Safety of 222 nm Band-Pass Filtered Irradiation: A Review and Analysis of Current Data

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Abstract

Ultraviolet radiation (light at wavelengths shorter than 400 nm) has well-known disinfectant properties. These properties stem from the ability of UV light to damage the proteins and genome of microbial cells and viruses through the disruption of chemical bonds. Unfortunately, for the same reasons, exposure to UV light in the 250–300 nm region of the spectrum (254 nm sources being most prevalent) is also known to cause damage, including DNA lesions, erythema, eye injuries, photo-keratitis and other associated effects. An examination of the historical action spectrum calculation, in light of the exposure not being limited to wavelengths below 230nm due to the use of a monochromator, is presented.

Recent studies suggest that such tissue damage is not caused by shorter (222 nm) wavelengths, due to reduced penetration depths in live tissue when compared to 254nm light. While the effects on live tissue are diminished, 222 nm light has *increased* efficacy for killing bacteria, and deactivating viruses. Current safety guidelines do not, however, account for the true 222 nm exposure limits, in part resulting from poorly characterized light sources in heritage publications. We find the historical data taken at 222 nm to be lacking and propose a reexamination herein.

In this paper, we provide a review of existing literature, including a summary of the efficacy of 222 nm light for disinfection. Based upon recent empirical data, we propose that the accepted spectral effectiveness of 222 nm light should be reexamined and that the Threshold Limit Values for 222 nm light be newly established.

I. Introduction

On March 11, 2020, the World Health Organization (WHO) declared the SARS-CoV-2 outbreak a pandemic. Preliminary research on patients from two hospitals in Wuhan, China indicates that SARS-CoV-2 has the potential to spread via aerosol particles (1) and in a later study that infection via the fomite route is also possible (2). SARS-CoV-2 has also been shown to be transmitted by asymptomatic individuals (3).

Although 254 nm light is the prevalent UV source in current disinfection devices, the SARS-CoV-2 outbreak has focused interest on the potential to instead use 222 nm band-pass filtered (BPF) light for disinfection. Irradiation with 222 nm light is an attractive alternative because unlike irradiation with 254 nm light, it has been shown that 222 nm light kills bacteria and deactivates viruses without causing DNA lesions, erythema, photo-keratitis and other associated effects of 254 nm light in biological tissue (4) (5) (6) (7) (8). The lack of hazard is due to the fact that far-UVC light (wavelength < 230 nm) has a penetration range of only a few micrometers when interacting with cellular system components, and thus cannot reach the genetic material of living mammalian cells. That penetration range nonetheless suffices for far-UVC light to kill bacteria and deactivate viruses smaller than 5 μm in diameter (7). Far-UVC light is not as effective at killing larger microbes, thus bacteria or viruses exceeding 5 μm can be expected to have a higher survival rate.

Airborne-mediated microbial diseases such as influenza and tuberculosis have been extensively studied. A direct approach to prevent airborne transmission is inactivation of airborne pathogens, and the airborne antimicrobial potential of broadband UVC light has long been established (9) (10). However, its widespread use in public settings is limited because conventional UVC light sources, typically at 254 nm, cause damage to biological systems beyond their intended pathogen targets.

The purpose of this paper is twofold: First, to present literature that describes the effects and efficacy of 222 nm light; and second, to propose a new spectral effectiveness value that was calculated based on the reviewed data. Spectral effectiveness is a unit-less quantity capturing the action spectra which measures the minimum dose that causes a biological effect. Mathematically, the action spectrum describes the inverse quantity of light required to evoke a constant response. Action spectra do not describe the level of biological activity, since biological responses are often nonlinear with intensity (11).

Errors Identified – Earlier methods for establishing the action spectrum were hampered, for example, by the use of a monochromator for producing the short wavelength UV light used to irradiate the eyes of test animals. Any frequency selective device (such as a monochromator) will be characterized by the so-called rejection ratio. The

rejection ratio is the percentage of light at the *non-selected* setting that will still be present at the device exit, e.g., in a monochromator, the slit height defines the level of scattered light rejection. Monochromators generally will only have a rejection ratio of 10^{-2}. In this case, if the spectral source light at the shorter wavelength input to the monochromator is already 10^{-2} weaker than the longer UV wavelength, the light emanating from the monochromator will contain equal intensities of both longer and shorter UV wavelengths. The stray light from longer wavelengths common to earlier monochromator designs, caused damage to the eyes of test animals. Current studies avoid these issues by using band-pass filters with high-orders-of-magnitude reduction in light from longer wavelengths.

