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# **Disinfection with UVC**

**General information, UV lamps and disinfection systems,  
UV measurement for UVC disinfection applications**

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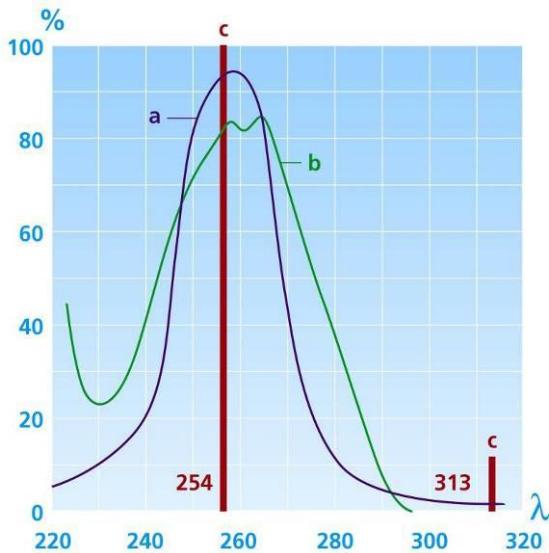


More informationen about UVC systems you can find [here](#).

## 1 General information

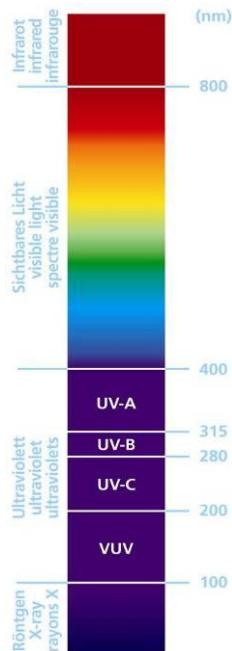
In 1877 the English scientists Thomas P. Blount and Arthur Downes found that micro organism reproduction is stopped if it is irradiated by sun light [1]. Further research show that this effect comes from the invisible part of sun light below 320 nm [2]. This means that by using artificial radiation, disinfection of bacteria must be possible too.

Today we know that this radiation has a strong germicidal effect and is provided by the short-wave band of ultraviolet spectra known as UVC, which effects the disinfection between 240 and 270 nm:



- a) Optimal germicidal effect between 250...270 nm
- b) Absorption curve of DNA
- c) The radiation of a UV low pressure lamp consists almost exclusively of a spectral line at 254 nm, which is close to the maximum of the germicidal effect.

Fig. 1: Germicidal effect of UVC



As with light or radio waves, uv radiation is an electro-magnetic wave radiation (photon radiation), which is only different in wavelength to the other stated radiations. UVC is the short wave part of the ultraviolet radiation spectrum that is not naturally occurring on the earth. So it must be produced artificially. UVC is the wavelength between 100 and 280 nm [3]. The shorter the wavelength the more energetic the radiation ( $E = h \times v$ ) <sup>1)</sup>.

It depends on the energy to differentiate if radiation is ionising or not ionising. If the energy is  $> 34$  eV ionisation occurs, which cannot be reached with UVC (approx. 4.9 eV).

As a source for UVC UV low pressure lamps and UV medium pressure lamps can be used.

Fig. 2: Electro-magnetic wave radiation, extract

<sup>1)</sup> Note:

h: Planck constant =  $6.6 \times 10^{-34}$  Js  
v: Frequency of the radiation in Hz

The fig.3 demonstrates how the DNA is damaged and the replication is suppressed [7].

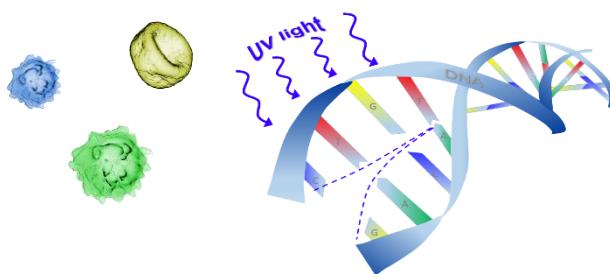


Fig. 3: UV-C Inactivating mechanism

By comparing the absorption curves of different substrates which are responsible for the cell structure the highest similarity is given by the deoxyribonucleic acid (DNA) a substance to be made up the chromosomes. With UVC radiation the DNA is modified and no further replication happens.

