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as at 23/03/03
UV DISINFECTION OF DRINKING-WATER

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Introduction

In Europe, UV has been used for the bacteriological disinfection of water for a number of years. Some 350 drinking-water supplies in New Zealand currently use UV for disinfection but a significant proportion of these have failed to produce water that complies with the NZ bacteriological standards.

This demonstrates the need for guidance to water suppliers in the specification and operation of UV systems for drinking-water disinfection in New Zealand. In addition, many studies during the last few years have demonstrated the efficiency of properly designed and operated UV disinfection systems in inactivating the protozoa *Cryptosporidium* and *Giardia*, which offers a potential option for meeting the protozoa standards as well as the bacteriological ones.

Drinking-Water Standards for New Zealand 2000 section 13.1.2 requires that, where treatment does not include filtration but relies on disinfection, inactivation of protozoa by disinfectants must accomplish at least 99.9 percent inactivation of *Cryptosporidium* and *Giardia*.

It is therefore proposed to establish a standard for the use of UV for disinfection of drinking-water in New Zealand to supplement the Drinking-Water Standards for New Zealand 2000 and provide guidance on the use of UV for disinfection of drinking-water.

This draft standard is intended to apply to UV disinfection used in treatment plants servicing community supplies of over 500 people. It is not intended to be suitable for domestic drinking-water treatment appliances

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DRAFT PROPOSED UV DISINFECTION STANDARD

Proposed New Protozoa And *E. Coli* Inactivation Criteria For Drinking-Water Standards For New Zealand

The shaded section below shows the proposed new protozoa and *E. coli* inactivation compliance criteria that are proposed for insertion in the Drinking-Water Standards for New Zealand 2000:

Section 3.2.3.1 Protozoa compliance criteria a-d (for drinking-water leaving a treatment plant) where UV irradiation is the disinfection process.

(Also *E. coli* compliance criteria 1C)

The water to be treated in the disinfection appliance must have a per cent transmittance of at least 94% cm^{-1} at 253.7 nm [measured in a silica cell of at least 40mm pathlength]¹, of which the turbidity component shall be less than 1.0 NTU.

The appliance must be certified by the manufacturer to perform in accordance with the following specifications.

The UV irradiance in the appliance must be continuously measured by a sensor that is situated at the point at which the irradiance was measured during the bioassay used to validate the performance of the appliance. The sensor must be positioned at a position in the appliance remote from the lamp assembly that gives a reading that provides a representative estimate of the radiation levels in the appliance even in the event of variation or failure of the irradiance emitted by individual lamps.

All the water leaving the treatment plant must have passed through the UV disinfection appliance. It must have been subjected to at least that level of UV irradiance measured at the sensor which has been established by bioassay to correspond to a germicidal effectiveness equivalent to that resulting from a fluence [UV dose] of at least 400J/m^2 at 254.7 nm when the water has the maximum spectral attenuation [minimum percent transmittance] permitted by this standard and is passing through the appliance at the prevailing water flow rate.

The sensor used to monitor the UV irradiance level in the appliance must be appropriate for the purpose and calibrated to a traceable international standard.

Each procedure in the bioassay used to establish the disinfection efficiency of the appliance; the flow measuring equipment and the calibration of the sensor shall be carried out by a National Metrology Institute or by an agency accredited to ISO/IEC 17025 standards for the purpose.

¹ [This is equivalent to a path-length dependent transmittance at 253.7 nm of:
94% measured in a 10mm cell
76% measured in a 40mm cell
71% measured in a 50mm cell
50% measured in a 100mm cell]

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The shaded material below shows the proposed guideline specifications that are intended to assist suppliers in developing specifications for UV disinfection equipment intended for use in their treatment plant.

Manufacturer's certification of appliance

The manufacturer shall provide full certification of the compliance of the appliance with the requirements of this standard and the performance of the appliance in regard to the following aspects. This certification should be provided by a National Metrology Institute or by a certifier accredited for the purpose to ISO/IEC 17025 or 17020 standards.

The manufacturer shall certify that the performance of the disinfection appliance has been verified by bioassay to accomplish at least 2 log inactivation of UV-resistant *Bacillus subtilis* spores and of MS2 phage, at maximum water flow rate permitted for the appliance and at the minimum design operating irradiation as measured by the sensor.