The error made by not having a narrow band light source is not limited to methods used many decades ago. Indeed, Woods et al. found the presence of CPDs and erythema (reddening caused by dilatation of the capillaries) in human skin when exposed to the 222 nm wavelength with 97% emission less than 250 nm (12). However, the formation of CPDs and erythema was later attributed to the 3% of emission above 250 nm, thus underscoring the importance of efficient band-pass filters (12) (4) (13). The irradiance at different wavelengths in the Woods paper can be seen in Figure 1 where Figure 1a (top) is plotted on a linear scale and Figure 1b (bottom) in logarithmic scale; the latter clearly shows the additional irradiance peaks above 230 nm that are barely visible in the original graph of the Figure 1a data. Indeed, human skin, when exposed to BPF 222 nm wavelength light, does not form covalently linked cyclobutane pyrimidine dimers (CPDs), and pyrimidine-pyrimidone (6-4) photoproducts (6-4 PPs) deoxyribonucleic acid (DNA) lesions, which are associated with causing UV-induced skin cancer (14).

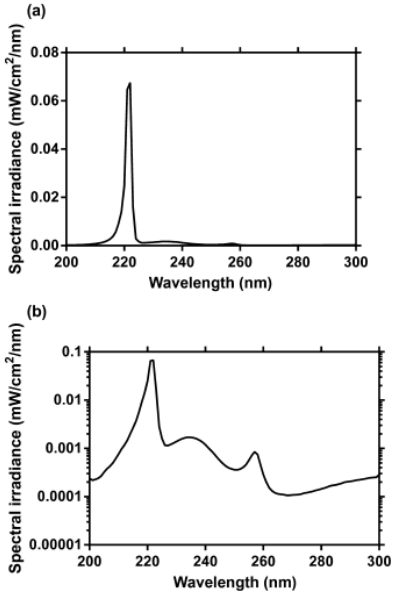

Figure 1 Linear (a) and semi-logarithmic (b) spectral irradiance of unfiltered 222nm light (12)

II. Potential for Change

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has established limits of exposure to UV radiation at certain wavelengths. These guidelines were established in 1989 and reaffirmed in 2004 (15). For the 220 nm wavelength, the exposure limit is 25 mJ/cm^2 (15). For 225 nm light, the exposure limit is 20 mJ/cm^2 (15). Interpolating between these two values we approximate an exposure limit for the 222 nm wavelength of 23 mJ/cm^2, or 0.000833 mW/cm^2 for a continuous 8 hour period of exposure.

Buonanno et al. demonstrated that an exposure level of 0.4 mJ/cm^2 resulted in 90% viral inactivation in the aerosol phase over approximately 8 minutes while using two different seasonal human coronaviruses (7). While this period of exposure may be too long to be effective against close contact spread of the SARS-CoV-2 virus via the aerosol route, it nonetheless demonstrates the desired effect. If the limit for 222 nm BPF light could be increased, the deactivation period may be correspondingly shortened (4).

The question at hand is whether or not the action spectrum and thus the threshold limit values (TLVs) set by the American Conference of Governmental Industrial Hygienists (ACGIH) and adopted by ICNIRP for far-UVC

wavelengths should be modified, incorporating the recently published results for the far-UVC range. The newly published data provide depth and clarity that were not available when the original action spectrum (spectral effectiveness) was defined.

The data used in 1984 informed the ACGIH guidelines which were later adopted by ICNIRP. In these earlier studies, epidermis and stratum corneum samples were exposed to different wavelengths of light and transmission was measured (16). However, these studies have two limitations. First, transmission was only measured for wavelengths between 248 and 546 nm and not in the far-UVC range (16). The sensitivity of the set-up used by Bruls was too low to measure epidermal transmission of shorter wavelengths in UV-exposed skin; the penetration distance for shorter wavelengths was instead extrapolated from the data. Second, skin thicknesses were varied by exposure to water to increase thickness and salt water to decrease the thickness of the skin. As a result, the variations in transmission may be due to the contribution of confounding factors, including the optical response of water and salt, irrespective of the molecular makeup of the skin itself. Given that photon energies in this region of the spectrum are starting to exceed the electronic excitations limits of bonding electrons, transmission levels may be due to the hydration state of the skin rather than only its thickness.

The World Health Organization (WHO) defines spectral effectiveness as a unit-less quantity capturing the action spectra. An action spectrum measures the minimum dose that causes a biological effect. The action spectrum, as captured by the spectral effectiveness, is used to define exposure limits. Note again the action spectrum describes the inverse quantity of light required to evoke a constant response (11), therefore a smaller spectral effectiveness value corresponds to a higher exposure limit. The spectral effectiveness in the UVC range below 246 nm is a simple curve-fitted to an exponential or a straight line in semi-log space. The spectral effectiveness was curve fit by Wester in the three ranges of the UV spectrum (17). The action spectrum used to inform exposure limits appears to have been originally a hand drawn curve, and Wester fit a curve to mathematically interpolate between points on the curve to allow analysis at any wavelength (17). Though this provides a usable basis to interpolate, current research findings provide additional data points at lower wavelengths which can provide a better spectral effectiveness to inform and update guidelines that were established from incomplete data.

