Appropriate Uses for UVC LED Technology for Disinfection Applications

With the recent threat of COVID-19, there is a strong focus on UV disinfection and many companies are pushing to sell their UV products. It is certainly a fact that UV LEDs deliver precisely controlled light intensity and dosage to provide various levels of inactivation, but there are still open questions and concerns that need to be answered and discussed: Are UV LEDs really suitable for COVID-19? Which wavelengths are, in general, the right choice for disinfection? Is it safe to use them? Theresa Thompson, PhD Application Scientist at Phoseon, casts light on these and many more UV light questions, especially UV-C light for disinfection applications.

UV-C light is known as "germicidal UV" for its effectiveness in decontamination and disinfection. While particular wavelengths affect different bonds within biological molecules, both nucleic acids and proteins can be modified by deep ultraviolet light. Thus, both microorganisms and biological material can be inactivated with the right dose and wavelength of light. This article will highlight the appropriate uses for UVC LED technology for disinfection applications along with supporting research related to the different levels of inactivation.

The Difference Between Decontamination, Disinfection and Sterilization

These terms are often used interchangeably, and can even have different meanings for different groups. Therefore, it is important to clearly define their meaning for a common understanding (**Table 1**).

Common Applications for UV LED Disinfection/Decontamination

While UV LED technology can be a great ally for most laboratories by increasing accuracy and consistency of results while reducing time and cost in experiment trials, there are specific areas of study were UV LED can make a tremendous impact.

Specific areas where UV LEDs have greatest impact:

- **Improving RNA driven protocols and results:**
  Completely inactivating RNase [1], an enzyme that degrades RNA samples, can improve results. RNases are present on most surfaces
- **Vaccine development research and manufacturing:**
  Testing with UV LED can be a fast track to rapid and cost-effective virus inactivation; an essential technique when developing vaccines
- **Microbiology laboratories:**
  Whether the purpose is to reuse or to properly dispose of equipment, disinfection is an everyday necessity in microbiology labs. As opposed to other techniques, UV LED technology has proven to achieve high levels of disinfection in microplates or pipets [2] while leaving no chemical residue behind. This zero-trace result is rarely seen by other disinfection approaches.

How to Choose the Best Wavelength for Disinfection

The standard recommendation is a comparison model approach, starting with literature review: what have others done in similar situations and how successful were they? As you look for wavelengths that match your specific goals, make sure to keep in mind some characteristics about the target species for inactivation.

Relevant characteristics of the target species:

- Size
- Structure (including similar amino acids and ionic behavior)
- Kingdom and Family
- Biochemical information such as reaction pockets or active sites
- The microenvironment of chromophores

Wavelengths, dosage levels, and exposure time will all be impacted by the charac-

teristics above. In addition, the object or organism that will be released from contaminants must be taken into consideration as well. For example, if mammalian cells or culture media will be subject to disinfection, it's important to be aware of the possible UV cellular response(s).

Wavelengths Used for Common and Challenging Contaminants

$\lambda \leq 222$ nm

Studies of the 200–222 nm wavelength range predict its ability to inactivate microbes while remaining safe for humans. This is due to the fact that light in the 200–222 nm range can only transverse small organisms such as bacteria or viruses, and generally does not affect larger biological samples like stratum corneum [4]. There are not many conclusive and specific reports on the 222 nm mechanism of action, most assume DNA damage through dimer formation. Protein UV absorption at this range is attributed to peptide bonds [5]. Given sufficient irradiance and dose, some argue inactivation due to protein damage could be possible.

$\lambda = 254$ nm

254 nm UV light deactivates biomolecules by attacking the structure of nucleic acids. This is the common wavelength used by low pressure mercury UV lamps.

$\lambda = 260$–265 nm

It is known as an effective bactericide and has shown great results against viruses like the Influenza A [3]. It also relies on nucleic acid damage as a mechanism of action and it is available in UV LED lamps.

$\lambda = 275$–280 nm

This wavelength range is able to deactivate biomolecules through disturbing their protein structures. This is due to the peak absorption of the aromatic amino acids Tryptophan (W) and Tyrosine (T) at this wavelength range [5]. These structural modifications interfere with protein functionality, therefore resulting in the inactivation of the target organisms. For example, this wavelength acts on RNase A via an effect on the aromatic amino acids proximal to disulfide bonds, reaching its complete inactivation (Column 1 of **Table 1**). It has shown great results against common bacteria (such as *S. aureus*) and proven effective against fungi like *Aspergillis brasiliensis* and *Clostridium difficile* (in synergy with 365 nm) [3].

$\lambda = 365$ nm

This wavelength is thought to target the Lysine side chain and help destabilize the reaction pocket of enzymes like RNase A. RNase A is one of the most challenging contaminants in laboratories. The complete inactivation of this enzyme in a matter of minutes (or even seconds) opens up new possibilities, making research faster and more accurate. The 365 nm wavelength has also been effective in synergy with 278 nm for fungi inactivation [3], and 365 nm has been shown to produce single-strand DNA break [6].

