1. Effects of ultraviolet radiation

Electromagnetic radiation with a wavelength of 10...400nm is called ultraviolet (UV) radiation. Due to practical reasons the UV spectrum is divided into three sub areas:

- UV-A (long wave; Europe: 400nm-315nm)
- UV-B (medium wave; Europe: 315nm-218nm)
- UV-C (short wave; Europe: 280nm-100nm and beyond)

UV-A radiation is also part of sunlight that comes down to earth's surface. It causes different actinic processes, has a noticeable pigment effect, but does practically not cause erythema.

UV-B radiation causes pigment effect and erythema and it forms previtamin D. In most cases this radiation is used for therapeutic purposes.

Short wave (UV-C) radiation has a strong germ-killing effect. It causes erythema and ophthalmitis (pink eye). This radiation can be generated by low-pressure mercury discharge. The nature and the effects of this radiation and the application are described in the following chapters. UV radiation with a wavelength shorter than 200nm is called vacuum UV.

Usually three different kinds of quartz glass or glass are used to manufacture low-pressure lamps:

- non-ozone generating
- ozone generating
- synthetic (strong ozone generating)

The UV transmission of particular quartz glass or glass depends on tube thickness and manufacturer.

1.1. Ozone generation

UV radiation with wavelength <240nm generates ozone (O_3) out of air. Ozone has a strong oxidizing effect and causes a keen smell. In most cases the generation of ozone is unwanted. It changes the taste of different fat containing food (butter, milk). For some application it is required (such as whirlpool bath).

UV-C radiation transfers molecular oxygen into ozone (O_3) via photolysis. Ozone is generated, if the tube of the lamp is transparent for UV radiation with a wavelength <200nm. Splitted O_2 molecules interact with nitrogen (N_2) as a part of air and form nitrogen oxides. Though ozone is a colorless and odorless gas, the typical ozone smell comes from the resulting nitrogen oxides and byproducts, if the splitted oxygen reacts with impurities of surrounding air. Even relatively small concentrations of ozone can cause dry nose, burning throat, headache, sickness and mucous membrane irritation. There is no simple way to predict the ozone concentration and the resulting effects on a human body. If an ozone generating lamp is operated in a small room, high ozone concentration may be measured. If the same lamp is operated in well ventilated lab, there may be no problem.

Recommended maximum concentration values are:

- 0.1ppm at 8h exposure (is equivalent to 0.22mg O_3/m³ air)
- 2ppm at 2h exposure

Generally, the operation of ozone generating equipment at workplace is prohibited!

At an ozone concentration of 0.3-0.5ppm first symptoms may occur. People with very sensitive noses may be able to detect ozone concentration down to 0.015ppm. 1ppm makes off odors. As a rule of thumb, ozone concentration is too high, if someone smells it.

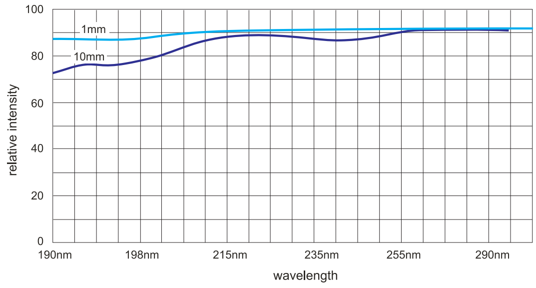


fig.C1
typical transmission characteristic of quartz glass

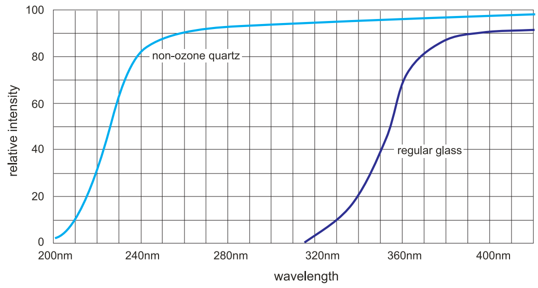


fig. C2
transmission characteristics of non-ozone quartz and regular glass

1.2. Safety measures for operation of UV lamps

If non ozone generating UV-C lamps are used, skin and eye protection is required. In many cases it can not be avoided to exposure humans to this radiation. High intensity UV radiation can harm eyes cornea, lens and retina. Unfortunately harmed eyes show effects like strong lacrimation or the feeling some foreign body scratches in the eye just afterwards. Consult an eye specialist, if any of these symptoms occur. UV-C radiation can also cause sunburn. Usually this sunburn disappears after 1-2 days. The penetration depth of UV-C radiation is relatively low. Only top layer of human skin is affected. Clinical tests could not find a correlation between continuous UV-C radiation and skin cancer.