III. Literature Study Methods

Recent studies provide evidence for the safety and efficacy of 222 nm BPF light. The studies used either in vitro or in vivo methods to study both short-term and chronic effects. ACGIH defines the short-term exposure limit as the level to which workers can be exposed continuously for a short period of time without suffering from irritation, chronic or irreversible tissue damage, or narcosis of sufficient degree to increase the likelihood of accidental injury, impairment of self-rescue, or materially reducing work efficiency (18). In comparison, chronic exposure limits consider continuous, repeated contact with a hazard over a long period of time. Assuming the BPF 222 nm light source is used daily during the study, the exposure would be considered chronic. Three particularly relevant studies will be discussed herein (5) (6) (7).

Germicidal Efficacy of 222 nm Light and Health Implications

Antimicrobial ultraviolet (UV) light has been shown to kill drug-resistant bacteria and deactivate viruses (6). In recent work, two human coronaviruses from subgroups alpha (HCoV-229E) and beta (HCoV-OC43) were utilized to test the germicidal efficacy of 222 nm light (7). A 12 W 222 nm Kr-Cl excimer lamp, fitted with a custom band-pass filter to reduce emissions outside of 222 nm, was used to irradiate aerosols carrying the pathogen under study (7). Samples were then collected and incubated with normal human lung cells (7). Light at 222 nm works as well as 254 nm light as a disinfectant and may not result in the hazardous effects that 254 nm causes (5).

Buonanno et al. explored in vitro killing of methicillin-resistant *Staphylococcus aureus* (MRSA) with UV light, CPDs and 6-4 photoproduct formation in a 3-D human skin model (5).

To explore in vitro inactivation of MRSA, the team used a krypton-chlorine (Kr-Cl) excimer lamp with a band-pass filter to limit wavelengths outside of 222 nm. To explore the reaction of a 3D human skin model, the same Kr-Cl excimer lamp with the custom band pass filter was used. The lamp was positioned 9 cm away from the MRSA and 3D human skin model samples, so that the irradiance was 0.224 mW/cm^2. Zero exposure and 254 nm broadband exposure were used as controls. The 254 nm lamp was positioned 99 cm away from the samples which corresponded to an irradiance value of 0.218 mW/cm^2. (5)

Chronic in vivo effects of 222 nm UV light

Yamano et al. exposed Xpa-knockout mice and wild-type mice to 222 nm BPF light and then assessed them for skin tumor production and eye degeneration (6). To obtain 222 nm light, the team used a Kr-Cl excimer lamp with a band-pass filter that restricted emission to wavelengths between 200 and 230 nm. Xpa-knockout mice are generally hypersensitive to UV and highly susceptible to carcinogenesis caused by sun exposure (19). This is due to an autosomal recessive hereditary disorder in which these mice have a high risk for multiple early-onset malignant skin tumors due to a repair deficiency of dipyrimidine photoproducts (20). The mice were positioned 30 cm from the light source, with a measured irradiance of 1 mW/cm^2. Wild-type mice were irradiated with 500 mJ/cm^2 (500 seconds of exposure) three times a week, while Xpa-knockout mice were irradiated with either 50 mJ/cm^2 (50 seconds of exposure) or 100 mJ/cm^2 (100 seconds of exposure) twice a week. An exposure of 500 mJ/cm^2 is approximately 50 times the sterilization dose for microorganisms. The mice were irradiated for a total of ten weeks. A positive control of mice with similar exposure to 254 nm light was used (6).

Buonanno et al. also investigated the effect of 222 nm light on mice. For these in vivo studies, 222 nm BPF light at 157 mJ/cm^2 was delivered in a 7-hour period (25,200 seconds). The same Kr-Cl lamp with a custom band-pass filter was used and positioned 41 cm away from the samples, so that irradiance was 0.0062 mW/cm^2. Six- to eight-week-old male hairless mice (SKH1-Elite strain 477), which have histological, physical, and visible changes similar to how the human skin behaves, were used. Again, zero exposure and 254 nm exposure were used as controls. The 254 nm light was positioned 205 cm away, corresponding to an irradiance of 0.0062 mW/cm^2. Irradiance was measured with an ILT1400 sensor and a SEL220 detector. Epidermal thickness, percentage of proliferating keratinocytes, formation of CPD and 6-4PP, number of neutrophils and mast cells, and expression of keratin (K) K6A were measured to determine if 222 nm BPF light has hazardous effects on mouse skin (5).