$\lambda = 405$ nm

Wavelengths in the 400–420 nm blue-purple range have been shown to have antimicrobials effects, with peak effect on *S. aureus* at 405 nm [7]. The proposed mechanism of action relies on the formation of oxygen radicals, highly reactive oxygen species, which often lead to oxidative damage and cell death [8]. Research on visible light used for disinfection is at an early stage. Its germicidal efficiency is known to be less of that of UVC light, however with high enough dosages, complete inactivation of organisms may be possible.

What is the Best Wavelength for Disinfection?

The answer to this question is highly dependent on experimental goals, however, there are two competing candidates for the leading position. Traditionally, the standard peak wavelength for disinfection has been 265 nm, since this is the known absorption maxima for nucleic acids. Inactivation occurs due to dimer formation [9]. For many decades mercury lamp systems have been available for disinfection utilizing one of the emission peaks of mercury, 254 nm (which also deactivates molecules by attacking nucleic acids). This wavelength is close enough to the absorption peak to be effective.

In the last decades, 275–280 nm has been known as the peak absorption for proteins, essential aromatic amino acids being most affected at these wavelengths. Biomolecules can then be inactivated by disrupting bonds and thereby influencing secondary and tertiary structures. For example, the 280 nm wavelength excites the aromatic group of the amino acid Tryptophan, which destabilizes nearby disulfide bonds. The resulting chemical damage to these vital structures (S-S bonds) can be deactivation of molecules with minimal chance of reformation. One of the greatest challenges for disinfection and decontamination is the ability of microorganisms and enzymes to repair or reform after a period of time. Most cells contain a dimer repair mechanism for nucleic acid repair and damaged proteins are generally recycled within cells. Viruses cannot directly repair

Decontamination	Disinfection	Sterilization
Inactivation of biological molecules DNA, RNA, Enzymes	Inactivation of microorganisms Virus, Bacteria, Fungi	Inactivation of all mcroorganisms that reaches at least 6 log reduction
Current Techniques: Chemicals, Heat, Scrubbing, Rinsing	Current Techniques: Chemicals, Heat, Ethlene Oxide, Steam	Current Techniques: Chemicals, Heat, Ethlene Oxide, Steam
UV LEDs effectively inactivate hard-target biological molecules, even RNase A	UV LEDs effectively inactivate microorganisms such as Influenza A, Clostridium difficile spores, Aspergillis brasiliensis, and Staphylococus aereus	UV LEDs are on the verge of reaching sterilization levels for difficult and clinically-relevant pathogens

Table 1: Definition of the terms decontamination, disinfection and sterilization as used in this article

themselves and must infect a host in order to take advantage of any cellular repair mechanisms. The main objective is then to either damage the host organism so much that the repair mechanism starts failing, or damage the virus enough that it cannot be readily repaired. Both greater dosages and the synergistic effect mentioned previously could contribute to the lack or repair.

265 nm and 275–280 nm are the most effective wavelengths for disinfection. Depending on the assay in question one may be more beneficial than the other. If working at the DNA level, 265 nm would ideal; if at the protein level, 275–280 nm works best. All in all, the high-power UV LED systems available at 275 nm have enhanced performance that positions them well above any mercury lamp.

Can UVC LED Technology be Used for SARS-Cov-2 Virus?

UV LEDs have proven effective against some of the most challenging contaminants, raising the question of whether it would work against the biggest current global threat, SARS-CoV-2. UVC LED technology can be used to decontaminate surfaces and instruments in a laboratory setting, and potentially air and water that have come in contact with the SARS-CoV-2 virus. It should be used in applications where no one is present at the time of disinfection. UV-C light in the 260–280 nm range most relevant for disinfection is harmful to human skin. In fact, the World Health Organization warns against using ultraviolet disinfection lamps to sanitize hands or other areas of the skin - even brief exposure to UVC light can cause burns and eye damage [10].

While data is limited in regards to this novel virus and the best wavelength for its complete inactivation, the information gathered to date can point us in the right direction. Many research efforts are focused on developing "information libraries". Whether they contain active sites, mutations, or genomic information; having a place where this knowledge is accessible to scientists is imperative for progress. Similarly, developing a wavelength library can be very useful to research labs. So far, we know that novel SARS-CoV-2 and Influenza A (inactivated at 265 nm) are both enveloped RNA viruses and may be susceptible to UV inactivation under similar conditions. The presence of envelope and nucleoproteins suggest that both could be susceptible to inactivation at 280 nm.

UV Light Safety Precautions

Since ultraviolet light has proven to be damaging to humans when in direct contact, protective measures are recommended: wearing safety goggles and gloves, restricting access to areas where UV light is in use, and preventing skin exposure to the light source. When working with UVC LED light, shielding is required to eliminate the possibility of direct eye or skin exposure.

