ENGINEERING AND MEDICINE COME TOGETHER IN THE TIME OF THE PANDEMIC

*A team within the Department of Electronic Systems Engineering, led by **Dr Inġ. Marc Anthony Azzopardi**, has designed and built prototype equipment that uses short-wavelength Ultraviolet Germicidal Irradiation (UVGI) to substantially reduce the viral bioburden of up to nine disposable face respirators concurrently, so that they may be reused in greater safety by medical personnel facing shortages. Engineering Today Editor, **Rebekah Cilia**, visits the laboratory to discuss this novel biomedical engineering invention.*

Given that Dr Inġ. Azzopardi works in electronics, and sometimes handles toxic materials and fine powders, he frequently uses Personal Protective Equipment (PPE). Some of the best PPE for aerosols are Face Facepiece Respirators (FFRs), which fall under several different categories. FFRs are different from surgical masks and are much better fitting to the face. These high-performance respirators (such as those rated to the American NIOSH N95/ N100, or the European EN149 FFP2/FFP3 standards), use electrostatics to attract and then trap the tiniest of particles inside their non-woven polypropylene filters.

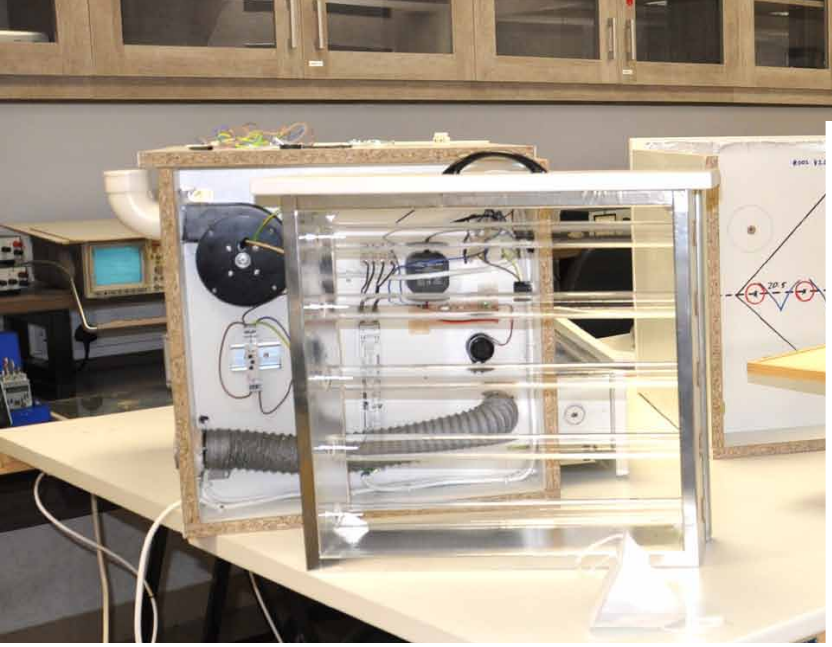
Electret materials are dielectric materials that retain a semi-permanent electrical charge within them. As long as this electrical charge persists inside the material making up a face respirator, very small particles (down to a few tens of nanometres) are reliably lodged within the mask. This is what gives these respirators the prized 95 percent (or higher) filtration efficiency, without making it unduly difficult to breathe through.

Dr Inġ. Azzopardi also has experience using ultraviolet (UV) for water treatment. This was, initially, a hobby for Dr Inġ. Azzopardi, using UV to treat pond water. He explains that UV works by affecting the DNA of all microorganisms - by using a particular wavelength that damages the DNA in a way which creates crosslinks and dimerization, which does not allow the microorganism to replicate.

Having this background at the start of the year, following the news in China that a novel Coronavirus had been discovered, Dr Inġ. Azzopardi got thinking. He knew, immediately, this virus would be serious and foresaw that it would be difficult to contain. Dr Inġ. Azzopardi stocked up on PPEs for the medical practitioners in his family, but there was a limit to how much he could purchase.

He explains that before the pandemic broke out, masks of a renowned brand, were in the region of about €10, but then prices started to soar to the point that the same mask was being sold for as much as €300. These masks were no longer available through the normal channels but only found on the black market.