IV. Results and Discussion

Efficacy of 222 nm Light on Aerosolized Coronaviruses

Results indicated that inactivation of two coronaviruses (7) and other pathogens (10) with 222 nm light followed a typical exponential disinfection model, with doses of 1.7 and 1.2 mJ/cm^2 able to inactivate 99.9% of aerosolized HCoV-229E and HCoV-OC43, respectively (7). The inactivation constants for HCoV-229E and HCoV-OC43 were found to be k = 4.1 cm^2/mJ and k = 5.9 cm^2/mJ, respectively, indicating that both coronaviruses have high sensitivity to 222 nm BPF light (7). Since genomic size is an important factor in UV sensitivity, SARS-CoV-2 is predicted to show similar inactivation efficiency (21) as these other coronavirus exemplars. The results, when compared to conventional germicidal lamps (254 nm light), suggest that 222 nm BPF light performs similarly to 254 nm light in terms of inactivation efficiency for aerosolized coronaviruses (8). The fractional survival of aerosolized coronaviruses can be seen in Figure 2. Cells were tested for the expression of the viral spike glycoprotein. Green fluorescence (Alexa Fluor®-488, used as a secondary antibody against anti-human coronavirus spike glycoprotein antibody) was used to qualitatively show virus-infected cells. Nuclei of cells were stained with DAPI (blue fluorescence) for greater contrast. Qualitatively, the more green fluorescence seen, the higher the concentration of active virus present (Figure 3), (7).

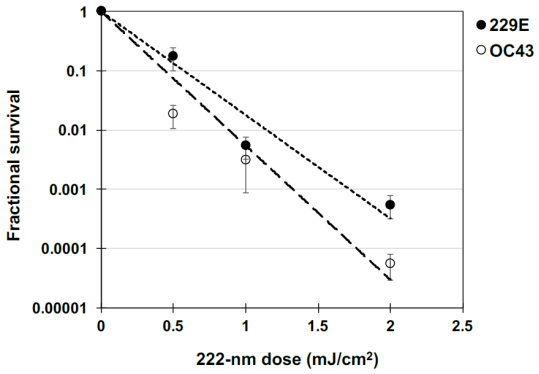

Figure 2 Coronavirus Survival after exposure to UV light (7)

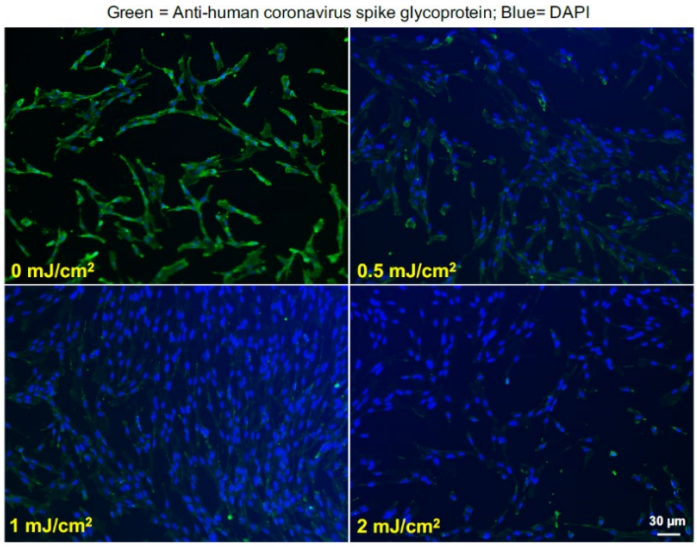

Figure 3 Effect of 222 nm irradiation on aerosolized HCoV-229E in human lung cells (7)

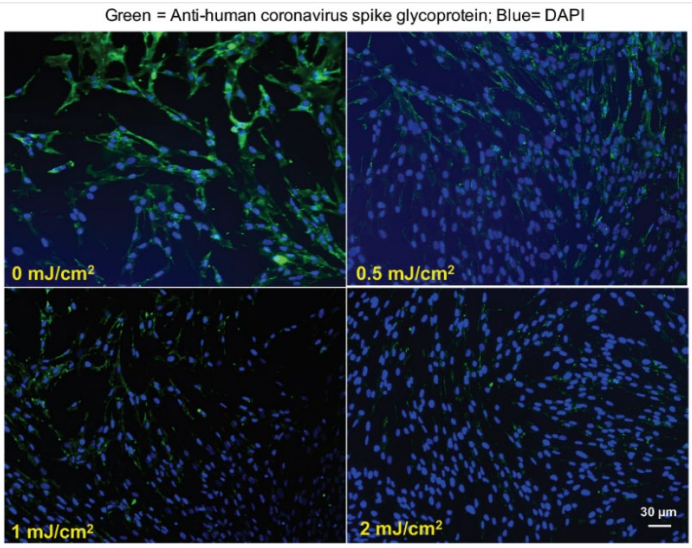

Figure 4 Effect of irradiation on aerosolized HCoV-OC43 in human lung cells (7)