The International Ultraviolet Association (IUVA) and RadTech North America are educational and advocacy organizations that would like to inform the public that there are no protocols to advise or to permit the safe use of UV light directly on the human body. UV light under the conditions known to kill such viruses can cause severe skin burns, skin cancer, and eye damage. There is information that a specific type of UV light, sometimes called "far UV-C" (at wavelengths from 200–225 nm) can disinfect viruses without damaging skin and eyes, but this information is considered to be preliminary and there are no protocols to ensure that it is applied effectively and safely. These organizations strongly recommend that anyone using UV light to disinfect medical equipment, surfaces, or air follow all recommended health and safety precautions and to avoid direct exposure of the body to the UV light [11].

Conclusions

Applied correctly, using the correct wavelength and intensity for the target contaminant UV-C is a mighty weapon against dangerous bacteria, viruses and other germs. To defend COVID-19 viruses, 260–280 nm is seen to be ideal as the best absorbance

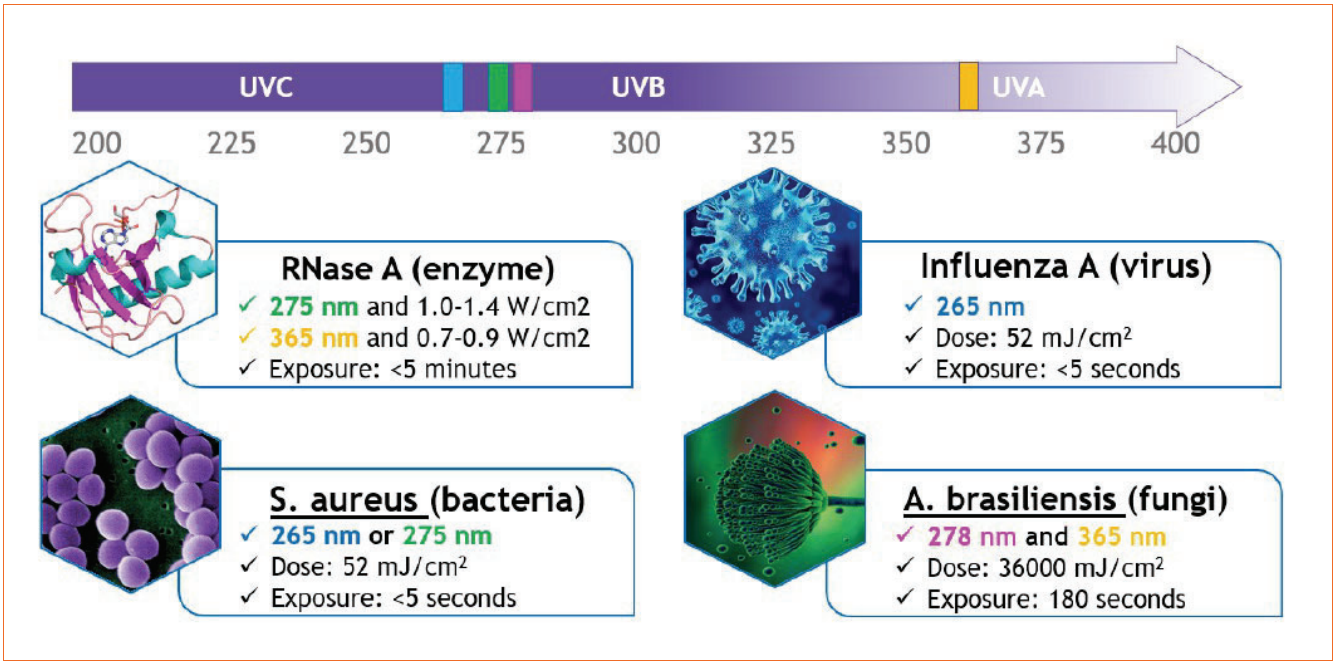

Table 2: Overview on the different UV wavelengths and their target contaminants

range for nucleic acids is 240–275 nm and 275–280 nm corresponds to absorbance by protein aromatic side groups [5]. However, it is important to keep in mind that safety precautions have to be taken seriously as UV light does not selectively just damage germs but may also affect any other tissue and cell. ■

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About Phoseon
Phoseon's UV LED curing solutions are one of the most reliable on the market. Starting from 2002 in Portland Oregon USA, Phoseon Technology foresaw the value of LEDs for both Industrial Curing applications and Life Sciences solutions. Building from their strong background in solid-state semiconductor devices, Phoseon utilizes native diodes and Semiconductor Light Matrix™(SLM) technology to manufacture LED systems. With over 300 patents worldwide, Phoseon has earned the reputation for technological innovation, quality and reliability. As a market leader with a broad portfolio of UV LED units and offerings for key markets, Phoseon welcomes the opportunity to work jointly with clients in developing further innovative solutions.

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