WATER CORPORATION

Assets Planning and Delivery Group
Engineering

DESIGN STANDARD DS 110

Ultraviolet Disinfection Systems

VERSION 2
REVISION 1

APRIL 2021

FOREWORD

The intent of Design Standards is to specify requirements that assure effective design and delivery of fit-for-purpose Water Corporation infrastructure assets for best whole-of-life value with least risk to Corporation service standards and safety. Design standards are also intended to promote uniformity of approach by asset designers, drafters and constructors to the design, construction, commissioning and delivery of water infrastructure and to the compatibility of new infrastructure with existing like infrastructure.

Design Standards draw on the asset design, management and field operational experience gained and documented by the Corporation and by the water industry generally over time. They are intended for application by Corporation staff, designers, constructors and land developers to the planning, design, construction and commissioning of Corporation infrastructure including water services provided by land developers for takeover by the Corporation.

Nothing in this Design Standard diminishes the responsibility of designers and constructors for applying the requirements of WA OSH Regulations 1996 (Division 12, Construction Industry – consultation on hazards and safety management) to the delivery of Corporation assets. Information on these statutory requirements may be viewed at the following web site location:

https://www.commerce.wa.gov.au/worksafe/about-occupational-safety-and-health-regulations-1996

Enquiries relating to the technical content of a Design Standard shall be directed to the Senior Principal Engineer – Water Treatment, Engineering. Future Design Standard changes, if any, will be issued to

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Head of Engineering

This document is prepared without the assumption of a duty of care by the Water Corporation. The document is not intended to be nor should it be relied on as a substitute for professional engineering design expertise or any other professional advice.

Users should use and reference the current version of this document.

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This Standard is intended solely for application to the acquisition of water infrastructure in Operating Areas in Western Australia where the Water Corporation has been licensed to provide water services subject to the terms and conditions of its Operating License.

This Standard is provided for use only by a suitably qualified professional design engineer who shall apply the skill, knowledge and experience necessary to understand the risks involved and undertake all infrastructure design and installation specification preparation work.

Any interpretation of anything in this Standard that deviates from the requirements specified in the project design drawings and construction specifications shall be resolved by reference to and determination by the design engineer.

The Corporation accepts no liability for any loss or damage that arises from anything in the Standard including loss or damage that may arise due to the errors and omissions of any person.

REVISION STATUS

The revision status of this standard is shown section by section below:

REVISION STATUS						
SECT.	**VER./ REV.**	**DATE**	**PAGES REVISED**	**REVISION DESCRIPTION (Section, Clause, Sub-Clause)**	**RVWD.**	**APRV.**
1	1/0	08.11.11	All	New Version/Revision	IB	NH
1	1/1	29.11.12	13	Figure 2 deleted because the source of its data could not be validated.	SP	NH
1	2/1	30.03.21	8	Section 1.4: updated table of standards	ML	DH

2	1/0	08.11.11	All	New Version/Revision	IB	NH
2	1/1	29.11.12	14	Section 2.4.1 edited to include WC requirements for dose validation	SP	NH
2	1/1	29.11.12	18	Section 2.4.2 ‘Treatment Validation’ deleted because it did not provide specific guidance.	SP	NH

3	1/0	08.11.11	All	New Version/Revision	IB	NH
3	1/1	29.11.12	17	Section 3.3.1: Dose targets and alarms defined	SP	NH
3	1/1	29.11.12	18	Section 3.3.2: New section added	SP	NH
3	1/1	29.11.12	18	Section 3.3.4.1: UVT allowance for design defined	SP	NH
3	2/1	30.03.21	17	Section 3.2: Key design parameters defined	ML	DH
3	2/1	30.03.21	17	Section 3.2.1: UVDGM operation requirements defined	ML	DH

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4	1/1	29.11.12	25	Section 4.6.6: Flow Switch added	SP	NH
4	1/1	29.11.12	27	Section 4.11.4.2: Basis for choosing dose delivery method defined	SP	NH
4	1/1	29.11.12	28	Section 4.11.5.1: Valving sequence upon starting and changeover for units requiring cooling water added.	SP	NH
4	2/1	30.03.21	25	Section 4.5: UVT dose validation added	ML	DH
4	2/1	30.03.21	26	Section 4.6.2: CIP appurtenances added	ML	DH
4	2/1	30.03.21	28	Section 4.11.4.2: UV calculated dose control methodology added	ML	DH
4	2/1	30.03.21	29	Section 4.11.5.1: Valving sequence for source first start up added	ML	DH
4	2/1	30.03.21	31	Section 4.12.4: UPS requirements defined	ML	DH

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4	2/1	30.03.21	32	Section 4.12.5: Total power failure section added	ML	DH
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App. C	2/1	30.03.21	38	New UV screen Template added	ML	DH

DESIGN STANDARD DS 110
Ultraviolet Disinfection Systems

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1 INTRODUCTION

1.1 Purpose

This document explains the Water Corporation's design and installation requirements for Ultraviolet Disinfection Systems used in water treatment. It provides specific information relating to the Corporation's preferences and best practices that have evolved over many years of experience.

1.2 Background Information

There is an increasing use of ultraviolet (UV) disinfection systems in the Water Corporation's potable water and recycled water treatment plants. A strategic decision was made by the Corporate Water Quality Committee (CWQC) in 2006 to deploy ultraviolet disinfection plants to regional schemes where catchment risk assessments highlighted the potential for chlorine-resistant pathogens such as *Cryptosporidium* and *Giardia* to be present in the source water (Zappia, 2010).

Assessment of the Corporation's Asset Management Register showed that there are a lot of UV systems currently in service across the state. Most of them are employed as primary water treatment disinfection barriers; others are in-line (e.g. pre-treatment prior to RO) or Point-of-Use (i.e. small-scale under-bench) systems. The capacity of these plants ranges from 0.1 to 3.1 ML/d (Zappia, 2010).

1.3 Design Considerations

This Standard applies to UV disinfection systems for potable water production. All design shall comply with Water Corporation standards specified in Section 1.4.

This Standard may also be applied to water recycling, though considerations of level of treatment will be determined from the Department of Health's document Guidelines for Non-Potable Uses of Recycled Water in Western Australia. Also, note that UV transmittance is generally lower for treated wastewater compared to potable water.

1.4 Standards

This design standard refers (directly or indirectly) to the following standards and regulations:

Australian Standards

AS 1170.1	Structural design actions – Permanent, imposed and other actions
AS 1158.3.1	Lighting for roads and public spaces: Pedestrian area (Category P) lighting – Performance and design requirements
AS 1319	Safety signs for the occupational environment
AS 1345	Identification of the contents of pipes, conduits and ducts
AS 1657	Fixed platforms, walkways, stairways and ladders – Design, construction and installation
AS 1680.2.4	Interior and Workplace Lighting – Industrial tasks and processes
AS 1668.2	The use of ventilation and air-conditioning in buildings – Mechanical ventilation in buildings
AS 2032	Installation of PVC pipe systems
AS 2293.1	Emergency Escape lighting and exit signs for buildings – System design, installation and operation
AS 3500	National plumbing and drainage code (provision of backflow prevention devices)
AS 3780	The storage & handling of corrosive substances
AS 3879	Solvent cements and priming fluids for PVC (PVC-U and PVC-M) and

	ABS pipes and fittings
AS 4041	Pressure piping
AS 4087	Metallic flanges for waterworks purposes
ASME RTP-1	Reinforced Thermoset Plastic Corrosion Resistant Equipment
BS EN 13923	Filament-wound FRP pressure vessels. Materials, design, manufacturing and testing
BS EN 13121-3	GRP Tanks & Vessels for use above ground. Design & Workmanship
DVS 2205-1	Design Calculations for Tanks & Apparatus Made of Thermoplastics
DVS 2207-1	Welding of Thermoplastics
DG Regs 2007	Guidance Note for Placarding Stores for Dangerous Goods and Specified Hazardous Substances

Water Corporation Standards

DS 20	Design Process for Electrical Works
DS 21	Major Pump Station - Electrical
DS 22	Ancillary Plant & Small Pump Stations – Electrical
DS 24	Electrical Drafting
DS 26	Type Specifications - Electrical
DS 27	Regulating Valve Control - Electrical
DS 28	Water and Wastewater Treatment Plants - Electrical
DS 30	Mechanical General Design Criteria & Glossary
DS 31	Pipework, Valves & Appurtenances - Mechanical
DS 32	Pump stations - Mechanical
DS 33	Water Treatment Plants - Mechanical
DS 34	Wastewater Treatment Plants - Mechanical
DS 35	Ancillary Plant - Mechanical
DS 38	Installation - Mechanical
DS 40	SCADA General Standards
DS 40-09	Field Instrumentation
DS 41	SCADA Master Standards
DS 42	Communication Standards
DS 43	SCADA Protocols Standards
DS 79-02	Emergency Safety Showers and Eyewash Stations
DS 79-04	Chemical Signage, Labelling and Markers
DS 80	Drawing Management
DS 81	Process Engineering
S151	Prevention of Falls Standard
S226	Surface Water Treatment Monitoring Standard
S399	Plant Safety Signage Standard
	Strategic Products Register

Water Corporation Manuals

SWTM	Surface Water Treatment Manual
CDWS	Criteria for Drinking Water Supply

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1.6 Abbreviations

BOD	Biological Oxygen Demand
DBP	Disinfection By-Product
DNA	Deoxyribonucleic Acid
GFI	Ground Fault Interrupt
HAA	Halogenic Acetic Acid
LP	Low Pressure
LPHO	Low Pressure High Output
MCC	Motor Control Centre
MP	Medium Pressure
ODSS	Operational Data Storage System
OIP	Operator Interface Panel

ORP	Oxidation Reduction Potential
PI	Plant Information
PLC	Program Logic Controller
RED	Reduction Equivalent Dose
SCADA	Supervisory Control and Data Acquisition (System)
THM	Trihalomethane
TLV	Threshold limit values
TSS	Total Suspended Solids
UPS	Uninterruptible Power Supply
UV	Ultraviolet
UVDGM	Ultraviolet Disinfection Guidance Manual
UVT	Ultraviolet Transmittance
VFD	Variable Frequency Drive
WTP	Water Treatment Plant

2 UV DISINFECTION OVERVIEW

2.1 UV Light generation and transmission

The use of UV light for disinfection involves generation of UV light in the wavelength range and at an intensity that has germicidal properties, and exposure of pathogens to that light.