“All the manufacturing nations stopped exports of these products and by March it was nearly impossible to get them. That is



when we started worrying in Malta," Dr Inġ. Azzopardi explains. Although with careful rationing his stock would last for a while, there came a time when he knew it would not be enough and he needed to find a way to reuse them.

Dr Inġ. Azzopardi explains that such FFRs are always meant to be disposed of since once they are exposed, they are contaminated. He, however, notes that in certain industries it is allowable to reuse some mask brands, more than once, if used in a specific way. In the case of the novel coronavirus pathogen, however, this is problematic, since the mask will become contaminated once worn and touched. Research suggests that it may take many hours, possibly several days for viable virus concentrations to drop sufficiently to make used masks safe to handle or reuse.

As a side note, Dr Inġ. Azzopardi remarks that when the public uses masks, the situation is different. The probability of exposure to the virus is low, and the mask is there to protect others and lower the rate of transmission, whereas in a medical setting, where the probability of encountering the virus is much higher, using high performance FFRs, rather than surgical masks, is needed to protect the user, as well. "The user's face is completely sealed to the mask, like an O-ring."

Dr Inġ. Azzopardi notes that in medical settings it is never recommended to reuse FFRs but in the pandemic situation, a solution had to be found, since buying new ones of the requisite quality, became close to impossible. "We started thinking about different possibilities. This problem was being thought about worldwide and there were a few papers, written a while ago, that had foreseen this issue."

It was quickly discovered that if these masks are sterilized using conventional methods, such as washing in alcohol and autoclaving, the masks are destroyed - the electrostatic charge is discharged. Once the charge is removed, the pores are open and most airborne pathogens can pass through. An N95 FFR would be de-rated to around N25.

In a hospital, UV-C tower lamps are used in operating theatres to sterilize all surfaces, Dr Inġ. Azzopardi explains, adding that within a matter of seconds all pathogens, exposed to UV-C, are deactivated.

"A US team in Nebraska had some of these UV-C towers available, and were being faced with a growing pile of used masks needing decontamination, but they did not have the equipment to decontaminate the masks in. Their solution was using a room and hanging the masks on a washing line in front of the UV-C tower lamps!" Dr Inġ. Azzopardi explains this was one of various makeshift solutions, around the time of March, and although protocols were set up, it was each hospital trying their best.

At the same time, Dr Inġ. Azzopardi had started to experiment by making a box, lining it with reflective aluminum foil and

using this UV-C process at home. “Most of my family work in the health sector, so at this point, the aim was to try to find a solution for them.”

“I started reading up and stumbled on the process being used in the US and thought there must be a better way than washing lines,” Dr Inġ. Azzopardi says with a slight chuckle. The process needs to be more controlled, delivers repeatable doses, and less prone to human error, so he got to designing a cabinet with a drawer for the FFRs, made at a carpenter, and assembled the working prototype in one week. It was announced in the media to gauge feedback.

Within just a few hours, Mater Dei Hospital approached Dr Inġ. Azzopardi and within just a few days, the medical and engineering field collaborated to work on improving this new biomedical engineering technology.

All sorts of questions were put to Dr Inġ. Azzopardi and the prototype was fine-tuned. “Whereas the US was collecting masks and putting them through a central decontamination room, causing somewhat of a logistical problem, we decided on one unit for each ward. All nurses would be in control of the process.”

The unit includes a quartz tube rack, where the masks are flipped open and placed on top. Dr Inġ. Azzopardi notes the importance of masks being placed properly, “you need to create something which forces the user to open the masks, so as they would be completely irradiated on both sides. In this case, they would just fall through, if not opened properly.” Quartz was used because ordinary glass completely blocks UV-C and a local manufacturer of quartz was available.

Dr Inġ. Azzopardi notes that “It had to be made quickly with the materials available in a pandemic, when everyone is in lockdown and all the shops are practically closed, no import, no export, and postal services working at a very slow rate. It was a matter of building something with what we could find.”

“It is simple in reality, although it took some thought,” he goes on to say. It was not possible to seal the unit, so negative pressure had to be created with a blower, and the air filtered. The filter used is equivalent to the N100 masks but is actually from a vacuum cleaner. The UV kills any pathogens before they can leave the unit, since the filter is itself irradiated at the same time as the respirators.