The manufacturer shall provide performance curves demonstrating the relationship between the measured irradiance at the sensor and the water flow through the appliance over the range of 2.0 log inactivation to the highest log removal of the test organism(s) achievable by the appliance when the per cent transmittance of the water is no more than 94 cm^{-1} at 253.7 nm [measured in a silica cell of at least 40mm path length] and the turbidity at least 1 NTU.

[This is equivalent to a path-length dependent transmittance at 253.7 nm of
94% measured in a 10mm cell
76% measured in a 40mm cell
71% measured in a 50mm cell
50% measured in a 100mm cell]

An example of appropriate culture conditions for the preparation of the test organisms is given below, and the physiological condition of the test organism [biodosimeter] used for the bioassay must be shown to be such that it has a resistance to UV irradiance when that is at least equivalent to that illustrated in the inactivation curves below when the resistance of the culture of the bioassay test organism to inactivation by UV is assayed in a "collimated beam" UV susceptibility apparatus in accordance with the procedures given in:

James R. Bolton and Karl G. Linden; Standardization of Methods for Fluence (UV Dose) Determination in Bench-scale UV Experiments, *J. Environ. Engng.* 2002 (in press)

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Manufacturer's literature

The manufacturer shall supply:

- Fully detailed and illustrated manuals covering all aspects of operating and maintenance of the appliance.
- Full details of the biosimetric performance testing of the appliance.
- Flow and radiation dose curves corresponding to 2, 3 and 4 log inactivation of the specified test organisms, covering the designed water flow rate and UV irradiance operating range of the appliance.

The manufacturer must specify the uncertainty of accuracy of the installed system sensors including temperature and age dependent variations. This must be less than 10%.

Certified compliance with one of German DVGW Technical Standard W 294, Austrian Standard NORM M5873-1 or Austrian Standard NORM M5873-2 by an appropriately accredited inspection body will meet the requirements of this standard. The Ministry of Health may, from time to time, recognise other equivalent performance standards.

Sensor characteristics

The sensor must have a working range that covers the full range of irradiance encountered at the position at which the sensor is installed in the appliance.

The spectral selectivity of the sensor must be greater than 90 per cent over the range 240 – 290 nm.

The sensitivity of the sensor should not deviate by more than 5 per cent over a 5,000-hour working period

The acceptance angle of the sensor must be a uniform 30° measured in air.

The sensor must be positioned to monitor the middle section of the lamp assembly in such a way that the failure of a lamp will be detectable from the sensor output signal.

Commissioning checks

- The installer shall carry out tests to determine that the fail safe alarms, flow cut-off etc are functioning in accordance with the operating specifications for the unit, the sensor is correctly calibrated, and a certified reference sensor is available when needed for routine sensor calibration.
- The installer shall provide full documentation of the installation checks carried out and certify that these were satisfactorily passed.

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Operational checks

- Manufacturer's designated checks to be carried out as specified, including sensor calibration.
- Sensor to be checked [and if necessary recalibrated] annually by a certifier accredited for the purpose to ISO/IEC 17025 standards.
- Alarm system to be tested at least once every week.
- records of all performance checks, maintenance and occurrences to be kept up to date.
- Checks shall be carried out by an appropriately qualified operator.

[An appropriately qualified operator could be, for example, an operator who was certified by the manufacturer to be competent to carry out the necessary checks and maintenance on the appliance concerned. an operator accredited to ISO/IEC Guide 17025 for this purpose, or possibly with NZQA certification for the purpose.]

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“Guidelines” Information

The following is a first draft of information relating to suitable specifications for UV disinfection appliances to be developed for insertion in the Guidelines for Drinking-Water Quality Management for New Zealand. Additional information on the principles and terminology of UV disinfection will be incorporated as more information becomes available.

