TROJAN UV™

WATER CONFIDENCE™

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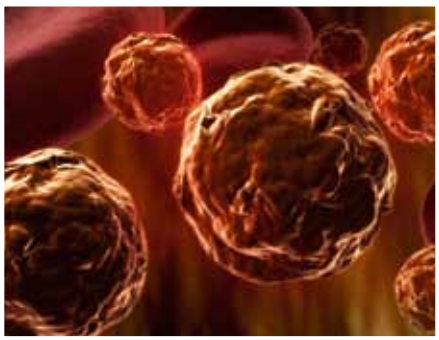
UV DISINFECTION

Multi-Barrier Strategy with UV

Bacteria (e.g. E.coli, Salmonella)



Viruses (e.g. Polio, Hepatitus A)

Protozoa (e.g. Cryptosporidium, Giardia)

Introduction to UV disinfection for Drinking Water

In many European countries, drinking water is extracted from surface water or groundwater under the direct influence of surface water. This implies an increase of risk of contamination from protozoa (*Cryptosporidium*, *Giardia*), bacteria (*E. coli, Salmonella*), and viruses (Hepatitis A, Hepatitis B, Poliovirus, Rotavirus) associated with waterborne outbreaks.

Microbiological contamination

Microbiological contamination of water sources has been linked as a major indicator for national health. Poor sanitary systems, poor hygiene, increased industrial uses and increased agriculture, have led to breakouts of waterborne diseases. In many countries, statistics of early childhood deaths have been traced back to contamination of water. As a result, disinfection of water became an indispensable part of the water treatment process.

Microbiological contamination

Infectious waterborne micro-organisms

Table 1 shows typical waterborne pathogenic organisms and the disease they may cause. Although these micro-organisms are mostly found in surface water, they are nowadays a concern for groundwater wells since water infiltration of pathogenic organisms is possible. Outbreaks have been reported in many of the West European countries. Recently in 2007, a *Cryptosporidium* breakout occurred in Ireland. The Irish government responded immediately by implementing the Remedial Action List involving, amongst other things, a multi-barrier upgrade of the water supplies.

UV systems must undergo bioassay validation

Since it is not possible to conduct testing on every micro-organism, representative organisms are typically used for bioassay validation. The European guidelines for drinking water have identified the minimum standard for microbial contamination in Table 2. Following these guidelines, combined with good housekeeping (e.g. sanitary systems), have lowered the risk of epidemic breakouts and increased public health. For many years, drinking water quality was assumed to be safe if the microbial counts were lower than what was specified in Table 2.

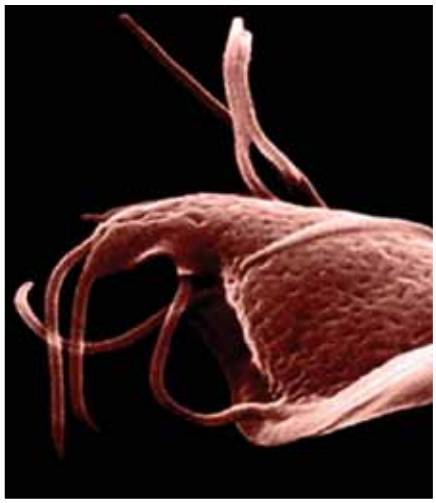
Despite having drinking water that was in compliance with the microbiological requirements as per the EU regulations in Table 2, countries have experienced breakouts of *Cryptosporidium* and *Giardia*, resulting in illnesses and even deaths. Therefore, there is a growing concern from chlorine-resistant protozoa like *Cryptosporidium* and *Giardia*.

Table 1: Typical Waterborne Pathogenic Organisms

Micro-organism	Disease
BACTERIA	
Salmonella typhy	Typhoid
Salmonella paratyphy A, B, C	Paratyphoid
Shigella species	Ruhr
Escherichia coli	Enteriticen, Enterotoxamien
Brucella species	Bang`sche disease or Maltafeaver
Vibrio cholerae	Cholera
Leptospira species	Weil`sche disease
Listeria monocytogenas	Listeriose
Bacillus anthracia	Anthrax
Clostridium botulinum	Botulismus
Mycobacterium species	Hautulzerationen, Tuberculosis
Chiamydia trachomatis	Conjunctivitis
VIRUS	
Poliovirus	Meningitis, Polio
Coxsackievirus A, B	Meningitis, Eczema
ECHO-Virus	Meningitis, Diarröhen
Hepatitis A	epidemic Hepatitis
PROTOZOA	
Entamoeba histolytica	Amoebaeruhr
Giardia lamblia	Lambliaeruhr
Cryptosporidium parvum	Cryptosporidiosis
WORMS	
Ascaris lumbricoides	Askariasis
Taenia species	Tapeworm

