guardians of drinking water quality

Guidance on the use of ultraviolet (UV) irradiation for the disinfection of public water supplies

August 2016

DOCUMENT CONTROL

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Revision History

Issue No	Date	Purpose	Author(s)
1.0	February 2010	Initial guidance	SL, SJ, EC, AQ, JF
Revision No	**Revision date**	**Purpose of revision**	**Revised by**
1.1	August 2016	Review	GF, AM, MP

Preface

Intended audience:	This document is aimed primarily at **water suppliers in England and Wales**. The devolved administrations in Scotland and Northern Ireland, as with the rest of Europe, have separate but parallel legislation and associated guidance. Use of the term 'water supplier' in this document refers to • a water undertaker, • a holder of a combined licence, within the meaning given by section 17A(6) of the Water Industry Act 1991, and • a holder of an appointment referred to in section 7(4)(bb) of the Water Industry Act 1991 but, unless the contrary intention appears, does not include the holder of a retail licence (within the meaning given by section 17A(4) of the Water Industry Act 1991).
Legal status:	This document has been produced to provide guidance on the use of ultraviolet (UV) irradiation for disinfection of public water supplies in relation to the requirements of the Water Supply (Water Quality) Regulations 2016[1]. The text should not be taken as an authoritative statement or interpretation of the law. Every effort has been made to ensure that these guidance notes are as accurate and helpful as possible, although it is ultimately the responsibility of individual water suppliers to ensure compliance with the law. Water suppliers with specific queries may wish to seek advice from DWI.
Purpose:	This document is intended to provide guidance on the design, operation and monitoring of UV irradiation as a process for the disinfection of public water supplies intended for domestic or food production purposes. The guidance may also be appropriate to the disinfection of waters analogous to public water supplies, such as unregulated or private water supplies. UV equipment or methods of operation, design and validation will evolve. Water suppliers are therefore not limited by the information provided in this guidance, and are still obliged to comply with the requirements of the Water Supply (Water Quality) Regulations (as amended) at all times. This guidance does not consider the principles of disinfection, alternative methods of disinfection or other aspects of disinfection. It is also not intended to apply to sources of water not used for domestic or food production purposes.

[1] Water Supply (Water Quality) Regulations 2010 as amended in Wales

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1. Summary

1.1. The disinfection of public water supplies is a statutory requirement in England and Wales. Water supplied for domestic or food production purposes must not contain any micro-organism or parasite at a concentration which could constitute a potential danger to human health. Water suppliers should, therefore:

- have in place a water treatment policy and a disinfection policy covering all the requirements of regulation 26 of the Water Supply (Water Quality) Regulations;
- have documentation and procedures in place which ensure that at every works it is unambiguous how regulation 26 is being met, both in principle and in practice; and
- in accordance with regulation 27, adopt a comprehensive, system-specific risk assessment and risk management ('water safety plan') approach, that identifies appropriate controls, and incorporates multiple barriers from catchment to consumer.

1.2. Water suppliers must pre-treat waters to modify their quality in respect of any property known to adversely affect the performance of disinfection processes. In particular the turbidity of waters to be disinfected should be maintained below 1 NTU. In addition the recommendations of the various Expert Groups on *Cryptosporidium* in water supplies, as summarised in the 'Badenoch' and 'Bouchier' reports, are still relevant and considered as good operational practice. In the case of water to be disinfected using UV treatment chemical residuals which are strong UV absorbers should be kept to a minimum. Chlorine and chloramine used to provide a residual chemical disinfectant concentration into supply should be dosed after UV processes.

