

ADVANCED UV SOURCE FOR BIOLOGICAL AGENT DESTRUCTION

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1.0 EXECUTIVE SUMMARY

Under Defense Advanced Research Projects Agency (DARPA) sponsorship, Novatron, Inc. has developed a unique new technology that can be used to protect facilities and personnel against bio-terrorism attacks. Applications include protection of military and government facilities worldwide and protecting important civilian facilities as part of a homeland defense strategy.

The bio-defense technology described in this paper is based on a novel, very high intensity, pulsed Advanced UV Source (AUVS) that very rapidly and effectively destroys biological agents. The technology can be used to protect buildings against biological weapon (BW) attack and / or create safe zones within buildings. The technology can also be used to destroy some chemicals, and with additional development, could potentially provide protection against chemical agents.

The AUVS can be inserted into HVAC air ducts to eliminate BW agents, used to purify water, and / or used to reduce BW contamination on surfaces. When used to treat air in an air duct, the pressure drop created by the system is negligible and the projected operating costs are very low. **The technology has been shown to be very effective for destroying *Bacillus pumilus* endospores that are significantly more resistant to UV than anthrax spores. Up to 7 orders of magnitude (7 logs) kill of *B. pumilus* spores have been demonstrated with the AUVS technology.**

The technology is ideally suited to protecting critical government, military and civilian facilities against BW attack by treating incoming air. Other applications include air treatment for portable shelters, field hospitals, aircraft, ships, land vehicles, and military and civilian housing. In addition, the technology has applications for water purification and surface decontamination.

AUVS development to date has led to major advances in capabilities to destroy biological agents. Operating power requirements have been reduced by two orders of magnitude as a result of significant technology developments, resulting in small appliance-like power levels. Laboratory testing has been performed, and an alpha prototype system will be tested in a DARPA test building

2.0 TECHNOLOGY AND APPLICATIONS

2.1 AUVS Technology Overview

Novatron, Inc has developed an intense pulsed UV technology that provides highly effective and efficient disinfection of air flowing at high velocity in HVAC air ducts. This technology represents a significant improvement in capability to protect buildings against BW agent attack and create safe shelter zones for key personnel and assets within critical government and civilian facilities.

Development at Novatron over the past two years has resulted in major technical advances in the AUVS technology and in the capability of the technology to destroy BW agents in air ducts. As a result

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of significant innovations that have occurred within the past year, the power required to destroy 6 logs of endospores having higher UV resistance than anthrax has been reduced by ~ 2 orders of magnitude from approximately 25 Watts / cfm to about 0.15 Watts / cfm. This means that a 10,000 cfm air disinfection system could be operated with ~ 1500 Watts, about the same power as that required for a typical hair dryer or other small appliance. (See Figure 2.1-1.)

