The Case for Ultraviolet Germicidal Irradiation (UVGI)

A summary report prepared for UK and Scottish governments

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Summary Statement

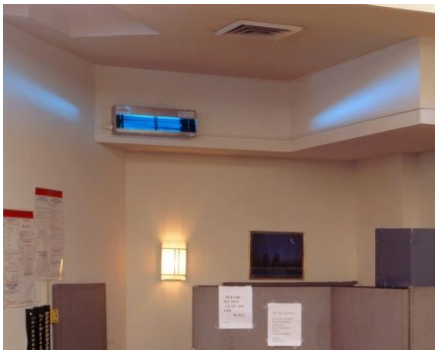
As a means of preventing airborne transmission of SARS-CoV-2 we advocate the immediate installation of the safe and proven upper room 254nm UVGI in indoor public spaces with low air changes per hour and/or recirculated air. We further believe that if the on-going research into the new 222nm UVGI continues to demonstrate its safety, then this technology should be adopted as it is likely to be even more effective than 254nm UVGI, working continuously to inactivate viruses and bacteria in the air we breathe and on surfaces we touch.

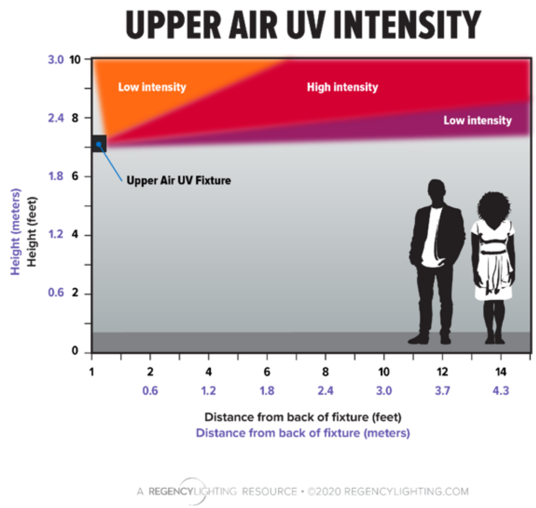
Two types of UV-C technology:

- 254 nm upper-room UVGI
- 222 nm full room illumination

254 nm upper-room UVGI

- Existing technology that could be implemented now and has appropriate regulation and guidance
- Ultraviolet-C (UV-C) inactivates viruses and bacteria in air, on surfaces and in water (*Kowalski 2009*)
- UV-C inactivates SARS-CoV-2, the virus responsible for Covid-19 pandemic (*Heilingloh et al. 2020; Inagaki et al. 2020, Kitagawa et al. 2020, Ozog et al. 2020*)
- For surfaces and water, UV-C is used extensively and routinely (water treatment plants, hospitals) with excellent UK companies operating in this area (*DWI 2016, SAGE 2020*)
- Upper-room UVGI is a beam of 254-nm UV-C that is above head height and decontaminates the air circulating through the beam
- Upper-room UVGI is proven to reduce the spread of airborne viruses:
    - 1957 influenza pandemic infection rates
        - Hospital wards with upper-room UVGI **1.9%**
        - Without upper room UVGI **18.9%** (*Sabino et al. 2020*)
    - 1937 – 1941 measles infection rates
        - Classroom with upper-room UVGI **13.3%**
        - Classrooms without upper-room UVGI **53.6%** (*Nardell and Nathavitharana 2019*)





- “Upper-room UV lights and negative air ionization each prevented most airborne TB transmission detectable by guinea pig air sampling. Provided there is adequate mixing of room air, upper-room UV light is an effective, low-cost intervention for use in TB infection control in high-risk clinical settings” conclusions from a study involving SAGE member Catherine Noakes (*Escombe et al. 2009*).
- Health Facilities Scotland, NHS National Services Scotland have a review for light based technologies for the decontamination of air, year of publication unknown (http://www.hfs.scot.nhs.uk/publications/1478698837-Light%20Based%20Technologies%20final%20version.pdf)

