NOVATRON INC

WHITE PAPER

ADVANCED UV SYSTEM (AUVS) TECHNOLOGY

Background

Ultraviolet (UV) radiation has been used to kill microorganisms in air since about 1900. Early applications included, for example, placing UV germicidal lamps near the ceiling in hospital rooms to help control and reduce the spread of airborne microorganisms such as *Mycobacterium tuberculosis* (TB) and other pathogenic organisms. Because of the low UV output of the lamps used and the fact that the UV intensity produced by a UV lamp decreases very rapidly as the distance from the lamp increases, these devices were not very effective. This approach essentially relied upon natural convective air circulation within the room to bring air containing microorganisms into proximity with the lamp where sufficient UV radiation was present to cause at least some weak germicidal effects.

In general, UV energy causes germicidal effects by interacting with the DNA of microorganisms and creating thymine dimers within the DNA strands. This disruption of the DNA prevents the organism from functioning and reproducing. Although some damage can also occur to proteins in the cell walls and cellular material, the primary germicidal effects are believe to be due to disruptive changes in the DNA.

Ultraviolet radiation consists of the portion of the electromagnetic spectrum with wavelengths shorter than those of ordinary light visible to the human eye, but longer than those of x rays. In general, UV wavelengths span the range of about 100 nm to 400 nm. (One nanometer (nm) is 10^{-9} meters, or one-billionth of a meter.)

UV Germicidal Effects

The most effective UV wavelengths for inactivation of microorganisms are in the 220 to 300 nm range, with peak effectiveness near 265 nm. The portion of the UV spectrum between 100 and 280 nm is often referred to as UVC. Hence, the term UVC is sometimes used in discussions of UV germicidal effects. Figure 1 shows a plot of effectiveness of UV for inactivation of microorganisms as a function of wavelength.

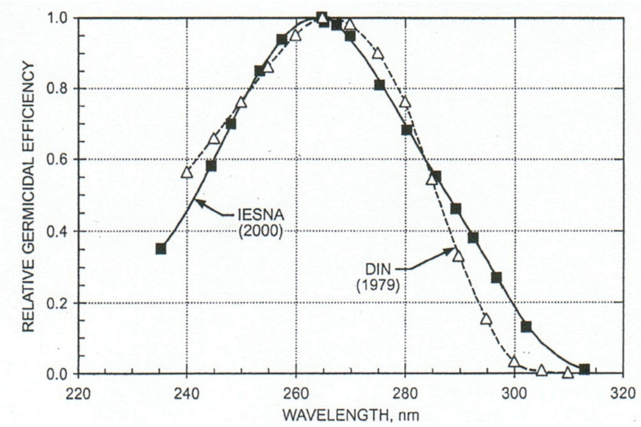

Figure 1: Relative Germicidal Efficiency – From 2008 ASHRAE Handbook – HVAC Systems and Equipment, Chapter 16, p.16.1.

The amount of UV energy required for kill of microorganisms varies from one organism to another. The UV energy is typically measured in units of microwatt–seconds/cm^2 (μW-S/cm^2), which is equivalent to microjoules/cm^2. This is a measure of the UV energy density per unit area incident on the microorganism. UV power density is typically measured in μWatts/cm^2 and is known as UV flux or irradiance. The energy density, which is the product of the UV irradiance and the exposure time in seconds, is sometimes referred to as the UV dose. Table 1 shows the energy density required for one log kill of some selected microorganisms.

Table 1: UV energy density at 253.7 nm required for 1 log kill of selected microorganism.

Organism	Type	Reference	Test Medium	D-Value (90% Kill) (micro Watt-Sec/cm2)
Bacillus subtilis	**Bacterial spores**	**Novatron, 2003**	**Plates, Air**	**25000**
Bacillis anthracis	**Mixed spores**	**Sharp, 1939**	**Plates**	**4517**
Influenza A	**Virus**	**Jensen, 1964**	**Air**	**1937**
Vaccinia	**Virus**	**Jensen, 1964**	**Air**	**1505**
Mycobacterium tuberculosis	**Mycobacteria**	**David, 1973**	**Air**	**2330**
Legionella pneumiphila	**G- Bacteria**	**Gilpin, 1984**	**Water**	**1124**
Staphyloccus aureus	**G+ Bacteria**	**Sharp, 1939**	**Plates**	**2596**
Escherichia coli	**G- Bacteria**	**Sharp, 1939**	**Plates**	**2479**

A kill level of 1 log corresponds to a reduction by a factor of 10 (one order of magnitude) of the number of viable microorganisms. For example, if 1 million microorganisms were exposed to a 1 log kill process, 100,000 would survive. Similarly, 2 logs kill corresponds to a 99% reduction, or 2 orders of magnitude reduction, and 10,000 organisms would survive, etc.