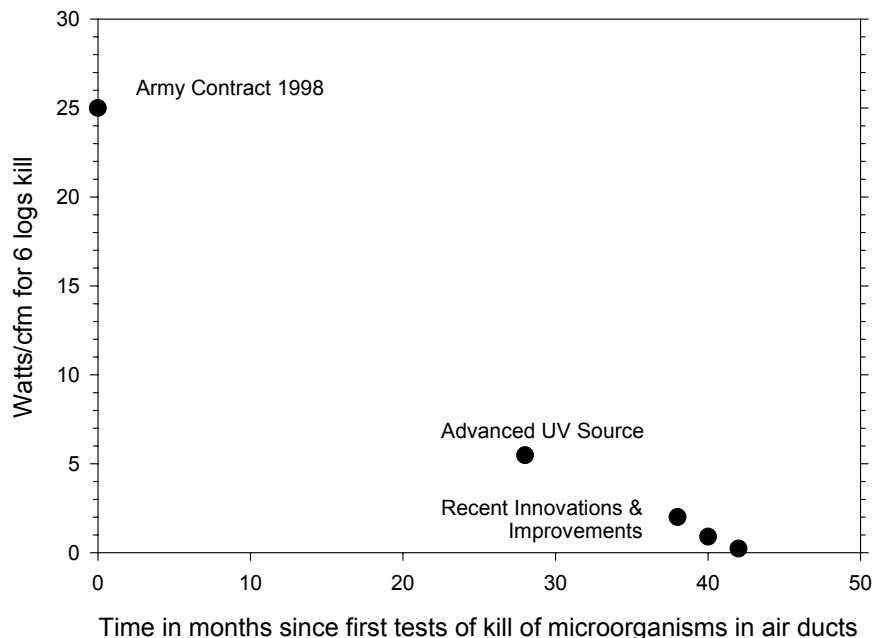


Figure 2.1-1. Improvement in efficiency of kill of UV resistant *B. subtilis* endospores.

The AUVS technology has a number of advantages over other potential BW protection technologies. **The technology provides very high kill / destruction levels of all microorganisms, including viruses, which, because of their small size are difficult to trap with filters, vegetative microorganisms and bacterial endospores such as anthrax. The technology also destroys proteins, which are the basic building blocks of bio toxins.**

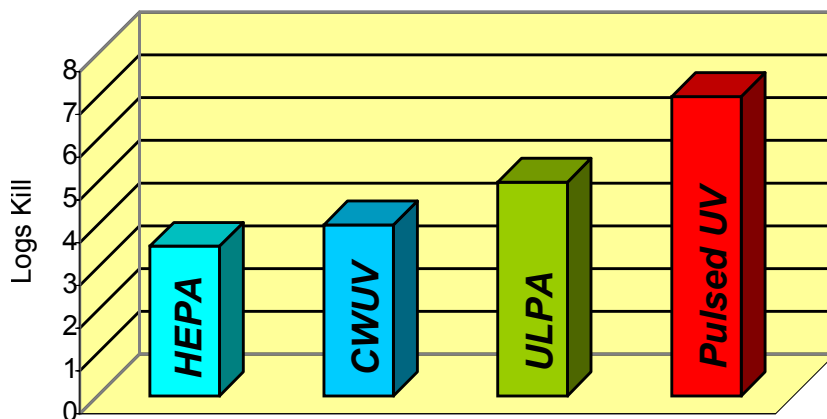


Figure 2.1-2. Comparison of effectiveness of filters, CWUV and Pulsed UV for removal / destruction of microorganisms.

Compared to filtration, the AUVS has the advantage that it destroys BW agents rather capturing and concentrating them. As shown in Figure 2.1-2, the AUVS can also provide much higher levels of agent destruction than other technologies. Figure 2.1-2 illustrates the relative effectiveness of pulsed UV from flashlamps, Continuous Wave UV (CWUV) and other removal technologies, including HEPA and ULPA filters. **As is**

indicated in the figure, pulsed UV is considerably more effective than CWUV and filters in removing microorganisms.

The AUVS technology creates negligible pressure drop in air ducts, a key issue for retrofitting protection technology into existing building as well as in the design of new facilities. In addition, the system can be turned on instantaneously. This allows the technology to potentially be operated in a passive mode or stand-by mode and activated only when a sensor indicates that a threat exists. Another advantage is that the performance of the system can be correlated to the UV intensity being produced. This gives a positive assurance of effectiveness, eliminating “silent” or undetected failure modes that can result from filter leakage. Finally, the time required to achieve high kill levels is very short (microseconds). This makes it possible to effectively and efficiently treat air flowing in air ducts at high velocities.

In summary, the important advantages of the AUVS are:

- Much higher kill / removal than other technologies
- Destruction / kill of BW agents rather than capture / concentration
- Instant turn on capability permits detection / passive mode operation
- Can monitor performance – eliminates “silent” failure scenarios
- Low operating power and negligible pressure drop in air duct
- Rapid treatment, high flow velocity capability

In addition to treating air in air ducts, the AUVS technology has other important applications related to destruction of BW agents, such as clean up and decontamination of surfaces and destruction of BW agents in water.