* Airborne transmission of SARS-CoV-2 can occur in enclosed spaces with inadequate ventilation or air handling and where there is prolonged exposure to respiratory particles, particularly when under exertion such as shouting, singing and exercising (*CDC 2020*)
    - As of 21/10/2020 WHO state that large droplets are the primary mode of transmission. However there is a large contingent of scientists who believe aerosol transmission is the likely dominant transmission route (American Association for Aerosol Research https://youtu.be/g9CHnUMt2gY)
* Therefore research indicates upper-room UVGI would be useful to reduce the spread of SARS-CoV-2
    - UK academic research shows possible to achieve >90% disinfection rates with upper-room UVGI (*Beggs and Avital 2020*)
    - Expected equivalent air changes per hour (AC/h) from upper-room UVGI = **109 AC/h**
    - Worst case equivalent air changes per hour (AC/h) = 11 AC/h
    - CDC recommends 6 – 12 AC/h for effective air disinfection
    - With 10 AC/h there is 99% removal by efficiency of airborne contaminant in 28 minutes
    - With **50 AC/h** there is 99% removal by efficiency of airborne contaminant in **6 minutes** (*CDC Enivornmental Infection Control Guidelines, Appendix B. Air* https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html#tableb1)
* Upper-room UVGI well established technology in countries with a high TB burden, such as homeless shelters in USA and prisons in Russia. No commercial demand in UK prior to 2019 and therefore discontinued by many companies (*personal communication*).
* Upper-room UVGI is safe as people are not irradiated with the UV-C radiation (*Nardell et al. 2008*). If 254 nm is incident on skin and eye it will cause an acute sunburn and keratitis (inflamed front of the eye) but it is **not** linked to long term effects such as skin cancer (*Kowalski 2009*)
* Movement of air in the room and proper installation in locations that are the primary transmission route are key (*Nardell and Nathavitharana 2019*)
* UVGI Best Practice guidelines exist (*Martin et al. 2008*)
* Unsure of manufacturing capabilities within the UK
* Estimated cost: $1000 for 28 m^2 (https://insights.regencylighting.com/how-much-does-upper-room-germicidal-uv-cost)

Suggested next steps

- Upper-room UVGI could be installed in locations with low AC/h
- Initially high-risk areas, primary transmission routes, and areas with aerosol generating procedures
- Examples could include: care homes, high risk hospital clinics (e.g., dialysis units), dentist surgeries
- Further roll out to businesses, e.g., hospitality, indoor sports and retail sector

222 nm full room illumination

- New technology just coming to market that requires implementation and would benefit from further research
- UV-C radiation of wavelength 222 nm is as effective as 254 nm at inactivating viruses and bacteria, including SARS-CoV-2 (*Buonanno et al. 2017, Buonanno et al. 2020, Kitagawa et al. 2020, Narita et al. 2020*)
- 222-nm UV-C would illuminate all of an occupied space, continuously decontaminating the air we breathe and the surfaces we touch
- This wavelength does not have the same acute effect on the skin or eyes. Human, animal studies and computer simulations suggest it is also not going to induce skin cancers (*Barnard et al. 2020, Buonanno et al. 2017, Fukui et al. 2020, Kaidzu et al. 2019, Narita et al. 2018,Yamano et al. 2020)*
- If the above is true then, in an ideal future, 222 nm will illuminate every public space, inactivating viruses and bacteria in the air as we breathe. With direct illumination of the environment, instead of just the upper-room, it is thought it would be faster at inactivating micro-organisms reducing the chance for spread further.
- Limited number of manufacturers in this area but more coming online. Unsure of the potential manufacturing capability in the UK.
- Several systems now installed in countries where there are major manufacturers of this technology, i.e., at hospitals throughout Japan (Ushio headquarters) and at various businesses in USA (Healthe headquarters - https://youtu.be/WxFbPkCvAE0)
- Research in this area is of the highest quality but limited due to small number of research groups and relatively limited period of investigation. There is lots of research that could be performed.
- University of St Andrews and Photobiology Unit at Ninewells Hospital in Dundee have built a number of relationships with industry, academia and healthcare and are in an excellent position to co-ordinate and collaborate on far-UV-C research
- This new technology requires standardisation, regulation and public health opinion
- Estimated commercial cost: \$1000 - \$2800 for ~7m^2 (https://www.newsweek.com/uv-lamp-coronavirus-japan-1533559)

Suggested next steps

- Controlled skin safety study (Photobiology Unit, Ninewells Hospital, ~ £150K)
- Longer term skin safety studies (University of St Andrews & Ninewells Hospital, ~£150K)
- Efficacy of far-UV-C to inactivate aerosolised micro-organisms (£50K applied for, University of St Andrews)
- Modelling of light distribution and computational fluid dynamics for far-UV-C room illumination (£50K applied for, University of St Andrews)
- Far-UV-C has been demonstrated to inactivate viruses in aerosolised chamber experiments. We would like to see such experiments scaled up to large area studies at secure facilities such as Porton Down.

Appendix: Further Information

History

Ultraviolet radiation has been known to destroy and inactivate bacteria and pathogens since the 1880s. It was widely adopted from the 1930s onwards with trials of shielded "upper room" UVGI lamps demonstrating its efficiency in reducing the transmission of measles among schoolchildren and tuberculosis within hospital wards. It is still used in hospitals today as a means of disinfection, but rooms and wards must be unoccupied because the conventional mercury vapour lamps emit at UV wavelengths around 254nm that can penetrate the skin and eyes presenting a small but not insignificant health risk.

