DEPRECATED: see updated version: Far UVC Executive Summary (2023-06-29) [Shared]

Germicidal ultraviolet light is highly effective for airborne pathogen biodefense

Summary: The transmission of airborne pathogens in indoor environments is a key biodefense vulnerability. Germicidal ultraviolet-C (UVC) light is a pathogen-agnostic, continuously operating intervention to address it. Upper-room UVC has an established track record and can be immediately deployed. Far-UVC could drastically reduce close-contact transmission if deployed at high doses. Funding should be directed at comprehensive far-UVC safety and efficacy research, and the development of an efficient far-UVC emitter.

Background: Ultraviolet light has shorter wavelengths than visible light, and can be broken into categories. UVA and UVB are present in sunlight, while UVC is filtered out by the atmosphere, and inactivates pathogens by damaging their DNA, RNA and proteins. It likely cannot cause skin cancer, but conventional UVC may cause sunburn and temporary eye damage. It must be installed away from humans, usually in the upper part of the room. Far-UVC also inactivates pathogens, and appears to be much safer for direct human exposure than conventional UVC, and is usually installed as direct overhead lights *(Table 1)*.

	Far-UVC (200-230 nm)	**Conventional UVC (230-280 nm)**	**UVB (280-320 nm)**	**UVA (320-400 nm)**
Germicidal?	Yes	Yes	Some	No
Exposure Risks	Potentially minimal	Erythema, temporary eye damage	Sunburn, skin cancer	Minimal

Table 1. *Summary of UV wavelengths*

Conventional UVC: Germicidal UVC for air disinfection has been used for the control of pathogens since the 1940s. Better vaccines and a few mishandled efficacy studies resulted in waning enthusiasm for UVC air disinfection, though it remains in wide use for water disinfection.

Conventional UVC is primarily installed as upper-room UVC, where lamps are installed on walls or erected on tripods at a height of 7 feet (≈ 2.1 m), directing light away from occupied areas. The light inactivates pathogens as air circulates vertically through the room. Upper-room systems are well-studied, significantly reducing pathogen transmission in epidemiological studies. Upper-room systems are also limited by room dimensions and amount of air circulation, and they carry a small risk of human UVC exposure due to user error. Though upper-room systems are most effective, UVC lamps may also be installed inside air ducts or mobile air-cleaners. Though it cannot prevent close-contact transmission, upper-room UVC is a highly cost-effective method for reducing the transmission of airborne pathogens.

Currently, low-pressure mercury lamps are the primary source of UVC light. They are normal fluorescent lamps made of UV-transparent glass and emit mostly at 254 nm. They are low cost, highly efficient at converting power to light, and last around one year of continuous operation. Health risks from these lamps are low, but mercury is a hazard and is subject to significant regulation. UVC LEDs do not contain mercury, can operate at low power, have flexible form-factors, are more convenient to integrate into an upper-room system, and can be tuned to the maximally efficient germicidal wavelength of 265 nm. However, they are currently much less efficient and more expensive than mercury lamps (*Table 2)*, and have issues with heat dissipation and consistent

manufacturing. Nevertheless, UVC LEDs are rapidly developing, and within a decade these issues are expected to disappear.

Far-UVC: Far-UVC (200-230 nm) inactivates pathogens at similar rates to conventional UVC. Because far-UVC disrupts primarily proteins and not DNA, it can inactivate pathogens relatively resistant to conventional UVC. It may be safe for direct human exposure even at high doses, as it is fully absorbed by the nonliving outer layer of the skin and eye, while readily penetrating single-celled organisms. However, current exposure limits for far-UVC likely do not allow it to perform significantly better than upper-room systems. These exposure limits were raised significantly in 2022, and with more evidence, will likely be raised again. If uncertainties around its safety and efficacy are resolved and a low-cost light source becomes available, widely deployed high-power far-UVC has the potential to drastically curtail the spread of airborne pathogens, even those spreading at close contact.

While far-UVC sources have generally been found to have little-to-no effect on the skin or eye, more evidence is required before wide deployment. No field trials on far-UVC efficacy have yet been carried out, and only one long-term exposure study. Relatively little data is available for eye and damaged skin exposure, and none on potential effects on the skin microbiome or on photosensitive individuals. Far-UVC also generates ozone, itself a hazard. Current systems do not produce enough to be of concern in a typical indoor environment, but ozone generation may become a problem at higher doses. Finally, far-UVC is known to degrade plastics, though this effect may be mitigated by UV-resistant paint.

	Wavelength	Efficiency	Cost per Watt	Lifetime (hours)
Low-pressure mercury UVC	254 nm	30-40%	$2	10,000 (~1 year)
UVC LED	250-280 nm	1-5%	$100-$400	1,000-10,000
Far-UVC KrCl Excimer	222 nm	1-2%	>$1000	4,000
Far-UVC LED	200-230 nm	<1%	N/A	N/A
Blue LED	400-450 nm	60%	$1	30,000-50,000

Table 2. *UVC emitter characteristics. Blue LEDs are given for comparison.*

Wide deployment of high-dose far-UVC is also hindered by the lack of a low-cost light source. Currently, the only practical far-UVC sources are krypton-chloride excimer lamps, which emit at 222 nm and must be filtered to eliminate wavelengths outside the far-UVC range. While they are likely to improve, they remain inefficient and expensive (*Table 2)*. Far-UVC LEDs have been demonstrated in labs, but are not yet commercially viable. It is unclear whether advancements in conventional UVC LEDs will also improve far-UVC LEDs, if novel semiconductor materials are required, or if an entirely new technology will emerge.

Conclusion: The transmission of airborne pathogens in indoor environments is a key biodefense vulnerability. Germicidal UVC light is a promising intervention to address it. For low-cost reduction of airborne illness, conventional upper-room UVC can be immediately deployed. This deployment will also enable larger-scale studies of its performance under a larger variety of scenarios. Far-UVC could drastically reduce close-contact transmission if deployed at high doses, but uncertainties remain. Comprehensive safety trials of high-dose far-UVC should be funded, as well as field-trials of its efficacy, and research into the mitigation of far-UVC's other problems, such as ozone generation and degradation of plastics. Independent of the outcome of high-dose far-UVC

safety trials, far-UVC is still a viable whole-room disinfection strategy. Therefore, funding should be directed at research into cheap, efficient far-UVC emitters.