The history and science behind airborne infections and the use of ultraviolet irradiation for disinfecting indoor air

Interview with Dr. Ed Nardell, part 2

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Dr. Ed Nardell has dedicated close to a half century of his life to the study and examination of airborne infections such as tuberculosis and the use of ultraviolet irradiation for disinfecting indoor air. After completing his pulmonary medical training at Massachusetts General Hospital in 1977, he began working for the Boston Department of Public Health.

Two events in the mid-80's, an outbreak of TB among Haitian immigrants in Cambridge and then the resurgence of TB reinfections at the Pine Street Inn homeless shelter in Boston, shaped Nardell's life-focus in its current direction. In considering how he could stop TB, he recalled a lecture by famed pulmonologist and TB expert, Dr. Richard Riley, who had recently retired. Riley had explained that ultraviolet (UV) germicidal irradiation was very efficient at killing airborne bacteria and viruses.

Nardell contacted Riley, who guided him on the installation of upper room UV fixtures (near or at ceiling level). The collaboration led to a life-long professional relationship until Riley's death in 2001. Nardell has continued the legacy left behind by famed Harvard sanitary engineer, William Wells, and his successor Riley, through his extensive work in countries where the burden of TB is high. He has also analyzed air purification systems which use ventilation principles. These are good at providing comfort in indoor spaces but are less effective at addressing the risks associated with airborne pathogens.

As Dr. Nardell has noted, "Lighting experts may know about UV irradiation, but they are not involved in public health issues. UV irradiation technology is not taught to engineers, so it really has fallen between disciplines, and a lot of people don't know about it." The COVID-19 pandemic has brought these issues to the fore in public health discussions. The World Socialist Web Site *reached out to Dr. Nardell, and he graciously consented to an interview which was conducted in early January 2023.*

The discussion was critical in the drafting of the two-part series ultraviolet irradiation recently published on the web site and available here: Part 1 and Part 2.

In part one of this interview, Dr. Nardell began recounting the history of his work with Dr. Riley, one of the pioneers in investigating airborne infectious diseases and the role of germicidal ultraviolet (GUV) irradiation in combatting them. Dr. Riley was frustrated by losing access to facilities at a Veterans Administration hospital in Baltimore, which prevented him from conducting an experiment in upper room ultraviolet irradiation. Part two continues this discussion with WSWS writer Dr. Benjamin Mateus.

ED NARDELL (ED): So, in our long relationship, we talked about the need to redo this experiment. Now, I was active in the American Thoracic Society. Riley had been its president … I'm not remembering the year, but I invited Riley to a meeting in San Francisco where we were going having a panel on airborne infection and germicidal UV. At lunch after the meeting, Solbert Permutt (1925-2012), a brilliant experimental physiologist—and Riley was as much a physiologist as he was an airborne guy—said, "Here's the experiment you need to do if ever you do this."

[Email from Dr. Nardell on his friend and colleague Sol Permutt: *He was a brilliant research physiologist at Hopkins who trained under Riley at Hopkins where he spent his career. He was Riley's first research fellow and I consider myself, informally, his last. Like Riley, and more so, he was very mathematically minded. Sol related that they would drop his kids off at school and drive into Hopkins with Riley, writing equations on the frosted glass of the car at stop lights. Although primarily a lung physiologist, he had worked with Riley on some UV experiments and did two-compartment models of UV that I still use for teaching. I had mentioned that I had invited both Sol and Dick to San Francisco to speak at a symposium on airborne transmission that I organized. It was at the lunch afterwards that Sol explained to me the human to guinea pig experiment that I should do if ever I could find a place and the funding to recreate the landmark Wells-Riley experiment. Sol wrote a nice obituary for his mentor. I became friends with Sol in his later years. He died of esophageal cancer—my last visit was not too long before he died*.]

He drew on a napkin a diagram and method for the study where there were two chambers and where you would send the air to one chamber on even days, and the other chamber on odd days … an alternative day strategy where every aspect of the experiment was perfectly controlled. And I carried that piece of paper around and we looked for a place to conduct our studies.

