending upon the validation protocol chosen and the target pathogen (*Cryptosporidium*, *Giardia*, adenovirus, or rotavirus), different challenge microorganisms may be used. Challenge microorganisms are non-pathogenic surrogates and include bacteria-specific viruses such as MS2 bacteriophage and bacterial spores such as *Bacillus subtilis*. Challenge microorganisms are set out in Table 2 for each of the validation protocols recognized by the Province of British Columbia. Section 5.3 of the UVDGM provides information on factors to consider during challenge microorganism selection.

**Table 2: Challenge Microorganisms**

| Validation Protocol | Challenge Microorganisms |
|---|---|
| DVGW W294 | Bacillus subtilis ATCC #6633 |
| ÖNORM M 5873 | Bacillus subtilis ATCC #6633 |
| UVDGM | MS2 Bacteriophage ATCC #15597-B1<br>Bacillus subtilis ATCC #6633<br>Or other (see Table 5.2 in the U.S. EPA UVDGM) |

ATCC – American Type Culture Collection

For the DVGW and ÖNORM validation protocols, the challenge microorganism *B. subtilis* is used to confirm that the minimum RED of 40 mJ/cm$^2$ is delivered by the reactor. The UVDGM validation protocol allows for different REDs to be targeted, which allows for more flexibility in terms of treatment objectives and operational needs (for example, the UV system may be designed for 1-log reduction of *Cryptosporidium* and *Giardia*, which will reduce power and operational costs compared to a DVGW-validated reactor). Furthermore, the 2020 U.S. EPA document "Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems" (discussed in Section 6.4) recommends using two or more challenge microorganisms with different UV dose-response, such as MS2 and T1UV phage.

## 6.3 Considerations for UVDGM-validated Reactors

For UVDGM-validated reactors, ideally the challenge microorganism should have the same UV dose-response (at 254 nm) and action spectra (dose-response over the germicidal range of UV wavelengths) as the target pathogen. In practice, both the UV dose-response and the action spectra of challenge microorganisms and target pathogens differ. Correction factors must be applied, otherwise the log reduction of the target pathogen may be overestimated.

The RED bias is defined as the ratio of the RED measured using the challenge microorganism used to validate the reactor and the RED that would have been delivered to the target pathogen. If the challenge microorganism has the same UV dose-response as the target pathogen, the RED bias is 1.0. If the challenge microorganism is more resistant to UV light than the target pathogen, the RED bias is greater than 1.0. Conversely, if the challenge microorganism is more sensitive to UV light than the target pathogen, the RED bias is less than 1.0.

Under the UVDGM validation protocol, the RED bias factor is a correction factor that accounts for the difference in the UV dose-response (at 254 nm) of the challenge microorganism and target pathogen. More information, including RED bias values based on UVT, log reduction targets, and challenge microorganism UV sensitivity, can be found in the U.S. EPA UVDGM.

The action spectra correction factor (ASCF) accounts for differences in spectral response. The ASCF is applicable to medium pressure UV reactors and other lamps which emit UV light at wavelengths other than 254 nm (for example, LEDs). Action spectra bias is particularly an issue as many challenge microorganisms are more susceptible to inactivation from low-wavelength UV light (<240 nm) than target pathogens, which leads to an overestimation of UV performance. Furthermore, most UV sensors cannot accurately measure intensity in the low-wavelength range, although low-wavelength sensors are now available[16]. Tabulated ASCFs for different challenge microorganisms and target pathogens can be found in the U.S. EPA UVDGM; however, these values do not account for factors which may lead to underestimation of the delivered UV dose (e.g. UV transmittance of the quartz sleeve, changes in water quality compared to the validation water, and lamp aging/fouling). The WRF Report #4376 "Guidance for Implementing Action Spectra Correction with Medium Pressure UV Disinfection" (2015)[17] provides details on different ASCF options, including:

- updated generic tabulated ASCFs;
- development of reactor-specific or site-specific ASCFs using computational fluid dynamics and UV intensity field models (CFD-I); and
- development of reactor-specific or site-specific ASCFs through validation tests.

[16] USEPA (2020). Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems.
[17] Table ES.1.

Additional information about ASCF calculation using low-wavelength data is set out in the U.S. EPA 2020 document "Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems".

There are two other important considerations for UVDGM-validated reactors:

- because the action spectra of *Cryptosporidium* and *Giardia* are statistically similar, the ASCFs for *Cryptosporidium* can be directly used for *Giardia*[18]; and
- because adenovirus was used as the target pathogen for viruses, there are no tabulated RED bias or ASCF values for rotavirus. Appropriate correction factors should be discussed with an issuing official.

## 6.4 Innovative Approaches for Dose Monitoring and UVDGM Reactor Validation

New approaches and procedures for dose monitoring and UVDGM reactor validation are set out in the 2020 U.S. EPA document "Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems" (also referred to as the "Innovative Approaches" document). 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 UV transmittance monitor for simplified UV system operations;
- For UV reactors equipped with medium pressure UV lamps, implementation of "low wavelength" UV sensors and approaches for the development of 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 viruses 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; and
- Modifications to the operating recommendations of the UVDGM to improve the accuracy of UV dose-monitoring with the water treatment application.

[18] WRF (2015) Report #4376 - Guidance for Implementing Action Spectra Correction with Medium Pressure UV Disinfection.

The approaches and procedures in the "Innovative Approaches" document are presented for consideration when applying UV disinfection for the inactivation of *Cryptosporidium*, *Giardia*, and viruses, and should not be construed as a replacement or revision to the UVDGM.

## 6.5 Validation Certificates and Validation Reports

Validation Certificates and Validation Reports document validated operating conditions for UV reactors. This documentation allows an issuing official to assess whether a UV reactor is appropriate for the specified application and it must be provided to the issuing official during the construction permit application review and approvals process.

Validation Certificates are used to document validated operating conditions for reactors that have been validated using the DVGW Guideline and the ÖNORM standard. Validation Certificates specify minimum UV intensity and the maximum flowrate through the reactor.

Validation Reports are used to document validated operating conditions for reactors that have been validated using the U.S. EPA UVDGM protocol. Validation Reports provide detailed documentation of all validation testing results and should include all elements of the validation test plan and a summary of the field-verified UV reactor properties. Validation Reports should also include the reactor's validated dose or range of validated doses, validation factors, log reduction credits for target pathogens, validated operating conditions, and the UV intensity set point(s) if the UV intensity set point monitoring/control strategy is used or the dose monitoring equation if the calculated dose monitoring/control strategy is used.

