Effectively using ultraviolet-C light for supply decontamination on swine farms

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Summary

The application of ultraviolet-C (UVC) light is not well understood in the swine industry, and best practices for applying UVC technology effectively and safely are lacking. This paper aims to summarize swine industry best practices for using UVC safely and maintenance requirements created as a result of a UVC workshop organized by the Swine Health Information Center. By understanding basic UVC physics, mechanism of action, safety procedures, and general maintenance requirements, the swine industry will be able to use UVC technology safely and effectively for decontamination of surfaces on swine farms.

Keywords: swine, ultraviolet-C light, biosecurity, surface decontamination

Received: December 30, 2020
Accepted: June 22, 2021

Resumen - Uso efectivo de la luz ultravioleta-C para la descontaminación del suministros en granjas porcinas

La aplicación de la luz ultravioleta-C (UVC) no se comprende bien en la industria porcina, además no se tienen las mejores prácticas para aplicar la tecnología UVC de manera efectiva y segura. Este documento tiene como objetivo resumir las mejores prácticas para el uso seguro de UVC en la industria porcina, y los requisitos de mantenimiento establecidos como resultado de un taller de UVC organizado por el Centro de Información de Salud Porcina. Al entender la física básica de la UVC, el mecanismo de acción, los procedimientos de seguridad y los requisitos generales de mantenimiento, la industria porcina podrá utilizar la tecnología UVC de manera segura y eficaz para la descontaminación de superficies en granjas porcinas.

Résumé - Utilisation efficace de la lumière ultraviolette-C pour la décontamination de l'approvisionnement dans les élevages porcins

L'application de la lumière ultraviolette-C (UVC) n'est pas bien comprise dans l'industrie porcine, et les meilleures pratiques pour appliquer la technologie UVC de manière efficace et sécuritaire font défaut. Ce document vise à résumer les meilleures pratiques de l'industrie porcine pour utiliser les UVC en toute sécurité et les exigences de maintenance créées à la suite d'un atelier UVC organisé par le Swine Health Information Center. En comprenant la physique de base des UVC, le mécanisme d'action, les procédures de sécurité et les exigences générales de maintenance, l'industrie porcine sera en mesure d'utiliser la technologie UVC de manière sûre et efficace pour la décontamination des surfaces dans les fermes porcines.

Ultraviolet-C (UVC) light is widely used for decontamination in many industries, including human medicine and food processing. The practical application of this technology in livestock production is a more recent development. It is increasingly being used on swine farms as producers look for ways to improve biosecurity in response to the threat of African swine fever virus (ASFV). However, many swine producers and veterinarians are unfamiliar with the physics of UVC, the mechanism of action, the doses required to inactivate swine pathogens, and practical conditions under which UVC can operate effectively and practically on swine farms. The swine industry lacks best practices to apply this technology effectively and safely. To address the need for a better understanding of UVC application on swine farms, the Swine Health Information Center (SHIC) organized a one-day workshop with practicing swine veterinarians and academic

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DM: New Fashion Pork, Jackson, Minnesota.

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CJ: Carthage Veterinary Services, Carthage, Illinois.

PZ: National Pork Board, Clive, Iowa.

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Ruston C, Holtkamp D, Li P, Koziel JA, Stephan A, Loesekann T, Torremorell M, Murray D, Wedel K, Johnson C, Zaabel P, Sundberg P. Effectively using ultraviolet-C light for supply decontamination on swine farms. *J Swine Health Prod*. 2022;30(2):101-106. **https://doi.org/10.54846/jshap/1248**

experts in epidemiology, infectious disease, biosecurity, chemistry, and agricultural engineering to outline and define best practices for UVC in the swine industry.

This paper aims to describe swine industry best practices for using UVC safely and effectively developed during the UVC workshop. Development of industry best practices for UVC will allow people in the swine industry to use UVC effectively and safely.

