Crystal IS
High Performance UVC LEDs

APPLICATION NOTE:

UVC LEDs for Disinfection

July 17, 2014

THIS APPLICATION NOTE DESCRIBES HOW UVC RADIATION IS EFFECTIVE IN DISINFECTION. RELATIVE EFFECTIVENESS OF UV LEDS VERSUS UV LAMPS IS COMPARED. BASIC GUIDELINES ON SELECTION OF UVC RADIATION SYSTEMS FOR DISINFECTION APPLICATIONS ARE ALSO DISCUSSED. FURTHERMORE, UV DOSE LEVELS FOR LOG REDUCTION OF BACTERIA, PROTOZOA AND VIRUSES ARE PRESENTED.

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Introduction

Ultraviolet (UV) disinfection technology has existed for many years, but chemicals are still very prominent in disinfection applications today. UV disinfection does, however, provide many benefits over chemical options. It cannot be overdosed, and does not produce by-products, toxins, or volatile organic compound (VOC) emissions. It does not require the storage of hazardous materials, and will not affect smell or taste in water and food disinfection applications. In addition, UV light is known to kill more waterborne microbes than chlorination.

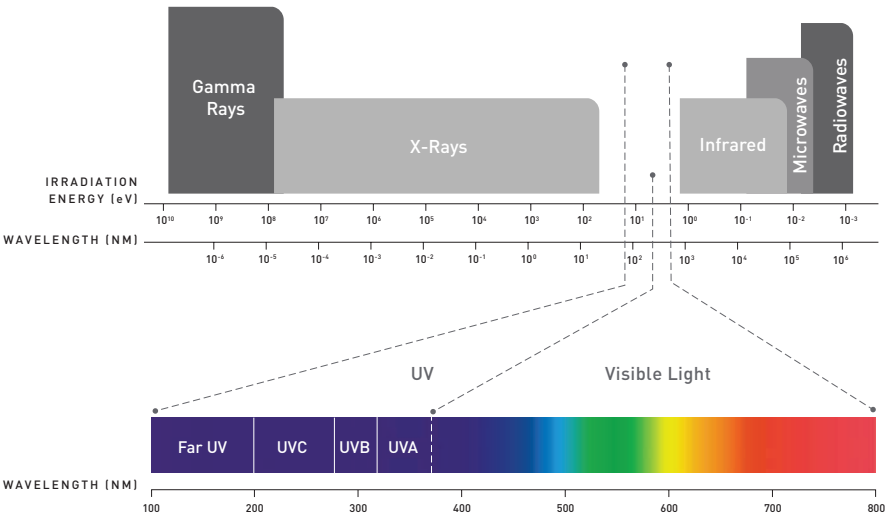
Crystal IS, by developing aluminum nitride (AlN) substrate technology to produce UV LEDs, has harnessed the benefits of UV disinfection while eliminating the drawbacks of traditional UV light sources.

What is UV Light?

UV light is a component of sunlight that falls in the region between visible light and X-rays on the electromagnetic spectrum, with a wavelength range of 100-400 nanometers (nm), as shown in Figure 1. This light can be further categorized into separate regions as follows:

- UVA: 315—400 nm
- UVB: 280—315 nm
- UVC: 200—280 nm
- Far UV (or "vacuum"): 100—200 nm

FIGURE 1: ELECTROMAGNETIC SPECTRUM



In the UVC range, ultraviolet light has powerful germicidal properties that may be used in a range of disinfection applications.

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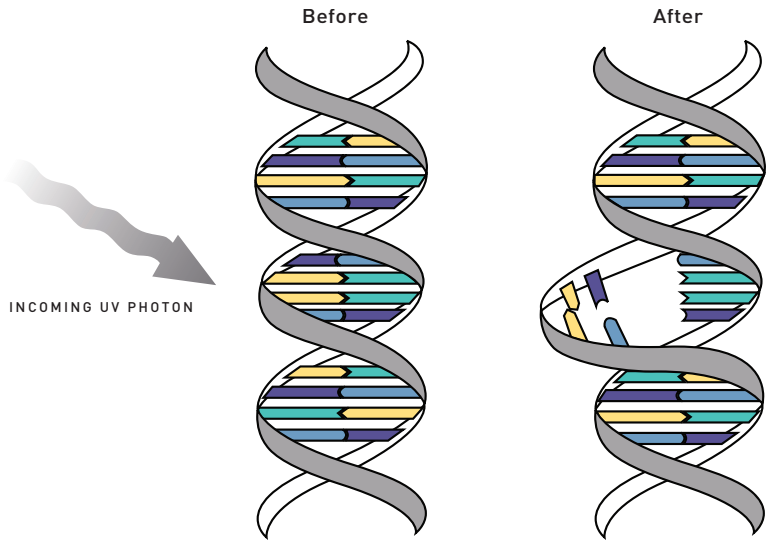
How Does Germicidal UV Work?