But we didn't have enough tuberculosis in the US. And then finally at a meeting in Paris, a friend of mine from South Africa listened to the idea. He said there was an agency in South Africa that was building a new MDR [multi-drug resistant] treatment facility, and maybe I can convince him to build a few extra rooms and we could at least have the shell to start with and find funding. And then Charles Wells, coincidental last name, from the CDC, who oversaw the relationship between CDC and USAID, knew that USAID was spending a lot of money on buildings and interventions.

They didn't know what worked and what didn't work, and they helped fund what we call the *airborne research facility*in South Africa. The facility was built in 2005, modeled after what Riley had proposed, and since renovated in 2015. And it's still going. We've been studying COVID transmission in it since the pandemic; COVID transmission human to hamster. We're waiting, as we speak, for the results of the first pilot study to see whether we can test 254-nm Upper Room Germicidal

UV, LED UV, and Far-UVC 222-nm against SARS-CoV-2 in that facility.

But anyway, Riley had suggested that idea and it eventually took 10 years from the time he wrote it on the napkin till we got it going. So, that was 1995. And I think it was 2005 when we had the facility grand opening. It's the only one left in the world.

I talked about it so much that a colleague from the UK who was working in Peru made a quick and simple facility literally using farm-raised guinea pigs in a hospital in Lima and did a study of UV proving airborne infection. He beat us to it, but that only lasted a couple years and we've been able to do a lot more studies over the years with the facility in South Africa.

BENJAMIN MATEUS (BM): And I'm assuming your study showed that upper room germicidal UV was able to prevent TB infections?

EN: Yes. Again … we studied room air cleaners, we studied masks on patients, and we studied UV. We tried to do one study at high humidity, which is supposed to make it less effective, but we were unsuccessful in doing the experiment because it was difficult to maintain the high humidity in the facility that was air-conditioned.

But at any rate, we showed about 80 percent reduction in transmission on the days the UV was on compared to the days that UV was off, and that was equivalent in terms of air changes to adding 24 changes to the six air changes that were required to deliver the air to the guinea pigs. And, as a hospital, we had to have some ventilation for the patients. So, there was the existing six air changes. We added 24. Meaning 30 air changes against human-generated TB were able to reduce transmission by 80 percent.

By the way, do you have the article on the history of UV by Nick Reed?

BM: Yes, I used it for the manuscript we are working on. It's quite comprehensive.

EN: Another person doing an in-depth history is Carl Zimmer from the *New York Times* who writes a series of science books for the public. We sat down … I was given by the Riley family his papers, and I wasn't skilled on how to archive these. I wanted to make sure they were preserved and very happy they gave them to me. And they're deposited at the Countway Library.

Zimmer and I spent a better part of an afternoon going through them so that he could look at them and see if there was anything he needed for his work. Unfortunately, there was a biography that Wells's assistant Cretyl Mills was writing and when she died no one could find it.

BM: You've commented on this before, but I'm interested in hearing you speak on it, how interest in UV treatment of airborne infection fell off by the late '40s and '50s, with the advent of vaccines and antibiotics, and the fact that other researchers couldn't reproduce Wells's success with the measles experiment using upper room UV germicidal fixtures at two schools in Pennsylvania. Also, there were the concerns being raised on the safety of UV irradiation. Meanwhile, studies conducted on infected military recruits sharing barracks appeared to support Chapin's droplet theory of infection.

EN: Yeah, the military ones, I've never really examined a lot of those. I know they used some unconventional applications like having UV fixtures along the floor. Probably there was insufficient ceiling height to use the upper room [irradiation]. But nonetheless, most of these studies in barracks were interested in adenovirus … you have to go consider pathogen by pathogen, but some of those may be droplet spread, and so you wouldn't expect germicidal UV to necessarily impact close contact droplets that get on your hands and infect through your eye mucosa. And some are multiple pathways. There's a huge controversy over common colds, for example.

The explanations, or at least the rationale, how the Germantown-Swarthmore schools were very fortuitous choice of places to do the study was because they were in a fairly wealthy suburb of Philadelphia and kids got picked up after school and for the most part went straight home. But when others repeated the study in upstate New York, the kids were riding school buses, and in the London study the kids went back to crowded tenements. [*In the Germantown-Swarthmore studies, Wells and his colleagues made a concerted effort to ensure students in classrooms with upper room UV fixtures didn't share spaces with children in classrooms where UV fixtures were not installed. They demonstrated that UV lights dampened the rates of measles transmission and made the case that the disease was transmitted through air. See Link for details*.]