Over the last few years there is a growing body of research on shorter wavelength UVGI lamps (primarily KrCl excimer lamps) that operate at far-UV-C wavelengths around 222nm. Studies show these lamps are just as efficient in their germicidal properties as conventional 254nm lamps. At far-UV-C wavelengths shortward of 230nm, proteins in the surface layers of the skin and eyes prevent the light from penetrating and causing harm, making such devices safe to be used in occupied spaces and presenting a new and potentially very efficient technology for rapidly inactivating viruses and preventing their airborne transmission.

With the increased use of anti-viral drugs and vaccination programmes, UVGI lighting slowly fell out of widespread use, but we believe that both conventional upper room and the emerging far-UV-C lighting have an immediate role to play not just for the current pandemic, but to cut down transmission of other airborne pathogens including influenza and hospital acquired infections (HAI) which are major causes of death and burdensome to healthcare organisations worldwide.

Safety & Efficacy

Studies stretching back over eighty years have demonstrated the efficacy of upper room UVGI lighting for destroying bacteria and inactivating viruses. Properly installed upper room UVGI can be equivalent to twenty-four air changes per hour and can have an immediate impact in poorly ventilated environments. The upper room UVGI lighting is installed in enclosures that prevent any of the harmful UV light shining on people. For the new far-UV-C lighting, the outer layers of the skin and eyes provide natural protection and on-going animal and human studies indicate the safety of this technology.

Although the far-UV-C lamps emit the majority of their radiation around 222nm, they also emit longer wavelengths that can penetrate the skin and cause burning and the production of pre-cancerous cells. It is therefore essential that light at these harmful wavelengths is suppressed to allow the safe deployment of far-UV-C lighting in occupied spaces. Commercial filters exist and are used to suppress the harmful light.

For the current pandemic, studies show that very low doses of UVGI are required to inactivate SARS-CoV-2 and can be delivered in around twenty-five minutes at current safety limits. As the safety of far-UV-C devices is demonstrated, raising the current regulatory limits would allow lamps to deployed at increased intensity levels and reduce the virus inactivation times to seconds.

Current safety limits are for maximum accidental exposure and not seen as a limit for normal daily exposure. We would like this to be addressed based on the results of recent and on-going safety studies.

Long term studies are needed and are being planned, but we believe that with the on-going impact the virus is having on lives and livelihoods, the benefits of installing filtered far-UV-C lighting outweigh the risks.

The manufacture of filtered far-UV-C lighting is still at a very low level, but since the onset of the COVID-19 pandemic the production is being increased in Japan (USHIO) and the USA (Eden Park). USHIO's "Care 222" lamps are being installed in hospitals throughout Japan and they have signed agreements with Acuity in the USA and Signify in Europe. Eden Park's lighting is now being installed in the USA in hospitality venues and the locker room of The Miami Dolphins.

We would like to see the regulatory limits reassessed in light of new safety studies. With current limits, the virus can be inactivated (to the 99.9% level) in around 25 minutes. Published and on-going safety studies indicate the safety limits at 222nm could be increased by a factor of at least ten and possibly up to 100. This would allow the installation of lighting with higher wattages thereby reducing the inactivation time to less than a minute.

Ultraviolet radiation

Ultraviolet radiation is broadly defined as light with wavelengths in the range 100nm to 400nm (1nm = one billionth of a metre) and is further subdivided into three broad categories by wavelength, UV-A (315nm-400nm), UV-B (280nm-315nm), and UV-C (100nm-280nm). The Sun emits light at all UV wavelengths, but only UV-A and UV-B can reach us on Earth, with ozone in the atmosphere absorbing all of the UV-C light. It is well established that UV-A and UV-B can penetrate into the skin and cause DNA damage and skin cancer, hence the public health information campaigns to use sunscreen and avoid excessive exposure to sunlight. UV-C light cannot penetrate as far into the skin, but UV-C wavelengths from 230nm-280nm can all lead to skin and eye damage, although there is little evidence of cancer risks and any damage due to accidental exposure to UV-C generally clears up in a day or two. At wavelengths shorter than 230nm, UV-C light is strongly absorbed by proteins in the stratum corneum (the uppermost skin layer containing dead cells) and tear layer of the eye. Recent studies of animals, humans, and computer simulation all demonstrate the effectiveness of this natural protective barrier allowing filtered far-UV-C devices to be deployed in occupied public places.

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