Physics and mechanism of action

Ultraviolet (UV) light is a range of electromagnetic radiation immediately more energetic than the visible light range. The generally accepted range of UV wavelength lies from 100 to 400 nm, which is shorter than the visible light spectrum (400 to 800 nm) seen by humans. The essential physical consequence of the shorter wavelengths is that the photon energy meets or exceeds the energies of chemical bonds, ionization potentials, and band gaps of most materials, although this varies with the exact wavelengths under consideration. There are four UV categories defined based on the wavelength range.[1]

1. vacuum ultraviolet (VUV), 100-200 nm
2. ultraviolet C (UVC), 200-280 nm
3. ultraviolet B (UVB), 280-315 nm
4. ultraviolet A (UVA), 315-400 nm

Ultraviolet-C light has been used for decontamination in a variety of areas, including but not limited to air decontamination, water (and wastewater) treatment, laboratory decontamination such as inside biosecurity cabinets, food and beverage preservation, and medical applications, such as wound care.[2,3] Ultraviolet-C light is readily absorbed by nucleic acids and proteins and induces photochemical reactions of multiple bonds in many organic molecules. Of particular relevance for the mechanism of action is the formation of a cyclobutane ring that covalently joins two previously separate moieties that each contained a C = C double bond. Along with DNA or RNA strands, adjacent thymine or uracil residues are particularly susceptible to such photodimerization. The dimerization along with the DNA or RNA strand causes that particular section of the biopolymer to no longer be recognized correctly, and changes or terminates its biological function. These compounds are essential for cells to function and reproduce.[3] The effect of UVC varies for different materials and microorganisms. Protein has a peak absorption of UV light energy at about 280 nm, while for DNA and RNA, the peak is 260-265 nm,[4,5] where the germicidal effectiveness is at its maximum. The typical 254 nm lamp, which is sold for decontamination purposes, is sufficiently close to this maximum to be effective.

UVC terminology

There are several terms and equations that are important to define and understand when applying UVC technology. Irradiance, also described as light intensity is the UVC light arriving at a surface, at all angles, at a point in time.[3] The unit for irradiance is typically expressed as milliWatts (mW) per unit area, such as square meters (m^2) or square centimeters (cm^2). In idealized conditions, assuming that UVC light comes from a point or line source, light irradiance decreases by the square of the distance from that point or line source, and the relationship is known as the inverse square law, expressed as:

$$\frac{I_1}{I_2} = \frac{d_2^2}{d_1^2}$$

where I_1 = irradiance measured at one point, I_2 = irradiance measured at a second point, d_1 = distance between the light source and one point, d_2 = distance between the light source and the second point.

This relationship demonstrates that with a doubling of the distance from a source (lamp) to a surface to be decontaminated (decontamination surface), the decontamination surface will receive a quarter of the irradiance. Consequently, it is vital to maintain an appropriate distance between the UVC light source when applying UVC to decontaminate objects.

Inactivation of pathogens by UVC is a function of the dose of radiation. The dose is a function of the irradiance on the pathogen-contaminated surface and time. The dose of UVC is measured in millijoules (mJ) per cm^2 for surface decontamination, which is defined by the following equation:

$$D\ (mJ/cm^2) = I\ (mW/cm^2) \times Time\ (s)$$

Because distance, irradiance, and exposure time can all affect the UVC dose, longer exposure times can be used to increase the dose delivered to a pathogen-contaminated surface when the distance from the source lamp is longer to obtain the same desired inactivation of pathogens.[3] A commercially available UVC chamber (Bioshift Series, UVC Germicidal Chamber, ONCE, Inc) delivers a UVC dose of about 150 to 190 mJ/cm^2. The interior of the chamber is approximately 50.80 cm × 50.80 cm × 50.80 cm, with 4 UVC bulbs approximately 45.72 cm long, located at each corner of the chamber. The shelf sits about 2.54 cm from the bottom. It is recommended supplies have a 5-minute exposure time. These are good guidelines to follow when trying to develop a UVC chamber for smaller pass-through items. Ultraviolet-C light has been applied in hospital rooms, and there is thought to whether it could be applied on a larger scale as in supply entry rooms, entry ways, or loadout areas. This concept may not be feasible on swine farms due to the varying levels of permable materials and organic material that may be present.

For the workshop, information about the dose of UVC required to inactivate various bacteria and viruses was assembled from summaries published by companies that manufacture and market equipment for UVC decontamination. Summaries from Once Incorporated, Clordisys Solutions Incorporated,[6] and ECO Scope[7] were used to identify primary references for the UVC dose requirements to inactivate viruses and bacteria. Nearly all the references identified were for microorganisms that were not swine pathogens, but many were in the same genus of swine bacteria or the same family of swine viruses. The summaries included studies applying UVC for physical decontamination of organic and nonorganic surfaces, as well as decontamination of air and water. In addition, a review of the literature for information on doses for swine pathogens was conducted for the UVC workshop.

