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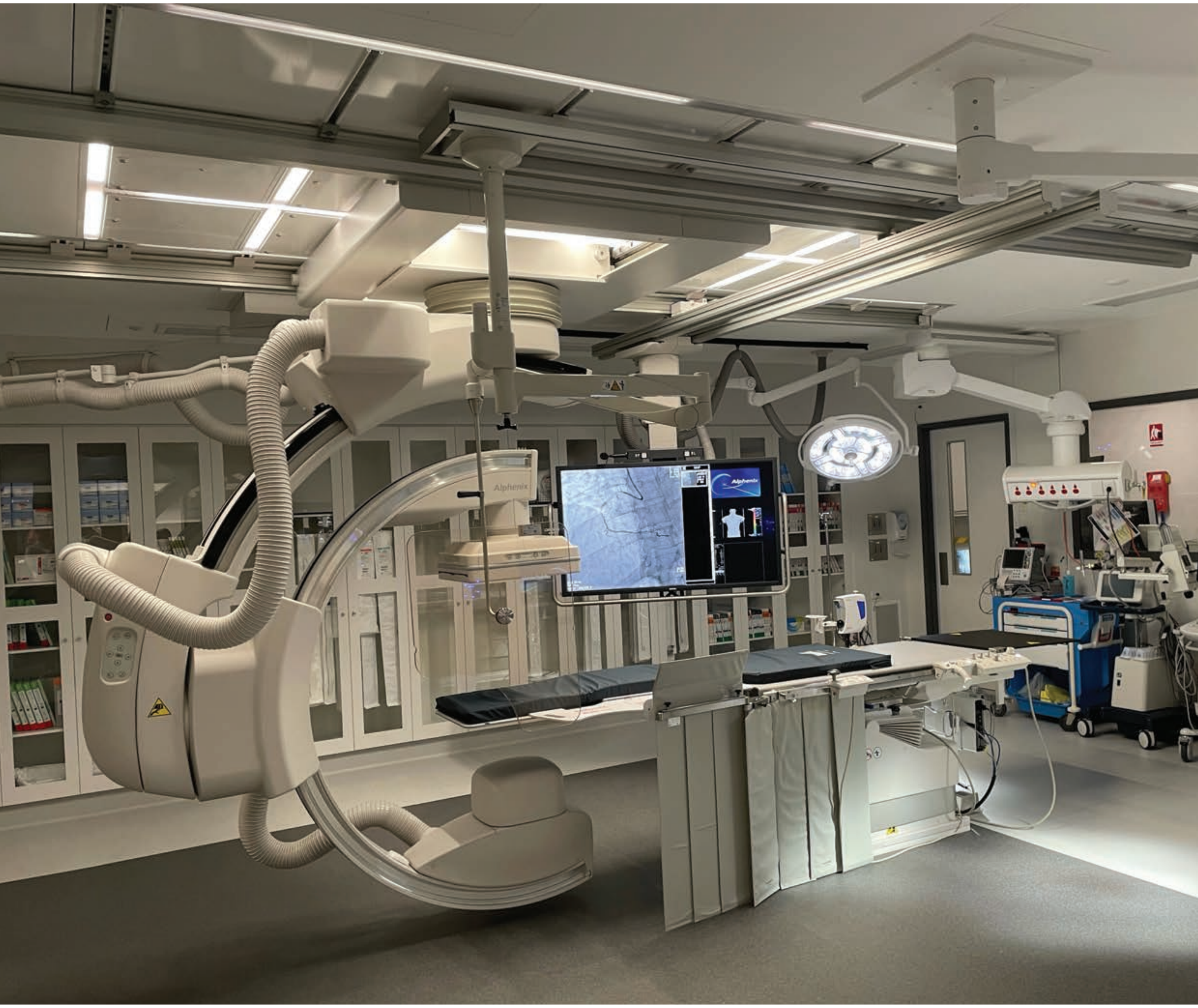

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AI – MAKING THE IMPOSSIBLE POSSIBLE

UV-C RADIATION TO COMBAT HEALTHCARE ASSOCIATED INFECTIONS

Samuel Walters

1.1.1 Healthcare Associated Infections and personal impact

The Australian Commission on Safety and Quality in Healthcare has disclosed data indicating that each year, there are approximately 165,000 patients in Australia who suffer from healthcare associated infections (HAIs). While this statistic seems significant, it does not fully convey the magnitude of impact this has on the lives of patients. Personally, I was one of the cases that experienced a HAI after a simple surgery in the middle of 2021. Ultimately, a day procedure evolved into a 3 night stay in the intensive care unit, 3 further surgeries, 3 weeks in hospital and 2 months away from work. This experience has led to the research within, detailing various emerging technologies which may reduce the likelihood of HAI's for future surgical patients. As an electrical engineer with experience in designing operating theatres and medical imaging rooms, this paper focuses on the impact buildings services engineers can have in improving the quality of healthcare to patients.