The American Medical Association has defined limits for permissible intensities for
UV-C radiation (253.7nm) that will not have unhealthy effects:

- For continuous exposure of human skin to UV radiation the intensity should not exceed 0.1 µW/cm². For a daily exposure time of 7 hours the intensity should not exceed 0.5µW/cm².

UV radiation can be reduced, if the room is painted with UV absorbing paint. Disinfection systems, that continuous process materials or items should be completely shielded.

Recommendations:

- turn off unused UV sources
- never look into a UV source directly without any face protection. Use at least safety goggles to protect your eyes
- do not look into reflected UV radiation that comes from a metal mirror or polished metal surfaces
- while working next to an UV source, always wear safety goggles and gloves

max. daily exposure time	max. permissible irradiation intensity [µW/cm²]	max. permissible irradiation intensity of UVC-Source [µW/cm²] (254nm)
8h	0.1	0.2
2h	0.4	0.8
0.5h	1.7	3.4
10min	5	10
1min	50	100
0,1s	3000	6000
1s	30000	60000

table C1
Reference - Threshold Limited Values for Chemical Substances and Physical Agents (ACGIH); Relative Spectral Effectiveness curve IEC 60335 - 2 - 59; sensitivity curve

1.3. Explanation of physical values

parameter	symbol	SI-unit
radiated power	P	W
irradiation intensity	E	W/m²
specific irradiation (dose)	D	Ws/m²

table C2

C1.4. Information on different types of low pressure lamps

In general there are four different types of low pressure lamps on the market at present time as summarized in the following table:

	low pressure	low pressure - HO	amalgam	amalgam - enhanced
lamp power	40W	80W	120W	140W
opt. temperature at tube surface	40°C	80°C	100°C	approx. 120°C
specific UV flux	0.5W/cm	1W/cm	1.5W/cm	1,8W/cm

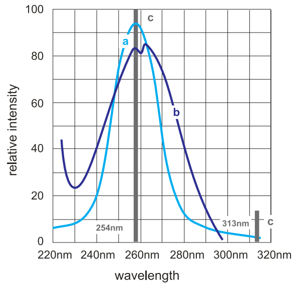
table C3
Comparison of different types of low pressure lamps with 15mm tube diameter and 850mm lamp length (dimensions identical to G36T5L)

Pure mercury (Hg) low pressure lamps are more dependant on ambient temperature than amalgam lamps. By adding amalgam the Hg vapor pressure is reduced.
The lamps mentioned above will reach their optimal UV efficiency at the listed tube surface temperatures. The operator has to make sure that this temperature is kept within tight limits. If the lamp is cooled down locally (e.g. by local air beam) mercury may condense and cause early failure. Please refer also to the information on dimmable ballasts.

2. Antibacterial effect

Downes and Blount discovered, that microorganisms do not multiply if exposed to sunlight long enough. A later conducted study came to the result, that the maximum bacterial-killing effect happens at a wavelength of 250-270nm. Probably is this caused by an actinic effect. Short-wave UV radiation is absorbed in some kind of substance that is present in a bacteria and causes a chemical reaction. From all substances that can be found in cells the absorption curve of deoxyribonucleic acid matches the above found wavelength range. Deoxyribonucleic acid is part of the cells chromosomes. UV radiation alters the chromosomes and blocks cell division and as a result reproduction will be interrupted. For protozoals like bacteria this is a deadly effect.

Different microorganism have different resistivity against UV radiation. The following information may be suited to establish a better understanding about the nature and characteristics of microorganism.