Fig. 3 shows a typical DNA absorption curve. The DNA has its maximum absorption close to 260 nm. At 300 nm the absorption falls to zero. Microorganisms are mostly sensitive to germicidal wavelengths around 260 nm.

Fig. 4 demonstrates how different micro organisms have different uv absorption rates. The reason for this is each micro organism has a different cell structure. With UVC radiation the DNA is modified and no further reproduction occurs.

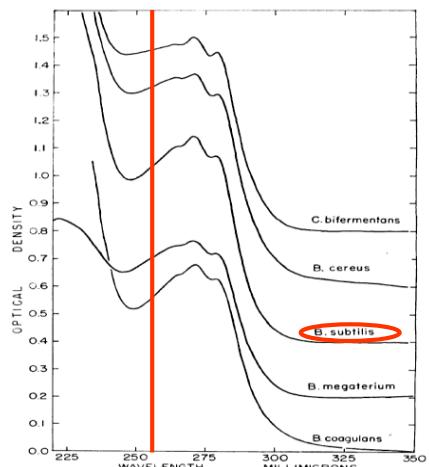


Fig. 4: Ultraviolet absorption of different dry bacteria spores (Source: Journal of Bacteriology, 1965)

## 2 Definition of disinfection and sterilisation

To clarify the definitions simply, disinfection means to remove or kill pathogenic micro organisms by using physical or chemical methods.

Sterilisation means to relieve a substrate of living or dead micro organisms.

Therefore the terminology disinfection should be used if there is a material which is contaminated with bacteria and which is treated by UVC. In colloquial terms both are used meaning the same.

Micro organisms are classified into:

- Bacteria
- Moulds
- Yeasts
- Viruses
- Spores

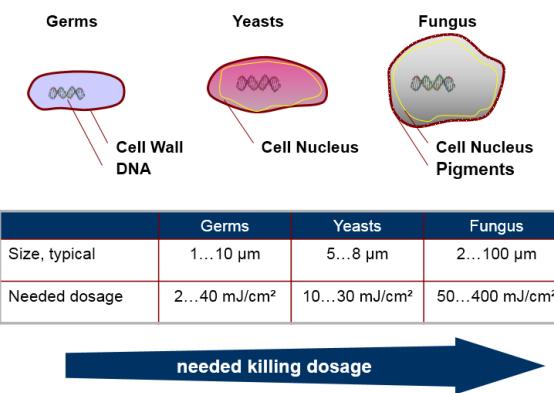


Fig. 5: Killing doses depending from type of germ, yeast or fungus

The effective resistance of many types of micro organisms to UVC varies considerably. It's important to know that the germicidal effect starts directly after the irradiation commences and is linear to the UVC dose. After this a plateau is reached (Fig. 6). As a guide to values please note the values in the attached tables.

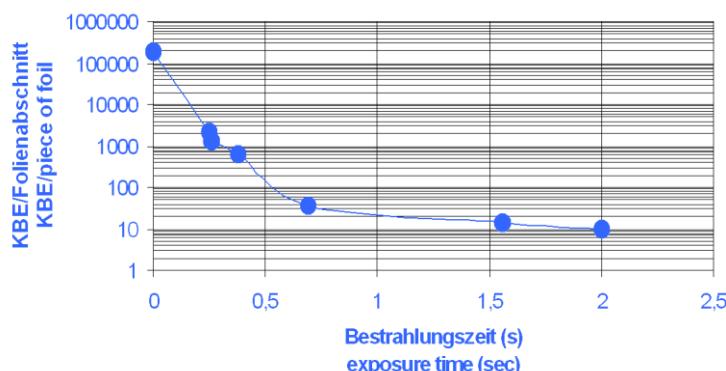


Fig. 6: UV disinfection of a polystyrol film with the disinfection kinetic of bacillus subtilis spores. The measurements have been conducted with the system **uv-ultimate** at the Fraunhofer Institut in Freising [6].