Table 2: Microbiological Parameters according to the European Community Directive 89/83/EC

Microbiological Parameters	
Escherichia coli	0 / 100 ml
Enterococci	0 / 100 ml
Microbiological Indicator Parameters	
Clostridia perfringens (incl. spores)	0 / 100 ml
Colony Count @ 22°C	Without abnormal changes
Coliform bacteria	0 / 100 ml



Giardia

Giardia is a genus of anaerobic flagellated protozoan parasites of the phylum Metamonada in the supergroup "Excavata" (named for the excavated groove on one side of the cell body) that colonize and reproduce in the small intestines of several vertebrates, causing giardiasis. Their life cycle alternates between an actively swimming trophozoite and an infective, resistant cyst. The genus was named after the French zoologist Alfred Mathieu Giard.

Cryptosporidiosis

Cryptosporidiosis is a parasitic disease caused by ***Cryptosporidium***, a protozoan parasite in the phylum Apicomplexa. It affects the intestines of mammals and is typically an acute short-term infection. It is spread through the fecal-oral route, often through contaminated water. The main symptom is self-limiting diarrhea in people with intact immune systems. In individuals with suppressed immune systems, the symptoms are particularly severe and often fatal. Despite not being identified until 1976, it is one of the most common waterborne diseases and is found worldwide. The parasite is transmitted by microbial cysts (oocysts) that, once ingested, excyst in the small intestine and result in an infection of the intestinal epithelial tissue.

EC Council Directive 98/83/EC

The EC Council Directive 98/83/EC, dated 3 November 1998, in article 5, requires that Member States set standards to water intended for human consumption. These standard microbiological parameters are listed in Table 2.

The mentioned microbiological indicator parameters are indicators for safe water. They can easily be monitored on a regular basis as per article 7 of the EC drinking water directive.

Every EC Member has adopted the 98/83/EC directive. Most of the EC Members have extended the directive to more rigorous regulations for surface water and groundwater under direct influence of surface water. They included a *Giardia* and *Cryptosporidium* requirement as listed in Table 3.

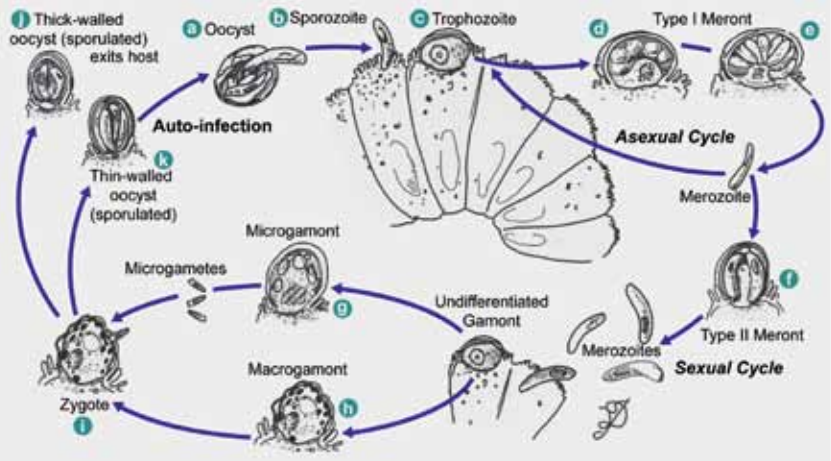
Disinfection is a vital step within the overall drinking water treatment process to ensure the treated water does not carry microbiological contaminants that could endanger the health of the consumer.

Table 3: Proposed maximum acceptable average concentration of protozoa in drinking water.

Organism	Proposed counts	Not in m³ drinking water
Cryptosporidium	$2{,}6 \times 10^{-5}$ /l	38
Giardia	$5{,}5 \times 10^{-6}$ /l	180

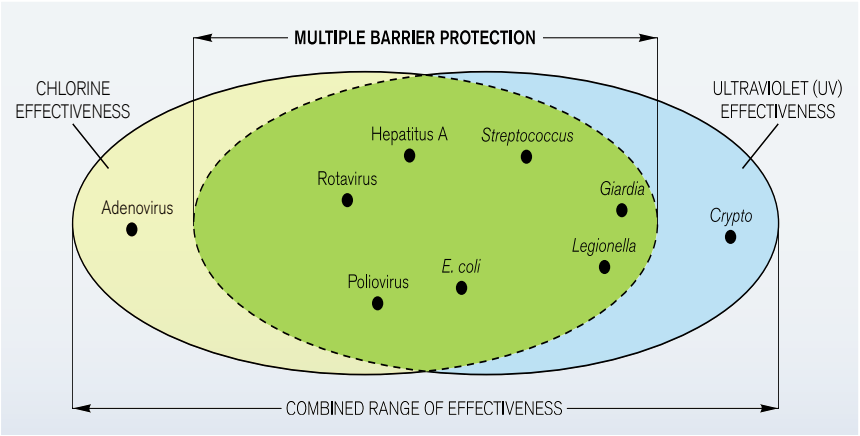
Several disinfection and removal technologies are available. The most common are:

- Filtration (such as membrane filtration)
- Ozonation
- Disinfection by ultraviolet rays
- Disinfection by chlorine or chlorine-related chemicals



Lifecycle of cryptosporidiosis

Combination instead of Competition



Despite the disadvantage of forming disinfection by-products (DBP), chemical disinfection with chlorine has one important benefit; it can be used as a residual disinfectant in the distribution system. This residual will maintain disinfection in the distribution network from the water works to the consumer. However, because chlorine forms carcinogenic by-products (e.g. THMs) and has little to no effect on chlorine-resistant *Cryptosporidium* and *Giardia*, chlorine is not ideal for the primary disinfection of drinking water.

The oxidative power of ozone can remove several organic compounds of the water and is a good disinfectant for bacteria, viruses and *Giardia* cysts. However the *Cryptosporidium* oöcysts survives ozone treatment. From an economical point of view, if ozone is applied for disinfection only, the payback period is substantial.

Traditional rapid and slow sand filtration will remove a percentage of the micro-organisms but would still pose a risk to public health. On the other hand, membrane filtration is efficient at removing micro-organisms. However, concerns about viruses passing through membranes and possible membrane damage could pose a risk to public health. Therefore, MF and UF do not provide sufficient protection.

With UV as the main disinfection step, many of the disadvantages of chemical disinfection and filtration do not exist anymore. UV can be used to inactivate bacteria, viruses and protozoa with low UV doses and Adenovirus at high UV doses. Fortunately, Adenovirus can be inactivated with chlorine and a combination of UV and chlorine would virtually eliminate all microbial contaminants.

The multi-barrier strategy

Multiple barrier protection provides additional public safety. The combination of traditional filtration, UV and residual chlorine has been accepted as the most effective barrier for the reduction of pathogens.

UV Disinfection

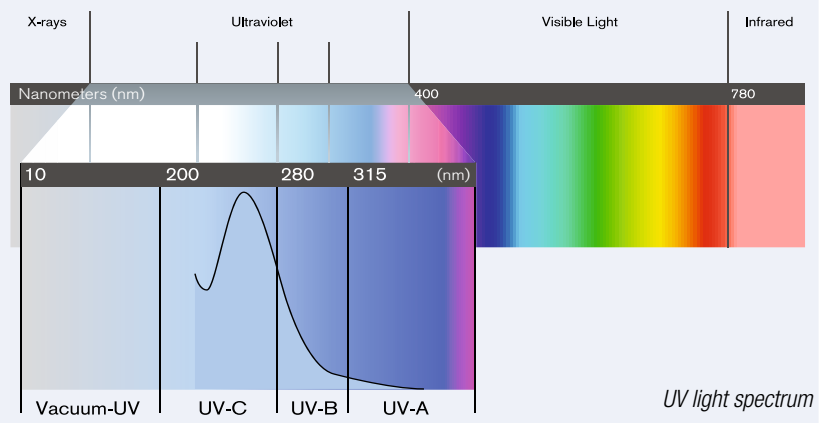
Unlike chemical approaches to water disinfection, UV light provides rapid, effective inactivation of micro-organisms through a physical process.

When bacteria, viruses and protozoa are exposed to the germicidal wavelengths of UV light, they are rendered incapable of reproducing and infecting. UV light has demonstrated efficacy against pathogenic organisms, including those responsible for cholera, polio, typhoid, hepatitis, *Giardia*, *Cryptosporidium* and other bacterial, viral and parasitic diseases. Furthermore, Trojan has successfully installed UV systems (either alone or in conjunction with hydrogen peroxide) to destroy chemical contaminants such as pesticides, industrial solvents and pharmaceuticals.

