Dipl.-Ing. Andreas Renzel

Disinfection with UVC

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

Content:

1 General information 2

2 Definition of disinfection and sterilisation 3

3 How to calculate the necessary UV dose 4

4 Disinfection systems for diverse applications 5

4.1 Surface disinfection / surface disinfection systems 5

4.2 Systems for direct irradiation (room disinfection) 6

4.3 Systems to store tools with UVC light 6

4.4 Air disinfection / air disinfection systems 7

5 UV lamp types / overview 8

6 National regulations 9

7 UV measurement for UVC disinfection applications 10

8 Safety precautions 11

9 Safety references for working with uv radiation 11

Appendix UV-254 nm doses for 90% and 99,9% inactivation of Different micro-organisms 13

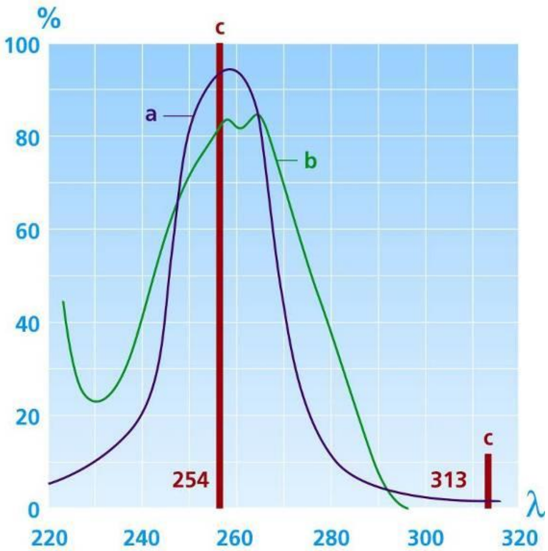
More information about UVC systems you can find here.

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

1 General information

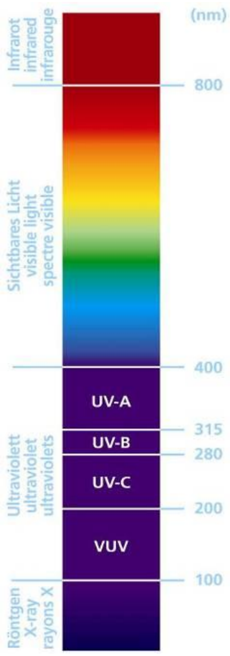
In 1877 the English scientists Thomas P. Blount and Arthur Downes found that micro organism reproduction is stopped if it is irradiated by sun light [1]. Further research show that this effect comes from the invisible part of sun light below 320 nm [2]. This means that by using artificial radiation, 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 ($E = h \times \nu$) [1)].

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

[1)] Note: h: Planck constant = 6.6×10^{-34} Js
ν: Frequency of the radiation in Hz

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

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

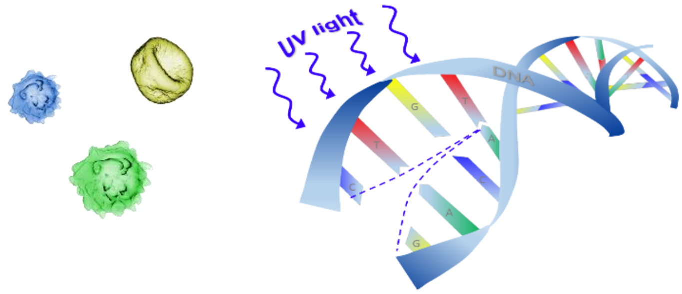


Fig. 3: UV-C Inactivating mechanism

By comparing the absorption curves of different substrates which are responsible for the cell structure the highest similarity is given by the desoxyribonucleis acid (DNA) a substance to be made up the chomosomes. 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.