### 3 How to calculate the necessary UV dose

To calculate it's important to know the wave radiation units:

Name	Symbol	SI-Unit
Power of the radiation	P	W
Irradiance	E	W/cm²
Dose	H	J/cm² = Ws/cm²

The dose relates to the irradiance as shown in the formula:

$$H = E \cdot t$$

H: Dose in mJ/cm²  
E: Irradiance in mW/cm²  
t: Irradiation time

For the deactivation of micro organisms it is important to know that the irradiation time required is calculated from the dose H and the irradiance E. So it is possible to reach the same dose with a longer time t and lower irradiance and vice versa because the product of both is still the same. On the other hand the irradiation time can be changed only in a specific range. A too low irradiance can cause an increase of micro organisms at the start of the process. So the rate of disinfection would be slower than stated in this equation.

A big influence for the disinfection is additionally caused by:

- Increased humidity (typically it's calculated with 60% relative humidity).
- Decrease of uv output due to the lifetime of the uv lamp.  
(Depending on the type of the lamp between 20 and 35% after typically 8.000 hrs.)

## 4 Disinfection systems for diverse applications

### 4.1 Surface disinfection

The success of surface disinfection is dependent on the type of the material to be disinfected. This not only relates to the type of germ (e.g. bacterium coli and their stains) but also relates to the texture of the surface. Disinfection can only occur if the germs see the UVC. This means that the overall texture of the surface cannot be too coarse. If it is too coarse, micro-shadows can reduce the germicidal reaction. Germs which are in shadow will not be treated due to the limited exposure to UVC.

The irradiation time can be calculated by multiplying the necessary UVC dose (see attached tables), the distance of the uv lamp to the material and the irradiance in this distance:

$$t = H / E$$

H: Dose in mJ/cm<sup>2</sup>  
 E: Irradiance in mW/cm<sup>2</sup>

The length of the irradiated zone is:

$$L = v \times t$$

t: Irradiation time in s  
 v: Feed speed in m/min  
 L: Length of irradiation in mm

After calculation of the lengths of irradiation L , the number of uv lamps can be calculated. The space between the lamps should be around the same as the distance of the uv lamps to the contaminated material.

If the machine is operated in cyclical operation, which is typical for packaging material machines, several disinfection units should be mounted side by side and close together, if necessary. To determine the number of disinfection units the number of cycles (clock pulse per minute), the resulting cycle and the feed length (to be radiated length) must be considered:

It is::

$$t_i = 60s / x$$

x: Number of cycles (in a minute)  
 t: Cycle in s

It must be valid that:

$$t_i \leq B / AL$$

AL: Feed length per working tact in mm  
 B: Radiated width of the disinfection unit  
 in feed direction in mm

### Surface disinfection systems



Fig 7: System **uv-fresh** type SD to disinfect surfaces or conveyor belts. An additional reflector can increase the irradiance and can shield the radiation in the opposite direction.



Fig. 8: System **uv-ultimate** type LH 4. A special lamp shape achieves the world's highest UVC output with a uv low pressure lamp. Typical application: Filling lines for dairy products.

#### 4.2 Systems for direct irradiation (room disinfection)

Different systems with direct irradiation (room disinfection) are available:



Fig. 9: UV-DIRECT  
Direct UVC light for room disinfection



Fig. 10: UV-STICK E  
Disinfection of air in storage rooms and production rooms



Fig. 11: UV REFLEX-SC  
reducing the germ content  
in drying cells and cold-storage rooms



Fig. 12: UV-PIPE  
used in sales displays for perishable foods  
for disinfection of the ambient air to prevent cross-contamination

#### 4.3 Systems to store tools with UVC light



Fig. 13: UV-BOX  
Typical use: Germ-free  
storage of surgical instruments



Fig. 14: UV-CABINET: Storage of substances  
and e.g. medical instruments under  
UVC light



Further information about UVC systems you can find [here](#).