More information on validation reports including checklists for report content and review, can be found in Section 5.11.3 of the U.S. EPA UVDGM, as well as in Section 2.9 of the U.S. EPA 2020 "Innovative Approaches" document.

## 6.6 Validated Operating Conditions

To receive pathogen log reduction credits, UV reactors should operate within their validated operating conditions (also referred to as the "validation envelope"). These operating conditions should be considered during validation testing and should be explicitly tested or fall within the range of conditions tested.

Validated operating conditions should include flow rate, UV intensity as measured by a UV sensor, UV lamp status and UVT if a calculated dose control strategy is used (see Section 8.1). Alarms should activate when the measured UV intensity is below the validated UV intensity set point or when the calculated UV dose is below the dose required to meet the pathogen log reduction target. Refer to Section 13 for Alarm Conditions.

With the approval of the issuing official, UV reactors may be permitted to operate outside of their validated range where the UVT is above the validated range and/or the flow rate is less than the validated range, as long as the reactor can operate safely (i.e. without overheating).

## 6.7 On-site Validation

UV reactors are typically validated off-site at specialized third-party testing centres or at a UV manufacturer's facilities. On-site validation is used when:

- A UV reactor's validated operating conditions (previously obtained through validation testing) do not encompass the specified design criteria for the proposed installation (for example, an extended UVT, flow rate, or UV intensity/lamp output range);
- A design change deviating from previous validation is being sought for the reactor (e.g. new lamp or sleeve type); or
- Existing inlet/outlet piping configurations are constrained and cannot follow standard installation.

Before choosing on-site validation, the water supplier should contact the issuing official to discuss the development of a work program that is acceptable to the issuing official.

The work program for on-site validation should include the following tasks:

1) The collection of background information to support the validation of the reactor;
2) The development of a work plan including high-level schedule, subsequent tasks, and budget for presentation to and review by the issuing official;
3) Where applicable, an initial site visit to review reactor installation and operation, and to identify any issues that could potentially impact on-site validation;
4) The development of a test plan to establish validated operating conditions for the reactor. Multiple test conditions should be proposed which adequately cover the range of operating conditions to be validated in terms of:
    - Flow rates;
    - UVT values; and
    - Lamp power and configuration.

    The test plan should also include consideration of:
    - The challenge microorganism selected;
    - The target pathogen (e.g. *Cryptosporidium, Giardia*, rotavirus, or adenovirus);
    - The preparation of water to be used in the validation test (including assessing the need for chlorine quenching, methods to adjust UVT for the testing range, and mixing requirements for the challenge microorganism and/or chemical addition);
    - A plan for the safe discharge of the validation test water (may require permits);
    - The inclusion of appropriate QA/QC samples; and
    - Whether sensor linearity needs to be established or extended (i.e. if UVT targets extend beyond the normal validated range).
5) On-site validation testing using the test plan including:
    - Equipment set-up and functional testing to verify the operation of the test systems (including power consumption);
    - UV sensor testing (including reference sensor tests and duty UV sensor functional testing to characterize duty UV sensor readings);
    - Biodosimetry testing; and

- Assessment of the site-specific aging/fouling factor.

6) A review meeting to discuss the on-site validation work with the water supplier and the issuing official and to present the draft report; and
7) The production of a final report that documents the work that was completed under the work program. The final report should be submitted to the issuing official.

On-site validation should be conducted by an independent third party that has the necessary competencies (knowledge, skills, and experience) to do the work. Individuals qualified for such oversight include professional engineers experienced in testing and evaluating UV reactors and scientists experienced in the microbial aspects of biodosimetry. The independent third party should provide oversight to ensure that validation testing and data analyses are conducted in a technically sound manner and without bias. A person independent of the UV reactor manufacturer should oversee the validation testing.

## 7. Reactor Certification

Some UV reactors are certified using NSF/ANSI Standard 55 which establishes minimum requirements for the reduction of microorganisms using ultraviolet microbiological water treatment systems. NSF Standard 55 also specifies the minimum product literature and labeling information that a manufacturer must supply to authorized representatives and system owners, as well as the minimum service-related obligations that the manufacturer must extend to system owners.

NSF-certified equipment complies with the standards and procedures imposed by NSF including extensive product testing and material analyses. Equipment manufacturers are subjected to unannounced plant inspections and regular product retesting.

Small drinking water systems typically use UV disinfection systems that are certified to NSF Standard 55. There are two types of systems certified under the Standard: Class A systems and Class B systems.

Class A systems are designed to inactivate and/or remove microorganisms, including bacteria, viruses, *Cryptosporidium*, and *Giardia* from contaminated water. Class A systems are intended for visually clear water and are not intended for the treatment of water that has obvious contamination, such as raw sewage, or for the conversion of wastewater to drinking water[19]. Class B systems are designed for supplemental bacterial treatment of disinfected public water or other drinking water that has been tested and deemed acceptable for human consumption.

It is recommended that NSF Standard 55 Class A certified systems should only be used for small water systems. Water systems that serve more than 500 people in any 24-hour period should use UV disinfection systems that have been validated using one of the validation protocols listed in Section 6. NSF Standard 55 Class B certified systems should not be used for the production of potable water.

[19] NSF/ANSI 55 - 2019 Ultraviolet Microbiological Water Treatment Systems.

Class A systems are certified to deliver a UV dose that is at least equivalent to 40 mJ/cm$^2$ at the alarm set point when the system is tested in accordance with the Standard. Recommended maximum pathogen log reduction credits for NSF Standard 55 Class A devices are listed in Table 4. An issuing official has discretion in assigning pathogen log reduction credits based on an assessment of risk for any specific application.

NSF Standard 55 Class A certified systems should have the following:

a) a dedicated power line;
b) a built-in flow restrictor or automatic fixed flow rate control;
c) a UV intensity sensor to detect when the UV intensity at the sensor is below the required minimum;
d) a visual alarm, audible alarm or a system that terminates the discharge of water when the UV system is not operating effectively;
e) an emergency shut-off valve; and
f) a performance data sheet that includes the rated service flow of the reactor in litres/minute or litres/day. Class A systems are typically available for flow rates ranging from 37.9 to 114 litres/minute.