As can be seen from Table 1, some organisms are more resistant to UV than others. In particular, some organisms form endospores, which are a semi-dormant form of the organism. Endospores tend to be quite resistant to many sterilization technologies, including heat, chemicals, x-rays, and UV. As shown in Table 1, endospores of *Bacillus subtilis var. niger* (also known as *Bacillus atrophaeus* due to a recent change in nomenclature) requires 25,000 μW-S/cm^2 for 1 log kill. Two logs kill would require 50,000 μW-S/cm^2, etc. Note that by comparison, a vegetative ("fully metabolizing") organism such as *Mycobacterium tuberculosis* (TB) requires only 2330 μW-S/cm^2 for 1 log kill. Thus, in theory, the UV energy density required for 1 log kill of *B. subtilis* endospores would produce more than 10 logs kill of the TB bacteria. A kill level of 10 logs would be quite hard to measure and verify and such kill levels are not normally considered in most practical situations. For most applications, kill levels above 6 logs are considered as sterilization.

In the development and testing of the AUVS technology discussed in this document, *B. subtilis* endospores were used as the test organism because of their high resistance to UV. Demonstrating that the AUVS technology can provide more than 6 logs kill of *B. subtilis* guarantees that kill levels will be higher for other less resistant organisms.

UV Lamp Technology

Germicidal UV lamps typically contain a combination of low-pressure mercury gas and a noble gas. An electrical discharge is created in the lamp causing the mercury atoms to become ionized. When ionized, the mercury atoms emit strong line radiation at 253.7 nm. This strong mercury emission line can contain approximately 85% of the emitted energy. The remaining energy is emitted at various wavelengths, mainly at 185 nm. Many UV germicidal lamps use a quartz envelope that blocks the 185 nm emission, since this wavelength creates ozone. These lamps are termed "ozone free". As can be seen from Figure 1, the wavelength of the 253.7 nm line is very close to the optimum wavelength for germicidal effectiveness, making, low-pressure mercury lamps an ideal source of UV for germicidal applications.

The irradiance or flux density in W/cm^2 from a UV lamp depends strongly on distance from the lamp. Depending on the lamp type and design, the total emitted UV flux per unit arc length from a UV lamp might vary from about 0.2 to approximately 0.9 W/cm. Depending on the length of the lamp and the flux per unit length, the irradiance at 1 meter from the lamp will be between about 10 and 1400 μW-S/cm^2.

As discussed above and indicated in Table 1, a UV energy density of approximately 25,000 µW-S/cm^2 is required for 1 log kill of *B. subtilis* endospores. An energy density of 150,000 µW-S/cm^2 would therefore be needed to produce a 6 log kill of this organism. Thus, in order to achieve a 6 log kill of resistant endospores, either a high irradiance or a very long exposure time in seconds is needed to reach the required 150,000 µW-S/cm^2 level. For example, a time of more than 100 seconds would be required to accumulate a dose of 150,000 µW-S/cm^2 at a distance of 1 meter from even a very high power UV lamp producing an irradiance at 1 meter of 1400 µW/cm^2. Such long exposure times are generally not feasible in rapidly flowing air since the air may move at a speed of the order of 10 ft/sec which would correspond to a travel distance of 1000 feet in 100 seconds.

AUVS Technology

Novatron has developed an Advanced UV System (AUVS) technology that provides unique benefits for air sterilization applications. The technology is based on a proprietary reflective cavity technology that significantly increases the intensity and uniformity of UV energy, enabling very high levels of UV flux. The high UV flux levels and high uniformity lead to previously unobtainable levels of air sterilization. The AUVS technology forms the basis for the Novatron BioPretector^{TM} line of air sterilization products.

The AUVS reflective technology developed by Novatron provides a multiplication of UV flux by a factor of 20 to 50 times that produced by UV lamps alone. This occurs due to cavity effects somewhat analogous to those in a high Q microwave or laser cavity, where energy is contained and intensity increases due to accumulation of reflected energy.

The result of Novatron's reflective cavity technology is that irradiances in excess of 150,000 µW/cm^2 can be produced. This means that the 150,000 µW-S/cm^2 dose required for 6 logs kill of UV resistant endospores can be delivered in less than 1 second, enabling single pass sterilization of air flowing at speeds of several hundred to 1000 ft/min. Without the reflective technology 20 to 50 times as many lamps would be required to achieve these sterilization effects. Such a large number of lamps is not only undesirable in terms of the electrical energy that would be consumed, it is not feasible in terms of system cost and the amount of physical space that would be required to install such a large number of lamps.