What all this means is that you can't stop transmission if you don't cover the main places where transmissions are occurring.

BM: Part of the resurgence of interest in UV before the pandemic came from Dr. David Brenner and his team at Columbia University. He gave a TED talk in 2017 explaining a friend of his had died from a multi-drug resistant infection and he was looking to use UV in preventing such occurrences in hospital settings.

What are your thoughts about the comparison between 222-nm wavelength UV (Far-UVC) that Columbia references and upper room germicidal irradiation that uses 254-nm mercury lamps?

EN: I must admit that in the beginning I was a little skeptical when I heard about this Far-UVC, thinking that it would unlikely be as effective as 254-nm. I thought 254-nm was around the sweet spot where you were close enough to the peak absorption of nucleic acids of around 265 to 270 that would fatally injure the pathogen, but far enough away [in the upper room] that was reasonably safe in the lower room where people resided, in essence having best of both worlds. But it didn't take long for me to be convinced that the lower wavelength I think are truly in advance over what we were doing. And David's [Brenner] lab has done an awful lot.

But they haven't been working on human-to-human or human-to-animal models. They are still dealing predominately with artificial aerosols. And there is concern at the CDC that because natural aerosols contain glycoproteins and polyglucans and all these kinds of things found in sputum that become part of the aerosol, and that they could absorb the UV which may lead to decreased effectiveness in real life and not be quite what they are seeing in the laboratory.

And real studies like Wells mounted in Philadelphia schools have been so difficult that there haven't been any. We tried … for instance the TUSS study (1997-2004)—tuberculosis, ultraviolet, shelter study—to pick two shelters in each city for six cities, and to randomize them and alternate after so many years so that we could look at TB infection rates among shelter workers and clients you could capture.

And at the end of literally millions of dollars in quite a few years, we didn't have enough transmission to say whether it worked or didn't work. But we did show that was incredibly safe because we had basically the same shelter under placebo conditions, meaning fixtures that looked like UV lamps were on, but weren't, or there was glass blocking the active UV. In both cases [actual UV on and placebo] six percent of people had skin and eye complaints and no other complaints in all these shelters with thousands of hours of people-time.

So at least as it was applied there, it turned out to be extremely safe. The only risks being for people who climb up on ladders, put UV fixtures on upside down, or in the case of the shelter study, someone moved a bunk bed from where it was originally to a place where the person on the top bunk was exposed to UV directly. And we have a paper from that study on the safety of UV that reviews other reports, and all the UV injuries were accidents. They were not because of UV used as intended.

Now, the safety of UV is highly controversial. Our European colleagues, particularly in Germany, think that UV is dangerous—full stop. They apparently don't accept that it doesn't penetrate and can be used safely. They don't want to hear about it. UV has been used largely in the US and more recently in high TB burden countries: South Africa, China, Russia, and South America.

In 2005, when there was an outbreak of XDR TB (extensively drug-

resistant tuberculosis) in South Africa, suddenly there was great concern about this untreatable tuberculosis. There was great interest in UV and a significant misuse of the technology—UV companies were taking ordinary fixtures and putting UV lamps in them and lots of people got eye burns and then they clamped down on them. And to this day, there's a moratorium on the use of germicide UV in South Africa with government money. That turns out to be, in part, because they don't want to spend the money and they don't have the money to spend. And if they said it does really work then everyone will want it.

At any rate, you asked about 222-nm versus 254-nm wavelengths, and I do believe that 222-nm is a true advance. Certainly, 254-nm can be used very safely, but 222-nm is safer. You don't have to worry about keeping it above people's eyes. And I think it's more effective because of two reasons: First, it impacts proteins beyond the nucleic acid effect, meaning it has multiple targets it damages. Secondly, it's being used between and around people in the room. So, you're not dependent on taking the air up, disinfecting it, and having it come down. You're disinfecting air between people which is what you want to do.

[Photo 7: Upper Room UVGI demonstrating the circulation of a room. Credit the US Centers for Disease Control and Prevention]

In my advanced age, I've become a nightclub singer. I sing at a club in Boston here, when they hold open mic night with a bunch of other people several times a week. They have a room called the Napoleon Room and we managed to get 222-nm lamps donated and placed there. And we've done a few studies there. We've even had David Brenner and his team come see it.