2.1.1 Nature of UV Light

UV light is the region of the electromagnetic spectrum that lies between X-rays and visible light. The UV spectrum is divided into four regions as illustrated in Figure 1.

- Vacuum UV (100 to 200 nanometres (nm));
- UV-C (200 to 280 nm);
- UV-B (280 to 315 nm);
- UV-A (315 to 380 nm).

The germicidal action of UV is mostly due to UV-B and UV-C light. The effect of UV-A light is minimal in comparison to UV-B and UV-C light. Although light in the vacuum UV range can provide germicidal action, its use is impractical because of the rapid dissipation in water over very short distances.

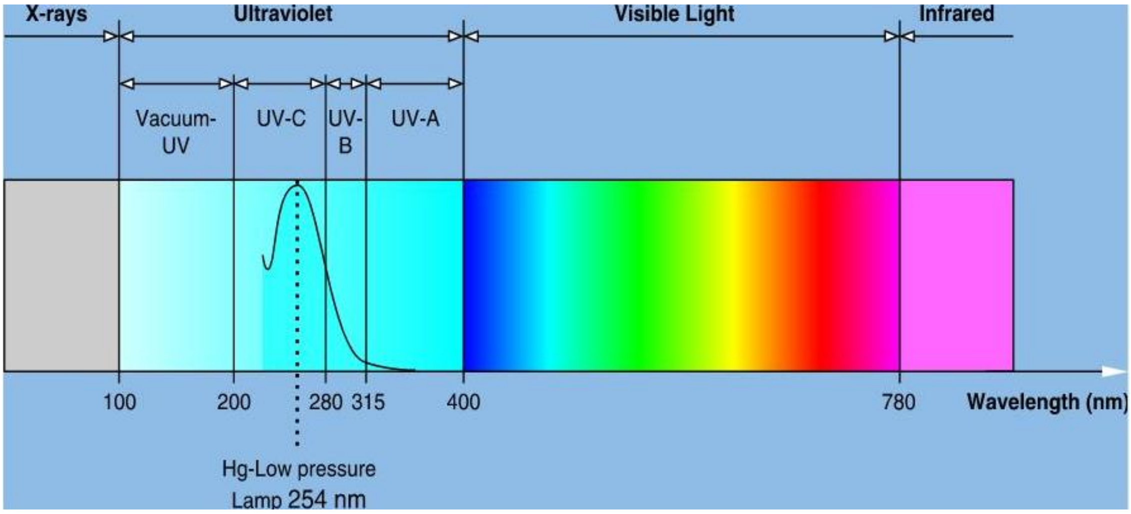

Figure 1 - Electromagnetic spectrum

Germicidal action reaches a maximum at or near 260 nm for most microorganisms, before dropping to zero near at 300 nm. A local minimum occurs around 230 nm. Whilst the most effective germicidal action occurs around 260 nm, there is currently no effective means of producing UV light at this wavelength. LP and LPHO lamps produce UV light at 254 nm, and this has become the industry standard.

2.1.2 Propagation of UV light

As UV light propagates from its source, it interacts with the materials it encounters through reflection, refraction, absorption and scattering. In disinfection applications, these phenomena result from interactions between the emitted UV light and UV reactor components (e.g., lamp envelopes, lamp sleeves, and reactor walls) and with the water (and particles) being treated.

UV light is absorbed by the reactor and by the water passing through it. Light which is absorbed is no longer available for disinfection. In UV disinfection, the absorption at 254 nm (A254) is used as a measure of the amount of UV light passing through the water and reaching the target organisms.

UV transmittance (UVT) is another parameter that is commonly used as a measure of absorption and scattering. UVT is the percentage of light passing through a material (e.g. a water sample or quartz) over a specified distance. UVT is calculated as shown in Equation 1.

Equation 1 - UVT calculation using light intensity

$$UVT = \frac{I}{I_o} * 100$$

where:

UVT = UV transmittance at 254 nm over a specified path length, usually 1 cm;

I = Intensity of light transmitted through the sample (W/m^2); and

I_o = Intensity of light incident on the sample (W/m^2).

The total UV intensity at a point in space is the sum of the intensity of UV light from all directions. The internal intensity profile is affected by the non-homogeneous placement of lamps within the reactor, lack of ideal radial mixing in the reactor, the scattering/absorption effects of particulate material and the absorbance of the liquid medium.

UVT can also be calculated by relating it to UV absorbance using Equation 2.

Equation 2 - UVT calculation using light absorbance

$$UVT = 100 * 10^{-A}$$

where:

UVT = UV transmittance at 254 nm over a specified path length (e.g. 1 cm); and

A = UV absorbance at a specified wavelength and path length (unitless).

2.2 Microbial response to UV light

2.2.1 Inactivation by UV light and repair mechanisms

UV light inactivates microorganisms by damaging their nucleic acid, thereby preventing them from replicating. There is evidence which suggests there are UV resistant bacteria. Viruses have no repair mechanism to reverse the damage created by UV light. However, bacteria and other microbes have enzyme systems that can repair damage caused by UV light. Repair mechanisms are classified as either photo-repair or dark-repair.

Photo-repair can be prevented by maintaining the disinfected water in the dark for at least two hours. It is important to check that the disinfected water will be retained in pipework, tanks and the distribution system for this period, before exposure to daylight. In most cases, the treated water will be chlorinated prior to entering the distribution system to provide chlorine residual.

Dark repair refers to processes of microbial DNA repair which do not require reactivating light. It is an enzyme-mediated process that removes and regenerates a damaged section of DNA, using an existing complimentary strand of DNA. Generally, the UV dose is set to include the effects of dark repair.

2.2.2 Microbial response

Microbial response is a measure of the inactivation achieved, which varies significantly from one microorganism species to another. The microbial response is determined by irradiating water samples containing the test microorganism over a range of UV doses, and measuring the concentration of microorganisms before and after exposure. At each dose, the inactivation is determined from the difference between the concentration of microorganisms before and after exposure. The result is usually expressed as the common logarithm (log10), as shown in Equation 3.

Equation 3 - Calculation of log inactivation

$$Log\ Inactivation = \log_{10}\left(\frac{N_o}{N}\right)$$

where:

N_o = Concentration of microorganisms before exposure; and

N = Concentration after exposure

The results obtained at each UV dose are then plotted, as shown in the example in Figure 2, to produce the dose-response curve for that particular species of microorganism.

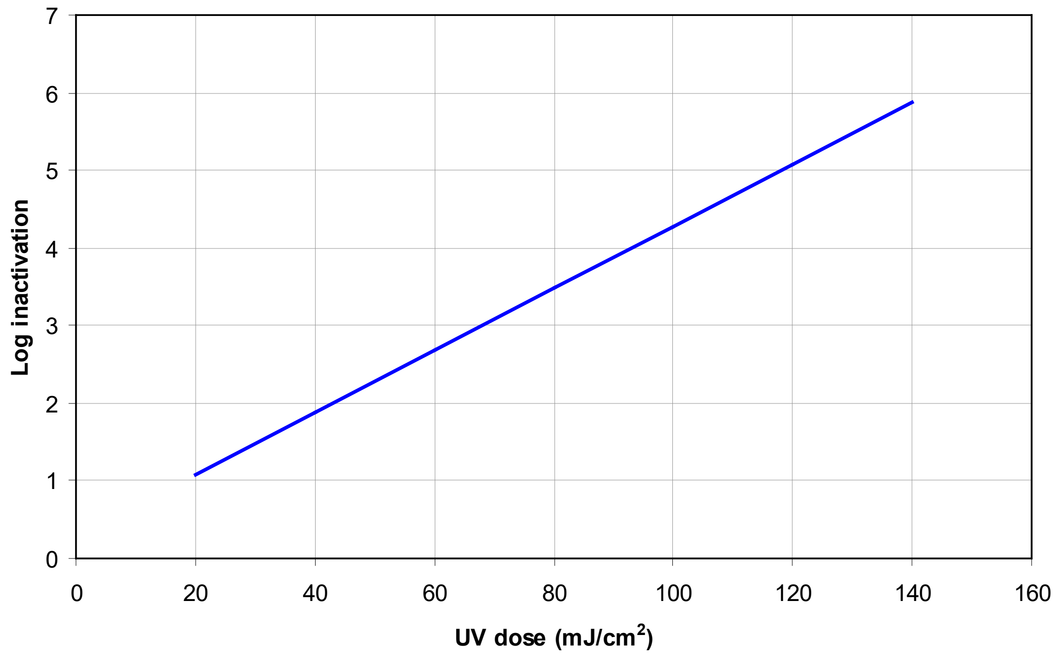

Figure 2 - Example of a dose-response curve obtained from irradiation testing

2.3 Operational factors affecting UV dose

Operational factors that influence the UV dose include the power supply, lamp ageing and fouling, reactor hydraulics, absorbance of UV by the water and the characteristics of the microbes sheltering within particulate matter. These factors will be described in more detailed in Sections 3 and 4.