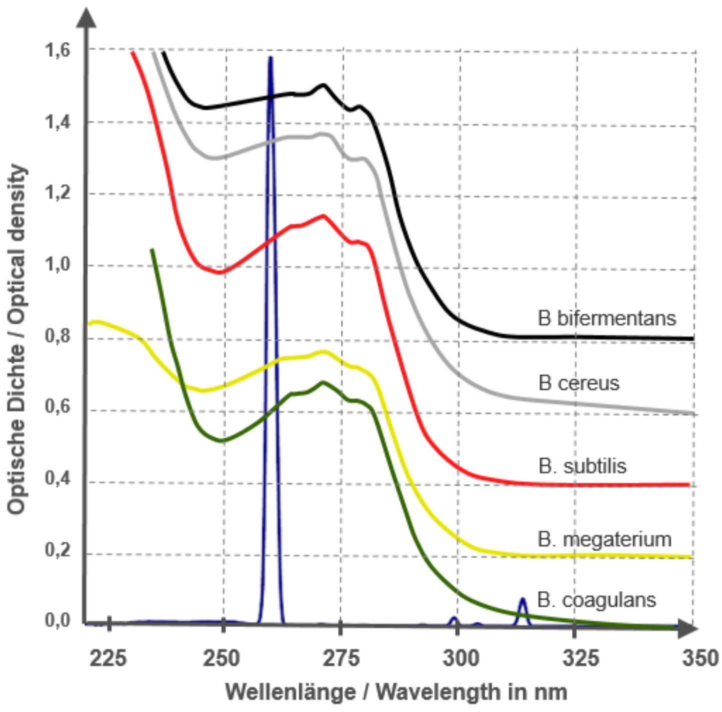


Fig. 4: Ultraviolet absorption of different dry bacteria spores and the 254 nm line of a UV low-pressure lamp; acc. to [8]

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.

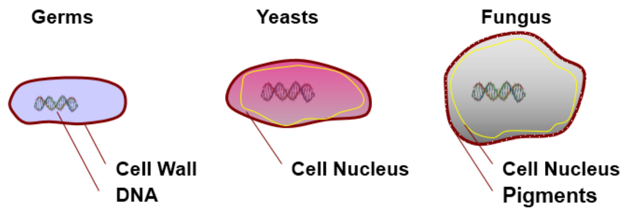
Sterilisation means to relieve a substrate of living or dead micro organisms.

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

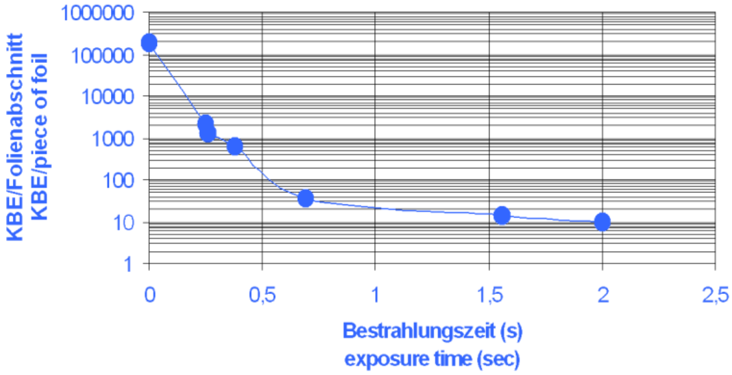
The effective resistance of many types of micro organisms to UVC varies considerably.



	Germs	Yeasts	Fungus
Size, typical	1…10 µm	5…8 µm	2…100 µm
Needed dosage	2…40 mJ/cm²	10…30 mJ/cm²	50…400 mJ/cm²

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

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.



Fraunhofer Institut Verfahrenstechnik und Verpackung

Fig. 6: UV disinfection of a polystyrol film with the disinfection kinetic of bacillus subtilis spores. The measurements have been made at the Fraunhofer Institut in Freising [6].

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

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 ralates to the irradiance as shown in the formula:

$$\mathbf{H = E \cdot t}$$

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/cm²
E: Irradiance in mW/cm²

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.

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

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::

$t_l = 60s / x$

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

It must be valid that:

$t_l \leq B / AL$

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: UV PIPE-NX and UV PIPE-BV

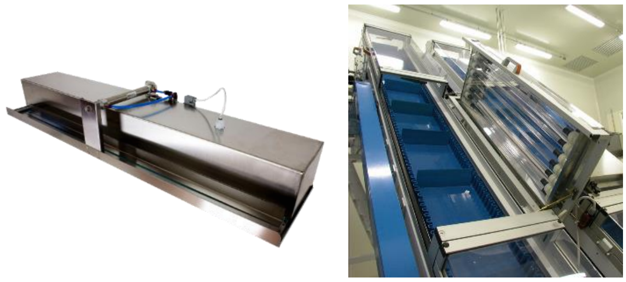


Fig. 8: UV-TEAM and UV-TEAM mounted on belt system (right picture)

4.2 Systems for direct irradiation (room disinfection)

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

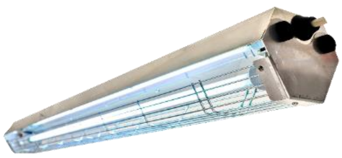


Fig. 9: UV-DIRECT
Direct UVC light for room disinfection

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

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

4.3 Systems to store tools with UVC light

Fig. 13: UV-BOX E2/40H
For disinfection and sterile
Storage of medical
Instruments, tools for
laboratories

