Supplemental Information— Inactivation of Coronaviruses and Influenza A Viruses by Solar UV-B Radiation

UV Radiation from Sunlight and its Germicidal Effect

Sunlight has three types of UV radiation, defined by wavelength: UV-A (315-400nm), UV-B (280-315nm), and UV-C (100-280nm). However, at the earth's surface, approximately 95% of UV radiation is UV-A and only 5% is UV-B; UV-C radiation is virtually undetectable since it is absorbed by ozone and other components of the atmosphere.[1] In addition, UV-A radiation has very little germicidal effect on viruses. Studies on the impact of UV-A light on SARS-CoV inactivation demonstrated ineffectiveness of UV-A on its own to eliminate infectious virus.[2,3] UV-B radiation, therefore, is the main component of solar UV radiation that has potential to affect viral viability.

Studies on Viral Inactivation by UV Radiation

Multiple studies have analyzed the ability of UV radiation to inactivate viruses; however, these studies primarily use UVC radiation at 254nm, which reveals little insight to the specific impact of solar UV.[4, 5] Past studies that attempt to analyze the impact of solar radiation are not empirical and, instead, are models using values derived from UVC radiation experiments.[6 ,7] The only source found that does provide empirical data on UV-B radiation is on caliciviruses and reported a dose of 34mJ/cm^2 required for a 3 log reduction in infectious virus.[8]

Caliciviruses, like influenza A viruses and coronaviruses, are single-stranded RNA viruses. However, while influenza A viruses and coronaviruses are enveloped, caliciviruses are non-enveloped. Additionally, caliciviruses are smaller in physical and genomic size.[9,10,11] Since genome type is a major factor in UV susceptibility, caliciviruses can be good substitute for influenza A and coronaviruses, but considerations for the above-mentioned differences are also important.

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[1] National Toxicology Program. Scientific Review of Ultraviolet (UV) Radiation, Broad Spectrum and UVA, UVB, and UVC. http://ntp.niehs.nih.gov/pubhealth/roc/listings/u/uv/summary/index.html. Last Update October 2014. Accessed October 2015.

[2] Darnell, M. E., & Taylor, D. R. (2006). Evaluation of inactivation methods for severe acute respiratory syndrome coronavirus in noncellular blood products. Transfusion, 46(10), 1770-1777. doi: 10.1111/j.1537-2995.2006.00976.x

[3] Darnell, M. E., Subbarao, K., Feinstone, S. M., & Taylor, D. R. (2004). Inactivation of the coronavirus that induces severe acute respiratory syndrome, SARS-CoV. J Virol Methods, 121(1), 85-91.

[4] Gerba, C. P., Gramos, D. M., & Nwachuku, N. (2002). Comparative Inactivation of Enteroviruses and Adenovirus 2 by UV Light. Appl Environ Microbiol, 68(10), 5167-5169. doi: 10.1128/aem.68.10.5167-5169.2002

[5] Tseng, C. C., & Li, C. S. (2007). Inactivation of viruses on surfaces by ultraviolet germicidal irradiation. J Occup Environ Hyg, 4(6), 400-405. doi: 10.1080/15459620701329012

[6] Kowalski, W. J., Bahnfleth, W. P., & Hernandez, M. T. (2009). A genomic model for the prediction of ultraviolet inactivation rate constants for RNA and DNA viruses.

[7] Sagripanti, J. L., & Lytle, C. D. (2007). Inactivation of Influenza Virus by Solar Radiation. Photochem Photobiol, 83, 1278-1282.

[8] Duizer, E., Bijkerk, P., Rockx, B., De Groot, A., Twisk, F., & Koopmans, M. (2004). Inactivation of caliciviruses. Appl Environ Microbiol, 70(8), 4538-4543.

[9] Swiss Institute of Bioinformatics. Coronaviridae. http://viralzone.expasy.org/viralzone/all_by_species/30.html. Last Update 2011. Accessed October 2015.