1.1.2 Background

As hospitals deal with sensitive and critical patients, it is necessary for these spaces to remain clean and free of pathogens that could cause infections and other health complications. Overall, 7% of all hospitalised patients acquire a healthcare associated infection, increasing the cost of these patients' admissions by an estimated 8.6% [1]. This is particularly relevant in the current global climate, with SARS-CoV-2 (COVID-19) placing significant strain on the healthcare system worldwide.

One potential method of combatting HAIs is through the use of UV disinfection, specifically a narrow band of the spectrum between 200-280nm known as UV-C. UV-C is capable of penetrating the nucleic acids that are essential for life (DNA/RNA) and neutralising bacteria and viruses [2]. This is not a new concept; UV-C radiation has been used throughout history as a form of disinfection in heating, ventilation and air conditioning (HVAC) systems and to assist with water disinfection and other reservoirs for microbial growth and proliferation. Due to the COVID-19 pandemic, there has been renewed interest in this technology to supplement traditional infection control methods in healthcare environments.

1.1.3 First Principals – UV-C Radiation and Safety

The UV spectrum exists on the electromagnetic spectrum between the wavelengths of 100nm to 400nm. Often, this is divided into four categories: UV-A (315nm to 400nm), UV-B (280nm to 315nm), UV-C (200nm to 280nm) and Vacuum-UV (100nm to 200nm) which is often considered as a subset of UV-C. Figure 1 - Wavelength Spectrum (UVC) [4] below demonstrates where these bands of wavelengths sit on the spectrum. It is understood that as the wavelength decreases in length, it is both more effective at inactivating viruses and more damaging to human cells. This strong inactivation characteristic is the reason why UV-C has been commonly used in the past for UV disinfection purposes. However, the World Health Organisation found that while the shorter wavelength increases the damaging effects of the UV radiation, it also decreases the ability for the radiation to penetrate the skin within the UV wavelength band [3].

The vast majority of bacteria and viruses tested to date have responded to UV-C disinfection including SARS-CoV-1, MERS-CoV and more recently COVID-19 [5]. Studies on the effectiveness of this these UV technologies have reported that UV-C technology can significantly decrease the bioburden of multidrug-resistant and spore-forming pathogens on contaminated surfaces in healthcare facilities by up to 4 log. This is a comparable effectiveness to cleaning with Hydrogen Peroxide. Further, these studies have found UV-C to be effective in inactivating airborne flu viruses [5].

With all these advantages, it also needs to be noted that typically UV-C radiation is harmful to human cells. UV-C radiation with a wavelength of 254nm (typical germicidal lamps) has been found to increase the likelihood of skin cancer and cataract damage. For this reason, UV-C radiation is not yet widely used throughout the industry as a passive disinfection method. However, recently there has been significant research into the 222nm spectrum of radiation, dubbed 'Far UV-C'. Research has found that radiation at this wavelength maintains its disinfecting abilities but is not able to penetrate the outer layer of skin (stratum corneum) nor the outer surface of the eye. This is because 222nm Far-UV-C radiation has enough range to traverse microbes smaller than human cells (less than 1μm as opposed to typical 10-25μm of