Construction

- All replaceable parts shall be readily accessible for maintenance and easily replaced.
- Materials used in the equipment must not cause the water to exceed the MAVs or Aesthetic Guideline values listed in Drinking-Water Standards for New Zealand 2000
- An automatic fixed flow rate control shall be provided to prevent flow above the maximum rated flow at the water supply plant operating pressure.
- The appliance control panel shall indicate:
 - Appliance on / off
 - Independent malfunction signal for each radiation installation
 - The irradiance in watts
 - The minimum irradiance alarm set point [established from bioassay data].
 - The operating hours of the UV lamps including the number of switching cycles
 - The flow rate
 - The maximum / minimum permitted flow rate.
- The system shall be provided with a visual means to check electrical operation of each lamp
- A fail safe visual and audible alarm shall be installed which provides warning to the treatment plant supervisor [off site in the case of a treatment system that is not supervised at all times] of irradiation intensity falling below the specified value or of any other malfunction of the appliance
- The instrument shall incorporate a 254nm selective sensor installed at the representative measuring position that was used to continuously measure the radiation dose during the biosimetric testing of the appliance
- The flow controller to the appliance shall be set up so that no flow occurs until the irradiation indicated by the sensor exceeds the minimum specified operating value.
- In the event of the sensor irradiance reading falling below the minimum specified operating value, or a power failure or malfunction occurring, the flow shall automatically shut down and the supply be diverted to an alternative treatment system.
- A means to bypass the sensor signal while exchanging the system sensor with the reference sensor shall be provided, in order to avoid plant shutdown. This device shall be protected against misuse

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Installation

The appliance shall be installed so that there is good access to all systems and components involved in maintenance and in performance testing, and no obstruction to the removal of any component involved.

Operating requirements

Irradiance can decrease as a lamp ages or becomes dirty.

Different UV appliances use different procedures for keeping the lamps clean to slow the rate at which the emissive power of the lamp deteriorates.

UV lamps are almost always enclosed in quartz sleeves to lower the temperature of the surfaces that are exposed to the water and, hence, diminish scale formation. The surfaces may be mechanically wiped, chemically cleaned, or may require manual cleaning.

The presence of calcium, magnesium or iron salts in the water can accelerate the fouling of the lamps due to scale deposition. Unless these are removed prior to irradiation effective lamp or sleeve cleaning will be required to maintain the required UV dose.

The effect of diminution of the irradiance emitted by the lamp because of fouling can be offset by using a sensor to measure the irradiation at a point in the unit distant from the lamp. This enables corrective action to be taken if the sensor reading drops below a predetermined level.

This will also at least partly compensate for diminution of irradiance due to light scattering or absorbance by substances in the water.

Measurement of the irradiance by a sensor may not compensate for the effects of turbidity because the pathogenic organisms may be hidden within the particles that give rise to the turbidity.

Because the disinfection efficiency will depend upon a number of characteristics whose effect on disinfection efficiency is hard to calculate, the NZ standard requires that the performance of each disinfection unit should be measured over a range of flows, measured irradiance and temperatures and calibrated using the unit's sensor.

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Bioassay of performance

1. Determination of the UV sensitivity of the biosimeters.

When testing UV inactivation appliances the micro-organisms used for bioassay must be tested to ensure that they exhibit an adequate resistance to UV irradiation. A dose-response curve carried out under standard conditions in a collimated beam UV irradiation apparatus must be prepared for each batch of micro-organisms before each test.

Check the irradiance with a radiometer that has been calibrated at 254nm by its manufacturer or the National Metrology Institute or by a uridine actinometer provided less than 2 percent of the total UV irradiance is in the spectral region below 260 nm.

Bacillus subtilis ATCC 6633 spores:

Inoculate 25 mL TSB in an Erlenmeyer flask with one colony of *B. subtilis* from a TSA plate. Incubate the broth culture in an Orbital Shaker at 37°C, 300 rpm for 48 h. Transfer the culture to a 50 mL polypropylene centrifuge tube and centrifuge at 10,000 x g for 10 min.

Wash the pellet with 5 mL 1 M KCl/0.5 M NaCl and centrifuge at 10,000 x g for 10 min. Resuspend the pellet in 2.5 mL 50 mM Tris-HCl (pH7.2) containing 1mg/mL lysozyme and incubate at 37°C for 60 min. Centrifuge the cells at 10,000 x g for 10 min. Aspirate the supernatant was aspirated and wash the spores by alternate centrifugation (10,000 x g for 10 min) and washing with 1 M NaCl, DI water, 0.05% SDS, Tris EDTA buffer (50 mM Tris-HCl, pH 7.2/10 mM EDTA) and three DI water washings.