[10] Swiss Institute of Bioinformatics. Influenzavirus A. http://viralzone.expasy.org/viralzone/all_by_species/6.html. Last Update 2010. Accessed October 2015.

[11] Swiss Institute of Bioinformatics. Caliciviridae. http://viralzone.expasy.org/viralzone/all_by_species/32.html. Last Update 2008. Accessed October 2015.

Estimating Solar UV Impact on Influenza A and Coronavirus Inactivation

Two sources were used to obtain data on UV radiation levels at different geographic locations in the United States. NOAA reports and archives the daily UV index at solar noon (approximately 1pm) for major cities in the United States.[12] The USDA working with Colorado State University reports hourly UV-B radiation levels at specific sites in the country as part of the UV-B Monitoring and Research Program.[13] Using these data and the reported value of 34mJ/cm^2 for caliciviruses, it is possible to calculate the amount of time needed for 3 log inactivation of virus under sunlight.

In Table S1, the UV index for June 21st, 2014, is converted into uW/cm^2 by multiplying by 2.5, based on a previous model created by Gryphon Scientific. Since Watts (W) = Joules (J)/ seconds (s), time for a 3 log reduction of infectious virus in seconds can be determined through dividing 34mJ/cm^2 by the converted UV-B radiation value.

Table S1. UV –B Radiation and Time for 3 log Reduction for Major Cities in the Summer

City	UV Index (at noon)	UVB Radiation (summer) uW/cm^2	W/cm^2	Time for 3 log Reduction (s)	Hours
NYC	8	20	2.00E-05	1700	0.47
DC	8	20	2.00E-05	1700	0.47
LA	10	25	2.50E-05	1360	0.38
SF	9	22.5	2.25E-05	1511	0.42

Table S2. UV –B Radiation and Time for 3 log Reduction for Major Cities in the Winter

City	UV Index (at noon)	UVB Radiation (winter) uW/cm^2	W/cm^2	Time for 3 log Reduction (s)	Hours
NYC	1	2.5	2.50E-06	13600	3.78
DC	1	2.5	2.50E-06	13600	3.78
LA	3	7.5	7.50E-06	4533	1.26
SF	2	5	5.00E-06	6800	1.89

The above calculations, however, do not account for the fluctuations in UV radiation throughout the day. Figures S1 and S2 demonstrate, using data from USDA/Colorado State how UV levels change from midnight June 20th, 2014, to midnight June 21st, 2014.

[12] National Weather Service Climate Prediction Center. UV Index Bulletins Archives. http://www.cpc.ncep.noaa.gov/products/stratosphere/uv_index/uv_archive.shtml. Last Update 1994. Accessed October 2015.

[13] UV-B Monitoring and Research Program. Erythemal Radiation. http://uvb.nrel.colostate.edu/UVB/da_queryErythemal.jsf. Last Update 2015. Accessed October 2015.

