
**Guidelines for performance evaluation
of treatment technologies for water
reuse systems —**

**Part 4:
UV Disinfection**

*Lignes directrices pour l'évaluation des performances des techniques
de traitement des systèmes de réutilisation de l'eau —*

Partie 4: Désinfection aux UV

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Contents

Page

Foreword	iv
Introduction	v
1 Scope	1
2 Normative references	1
3 Terms, definitions and abbreviated terms	1
3.1 Terms and definitions.....	1
3.2 List of abbreviated terms.....	3
4 Purpose and function of UV disinfection	3
4.1 Purpose.....	3
4.2 Function.....	3
5 System configuration	3
5.1 General.....	3
5.2 UV unit.....	4
5.3 Influent water quality monitoring devices.....	4
5.4 Flow meter.....	4
5.5 Power control panel.....	4
6 Functional requirements	5
6.1 General.....	5
6.2 Evaluation of the UV unit performance.....	5
6.3 Method of monitoring UV treatment system performance.....	5
6.3.1 Monitoring of influent water flow [M1].....	6
6.3.2 Quality control of influent water [M2].....	6
6.3.3 Monitoring of UV irradiation [M3].....	6
6.3.4 Monitoring of treated water quality [M4].....	7
6.4 Diagnosis of causes for system failure.....	8
7 Non-Functional requirements	8
7.1 Environmental performance.....	8
7.1.1 Energy efficiency.....	8
7.1.2 Chemical consumption.....	8
7.2 Safety.....	8
7.3 Cost effectiveness of systems — Economic evaluation by LCC.....	9
7.4 Reliability and resilience.....	9
Annex A (informative) Main treatment technologies and target constituents for water reuse	10
Annex B (informative) Experimental evaluation method for UV units	11
Annex C (informative) Experimental evaluation method in combination with CFD-I simulations	12
Bibliography	18

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 3, *Risk and performance evaluation of water reuse systems*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The rapidly growing global market for water reuse technologies inevitably demands standards which are applicable on a world-wide basis. Many regions in the world are facing water shortages, and there is great interest in the use of technologies that can treat wastewater and make the reclaimed water available for a wide range of reuse applications that can satisfy non-potable water demands, thereby conserving precious potable water supplies. Simultaneously, the implementation of water reuse schemes is raising public and regulatory concerns regarding potential human health, environmental and societal impacts. This has led to an increasing need to specify various aspects of water reuse projects and there is a growing need on behalf of regulators, reuse technology suppliers, and users of those technologies for international standardization. Without ISO water reuse standards, a great number of opportunities for sustainable development based on water reuse will be lost.

Standardization needs include objective specification and evaluation of levels of service and water reuse system performance dependability including safety, environmental protection, resilience and cost-effectiveness considerations. Hence, appropriate methods are needed to evaluate the performance of treatment technologies for water reuse systems.

The performance of treatment technologies for water reuse, *inter alia*, should be evaluated properly in order to select most appropriate technologies in an unbiased way to achieve the objectives of the water reuse project. Despite considerable research and development on treatment technologies, such scientific knowledge is largely held within commercial interests. Performance evaluations are also useful for assessing the efficiency of existing water reuse systems and operations, including the identification of continuous improvement opportunities. To address these challenges, this document provides methods and tools, which can be accepted by most stakeholders, to evaluate the performance of treatment technologies for water reuse systems from multitude of applications.

Based on the discussion in the meetings of ISO/TC 282/SC 3, ISO 20468-1 titled “Guidelines for performance evaluation of treatment technologies for water reuse systems – Part 1: General” has been developed to establish the standard of generic aspects for performance evaluation which can be applied to a variety of wastewater treatment technologies and their combinations, while descriptions specific to the representative technologies should be included in individual standards being submitted subsequently to ISO 20468-1. In this context, this document stipulating specific ways of performance evaluation of UV treatment technology for water reuse systems, based on ISO 20468-1 as the generic standard is established herein.

In non-potable water reuse systems, UV technology is used mainly for disinfection as indicated in [Table A.1](#) and works well with secondary or tertiary treated water as shown in ISO 20468-1:2018, Figure 1.

This guideline is intended as an integrated part of a framework for UV systems, consistent with other items in the work of TC 282. This framework includes several important aspects such as design, validation and verification (ISO 9000) and evaluation.

Guidelines focused on UV System Design, Validation and Evaluation are found in ISO 16075-5:2021, Clause 7.