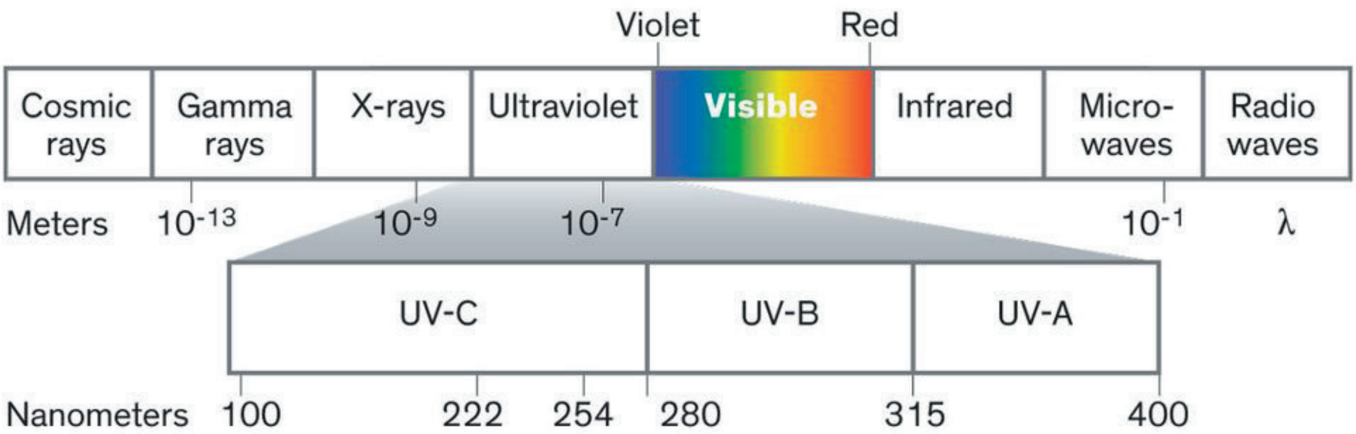

Figure 1 - Wavelength Spectrum (UVC) [4]

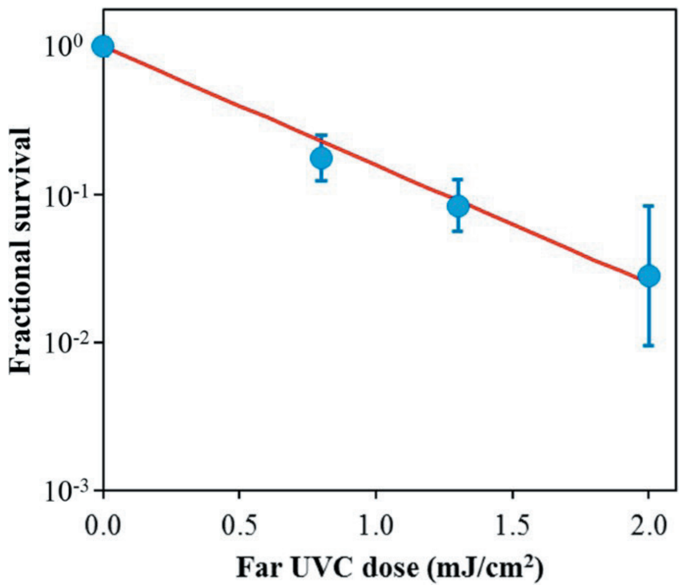

Figure *2* - Dosage Vs Fractional Survival rate of H1N1 Influenza *[7]*

human cells), but is largely absorbed and attenuated before reaching the human cell nucleus [6]. Similarly, the cornea has an approximate 500 µm thickness, essentially preventing 222nm UV radiation from penetrating through the cornea.

1.1.4 Passive Far UV-C Radiation

As discussed above, the development of Far UV-C radiation lends itself to the possibility of passive disinfection without causing damage to human occupants. A study performed in 2018 found that that Far UV-C radiation at 222nm was able to inactivate >95% of aerosolized H1N1 influenza virus with a relatively low dosage of 2mJ/cm^2 [7]. The figure below shows the disinfection capability in a measure of dosage compared with the fractional survival rate of the virus.

To put these dosage levels in perspective, Columbia University researchers performed a trial on mice administering a dosage of 157mJ/cm^2, approximately 78 times the dosage mentioned above. This study found that these mice experienced no statistical difference to the control (unexposed) mice in all categories measured to determine damage caused by exposure to 222nm Far UV-C radiation (Epidermal Thickness, Keratinocyte Proliferation, Premutagenic UV-Associated DNA Lesion, Skin inflammation and Skin Differentiation) [6]. This is not isolated research; in July 2020, researchers from Kobe University Osaka conducted a similar study on XPA knockout mice, a breed that is characterised by a highly photocarcinogenic phenotype to UV radiation [8].