Germicidal Efficacy of 222 nm Light and Health Implications

Buonanno et al. concluded that a far-UVC wavelength window (200–225 nm) is capable of inactivating bacteria without causing health hazards for mammals at certain exposure levels (5).

In vitro experiments compared MRSA survival immediately after exposure to 222 nm BPF light to its survival after exposure to conventional 254 nm germicidal UV light at similar doses. 222 nm light kills MRSA more efficiently than 254 nm (Figure 5) at low doses, and nearly as well at higher doses. However, 254 nm light is equally as efficient at damaging human cells, whereas 222 nm light is not (5). Analysis of the 3D skin model shows that exposure to 222 nm light did not induce CPD or 6-4PP formation in the tissue model, unlike the 254 nm light (5). Figure 6 shows that no CPD or 6-4PP formation occurs in the 3D skin model at any dose of 222 nm BPF light, but occurs in the positive 254 nm control.

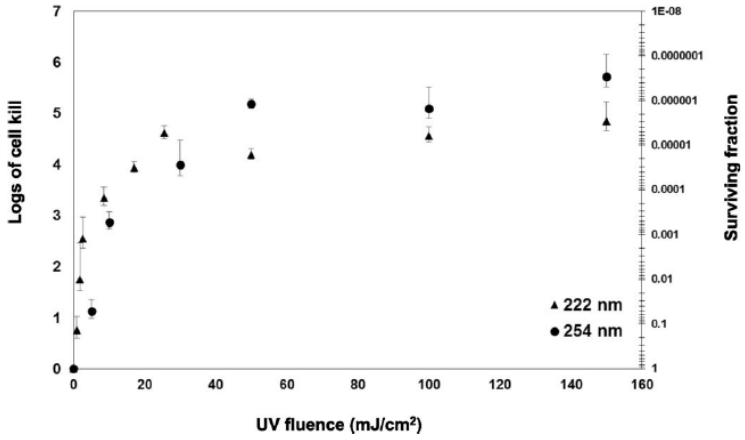

Figure 5 MRSA cell kill as a function of UV Dose (5)

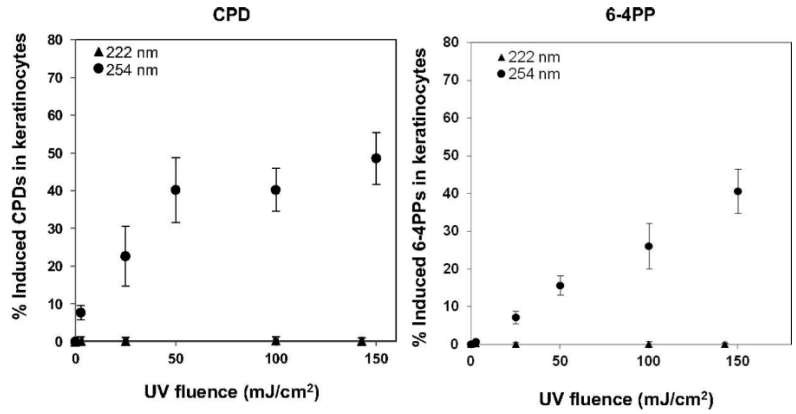

Figure 6 CPD and 6-4PP production as a function of 222 nm BPF and 254 nm light (5)

Chronic effects of 222 nm UV light

CPD formation was not detected 3 hours (10,800 seconds) after exposure to 50 mJ/cm^2 or at the high dose of 100 mJ/cm^2 222 nm BPF light. At a dose of 5 times greater, 500 mJ/cm^2, there was only faint staining for CPDs in the sub-corneal region of the skin in both genotypes of mice (6). The author postulated that the CPDs formation was due to a small fraction of 235-280 nm light which passed through their custom band pass filter. A new filter was constructed to further reduce the higher wavelengths, which decreased CPDs formation at 10,000 mJ/cm^2, but results were not presented at 500 mJ/cm2.