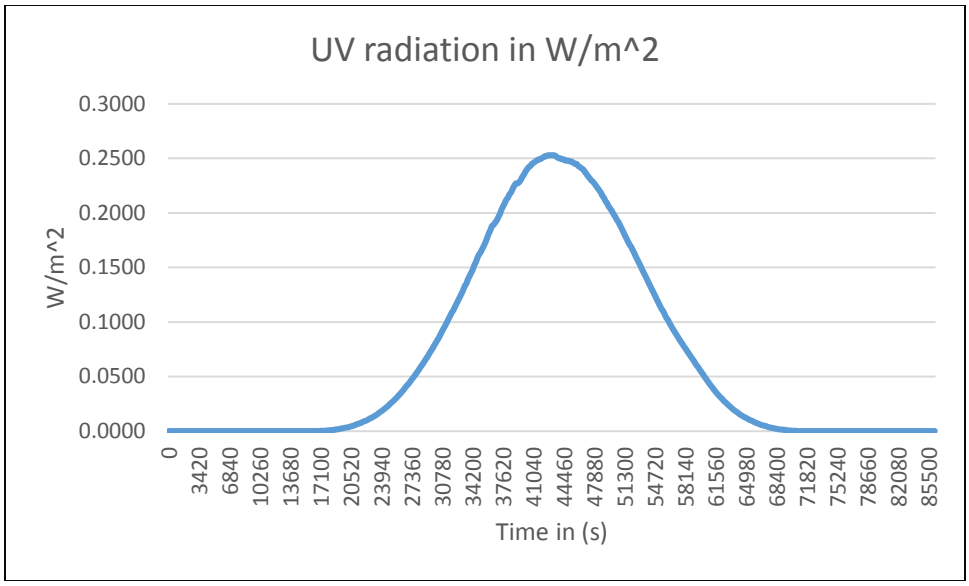

Figure S1. UV-B radiation in Davis, CA, captured every 180 seconds.

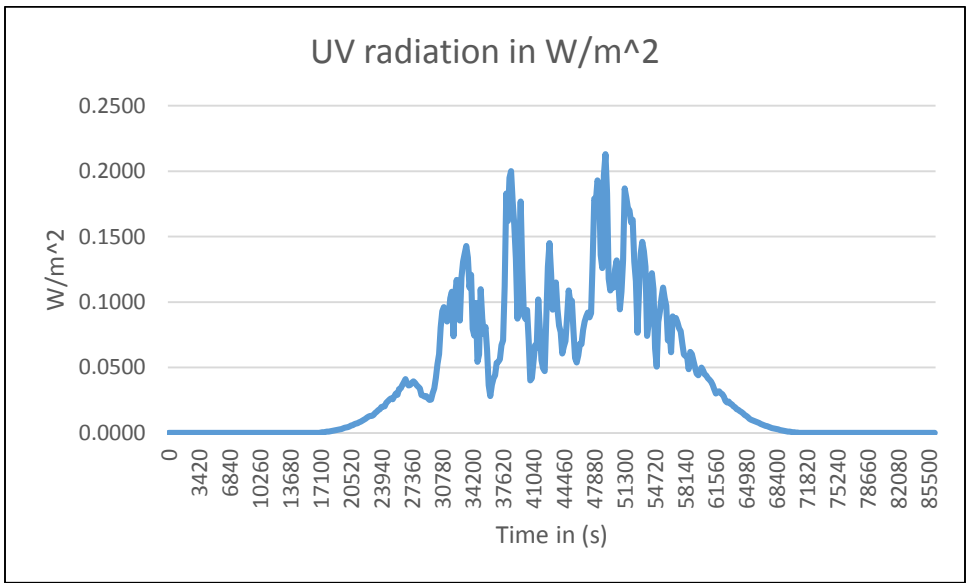

Figure S2. UV-B radiation in Geneva, NY, captured every 180 seconds.

In order to determine the mJ/cm^2 produced between any two points in time, the area under the curve must be estimated through integration, which was done by calculating the area of every trapezoidal section formed between every 180 second increment. In Table S3 and Table S4, the time needed for at least a 3 log reduction was determined by finding the time point at which the area under the curve was less than or equal to 34mJ/cm^2.

Table S3. Davis, CA, time needed for 3 log reduction in infectious virus				
Time at virus exposure to sunlight	**0:00**	**6:00**	**12:00**	**18:00**
Time at 3 log reduction	8:24	8:27	12:21	8:14 (the next day)
Elapsed Time	8hr. 24 min.	2hr. 27 min	21 min.	14hr. 14 min.

Table S4. Geneva, NY, time needed for 3 log reduction in infectious virus				
Time at virus exposure to sunlight	**0:00**	**6:00**	**12:00**	**18:00**
Time at 3 log reduction	8:42	8:45	13:09	8:36 (the next day)
Elapsed Time	8 hrs. 42 min.	2 hrs. 45 min.	1 hr. 9 min.	14 hrs. 36 min.