Heat shock the spores at 80°C for 10 min, titer and store at 4°C.

Determination of the UV sensitivity of the spores.

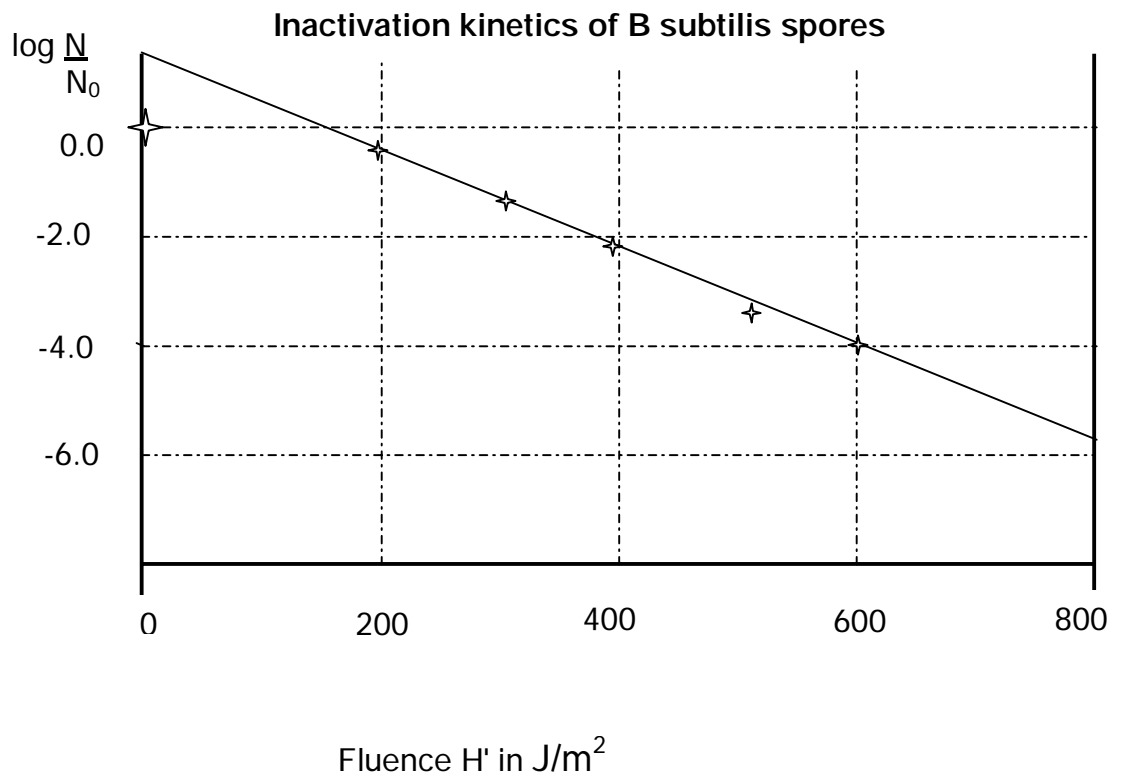
To check the UV sensitivity of the spores, irradiate in a collimated beam UV apparatus after diluting the *B. subtilis* spore stock with sterile DI water to the appropriate titer and transferring 15 mL of the spore suspension to a 60 x 15 mm Petri dish containing a sterile 1.2 cm stirrer bar. Place the Petri dish on a magnetic stirrer, stir, and expose the spores to the appropriate UV dose.

Irradiate two Petri dishes of spores at each UV dose in random order.

Perform serial dilutions each Petri dish and plate the spores that have been exposed to each UV dose level onto five TSA plates. Plot the inactivation curves.

Reference: Susceptibility of Multiple Strains of *Cryptosporidium parvum* Oocysts to UV Light, J.L. Clancy ¹, T.M. Hargy ¹, J.P. Durda ¹, D.G. Korich ², and M.M. Marshall, UV IUVA Conference

The similar procedure specified in DVGW W294 is also suitable. (DVGW W294 Appendix C)



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MS2 (MS) phage

Prepared in accordance with USEPA Method 1602 (proposed)