2.2 Background

Ultraviolet light of the proper wavelength has long been known to produce strong antimicrobial effects. The dominant mechanism for kill of microorganisms by conventional UV sources typically results from the absorption of UV at wavelengths of ~260 nm by nucleic acid (Jagger, J. “Introduction to Research in Photobiology,” Prentice-Hall Biological Technical Series, NJ, 1967).

Bacteria and fungi are inactivated by far UV* primarily through the production of cyclobutane pyrimidine dimers (CPDs) in DNA. This involves creation of a cyclobutane ring between the 5,6 positions of adjacent pyrimidines in one strand of the DNA. The formation of the CPD is shown in detail on the top and diagrammatically on the bottom of Figure 2.2-1:

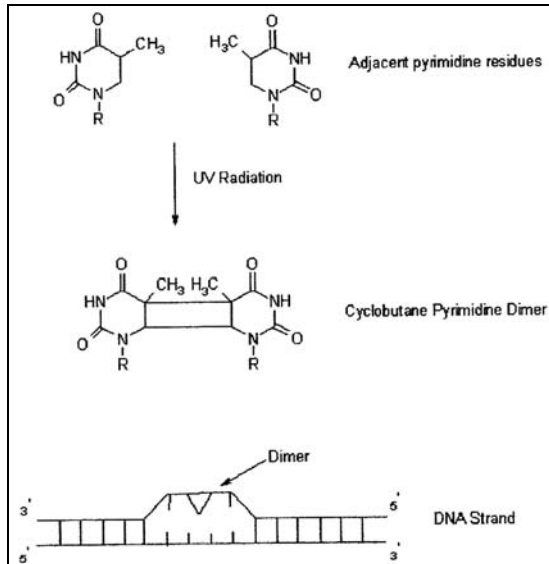


Figure 2.2-1. DNA Damage Mechanisms.

Production of dimers disrupts the hydrogen bonding between adjacent strands of the DNA and

* The wavelength range from 190 to 300 nm is called *far-ultraviolet* radiation. This range is also called UVC, and is distinguished from the longer wavelengths of *near-ultraviolet* radiation, which is also called either UVB (300-340 nm) or UVA (340-400 nm).

produces a block to DNA synthesis by the DNA polymerase. This will also block transcription by RNA polymerase at that point. Unless it is repaired, such a lesion will result in death or mutation of the cell.

Action spectra are a measure of the extent of a biological effect as a function of wavelength. The action spectra for killing of *E. coli* and *S. aureus* are shown in Figure 2.2-2. These action spectra, (Gates, F. L. "A Study of the bactericidal action of ultraviolet light. III. The absorption of ultraviolet light by bacteria. J. Gen. Physiol. **14**: 31-42, 1930), show almost a perfect match to the absorption spectrum of DNA, showing that DNA is indeed the target for far-UV killing of bacteria.