Guidelines focused on UV system Design, Verification and Evaluation are found in ISO 20468-4.

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Guidelines for performance evaluation of treatment technologies for water reuse systems —

Part 4: UV Disinfection

1 Scope

This document provides guidelines for performance evaluation methods of UV disinfection for full scale water reuse systems. It deals with the methods of measurement of typical parameters which indicate performance of UV disinfection systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670, *Water reuse — Vocabulary*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 20670 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 Terms and definitions

3.1.1

biodosimetry

procedure of measuring the UV *reduction equivalent dose* (3.1.7) of a specific microorganism in a UV unit and a comparing the results to the known UV dose-response curve of this microorganism determined by bioassay (typically collimated beam methods)

3.1.2

challenge microorganism

microorganism used for a *biodosimetry* (3.1.1)

Note 1 to entry: Common challenge microorganisms include Bacteriophages MS2, Q β and T1UV as well as *Bacillus subtilis* spores

3.1.3

computational fluid dynamics-intensity

simulation method to model a UV unit by performing a combination of computational fluid dynamics (CFD) and optical analysis

3.1.4

lamp protection component

apparatus for protecting the light source, including a lamp protection sleeve, tube or other component

Note 1 to entry: Lamp protection sleeve – the quartz tube or thimble that surrounds and protects the UV lamp. The exterior is in direct contact with the water being treated

3.1.5

low pressure lamp

mercury-vapour lamp that operates at an internal pressure of 0,13 Pa to 1,3 Pa (2×10^{-5} psi to 2×10^{-4} psi) and electrical input of 0,5 watts per centimetre (W/cm)

Note 1 to entry: This results in essentially monochromatic light output at 253,7 nm.

3.1.6

medium pressure lamp

mercury-vapour lamp that operate at an internal pressure of 13 kPa to 1,300 kPa (2 psi to 200 psi) and electrical output of 50 W/cm to 300 W/cm

Note 1 to entry: This results in a polychromatic (or broad spectrum) light output at multiple wavelengths, generally between 200 nm to 400 nm.

3.1.7

reduction equivalent dose

dose of UV in a given device which is determined by *biodosimetry* ([3.1.1](#))

Note 1 to entry: See “UV dose” and “biodosimetry”.

Note 2 to entry: This UV dose is determined by measuring the inactivation of a challenge microorganism after exposure to UV light in a UV unit and comparing the results to the known UV dose response curve of the same challenge organism determined via Bench scale collimated beam testing.

3.1.8

UV dose

UV fluence

amount of UV energy given as the time integral of the fluence rate or irradiance (W/m^2)

Note 1 to entry: This is given in units of mJ/cm^2 or J/m^2 .

3.1.9

UV irradiance

UV fluence rate

UV intensity

UV output emitted from a given light source and entering a unit area of the irradiated surface. The value is typically given in W/m^2 or mW/cm^2

Note 1 to entry: The terms UV irradiance, fluence rate or intensity are often used to mean the same thing.

Note 2 to entry: For details, refer to Bolton and Linden 2003.

3.1.10

UV intensity sensor

UV irradiance ([3.1.9](#)) meter or radiometer instrument to measure *UV irradiance* ([3.1.9](#))

3.1.11

UV transmittance

fraction of photons in the UV spectrum transmitted through a material such as water or quartz

Note 1 to entry: It is preferable that an online UVT sensor be installed and used to verify UVT.

Note 2 to entry: The wavelength of the UVT (unit %) should be specified, often using a path-length of 1 cm. The measurement is calibrated compared to ultra-pure water (ISO 3696 grade 1 or equivalent).

Note 3 to entry: UVT is related to the UV absorbance (A) by the following equation (for a 1- cm path length):
 $\% \text{ UVT} = 100 \times 10^{-A}$.

3.2 List of abbreviated terms

AOPs	advanced oxidation processes
BOD	biochemical oxygen demand
CFD-I	computational fluid dynamics-intensity
<i>E. coli</i>	Escherichia coli
LCC	life cycle cost
PCD	pitch circle diameter
POPs	persistent organic pollutants
RED	reduction equivalent dose
TDS	total dissolved solids
TSS	total suspended solids
UV	ultraviolet
UVT	ultraviolet transmittance

4 Purpose and function of UV disinfection

4.1 Purpose

To conduct water reuse, secondary or tertiary treated wastewater requires disinfection and sometimes further treatment by more advanced processes. The treated and disinfected wastewater is then used for various applications such as, urban, agricultural, industrial recreational and environmental uses.