The pH of the water has no effect on UV dose in the pH range of 6 to 9. Water temperature can influence the intensity of UV light emitted from older style LP lamps. Modern LP & LPHO lamps are less susceptible to changes in water temperature. De-gassing of water due to high temperature plays a part in the phenomenon. Scale formation on UV lamp sleeves is linked to water temperature, hardness and alkalinity.

Particulate matter in the water and the clumping of microorganisms can affect the UV dose response.

2.4 Emerging Practice

Two of the more important practices in UV technology that have emerged over the past ten years are Design Validation and Treatment Validation.

2.4.1 Design Validation

The objective of design validation is to determine a Validated Dose, which is defined as the UV dose in mJ/cm^2 that is delivered by a UV reactor, as determined through testing. The Required Dose is defined as the UV dose needed to achieve a specific log inactivation credit. The Validated Dose must be greater than or equal to the Required Dose for a UV reactor to receive a log inactivation credit for a target pathogen.

Validation is carried out at the manufacturer's testing facilities, using bio-dosimetric techniques to assess the dose-delivery performance of UV reactors, whereby the inactivation of a non-pathogenic surrogate "challenge" organism is measured as it passes through the reactor and compared to its dose-response behaviour. This produces an estimate of the Reduction Equivalent Dose (RED) delivered by the UV reactor. RED values are always specific to the challenge microorganism and the test conditions - flow rate, UVT, lamp status, and UV intensity.

The Validated Dose is obtained by dividing the RED by a Validation Factor (VF). The VF accounts for biases associated with using a challenge microorganism instead of the target pathogen, and for experimental uncertainty.

Equation 4 - Calculation of Validated Dose

$$D_{val} = \frac{RED}{VF} \geq D_{req}$$

where:

D_{val} = Validated Dose

RED = Reduction Equivalent Dose

VF = Validation Factor

D_{req} = Required Dose

Several guidelines have been published on the validation of UV reactor designs:

- USA: EPA UVDGM, 2006 and NWRI, 2012 and NSF/ANSI 55-2018,
- Austria: ONORM M 5873-1 (Low Pressure), 2001, and ONORM M 5873-2 (Medium Pressure), 2003
- Germany: DVGW (W294 Part 3) 2006

However, the US EPA Ultraviolet Disinfection Guidance Manual (UVDGM) For the Final Long Term 2 Enhanced Surface Water Treatment Rule (US EPA, 2006) is the only guideline approved by the Water Corporation.

Water Corporation requires all new UV installations to be validated against US EPA UVDGM, 2006.

3 DESIGN CONSIDERATIONS

3.1 Level of Treatment

One of the first decisions in a project is to define the level of treatment required. The procedure varies depending on the source – surface water or groundwater - as outlined below.

3.1.1 Surface Water Sources

Direction on how to define the surface source water quality risk category is provided in the Water Corporation Manual 'Surface Water Treatment'. These are then used as key inputs in Table 3-1 (Table 5 in the Surface Water Treatment Manual).

Table 3-1: The Water Treatment matrix (WTM)

Raw water challenge to downstream barriers Bacterial and Viral risk	**Maximum microbiological challenge (raw water monitoring results for *E.coli* or thermotolerant coliforms)**				**Raw water challenge to downstream barriers** *Cryptosporidium and Giardia* risk
	Protected; impounded upland water; essentially free of faecal contamination	Unprotected; impounded water or upland run of river source; faecal contamination present	Unprotected; lowland run of river source or unprotected water shed; faecal contamination present.		
	<20 MPN/100 mL plus storage	**20-2,000 MPN/100 mL**	**2,000-20,000 MPN/100 mL**	**>20,000 MPN/100 mL**	
Extreme		UNSUITABLE	UNSUITABLE	UNSUITABLE	
High		LEVEL IV	LEVEL IV	UNSUITABLE	**High**
Medium	Further investigation required to determine why *E.coli* results are unexpectedly low	**LEVEL III**	**LEVEL IV** Not preferred as a drinking water source	**UNSUITABLE**	
Low		**LEVEL II**	LEVEL IV	Further investigation required to determine source of contamination	**Low to Medium**
Very Low	**LEVEL I**	LEVEL II			**Very Low**

3.1.2 Groundwater Sources

For groundwater sources, the Water Corporation manual "Criteria for Drinking Water Supply" shall be consulted. The level of treatment required shall be planned and designed using Table 3-2 (Table 8.1 in the manual) as the decision making tool.

Table 3-2: Groundwater Treatment Guidelines based on Raw Water Microbiological Quality and Turbidity

<table>
<tr><td rowspan="6">Sanitary Survey Risk Rating (8)</td><td colspan="3">Well Field Description</td></tr>
<tr><td>Protected wells (13); essentially free of faecal contamination</td><td colspan="2">Unprotected wells (13); faecally contaminated</td></tr>
<tr><td colspan="3">Maximum raw ground water microbiological monitoring results (12) for E.coli or thermotolerant coliform bacteria</td></tr>
<tr><td>< 20 cfus / 100mL plus presence of Cryptosporidium and Giardia rated as rare (1)</td><td>20 – 2000 cfus / 100 mL</td><td>> 2 000 cfus / mL</td></tr>
<tr><td colspan="3">Turbidity (9)</td></tr>
<tr><td>Median < 1 NTU
Max < 5 NTU</td><td>Average < 50 NTU
Max < 300 NTU</td><td>Average > 50 NTU and /or Max > 300 NTU
(Consult Water Treatment Design)</td></tr>
<tr><td>Very High
> 1000</td><td rowspan="3">Further investigation required to determine why E.coli results are unexpectedly low</td><td rowspan="2">Further investigation required to determine why E.coli results are unexpectedly low</td><td rowspan="2">Not recommended as a drinking water source (10)</td></tr>
<tr><td>High
500 – 1000</td></tr>
<tr><td>Moderate
50 – 500</td><td rowspan="3">• Coagulation
• Filtration (3, 4) and
• Continuous disinfection (Ct > 15) (2)</td><td rowspan="3">Further investigation required to determine source of contamination</td></tr>
<tr><td>Low
10 - 50</td><td rowspan="2">• Continuous disinfection (Ct > 15) (2)</td></tr>
<tr><td>Very Low
< 10</td></tr>
</table>

3.2 Key Design Parameters

The key design parameters are the target pathogen inactivation, flow rate, water quality, lamp fouling and ageing factors, and reliability of the power supply. The first step in planning a UV disinfection facility is to define the goals for the unit as part of a comprehensive disinfection strategy for the entire process. Initially the target pathogen(s), target log-inactivation and corresponding required UV dose shall be identified. The number of UV reactors needed to achieve the required UV dose is determined by the design flow, design UVT, the range of UVT expected, and the lamp fouling and ageing factors.

3.2.1 Target Pathogens and Required UV Dose

Planning shall include identification of the pathogens to be targeted and the log reduction required for each. Generally, the target pathogens that shall be considered include Cryptosporidium, Giardia and Viruses (Adenovirus 40).

Guidance on the required UV dose to achieve specific log reductions is shown in Table 3-3 as per US EPA UVDGM, 2006.

Table 3-3: UV doses for inactivation of target pathogens (mJ/cm^2)

Target pathogens	*Log Inactivation*							
	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
Virus (Adenovirus 40)	39	58	79	100	121	143	163	186

During UV reactor selection, advise the vendor that Virus in Table 3-3 refers to Adenovirus 40.

During operation, if the UV dose delivered by the reactor is less than the target dose then water flow must be automatically stopped. To receive the required log inactivation credit (to meet the treatment requirements described in the UVDGM) requires that a minimum of 95% of water delivered to the public during each month is treated by UV reactors operating within the validated limit. Operating outside of the validated limit is defined as off-specification operation.

3.2.2 Verification and Calibration of Dose Control Instrumentation

A UV unit shall be able to verify as a minimum that the RED target dose is always being achieved . Instrumentation supporting the dose control must have an ability to be verified on a monthly basis in the field and be calibrated on an annual basis. This can be completed using a UV spectrophotometer.

3.2.3 Design Flow Rate and Operating Pressure

The design criteria shall identify the average, maximum and minimum flow rates that will pass through the UV reactors.

The design of the reactor and pipework shall also consider the pressure during normal operation (including start-up and shutdown) and emergency/power failure shutdown. Surge and shut-in conditions shall also be considered when specifying the required design pressure of UV reactors. The design shall provide appropriate pressure relief devices as necessary to prevent exceedance of the UV reactor design pressure rating.

3.2.4 Feed Water Quality

The performance of the UV disinfection system can be adversely affected by the feed water quality. The most common problems encountered are the reduction in UVT due to absorbance by colloidal/particulate matter, turbidity (seasonal or engineered change), scaling due to mineral precipitation on the lamp sleeves, and fouling due to organic growth. The importance of feed water characterisation cannot be over-emphasised. Ideally, a sampling program shall be carried out to capture the typical water quality and any variations that may arise due to storms, reservoir turnover, seasonal changes, source water blends, and variations in upstream treatment. Sampling frequency shall be based on flow rate variability, the consistency of the source and treated water qualities, and the potential for obtaining cost and energy savings by enabling refinements in the design criteria.

3.2.4.1 UV Transmittance

UV Transmittance has a direct impact on UV dose delivery, and it is therefore important that this feed water characteristic is correctly assessed. A conservatively low design UVT may result in over-design and increased capital costs, energy costs and maintenance cost, whereas an optimistically high value may result in under dosing and frequent water quality failures. Note that a typical UV reactor provides turndown only to approximately 30%-50% so an oversized unit may use much more power than is necessary. For planning purposes it is important to test a range of water samples for UV absorbance at 254 nm. UVT is commonly measured using a spectrophotometer. It is important to determine both a design UVT value and the full range of UVT expected during operation. It may be useful to develop a matrix of flow and UVT conditions. Some UV manufacturers require this information to determine the power turndown required.