Putting the unit together was not the only task, however, as Dr Inġ. Azzopardi rhetorically questions: “what if a lamp goes out? You would have a false sense of security. You also have to control who accesses the unit.” Looking through a peephole in the unit, one would notice if a lamp is off but that would not be practical as routine UV-C exposure would damage the eyes, so fluorescent Polymethylmethacrylate (PMMA) windows are used. Fluorescent PMMA, once exposed to UV, turns it into safe visible light, therefore confirming both lamps are on.

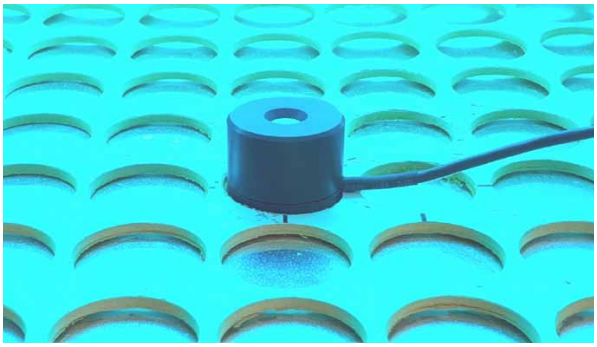
As an additional safety measure, electrical currents to the lamps are measured using a resistor, so if there is a decrease in the voltage drop, and therefore a drop in current, it is connected to an opto-coupler to drive a sounder. “But what if the sounder goes out? Our solution to this was to test the sounder every time the unit is switched on and off,” Dr Inġ. Azzopardi continues.

The length of time the masks need to be exposed to the UV-C radiation needs to be carefully regulated since too little will not decontaminate the masks, and too much will destroy the masks. A few papers were already studying the endurance of the masks, but Dr Inġ. Azzopardi had to perform his tests. "Initially we had to make educated guesses and err on the side of caution."

The UV-C penetrates the mask layers but with each layer, the intensity of the UV-C decreases. Dr Inġ. Azzopardi notes that they had to study how each layer was being hit by the UV and to make sure the innermost layer is also reached, with the required intensity.

"Initially, there was no data on the novel coronavirus pathogen to know how much UV-C is required to deactivate it, but there are for other similar viruses and they replicate quite well for other viruses. These are known as surrogate viruses. Based on this data, you can come up with the time and intensity needed to destroy the virus with UV-C, always keeping a factor of contingency."

Initially, the team did not even have the equipment to measure UV-C, so it was simply based on calculations – the lamp power and efficiency, surface reflectance and exposed area. Once the equipment arrived, they could verify their calculations, and Dr Inġ. Azzopardi notes "it was quite close!"



Reflectors were also added to the unit to make it more efficient, but only polished metal could be used. An ordinary mirror, using glass, would absorb all the UV-C, so aluminum foil was used.

Ten units were produced with only one return, having a minor issue with the alarms. One will be kept for research purposes, Dr Inġ. Azzopardi notes, adding, "since the situation is currently not so bad" (at the time of writing). He adds that although he does hope the pandemic will end soon, he notes a problem with PPEs will always be present, since they expire. The electrostatic charge is lost gradually so large quantities of PPEs cannot be stockpiled, "so it is always a good idea to have this [unit] as a backup".

"Now we have the luxury of time, so we can keep on researching it, so that health professionals can use it with more peace of mind. Having such an expensive, technologically advanced mask used only once is also a waste, and such waste could be reduced with this unit."

Marc Anthony Azzopardi is an aerospace electronics engineer by profession. He graduated in Electrical Engineering in 2002 and joined the University of Malta to embark on a research career. He holds a Masters in electronic systems and obtained a PhD in Aerospace Engineering from Cranfield University in 2015. Dr Azzopardi manages an active electronics research portfolio that led to internationally granted patents and several scholarly publications. He is a principal investigator of various state-funded product design projects, including developing Malta's first spacecraft. His research interests include ruggedizing electronics for extreme environments such as mitigating the effects of ionizing radiation on electronic devices and other spacecraft materials in Earth orbit. His interest in N95 decontamination stems from prior use of FFR masks in a variety of settings as well as first-hand experience with UV-C equipment design for water sanitization applications and aquaculture.