The NSF Standard 55 does not require Class A certified systems to have a UV monitor, which provides an online readout of UV intensity and/or dose delivered. However, provision of a UV monitor and a reference UV sensor may be requested by the issuing official to allow for monthly calibration verification checks of the duty UV sensor (refer to Section 12 – Equipment Verification and Calibration for more information).

Certification information for NSF/ANSI 55 Ultraviolet Microbiological Water Treatment Systems is available online via NSF's website. The information identifies manufacturer name, brand name/trade name/model, flowrate, and disinfection performance claim for Class A and Class B systems. The following organizations have also been accredited in Canada to certify UV reactors as meeting NSF/ANSI Standard 55:

- Water Quality Association (WQA);
- International Association of Plumbing & Mechanical Officials (IAPMO); and
- CSA Group.

# 8. Dose Monitoring/Control Strategies

There are two main dose monitoring/control strategies that are commonly used by UV equipment manufacturers: calculated dose and UV intensity set point.

## 8.1 Calculated Dose

The calculated dose control strategy uses a dose monitoring equation to estimate UV dose based on the operating conditions of the UV reactor (e.g. measured flow rate, UV intensity and UVT[20]). The calculated dose is divided by the reactor's Validation Factor and the resulting validated dose is compared to the required dose for the target pathogen and the targeted pathogen log inactivation level. When the validated dose is less than the required dose for the targeted pathogen log inactivation level, the produced water would be considered off-specification and an alarm condition should be activated.

This control strategy is only available for reactors validated using the U.S. EPA UVDGM protocol. Development of the dose monitoring equation is described in the UVDGM (Chapter 5) as well as in the EPA 2020 "Innovative Approaches" document.

## 8.2 UV Intensity Set Point

The UV intensity set point strategy is available under all validation protocols listed in Section 6. This strategy relies on one or more set points for UV intensity that are established during validation testing. These set points achieve a specific UV dose based on a maximum flowrate and either one or multiple minimum UV intensity values.

The simplest approach is "single set point" operation, which uses one UV intensity set point which achieves the targeted UV dose at a maximum flowrate. NSF 55 Class A certified systems operate with a "single set point" strategy. A "variable set point" approach validates multiple set point pairs of minimum UV intensity which are associated with different flow rates. During UV reactor operation, the measured UV intensity must meet or exceed the set point(s) to ensure the delivery of the required dose. UV reactors must also be operated within validated operating conditions for flow rate and lamp status.

UVT does not need to be monitored separately to confirm the UV dose delivered since the UV intensity readings account for changes in UVT. However, UVT should be monitored on a periodic basis (e.g. with grab samples) to confirm that it is within the range of validated operating conditions.

[20] UVT may not be required for some calculated dose monitoring approaches. See USEPA (2020), Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems.

## 9. Design and Installation Considerations

UV equipment design and installation should consider:

1. **Source Water Characterization Data** – For surface water and GARP water supplies, filtration should be installed upstream of UV disinfection to ensure that UV reactor performance is not compromised due to poor or changing water quality and UV reactors continuously operate within their validation envelope or range of certified operating conditions. If filtration is not installed upstream of UV disinfection, a water supply system must be approved for filtration exemption and meet the conditions for exemption set out in the 'Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia'.

   For a water supply system that meets the conditions for filtration exemption, source water characterization data should identify seasonal changes and annual trends in drinking water quality that may affect UV reactor performance (particularly for UVT). Ideally, at least two years of data should be used to inform reactor design decisions.

   If a MP reactor using a calculated dose control strategy is proposed which uses wavelengths shorter than 240 nm in the dose monitoring equation, low wavelength UVT (at ~220 nm) should also be characterized in the source water[21]. UVT data below 240 nm is not required for MP systems if ASCFs are applied per WRF Project 4376, because the ASCF values assume no dose delivery below 240 nm.

2. **Water Quality Requirements for Water Entering a UV Reactor** – UV reactor performance is affected by UVT, particle content, algae, upstream water treatment processes, and constituents in the water that foul reactor components. Water entering a UV reactor should meet water quality requirements specified by the UV equipment manufacturer and should ideally be of sufficient quality to minimize cleaning requirements.

   If the UV equipment manufacturer has not specified water quality requirements for water entering the reactor, the values in Table 3 are recommended. Different values for these parameters may be acceptable to an issuing official if:
   - The reactor was validated for different values (e.g. for an extended UVT range);
   - Experience with similar water quality and reactors demonstrates that adequate treatment is provided; or
   - For elevated inorganic constituents (iron, manganese, hardness) or pH, the combined aging and fouling factor (CAF) is determined during on-site commissioning. Refer to point 23 – Fouling/Aging Factors.

[21] USEPA (2020). Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems.

**Table 3: Recommended Water Quality for Water Entering a UV Reactor**

| **Parameter** [a] | **Value** |
|---|---|
| Turbidity | < 1.0 NTU |
| Hardness | < 120 mg/L |
| Iron | < 0.3 mg/L |
| Manganese | < 0.05 mg/L |
| Hydrogen sulphide (if odour present) | Non-detectable |
| Total suspended solids (TSS) | < 10 mg/L |
| pH | 6.5 to 9.5 |
| Total coliform | < 1000/100 mL |
| UVT [b] | > 75 % |

[a] Parameters from 10 State Standards (2018), except [b].
[b] UVT for fair water quality, U.S. EPA Guidance Manual on Alternative Disinfectants and Oxidants (1999).

3. **Design Flow Rate** – UV facility design should consider the average, maximum and minimum flow rates that the UV equipment will experience. Long-term population projections should be considered as well as current and long-term maximum day demand.

4. **Maximum Flow Rate and Pressure** – Design and installation should ensure that the maximum rated flow rate and pressure cannot be exceeded for the UV equipment.

5. **Inlet and Outlet Piping Configuration** – Inlet and outlet piping to a UV reactor should result in UV dose delivery that is equal to or greater than the UV dose delivered when the UV reactor was validated for the targeted pathogen log inactivation level. The piping configuration used for validation is usually included in the Validation Report. The issuing official may request a preferred piping configuration as recommended in sections 3.6.2 and 4.1.1 of the U.S. EPA UVDGM.