UV Validation

The sizing of a UV system should be determined and substantiated through a bioassay (field testing). This full size testing ensures that UV systems are sized properly using real-world performance data instead of theoretical assumptions (e.g. out-dated software programs such as UVDIS). Several procedures and industry standard protocols for field validation have been established:

- 1986 USEPA Design Manual: Municipal Wastewater Disinfection
- 2003 NWRI/AwwaRF Ultravoilet Disinfection Guidelines for Drinking Water and Reuse
- USEPA Ultraviolet Disinfection Guidance Manual for the Long Term 2 Enhanced Surface Water Treatment Rule (2006)
- Deutsche Vereinigung des Gas- und Wasserfaches (DVGW) W294 Standard
- Österreichisches Normungsinstitut (ÖNORM)



UV light spectrum

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UV Dose

Micro-organisms are inactivated by UV light as a result of damage to nucleic acids. The high energy associated with short wavelength UV energy, primarily at 254 nm, is absorbed by cellular RNA and DNA. This absorption of UV energy forms new bonds between adjacent nucleotides, creating double bonds or dimers. Dimerization of adjacent molecules, particularly thymine, is the most common photochemical damage. Formation of numerous thymine dimers in the DNA of bacteria and viruses prevents replication and their ability to infect.

The germicidal effects of UV are directly related to the dose of UV energy absorbed by a micro-organism. The UV dose is the product of the UV intensity and the time that a micro-organism is exposed to UV light (often referred to as residence time). The required disinfection limit or log-reduction will dictate the required UV dose. UV dose is typically expressed in mJ/cm², J/m² or µWs/cm². The exposure time of the UV system is determined by the reactor design and the flow rate of the water. The intensity is affected by the equipment parameters (such as lamp type, lamp arrangement, etc.) and water quality parameters (such as UV transmittance, TSS, etc.). Unlike chemical disinfectants, UV disinfection is not affected by the temperature, turbidity or pH of the water.

Taking all the different equipment and water quality parameters in account, the calculations of the delivered dose is complex. Theoretical models, created to perform CFD and/or Point Source Summation dose calculations, do not provide accurate result and cannot guarantee performance. Therefore, to accurately determine the dose of the UV system for a given flow rate and water quality, bioassay validation must be conducted to take into account all the variables that can affect the delivered dose, such as hydraulics, reactor mixing, quartz sleeve transmission, etc.

The microbiological response of a micro-organism is a measure of its sensitivity to the exposure to UV light and is unique to each micro-organism. A UV dose response curve is determined by irradiating water samples containing the micro-organism with various UV doses and measuring the concentration of viable infectious micro-organisms before and after exposure. The resultant dose response curve is a plot of the log inactivation of the organism versus the applied UV dose rate. 1-log inactivation corresponds to a 90% reduction; 2-log to a 99% reduction; 3-log to a 99,9% reduction and so on.

Both the DVGW and the USEPA have published comparable inactivation doses of different water borne pathogens as per Table 4. These doses must be validated by independent bioassays for each different UV unit at different operating conditions.


DNA effected by UV light

UV Dose (J/m²) = UV intensity (W/m²) x Exposure time (s)

Table 4: Data summarized from the US EPA Workshop on UV Disinfection of Drinking Water, April 28-29, 1999

Pathogen	Average UV Dose (mJ/cm²) Required to Inactivate			
	1log	2log	3log	4log
Cryptosporidium parvum oocysts	3.0	4.9	6.4	10
Giardia lamblia cysts	NA	<5	<10	<10
Giardia muris cysts	1.2	4.7	NA	NA
Vibrio cholerae	0.8	1.4	2.2	2.9
Escherichia coli O157:H7	1.5	2.8	4.1	5.6
Salmonella typhi	1.8-2.7	4.1-4.8	5.5-6.4	7.1-8.2
Salmonella enteritidis	5	7	9	10
Legionella pneumophila	3.1	5	6.9	9.4
Hepatitis A virus	4.1-5.5	8.2-14	12-22	16-30
Poliovirus Type 1	4-6	8.7-14	14-23	21-30
Rotavirus SA11	7.1-9.1	15-19	23-26	31-36

UV Disinfection System Validation

Bioassay validation results in a Reduction Equivalent Dose (RED). If the RED for a UV system is 40 mJ/cm², it means that the UV system is delivering 40 mJ/cm² as measured by the validation organism. In a bioassay validation test procedure, it does not matter how the UV unit has been designed, how many lamps are installed or how much power the system consumes. The measured microbiological log reduction determines the efficiency of the system in relation to operational conditions.

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Calculated doses from Point Source Summation method or with CFD modelling typically predict much higher UV doses than reality. This is the main reason that bioassay validation is critical in water disinfection applications.

General Validation Steps

Step 1: Determine UV Dose Response Curve of Challenge Microbe

Using a Collimated Beam, the microbial inactivation based on various UV doses can be plotted. This is the Dose Response Curve for the challenge organism.