Fig. 14: UV-BOX:
Typical use: Germ free
storage of surgical instruments

Fig. 15: UV-CABINET
Storage of substancesn
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 and systems for HVAC applications (Heating, Ventilation and Air Conditioning)

Fig. 16: UV FAN Air disinfection
in rooms of 30 – 50m³

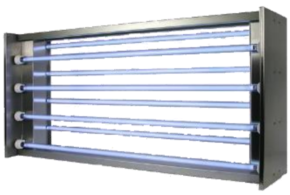


Fig. 17:UV-DUCT for HVAC
installations

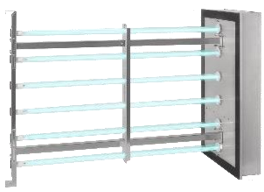


Fig. 17: UV-RACK for cross-
insertion in HVAC systems

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

5 UV lamp types

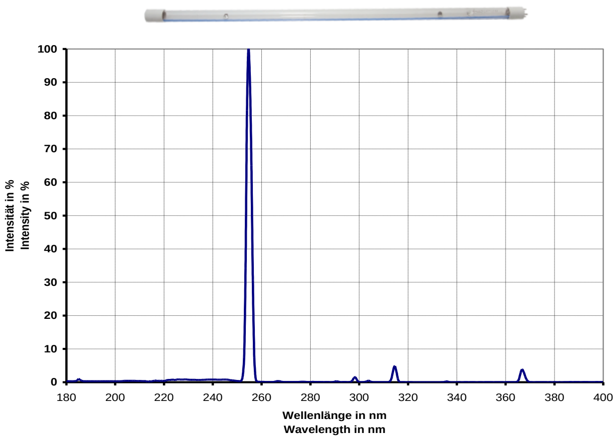
This data sheet gives an overview of the different lamp types which are used for disinfection. For disinfection both uv low pressure lamps and uv medium pressure lamps can be used. Both types of lamps are produced at uv-technik.

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-wounded 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.

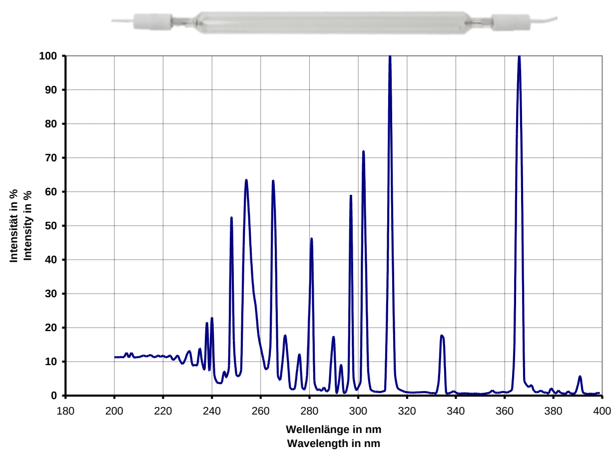
UVI, UVX: High-output amalgam lamp with a specific power of 1.3 …1.7 W/cm depending on the size of the lamp.
UVX lamps have an extra long lifetime by using special internal quartz glass tube coating.



Spectrum uv low pressure lamp

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 medium pressure lamp

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

Overview lamp types

Lamp type	uv-fresh®				
	TUV and 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	up to approx. 33 %	up to approx. 33 %	up to approx. 36 %	up to approx. 37 %	approx. 10%
Specific lamp power in W/cm	ca. 0,6	ca. 0,6	1,7	1,7	160 (typical)
Typical irradiances @ 254 nm in mW/cm² when using a disinfection system, approx.:**					
	11	11	30	30	n.a.

* : The guarantee lifetime refers to max. 3 switching cycles/day
** : Measured with SI 1 at 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.

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

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/cm², q.v. chapter 3), and/or
ii. The uv radiation ("dose" in mJ/cm²)

The measurement of the irradiance (mW / cm ² or W / m²) 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/cm²) 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/cm²)

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.

Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

8 Safety precautions

The American Conference of Governmental Industrial Hygienists (ACGIH) has identified UV values that should not be exceeded [4]. These are also adopted in the ICNIRP guidelines (International Commission on Non-Ionizing Radiation Protection, [9]). It is taken into account that the maximum permissible UV irradiation intensity and dose to the eyes and skin varies at different wavelengths. The greatest sensitivity is where the DNA is strongest damaged, i.e. at about 270 nm (see chapter 1 of this script).