6. **UV Intensity Sensor** – UV reactors should have a UV intensity sensor to verify that sufficient UV light is being delivered to the reactor. Water should not be able to flow through the reactor when the reactor lamps are off or not fully energized unless the reactor was validated with some of the lamps off and the reactor is operating within its validation envelope.

7. **Temperature Sensor and Control** – UV reactors should have a temperature sensor to monitor water temperature within the reactor. If water temperature exceeds the recommended operating range for the reactor, the reactor should shut off to minimize the potential for reactor lamps to overheat. Some reactors may require provisions for cooling water which should be considered during design.

8. **Lamp Status** – UV equipment should have a lamp status indicator that indicates whether a UV lamp is on or off.

9. **Lamp Sleeve** – UV assemblies should be insulated from direct contact with influent water by a natural or synthetic quartz lamp sleeve. The quartz lamp sleeve type used in day-to-day equipment operation should be the same type as was used for equipment validation.

10. **UV Assembly Inspection and Cleaning** – UV assemblies should be accessible for visual observation, cleaning and replacement of the UV lamps, lamp sleeves and sensor window/lens. Lamp sleeves may be cleaned via online mechanical cleaning (with an automated wiper), online mechanical-chemical cleaning (automated wipers with a cleaning solution), or offline chemical cleaning at prescribed frequencies. If online cleaning mechanisms are included, components (wipers, motors/drives, cleaning solution reservoirs, etc.) should also be accessible for observation and maintenance.

11. **Power Quality** – UV equipment installation must consider local power quality. A power quality assessment should be conducted for areas where there are known power quality problems or for remote areas where power quality is unknown. Where power quality is identified as a concern, provisions should be made for power quality monitoring and/or power conditioning, as well as sufficient emergency power supply and/or uninterruptible power supply (UPS) to fully operate the UV equipment.

12. **Lamp Power** – Under normal operating conditions, UV lamps should not run at or near 100% power. UV reactors should be sized appropriately, such that lamp power is efficient under normal operating conditions, and that normal water quality fluctuations do not trigger operation of standby reactors.

13. **Reactor Bypasses** – UV reactor bypasses should not be installed unless specifically authorized by a Drinking Water Officer for the provision of emergency water supply. Adequate safeguards should be put in place to protect public health.

14. **Off-Specification Events** – In the event that a UV reactor malfunctions, loses power, or ceases to provide the required level of disinfection, there should be a feature that causes an alarm to sound or ensures that water from the affected reactor is prevented from entering the distribution system. Refer to Section 14 – Off-Specification Water for more details.

15. **Audible Alarm** – For UV equipment with an audible alarm, the alarm should sound in the building or structure where the UV equipment is installed or at a location where an operator is normally present.

16. **Critical Alarm Conditions** – For UV equipment with an automatic shut-off, UV reactors should automatically shut down under critical alarm conditions (e.g. multiple lamp/ballast failures, low liquid level, or high temperature) to prevent damage to the UV equipment. These alarm conditions should be considered during design to reduce the potential for downstream

pressure transients in the distribution system during sudden shut-offs. For treatment facilities with duty and standby reactors, duty reactors should automatically switch to standby reactors during critical alarm shutdown to minimize disruption to the drinking water supply.

17. **On-line Lamp Breaks** – On-line lamp breaks occur when a lamp and lamp sleeve break while water is flowing through a UV reactor. On-line lamp breaks may be caused by debris, improper lamp orientation, loss of water flow and temperature increases, pressure related events, lamp handling and maintenance errors, and UV reactor manufacturing problems. Preventative measures should be considered, and emergency response procedures to protect customers from mercury and broken glass should be documented in the Emergency Response and Contingency Plan for the drinking water system. More information on UV lamp breaks including preventative measures for on-line lamp breaks can be found in Appendix E to the U.S. EPA UVDGM.

18. **Equipment Component Installation and Replacement** – When UV equipment components are installed or replaced, they should be the same as the components used for equipment validation and/or certification unless the UV equipment was revalidated or recertified. When lamps are replaced from a lamp row or group, the lamp with the longest run time should be moved closest to the UV sensor, and the new lamp installed in the remaining space.

19. **Automated/Unattended Operation** – For UV equipment with automated/unattended operation:

    a. **Real-Time Monitoring** – Real-time monitoring should be used to continuously monitor equipment operation at the remote location. UV dose, alarm history, lamp hours and any other parameters necessary for the proper operation of the equipment should be recorded. A historian function should be included which retains instrumentation and control data for unattended periods (i.e. overnight) for operator review;

    b. **Self-Diagnostic Testing** – UV equipment should have a self-diagnostic test feature that will not disengage the auto shut-off valve until proper disinfection is occurring; and

    c. **Automatic Shut-off Valves** – Automatic shut-off valves should be maintained and checked at the frequency recommended by the equipment manufacturer to ensure reliable operation. Maintenance records should be available for inspection by a Drinking Water Officer when requested.

20. **Equipment Redundancy** – To avoid interruption of flow and where physically possible, a minimum of two UV reactor trains should be installed at treatment facilities that have continuous flow requirements. Full redundancy should consider the effect of shutting down the largest UV reactor for routine maintenance and for changing UV lamps. Redundancy should also consider the effects of equipment failure and the time required for equipment repair. Additional replacement components for the reactor and monitoring systems should be stored onsite; refer to Section 6.3.3 of the UVDGM for a recommended spare parts inventory.

21. **UV Equipment Software** – UV equipment software should be compatible with the SCADA[22] software used for the drinking water system.

22. **Real-time UVT Monitoring** – Real-time UVT monitoring should be used for UV disinfection systems that use the calculated dose control strategy. The provision of multiple UV analyzers should be considered for redundancy, and to allow for one analyzer to be taken out of service for calibration and maintenance.

23. **Fouling/Aging Factors** – Sleeve fouling, sleeve aging, lamp aging, and UV sensor window fouling (if applicable) affect long-term UV reactor performance. Combined aging and fouling factors (CAF) are often used to size a UV reactor for a particular application (i.e. to make sure that the lamp output can still meet the targeted log inactivation, even with an estimated amount of fouling and aging on sleeves and sensors).