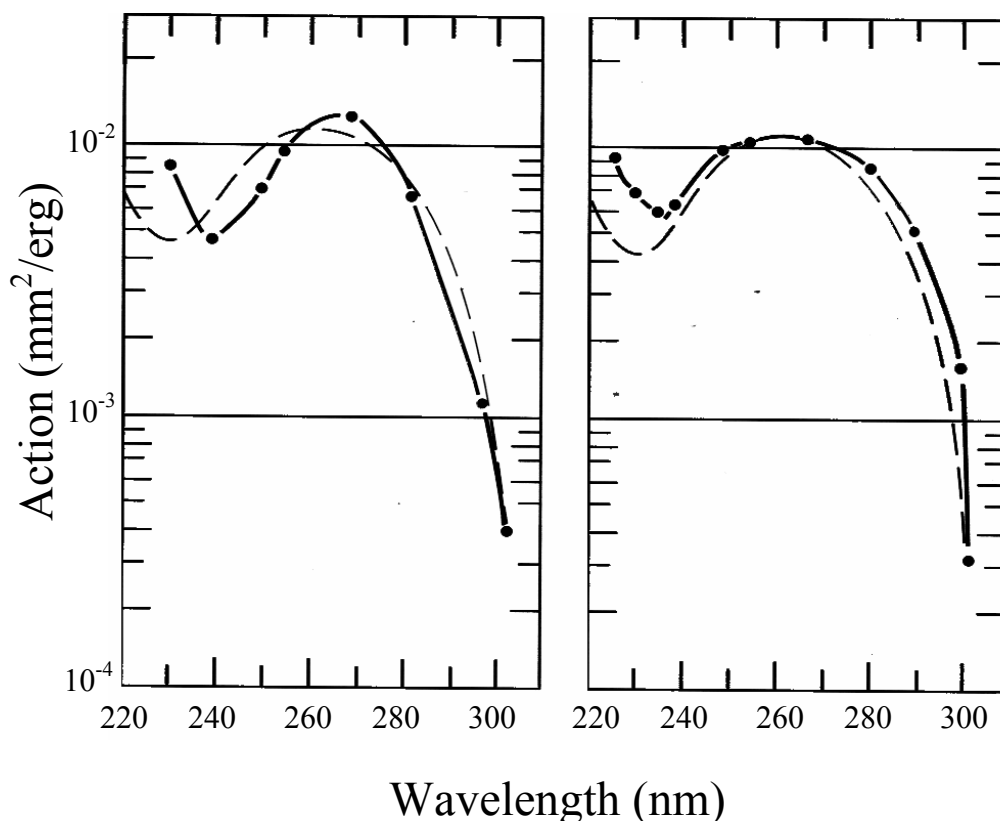


Figure 2.2-2. Action spectra for killing of *Escherichia coli* (left), and *Staphylococcus aureus* (right). The broken line shows the relative absorption of DNA. (Gates, 1930).

2.3 Intense Pulsed UV Effects

Flashlamps deliver a UV flux in the 200 – 300 nm wavelength range of about 0.1 J/cm² in a time on the order of one hundred microseconds. This UV flux is many orders of magnitude higher than that produced by even the highest power continuous wave UV (CWUV) sources. Extensive testing has shown that the high UV flux from flashlamps is very effective in deactivating a wide range of organisms. (Cover, W. H., "Advanced Technology for Rapid Sterilization of Pharmaceutical Products, Medical Devices, Packaging and Water," Report published by PurePulse Technologies, Inc., San Diego, CA, June 1999)

Figure 2.3-1 shows the survival curve for single flash kill kinetics of *Bacillus pumilus* on a dry surface. This data shows that a single pulse of about 1.8 J/cm² of total light output, which corresponds to about 0.14 Joules/cm² of 200 – 300 nm UV, can reduce the surviving population to one millionth of its

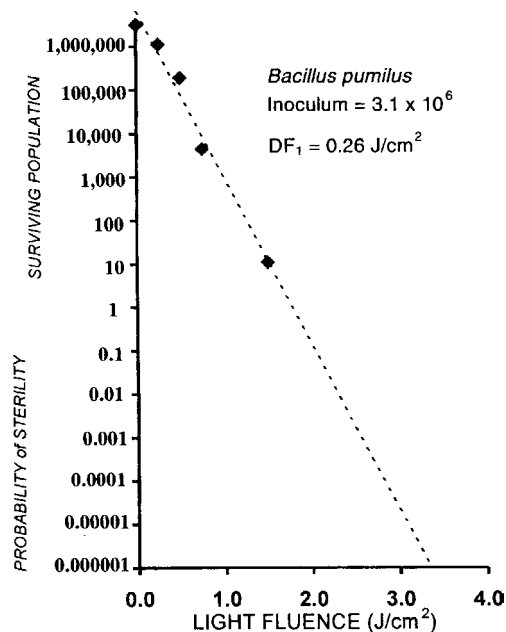


Figure 2.3.1. Pulsed UV single flash kill kinetics of *B. pumilus* endospores. (Cover, 1999.)

between the AUVS at 15,000 degrees Kelvin and conventional flashlamps that typically operate at 10,000 degrees Kelvin is shown in Figure 2.3-2.