4.2 Function

UV light has been proven effective against microorganisms including bacteria, protozoa and viruses (see [Annex A](#)). UV disinfection is achieved mostly by the absorption of photons by the genome of microorganisms, resulting in the formation of damage such as pyrimidine dimers on DNA or RNA. Such lesions hinder the self-replication in the microorganisms and thus deprives the infectivity. Accordingly, UV disinfection does not require chemical addition and results in limited by-product formation.

5 System configuration

5.1 General

A UV disinfection system for water reuse can consist of the following components and systems may have several of each component based on the disinfection application requirements.

- UV unit;
- influent water quality monitoring devices;
- flow meter;

- power control panel.

Each component will be explained in [5.2](#) to [5.5](#).

5.2 UV unit

A UV unit has simple components including irradiation chamber, a light source, an automatic cleaning system and a UV intensity sensor. A specific UV unit may need one or more UV intensity sensor and one or more irradiation chamber and light source, depending on the specifics of the application. UV units may be categorized into closed and open systems, based on the configuration of UV units in the irradiation chamber. The closed system has a UV unit, comprised of UV lamps and their sleeves, placed in the closed vessel flow chamber. Meanwhile, the open system has a UV unit immersed in an open channel or chamber with gravity flow and water level control device. UV systems can also consist of non-contact unit designs with UV lamps suspended outside a transparent conduit that carries the wastewater.

- light source

A light source for UV disinfection should have a germicidal emission at wavelengths appropriate to the task, often at the wavelength of 253,7 nm or a combination of wavelengths between 200-385 nm. Options include low-pressure mercury lamps, medium-pressure mercury lamps, excimer lamps, pulsed-Xenon lamps, and ultraviolet light emitting diodes. The light source should be housed in a lamp protection component.

- cleaning system

A cleaning system is the device having a wiper driven by electric power supply, hydraulic power supply or pressurized air, or ultrasonic wave, etc. Options include a mechanical wiper consisting of a brush, ring or a mechanical chemical wiper consisting of a chamber with rings filled with a washing liquid.

- UV intensity sensor

A UV intensity sensor is installed to measure the UV irradiance in the irradiation chamber so that the irradiance can be tracked and it can be determined whether the required dose has been provided.

- ballast

A ballast is installed when using a UV lamp as a light source. Ballasts provide the power that the lamp converts to UV photons (energy).

5.3 Influent water quality monitoring devices

A UV transmittance monitor can be used to feed data to the system controller to adjust the power of the lamp to assure that the required dose is provided. To check whether or not the water quality of the influent has changed from the design conditions, water quality monitors including a UV transmittance monitor, a turbidity meter (optional) etc. are used.

5.4 Flow meter

Generally, each UV unit should have a dedicated flow meter for several reasons, including to confirm that the unit is operating within the validated flow rate range. The measured flow rate data may be sent to control panel and may be utilized for light-source controlling, monitoring and operating in order to achieve system performance. The method of flow rate measurement should be selected according to the variability in plant flow rate and installation conditions.

5.5 Power control panel

The control panel has the following functions: power receiving, power supplying, controlling, monitoring and operating, and other functions for the light source and other apparatuses.

6 Functional requirements

6.1 General

Functional requirements for treatment technologies address the transformation of influent water quality constituents to produce reclaimed water and include both water quality and water quantity parameters.

One of the functional requirements of a given UV treatment system is to secure, at all times, enough UV dose to obtain a target quality of the reclaimed water that is appropriate for application of such water. The UV dose is the time integral of the fluence rate or irradiance. What is necessary to this end includes: use of a UV light source with appropriate irradiance; and retaining the reclaimed water in a UV irradiation chamber for a predetermined time period.

In actual equipment, the irradiation time and UV irradiance in the UV irradiation chamber vary from one portion to another due to the shape of the chamber, as well as the location and number of the light sources, and other similar factors. Water quality determined by, for example, suspended matter and UV absorbing components also reduces UV transmittance, and thereby affects UV dose distribution. By taking these influences into consideration, a predetermined UV dose, or higher dose that is sufficient for the water flow passing through the UV irradiation chamber, shall be secured at all times.

Methods for evaluating the performance of the UV unit in the design stage and for subsequently monitoring the performance of the UV disinfection system in operation are provided below.