1.3. In accordance with appropriate risk management (a water safety plan approach), each UV reactor must be designed as a control for the identified hazards at each works taking into account the physical and chemical characteristics of the water to be disinfected. The performance of UV reactors must be **validated** to demonstrate that they meet the intended performance criteria. Independent validation testing is commonly (but not always) undertaken by the manufacturers. Key considerations to take into account are:

- only UV reactors that have undergone validation testing should be used for disinfection purposes, DWI currently considers full-scale biodosimetry testing to be the most appropriate method of validation until such time as another technique has been proven to be equivalent or better;
- reactor validation should take into account all operational, water quality, and other factors that may impact on the UV fluence to which pathogens are exposed at each works;
- reactors must not be operated outside of their range of site-specific validated conditions unless an alternative appropriate risk control measure is in place; and

- reactors should be revalidated if changes occur that substantially change their performance.

1.4. Whether UV irradiation is used alone or in combination with other processes for the disinfection of drinking waters, water suppliers will be required to have evidence-supported justification for the UV fluences used at specific works.

1.5. The effectiveness of UV disinfection processes must be **verified**. This will involve the continuous monitoring and recording of the conditions of operation at critical control points. Water suppliers should therefore monitor and record, as a minimum :

- water flow, lamp status and UV fluence rate within each reactor;
- UV absorbance where a 'Calculated Dose' approach is employed;
- turbidities (representative of that within each UV reactor);
- reactor cleaning, inspection and maintenance; and
- lamp operating times and dates of lamp replacement

1.6. The introduction of chemical agents into treated waters to provide a residual disinfectant during distribution should not be used to compensate or as a substitute for inadequate disinfection of the water at a works.

1.7. Water suppliers are expected to have documented action plans for identifying and responding to lamp or sleeve breakages

1.8. DWI recommends any water company considering the use of UV irradiation for the disinfection of public water supplies to consult the USEPA Ultraviolet Disinfection Guidance Manual (UVDGM) as a useful source of background information. A Bibliography containing this and other relevant information sources, as well as a Glossary of Terms, is appended to the end of this document.

2. Introduction

2.1. The primary European legislation relating to the quality of water intended for human consumption is the 1998 EU Drinking Water Directive (98/83/EC). The requirements of this Directive are implemented in England and Wales by the Water Supply (Water Quality) Regulations[2] ("the Regulations").

2.2. The Regulations require water to the disinfected prior to supply and for the risks posed to each supply system to be assessed. DWI considers the most effective means of ensuring all consumers consistently receive drinking water that is clean, compliant with the Regulations and demonstrably safe is through the use of a comprehensive, system-specific risk assessment and risk management ('water safety plan') approach[3], that identifies appropriate controls, and incorporates multiple barriers from catchment to consumer. Accordingly, the provision of safe drinking water supplies should be achieved through a combination of:

(i) selection and protection of reliable, high-quality drinking water sources,
(ii) selection and continuous operation of appropriate treatment controls, and
(iii) active management and maintenance of water distribution systems.

2.3. DWI expects water suppliers to place an emphasis on preventing or reducing microbial risks at source, additional treatment barriers are required as a means of reducing microbial risks and ensuring the supply of consistently safe water to consumers.

2.4. The disinfection of public water supplies is a statutory duty on water suppliers although the regulations do not prescribe the method of disinfection. This document is intended to provide guidance on the issues that water suppliers should consider when designing and operating UV processes for the purposes of disinfection.

3. Disinfection of public water supplies[4]

3.1. The Regulations define disinfection as being a process of water treatment to remove, or render harmless to human health, every pathogenic micro-organism and pathogenic parasite that would otherwise be present in the water.

3.2. Disinfection, as defined, relates to the arrangements and equipment a water company has in place to treat raw water before it is supplied. These disinfection arrangements may be a single process of inactivation (such as chlorination, ultraviolet irradiation, or ozonation), a single process of removal (such as membrane or other equivalent filtration technology), or it may be achieved through a combination of two or more processes (for example UV irradiation followed by chlorination). However, it is important that the technical performance characteristics of the disinfection arrangements at each of works is known in relation to the ability of each process or combination of processes (when operated in the manner intended) to remove or inactivate pathogens, and that these performance characteristics are validated in advance.