#### 4.4 Air disinfection

Micro organisms floating freely in room air are treated without fail by UVC radiation, whereas conventional means for disinfecting room air are often inadequate or unusable. Air disinfection leads to an appreciable reduction of the number of airborne organisms in a room, because the air is forced by natural convection into the irradiated region. So the danger of airborne infection, which is a factor in many illnesses, is considerably reduced. The lamps should be mounted and should radiate upwards. No person or livestock should be irradiated directly or indirectly by UVC (e.g. absorbing ceiling colour, adequate shielding...).

Alternatively it is possible to use circulation disinfection systems with integrated UVC lamps. The advantage is that the uv light is perfectly shielded.

The calculation for the needed irradiation and air flow depends on the room dimensions and the amount and type of germs. The dimensions of these parameters are calculated at uv-technik with years of experience.

#### Air disinfection systems



Fig. 15: PARROT Air disinfection in rooms smaller than 30 m<sup>2</sup>



Fig. 16 : UV FAN Air disinfection in rooms of 30 – 50m<sup>3</sup>



Fig. 17: UV UNIT Air disinfection for industrial of 2-3000m<sup>2</sup>

## 5 UV lamp types

This data sheet gives an overview of the different lamp types which are used for disinfection. For disinfection both uv low pressure lamps and uv medium pressure lamps can be used. Both types of lamps are produced at uv-technik.

UV low pressure lamps mainly emit radiation at 253.7 nm. This is the peak absorption area of Thymonuklein. This means that germs and bacteria are killed effectively.

All low pressure lamps for disinfection have a 4-pin connector. The electrodes of these lamps are spiral-wound filaments to ensure that the run-up time to reach optimal uv output is minimal (maximum 2 minutes).

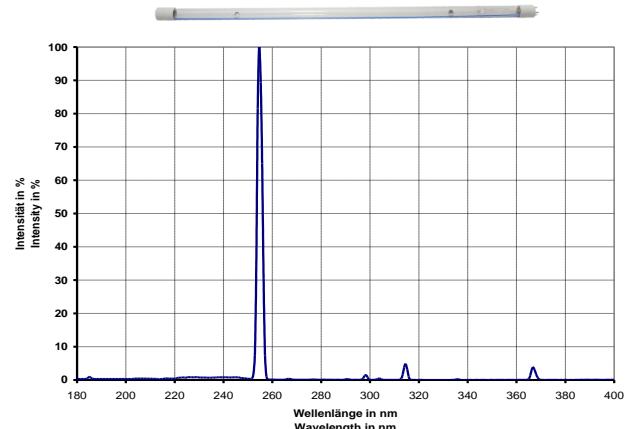
**TUV, UVN:** Standard-Types with a specific lamp power of approx. 0.6 W/cm.

**UVI, UVX:** High-output amalgam lamp with a specific power of 1.3 ... 1.7 W/cm depending on the size of the lamp.  
UVX lamps have an extra long lifetime by using special internal quartz glass tube coating.