    If a higher (less conservative) CAF is used and the water being treated causes heavy fouling, the reactor will produce off-spec water unless the cleaning frequency is increased (i.e. more wiper cycles or offline chemical cleans). In this case, an on-site fouling study should be conducted to inform the cleaning schedule; refer to Section 3.4.5 of the U.S. EPA UVDGM for details on fouling study considerations. Alternatively, a lower (more conservative) CAF could be used during UV equipment design.

    Warranties from UV vendors should be based on the CAF measured in the field by UV sensors.

24. **UV-LED Equipment** – Ultraviolet light-emitting diodes (UV-LEDs) are emerging as a viable technology for drinking water disinfection. Compared to conventional mercury UV lamps, UV-LED lamps are mercury-free, compact, robust, suffer minimal damage from repeated cycling, have longer life and reach full power faster. These advantages, along with virtually instantaneous start-ups and tunable wavelengths, offer great flexibility in UV-LED reactor design. Many applications of UV-LED reactors have focused on small-scale, point-of-use systems due to cost and power considerations (Jarvis *et al.* 2019); however, some larger-scale applications have been developed and approved for installation under the U.S. EPA UVDGM validation protocol.

    To be considered for pathogen log reduction credit assignment, UV-LED equipment for drinking water disinfection should be validated under an approved validation protocol or have NSF Standard 55 Class A certification (see Section 7 – Reactor Certification).

[22] SCADA (Supervisory Control and Data Acquisition) is a process control system that enables drinking water treatment operators to collect data from process sensors and/or to control equipment manually or automatically. The SCADA system may be accessible in the treatment facility and/or from a remote location.

## 10. Pathogen Log Reduction Credit Assignment

In order for a UV disinfection system to receive pathogen log reduction credits, it should be validated or certified by an accredited or independent third party based on a validation protocol or certification standard recognized by the Province of British Columbia. Independent third-party oversight ensures that validation and/or certification testing, and data analyses are conducted in a technically sound manner and without bias. A person independent of the UV equipment manufacturer should oversee the validation and/or certification testing.

Full-scale UV reactor validation and/or certification testing should document the operating conditions (maximum flow rate, UV intensity, UV lamp status (on/off) and minimum UVT) under which the reactor can deliver the required UV dose to achieve the required pathogen log reduction.

Pathogen log reduction credit assignment is based on:

1. Post-filter applications of UV equipment, or application of UV equipment to drinking water systems that use:
    a. A groundwater source at low risk of containing pathogens;
    b. A 'GARP-viruses only' water source; or,
    c. A water source that has been granted a filtration exemption by a Drinking Water Officer.
2. The UV equipment being fully operational; and
3. The recommended pathogen log reduction credit assignment criteria being met (see Section 7 of the 'Guidelines for Pathogen Log Reduction Credit Assignment').

Pathogen log reduction credit assignment is set out in Table 4 for the validation protocols and certification standards that are recognized by the Province of British Columbia.

### Table 4: Pathogen Log Reduction Credit Assignment

| Validation Protocol or Certification Standard | Minimum UV Dosage [a] | Maximum Pathogen Log Reduction Credits Assigned [b, c] | | |
|---|---|---|---|---|
| | | *Cryptosporidium* Oocysts | *Giardia* Cysts | Viruses [d] |
| DVGW W294 | RED = 40 mJ/cm$^2$ | 3 | 3 | 0.5 or 2 |
| NSF Standard 55 (Class A Systems only) | 40 mJ/cm$^2$ | 3 | 3 | 0.5 or 2 |
| ÖNORM M 5873 | RED = 40 mJ/cm$^2$ | 3 | 3 | 0.5 or 2 |
| UVDGM | Validated dose ≥ required dose for target pathogen log inactivation [e] | Determined on a case by case basis | Determined on a case by case basis | Determined on a case by case basis |

RED = Reduction Equivalent Dose. May also be called the REF (Reduction Equivalent Fluence).

[a] Validated reactors establish a RED for a specific organism (e.g. an MS2 RED or a *B. subtilis* RED). Similarly, NSF Standard 55 Class A certified systems are designed to deliver a UV dose that is at least equivalent to the MS2 bacteriophage dose-response at 40 mJ/cm$^2$ when the systems are tested in accordance with the Standard.

[b] Pathogen log reduction credit assignment is based on post-filter applications of UV equipment, or application of UV equipment to drinking water systems that use a groundwater source at low risk of containing pathogens; a 'GARP-viruses only' water source; or a water source that has been granted a filtration exemption by a Drinking Water Officer.

[c] Pathogen log reduction credit assignment is based on UV equipment being fully operational and the applicable pathogen log reduction credit assignment criteria being met (see Section 7 of the Guidelines for Pathogen Log Reduction Credit Assignment).

[d] For drinking water sources that a Drinking Water Officer considers to be at risk from human fecal contamination, a 0.5-log reduction credit should be assigned because of the high level of resistance of adenovirus to UV treatment. For drinking water sources that a Drinking Water Officer does not consider to be at risk from human fecal contamination[23], a 2-log reduction credit should be assigned based on rotavirus inactivation.

[e] Refer to Table 1 for the required dose for target pathogen log inactivation.

[23] The DWO may use their discretion to determine whether a drinking water source is at risk of fecal contamination, based on a source water assessment from the water supplier, or other studies conducted by the water supplier and provided to the DWO. Key considerations could include hydraulic connection to a known human sewage source and elevated presence of fecal indicators (i.e. *E. coli* > 20 colony forming units/100 mL).

# 11. Monitoring Parameters

Depending upon the UV control strategy used and in addition to any other sampling, analysis and recording that may be required by a Drinking Water Officer, the monitoring parameters set out in Table 5 should be tested at a minimum frequency of once every five minutes and should be recorded at a minimum frequency of once every four hours. If there is an alarm condition, the test parameters should be recorded at a minimum frequency of once every five minutes until the alarm condition has been corrected.

**Table 5: UV Equipment Monitoring Parameters**

| UV Control Strategy | Parameter Used as the Operational Set Point | Monitoring Parameters |
|---|---|---|
| UV Intensity Set Point | UV Intensity | Lamp Status<br>UV Intensity<br>Flow Rate [a] |
| Calculated Dose | Calculated or Validated Dose [b] | Lamp Status<br>UV Intensity<br>Flow Rate<br>UVT [c] |

[a] Not required for UV reactors that have a device that limits the maximum flow rate through the reactor based on the reactor's validated or certified operating conditions.