[2] Water Supply (Water Quality) Regulations 20016 (SI 2016 No 614) in England; and The Water Supply (Water Quality) Regulations 2010 (2010 No. 994 (W.99)) (as amended) in Wales
[3] As described in WHO (2011) Guidelines for drinking-water quality, Fourth edition, World Health Organization, Geneva. ISBN 978 92 4 154815 1
[4] See also DWI guidance on the regulations available on www.dwi.defra.gov.uk

3.3. Whilst the choice and appropriateness of specific treatment processes (or combination of processes) are not specified in the Regulations, DWI expects Water suppliers to have in a place a water treatment policy and a disinfection policy covering all of the requirements of regulation 26. Design and operation must be covered by this policy, which should be kept under regular review and be informed by appropriate studies and technical performance data. Water companies must have documentation, procedures and monitoring in place which ensure that it can demonstrate continual verification of the effectiveness of disinfection both in principle and in practice at every treatment works. These procedures must identify all the critical controls. Water suppliers must also ensure that there is current and archived verification data for each critical control for disinfection.

4. Water pre-treatment

4.1. In addition to the disinfection of all public water supplies, and consistent with a multiple barrier approach, regulation 26 requires that water suppliers subject water to sufficient preliminary treatment to prepare them for disinfection. Thus, where necessary, water suppliers must treat waters to modify their quality in respect of any property known to adversely affect the performance of disinfection processes. Where no preliminary treatment takes place DWI expects water suppliers to be able to demonstrate from robust data why no preliminary treatment is required.

4.2. A number of water quality properties may adversely affect the performance of UV disinfection processes. Of primary importance is the production of waters with consistently low turbidities. Accordingly, treatment works should be designed and operated at all times in a manner that minimises turbidity in the water entering processes used for disinfection, as well as the size, frequency and duration, of any turbidity peaks. Regulation 26 requires that turbidities remain below 1 NTU, reflecting long standing WHO disinfection criteria. It should also be noted that, for effective disinfection, WHO currently advise that median turbidities should ideally be below 0.2 NTU (WHO, 2011). Water suppliers are additionally reminded of the various recommendations arising out of the Group of Experts (Badenoch, 1995; Bouchier, 1998), which DWI continues to endorse as good operational practice, irrespective of the microbiological challenge or disinfection process used.

4.3. Other water quality properties may also directly or indirectly affect the performance of UV disinfection processes. Natural organic matter, metals such as iron and manganese, and anions such as nitrates and sulphites, may reduce the UV Transmittance (UVT) of influent waters and, consequently, the UV fluence ultimately delivered for the inactivation of pathogens. Many of these properties, as well as hardness and alkalinity, may also reduce the UV fluence delivery and measurement by contributing to the fouling of lamp sleeves and UV monitoring windows, respectively. The presence and concentrations of some of these parameters may vary seasonally or over time.

4.4. Whilst the pre-treatment of influent waters with filtration, oxidation or adsorption processes may help ensure the effectiveness of UV disinfection, other processes can adversely affect or be adversely affected by UV processes. For example, ozone and permanganate residuals, if present at sufficiently high concentration, may adversely affect the performance of subsequent UV

disinfection processes and may give rise to disinfection by-products. UV irradiation can also reduce chlorine and chloramine concentrations in water and thus potentially impact on disinfection processes relying on such agents, or the maintenance of disinfectant residual concentrations into supply, unless they are dosed post-UV irradiation.

4.5. Water suppliers should therefore ensure that they incorporate into their UV process design the appropriate pre-treatment, maintenance and redundancy measures to account for the impacts of specific water sources at each works on UV dose and, ultimately, successful disinfection.

5. UV disinfection

5.1. UV radiation in the wavelength region between 200 nm and 300 nm is biocidal and effective, over a wide temperature range, for the inactivation of pathogens[5]. However, the sensitivities of different pathogens to UV radiation within this wavelength range, and thus the UV fluence requirements to effect a desired level of inactivation, varies considerably. Amongst the pathogens of most interest to drinking water applications, protozoa are the most sensitive to UV in this range, followed by bacteria, with viruses the most resistant.