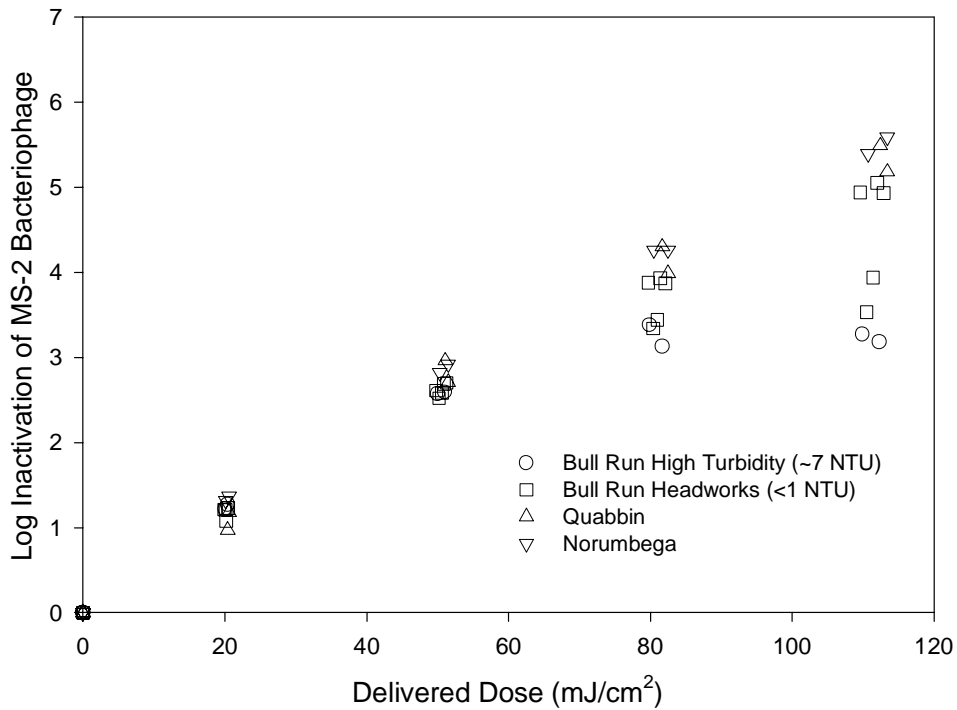
MS2 Bacteriophage ATCC 15597-B1: 100 mL Difco tryptic soy broth (TSB) is inoculated with 2 mL of an overnight culture of *E. coli* ATCC 15597. The culture is incubated in a Lab Line Environ Orbital Shaker at 37°C, 175 rpm for 4 h. MS2 phage (0.2 mL) is added and the culture incubated overnight at 37°C without shaking. After 16 h incubation, 40 mL of the culture is dispensed into a 50 mL polypropylene centrifuge tube and 2 mL chloroform added. Shake the tube by inverting five times and then centrifuging at 5000 x g for 10 min. Remove the supernatant, leaving behind the bacterial debris and the chloroform. Filter the supernatant through a sterile 0.45 µm filter, titer and store at 4°C.

Carry out the checks on UV sensitivity by diluting the MS2 stock to the appropriate titer with sterile DI water and transferring 15 mL of the MS2 suspension to a 60 x 15 mm Petri dish containing a sterile 1.2 cm stir bar. Stir on a magnetic stirrer, and expose the phage to the appropriate dose of UV in a collimated beam UV apparatus. Irradiate two Petri dishes at each UV dose level in random order.

Do serial dilutions from each Petri dish and plate the exposed phage from each dose level onto five tryptic soy agar (TSA) plates using the agar overlay method with *E. coli* ATCC 15597 as the host.

Ref: Susceptibility of Multiple Strains of *Cryptosporidium parvum* Oocysts to UV Light, J.L. Clancy ¹, T.M. Hargy ¹, J.P. Durda ¹, D.G. Korich ², and M.M. Marshall, UV IIVA Conference.

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Inactivation curve of MS2 phage

Passatino L B et al, Proc Universities Forum AWWA Ann Conf June 14-19, 2001 Washington, D.C.

2. Determination of the performance curves for a specific appliance

To follow.

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Rationale

The germicidal effectiveness of UV depends upon its wavelength (λ) and energy (W).

254nm is usually the most effective wavelength although microbicidal activity also occurs at other wavelengths.