The following substances have a high propensity to absorb UV light and can result in a substantial reduction in UVT:

- Humic and fulvic acids;
- Algae;
- Oil and grease;
- Turbidity;
- Iron; and
- Manganese.

UVT is calculated on the basis of UV absorbance data (refer to section 2.1) that can be measured or determined from historical data in ODSS or PI. For all future Water Corporation UV installations, UVT of 80% is considered the maximum value to be adopted unless historical water quality data for the site justifies otherwise. If the WTP is equipped with filtration upstream of the UV disinfection, then UVT may be higher and a review of historical UVT is necessary to determine the UVT for design.

UVT for raw waters calculated based on UV absorbance data shall allow a 3% lower UVT to account for the filtration that occurs in the UV absorbance testing method. However, if the UV disinfection is to be installed downstream of a filtration step (as is common), then this safety factor is not considered necessary, especially if the design considers the lowest UVT measured during a significant period of time (2 to 3 years as an example).

The average feed water turbidity must not exceed 1 NTU. In cases where the feed water turbidity exceeds 1 NTU, filtration will be required upstream of the UV reactors. The filter backwash cycle must include strategies - to ensure 1 NTU is not exceeded - such as a ripening period with filter-to-waste.

3.2.4.2 Scaling

Scaling is the result of precipitation of mineral salts and requires regular cleaning of the lamp sleeves. Scaling can also occur on monitoring windows, which affects the measurement of UV intensity and dose monitoring. The substances most commonly associated with scaling are:

- Mineral salts of iron, magnesium, aluminium and manganese which, under favourable conditions, may oxidise and precipitate. Removal of iron and manganese upstream of the unit, by means of oxidation followed by filtration, can reduce the rate of scale formation;

- Compounds with low solubility, which readily precipitate, e.g. $Fe(OH)_3$, $Al(OH)_3$; and

- Compounds whose solubility product reduces with increase in temperature, e.g. $CaCO_3$, $CaSO_4$, $MgCO_3$, $MgSO_4$, $FePO_4$, $FeCO_3$, $Al_2(SO_4)_3$. The heat generated by UV lamps results in localised temperature increase of the water near the surface of the lamp sleeves which can result in deposition of these compounds. Scaling on MP lamps is more rapid than on LP lamps because MP lamps operate at higher temperatures.

The rate of scale formation, and hence the frequency of cleaning can vary from hours to months. In severe UV scaling cases, the rate of scale formation can be significantly reduced by changing the process pH or by Calgon dosing upstream of the UV reactor(s).

As may be justified by the rate of scale formation, the design shall make provision to undertake Clean In Place (CIP) operations to remove scale on lamps and sensors. Two connections (buttons) upstream and downstream of the UV reactor (typically DN 25) allow connection to a mobile or fixed CIP system to recirculate a cleaning solution through the UV vessel(s). The cleaning solution is made of phosphoric acid (11%) and can be neutralised by soda ash upon completion of CIP operations. The design shall provide sufficient space near the UV reactors to undertake these operations ergonomically and safely.

3.2.4.3 Fouling

Fouling is the result of biofilm growth on the lamp sleeves. A further problem is that biofilms can harbour and effectively shield bacteria. Medium pressure UV lamps, which emit some light in or near the visible light range, can stimulate the growth of biofilms on exposed surfaces. Studies have found that fouling rates increase as the redox-potential increases (US EPA, 2006).

3.2.5 Lamp Ageing

Lamp ageing is caused by the number of hours in operation, the number of on/off cycles, the power applied, the water temperature, and heat transfer from lamps. As UV lamps age over time, there is a gradual reduction in output, which results in a decline in UV dose. This necessitates periodic replacement of the UV lamps.

3.2.6 Sleeve Ageing

Lamp sleeves degrade over time due to solarization (a change in the structure of the quartz as a result of exposure to UV light) and internal sleeve fouling, which results in cloudiness and loss of UV transmittance. This may necessitate the eventual replacement of the lamp sleeves.

3.3 Accounting for fouling and ageing in design

The long-term performance of UV reactors is affected by sleeve fouling, sleeve ageing, lamp ageing, and UV sensor window fouling.

Fouling is accounted for by defining a fouling factor, which is the amount of UV light passing through a fouled sleeve, compared to a clean sleeve.

Lamp ageing is accounted for by defining an ageing factor, which is the amount of UV light emitted from aged sleeves and lamps compared to new sleeves and lamps. The ageing factor is usually in the range of 0.5 to 0.8 and shall be available from the UV manufacturer.

The UV dose from clean lamps multiplied by the fouling and ageing factors must be greater than or equal to the design UV dose

Equation 5 - Design UV dose

$$D_{cl} \times f_f \times f_a \geq D_{req}$$

where:

D_{cl} = UV dose achieved with clean lamps

f_f = fouling factor

f_a = ageing factor

D_{req} = Required UV dose

The fouling and ageing factors shall be selected together with a guaranteed lamp life. This will ensure that the fouling and ageing factors will not be exceeded within the guaranteed lamp life.

It should be recognised that there will be a trade-off between maintenance costs - the frequency of lamp replacement and chemical cleaning required, and capital cost - the size of the UV reactors.

The selection of low fouling and ageing factors will result in less frequent replacement because the UV reactors are fitted with more lamps to achieve the design UV output at the guaranteed lamp life. However, this is likely to increase the size of the UV reactor or result in higher power requirements.

Alternatively, the selection of optimistically high factors could underestimate the reduction in lamp output and potentially result in frequent off-specification operation or more frequent lamp replacement.

3.4 Disinfection By-products

The formation of disinfection by-products (DBPs) is usually associated with the use of chlorine. Some research has been carried out on the effects of chlorinating UV disinfected water, the transformation of organic material to more degradable components, and the potential formation of other DBPs (US EPA, 2006).

3.4.1 Trihalomethanes (THMs) and Halo acetic acids (HAAs)

Chlorination of UV disinfected water, at doses less than 400 mJ/cm^2 has not been found to significantly affect the formation of THMs or HAAs (US EPA, 2006).

3.4.2 Nitrite

With the use of MP lamps that emit wavelengths below 255 nm, there is the possibility of nitrate converting to nitrite. However, a nitrate level of 10 mg/L or more would be required to produce a nitrite level of 1 mg/L (US EPA, 2006).

3.5 Location of UV Units and Chlorination Units

UV disinfection units shall be located prior to the disinfection chlorine dosing in order to avoid the destruction of free chlorine and transformation of chlorination by-products. Locating UV units upstream of chlorine disinfection dosing also avoids the possibility of any iron or manganese in the water oxidised by chlorine from fouling the UV lamps.

If it is not possible to install the UV unit prior to chlorine dosing, the design shall consider sections 2.5.2 (chlorine reduction through UV reactors) and 2.5.3 (by-products from UV disinfection) of the US EPA UVDGM. As examples, UV RED doses of 50 and 70 mJ/cm^2 destroy respectively 0.13 and 0.2 mg/L of free chlorine. In this scenario, for an existing WTP, the design shall also consider potential by-products formation increase due to the higher rate of chlorine dosing required to compensate for UV degradation of the chlorine residual.

4 SYSTEM COMPONENTS AND CONFIGURATIONS

The main components of a UV disinfection system are lamps, lamp sleeves, ballast, cleaning mechanisms, sensors and reactor housing.

4.1 UV Lamps

The lamps most commonly used are low-pressure (LP), low-pressure high-output (LPHO) and medium pressure (MP) mercury-vapour lamps. The major features of these lamps are shown in Figure 3. Most of the Water Corporation's UV installations utilise LP or MP lamps. MP lamps tend to be more cost effective.

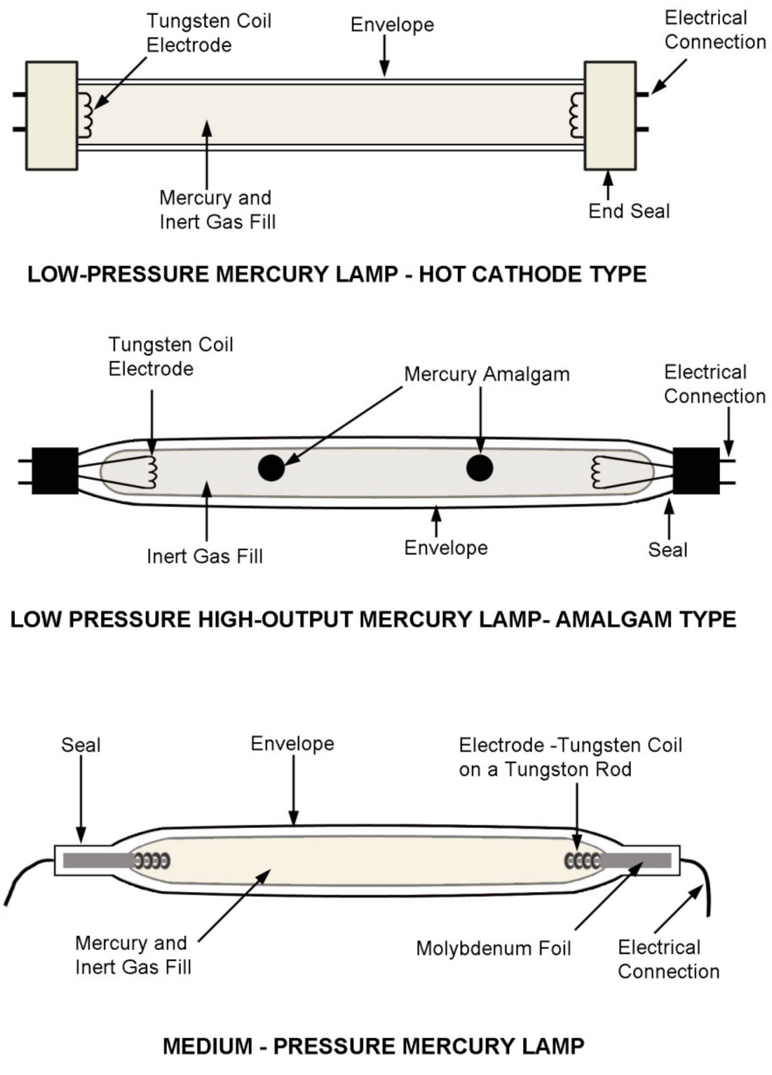

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Figure 3 - Illustration of LP, LPHO and MP lamps

LP and LPHO lamps have the advantage of:

- A higher germicidal efficiency (most output is at 254 nm);
- Lower power consumption for equivalent UV output (approximately 50% of a MP system).
- Lower UV output per lamp (hence a lower loss in dose if a lamp fails);
- A lower operating temperature resulting in lower potential for scaling problems; and
- A longer lamp life (150% – 200% of MP lamps).