And they have a film technique where they put badges on people's shoulders that measures the amount of exposure to the UV light. And it turns out to be a very interesting way to measure both safety and efficacy of 222-nm Far-UVC. Shoulders are in the "breathing zone." That's the dose that the air is getting in that vicinity of your shoulders. It's also close to your head and neck, which is where there's the only thing that's getting exposed intensely is [the skin of] your head and neck. [*Clothes absorb the UV irradiation.*]

The eyes are better protected than anything because they're set in your head, not coincidentally, because they need to be protected from solar UV. So, really, very well protected from UV coming from above. But the skin of your head is exposed and the shoulder is a good surrogate for that.

We had waiters, singers, and pianists all wearing these badges. And then we did the same in the dental clinic that has been outfitted in New York by David and his group. And we'll be publishing that—as soon as I can get the paper going—on the safety and efficacy, and a new method. Really, this badge monitoring that tells us what the dose is by occupants doing what they do [instead of measuring the dose at a fixed point and fixed intensity and then determining exposure limits and a person's stay times].

With the Far-UVC lamps, we got in the Napoleon Room for SARS-CoV-2 an equivalent of about 34 air changes at the breathing zone level and at a dose of only five percent of the new threshold limit values that have been regulated for 222-nm lamps.

BM: Can you speak to threshold limit values for clarification?

EN: Sure. For all potential hazards, the American Conference of Governmental Industrial Hygienists (ACGIH) publishes a little book every year that tells how much *sound, chemicals, toxins* of all kinds, and also UV radiation a worker can be exposed to for eight hours. We had that for 254-nm for a long time. And it was the basis for estimating how many lamps we could put in for a certain lamp intensity.

Now there's a problem and I hope you will appreciate this as it is worth going into, because the way it has been done has always been wrong.

Basically, the way these estimates have been measured is by taking a UV measuring device at eye level and look for the hottest spot in the room where you've got the most reflection. In the case of 254-nm you keep that 0.2 microwatts. And the 0.2 microwatts turns out to be the "eight-hour stare time" that would give you the threshold limit value or the limit in eight hours you should not exceed.

So, the assumption is that you're looking at the fixture in that position for eight hours, which of course is totally unrealistic. When we put UV monitors on people years ago, a version of what we did with the film, and we published this data, we found that the highest dose received by patients and nurses on wards and with badly designed fixtures that were putting out way too much UV was only one-third of the threshold limit value.

Even though the measurements would suggest these are dangerous, the actual dose received, taking time and motion into consideration, is much lower. The problem is that UL [*Underwriters Laboratories—a global safety science company headquartered in Northbrook, Illinois*] people that tell you that your toaster is not going to kill you, have gotten involved and they want to assure that UV fixtures that are sold are safe.

And they've taken that 0.2 microwatts limit, cut it in half, and said that every fixture at seven feet, which is higher than eye, must be at 0.1 microwatts or less. Now, that has cut down the efficacy of upper room germicidal UV dramatically, which also applies to Far-UVC 222-nm and LEDs as well. One size fits all.

They don't care about efficacy. They only care about safety, but not really. Their business model is to sell a sticker to put on the appliances. It's a commercial entity, UL, and they sell stickers that say this product is safe and they have countless organizations in the country and in the world that won't buy a device if it doesn't have their sticker.

They are requiring an unrealistically achievable safety requirement. Now some companies have done it, but at the expense of efficacy. They made a very high hurdle for the safe use of germicidal. That's why we need to publish this time motion, another time motion study, to show that people are getting a fraction of the exposure they are claiming and therefore very safe.

But, and this is an important but, we're talking about preventing potentially lethal infections—this pandemic, and the next pandemic—and they are worried about the potential for some eye irritation that will resolve in a day or two *if* you were to stare at the lamp for eight straight hours. With germicidal UV—254-nm—if you were to look into the light fixture for some time, you get a temporary photo-keratitis, or eye inflammation. Within a day or two, the cornea layer has replaced itself. There are no long-term effects whatsoever. And with the skin you get some erythema but not a true sunburn, because the penetration is so limited.

BM: That's mainly with 254-nm, but not 222-nm? With 222-nm, you don't even get this.