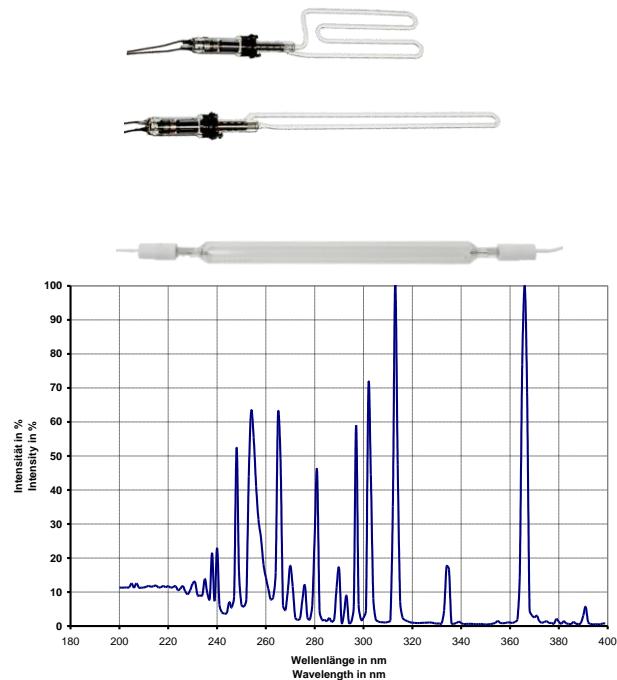
**XI, AC:** High-output Systec lamps with a usable specific power of 2.5 W/cm depending on the shape. The special shape and construction combined with accelerated cooling leads to the world's highest UVC output from a low pressure lamp for industrial applications.

UV medium pressure lamps have a higher internal pressure compared to low pressure lamps (1 to 10 bar instead of a number of mbar). Because of this uv medium pressure lamps emit not only at 254 nm but also at other wavelengths. The electrical power of uv medium pressure lamps is much higher than low pressure lamps that have the same lighting length.

**UVH:** UV medium pressure lamps. The typical specific lamp power is between 100...160 W/cm. Active air cooling is usually used as required. Because of the higher power level, warming up of the radiated surface under the uv medium pressure lamp is possible.



Spectrum uv low pressure lamp



uv spectrum medium pressure lamp

## Overview lamp types

Lamp type	TUV	UVN	UVI	UVX	UVH
Type	uv low pressure lamp	uv low pressure lamp	High-output amalgam lamp	High-output amalgam lamp	uv medium pressure lamp
Emitted wavelength @ UV-C in nm	253.7	253.7	253.7	253.7	200 - 280
Useful lifetime	8.000 hrs.	8.000 - 10.000 hrs.	8.000 - 10.000 hrs.	12.000 - 16.000 hrs.	ca. 3.000 hrs.
Guarantee lifetime	8.000 hrs. with EVG*	8.000 hrs. with EVG*	8.000 hrs. with EVG*	12.000 hrs. with EVG*	1.500 hrs.
Average drop in radiation	20% after 8.000 hrs.	35% after 8.000 hrs.	35% after 8.000 hrs.	25% after 10.000 hrs.	25% after 1.500 hrs.
Optimal quartz glass tube temperature in °C	30 – 35	30 – 50	100 – 120	100 - 120	700 – 900
Typical lighting length in mm	150 – 1120	150 – 900	234 – 1553	224 – 1553	50 – 2700
Possible lamp power in W	6 - 75	6 - 80	6 - 80	40 – 400	500 W - 40 kW
UV-C Output @ 254 nm	bis ca. 33 %	bis ca. 33 %	bis ca. 36 %	bis ca. 37 %	ca. 10%
Specific lamp power in W/cm	ca. 0,6	ca. 0,6	1,7	1,7	160 (typical)
System	Irradiance @ 254 nm in mW/cm² when using a disinfection system, approx. :**				
BD, SD	11	11	30	30	n.a.

\* : The guarantee lifetime refers to max. 3 switching cycles/day

\*\* : Measured with SI 1 with 20 mm distance

Note: Our lamps for disinfection applications do not produce ozone. This is achieved by using a special quartz glass that avoids radiation < 240 nm.

## 6 National regulations

National regulation varies worldwide. Disinfection with direct UVC light is not permitted in some countries. Please ensure that the national and local regulatory requirements are adhered, too.

## 7 UV measurement for UVC disinfection applications

To evaluate the effectiveness of UV disinfection, there are several options:

- Sampling / contact plate samples
- measurement of the UV-irradiation in a known correlation between the germ load

Samples are to ensure a continuous security usually taken at regular intervals and analyzed in the laboratory.

Due to physics, the radiation emitted by UVC lamps decreases with the lifetime. The easiest way to determine this is the regular measurement of UV radiation using capable uv measurement equipment.