6.2 Evaluation of the UV unit performance

Evaluation of the UV unit performance should be done; a number of experimental methods may be used including those described in [Annex B](#), while the method in [Annex C](#) is accepted as a second option.

NOTE The amount of upscaling varies from no upscaling permitted to a specific level of upscaling permitted depending on country regulations.

Method I: Annex B (Experimental evaluation method)
I-1: Experimental testing using a challenge microorganism
I-1-1: Preliminary testing
I-1-2: Full-scale unit testing
I-2: Determine the RED
Method II: Annex C (Experimental evaluation method in combination with CFD-I simulations)
II-1: Experimental testing using a challenge organism for reference unit
II-2: Intensity measurement test on UV light source
II-3: Development of the CFD-I simulation models
II-4: Determine the RED in the unit of interest

6.3 Method of monitoring UV treatment system performance

The UV treatment system can be run automatically, so that its usual operation is generally simple compared to other disinfection processes. What is important for routine maintenance includes: monitoring the amount and the quality of UV treatment target water; and monitoring the UV dose. [Figure 1](#) shows the water flow through the UV treatment system and the monitoring points situated in the system.

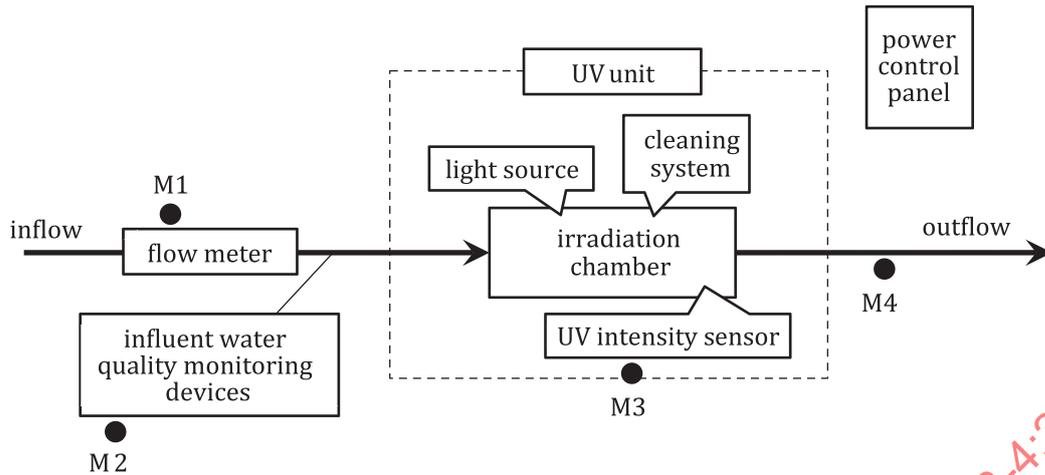


Figure 1 — Typical configuration of UV disinfection system and monitoring points in UV disinfection system

6.3.1 Monitoring of influent water flow [M1]

To check the water flow rate through the UV unit for deviation from the design flow rate, a flow meter is required as ancillary equipment. To check whether the flow meter is functioning problem-free, it is recommended to perform calibration within a period specified by the manufacturer.

EXAMPLE Manufacturer's recommendations: once a year.

6.3.2 Quality control of influent water [M2]

Colloidal solids, suspended solids, colour and dissolved solids (particularly dissolved organic compounds) can absorb UV radiation, reduce UV transmission and decrease UV disinfection. If, in addition, UV absorbing substances such as iron, manganese, sulphurous acid, nitrous acid, and phenol exist, they reduce UV transmittance and thereby affect the treatment effect. Furthermore, constituents such as iron, calcium and magnesium can cause scaling and interfere with UV irradiation and intensity. Consequently, the presence and potential of these constituents to adversely impact disinfection shall be addressed during the design stage and appropriate O&M cleaning procedures implemented to reduce or eliminate their impact on disinfection.

Accordingly, these water quality parameters need to be measured and monitored on a regular basis. If the water quality of the treatment target water does not satisfy the conditions for UV application, a possible halt in the treatment shall be taken into consideration.

NOTE Generally, when these water quality parameters are well controlled by pre-treatment, fluctuations are small but could be significant depending on capacity and performance of the pre-treatment.

6.3.3 Monitoring of UV irradiation [M3]

In the course of the evaluation of the UV unit, the minimum UV irradiance for a maximum flow at a minimum UVT of the water is defined.