EN: Now, remember LED (light-emitting diode), and we haven't talked about LED yet, that's the other big advance in germicidal UV. An advance I would say because the Department of Energy is putting a huge amount of money into developing LED UV. Just as they did in developing LED in general, and white light came out of the Department of Energy's efforts to save energy. They understand, and they've written papers on this, that UV can save an enormous amount of energy as a way of it disinfecting air compared to ventilation and that LEDs have got to replace mercury. Nobody wants mercury. And 222-nm will never be an LED in our lifetime.

You can get very little power out of something in that range, but nothing useful. Something on your desk maybe.

The current LEDs—265 to 270-nm—the threshold limit values are in fact half at 0.1 microwatts. And this threshold limit value is an appropriate number at eye level for eight-hour stare time. It isn't an appropriate number to worry about for occupants, but 265 to 270 LEDs, you need to be more careful with. [*The penetration into the skin and eye layers go deeper at the longer wavelengths.*]

The good side is that they're incredibly directional. You don't need to have all these louvers and stuff on LEDs because the light goes where you

want it to go … at any rate, how did we get there?

BM: We were discussing 222-nm versus 254-nm lamps and their impact on skin and eyes.

EN: Right … we have three wavelengths we are dealing with. There are commercial LED fixtures out there now. They are used in schools, etc. They are less efficient. The most efficient way to make germicidal UV is through mercury lamps which have the highest efficiency, but they have mercury and as a technology at some point is apparently doomed. Nobody wants to deal with the mercury waste.

LEDs, if the track record continues, we'll get cheaper and more powerful and maybe the wavelength will come down a little. If we can get down to 255-nm, we'll be at the same point as mercury lamps in terms of upper room application.

I'm working with an inventor and physicist living in China who will be moving to Australia soon. He thinks he has a new source of Far-UVC light that will be cheap and not require filtration. [*UV lights that emit a particular wavelength may also emit radiation at other wavelengths requiring filtering their output to ensure safety. Shorter wavelengths can generate more ozone and longer wavelengths pose health hazards to skin and eyes*.]

The major cost of producing 222-nm wavelengths is the need to filter it because it contains extraneous wavelengths that will cause skin irritation if used directly into the room, so you can't have those or you'll get skin irritation, eye irritation, so they must be filtered.

And all the reputable companies are filtering their UV. For instance, Ushio's UV fixtures are properly filtered, though not all filters are the same. The first company making 254-nm, Sterilray from New Hampshire, does not filter their UV. They make very powerful lamps that have been used for plants, but they refuse to filter it. They say it's not necessary. They are wrong.

Every Friday, going on three years, we have had Zoom calls with David Brenner and others, several legendary people in the lighting industry, who are interested in this topic. There aren't many people knowledgeable in this area but most of them are on that call every Friday. And we discussed mostly these issues. I forgot to mention, this includes the two investigators from Scotland who did UV skin studies.

[Photo 10: Dr. Ewan Eadie investigator of UV Skin studies. Credit WHO Webinar.]

About ten years ago they exposed humans to radiation and measured early changes in their cells. They showed that 222-nm was dangerous. But they had used Sterilray unfiltered wands. They then did a subsequent paper and analyzed the output and the percentage of damaging rays and it was all coming from the unfiltered component. When you filter it, they get no damage. Eye studies from Japan, no injury. So, in my opinion, [filtered] 222-nm is incredibly safe.

But people still say, "What about the long-term effects?"

The answer is that the physics is so much in your favor. If it doesn't get to the cell of interest then it doesn't get there, and it doesn't get there tomorrow, or the next day either. It won't get through.

So, I think 222-nm is incredibly safe and appears to be highly effective. And right now, we're at the very earliest stages of the technology development in terms of producing more efficient sources. But some people are also doing crazy things to meet the old threshold limit values. For instance, some companies are cycling their lamps—one second on and one second off—or a couple of minutes off. That makes no sense for air disinfection. You can't disinfect the air a small fraction of the time, meet the threshold limit value, and think you are going to kill the virus you're about to inhale. You need to have continuous UV irradiation. At the nightclub club cafe we use continuous UV filtered lamps properly done.