[b] The calculated dose is estimated using a dose-monitoring equation. For the calculated dose control strategy, the validated dose is equal to the calculated dose divided by the validation factor for the target pathogen to account for biases and experimental uncertainty. Refer to the U.S. EPA UVDGM for more information.

[c] UVT may not be required for some calculated dose monitoring approaches. See USEPA (2020), Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems.

## 11.1 Lamp Status

UV lamp status indicates whether a particular UV lamp in a reactor is on or off. Lamp status is sometimes used in the dose monitoring equation and is considered to be a validated operating condition.

## 11.2 UV Intensity

UV intensity measured as milliwatts per square centimeter of exposed area ($mW/cm^2$) describes the magnitude of UV light measured with a radiometer in bench-scale UV experiments and by a UV sensor

in a reactor[24] (USEPA, 2006). Depending on the reactor design there may be multiple sensors at different points in the reactor.

UV intensity measurements are influenced by changes in lamp output due to lamp power settings, lamp aging, lamp sleeve aging, and lamp sleeve fouling. UV intensity measurements may also be influenced by the UVT of the water being treated and substances in the water which absorb or block UV transmission, such as inorganic compounds (especially iron and manganese) and natural organic matter.

### 11.3 Flow Rate

Water flow rate through a UV reactor should be monitored using a flow meter (either installed separately upstream or as part of the reactor); otherwise a device that limits the maximum flow rate into the reactor should be installed. A UV reactor should operate only at flow rates that are within its validation envelope or certified operating conditions.

For UV reactors that require flow rate monitoring, the method of flow measurement should be selected based on the flow rate variability of the treatment facility. Each UV reactor should have a dedicated flow measuring device to confirm that the reactor is operating within its specified operating range. The flow rate should be displayed locally and where required, be input directly into a control loop for the UV reactor and/or SCADA system. Minimum, maximum, and average daily flow rates should be clearly identified and recorded.

### 11.4 UV Transmittance

UV transmittance (UVT) is a measure of the percentage of incident light at a specified wavelength transmitted through a material (e.g. water) over a specified distance (pathlength normally 1 cm). UVT is typically measured at 254 nm.

## 12. Equipment Verification and Calibration

Equipment verification and calibration tests should be conducted on a regular basis to ensure that UV equipment is operating within validated or certified operating conditions and is delivering the correct UV dose for the required pathogen log inactivation.

Procedures for equipment verification and calibration tests are set out in the U.S. EPA UVDGM, DVGW W294 and ÖNORM M 5873.

### 12.1 Duty and Reference UV Sensors

Duty UV sensors are online sensors that are installed in a UV reactor to continuously measure UV intensity during reactor operation. Reference UV sensors are offline sensors that are used to evaluate

[24] One watt = 1000 mJ/s.

and confirm duty UV sensor performance. Both types of sensors should be checked and calibrated on a regular basis to ensure that accuracy does not drift over time.

Duty UV sensors should be checked against a reference UV sensor at a minimum frequency of once every month or on a more frequent basis depending upon the recommendations of the equipment manufacturer. The calibration ratio (intensity measured with the duty UV sensor/intensity measured with the reference UV sensor) should be less than or equal to 1.2. If the calibration ratio is greater than 1.2, the duty UV sensor should be replaced with a calibrated UV sensor or a UV sensor correction factor should be applied while the problem with the duty UV sensor is being resolved.

Reference UV sensors should be factory calibrated by the sensor manufacturer at a minimum frequency of once every three years or on a more frequent basis depending upon the recommendations of the manufacturer. Reference UV sensors should be calibrated against a traceable standard such as the NIST, NPL, ÖNORM, or DVGW standards. A factory calibrated sensor should have a valid calibration certificate.

## 12.2 Flow Meters

Flow meters should be calibrated based on the frequency recommended by the flow meter equipment manufacturer or on a more frequent basis at the discretion of a Drinking Water Officer. Flow meter measurements should be within +/- 5% accuracy.

## 12.3 UVT Analyzers

UVT can be measured with a benchtop spectrophotometer or can be continuously measured by an online UVT analyzer. If the calculated dose monitoring/control strategy is used to estimate UV dose, online UVT analyzer measurements should be evaluated on at least a weekly basis by comparing online UVT measurements to UVT measurements using a calibrated benchtop spectrophotometer. The benchtop spectrophotometer should be maintained and calibrated at the frequency required by the equipment manufacturer. Calibration of UVT analyzers is necessary to determine whether a reactor is operating within its validated operating conditions. The calibration monitoring frequency can be decreased or increased based on the performance demonstrated over a one-year period. 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[25].

During UV reactor operation, the difference between the online UVT analyzer measurement and the UVT measured by the benchtop spectrophotometer should be less than or equal to 2%.

[25] USEPA (2006). Ultraviolet Disinfection Guidance Manual for The Final Long Term 2 Enhanced Surface Water Treatment Rule.

## 13. Alarm Conditions

Alarm conditions may be designated as minor, major, or critical depending upon the severity of the condition being indicated[26]:

- Minor alarms generally indicate that a UV reactor requires maintenance but that the reactor is still operating within its validated or certified operating conditions.
- Major alarms indicate that the UV reactor requires immediate attention, and that the reactor may be operating outside of its validated or certified operating conditions.
- Critical alarms typically shut down the reactor until the cause of the alarm condition can be fixed to prevent damage to the UV equipment.

**Table 6: Typical Alarm Conditions**

| Minor Alarms | Major Alarms | Critical Alarms |
|---|---|---|
| • Lamp Age<br>• UV Sensor Calibration Check [a] | • Low UV Validated Dose [b]<br>• Low UV Intensity<br>• Low UVT [c]<br>• High Flow Rate (if flow restrictor not used)<br>• Mechanical Wiper Function Failure (if applicable)<br>• Single Lamp/Ballast Failure | • Multiple Lamp/Ballast Failures<br>• Low Liquid Level and/or High Temperature [b] |

[a] May not be applicable to NSF 55 Class A certified devices, although UV sensors can be calibrated with the provision of a UV monitor (see Section 7. Reactor Certification).

[b] May not be applicable to NSF 55 Class A certified devices.

[c] Only applicable to UV reactors with online UVT monitoring (e.g. using UV intensity set point dosing strategy).