5.2. Water suppliers are required to demonstrate that any approach to disinfection is robust and appropriate. Consequently, where UV irradiation is used for disinfection purposes, each UV reactor must be designed as a control for the identified hazards at each works, taking into account the physical and chemical characteristics of the water to be disinfected. Whether used alone or in combination with other processes therefore, this will require water suppliers to have evidence of and supporting justification for:

- The potential pathogen challenge present in the raw water supplying a works;
- The minimum UV fluence required to inactivate these pathogens (to include the pathogen least sensitive to UV inactivation);
- Evidence of validation, i.e. that each UV reactor is capable of consistently achieving the required level of performance; and
- The UV fluence to which potential pathogens are exposed at each works (ie. verification of the control measure).

Process validation

5.3. The specific fluence to which pathogens are exposed varies, depending upon individual UV lamp outputs, the flow rate and UVT of the water being irradiated. In continuous flow reactors, hydraulic properties are also of particular importance, with pathogens travelling close to UV lamps or relatively slowly through a reactor experiencing higher fluences than those travelling relatively rapidly or close to the reactor walls.

5.4. The fluence distribution that UV reactors deliver under any set of operating conditions can be estimated by a number of evolving techniques. Due to

[5] UV radiation at 260 nm is the most effective wavelength for the inactivation of a majority of microorganisms. The occurrence of significant differences in microbial response and an increased potential for by-product formation should also be noted at wavelengths below 240 nm.

uncertainties currently associated with these techniques, any such estimates need to be further validated. It is currently recommended that any estimates of reactor performance be validated by biodosimetry techniques.

5.5. Validation testing by biodosimetry uses the log inactivation of specific challenge microorganisms passing through a UV reactor, in combination with known $UV_{253.7nm}$ fluence-response relationships, to determine a corresponding Reduction Equivalent Fluence (REF) and, thereafter, a validated fluence for target pathogens. Minimum required fluences derived during reactor validation should be expressed in terms of a $UV_{253.7nm}$ equivalent fluence.

5.6. Validation testing is commonly undertaken off-site by the reactor manufacturer or supplier and, in accordance with a water safety plan approach:

- should incorporate full-scale UV reactors that conform uniformly to the reactors to be used, with a biodosimeter appropriate to any pathogen of concern;
- must account for all operational, water quality and other factors that may impact on the UV fluence delivered by each reactor at a works; and
- should delineate a range of conditions at each works within which the company must operate and monitor in order to verify that the minimum validated fluence is maintained.

Reactors operating outside of their range of site-specific validated conditions cannot be considered to be disinfecting the water. Thus reactors must not be operated outside of their range of site-specific validated conditions unless an alternative appropriate risk control measure is in place.

Recognised standard protocols for validation testing have been published by others[6]. However, the minimum requirements for such testing are reproduced in Table 1.

[6] Current protocols include Austrian Standards Institute (ÖNORM M 5873-1, 2001; ÖNORM M 5873-2, 2003); German Association for Gas and Water (DVGW W294, 2006); United States Environmental Protection Agency (USEPA, 2006).

*Table 1. Minimum requirements for validation testing **

Requirement	Conditions
Validated operating conditions must include:	• Flow rate • UV fluence rate (in mW/cm^2 or comparable units, as measured by UV sensors) • UV lamp status
Biodosimetric validation testing must include:	• Full-scale testing of the reactor, or a reactor that conforms uniformly to the UV reactor to be used • Inactivation of a test microorganism whose UV fluence-response characteristics are known, have been appropriately quantified and are representative of the raw water challenge of the intended application
Validation testing must account for:	• UV transmittance / absorbance of the water • Aging and fouling of lamps and sleeves, respectively • Measurement uncertainty of on-line sensors • UV fluence distributions arising from differing velocity profiles through the reactor to demonstrate that the entire reaction chamber receives the minimum required dose • Failure of UV lamps or other critical components • Inlet and outlet piping configurations of the UV reactor