Monitoring UV irradiation cannot be performed by biosimetry in routine operation and maintenance. Instead, the UV system is operated in a way that the UV irradiance is kept within the designed range, which is monitored by one or more online UV intensity sensors mounted on the UV irradiation chamber.

To keep the appropriate UV irradiance, the following items shall be monitored, and maintenance work shall be conducted if necessary.

- UV light sources

Check the cumulative use time of the UV light source. Replace the light source according to its service life (operating time) or performance parameters presented by the manufacturer.

— Lamp protection component

When fouling substances adhere to the surface of the lamp protection component, the amount of UV that can enter the water decreases. The extent of sleeve fouling can be monitored based on the UV intensity sensor signal. Most UV systems have low intensity alarms that trigger when too much fouling builds up on the lamp protection component. However, relying on the UV intensity sensor signal to assess the extent of fouling is not always sufficient. Visually, check the degree of fouling on the surface regularly. Make sure the UV light sources are turned off before looking at the sleeves. In addition, cleaning of the lamp protection component should be conducted. Possible cleaning methods include physical cleaning using automatic cleaner online and offline chemical cleaning.

EXAMPLE Automatic cleaner (online): Details of such automatic cleaner are described in 5.2. Chemical cleaning (offline): Protection components are soaked and/or washed with acid such as citric acid and phosphoric acid.

— UV intensity sensor protection glass

A dirty protection glass pane in the UV intensity sensor results in a lower reading than is supposed to be shown without any problem with UV lamp and lamp sleeve. Therefore, frequent cleaning of the protection glass pane is needed.

— Deterioration of the UV intensity sensor receiver

The UV intensity sensor receiver constantly receives UV irradiation, resulting in dispersions in UV intensity sensor reading due to deterioration under exposure. Therefore, periodical calibration or replacement of UV intensity sensor is needed. (at intervals recommended by the manufacturer).

EXAMPLE Calibrating the UV intensity sensor. In addition to the UV intensity sensor provided with the UV unit, own a standard UV intensity sensor. Use the standard UV intensity sensor periodically to calibrate the provided UV intensity sensor. For the standard UV intensity sensor, have it calibrated by the manufacturer within a time interval specified by the manufacturer.

— UV transmittance

If the method of monitoring UV dose is based on the UV irradiance setpoint approach, regularly check that the UV transmittance is not below the set lower-limit value. If the method is based on the calculated dose approach, UV transmittance needs to be monitored continuously because it is required in the UV dose calculation. UV transmittance can be assessed from a sample, but due to the potential for variation in constituent(s) presence and concentrations that can interfere with UV transmission, it is preferable that an online UV transmittance sensor be installed and used to verify UV transmittance.

— Power control panel

The lamp power supplies are temperature sensitive. Most UV system power control panels have air ventilation or air conditioning to cool the lamp power supplies. The filters mats on cooling fans or air conditioning exhaust fans shall be cleaned regularly to avoid overheating the lamp power supplies inside the power control panel.

6.3.4 Monitoring of treated water quality [M4]

UV treated water quality should be measured, to confirm satisfactory disinfection, by monitoring the concentration of microorganisms present in the water (e.g. indicators like *E. coli* (or thermo-tolerant coliform bacteria), somatic or FRNA-coli phages, clostridium perfringens spores).

This may include comparing the original design requirements to the actual performance over time based on specific aspects of UV performance.

6.4 Diagnosis of causes for system failure

If one or more operating objectives or water quality requirements are not being attained, the UV system may be malfunctioning and countermeasures are required. This section describes some examples of how to deal with any failures in the UV system.

a) UV irradiance decrease:

- Check light source degradation or light out.
- Check power supply.
- Check UV intensity sensor works properly. Deterioration of the UV intensity sensor can be confirmed by calibration, or comparison with the initial intensity, using a standard light source.
- Check fouling and scaling on lamp protection component. Fouling/scaling on the lamp protection component can deteriorate the performance of cleaning system.

b) Degradation of treated water quality:

- Check UV irradiance by referring to a).
- Check UV transmittance of the water. If UV transmittance is below the design value, either temporarily stop the treatment or temporarily reduce the flow rate to secure the necessary UV dose and wait for the water quality to recover.

c) Extremely high light source temperature:

- To minimize a risk of damage to the device, immediately stop the system.

d) Water leakage:

The following can be assumed as the cause of the water leakage alarm:

- Breakage in the seal part of lamp protection component.
- Breakage in lamp protection component.
- False detection due to condensation.