If a UV reactor malfunctions, loses power, or ceases to provide the appropriate level of disinfection, an operator should take the appropriate action at the location where the equipment is installed before water is again directed to users of the drinking water system (for systems with automatic shut-off) or before the alarm is deactivated.

For power quality alarms, if within two minutes of the alarm a further test indicates that power quality is no longer a concern, an operator need not be present at the location where the equipment is installed before water can be again directed to users of the drinking water system. The two-minute window allows a UV reactor to undergo a self-diagnostic test and to automatically reset itself.

Within 30 days following the end of a calendar month, a monthly summary report should be prepared which sets out the time, date, and duration of each major or critical UV equipment alarm that occurred

[26] USEPA (2006). Ultraviolet Disinfection Guidance Manual for The Final Long Term 2 Enhanced Surface Water Treatment Rule. Refer to Tables 4.2, 6.7 and 6.8 for alarm and monitoring schedules.

during the month, the reason for the alarm, the volume of water treated during each alarm period and the actions taken by the water supplier to correct the alarm situation. Unless otherwise notified, these summary reports should be stored onsite by the water supplier for inspection at the discretion of the DWO.

## 14. Off-Specification Water

Off-specification water[27] is produced when UV equipment is not achieving the required UV dose or log inactivation, as determined by at least one of the following criteria:

- The flowrate through the equipment is higher than the validated range;
- UVT is lower than the validated range[28];
- UV sensors are not properly calibrated; or
- UV equipment does not conform uniformly to the validated unit (i.e. the equipment does not have the same specifications as the equipment that was used for full-scale reactor validation).

Some regulatory bodies/agencies specify that in order to receive pathogen log reduction credits, at least 95% of the water delivered to the public each month should be treated by UV equipment that is operating within its validation envelope. This means that up to 5% of the water provided to drinking water users each month could be off-specification and in the absence of any other form of treatment, could potentially pose a risk to human health. This rule is intended to accommodate operational anomalies or unexpected issues, such as power outages or surges.

Production and management of off-specification water is typically addressed in terms and conditions to a water supply system's operating permit. UV equipment should be designed and selected to prevent off-specification water from entering the distribution system.

## 15. Training

Training should be provided to all personnel who are associated with UV disinfection equipment.

The training should include classroom and hands-on sessions, and should cover at least the following topics:

- An overview of how the UV equipment (as part of the water treatment facility) meets the provincial drinking water treatment objectives, including guidelines and standards that pertain to UV disinfection;
- An overview of UV disinfection principles;
- Water quality and performance monitoring;

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[27] Definition adapted from AWWA Standard F110 Ultraviolet Disinfection Systems for Drinking Water (2016).

[28] Note that flowrate through the equipment and UVT will be linked for reactors using calculated dose strategies or UV intensity variable set point strategies (i.e. units can deliver target UV dose at low UVT and low flow rates but can also deliver target UV dose at higher flow rates when UVT is higher). This validation envelope is specified in the Validation Report or Validation Certificate.

- Normal and emergency operating procedures;
- UV equipment operation and maintenance;
- UV equipment alarms and reporting requirements;
- UV equipment verification and calibration; and
- Safety requirements for operating and maintaining UV equipment, including exposure to UV light, and responding to lamp/sleeve breaks.

## 16. Equipment Start-Up and Commissioning

Before the start-up and commissioning of new UV equipment, the following documents should be submitted to the issuing official for review:

1. A commissioning plan for the new equipment including equipment calibration, functional testing, and performance testing per Section 6.1 of the U.S. EPA UVDGM;
2. A draft Operation and Maintenance Manual (O&M Manual); and
3. A training plan for all personnel who are associated with the UV disinfection facility, including operators, maintenance workers, instrumentation technicians, electricians, laboratory staff, custodial staff, engineers, and administrators (refer to Section 15 – Training).

After UV equipment installation, the following steps should be included in the reactor start-up and commissioning stages[29]:

- Prior to reactor start-up, a written certification should be obtained from the UV equipment manufacturer confirming that the UV equipment has been installed correctly.
- Upstream piping should be verified as free of sediment or debris that could damage sleeves and lamps.
- A lamp-break response procedure should be prepared, including mercury release response and cleanup procedure.
- The UV system O&M Manual standard operating protocol should be reviewed.
- Calibration checks should be performed on the instruments, sensors, and meters that will be used during equipment testing, including UVT analyzers, UV intensity sensors, and power consumption meters.
- Dry testing should be conducted with a follow-up period of wet testing. The UV equipment supplier should identify the tests that require testing with a dry reactor and those that require wet testing. Ancillary equipment should be included, such as flow meters and modulating valves.
- The UV system should be tested under all design conditions to verify that:
  - The UV dose programmed into the UV system controller matches validation with proper response to the validated range ("verification testing").
  - The UV reactor is adjusting power to maintain the target UV dose at varying flows and UVTs.

[29] Washington State Department of Health (2019). Water System Design Manual.

  - The UV system records and displays correct information for continuous monitoring and monthly reporting.
  - All alarm set points are working correctly.
  - The values reported on the UV control panel(s) match the values displayed and recorded in the SCADA system.
  - Automatic shut-off valves are working correctly (e.g. under a power failure scenario).
  - Alarms and/or automatic shut-off valves operate correctly under major and critical alarm scenarios.
  - The sleeve cleaning system is operating correctly, if included.
- The UV system should be tested for several days to verify proper performance under normal operation.

In addition to the above:

- Where required, an on-site fouling study should be conducted to inform the reactor cleaning, maintenance, and parts replacement schedule. Refer to Section 3.4.5 of the U.S. EPA UVDGM for details.

## 17. Conclusion

The information in this guideline provides provincial guidance on the reduction of pathogenic microorganisms in drinking water using UV disinfection and the design, operation, and maintenance of UV equipment for drinking water applications. Additional guidance is set out in the Design Guidelines for Drinking Water Systems in British Columbia, the Guidelines for Pathogen Log Reduction Credit Assignment and in the validation protocols and certification standard referenced in this document. In all cases, a Drinking Water Officer should be consulted when planning or considering upgrades to a drinking water supply system.

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## 19. Glossary

**Action Spectra Correction Factor (ASCF)** – a correction factor that is used to account for the greater proportional inactivation of a challenge microorganism compared to the target pathogen that results from differences in action spectra.