Exposure to 222 nm BPF light showed no inflammatory response, even in the Xpa-knockout mice, which are highly susceptible to inflammation. Neither erythema nor ear swelling was observed in mice exposed to 222 nm BPF light, whereas both were observed in mice exposed to 254 nm broad spectrum light. Serum level of CXCL1 (C-X-C Motif Chemokine Ligand 1, a key inflammatory chemokine), did not elevate after one exposure to 222 nm BPF light (6).

No tumors were observed in any of the mice with 222 nm BPF UVC irradiation (Figure 7: note that 5.0, 0.5 and 1.0 kJ/m^2 are 500, 50, and 100 mJ/cm^2). It is hypothesized that chronic 222 nm BPF light exposure is not carcinogenic because its shorter wavelength can only reach the outermost layer of the epidermis and not penetrate to the basal layer where induction of skin tumors occurs (22) (6). This is assuming no basal layer is exposed via an open wound or other skin surface issues.

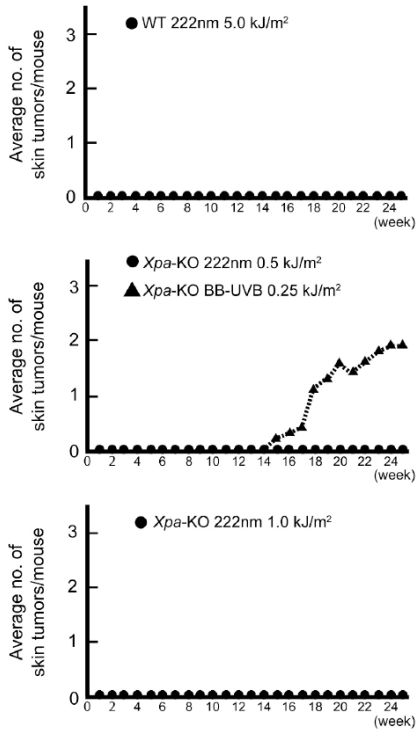

Figure 7 Average number of tumors in mice exposed to Broad Band UVB and 222 nm UVC light (6)

In addition, no effect of 222nm BPF light was observed on the eyes of mice. Macroscopic observations and histopathological evaluations were completed for mice exposed to either 222 nm BPF light or 254 nm light and subsequently compared. All mice irradiated with 222 nm light showed no significant change in retinal tissue (no disorganization of the lens cortex, ulcers with scarring, abnormal increment cells, neovascularization, corneal haze, or cataracts were observed), whereas the mice exposed to 254 nm did have significantly different retinal tissue (6).

Other wavelengths studied – In recent studies 3-D skin modeling was also performed highlight the safety and efficacy of 207 nm light (9) (23). Buonanno et. al. showed that there was no statistically significant difference in epidermal thickness and keratinocyte proliferation, pre-mutagenic UV-associated DNA lesions, skin inflammation, or skin tissue differentiation between BPF 207 nm light and zero exposure controls (23). Additionally, BPF 207 nm light is approximately as effective at killing MRSA when compared to conventional germicidal lamps (9).

In vivo results

Epidermal thickness after 48 hours (172,800 seconds) exposure at 157 mJ/cm^2 of 222 nm light is not statistically different than before exposure. Ki-67 expression in keratinocytes of skin was not different than the controls. There was no increase in UV induced DNA photo-damage when compared to controls. Inflammation was also measured by the density of mast cells markers and neutrophils (myeloperoxidase (MPO)-positive cells). The density was not statistically significant when compared to controls. Finally, keratinocyte differentiation was measured as K6A expression. Again, keratinocyte differentiation in skin of mice exposed to 222 nm light was not statistically significant when compared to controls. All of these measurements reinforce the safety 222 nm on the skin. Since epidermal thickness, Ki-67 expression, inflammation, DNA photo-damage, and keratinocyte differentiation do not increase as compared to the control, it indicates that 222 nm light does not cause the typical reactions and pre-mutagenic DNA lesions in skin due to exposure to longer wavelength UV-light. These results suggest that there are no hazards to the skin of mice brought about by exposure to 222nm BPF light. (5)

The results of slit lamp bio-microscopic exams of the anterior segment of each eye including the ocular adnexa, limbus, cornea, iris and lens, where photokeratitis would be identified in the cornea by epithelial haze and stippling. These have shown no ill effects after 43 weeks of chronic exposure (data to be published in 2020, Columbia University study currently underway). This study covers sixty weeks of eight hour per day illumination, five days

per week, again using the same strain of mice (SKH1-Elite strain 477). This study also has assessed inflammation, neovascularization, intraocular pressure, abnormal cell growth, and corneal/lens transparency along with methods previously described (5) (23).