7 Non-Functional requirements

7.1 Environmental performance

7.1.1 Energy efficiency

UV units meeting the performance requirement for water reuse systems are to be evaluated for energy efficiency regarding the electricity consumption per unit volume of treated water (kWh/m^3) or on the water treatment volume per unit electricity consumption (m^3/kWh).

7.1.2 Chemical consumption

Chemical reagents consumption and water consumption used for cleaning should be evaluated.

7.2 Safety

In the operation of the UV system, pay attention to the following matters for safety and take precautions as necessary.

- UV light exposure: It is best to wear personal protective equipment (gloves, UV goggles and long sleeve shirt.) at all time when working by the UV unit.

- Electrical safety.
- Burns from hot lamps or equipment.
- Abrasions or cuts from broken lamps or sleeves.
- Potential exposure to mercury from broken lamps.
- Moving part.

7.3 Cost effectiveness of systems — Economic evaluation by LCC

LCC of UV disinfection process is composed of capital cost, operating cost, and disposal cost. Capital cost for UV system is associated with construction costs and the purchase cost of UV unit, and their associated piping, instrumentation and control systems. Operating cost equals the cost required for system operation (e.g. electricity, light source replacement, cleaning reagents and labour). Disposal cost consists of disposal expenditure of consumables and disposal cost of waste generated at plant dismantling. For the fair evaluation, LCCs which are divided by volume of treated water at the project lifetime (i.e. the unit is “costs/m³”) should be used.

7.4 Reliability and resilience

The UV disinfection system ensures its reliability because the following items are functioning normally:

- Flow meter.
- Influent water quality monitor.
- Light source.
- Cleaning system.
- UV intensity sensor.
- Lamp power supply.

Especially, it is important that the UV intensity sensor is calibrated on a regular basis. If the UV intensity sensor shows an abnormal value, check whether the earlier items including the UV intensity sensor are operating properly. Then, by correcting or exchanging items for which a problem has been detected, the function of the UV system can be restored.

In addition, it is necessary to prepare in advance an emergency response plan for the assumed trouble event so that prompt recovery can be achieved when trouble occurs in the UV system. Furthermore, if there is a risk that inadequately treated reclaimed water is supplied to the user, procedures for properly notifying the reclaimed water users and the responsible agencies, and other agencies should be included in the emergency response plan.

Annex A (informative)

Main treatment technologies and target constituents for water reuse

Table A.1 indicates main treatment technologies and target constituents after BOD removal for water reuse systems. It is summarized by focusing on typical technologies for advanced treatment and disinfection described in ISO 20468-1 with related functions required for water reuse.

Table A.1 — Main treatment technologies and target constituents (After BOD removal)

Required functions		Separation	Disinfection			Desalination	Oxidation or others		
		Target constituents							
Technologies		Turbidity or TSS	Pathogens			Conductivity or TDS	Colour	Odour	POPs (Persistent organic pollutants)
			Bacteria	Viruses	Protozoa				
Membrane Separation	MF	✓	✓		✓				
	UF	✓	✓	✓	✓				
	NF/RO		✓	✓		✓	✓	✓	✓
Ion Exchange	Resin					✓	✓		
	Membrane					✓			
Distillation (preparing)									
Ozone			✓	✓	✓		✓	✓	✓
UV			✓		✓				
AOPs			✓		✓		✓	✓	✓
(Note)		Typical monitoring parameter ^a			Additional target constituents				

^a Reference: ISO 20468-1.

Annex B (informative)

Experimental evaluation method for UV units

A method based on biosimetry is commonly used as an experimental evaluation method. An outline of its procedure is described below.

Details of such procedure are defined by standards of a number of public institutions: DVGW (worksheet W294), Austrian Standards International (ÖNORM M 5873-1 and ÖNORM M 5873-2), USEPA, NWRI.

B.1 Preliminary testing

Preliminary testing using collimated beam apparatus is commonly used to characterize the UV dose-response relationship of the challenge microorganism. 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 as a function of UV dose.

B.2 Full-scale testing

In these experiments, the challenge microorganisms are injected upstream of UV unit. Samples are analyzed to determine the log inactivation at the test conditions of flow rate, UVT, lamp status, and UV irradiance as measured by UV intensity sensors. Full-scale unit testing can be performed on-site at a water treatment plant or off-site at a performance evaluation organization.