MP lamps have the advantage of:

- More compact unit for similar UV output (due to fewer lamps);
- Lower overall maintenance/labour cost (due to fewer lamps);
- Lamp output is not affected by water temperature;
- Some studies show lower rates of pathogen repair after MP UV;
- More cost-effective to incorporate automatic cleaning systems.

The selection between LP and MP lamps shall be based on whole of life cost analysis. A cost analysis shall be made during design phase to recommend the preferred type of lamps and installation.

An emerging technology in UV disinfection is LED type UV lamps. These are currently mostly applied to very small UV reactors only and are not covered in this standard. Their application in increasingly larger UV systems is noted and is being monitored by the Water Corporation.

4.1.1 Lamp characteristics

The characteristics of the three lamp types are compared in Table 4-1.

Table 4-1: Lamp characteristics

Parameter	***Low pressure***	***Low pressure High intensity***	***Medium pressure***
Germicidal UV light	Monochromatic at 254 nm	Monochromatic at 254 nm	Polychromatic (200-300 nm)
Operating Temperature (ºC)	Around 40	60 - 100	600 - 900
Electrical input (W/cm)	0.5	1.5 - 10	50 - 250
Germicidal UV output (W/cm)	0.2	0.5 – 3.5	5 - 30
Electrical to UV conversion efficiency (%)	35 - 39	30 - 35	10 – 20
Power consumption (W)	70 – 100	1200	2000 - 5000
Lamp output at 254 nm (W)	25 - 27	60 - 400	Variable
Lamp Length (cm)	35 – 150	Variable	Variable
Lamp diameter (mm)	15 - 20	Variable	Variable
Lamp current (mA)	350 - 550	Variable	Variable
Lamp voltage (V)	220	Variable	Variable
Relative number of lamps needed for a given dose	High	Intermediate	Low
Lifetime (hour)	8,000 – 12,000	8,000 – 12,000	4,000 – 8,000

4.2 Lamp Sleeves

UV lamps are housed in sleeves to keep the lamp at optimal operating temperature and to protect the lamp from breaking. The sleeves are made of quartz and are open at one or both ends. The sleeve diameter is typically 25 – 50 mm for LP and 35 – 100 mm for MP lamps. The annular space between the outside of the lamp and the inside of the sleeve is approximately 10 mm.

Lamp sleeves are particularly susceptible to breakage if significant pressure surges occur through the UV reactor, particularly where operating pressure is close to the reactors pressure rating. Such surges can occur during system start-up or shutdown and shall be considered during design.

4.3 Ballasts

Ballasts are needed to regulate the incoming power supply to the level needed to energise and operate the UV lamps. UV reactors typically use magnetic ballasts or electronic ballasts.

Many of the UV systems on the market utilise electromagnetic ballasts because they are inexpensive and reliable. Nevertheless, they have some inherent limitations relating to poor regulation of line and load variations. Most electromagnetic ballasts allow step adjustment of lamp intensity only.

Electronic ballasts can provide continuous adjustment of lamp intensity and are generally more reliable and efficient than electromagnetic ballasts. There is a limitation on the length of cable between the ballast and lamp, which requires the control cubicle to be positioned close to the lamps; this shall not exceed 20 metres. However, higher efficiency and additional features can increase the capital cost of an electronic ballast.

UV lamps that are powered by electromagnetic ballasts tend to have more lamp end-darkening (i.e. electrode sputtering) and shorter lives, compared to lamps powered by electronic ballasts, which operate at higher frequencies.

Electronic ballasts are generally more susceptible to power quality problems, compared to electromagnetic ballasts. However, power quality tolerances of both types depend on the electrical design. A comparison of magnetic and electronic ballast technologies is provided in Table 4-2.

Table 4-2: Technological comparison between electromagnetic and electronic ballasts

Electromagnetic ballast	***Electronic ballast***
Slightly Less expensive	Continuous power adjustment and ability to adjust power levels
More resistant to power surges	More power efficient
Allows greater separation distance between the UV reactor and control panel	Lighter weight and smaller size
	Enables longer lamp operating life and less lamp end-darkening

A ballast cooling system could be required to maintain the ballast temperature below the maximum specified limit. This should be confirmed with the Vendor during reactor selection.

The rationale for selection of ballast shall be documented on a project by project basis.

Heat dissipation from the UV ballast should be considered in building HVAC design.

4.4 Cleaning systems

The methods for cleaning UV lamps tend to be supplier-specific, but generally fall into one of two categories: off-line and on-line cleaning. On-line cleaning shall be incorporated unless project requirements specify otherwise. It should be recognised that reactors fitted with a mechanical cleaning system may still require manual cleaning.

On-line cleaning methods consist of mechanical wipers that are moved along the sleeves by means of electric motor or pneumatic piston drives. The wipers are usually stainless steel brush collars or Teflon rings, as shown in Figure 4. Some cleaning systems utilise a moving collar that is filled with cleaning solution to dissolve the material fouling the sleeves. The great advantage of on-line cleaning is that the reactor does not have to be drained. Online cleaning can significantly reduce the frequency of required offline cleaning.

Figure 4 - Example of a mechanical cleaning system

4.5 Sensors and analysers

4.5.1 UV Intensity Sensors

UV intensity is usually monitored at a point inside the reactor by means of a UV sensor. Sensors may be mounted on the outside of the reactor, making use of a monitoring window, or inside the reactor in direct contact with the water. Most monitoring windows and wet sensors will foul over time and will require cleaning as with the lamp sleeves.

The sensor shall respond to changes in lamp output, lamp ageing and sleeve fouling. The reading is commonly fed into the control algorithm together with the flowmeter reading (and UVT if available) to provide an indication of UV dose.

UV intensity sensors are normally a component that is specified in the validation certification for a specific UV system and are factory calibrated based on the validation testing.

UV installations fitted with MP lamps shall have a UV sensor for each lamp.

UV intensity sensors shall include automated wipers to minimise build-up and ensure accuracy of readings. Modern UV systems have a wiper manifold capable of cleaning both UV lamps and the UV intensity sensor concurrently.

4.5.2 Temperature sensors

The energy input to UV reactors that is not converted to light (approximately 60 – 90 percent) is converted to heat and is absorbed by the water as it passes through the reactor. The UV reactor is cooled by the water flowing through it. If the water level were to drop, exposing the lamps, or if the flow were to stop for longer than a minute or so, there is a risk that the reactor may overheat. It is important, therefore, that the reactor is fitted with a temperature sensor to monitor the vessel shell and/or reactor water temperature, and that the PLC is programmed to shut the system down should the temperature rise above the recommended operating range for a described period of time. This is to avoid the risk of damage to the lamps due to overheating or exceeding the design pressure of the UV vessel.

4.5.3 UV Transmittance sensor

Modern UV systems are supplied with a UVT sensor which is located on a common feed. The sensor reading is fed into a control algorithm, which calculates the UV dose and adjusts lamp output or the number of lamps operating, to maintain the UV dose set-point. In other systems, the sensor reading is used solely for monitoring water quality and detecting operational problems. The UVT is used to confirm validation of the dose requirements being met in operation of the UV unit. A target UV dose shall be provided for the setting of log removal requirements for target pathogens or viruses.

4.6 UV Reactors

Most reactor designs are based on the cross-flow configuration, in which the direction of flow is perpendicular to the placement of the lamps, as shown in Figure 5. However, some designs are based on the parallel configuration, in which the direction of the flow is parallel to the lamps, as shown in Figure 6. The Water Corporation's preference is to use cross-flow configuration, but final selection shall be done as per discussion in section 4.1.

4.6.1 Materials

The UV reactor shall be fabricated from materials that do not corrode, do not transmit UV light, and do not impart taste, odour, colour, or toxic materials to the water. The Water Corporation's requirement is for the reactor and connecting flanges to be fabricated in 316L stainless steel unless water quality dictates use of materials with higher corrosion resistance.

Figure 5 - Cross-flow configuration

Figure 6 - Parallel -flow configuration

4.6.2 Appurtenances

Inline strainers shall be fitted on both the inlet and outlet of the reactor. These shall normally have 1mm mesh size. The purpose of the inlet strainer is to trap objects such as nuts and washers that might damage the lamp sleeves and UV lamps. The purpose of the outlet strainer is to trap any loose objects originating from within the UV reactor. The inlet strainer may be omitted where there is a process unit that ensures equivalent protection of the lamp sleeves located immediately upstream and directly piped to the UV reactor. Note that an inlet strainer is required when the upstream process is media filtration, because there is the risk of damage to the lamp sleeves from filter media which may escape through damaged filter nozzles.