(a) the best effect is measured at a wavelength of 250 - 270nm
(b) absorption curve of deoxyribonucleid acid
(c) primary radiation of mercury (Hg) low pressure discharge

fig. C3
coherence between wavelength and bacterial killing rate

2.1. Bacteria

Bacteria are a large group of single-celled herbal creatures that multiply themselves by cell division. Diseases, fermentation and sepsis are caused by bacteria.
Basic shapes of a bacterial cell are:

- spherical (coccus)
- rod shaped (bacillus and bacteria in the narrow sense of the word)
- spiral shaped (vibrio, spirillum or spirochete)

The absorption curve for killing rate matches curve b of fig. C3. The dose rates may differ by multiple magnitudes, depending on the kind of bacteria.

In worst case many bacteria form resistant resting spores (this spore-forming bacteria are called bacilli). Under favorable environmental conditions spore form a new bacteria cell. In general, spores are more resistant against UV radiation and high temperatures than bacteria. Due to that reason the dose rate should be selected 10 times larger.

2.2. Mold

This is a group of microorganism that multiply by spores. Mold forms cotton like, felted and powder like coating layers on animal and crop products and cause rottenness. In some cases it causes diseases. Some kind of mold are:

- mucor (mostly found on fruit and bread)
- aspergillus on wet plants, fruits, bred and leather
- penicillium, grape rot and fruit rot
- gray mold (botrytis cinera), fruit rot, especially at strawberries and half ripe grapes

Other kinds of mold are used to make antibiotics, such as penicillin and streptomycin.
Mold (and yeast) is activated at low UV doses. Higher doses have a destructive effect. The spectral dependency is alike those of bacteria. Spores are more resistant than the vegetative forms.

2.3. Yeasts

Yeasts are single cell plant like microorganism (saccharmyces and other genera of ascomycota). Yeasts do not contain chlorophyll and are different from mold because of different kind of reproduction. Like some bacteria, yeasts can form spores. There are many technical application for yeasts. Brewer's yeast (top and bottom fermentation yeast), baker's yeast, wine yeast and nutritional yeast (dried yeast). Yeasts show the same behavior like mold if exposed to UV radiation. In most cases UV radiation is used to kill so called wild yeast.

2.4. Algae

Algae are a group of cryptogams.There are known 8000 living species ranging from unicellular to multicellular forms. Some important groups are:

- blue-green algae
- diatom
- green, brown and red algae

Since algae contain chlorophyll and sometimes other colorants they can support themselves by assimilation. It is noticeable, that the necessary dose for some algae differ from those of bacteria by a couple of magnitudes.

2.5. Viruses

The nature of viruses as a group of microorganism is widely not known. They are all disease causing for humans, animals and plants. Viruses are too small to be blocked by bacteria blocking filters. Only by use of an electron microscope algae can be observed. Viruses can only survive and multiply in living substances. Even viruses can be killed by exposure to UV radiation with a wavelength of 253.7nm. For some kind of virus the UV dose is known to kill them but for the majority only general information are available. There are differences in resistivity, compared to other microorganism. The killing rate has a none-linear relationship to UV dose. As can be seen in fig. C4 there is no threshold value to kill bacteria, but just a small dose can kill bacteria randomly. On the other hand there is no level of UV dose known that kills absolutely all bacteria. Some random selected bacteria will always survive.

The statement, that the level of disinfection is proportional to the product of irradiation intensity (E) and exposure time (t) may not be valid for a wide range of E and t. For a large time (t) and low irradiation intensity (E) the microorganism will be able to reproduce themselves with a high rate at the beginning, resulting in lower disinfection level.

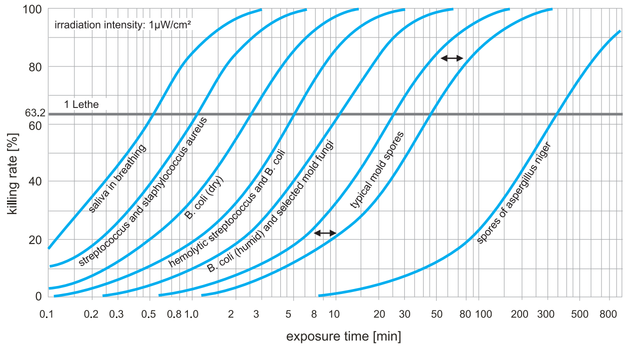


fig. C4
killing rate of various important microorganism vs. exposure time (irradiation intensity: 1µW/cm²)

The environment has a considerable influence on the level of disinfection, e.g.: coli are 10 times more resistant in water, compared to air. Even higher air humidity may considerably decrease the disinfection level.