Guidelines – ICNIRP's dose limit guideline for 222 nm light is 23 mJ/cm^2 per 8 hour exposure (24). For the *in vivo* studies (5), 157 mJ/cm^2 was delivered during a 7 hour (25,200 second) period, or approximately 0.00623 mW/cm^2. This shows that even when the dose is increased sevenfold, no CPD or 6-4PP formation occurs in the EpiDerm-FT human skin model. For applications like a persistent UV disinfectant source for aerosol deactivation of pathogens, higher dosages are favorable so that inactivation of the virus can occur faster.

Proposed Spectral Effectiveness

Using the experimental data discussed (5) (6) (7) and the ACGIH guidelines as baseline inputs, a new spectral effectiveness was calculated for both 207 and 222 nm light using Equation 1 and 2 below. The ACGIH exposure durations were stated in terms of effective irradiance, and a sum that takes into account the irradiance at each wavelength was weighted by a spectral effectiveness value. To do this, the ACGIH exposure durations were plotted and curve fitted (Table 1). Equation 1 is the curve fit and describes the effect of inverse duration on effective irradiance.

Table 1 ACGIH current exposure durations

Duration (s)	$E_{effective}$ (W/m^2)	$E_{effective}$ (mW/cm^2)
28800	0.001	0.0001
14400	0.002	0.0002
7200	0.004	0.0004
3600	0.008	0.0008
1800	0.017	0.0017
900	0.033	0.0033
600	0.05	0.005
300	0.1	0.01
60	0.5	0.05
30	1	0.1
10	3	0.3
1	30	3
0.5	60	6
0.1	300	30

$$E_{effective} = 30.148 * (\frac{1}{Duration})^{1.0032}$$

Equation 1

The $E_{effective}$ was calculated for both 207 and 222 nm BPF light data from each paper, then using Equation 2 the proposed spectral effectiveness was calculated, and the results were recorded as seen in Table 2. Note that 254 nm and 270 nm have the current ACGIH spectral effectiveness values that the guidelines have currently been set for those wavelengths, considering there has been no evidence to support change. The values for 222 nm and 207 nm wavelengths are the newly predicted values using data collected from studies discussed earlier.

$$E_{effective} = \sum E_\lambda * S(\lambda) * \Delta\lambda$$

Equation 2

Where $E_{effective}$ is the effective irradiance in μW/cm² [μJ/(s • cm²)] or W/m² [J/(s • m²)] normalized to a monochromatic source at 270 nm; E_λ is the spectral irradiance from measurements in μW/(cm² • nm) or W/(m² • nm); $S(\lambda)$ is the relative spectral effectiveness (unitless); $\Delta\lambda$ is the bandwidth in nanometers of the calculation or measurement intervals(14).

Table 2 Proposed spectral effectiveness for various wavelengths

Wavelength (nm)	Spectral Effectiveness (unit-less)
207	0.019
222	0.006
254	0.502
270	1.000

The calculated spectral effectiveness (orange) can be seen in Figure 8 and Figure 9 compared with the current spectral effectiveness (blue) (11). The proposed spectral effectiveness is shown below. Due to the small amount of data currently, the points were not connected for easier viewing.