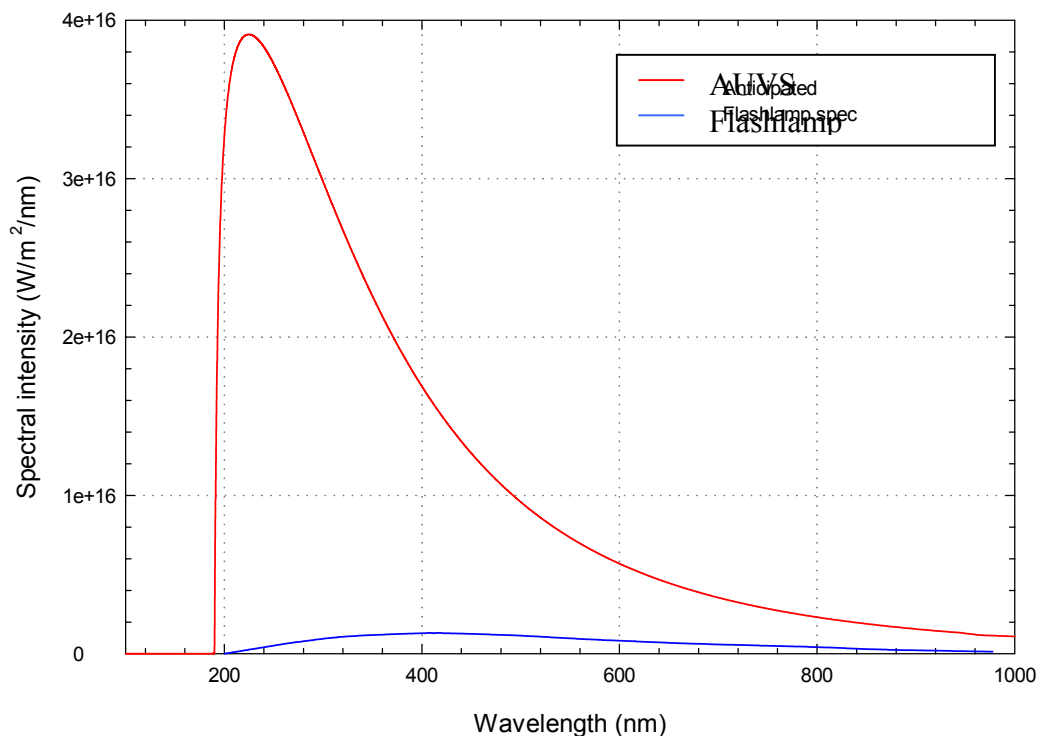


Figure 2.3-2. Comparison of AUVS and flashlamp spectra.

initial value (6 logs of kill). This is a much higher level of kill than can be obtained using even the highest power conventional CWUV sources.

Continuous wave UV (CWUV) sources are not suitable for treating flowing air since the required exposure time can be several minutes to accomplish just a few logs of kill due to the inherently low fluence. At flow velocities typically found in HVAC systems, this would lead to impractical treatment system sizes. For example, for air flowing at 15 ft/sec and a required treatment time of 15 seconds, a treatment region of 225 feet would be required.

Compared to other sources of intense pulsed UV such as flashlamps, the AUVS provides much higher efficiency. **The AUVS has ~ 30 – 35 % of its emitted light in the 200 to 300 nm band compared to about 8 % for flashlamps.**

In addition to having a much greater percentage of its output in the critical 200 to 300 nm band, the AUVS has approximately 100 times the intensity of a conventional flashlamp. A comparison of UV output

The AUVS technology is based on the use of a high temperature plasma UV emission source. A pulsed voltage is applied between two electrodes to generate a discharge in a gas, creating a high temperature plasma. The low circuit and emitter inductance leads to high plasma current and high plasma temperature, which are essential for generating intense UV radiation.

Novatron has achieved energy coupling efficiency from electrical energy storage capacitors to the plasma surface discharge of 87.5% and has developed the know-how to achieve high coupling efficiency. Novatron has also demonstrated conversion of 50.4% of the coupled energy into total light, with greater than 30% of the emission in the 200 to 300 nm wavelength region.

