Germicidal far-UVC light is highly effective for airborne pathogen inactivation

J. Vivian Belenky - Research Fellow, Convergent Research

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. Far-UVC is thought to be safe for direct human exposure and could drastically reduce close-contact transmission if deployed at high doses. Funding should be directed at comprehensive far-UVC safety and efficacy research, the development of clear far-UVC standards and recommendations, 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. (*See Table 1.)*

	Far-UVC (200-235 nm)	**Conventional UVC (250-280 nm)**	**UVB (280-320 nm)**	**UVA (320-400 nm)**
Germicidal?	Yes	Yes	Some	No
Exposure Risks	Potentially minimal	Sunburn, 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. It is widely used for water disinfection, but has until recently been neglected for the sanitization of air. Since it is a skin and eye irritant, it must be installed away from humans, ideally in the upper part of the room. Since pathogens are inactivated as air circulates vertically through the room, upper-room UVC works best with other indoor-air interventions, such as ventilation and filtration. Compared to ventilation and filtration alone, conventional upper-room UVC is highly cost-effective, with low maintenance and low energy costs. However, it requires expert installation, and cannot prevent close-contact transmission.

Far-UVC: Far-UVC (200-235 nm) inactivates pathogens at similar rates to conventional UVC. It is thought to be safe for direct human exposure even at high doses, as it is fully absorbed by the outer layers of the skin and eye, while still readily penetrating and inactivating pathogens. This allows it to be installed as overhead light fixtures. Far-UVC has the potential to drastically curtail the spread of airborne pathogens, even those spreading at close contact. However, several barriers remain to wide deployment:

Safety: At currently allowed doses, far-UVC is likely as good or better than upper-room conventional UVC. At much higher doses, far-UVC has the potential of being *much* better than conventional UVC, perhaps even to the point of inactivating 99.9% of pathogens within one second of exhalation. Far-UVC has already been found to have little-to-no effect on the skin at very high doses. However, evidence is more limited for the eye, and on long-term exposure. There is also limited evidence for the effect of far-UVC on sensitive phototypes, open wounds, and on the skin microbiome.

Another major uncertainty far-UVC is its secondary chemistry. Far-UVC may degrade certain plastics, which may release volatile organic compounds into the air. It also produces ozone, which may react to produce secondary organic aerosols and particulate matter. Adequate filtration and ventilation

substantially mitigate the risks from ozone produced by low-power far-UVC, but high-power systems will require much more care in system design. Though there is reason to be optimistic, all these safety questions must be comprehensively addressed before wide deployment is possible.

Efficacy: Far-UVC has not yet been demonstrated in a real-world setting. For wide adoption, it is crucial to get these early studies right. Upper-room UVC lost traction for air disinfection in the 1950s partly because early efficacy studies were not designed appropriately. Far-UVC efficacy studies must be designed to robustly capture the effects of far-UVC on transmission. This requires an isolated population, a sufficiently high attack rate, and sufficiently high-power irradiance. Proposed settings allowing for this include cruise ships, oil rigs, long-term care homes, or military barracks.

Standards: A key outcome of both safety and efficacy testing will be the development of clear standards for manufacturers of far-UVC devices. Currently, manufacturers exist in a state of uncertainty over conflicting standards. As a result, many available far-UVC devices are unlikely to have significant disinfection ability, and some may have safety risks. Clear standards will ensure that available far-UVC systems have adequate disinfection ability while not compromising safety.

Emitters: Currently, the only practical way of generating far-UVC light is with krypton-chloride (KrCl) 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 significantly, they remain relatively inefficient, expensive, and are limited in scalability. In the same way that the white LED is displacing most other visible light sources, a solid-state far-UVC source is likely required to achieve ultra-scalability, high efficiency, and long lifetimes. Far-UVC LEDs have been demonstrated in labs, but are not yet commercially viable. Current material and device platforms may never reach efficiencies and lifetimes comparable to the white LED, but development of a novel material or a major breakthrough in device design may change this.

Conclusion: The transmission of airborne pathogens in indoor environments is a crucial challenge in public health. Far-UVC could drastically reduce indoor transmission at currently allowable doses, and could significantly reduce even close-contact transmission if deployed at high doses. In order to achieve wide-deployment, funding should be directed into:

1. Comprehensive far-UVC safety testing
2. Robust efficacy trials of far-UVC effects on pathogen transmission
3. Development of clear far-UVC standards for manufacturers
4. Development of a cheap, scalable, highly-efficient far-UVC emitter

Key Papers:

Reed, N.G., 2010. The History of Ultraviolet Germicidal Irradiation for Air Disinfection. Public Health Rep 125, 15–27. doi: 10.1177%2F003335491012500105

Welch, D., Buonanno, M., Grilj, V., et al., 2018. Far-UVC light: A new tool to control the spread of airborne-mediated microbial diseases. Sci Rep 8, 2752. doi: 10.1038/s41598-018-21058-w

Görlitz, M., Justen, L., Rochette, P.J., et al., 2023. Assessing the safety of new germicidal far-UVC technologies. Photochemistry and Photobiology. doi: 10.1111/php.13866