Only peer-reviewed journal articles discussing the UVC dosage for decontamination of nonorganic surfaces were included since this is the primary purpose for which UVC would be applied as a biosecurity control measure on swine farms. Only studies related to surface decontamination in the United States and Europe were included. The review was conducted for both endemic and foreign viral and bacterial swine pathogens, which were deemed important to pork production in the United States, including those on the SHIC Swine Disease Matrix.[8] For swine bacteria and viruses, such as porcine epidemic diarrhea virus and porcine reproductive and respiratory syndrome virus,[9] where published studies with information on UVC dose is available, all the doses required for a 3-log reduction (approximately 99.9% kill) are less than the 150 to 190 mJ/cm^2 delivered by a commercially available UVC chamber (ONCE, Inc). For swine bacteria and viruses where published studies with information on UVC dose is not available, but the information is available for bacteria in the same genus or viruses in the same family, the doses required for a 3-log reduction (approximately 99.9% kill) are also less than the 150 to 190 mJ/cm^2 delivered by a commercially available UVC chamber (ONCE, Inc). A significant gap in the literature exists for swine bacteria and viruses where no information is published for them or other bacteria in the same genus or viruses in the same family. Foremost among them is ASFV and classical swine fever virus, two important foreign animal disease pathogens.

Safety and maintenance requirements

Safety best practices

When applying UVC on farms, it is important to remember that UVC is mutagenic and carcinogenic.[10] Exposure to any part of a person's or an animal's body or eyes should be avoided. Exposure to the eyes may result in the development of cataracts, actinic keratosis, or both. Short-term effects of exposure to the skin include sunburn, while long-term cumulative effects of exposure include cancer.

Several general safety practices are recommended:

- Ensure complete enclosure of the UVC chamber without any light leakages.
- Verify with a UVC meter that there is no UVC penetration through the chamber window. Glass windows are safe, quartz windows are not.
- Connect a hard-wired safety shutoff to doors and latches or purchase UVC chambers or lamps with this feature.
- Install warning labels for human safety.
- Properly train all personnel and refresh training annually.
- If exposure to UVC cannot be avoided, consider using personal protective equipment as secondary protection, which may include goggles or face shields (such as American Ultraviolet's Ultra-Spec 100 Safety Goggles and Ultra-Shield Face Shields designed for ultraviolet exposure), and clothing or sunblock.
- Discontinue use and contact the manufacturer if safety controls are malfunctioning.

Following these standard guidelines will help ensure the safety of people working in the swine industry when applying UVC technology.

Maintenance best practices

Proper maintenance of the UVC chamber or lamps used on-farm is important to ensure effective decontamination of surfaces. Ultraviolet-C lamp bulbs should be checked approximately every 3 months. If dirty, the bulbs should be cleaned by applying an alcohol-based disinfectant on soft cotton cloth or gauze. Gloves should be worn, and bulbs should not be touched with bare hands. Oils transferred from the skin surface to the lamp can block UVC light and decrease performance. Regular cleaning of UVC bulbs will also maximize the life of the bulb. Ultraviolet-C chamber walls should be coated with reflective surfaces or panels, such as polished aluminum, to increase UVC efficiency by reflecting and redirecting UVC light and obtain coverage over surfaces not directly under the UVC bulbs.[11] These reflective aluminum panels or surfaces on the inside of the chamber should also be cleaned with nonabrasive cleaners when dirty. The chamber will be less efficient at distributing UVC light when the panels have dull spots.

Temperature and relative humidity (RH) have the potential to decrease UVC performance. The temperature of the UVC bulbs has a significant impact on the decontamination efficiency of UVC chambers. It is recommended that the bulbs be cycled once in the morning to bring the bulb energy level up before the first decontamination cycle. If the RH is high, condensation may form on the bulbs when they cool off. Condensation on the bulbs is a safety concern and should be monitored closely in high humidity environments. Furthermore, RH can affect the overall efficacy of UVC decontamination. Two trends of inactivation related to RH were observed by researchers: 1) inactivation of pathogens decreases as RH increases[12,13] and 2) inactivation of pathogens peaks between 25% to 79% RH and decreases on both ends.[14] Therefore, monitoring humidity in rooms or chambers where UVC technology is being applied is warranted.