There are two physical units that can be collected:

- i. The uv irradiance ("intensity" in mW/cm<sup>2</sup>, q.v. chapter 3), and/or
- ii. The uv radiation ("dose" in mJ/cm<sup>2</sup> )

The measurement of the irradiance (mW / cm<sup>2</sup> or W / m<sup>2</sup>) is done with a wired sensor type SI 1 for UV-C. The measured values can be read on handheld HI 1:



UV Sensor SI 1 for UV-C intensities



Handheld HI 1

If you want to measure the dose (mJ/cm<sup>2</sup>) the measurement time is multiplied with the intensity (q.v. chapter 3). Suitable for this purpose especially in continuous processes is the UV Disc:



UV Disc for uv dose measurements (in mJ/cm<sup>2</sup>)

To achieve correct results it's important to select the right measuring device. On the one hand the choice of the right wavelength range (UVC) on the other hand a suitable UV measurement range is important (means which intensities are expected in the desired distance). If you have any questions the uv-technik team will be happy to assist you.

## 8 Safety precautions

With constant irradiation the intensity on the skin must be limited to  $0.1 \mu\text{W}/\text{cm}^2$ . With an irradiation time of 8 hrs a day the max intensity must be limited to  $0.5 \mu\text{W}/\text{cm}^2$ .

According to Am. Conf. of Ind. Hygienist (ACGIH) we can summarise [4]:

Max. irradiances for the human skin		
Max. irradiance time each day	Permitted Irradiance in $\mu\text{W}/\text{cm}^2$ related to total uv	Permitted max. irradiance in $\mu\text{W}/\text{cm}^2$ @ 254 nm
8 Hours	0,1	0,2
10 Minutes	5	10
1 Second	30.000	60.000

## 9 Safety references for working with uv radiation

UV radiation can be hazardous. There are very simple and uncomplicated methods to protect people. We want to advise you on the following points:

1. UV radiation is dangerous to eyes and skin. People who are in the same room where uv lamps are used have to be protected against uv radiation.
2. By using standard sheet glass (Borosilikat, Duran, etc.), transparent plastic like Makrolon®, Plexiglas® and nearly all non transparent materials, UVC radiation can be shielded. To reduce the dazzle effect, pigmented material can be used.

Objects can change colour if they are in contact with uv. We recommend the use of uv resistant materials.

### Bibliography:

- [1] Downes A., and Blunt T. P., Researches on the Effect of Light upon Bacteria and Other Organisms, Proceedings of the Royal Society of Medicine, 26; 488, 1877.
- [2] Alex. Hollander, Abiotic and Sublethal Effects of Ultraviolet Radiation on Microorganism, Div. of Industrial Hygiene, Nat. Inst. of Health, Bethesda MD, 1942, S. 156 – 165.
- [3] DIN 5031, Teil 7
- [4] Threshold Limit Values for Chemical Substances and Physical Agents; Relative Spectral Effectiveness curve IEC 60335-2-59; Sensitivity curve
- [5] Philips Produkt-Information. Desinfektion mit UV-Strahlung – Strahlungsquellen, technische Hinweise, Anwendung. 1995
- [6] Joachim Wunderlich. Untersuchungen zur Optimierung der Entkeimung von Packstoffoberflächen durch UV-Bestrahlung. Fraunhofer Institut Verpackungstechnik und Verpackung, Freising, 1999
- [7] Dr. Ralf Kriehuber. Kurze Einführung in die Strahlenbiologie. 2001. [www.biologie.unirostock.de/abt/tierphys/KRI/RH-Strahlung.html](http://www.biologie.unirostock.de/abt/tierphys/KRI/RH-Strahlung.html)

Additionally we want to advise you to the following sources:

- DIN EN 62471 and Guideline 2006/25/EG
- P. Schreiber & G. Ott. Schutz vor ultravioletter Strahlung, 1984

The photos show an assortment of products of the uv-technik meyer gmbh.