Recently, multiple human tests have been conducted to assess the safety concerns posed by UV-C disinfection. One study found that the unfiltered lamp spectrum contains UVB (3%) and UVA (4%) which are both known to cause DNA damage [9]. However, these waveforms can be filtered to reduce the amount of UV-A and UV-B radiation that humans are exposed to. This study concluded that even at high exposure doses, filtered 222nm UV-C is unlikely to present a carcinogenic risk due to direct DNA damage. This same conclusion has also been reached by a separate human trial where 16 patients were exposed to UV-C dosage. In this study, each patient was exposed to a number of filtered UV-C sessions. None of the 16 patients involved in these tests had observable complications or side effects [10]. It is important to note that this testing did not involve continual passive exposure and as such only evaluates the short term exposure of passive Far UV-C lighting.

To address the safety concerns associated with UV-C, there are some products available outside Australia which currently use motion detectors so they only operate while a space is unoccupied. Of note, a recent study evaluated the efficacy of a 222nm emitting device within a shared bathroom. This study found that the colony forming units of aerobic bacteria were reduced compared to the control bathroom [11].

In 2021, products have been released to the Australian market incorporating 222nm Far-UVC radiation. While this technology is under continued development, it appears to be a promising method of passive disinfection to assist with the reduction of HAI's in a healthcare setting and may become a prominent technology in the future.

1.1.5 UV Disinfection Robots

As mentioned in section 1.1.3, there are inherent safety issues with traditional forms of UV-C disinfection. A solution that has been implemented internationally involves UV-C emitting disinfection robots, which rely on the rooms being unoccupied for disinfection. These robots can traverse floors and rooms, disinfecting spaces that are scheduled to be unoccupied. This allows the rooms to be disinfected using 254nm UV-C radiation which has proven germicidal effects. These robots can disinfect a standard hospital patient room within 10-15 minutes, emitting a dosage of 20J/m^2/s [12].

There are many advantages of UV disinfection robots. These robots have been found to remove the human error associated with traditional manual UV disinfection by following a set automated route. Further, the disinfection robots also provide added protections to healthcare workers by performing disinfection prior to manual cleaning of spaces. Compared to the Far UV-C method mentioned above, these robots are restricted by their inability to operate in occupied spaces. This prevents any UV-C disinfection from occurring while patients are in the room, reducing its effectiveness in virus suppression.

1.1.6 Entry/Exit Disinfection

To assist in managing the COVID-19 pandemic, various countries have implemented 'sanitisation gates' which effectively administer brief bursts of 254nm UV-C radiation to people as they pass through a gate. There have been concerns raised over this repeated and uncontrolled UV exposure, because it had not been fully tested prior to implementation. Further, a paper produced by the King Edward University notes that this may provide people with a false sense of security and may lead to less observance of scientifically backed methods of disinfection such as hand washing [13]. Consequently, in the absence of further research regarding safety and effectiveness, this is not yet an industry recommended approach to assist in reducing HAI's.

1.1.7 Passive 405nm Lighting – Visible Spectrum

Recently, manufacturers released luminaires incorporating lighting with a wavelength of 405nm as a method of achieving continuous environmental disinfection. This wavelength sits within the visible spectrum and appears 'blue-violet', however products have been created to balance this with a white light to reduce the coloured glow that is produced. While this spectrum of light is not considered dangerous to human occupants, it is not capable of inactivating most viruses and is generally not considered to be an effective germicide compared to its UV-C counterpart [14].

Although this form of disinfection is not as germicidal as UV-C lighting, it presents a low risk to healthcare facilities and is currently being developed for use in the Australian market. Laboratory tests performed by Hubbell revealed that salmonella can be inactivated within 11 hours under exposure to this spectrum of light [15]. Although this is not as effective as the UV-C radiation considered by this report, this technology is capable of supplementing current disinfection methods to further decrease the risk to patients and healthcare workers.

1.1.8 Conclusion

While there is still ongoing research regarding the safety of various UV-C radiation measures, it appears that this technology will play a significant role in the future of our healthcare industry. If further testing confirms that Far UV-C radiation is safe for human exposure, this has the potential to radically transform the sterility of our hospitals and decrease the rate at which HAI's occur. It is recommended that new developments in this technology are closely monitored to ensure our healthcare system is always adapting and progressing to provide the best care possible.

1.1.9 References

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