A reactor drain-down tapping shall be provided to enable the water to be drained from the reactor when it is taken out of service. Tapping points and valves upstream and downstream of the reactor shall be considered to enable flushing, CIP, venting and sampling. As CIP will not be performed often, common tappings can be used for CIP and sampling.

4.6.3 Redundancy

All UV installations shall incorporate a standby reactor in parallel; configured to automatically take-over should the duty reactor fail. Fast-closing actuated isolation valves shall be provided on the inter-connecting piping to enable a reactor to be isolated from the others.

4.6.4 Inlet and outlet pipework

As per US EPA UVDGM, it is required to design and supply a minimum of five pipe diameters of straight pipe upstream of UV reactor (i.e. an elbow at the reactor inlet is forbidden). Similarly, no isolation valves are permitted in that length of pipe. It is common for some UV light to spill out of the UV reactor into the connecting piping due to reflections and diffusion. This spilled UV light can cause embrittlement and failure of plastic piping materials or elastomeric linings; therefore, such pipe materials shall not be used close to the UV reactor. The UV vendor should be consulted.

Piping design shall ensure the UV reactor always remains full of water during operation.

4.6.5 Flow Distribution and Control

For system designs that have greater than one duty UV reactor, the pipework in each UV train shall be sized and configured to provide an approximately equal head loss over the range of design flow rates (i.e. the design objective is to ensure flow variation between reactors does not exceed 10%; hence, flow in each reactor shall be within 5% of the equally divided combined flow).

The power supplied to each UV reactor shall be controlled in response to the flow rate passing through the reactor.

4.6.6 Flow Measurement

A dedicated flow meter shall be installed on each UV train to confirm that the reactor is operating within the design range and to allow calculation, display and alarms related to UV Dose on the control system. The Water Corporation's preference is to use magnetic flow meters.

4.6.7 Air Release Valves

UV reactors need to be kept free of air to prevent lamp overheating. Air release valves, air/vacuum valves, or combination air valves may be required to prevent air pockets and negative pressures developing. Confirmation shall be sought from the manufacturer to determine specific air release requirements.

In situations where there is low downstream head, an alternative to air valves shall be considered.

4.6.8 Isolation Valves

For duty/standby configuration, each UV reactor shall be capable of being isolated and taken out of service. Isolating a UV reactor will require valves upstream and downstream of the reactor. The actuated valve on the reactor inlet may be used as the isolation valve subject to it being appropriately specified to comply with the Corporation's lock-out tag-out (LOTO) requirements. Confirmation shall be sought from the manufacturer on the inlet and outlet valve configuration to ensure that the reactor performance will not be adversely affected.

Valve seats, seals and fittings located in the straight pipe lengths adjacent to UV reactors shall be constructed of materials that are resistant to UV light, heat and any chemicals that may be used for lamp cleaning.

4.7 Equipment Layout

The following items shall be considered when developing the UV reactor and piping layout in the planning phase:

- Number, capacity, dimensions, and configuration of the UV reactors (including redundancy and interconnecting piping);
- Maximum allowable separation distance between the UV reactors and electrical controls, if distance limitations apply. This information is unique to each UV reactor and shall be obtained from the UV manufacturer;
- Adequate distance between adjacent reactors to provide access for maintenance (e.g. lamp replacement);
- Adequate space for mobile or fixed clean-in-place equipment;
- Configuration of the connecting pipework and the inlet/outlet pipework; and
- Space for electrical equipment, including control panels, transformers, ballasts, backup generators, and back-up power supplies.

4.8 Accessibility

The layout of equipment shall be arranged to provide ample access for maintenance activities. Operators need to be able to calibrate monitoring sensors, check fail-safe devices, clean lamp sleeves, inspect and clean reactor inner surfaces, execute CIPs, examine seals, replace aged lamps, and monitor water quality. Sufficient space needs to be provided to enable lamps and sleeves to be removed and replaced; this may require access to both sides of the UV unit for the removal and cleaning/maintenance of UV components. Note that service areas defined in many UV system installation manuals do not include space or access for the person performing maintenance (they only show the clearances required for lamps being withdrawn from the reactor and similar). The designer shall make suitable allowance for personnel access, body positioning, movement and tool space during completion of maintenance activities.

4.9 Safety Signage

Safety signage shall be supplied in accordance with DS79-04 Chemical Signage, Labelling and Markers.

4.10 Spare Parts

Required spare parts including lamp(s), sleeve(s), sensor, wiper, and ballast, shall be kept in storage at the site or at the district depot depending on the Region’s preference. The required spare parts shall be defined based on criticality due to duty/standby configuration, availability and design life. During tender / quotation requests, Vendors shall be requested to provide details regarding spares availability, location of holdings and delivery timeframes. Spares shall be stocked and be readily available in Australia.

4.11 Instrumentation and control

4.11.1 Instrumentation

All instrumentation shall comply with the Water Corporation's:

- Design Standard - Part No. DS 40-09: Field Instrumentation;
- SCADA Approved Equipment List;
- S226 Surface Water Treatment Monitoring; and
- "Appendix B: Functional Description Overview" of this document.

4.11.2 PLCs and SCADA

The UV units shall be controlled by a dedicated local PLC equipped with a Modbus over Ethernet TCP/IP communication module for integration with the plant control system. SCADA must be provided for remote supervision and control. All monitored variables, status indications and alarms must be immediately transferred via SCADA to the Operations Centre.

4.11.3 Operator Interface Panels

All key performance indication, instrumentation, controls and monitoring of the UV unit must be communicated to a Local Operator Interface Panel. The Operator Interface Panel shall contain a data-logging system (containing last 7 days' historical data), alarms for key process variables and parameter set-points which are capable of meeting the equipment monitoring OEM requirements. The Operator Interface Panel shall be a touch-screen colour display type. An alternative is to use ViewX if it is available on site.

4.11.4 Dose monitoring

Dose-monitoring is required in order to confirm the UV dose delivery. Currently, the two main methods used for UV dose monitoring are:

- UV intensity set-point; and
- Calculated dose

The use of calculated dose is the preferred method of monitoring in modern UV systems.

4.11.4.1 Set-point method

The first method makes use of a set-point that is established during commissioning and testing. The control parameter that is monitored is UV intensity, which is used to account for changes in UVT. The UV intensity measured by the sensor is input into the control algorithm, which then adjusts the UV output to maintain the set-point.

The set-point may be fixed or variable. A fixed set-point is simpler to operate and control, but is not energy efficient, because for a lot of the time, the UV dose is higher than required. With a variable set-point, the set-point is continually adjusted according to the flow rate through the reactor. This allows the lamp output to be reduced during low flow conditions and enables energy costs to be reduced. Modern UV systems can operate in both fixed and variable set point. If available, UV systems capable of operating in variable set point mode are preferable for Water Corporation assets.

4.11.4.2 Calculated dose

Modern UV manufacturers have established an empirical relationship that allows the UV dose to be estimated from parameters which may include reactor flow rate, UV intensity, UVT and lamp status. In operation, readings of these parameters are fed into the control algorithm which calculates the theoretical UV dose. The control system continuously monitors the calculated dose and adjusts the UV output to maintain the target UV dose.

UV system control using calculated dose is the preferred method for control and monitoring of UV performance. The UV system shall operate with a UV dose Low and UV dose Low-Low set point to monitor, and if required shutdown and alarm, the UV system. The UV Dose Low-Low set point shall be set at the required UV dose and the UV Dose Low alarm shall be set at least 10% above the required UV dose.

4.11.5 System Automation

Operation of the UV installation shall be fully automated. Automatic shut-down and cessation of water flow under critical alarm conditions is essential.

4.11.5.1 Start-up Sequence

Start-up of the UV unit can be configured in either of two modes, “UV first” or “Source first”. Both modes shall have start-up sequences that are fully automated. UV first start-up mode is preferred but shall be confirmed as acceptable with the UV Unit supplier. Source first operation shall only be operated on sites with available waste diversion for the initial volume of under-dosed water.

“UV first” operation will normally include the following steps:

- Wait for re-strike timer to expire (if counting);
- Start UV (i.e. Ignite lamps) with closed inlet or outlet valve;
- Lamp warm-up, usually 30 to 90 seconds;
- Confirm UV intensity is sufficient to achieve minimum required UV dose based on maximum design flow and minimum UVT;
- Open inlet / outlet valve; and
- Call plant to start.

“Source first” operation will normally include the following steps:

- Wait for re-strike timer to expire (if counting);
- Open waste valve (outlet valve is closed);
- Open inlet valve;
- Call plant to start, wait for minimum required flow through UV unit;
- Ignite lamps;
- Lamp warm-up, usually 30 to 90 seconds;
- Confirm UV dose (UV intensity or UVT);

- Open outlet valve; and
- Close waste valve

Confirmation shall be obtained from the UV manufacturer whether a stream of cooling water is required whilst the lamps are heating up. Almost all LP, LPHO lamps and MP lamps do not require cooling water when heating-up. However, some UV lamps may heat the water above the safe operating temperature, which will result in a reactor shutdown. If the lamp requires cooling water while heating up, an arrangement (source first) must be provided to bypass initial water flow to waste (or to the source or head of the WTP) until the required UV dose is reached. This will also apply in change over situations where changeover is happening due to any alarm in the duty unit.

4.11.5.2 Shut-down Sequence

The UV reactor shall automatically shut-down on the generation of a major or critical alarm (refer Section 4.11.6). The main steps involved in shutting down a reactor are:

- Signal plant to shut down (or run to waste or head of WTP while the standby UV unit is brought online);
- Close isolating valves on faulted UV unit; and
- De-energize the faulted reactor immediately after the valves close.