The calculation of the maximum UV irradiance and dose of UV radiation sources with different wavelengths is corrected with a weighting function S(λ). For these sources, higher irradiances E_e ("UV intensity") and irradiantions H_e (doses) are permitted.

The ultraviolet radiation exposure in the entire UV range (the vacuum UV should not be taken into account here, since wavelengths from this range are absorbed in air anyway), i.e. in the wavelength range 180 to 400 nm, should not exceed an irradiation (dose) H_e (8 hrs) of 30 J/m² (=3 mJ/cm²).

It applies to the wavelength range between 210 and 270 nm according to [10]:

$$210 \leq \lambda \leq 270 \text{ nm: } S(\lambda) = 0{,}959^{(270 - \lambda)}$$

At a wavelength of 253.6 nm the result for the correction factor S is ≅ 0.5.

During an eight-hour UV irradiation, the intensity on the skin must not exceed a constant value of

$$E_{e,\ \lambda \cong 270 \text{ nm}} = H_e / t = 3 \text{ mJ/cm}^2 \times 28{,}800 \text{ s} = 1.04 \text{ µW/cm}^2$$

For shorter irradiation times, the permissible irradiance levels are correspondingly higher. According to Am. Conf. of Ind. Hygienist (ACGIH) it can be summarized [4]:

Max. irradiances for the human skin		
Max. irradiance time each day	Permitted Irradiance in µW/cm² related to total uv	Permitted max. irradiance in µW/cm² @ 254 nm
8 Hours	0,1	0,2
10 Minutes	5	10
1 Second	3.000	6.000

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.

UV Safety Visor
A003574

UV Safety Goggle
A008126

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

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 Sublethol Effects of Ultarviolett Radiation on Microorganism, Div. of Industrial Hygiene, Nat. Inst. of Health, Bethesda MD, 1942, S. 156 – 165.
[3] CIE (Commission Internationale de l'Eclairage; International Commission on Illumination)
[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.uni-rostock.de/abt/tierphys/KRI/RH-Strahlung.html
[8] Glen F. Bailey, Saima Karp, L. E. Sacks. 1965. Ultraviolet-Absorption Spectra of Dry Bacterial Spores. Journal of Bacteriology, Vol.89 No.4: 986
[9] International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines on limits of exposure to ultraviolet radiation of wavelengths between 180 nm and 400 nm (incoherent optical radiation); HEALTH PHYSICS 87(2):171-186. 2004
[10] Wester U. Analytic expressions to represent the hazard ultraviolet action spectrum of ICNIRP and ACGIH. Radiat Protect Dosim 91:231–232. 2000

Additionally we want to advise you to the following sources:

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

The photos show an assortment of products of the uv-technik meyer gmbh.
uv-fresh® is a registered trademark of uv-technik meyer gmbh.

Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com

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

Microorganism	90% disinfection rnWsec/cm²	99,9% disinfection mWsec/cm²	Microorganism	90% disinfection mWsec/cm²	99,9% disinfection mWsec/cm²
Bacterien, 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.tyyphimurium	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 paradysenteriae	1,7	5,2
13,prodiglosus	0,7	2,1	Spirillum rubrurn	4,4	13,0
B.pyocyaneus	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 diphteriae	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	Baccillus tuberculi	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 catarrhalls	4,4	13,0	Influenza	3,4	10,2
Phytomonas tumefaciens	4,4	13,0	Tobaco mosaic	240	720

Microorganism	90% disinfection rnWsec/cm²	99,9% disinfection mWsec/cm²	Microorganism	90% disinfection mWsec/cm²	99,9% disinfection mWsec/cm²
Yeasts			**Moulds fungus**		
Backhefe	3,9	11,7	Aspergillus amstelodami (meat)	66,7	200,1
Brauhefe	3,3	9,9	Aspegillus 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 cerevisae	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
Algae			Oospara lactis	5,0	15,0
Diatomeen (diatom)	360-600	1080,0-1800,0	Penicillium digitatum	44,0	132,0
Grüne Algen	360-600	1080,0-1800,0	Penecillium expansum	13,0	39,0
Blaue Algen	360-600	1080,0-1800,0	Penicillium chrysogenum (fruits)	50,0	150,0
Protozoen			Penicillium roqueforti	13,0	39,0
Paramecium	64-100	192-300	Rhizopus nigricans (bread)	111,0	333,0
			Scopulariopsis brevicaulis (cheese etc.)	80,0	240,0

uv-technik meyer gmbh
Glauburgstraße 34 | D-63683 Ortenberg
welcome@uv-technik.com | www.uv-technik.com