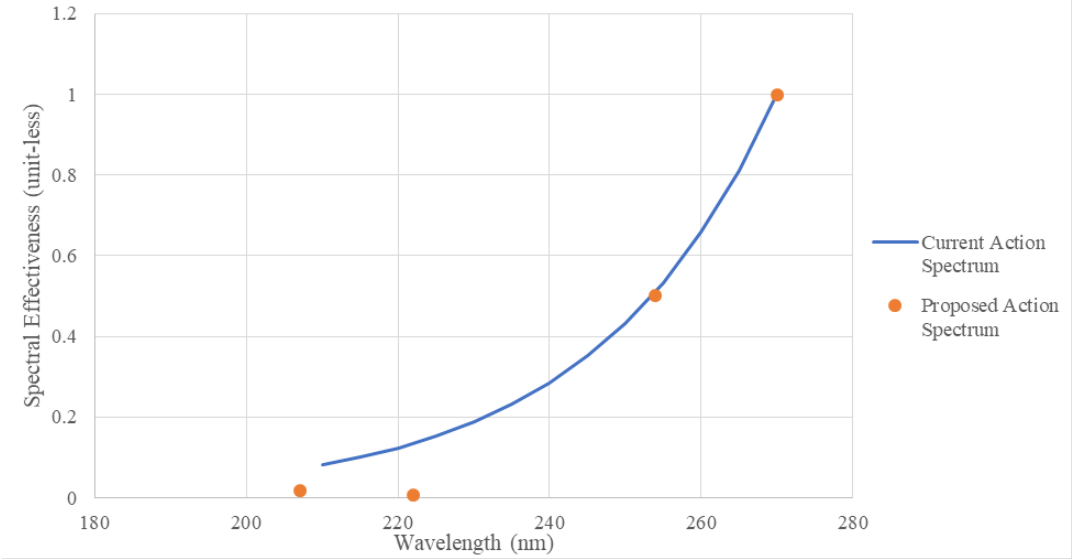

Figure 8 Proposed spectral effectiveness

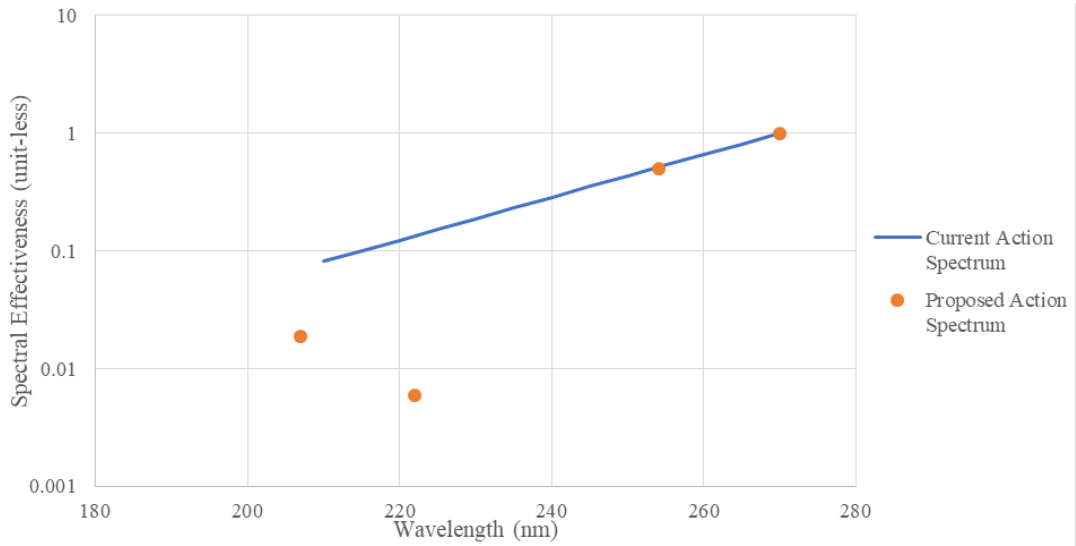

Figure 9 Proposed spectral effectiveness in semi log form

By plotting the radiant exposures from the 207 nm and 222 nm studies over the spectral effectiveness used to calculate exposure limits, it can be shown that higher exposure limits in the far-UVC range may be warranted. Research is required to reach a minimum spectral effectiveness that is more accurate. However, current experimental findings for 207 nm and 222 nm provides additional data points at lower wavelengths that can offer a better estimation to update the spectral effectiveness.

It should be noted that the data from 207 nm represent a dose in which no harmful effects were noted, not the threshold at which effects will occur. These were the only data available at the time, but again do not represent a threshold. This is why the action spectrum is higher at 207 nm as opposed to 222 nm. At 222 nm, there was a study that found a threshold limit based on the formation of CPDs in the sub-corneal region of the skin at 500 mJ/cm^2, which was used in the calculation (6). Note again that a smaller spectral effectiveness value corresponds to a higher exposure limit.

V. Conclusion

All studies that have utilized 222 nm BPF light as a germicidal lamp, including the three discussed in detail herein, suggest the safety of 222 nm light. When studied, 222 nm light at various dosages has not shown the adverse health effects seen at 254 nm (5) (6) (7), even at approximately 20-fold above the current 222 nm exposure limit (6). The proposed spectral effectiveness from Table 2 divided by the current ACGIH spectral effectiveness equals 20. Additionally, 207 nm light has also been studied and no hazardous health effects were detected (9) (23).

It is recommended that the spectral effectiveness, and thus the guidance from various bodies be updated, based on the wealth of new information presented. This is important for applications using persistent 222 nm BPF light sources as disinfectants. To speed the deactivation time however, an increase in the allowable threshold exposure level should be considered.

More data should be collected to provide a more accurate spectral effectiveness. However, in the meantime we propose a spectral effectiveness value of $S(\lambda) = 0.006$ at 222 nm based off of our analysis of experimental data in the literature. The impact of the proposed changes is invaluable in the current health crisis and those in the future where surface disinfection and aerosol deactivation of pathogens is desired.

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Conflict of Interest

The writing of this document was supported by The Boeing Company.

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