BM: Perhaps you can speak on ozone and the concerns raised by some on the secondary chemistries generated by the ozone produced by the Far-UVC lights. I've exchanged some emails with Dr. Jose-Luis Jimenez from Colorado. He's an aerosol physicist and working on secondary chemistries from ozone generation. Do you know his work?

EN: I do know Jose and am very concerned about this issue. Please don't take it wrong because I'm not attacking him. He pre-published a paper where they looked for secondary products and could not find evidence of any. Subsequently, they did a pure modeling exercise (no real data) suggesting that the harm done by secondary chemical reactions would outweigh the benefit of preventing Covid infections.

I have not examined the models but those who have think that a lot of his assumptions are not valid. He is to be a guest on one of our Friday a.m. UV Zoom meetings to discuss this. There are a group of industrial hygienists who think that having UV around is dangerous. As you know, germicidal UV (GUV) has been in use for over 100 years. I know of one instance where GUV caused an unexpected reaction with an aerosolized drug (pentamidine) early in the AIDS pandemic—but otherwise, no odors, no irritation, no cough—nothing to suggest harmful environmental chemistry. Now their concern is long-term effects of GUV if it came into use widely. The answer, by the way, is ordinary comfort-level ventilation, which removes all room contaminants and eliminates the problem. I would have no objection to his raising yet another concern to this otherwise safe and effective technology if they had data to back it up.

The other issue is that indoor environments are rich in VOCs [volatile organic compounds] already. In a room ventilated to control odor, is there an incremental increase in risk from environmental chemical reactions from GUV that truly does outweigh the risks of serious airborne infections? Models depend entirely on how effective one presumes GUV is, what the attack rate and lethality is, what chemicals are present and what chemicals might be produced by GUV. The unknowns are so many that rather than a prospective model I believe one must start with field evidence that there is actually a problem.

[Email follow up dated February 1, 2023: I asked Dr. Nardell on any updates regarding discussion with Dr. Jimenez. His reply: the Jimenez group is preparing to study UV installations with sensitive equipment to look for VOCs, PM2.5 [fine particles or particulate that measure 2.5 microns or less that can penetrate the respiratory tract and have potential health consequences] and ozone, so I don't expect any resolution on that issue for some time—but lots of ongoing discussion over the assumptions made in their modeling. There is still no actual data that there is a problem—so I am not convinced that there is a problem yet. I am afraid we have an inconclusive theoretical concern at the moment—but one that could have major impact if actual representative installations, not worst-case scenarios, show a buildup of PM2.5—their major concern.]

BM: Some have raised concerns with the potential impact of UV on infants and children.

EN: This has come up with the skin (Don Forbes, Ewan Eadie) and eye experts (Dave Sliney) on our Friday a.m. calls. Obviously, there can be no data on children as there have been no clinical trials per se and human experiments are limited to adults. But the experts agree that from the 222-nm perspective there is no reason to believe based on the anatomy that infant skin is more vulnerable than adult skin. 222-nm barely penetrates the outermost stratum corneum and those cells that it might reach are about to be sloughed off. The same with the eye—it barely penetrates the tear layer and corneal cells slough every 48 hours. I don't believe there is any possibility of any long-term effects. Brenner's mice models do have thinner skin than humans and they show little or no long-term consequences in mouse lifespan. The same for mouse eyes. In schools, of course, young children are lower down as well—[meaning] a lower dose compared to adults from ceiling lamps. The problem is that critics say, where are the studies? The physics of light and skin/corneal thickness is not convincing.

BM: Final thoughts you'd like to make?

EN: Thanks for your interest. We talk a lot about why this technology isn't more widely used. It's been around a hundred years. It's highly effective, but it seems obvious that we have a communication issue. Engineers don't learn about it. The public doesn't know about it. And what they do know relates to too much sun exposure and misconceptions about the various wavelengths and their biologic effects—risks of sunburn, risks of cataracts, risks of skin cancer, but none of these risks applies to low UV zones.

I've proposed we need something for the public like "Got Milk," or "The Incredible Edible Egg," that push back against old concepts—thinking eggs were bad to eat but now we understand they actually are healthy—and introduce a new thinking about air disinfection and UV technology. We need to change people's view on the healthful uses of UV.

BM: Thank you so much for your time, Dr. Nardell. I look forward to reading those articles and reports if you don't mind emailing them to me.

EN: Thank you.

Concluded