**Action Spectrum** – the relative efficiency of UV over a range of wavelengths at inactivating microorganisms. Each microorganism has a unique action spectrum.

**Ballast** – an electrical device that provides the proper voltage and current required to initiate and maintain the operation of a UV lamp.

**Biodosimetry** – a test procedure used to determine the reduction equivalent dose (RED) of a UV reactor by measuring the inactivation of a challenge microorganism after exposure to UV light in the reactor and comparing the results to the dose-response curve of the challenge microorganism determined by bench-scale collimated beam testing.

**Calculated Dose Approach** – a method that uses a dose-monitoring equation to determine a calculated UV dose based on the reactor's current operating conditions (flowrate, UV intensity and UVT where applicable). The calculated UV dose is divided by the reactor's Validation Factor to determine the validated UV dose. The dose-monitoring equation is normally developed during validation testing.

**Challenge Microorganism** – a non-pathogenic surrogate microorganism used in UV reactor validation testing with similar UV sensitivity and characteristics as the target pathogen.

**Collimated Beam Test** – a controlled laboratory bench-scale test that is used to determine the dose-response of a challenge microorganism. The collimated beam test apparatus uses a low-pressure UV lamp to produce collimated UV light (i.e. a beam with parallel rays and minimal dispersion) at 254 nm.

**Dose-Response** – the level of inactivation of a microorganism as a function of dose.

**EPA** – the United States Environmental Protection Agency.

**Groundwater at Low Risk of Containing Pathogens** – groundwater that is considered to be at low risk of containing pathogens as a result of a GARP assessment (i.e. no hazards were identified following a GARP Stage 1: Hazard Screening and Assessment, or the groundwater source was determined to be at low risk following a Stage 2: GARP Determination). Refer to the Guidance Document for Determining Groundwater At Risk of Containing Pathogens (GARP) when assessing the risk that groundwater may become contaminated with pathogens.

**Groundwater at Risk of Containing Pathogens (GARP)** – any groundwater supply likely to be contaminated from any source of pathogens, continuously or intermittently. Potential sources of pathogens include sewage discharge to land, leaking municipal sewage pipes (especially force mains), agricultural waste stockpiles, runoff intrusion into poorly constructed wells, and surface water.

**GARP-Virus Only** – any groundwater supply determined to be 'at risk' of containing viruses (i.e. if the DWO has reason to believe that the source is only at risk of containing viruses, and not other pathogens). This would include water supply system wells located within 300 m of a source of probable enteric viral contamination without a barrier to viral transport or other conditions indicating possible viral contamination, therefore requiring treatment of viruses;

**Rainwater** – water collected from natural precipitation from a roof or similar structure.

**Reduction Equivalent Dose (RED)** – the UV dose derived by interpolating the log inactivation measured during full-scale reactor testing on the UV dose-response curve that was derived through collimated beam testing. May also be called the reduction equivalent fluence (REF).

**Required Dose** – the UV dose in units of mJ/cm$^2$ needed to achieve the target log inactivation for the target pathogen.

**Supervisory Control and Data Acquisition (SCADA)** – a process control system that enables drinking water treatment operators to collect data from process sensors and/or to control equipment manually or automatically. The SCADA system may be accessible in the treatment facility and/or from a remote location.

**Surface Water** – water from a source which is open to the atmosphere and includes steams, lakes, rivers, creeks, and springs.

**Target Log Inactivation** – the log inactivation that the water supplier wants to achieve using UV disinfection for the target pathogen.

**Target Pathogen** – the microorganism targeted for inactivation credit using UV disinfection.

**UV Absorbance (A)** – a measure of the amount of light that is absorbed as it passes through a material (e.g. water) over a specified distance (pathlength, normally 1 cm). UV absorbance is normally measured at 254 nm, typically on a per centimeter (cm$^{-1}$) basis.

**UV Dose** – the UV energy per unit area incident on a surface, typically reported in units of mJ/cm$^2$. The UV dose received by a waterborne microorganism in a reactor vessel accounts for the effects on UV intensity of the absorbance of the water, absorbance of the quartz sleeves, reflection and refraction of light from the water surface and reactor walls, and the germicidal effectiveness of the UV wavelengths transmitted.

**UV Equipment** – the UV reactor and related components of the UV disinfection process, including (but not limited to) UV reactor appurtenances, ballasts, and control panels.

**UV Intensity –** the power passing through a unit area perpendicular to the direction of propagation. UV intensity is used in this guidance manual to describe the magnitude of UV light measured by UV sensors in a reactor and with a radiometer in bench-scale UV experiments.

**UV Intensity Set Point Approach** – a method that uses one or more UV intensity set points to determine UV dose. The set points are based on the validation testing for the UV reactor.

**UV Light** – light with wavelengths from 200 to 400 nm.

**UV Reactor** – the vessel or chamber where exposure to UV light takes place, consisting of UV lamps, quartz sleeves, UV sensors, quartz sleeve cleaning systems, and baffles or other hydraulic controls. The UV reactor also includes additional hardware for monitoring UV dose delivery; typically comprised of (but not limited to) UV sensors and UVT monitors.

**UV Reactor Validation** – experimental testing to determine the operating conditions under which a UV reactor delivers the dose required for inactivation credit of *Cryptosporidium*, *Giardia lamblia*, and viruses.

**UV Transmittance (UVT)** – a measure of the fraction of incident light at a specified wavelength transmitted through a material (e.g. water) over a specified distance (pathlength normally 1 cm). UVT is typically measured at 254 nm unless otherwise specified (i.e. as low wavelength UVT at ~220 nm).

**Validation** – the full-scale testing of a reactor to determine its disinfection performance under all operating conditions, including flow, UVT, and lamp power.

**Validated Dose** – the UV dose in units of mJ/cm$^2$ delivered by the UV reactor as determined through validation testing. The validated dose is compared to the required dose to determine log inactivation credit.

**Validation Factor** – an uncertainty term that accounts for the bias and uncertainty associated with validation testing under the U.S. EPA UVDGM protocol.

**Validated Operating Conditions** – the operating conditions under which a UV reactor is confirmed as delivering the dose required for pathogen log reduction credit. Operating conditions should include flowrate, UV intensity as measured by a UV sensor and UV lamp status.