The microbicidal effect of UV light at 254nm is due to photo-mediated reactions in the organisms, e.g. the dimerisation of pairwise arranged pyrimidine or other bases (thymine or cytosine in DNA and uracil or cytosine in RNA). Replication of the genome is blocked and cells are no longer capable of multiplying.

Re-growth of micro-organisms after UV disinfection can occur if the disinfected water stands in sunlight because, under these conditions, enzymes present in the cell can bring about some repair of the DNA. Thus, for acceptable UV disinfection it will be necessary to keep the water in the dark for at least 30min after irradiation or, better, follow UV disinfection by treatment with a persistent disinfectant such as chlorine. Regrowth can also be prevented by using a sufficiently high UV dose for disinfection. 40 mJ/cm² has been found sufficient to prevent photo regeneration¹

UV does not necessarily kill micro-organisms. At lower than the lethal dose it may inactivate them by damaging the DNA so that the organism can no longer reproduce. The inactivation dose and the germicidal wavelength may differ for different micro-organisms

The UV dose received by a micro-organism depends upon:

1. The irradiance emitted by the lamp(s) *
2. The extent to which UV is absorbed by the water and its contents [spectral absorption] *
3. The extent to which UV is scattered by particles in the water [related to turbidity] *
4. The flow rate of the water which affects the duration of the exposure of the organism *
5. The UV reflected from particles in the water and from appliance surfaces
6. The geometry of the UV irradiance cell

[Items marked with an asterisk * are amenable to routine monitoring].

Only four of the factors controlling the UV dose received by a micro-organism in a particular appliance lend themselves to being measured:

7. The irradiance emitted by the lamp(s)
8. The UV absorption of the water and its contents
9. The UV scattered by particles in the water
10. The flow rate of the water

The other factors are difficult to measure or compute.

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The UV dose [fluence] received by a micro-organism passing through a UV disinfection appliance is difficult to measure directly, or to compute, even though the irradiance is known because:

- a) The irradiance experienced by the micro-organisms is not the same as that emitted by the lamp because the irradiance from the lamp is both
- Augmented by light reflected from the appliance components and from suspended material in the water
 - Diminished by the absorbance of light by dissolved matter in the water and by the scattering of light by suspended particles.
- b) Micro-organisms taking different paths through the UV irradiation cell will receive different UV doses [fluences] because they will:
- be at different distances from the UV source
 - be exposed for different time periods
 - be subject to different amounts of reflected UV

For this reason the disinfection performance of the appliance is determined by bioassay using test organisms [biodosimeters].

An estimate of the irradiance experienced by organisms in the disinfection is obtained using a UV sensor positioned at a fixed place in the appliance, remote from the lamp(s). Curves of the log inactivation of the test organisms are obtained from measurements over the range of combinations of flow and UV lamp output that the appliance is certified for.

For lamps that have different spectral emission characteristics to the [almost] monochromatic low pressure lamps [e.g. medium pressure or pulsed lamps], the performance curves should be expressed as a ratio of the disinfection performance of the lamp to that of a low pressure lamp producing the same 254nm irradiance measured by the sensor.

MS2 phage and *Bacillus subtilis* spores are chosen as the test organisms because they are more resistant to UV than many of the pathogenic organisms of public health concern in drinking-water.

	UV dose [mW.s/cm ² = mJ/ cm ² =10J/ m ²]			
	3log	2log	1log	
<i>Bacillus megaterium</i> spores	52			a
<i>Bacillus subtilis</i> spores	58		12	a
<i>E. coli</i>	7-16			a
MS2 phage	60	40	20	c
MS2 phage			30	f
Rotavirus	24			a
<i>Cryptosporidium</i>	20, 40			d,e
<i>Giardia</i>	2			
<i>Campylobacteria</i>			1	c

a Wastewater depot

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- b Lenntech
- c Watercare Manukau
- d Water Res, **34**, (6) 1387-1398
- e Susceptibility of Multiple Strains of *Cryptosporidium parvum* Oocysts to UV Light: J.L. Clancy, T.M. Hargy, J.P. Durda, D.G. Korich, and M.M. Marshall, IUVA conference 2001
- f Comparative Inactivation of Norwalk Virus, Poliovirus 1, and Coliphage MS2 in Water by Low Pressure UV radiation: Sophie Newland, Gwy-Am Shin, and Mark D. Sobsey IUVA conference 2001