It is of utmost importance to monitor the UVC irradiance in the chamber to ensure it is in proper operating condition. The blue light visible when UVC lights are turned on is the result of a phosphor excitation and only serves as a visual safety indicator that the light is on. The blue light intensity does not correlate with UVC irradiance or intensity. Moreover, the illumination with visible light in the chamber can be misleading as to what areas are illuminated by the UVC light, since the reflective and refractive properties of UVC differ from visible light. Ultraviolet-C light may not fully illuminate fomites and tools in the chamber, even if visible light can be seen.

Ultraviolet-C irradiance may be monitored using a calibrated UVC meter such as the UV512C Digital UVC meter (General Tools & Instruments LLC) shown in Figure 1. This UVC meter, along with other meters available on the market displayed in Table 1, has the capability to record the UVC intensity after the allotted exposure time in a UVC chamber. It is recommended to first warm the bulbs by completing one cycle prior to measurements. Always record the same spot in the chamber, with the probe facing up, towards the UVC bulbs. If there are also bulbs located at the bottom of the chamber, then it is recommended to take a second measurement, facing the probe down towards the bulbs. This ensures all bulbs are giving an appropriate irradiance. To calculate the dose, multiply the irradiance (what was measured with the UVC meter) by exposure time in seconds. Ultraviolet-C dosimeters (ONCE Inc) have also been used to monitor UVC bulbs. These are paper coupons that change color according to the UVC dose they were exposed to. They are placed in the chamber for a set amount of time, and the color is immediately compared to a reference color. The color readout has to be done immediately after the light exposure, as the UVC dosimeter color may revert back toward yellow over time.

Ulatraviolet-C bulbs are rated for an expected life and must be changed periodically. Some commercial UVC germicidal chambers (eg, the BioShift series from ONCE Inc) come equipped with a built-in bulb change timer on their models. While bulb ratings are made for an expected life, the number of on-off

Figure 1: A portable, simple UV light meter (UV512C Digital UVC meter, General Tools & Instruments LLC) with a plugged-in sensor that can measure either UVC or UVA, with a data-logging SD card.

cycles is more important and can significantly shorten the life of the bulbs. For example, running 5-minute cycles is estimated to reduce the overall relative lamp life to 4.2% for the rated life. For example, the life of a bulb rated for 8000 hours is reduced to 336 hours (4.2% of 8000 hours) or about 4000, 5-minute cycles. At a minimum, bulbs and ballasts should be changed once a year or every 1000 cycles, whichever occurs earlier. Generally, it is good practice to replace bulbs and the ballast at the same time. Replacing the bulb alone sometimes does not resolve flickering, buzzing, or low output, therefore the ballast needs to be replaced as well. Be sure to check that UVC irradiance is at the desired level after the replacement. If bulbs and ballasts are changed at the same time, the rotation of bulbs is not necessary. Replacement bulbs can be purchased through the manufacturer of commercially available devices.

Practical applications in swine farms

On swine farms, UVC chambers are commonly located as a clean-dirty line between the outside farm entry or hallway, also considered the ‘dirty’ side, and the office/breakroom considered the ‘clean’ side of the farm. These chambers are designed as pass-through chambers where items from one side are placed into the chamber and retrieved from the other side of the chamber after being treated. Because of chamber capacity, UVC chambers are mostly used to decontaminate small- or medium-sized items such as lunch boxes, cell phones, small tools, medications, etc, that have surfaces that are nonpermeable and free of organic matter. It is important for the surfaces to be clean because organic material decreases UVC efficacy on surfaces.[15,16] It is important not to stack items in the UVC chambers due to UVC’s inability to penetrate most materials, except for quartz glass. Stacking items or placing them too close together will block surfaces from exposure to the UVC light, preventing the surfaces from being decontaminated. Staggering the arrival of personnel or implementing other biosecurity control measures to reduce the frequency of introduction of materials may be necessary to avoid creating a bottleneck in the system and reduce the temptation to stack or place lunch boxes and other supplies too closely together. One advantage of UVC is its inability to penetrate most materials, including plastic. Treatment of semen bags should not affect the viability of the semen, however, more research is needed to know what, if any, impact UVC may have on semen viability. It is known that repeat UVC exposure of certain plastics may result in a change in color and emission of compounds that may cause an odor over long exposure times.