The detailed shutdown or changeover sequence shall ensure that no under-dosed (and therefore potentially unsafe) water is sent to distribution, providing a constant barrier to prevent passage of (live) pathogens through the system.

4.11.6 Controls and Alarms

Sufficient controls and alarms shall be provided to allow remote operation of the plant in line with the System Automation requirements outlined above. ”Appendix B: Functional Description Overview” provides a listing of the minimum controls and alarms required to be provided.

4.12 Electrical

All electrical and control equipment must be in accordance with the Water Corporation and Australian Standards listed in Section 1.4.

4.12.1 Electrical Enclosures

All electrical enclosures shall be suitably IP rated for outdoor areas, with powder-coated finish.

Water Corporation Electrical design standards address the issue of switchboard IP rating

- For indoor switchboards, the minimum IP rating of the indoor enclosure shall be IP53
- For indoor switchboard controlling systems (control systems) the minimum IP rating of the indoor enclosure shall be IP52

Electrical enclosures shall be suitably rated, separated, segregated or otherwise protected from water sprays or flooding potentially originating from the UV unit and associated piping. Locating electrical enclosures in a separate room or providing a permanent separating wall between the process equipment and the enclosures is normal.

4.12.2 Power requirements and total load

Power requirements for the various components may be different - for example, the UV reactor may require a 3-phase, 415 V service, whilst the on-line UVT analyser may require a lower voltage service. The supply voltage and total load requirements shall be confirmed with the manufacturer.

4.12.3 Harmonic distortion

The varying nature of UV reactor loads can induce harmonic distortion into the upstream electrical power supply. This can lead to problems involving overheating and can affect VFDs, PLCs and OIPs. The potential for the equipment to induce harmonic distortion therefore needs to be carefully assessed. If necessary, harmonic filters may be installed on the power supply to control distortion.

4.12.4 Back-up power

Continuous operation of the UV reactor is dependent on the availability of power from the regional supply network. Availability of power from the network, however, cannot be guaranteed; hence a strategy to manage power-outages needs to be developed.

A UPS shall be installed in the UV disinfection plant switchboard and shall hold up power to the following critical equipment and instruments in the event of a site power failure:

- PLC
- OIP
- UV Control Circuit
- Flowmeter
- Motorised Valves

As the above critical equipment is supplied by the UPS, if the UV plant was in production at time of power outage the plant is able to perform a controlled shutdown. Upon restoration of site power, operation of the UV plant shall resume without any requirement for operator intervention.

System design shall ensure that no under-dosed water is passed into the water supply during power outages. This shall consider the inertial ramp down of pumps on power failure whereby the pump may continue to transfer water for many seconds after the power is lost. The closure time of isolation valves shall also be considered. In some cases it may be necessary to “hold” the UV unit with a UPS to avoid water transfer without disinfection before complete inlet valve closure.

The UPS shall be capable of supplying power to the UV Module Control Cubicle, including the OIP, Ethernet switch and corresponding UV plant instruments for a period of 8 hours. UPS has commonly a low IP rating therefore it shall be installed in a specific cabinet or with a specific design if in the same room as the UV units.

4.12.5 Total Power Failure

In the event of a total site power failure (including loss of UPS backup power), any and all actions being performed by the UV disinfection plant shall cease immediately. Upon restoration of site power, the UV plant shall automatically revert to the normal standby state ready for the next plant run request. This shall be performed without any requirement for Operator intervention.

4.12.6 Grounding and insulation

Grounding and insulation of electrical components are critical for protecting operators from electrical shock and protecting the equipment.

All UV systems shall be provided with Ground Fault Interrupt (GFI) circuits. The transformer in the ballast must not be isolated from the ground, otherwise ground faults will not be properly detected, and safety can be compromised.

UV reactors must be capable of being isolated and locked out for maintenance, both hydraulically and electrically in accordance with the Corporations' lock-out, tag-out requirements. The UV reactor must be shut down before it can be opened.

5 APPENDIX A: CHECKLIST FOR DESIGNING A UV DISINFECTION SYSTEM

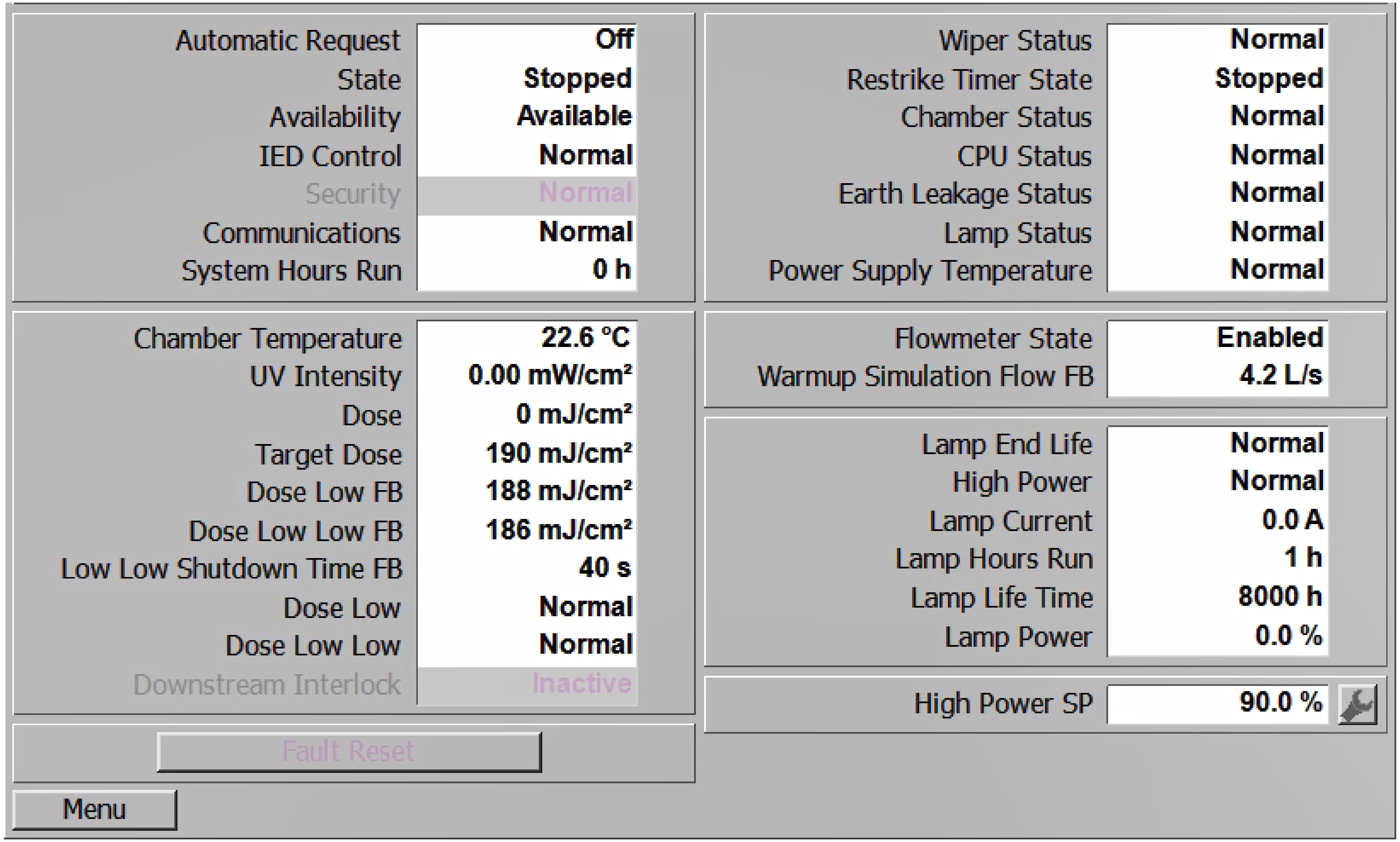
- Application of the UV system: Disinfection of drinking water
- Total number of disinfection trains
- Operation (e.g. 24/24h – 7 days/week)
- Installation conditions: outdoor/indoor
- Minimum and maximum temperature
- Humidity
- Environment
- Upstream treatment:
- Maximum/minimum water flow (daily and instantaneous)
- Maximum water pressure
- Minimum and maximum water temperature
- Minimum UV transmission at 254 nm
- Turbidity/Suspended particles content
- Bacteria
- Viruses
- Protozoa
- Total hardness
- Carbonate hardness
- Chloride
- Manganese
- Iron
- Sulphites
- Chromium
- Copper
- Nickel
- Cobalt

- Humic and fulvic acids
- Oil and grease
- Others
- Automatic cleaning of lamps: Yes or No
- Type of lamps: LP, LPHO or MP
- Power supply
- Guarantees at the disinfection system exit:
- Recommended spare parts for 1 or 2 years
- Vendor's or manufacturer's Australian spares holdings
- Distance of control panel to UV reactor
- Validation requirements
- Salinity (important in assessing if chamber corrosion will be an issue. Chloride above 250 mg/l is likely to result in corrosion of a SS316L chamber)
- Process Control requirements, for example - Data Communications: Ethernet, ModBUS, TCP/IP.