Microbial kill tests constituted an important part of the development of the AUVS technology. Tests were performed under U.S. Defense Advanced Research Projects Agency (DARPA) funding in aqueous solutions in the laboratory, in flowing air in the laboratory and in flowing air in tests at test sites operated by Bechtel Corporation and Battelle Memorial Institute. Subsequently, RTI International performed definitive third party tests for the Department of Defense Joint Program Manager for Collective Protection under the supervision and direction of the US Army Research and Development Command (RDECOM). Tests were also performed by the EPA. The RTI Department of Defense tests demonstrated kill levels for *B. subtilis endospores* in excess of 6 logs, which was the highest kill level that could be measured with the test equipment and protocol used.

Uniformity is another important factor in microorganism kill, since regions where air is exposed to lower levels of UV can significantly degrade the over-all kill achieved. As noted above, the irradiance from a UV lamp depends strongly on distance from the lamp. As a result, in conventional UV systems, the UV irradiance varies significantly from one location in the treatment region to another. If only a few percent of the air flowing through the treatment region is under-treated, the over-all kill level will be significantly decreased.

The reflective cavity technology developed by Novatron provides a very high level of uniformity throughout the cavity. This occurs because the cavity is designed to assure that UV energy reflects to every location in the cavity from every direction. UV irradiance has been measured in AUVS cavities to be uniform within a few percent throughout the cavity.

Another important feature of the AUVS technology is the ability to provide assurance of kill. Some systems, such as filters, can have leakage or by-pass paths that permit air to pass through the system without reduction of the organism load. It is even possible that systems may be initially sealed and subsequently develop leaks that seriously degrade their performance. The construction of the BioProtector AUVS products is such that air cannot pass from the inlet to the outlet without passing through the high intensity UV region. In fact, the UV intensity in the AUVS cavity can be continuously monitored to provide assurance and documentation that the proper kill level is being achieved.

While the AUVS technology effectively kills microorganisms, it does not remove particles from the air. However, BioProtector systems can be combined with filters to remove particulates. In some HVAC applications, a filter may be used upstream of a BioProtector unit to remove dust particles from the air before it enters the unit in order to keep the BioProtector clean. For this type of application, a MERV 13 filter operating at an efficiency of 80 – 85% might be used.

For applications involving critical high sterility requirements, it may be desirable to combine a BioProtector system with HEPA filtration. This provides a “belt and suspenders” approach to protect against contamination of air for critical applications. Combining high efficiency filtration with a BioProtector system, provides assurance that even if filter leakage occurs, any microorganisms that by-pass the filter will be deactivated when they pass through the BioProtector and will not be viable. In addition to providing particulate removal, another benefit of using HEPA filtration in conjunction with a BioProtector is that the two together provide an even higher sterility assurance level than either alone by combining the 3.5 log capability of HEPA filtration with the > 6 log capability of the BioProtector system.

Other benefits of the AUVS technology include low installation cost, low maintenance cost, low energy usage and low pressure drop. In addition, the technology is highly scalable, allowing systems to be designed for airflow volumes of from less than 100 cfm to more than 60,000 cfm. These benefits and the characteristics described above make the BioProtector systems and the AUVS technology upon which they are based an ideal solution for providing sterile air for critical clean air applications.

Summary

UV energy has long been known to kill microorganisms. The dose or energy density required for kill depends on the microorganism, with some organisms such as bacterial spores being more resistant than others. The amount of UV energy required to kill a wide variety of organisms has been documented in extensive tests and research dating back to the early 1900's.

In order to achieve high kill levels and produce true sterilization effects in rapidly flowing air in exposure times of the order of 1 second, very high UV irradiance levels are needed. The AUVS technology developed by Novatron provides a means of achieving the high UV intensities required to achieve true sterilization effects. No other technique, including ULPA filters can provide the levels of air sterilization achievable with the AUVS technology. Other features of the AUVS technology include the high degree of UV uniformity provided by the reflective technology used, the ability to monitor the UV intensity and provide assurance of kill, the opportunity to combine the technology with filters to provide particulate removal, and other advantages, including the fact that by-pass effects can be avoided.

References

1. Jagger, John, *Introduction to Research in Ultraviolet Photobiology,* Prentice-Hall, New Jersey, 1967.
2. ASHRAE Handbook – HVAC Systems and Equipment, Chapter 16, Ultraviolet Lamp Systems, 2008.
3. IESNA Lighting Handbook, 9th ed. M. Rea, ed. Illuminating Engineering Society of North America, New York, 2000.
4. DIN. Optical Radiation Physics and Illumination Engineering. Standard 5031. German Institute for Standardization, Berlin, 1979.
5. VanOsdell, Douglas and Foarde, Karin, *Defining the Effectiveness of UV lamps Installed in Circulating Air Ductwork*, RTI Report ARTI-21CR/610-40030-01, 2002.
6. Kowalski, W.J., *Immune Building Systems Technology,* McGraw-Hill, New York.