Several studies have shown that the efficacy of UVC may differ with different surface types. For the most part, UVC is more efficacious on nonporous, nonpermeable materials such as plastic, stainless steel, and glassware versus permeable or porous materials such as cardboard, cloth, and wood.[17-19] This could be due to the ability of permeable or porous materials to shield pathogens from direct exposure of UVC. Therefore, exposure of paper, cardboard, or cloth to UVC is unlikely to effectively decontaminate those materials due to the limited capabilities of the UVC light to penetrate them.

Ultraviolet-C chambers are presently installed most frequently in sow farms where biosecurity is considered a priority. It is recommended that farms train employees on the best practices outlined in this paper and provide simple on-site instructions or checklists of

Table 1: Examples of portable and low-cost UV light meters available on the market

Name	Model #	Spectral range	Manufacturer	Price*	Website
UVA-UVC light meter with data logging SD card	UV254SD	240-390 nm	General Tools & Instruments LLC	$688 (Amazon)	**https://www.generaltools.com/uva-uvc-light-meter-with-excel-formatted-data-logging-sd-card-and-k-j-port**
Solarmeter Model 8.0-RP UVC meter with a remote probe	8.0-RP	246-262 nm	Solarlight Inc	$425	**https://solarlight.com/product/solarmeter-model-8-0-uvc-meter-with-remote-probe/**
UVC light meter	UV512C	220-275 nm	General Tools & Instruments LLC	$485 (Home Depot)	**https://www.generaltools.com/uvc-light-meter**
UVA, UVC light meter	HHUV254SD	240-390 nm	Omega Engineering	$874	**https://www.omega.com/en-us/test-inspection/handheld-meters/light-meters/p/HHUV254SD-Meter**

* The price was recorded December 2020.

best practices highlighting how UVC chambers and lamps should be used and maintained. Sources to use for UVC best practices, are available on the SHIC webage (**https://www.swinehealth.org/wp-content/uploads/2020/10/SHIC_UVC_FactSheet10-2020.pdf**) and at the University of Minnesota's Swine Disease Eradication webpage (**z.umn.edu/UVbox**).

Conclusion

Ultraviolet-C technology can be effectively used to decontaminate surfaces in swine farms as long as users sufficiently understand how it works and follow best practices. Ultraviolet C is a technology that requires maintenance. Standardized protocols informing people about proper cleaning of UVC bulbs and chambers, maintaining and changing UVC bulbs and ballasts on a regular basis is important to ensure the industry is appropriately decontaminating incoming supplies and other surfaces on swine farms to prevent disease outbreaks. It is also important to educate people in the swine industry and create standard safety best practices to follow when using UVC due to its risk of damage to human skin and eyes. Overall, UVC can be an economically feasible tool to help prevent disease outbreaks by reducing the likelihood of bringing contaminated supplies into farms. Following best practices for use, safety, and maintenance will ensure it is used effectively and safely.

Implications

- Development of standardized protocols will guide safe and effective use of UVC.
- Need to understand UVC when applying it for surface decontamination.
- Ultraviolet C should only be used on nonporous, relatively clean supplies.

Acknowledgments

The UVC Workshop was funded by SHIC, which resulted in this information being created (#19-237 SHIC).

Conflict of interest

At the time the manuscript was drafted, Stephan Aaron and Tina Loesekann were employed by the company that manufactures the Bioshift Chamber mentioned throughout the manuscript.

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References

*1. Bolton JR, Cotton CA. *The Ultraviolet Disinfection Handbook*. American Water Works Association; 2008.

2. Gupta A, Avci P, Dai T, Huang Y-Y, Hamblin MR. Ultraviolet radiation in wound care: Sterilization and stimulation. *Adv Wound Care*. 2013;2(8):422-437. **https://doi.org/10.1089/wound.2012.0366**

3. Cutler TD, Zimmerman JJ. Ultraviolet irradiation and the mechanisms underlying its inactivation of infectious agents. *Anim Health Res Rev*. 2011;12(1):15-23. **https://doi.org/10.1017/S1466252311000016**

4. Harm W. *Biological Effects of Ultraviolet Radiation*. Cambridge University Press; 1980.

5. Kowalski W. *Ultraviolet Germicidal Irradiation Handbook UVGI for Air and Surface Disinfection*. Springer Berlin; 2009. **https://doi.org/10.1007/978-3-642-01999-9**