* Adapted from USEPA Ultraviolet Disinfection Guidance Manual (2006)

5.7. Inlet and outlet piping configurations can significantly affect reactor hydrodynamics and thus the minimum UV fluence to which target pathogens are ultimately exposed. Accordingly, the inlet and outlet piping configurations of each operational UV reactor should result in a UV fluence that is equal or greater to that delivered during reactor validation. The options recommended by the USEPA for attaining this with off-site validated reactors are described in Section 3.6.2 of the UVDGM.

5.8. Any routine maintenance activities or modifications that substantially change the UV fluence delivery or fluence monitoring of a reactor will necessitate the reactor being re-validation tested. Section 5.13 of the USEPA UVDGM describes some of the common types of modification necessitating reactor re-validation. Water suppliers will also be required to demonstrate that their activities and any modifications made have not compromised the disinfection performance of reactors that are not subsequently re-validated.

UV process start-up and restart

5.9. The conditions under which UV processes are validated depends upon the lamps within the reactors emitting a minimum UV output. Validation testing following recognised protocols accounts for the effects of lamp aging and other factors such as sleeve fouling. However, reduced UV outputs also occur upon initial lamp start-up and following power interruptions.

5.10. In order to avoid a reactor operating outside of its validated conditions upon process start-up, lamps should first be ignited and allowed to reach working temperature before any water intended for supply enters the reactor. If cooling water is required, this should be diverted to waste or recycled until the validated conditions of the reactor are attained. Process designs should also consider the

restart times of UV lamps following voltage dips or power interruptions and incorporate appropriate contingency measures.

5.11. The output of UV lamps also decreases with use due, amongst other factors, to the number of on/off cycles and hours spent in operation. UV lamps should be replaced once the maximum reduction in lamp output has been reached as specified by the lamp manufacturers. Cumulative lamp operating times and lamp replacement dates should be recorded and available for audit.

5.12. UV disinfection processes should not be by-passed, unless a process providing an equivalent, verifiable level of disinfection has been implemented and in continuous use.

5.13. **Water suppliers are reminded that it is an offence to supply water that has not been disinfected prior to leaving a treatment works.**

Process monitoring

5.14. Process monitoring is an essential operational control measure, and water suppliers must continuously monitor and record all the parameters necessary to demonstrate that each UV reactor is:

- operating within its range of validated conditions; and
- delivering the required minimum UV fluence or higher.

5.15. The specific parameters monitored may vary upon the reactor control strategy employed although should consist, as a minimum, of water flow, lamp status and UV fluence rate within each reactor. Fluence rates should be measured with appropriate and accurately calibrated UV sensors, installed at standardised measuring windows within each reactor.

5.16. Where a 'Calculated Dose' approach is employed UVT should also be monitored. UVT measurements should be representative of the water disinfected and water samples neither filtered or pH adjusted prior to analysis.

5.17. Monitoring of turbidity is a critical control in any inactivation stage of disinfection and should be continuously monitored immediately prior to UV disinfection. Where this is not the case (e.g. simple ground water sources where turbidity in the source water is always reliably well below 1 NTU) then DWI will interpret the readings from the final water turbidity monitor as if this was measuring the turbidity before it entered the disinfection process. It is for water suppliers to decide whether they are content to rely just on the measurements of a single final water turbidity monitor to demonstrate compliance with regulation 26.

5.18. Water suppliers should verify the calibration of all monitors and sensors, maintaining and recalibrating each at a frequency that maintains their sensitivity and reliability, and according to documented company procedures.

5.19. Operational monitors and sensors should input directly into appropriate control and monitoring arrangements, and trigger alarms in the event of critical failures in sufficient time to enable appropriate corrective action to be taken. Arrangements should also be in place to prevent water that has not been adequately disinfected from entering supply.