2.4 Chemical Agent Destruction

The AUVS is optimized to produce very intense UV fluxes of up to 30,000 watts/cm² in the 200-300 nm wavelength region. The 200-300 nm region is especially suitable for destruction of nucleic acids and proteins in microorganisms. This wavelength range is also the correct energy range for photolytic destruction of many chemical bonds, including bonds such as P-C, P-F and P=O in chemical warfare agents.

Tests performed by Novatron have shown destruction of some chemicals. For example, tests have shown destruction of MDCP, a chemical used as a chemical warfare agent simulant. However, as shown in Figure 2.4-1, the UV absorption cross section varies significantly among various chemical warfare agents, with the UV absorption for MDCP being in the mid range between the higher cross

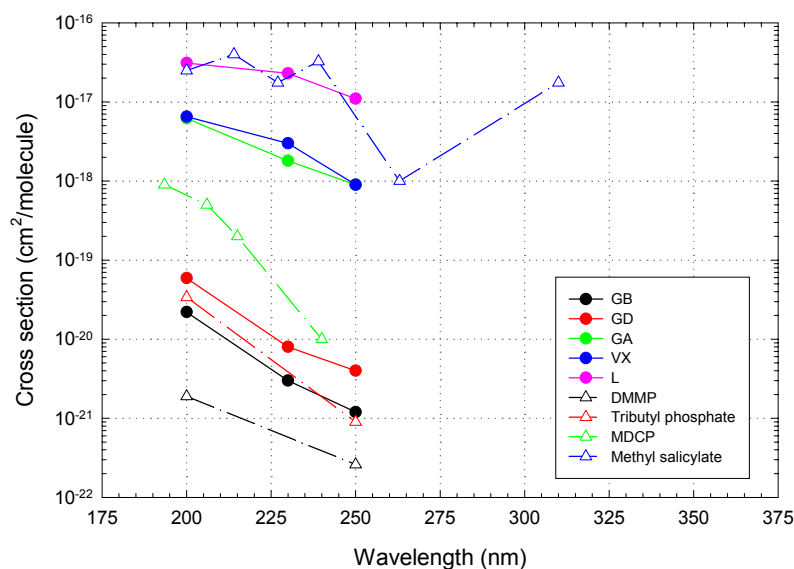


Figure 2.4-1. UV absorption cross sections for various chemical agents and simulants.

section agents and those with lower UV absorption cross sections. Based on this information, we believe that direct UV destruction of some chemical agents will not be practical. It should be possible to address the broader range of chemical agents using photo catalysis.

In addition to the energy produced in the 200-300 nm emission, the AUVS also produces significant energy in the 300-400 nm wavelength range. The 300-400 nm range is especially suitable for photo catalyst activation. Recent work performed at California Institute of Technology indicates that pulsed UV is much more effective than Continuous Wave

UV(CWUV) for photo catalyst activation. (Cornu, Catherine J. G., "Photocatalysis Under Periodic Illumination, Ph.D. Thesis, California Institute of Technology, September 24, 2001.)

Titanium dioxide (TiO₂) is one potential photo catalyst that should be investigated for use with the AUVS. Another potential approach would be to use the intense UV from the AUVS to create OH radicals in air containing water vapor.

2.5 Applications

The significant technology advancements, most notably the reduction in operating power, described above make a wide range of biological and chemical protection applications feasible. The technology can be used to disinfect air in HVAC systems for military installations and US government and civilian facilities both in the US and overseas as well as for a number of other applications.

Because air disinfection systems based on the technology can be small and operating power requirements are low, applications as diverse as air treatment for large buildings, small portable shelters, field hospitals, aircraft, ships and military and civilian housing are feasible.

In addition to air disinfection to protect buildings and other facilities and structures against biological and chemical attack and create safe zones within buildings, other applications of the AUVS technology such as water treatment to kill pathogens and surface decontamination are also feasible.