*6. ClorDiSys. Ultraviolet Light Disinfection Data Sheet. 2020. Application Note #12. Accessed May 10, 2021. **https://www.clordisys.com/pdfs/misc/UV%20Data%20Sheet.pdf**

*7. ECOscope. Inactivation of bacteria, viruses and other pathogens by UV-C irradiation in the Leica cryostat product family. Published December 10, 2010. Accessed May 10, 2021. **https://www.yumpu.com/en/document/view/6627254/certificate-inactivation-of-bacteria-viruses-and-other-pathogens-**

*8. Swine viral disease matrix. Swine Health Information Center. Updated September 2018. Accessed August 1, 2021. **www.swinehealth.org/swine-disease-matrix/**

*9. Stephen A. Reduction in Swine Pathogen Numbers by UVC germicidal chamber. National Hog Farmer. Published October 31, 2017. Accessed August 1, 2021.**https://www.nationalhogfarmer.com/animal-health/reduction-swine-pathogen-numbers-uvc-germicidal-chamber**

10. Narita K, Asano K, Morimoto Y, Igarashi T, Hamblin MR, Dai T, Nakane A. Disinfection and healing effects of 222-nm UVC light on methicillin-resistant *Staphylococcus aureus* infection in mouse wounds. *J Photochem Photobiol B*. 2018;178:10-18. **https://doi.org/10.1016/j.jphotobiol.2017.10.030**

11. Jelden KC, Gibbs SG, Smith PW, Hewlett AL, Iwen PC, Schmid KK, Lowe JJ. Ultraviolet (UV) – reflective paint with ultraviolet germicidal irradiation (UVGI) improves decontamination of nosocomial bacteria on hospital room surfaces. *J Occup Environ Hyg*. 2017; 14(6):456-460. **https://doi.org/10.1080/15459624.2017.1296231**

12. McDevitt JJ, Milton DK, Rudnick SN, First MW. Inactivation of poxviruses by upper-room UVC light in a simulated hospital room environment. *PLoS One*. 2008;3:e3186. **https://doi.org/10.1371/journal.pone.0003186**

13. Tseng C-C, Li C-S. Inactivation of virus-containing aerosols by ultraviolet germicidal irradiation. *Aerosol Sci Technol*. 2005;39(12):1136-1142. **https://doi.org/10.1080/02786820500428575**

14. Cutler TD, Wang C, Hoff SJ, Zimmerman JJ. Effect of temperature and relative humidity on ultraviolet (UV 254) inactivation of airborne porcine respiratory and reproductive syndrome virus. *Vet Microbiol*. 2012;159(1-2):47-52. **https://doi.org/10.1016/j.vetmic.2012.03.044**

15. Hamidi-Oskouei AM, James C, James S. The efficiency of UVC radiation in the inactivation of *Listeria monocytogenes* on beef-agar food models. *Food Technol Biotechnol*. 2015;53(2):231-236. **https://doi.org/10.17113/ftb.53.02.15.3966**

16. Holck AL, Liland KH, Dromtorp SM, Carlehog M, McLeod A. Comparison of UV-C and pulsed UV light treatments for reduction of *Salmonella, Listeria monocytogenes,* and enterohemorrhagic *Escherichia coli* on eggs. *J Food Prot*. 2018;81(1):6-16. **https://doi.org/10.4315/0362-028X.JFP-17-128**

17. Rastogi VK, Wallace L, Smith LS. Disinfection of *Acinetobacter baumannii* contaminated surfaces relevant to medical treatment facilities with ultraviolet C light. *Mil Med*. 2007;172(11)1166-1169. **https://doi.org/10.7205/MILMED.172.11.1166**

18. Wood JP, Archer J, Calfee MW, Serre S, Mickelsen L, Mikelonis A, Oudejans L Hu M, Hurst S, Rastogi VK. Inactivation of *Bacillus anthracis* and *Bacillus atrophaeus* spores on different surfaces with ultraviolet light produced with a low-pressure mercury vapor lamp or light emitting diodes. *J Appl Microbiol*. 2021.https://doi.org/**10.1111/jam.14791**

19. Ruston C, Holtkamp D, Zhang J, Scott J. Efficacy of ultraviolet C disinfection for inactivating Senecavirus A on contaminated surfaces commonly found on swine farms. In: Proc of the 51st AASV Annual Meeting*. American Association of Swine Veterinarians; 2020:374-375.

* Non-refereed references.