5.20. Routine recorded inspections should be carried out of reactors including sleeves and lamps. Any localised defects (including darkening of lamps or sleeves) should be rectified.

5.21. Suitable online or offline cleaning should be carried out at intervals based on manufacturer's instructions, monitored UV fluence or data from operational experience.

5.22. The information generated by operational monitors and sensors must be regularly reviewed by a competent person, and procedures put in place to initiate investigations and remedial action as soon as potential issues appear. Water suppliers are additionally encouraged to regularly review the adequacy, frequency and scope of their monitoring strategies as part of their risk assessment and risk management processes.

Process verification

5.23. Regulation 26 requires that water suppliers must verify the overall performance and effectiveness of their disinfection strategies.

5.24. Although organisms such as *E.coli* and enterococci are routinely used to indicate the presence of microbiological contamination and thus indicate the likely efficacy of chemical disinfection processes, water suppliers should note that such organisms are more sensitive to UV irradiation than many pathogens of concern (e.g. viruses) and thus should not be relied upon solely to verify the performance of UV disinfection processes. The verification of UV disinfection processes necessitates the operation of appropriately validated UV reactors within a well-defined range of site-specific conditions, as well as the continuous monitoring and recording of those conditions at critical control points.

5.25. Verification of disinfection processes will also necessitate an independent confirmation of the on-going microbiological safety of the water supply and, for example, require water suppliers to liaise with the Public Health England or Public Health Wales, as one of their key water safety plan stakeholders, to encourage and support enhanced surveillance for pathogens in drinking water supplies, including routine stool screening for protozoa such as *Cryptosporidium* where appropriate.

6. Disinfection by-products

6.1. Regardless of the disinfection process employed, water suppliers are required by regulation 26 to ensure that the formation of disinfection by-products is kept as low as possible without compromising the effectiveness of disinfection.

6.2. UV disinfection is not a chemical process incorporating halogens (such as chlorine) and halogenated by-products will not be formed as a direct result of the UV irradiation stage. However, other factors will need to be taken into consideration. For example, the absorbance of UV light by nitrate (at wavelengths below 240 nm) can lead to the formation of nitrite by photolysis. This can be managed through the selection of UV lamp or sleeve type. Bromate

formation has also been observed when pre-chlorination is practiced [78].

6.3. Thus, to ensure that a chosen method of disinfection incorporates controls to minimise possible disinfection by-products, water suppliers will need to take into account different precursors and by-product formation conditions than for chemically-based processes.

7. Disinfectant residuals

7.1. Disinfection is a process of water treatment to remove, or render harmless to human health, every pathogenic micro-organism and pathogenic parasite that would otherwise be present in the water. To manage risks in distribution systems once this has been accomplished, it is normal operational practice for water suppliers to maintain (or introduce and maintain) a concentration of residual disinfectant. For example, a supplier may introduce a residual level of free chlorine after UV irradiation.

7.2. Water suppliers should not regard the introduction of a residual disinfectant concentration as compensation or as a substitute for inadequate disinfection processes at a works.

8. Lamp and sleeve breakage

8.1. Lamp breakages in reactors may result in a risk to human health through exposure to mercury in the water supplied. Lamps and sleeves may both be liable to break as a result of:

- the impact of debris in the water;
- excessive water hammer;
- differential or over-heating; or
- mechanical forces such as wiper jams.

Correctly applied operating procedures should be in place to minimise the risk of breakages and appropriate monitoring should be in place to detect breakages.

8.2. Accordingly, water suppliers are expected to have documented action plans for identifying and responding to on-line lamp breakages.

8.3. A risk assessment should be carried out, appropriate mitigation documented and an action plan developed to address the risk of mercury, quartz or other debris being released and contaminating the water being treated in the event of a sleeve or lamp breaking. These should include clean up and monitoring requirements prior to the UV units being returned to service.