6 APPENDIX B: FUNCTIONAL DESCRIPTION OVERVIEW

Object No.	Asset/Processes	Physical Description	P&ID Tag	I/O Type			Control/Interlock/Permissive	Description	Location/Setting (C=Control, D= Display)			Severity
				Local	PLC	SM			Local	OIP	HMI	
101	UV Unit 1 Chamber	UV Chamber Flow	FIT101		AI			Flow going through the system	D	D	D	
		UV Chamber Flow High	FAHH101			DI	>>Shutdown the UV system	This alarm prevents very large flow passing through within the system due to any breakage upstream.		D	D	Critical
		UV Chamber Flow Totalised	FQT101		AI			Totalised flow through the system		D	D	
		UV Flow Discrepancy	YA101			DI	>>Shutdown the UV system	This alarm is initiated when there is disagreement about 'flow status' between flow switch and flow meter.		D	D	Critical
		UV Dose	AI101A			AI		Calculated dose based on UV intensity, flow and UV transmittance (optional)		D	D	
		UV Dose Low	AAL101A			DI	>>Switch on more UV lamps and/or Changeover to UV unit 2	For LP system an extended timer is activated for changeover. (Low and Low Low UV Intensity values are also used to generate the dose alarms if setpoint dose method is used.)		D	D	Warning
		UV Dose Low Low	AALL101A			DI	>>Shutdown the UV system & Water supply	System shuts down if Unit No.1 is faulted. (Low and Low Low UV Intensity values are also used to generate the dose alarms if setpoint dose method is used.)		D	D	Critical
		UV Chamber Lamp Runtime	KQT101B			AI		Displays the lamp runtime.		D	D	
		UV Chamber Lamp Current	AI101B		AI			Indicates lamp current.		D	D	
		UV Chamber Lamp Fault	YA101B			DI	>> Changeover to UV unit 2	Alarm is generated when UV lamp becomes faulty.		D	D	
		UV Chamber Temperature	AI101C		AI			Displays the chamber temperature.		D	D	
		UV Chamber Temperature High	AAH101C			DI	>> Changeover to UV unit 2	Alarm is generated when chamber temperature exceeds safe working temperature which is preset for UV chamber		D	D	Warning
		UV Intensity	AI101D		AI			Displays the UV intensity.		D	D	
		UV Intensity Low	AAL101D			DI		Warns of lamp and sleeve system performance decline.		D	D	Critical
		UV Sleeve Cleaning Fault	YA101C			DI	>> Changeover to UV unit 2			D	D	
102	UV Unit 2 Chamber	UV Chamber Flow	FIT102		AI			Flow going through the system	D	D	D	
		UV Chamber Flow High	FAHH102			DI	>>Shutdown the UV system	This alarm prevents very large flow passing through within the system due to any breakage upstream.		D	D	Critical
		UV Chamber Flow Totalised	FQT102		AI			Totalised flow through the system		D	D	
		UV Flow Discrepancy	YA102			DI	>>Shutdown the UV system	This alarm is initiated when there is disagreement about 'flow status' between flow switch and flow meter.		D	D	Critical
		UV Dose	AI102A			AI		Calculated dose based on UV intensity, flow and UV transmittance (optional)		D	D	
		UV Dose Low	AAL102A			DI	>>Switch on more UV lamps and/or Changeover to UV unit 1	For LP system an extended timer is activated for changeover. (Low and Low Low UV Intensity values are also used to generate the dose alarms if setpoint dose method is used.)		D	D	Warning
		UV Dose Low Low	AALL102A			DI	>>Shutdown the UV system & Water supply	System shuts down if Unit No.2 is faulted. (Low and Low Low UV Intensity values are also used to generate the dose alarms if setpoint dose method is used.)		D	D	Critical
		UV Chamber Lamp Runtime	KQT102B			AI		Displays the lamp runtime.		D	D	
		UV Chamber Lamp Current	AI102B		AI			Indicates lamp current.		D	D	
		UV Chamber Lamp Fault	YA102B			DI	>> Changeover to UV unit 1	Alarm is generated when UV lamp becomes faulty.		D	D	
		UV Chamber Temperature	AI102C		AI			Displays the chamber temperature.		D	D	
		UV Chamber Temperature High	AAH102C			DI	>> Changeover to UV unit 1	Alarm is generated when chamber temperature exceeds safe working temperature which is preset for UV chamber		D	D	Warning
		UV Intensity	AI102D		AI			Displays the UV intensity.		D	D	
		UV Intensity Low	AAL102D			DI		Warns of lamp and sleeve system performance decline.		D	D	Critical
		UV Sleeve Cleaning Fault	YA102C			DI	>> Changeover to UV unit 1			D	D	
103	UV Unit 1 System	UV Unit 1 Start/Stop	HS103A			DO		Hand switch for manual start/stop of the unit.		C	C	
		Power Supply Over Temperature	AAH103A			DI	>> Changeover to UV unit 2	Alarm is generated when power supply temperature is higher than the preset value.		D	D	
		Earth Leakage Fault	YA103A		DI		>> Changeover to UV unit 2	Alarm is generates when each leakage fault is generated.		D	D	
		Local Fault Reset	HS103B	Local						C		
		UV Unit 1 Unavailable	YA103C			DI				D	D	Urgent
		Remote Fault Reset	HS103C			DO					C	
		UV Unit 1 Local	YL103D		DI	DI				D	D	
		UV Unit 1 Running	YL103D			DI		Displays the status of the UV unit.		D	D	
		UV Unit 1 Runtime	KQT103D			AI				D	D	
		UV Unit 1 Comms Fail	YA103D			DI	>> Changeover to UV unit 2			D	D	Critical
		UV Unit 1 Warming Up	YS103A			DI		During warming up, flow will be managed based on cooling water requirements for UV unit.		D		
		Restriker Timer Running	KQT103E		DI			Indicates the current state of the re-strike timer. This timer runs for 7 minutes. UV unit restart is not possible when the timer state is running.		D	D	
104	UV Unit 2 System	UV Unit 2 Start/Stop	HS104A			DO		Hand switch for manual start/stop of the unit.		C	C	
		Power Supply Over Temperature	AAH104A			DI	>> Changeover to UV unit 1	Alarm is generated when power supply temperature is higher than the preset value.		D	D	
		Earth Leakage Fault	YA104A		DI		>> Changeover to UV unit 1	Alarm is generates when each leakage fault is generated.		D	D	
		Local Fault Reset	HS104B	Local						C		
		UV Unit 2 Unavailable	YA104C			DI				D	D	Urgent
		Remote Fault Reset	HS104C			DO					C	
		UV Unit 2 Local	YL104D		DI	DI				D	D	
		UV Unit 2 Running	YL104D			DI		Displays the status of the UV unit.		D	D	
		UV Unit 2 Runtime	KQT104D			AI				D	D	
		UV Unit 2 Comms Fail	YA104D			DI	>> Changeover to UV unit 1			D	D	Critical
		UV Unit 2 Warming Up	YS104A			DI		During warming up, flow will be managed based on cooling water requirements for UV unit.		D		
		Restriker Timer Running	KQT104E		DI			Indicates the current state of the re-strike timer. This timer runs for 7 minutes. UV unit restart is not possible when the timer state is running.		D	D	
105	UV Unit 1 Ballast System	Run-time for ballast	KQT105			AI		Indicates runtime for the ballast		D	D	
		Power Consumption	AI105		AI					D	D	
		Ballast failure (single ballast identified)	YA105A			DI	>> Changeover to UV unit 2			D	D	Warning
		Cooling system failure (if any)	YA105C			DI	>> Changeover to UV unit 2			D	D	
106	UV Unit 2 Ballast System	Run-time for ballast	KQT106			AI		Indicates runtime for the ballast		D	D	
		Power Consumption	AI106		AI					D	D	
		Ballast failure (single ballast identified)	YA106A			DI	>> Changeover to UV unit 1			D	D	Warning
		Cooling system failure (if any)	YA106C			DI	>> Changeover to UV unit 1			D	D	
107	UV Unit 1 Inlet Valve	Valve Open	ZSH107		DI							
		Valve Close	ZSL107		DI							
		Open Valve	ZCH107			DO		Command to Open Valve from SM				
		Close Valve	ZCL107			DO		Command to Close Valve from SM				
		Inlet valve UV reactor 1 fault-Failed to Close	ZAL107			DI	>>Shutdown the UV system & Water supply			D	D	Critical
		Inlet valve UV reactor 1 fault-Failed to Open	ZAH107			DI	>> Changeover to UV unit2			D	D	Urgent
108	UV Unit 2 Inlet Valve	Open Inlet valve UV reactor 2 switch	ZSH108		DI							
		Close Inlet valve UV reactor 2 switch	ZSL108		DI							
		Open Valve	ZCH108			DO		Command to Open Valve from SM				
		Close Valve	ZCL108			DO		Command to Close Valve from SM				
		Inlet valve UV reactor 1 fault-Failed to Close	ZAL108			DI	>>Shutdown the UV system & Water supply			D	D	Critical
		Inlet valve UV reactor 1 fault-Failed to Open	ZAH108			DI	>> Changeover to UV unit2			D	D	Urgent
109	UV Duty Selector Switch	UV System Duty Selector Switch-Off	HS109A		DI					C	C	
		UV System Duty Selector Switch-Alternate	HS109B		DI					C	C	
		UV System Duty Selector Switch-Duty 1	HS109C		DI					C	C	
		UV System Duty Selector Switch-Duty 2	HS109D		DI					C	C	
110	UV Plant	UV System CPU Fault	YA110B			DI	>>Shutdown the UV system & Water supply			D	D	Critical
		UV Plant Called (Pump Start Request)	YL110A			DO				C	C	
		Flow Switch	FSL110		DI			This confirms the flow status.				
		UV Transmittance	AI110E		AI					D	D	
		UV Transmittance Low	AI110			DI		Indicates UV transmittance is low and dose calculation may not be accurate.		D	D	Warning
		UV Security Alarm	YA110			DI				D	D	Critical

7 APPENDIX C: ULTRAVIOLET SCADA SCREEN OVERVIEW



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