**Appendix** UV-254 nm doses for 90% and 99,9% inactivation of different micro-organisms [5]

Microorganism	90% disinfection mWsec/cm <sup>2</sup>	99,9% disinfection mWsec/cm <sup>2</sup>	Microorganism	90% disinfection mWsec/cm <sup>2</sup>	99,9% disinfection mWsec/cm <sup>2</sup>
Bakterien, Viren			Proteus vulgaris	2,7	7,8
Bacterium coli (in air)	0,7	2,1	Pseudomonas aeruginosa	5,5	16,5
Bacterium coli (in water)	5,4	16,2	Pseudomonas fluorescens	3,5	10,5
Bacillus anthracis	4,5	13,7	S.typhimurium	8,0	24,0
S.enteritidis	4,0	12,0	Sarcina lutea	19,8	59,0
B.megatherium (veg.)	1,1	3,4	Serratia marcescens	2,5	7,2
B.megatherium sp.	2,8	8,0	Dysentery bacilli	2,2	6,6
B.paratyphosus	3,2	9,6	Shigella paradyenteriae	1,7	5,2
13,prodigiosus	0,7	2,1	Spirillum rubrum	4,4	13,0
B.pyocyanus	4,4	13,2	Staphylococcus albus	1,8-3,3	5,4-10,0
B.subtilis spores	12,0	36,0	Staphylococcus aureus	2,2-4,9	6,6-14,8
Cornynebacterium diphtheriae	3,4	10,0	Streptococcus hemolyticus	2,2	6,6
Eberthella typhosa	2,1	6,3	Streptococcus lactis	6,1	18,0
Escherichia coli	3,0	9,0	Streptococcus viridans	2,0	6,0
Legionella pneumophila	0,92	2,76	Bacillus tuberculii	10,0	30,0
Micrococcus candidus	6,3	19,0	Trichonomas	100,0	300,0
Micrococcus piltonensis	8,1	24,0	Poliovirus	3,2	9,6
Micrococcus sphaeroides	10,0	30,0	Infectus Hepatitis	5,8	17,4
Neisseria catarrhalis	4,4	13,0	Influenza	3,4	10,2
Phytomonas tumefaciens	4,4	13,0	Tobaco mosaic	240	720

Microorganism	90% disinfection rnWsec/cm <sup>2</sup>	99,9% disinfection mWsec/cm <sup>2</sup>	Microorganism	90% disinfection mWsec/cm <sup>2</sup>	99,9% disinfection mWsec/cm <sup>2</sup>
<b>Yeast</b>					
Backhefe	3,9	11,7	Aspergillus amstelodami (meat)	66,7	200,1
Brauhefe	3,3	9,9	Aspergillus flavus	60,0	180,0
gewöhnliche Backhefe	6,0	18,0	Aspergillus glaucus	44,0	132,0
Saccharomyces ellipsoideus	6,0	18,0	Aspergillus niger (bakery)	132,0	396,0
Saccharomyces spores	8,0	24,0	Cladosporium herbarum (cold store)	60,0	180,0
Saccharomyces cerevisiae	6,0	18,0	Mucur mucedol (meat, bread, cheese, fat)	65,0	195,0
Saccharomyces turpidans	9,0	27,0	Mucor rec.emodus A	17,0	51,0
Torula sphaerica (milk and cream)	2,3	6,9	Mucor racemodus B	17,0	51,0
<b>Algae</b>					
Diatomeen (diatom)	360-600	1080,0-1800,0	Oospora lactis	5,0	15,0
Grüne Algen	360-600	1080,0-1800,0	Penicillium digitatum	44,0	132,0
Blaue Algen	360-600	1080,0-1800,0	Penecillium expansum	13,0	39,0
			Penicillium chrysogenum (fruits)	50,0	150,0
<b>Protozoen</b>					
Paramecium	64-100	192-300	Penicillium roqueforti	13,0	39,0
			Rhizopus nigricans (bread)	111,0	333,0
			Scopulariopsis brevicaulis (cheese etc.)	80,0	240,0