8.4. Water suppliers should also consider whether an on-line lamp breakage is a notifiable event under the Water Industry (Suppliers' Information) Direction 2012 (taking into account current DWI guidance [9].

[7] . J Environ Sci (China). 2008;20(2):246-51. Bromate ion formation in dark chlorination and ultraviolet/chlorination processes for bromide-containing water. Huang X, Gao N, Deng Y.
[8] DWI, Drinking water 2013 Public water supplies in the Western region of England, July 2014, Page 37.
[9] see DWI Information Letter 10/2007

9. Water fittings and materials in contact with water

9.1. As with any installation, the introduction of any substance into drinking water supplies that might adversely affect its quality should be mitigated against. Accordingly, all materials from source to the point of delivery that come into contact with the water supplied, including all chemicals and construction products, must meet the requirements of regulation 31. The current list of approved materials, as well as details of how approvals may be obtained, are available from the DWI website (www.dwi.defra.gov.uk).

10. Contact

10.1. All enquiries relating to this guidance document or other related matters should, in the first instance, be directed to:
Drinking Water Inspectorate,
Area 7e, 9 Millbank, c/o Nobel House, 17 Smith Square, London, SW1P 3JR;
Tel: 0300 068 6400;
Email: DWI.Enquiries@defra.gsi.gov.uk

11. Glossary of terms

Biodosimeter – A surrogate (challenge) micro-organism with sufficient but similar sensitivity to UV as water transmittable microbial pathogens. *Bacillus subtilis* (bacterial spores) and MS2 coliphage (f-RNA virus) have frequently been used as biodosimeters for general UV reactor validation. Increasingly other biodosimeters, such as T1 phage, are being used for the validation of UV reactors used specifically for the inactivation of *Cryptosporidium*.

Biodosimetry – A method involving the application of a biodosimeter to a UV system and determination of the UV fluence from the log inactivation.

Fluence – Often referred to as UV dose. However, as the UV fluence rate is not constant for different trajectories within a continuous flow reactor chamber, as well as only a tiny fraction of the irradiated UV being absorbed by target micro-organisms, the term "dose" is not appropriate. Fluence is the product of the fluence rate (mW/cm^2) and exposure time (seconds), and commonly expressed in units of mJ/cm^2 or J/m^2 (where 1 mJ/cm^2 = 1 mWs/cm^2 = 10 J/m^2).

Fluence rate – Often referred to as irradiance or UV intensity. Commonly expressed in units of mW/cm^2.

LP lamp – Low pressure low output lamp. Such lamps operate at relatively low internal lamp temperatures and mercury vapour pressures, emitting predominantly monochromatic UV radiation at a wavelength of 253.7 nm (as well as in the visible wavelength region). LP lamps contain liquid elemental mercury.

LPHO lamp - Low pressure high output lamp. Such lamps operate at moderately low internal lamp temperatures and mercury vapour pressures, emitting predominantly monochromatic UV radiation at a wavelength of 253.7 nm (as well as in the visible wavelength region). LPHO lamps contain alloys of mercury and other metals such as indium and gallium.

MP lamp – Medium pressure lamp. Such lamps operate at relatively high internal lamp temperatures and mercury vapour pressures, emitting polychromatic UV radiation over the wavelength range from 200 to 400 nm (as well as in the visible wavelength region). MP lamps contain liquid elemental mercury.

Reduction Equivalent Fluence (REF) – Reduction under defined conditions of viable biodosimeter numbers in water flowing through a UV reactor. As the UV fluence delivered cannot be determined directly, and full-scale validation tests with actual pathogens impractical, the REF of challenge microorganisms (biodosimeters) is related through biodosimetry to the fluence received by target pathogens.

UV Transmittance (UVT) – Measurement of transmittance at 254 nm over a 1 cm pathlength. UV Absorbance is related to UVT by: A_{254nm} = -log(UVT%/100)

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