Step 2: Reactor Evaluation and Validation

The UV reactor is operated under various flow conditions (eg. different UV transmittances, different lamp outputs, etc.) with the same challenge organism to determine the microbial inactivation. By comparing the reactor's microbial inactivation against the Dose Response Curve established by the Collimated Beam test, the dose delivered (is the RED Reduction Equivalent Dose) by the reactor can be accurately determined and validated for various operational conditions.

The test, which is referred to as bioassay validation, is executed and administrated by an independent and recognized third party at a dedicated test facility.

Validation Parameters

Validation must confirm the target log inactivation requirements.
Bioassay validation allows systems to be accurately sized and take into consideration the following parameters:

- UV Transmission (UVT)
- Flow rate
- UV intensity
- Lamp configuration
- Reactor hydrodynamics
- End of lamp life

Table 5: UV Dose Requirements (mJ/cm²)

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	39	58	79	100	121	143	163	186

Source: USEPA UVDGM table 1.4.

Validated UV intensity sensor

Comparison USEPA and DVGW protocols.

The DVGW W294 has been developed in Germany for German drinking water producers in order to create standardization in UV disinfection industry. The DVGW W294 is widely accepted as the validation protocol for UV reactors. The DVGW standardization allowed the water industry to make a fair comparison between different kind of UV reactors and suppliers. The DVGW protocol was designed to be performed at the DVGW test facility. The DVGW test facility is limited to 3000 m³/hr.

The DVGW protocol testing determines reactor sizing with a fixed RED of 40 mJ/cm², with Bacillus subtillus spores as test micro-organism. Varying UVT, lamp powers and a 70% lamp aging is taken into account. Due to the demand for larger UV-reactors, large variations in local water qualities, different facility layouts and the existence of many different treatment procedures, there was a need to have a protocol that was more flexible.

The U.S. Environmental Protection Agency (USEPA) developed the Ultra Violet Disinfection Guidance Manual (UVDGM) describing on site validation protocols and design considerations for UV reactors. Due to the recent outbreaks, the manual is focused on the effective removal of the chlorine resistant *Giardia* and *Cryptosporidium*. The USEPA protocols are more flexible and complex. The test dose may vary from 10-120 mJ/cm² at various flow rates, UVT and power with a simulated end of lamp life. The test results in a validation testing curve that can be used for specific microbiological targets requiring a higher RED than 40 mJ/cm².

Differences between USEPA / DVGW

- The USEPA allows set-point and calculated dose methods that are interpolated as a function of flow rate, UVT and UV intensity
- DVGW works only with the RED 40 mJ/cm² biodosimetric dose
- USEPA typically uses MS2 Phage, DVGW uses bacillus subtilis spores
- USEPA can use DVGW or ÖNORM sensors
- Both allow 3rd party test facilities
- Both allow 3rd party analyses of microbiological data
- USEPA allows for 3rd party verification of lamp aging factor
- USEPA requires consideration be made to the design of the hydraulic profile (inlet conditions)
- USEPA allows online UVT measurement for dose adjustment
- USEPA allows PLC control

Table 6: Overview DVGW - USEPA

Subject	DVGW/ÖNORM	USEPA UVDGM
Test Point	UV-I set-point method	- either UV-I set-point method - or UV-I / UVT set-point method - or UV dose calculation method from UVI and UVT
Lamp aging	max. 70% (i.e. 30% ageing)	- not specified (lamp specifics have to be proven)
Inlet conditions	upstream with double DN600 bend ("worst case")	- not specified - hydraulic condition of installed UV reactor should be equal or better than validated UV reactor (typically validated with 90-degree elbow to simulate worst case)
UV Dose	RED 40 mJ/cm²	RED in relation to log credits
Operation points	Fixed	Variable
Interpolation – extrapolation	Not allowed	Interpolation allowed
Application	Compares performance of different reactors	Provides operation tools for different reactors
Disinfection focus	General disinfections. Suitable in all applications	Focused on Giardia and Crypto
Reactor validation	Experimental testing to determine the flow and UV transmission for a UV reactor at a RED of 40 mJ/cm²	Experimental testing to determine the operating conditions under which a UV reactor delivers the dose required for inactivation credit of Cryptosporidium, Giardia, and viruses
Test micro-organism	Bacillus subtilis	Typically male-specific-2 (MS2) bacteriophage

Some application guidelines:

- Use DVGW for smaller flow systems (<300 m³/hr)
- Use USEPA for *Giardia* and *Cryptosporidium* inactivation
- Use DVGW for general disinfection
- Use USEPA for multi-barrier protection in surface water
- Use DVGW for multi-barrier protection in ground water
- Due to target micro-organims and specific dose, USEPA validated systems allow higher flows

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