UVT can be monitored using online UV transmission sensors.

B.3 Determine the RED

[B.3](#) combines results from the two experimental tests in [B.1](#) and [B.2](#). The log inactivation of the challenge microorganism measured during the full-scale testing ([B.2](#)) is entered into the UV dose response equation ([B.1](#)) to calculate the RED of the unit.

RED values are always specific to the following:

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

Annex C (informative)

Experimental evaluation method in combination with CFD-I simulations¹⁾

C.1 General

This is an evaluation method for UV irradiation performance of having a larger design water flow UV units manufactured based on the same design concept as that of the reference UV unit by CFD-I simulations.

The “same design concept” mentioned above refers to:

- The unit is equipped with an identical light source or a light source having an identical emission characteristic.
- The structure, material, monitoring, control, etc. of the irradiation chamber are designed based on the same concept.

The reference unit is a device for constructing a simulation model to be used when the UV dose of the evaluation target unit is calculated by a CFD-I simulation. It is required that this reference device should have a known RED obtained through actual measurement.

C.2 Evaluation procedure

An evaluation procedure by CFD-I simulation is illustrated in [Figure C.1](#).

1) Excerpt from “*Technical examination standard for UV irradiation equipment*” Japan Water Research Center (2012).

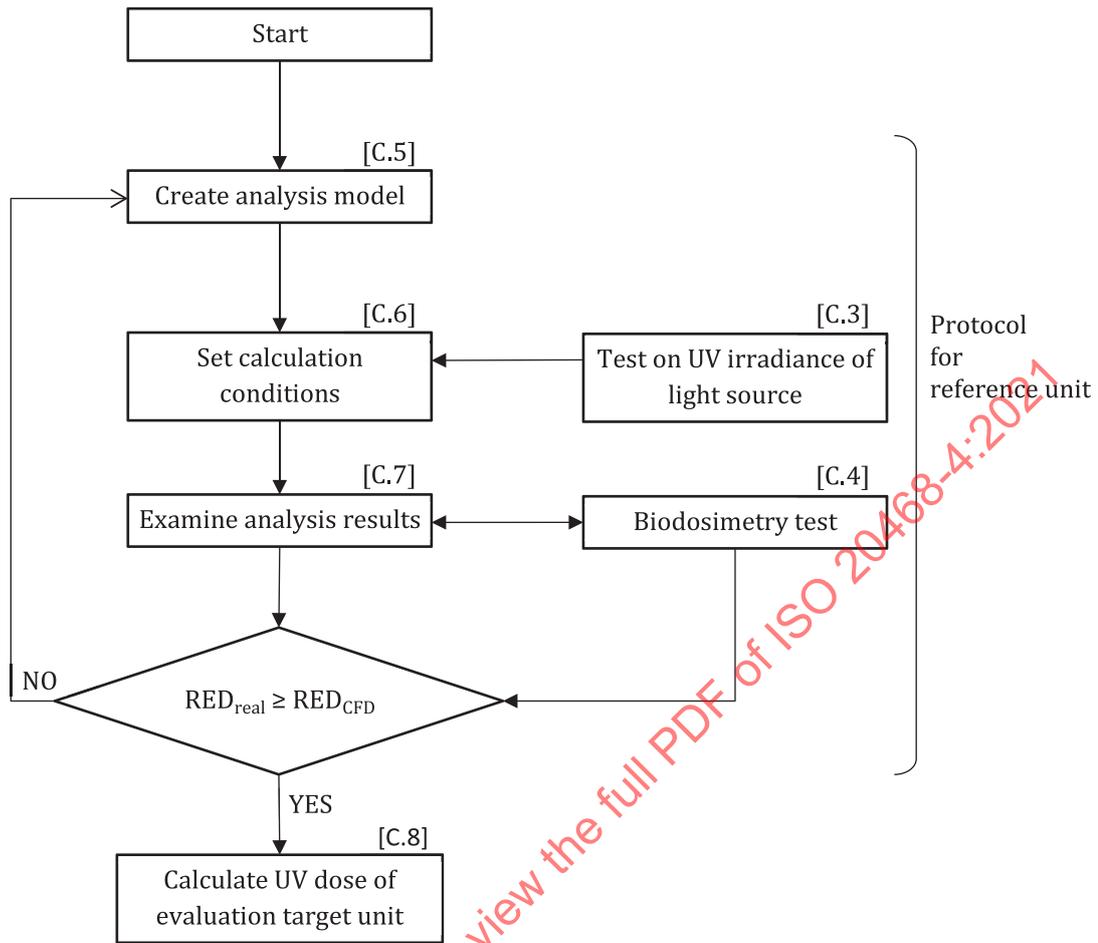


Figure C.1 — Procedure of evaluation by CFD-I simulation

C.3 UV irradiance test on lamps

Following is how to measure the irradiance of the UV lamps to be inserted in the UV unit:

- How to take measurements with a quartz irradiation chamber

Keep a quartz irradiation chamber at a constant atmospheric temperature for a lamp by using a water temperature controller, insert a UV lamp into the chamber, and turn on the UV lamp with the supply voltage kept at a constant level by a voltage stabilizer. With the UV output stabilized, and at a specified distance away, measure the UV irradiance with a UV irradiance meter²⁾ or chemical actinometer. Then use a water temperature controller to vary the atmospheric temperature inside the quartz irradiation chamber and measure the UV intensities at the different water temperatures.

- How to take measurements in the air by temperature correction

Keep the air at the supply voltage kept with a voltage stabilizer, then turn on the UV lamp. Keep it on until its UV output stabilizes. Then, at a specified distance away, measure the UV irradiance with a UV irradiance meter²⁾ or chemical actinometer. Ensure that, at that time, the UV irradiance is at or higher than an arbitrary level. Moreover, to evaluate the relative changes in UV irradiance due to the water temperature of the UV lamp, use a unit with a quartz glass pane (for measuring

2) UV irradiance meter: Use an irradiance meter calibrated as per national standards established by the National Institute of Standards and Technology (NIST), National Institute of Advanced Industrial Science and Technology (AIST), or similar organization.

UV irradiance) in it and a water temperature controller to measure the relative changes in UV irradiance (an example is shown below).

EXAMPLE Use a water temperature controller to keep the atmospheric temperature of the lamp at a constant level inside a stainless steel irradiation chamber (with a quartz glass pane in it), insert a UV lamp into it, keep the supply voltage at a constant level with a voltage stabilizer, and turn on the UV lamp under that condition. Stabilize the UV lamp and measure the UV irradiance with a UV irradiance meter²⁾ or chemical actinometer inserted through the window pane of the irradiation chamber. Measure the UV irradiance achieved when the water temperature in the stainless steel disinfection chamber is varied with the water temperature controller, then determine the relative changes in UV irradiance at the different water temperatures.

C.4 Bidosimetry test in reference unit

The RED (RED_{real}) of reference UV unit is calculated in accordance with the testing method specified separately.

C.5 Creation of analysis model of reference unit

Use an analysis software that has been verified sufficiently through experiments.

Use, for example, ANSYS Fluent, ANSYS CFX, STAR-CD, STAR-CCM+, etc.

A model of the reference UV unit is created that reflect appropriately the shapes and the dimensions of its body and its internal structural members. [Table C.1](#) shows some examples of input parameter items for the shapes.

Table C.1 — Example of input parameter items for shapes

Group	Item	Symbol	Unit
UV irradiation chamber's shape and dimensions	Inner diameter	D_R	mm
	Effective length	L_R	mm
Nozzle's shape and dimensions	Coupling type	U,L,S, etc. types	
	Inlet nozzle's inner diameter	D_I	mm
	Inlet nozzle's length	L_{NI}	mm
	Outlet nozzle's inner diameter	D_O	mm
	Outlet nozzle's length	L_{NO}	mm
Sleeve's dimensions and number of sleeves	Outer diameter	d_s	mm
	Thickness	t_s	mm
	Effective length	L_s	mm
	Number of sleeves	N_s	pcs
	Array diameter	PCD	mm
Wiper's shape and dimensions	Inner diameter	d_{wi}	mm
	Outer diameter	d_{wo}	mm
	Height	h_w	mm
Wiper holder's shape and dimensions	Input dimensions of each part		mm
Note for mesh creation			
Create a finer mesh near internal structural member so that the polygons approximate to circles.			
^a Setting standard values for the minimum mesh size and the number of meshes are thought to be impossible as their respective optimal values are determined case by case depending on the irradiation tank's shape. Hence, determine whether or not the meshes near the internal structural member are sufficiently fine for the dimensions of the structural member.			