Radiation in the UVC range of 250-280 nm deactivates bacteria, viruses, and other microbes by attacking their DNA. UVC light is able to penetrate the cells of microorganisms and disrupt the structure of the DNA molecules. It does this by destroying the genetic information inside the DNA (Figure 2). The microorganisms, in turn, lose their reproductive capability and are destroyed, rendering them inactive and no longer harmful. The germicidal nature of UV is well suited to treat microorganisms which become extremely resistant to chemical disinfectants, as they are unable to develop immunity to UV radiation.

FIGURE 2: UVC RADIATION DISRUPTS DNA



What is a UV Dose?

Different pathogens have unique resistances to UV light—some are very susceptible, while others require more UVC exposure for complete inactivation. A correct UV dose is critical to thoroughly deactivate the intended microbes.

UV dose, also called UV fluence, is calculated using the following equation:
UV Dose = UV Intensity (I) x Exposure time (t)

In other words, UV Dose = I x T, where:

- UV dose is measured in joules per meter squared (J/m^2) or millijoules per centimeter squared (mJ/cm^2)
- UV Intensity (also called UV irradiance) is measured in milliwatts per centimeter squared (mW/cm^2)
- Exposure time is measured in seconds

The UV intensity (I) at the light source can attenuate, or diminish, by the time it reaches the target micro-organism. This can be caused by a number of factors, including the transmittance of UV light in water (in water disinfection applications) and the distance of the target micro-organism from the original light source (for a point source that is cylindrical, like an LED, intensity falls off as 1/radius). The reduction of the pathogen may be calculated from the ultimate UV dose delivered to the target once these attenuation factors are accounted for.

In addition to understanding the theoretical dosage delivered at a target, it is important to understand that final equations used by UV system designers have additional complexity. Some UV reactor designs take advantage of local flow and optical effects which, when integrated over the entire volume of disinfection, are quite substantial. In addition, variation in target pathogens introduces another key factor which will influence dosage requirements and require additional design considerations. There is no one solution for every problem. That said, typical UV dosage requirements can be found in the appendix at the end of this article.

The NSF, a public health and safety organization, sets standards for water, food, and the environment. UV water disinfection systems that use 254 nm mercury lamps are classified as either Class "A" systems, for treating water that is assumed to be contaminated, or Class "B" systems, which provide only supplemental disinfection. As per the standards for this type of water disinfection, Class A systems need a UV dose of at least 40 mJ/cm^2 and Class B systems need a dose of at least 16 mJ/cm^2. Similar standards have not yet been established for disinfection systems that have upgraded to using 265 nm LEDs as the UV light source.

What is Log Reduction?

The predictable amount of dosage required for a specific degree of disinfection is referred to as a "log reduction" (i.e. logarithmic reduction). Log reduction relates to the percentage of microorganisms physically removed or inactivated by a given process. For example, a 1 log reduction will see the pathogen of interest reduced by 90% from the influent level before UV disinfection. The microbe count is reduced by a factor of 10—or 1 log. Thus, a 2 log reduction will see a 99% reduction, or microbe reduction by a factor of 100, and so on and so forth. Figure 3 shows the chart of log reduction.

FIGURE 3: LOG REDUCTION

LOG REDUCTION	REDUCTION FACTOR	PERCENT REDUCED
1	10	90%
2	100	99%
3	1000	99.9%
4	10,000	99.99%
5	100,000	99.999%
6	1,000,000	99.9999%

By determining the doses of the targeted microorganisms and pairing them with the desired log reduction, an effective disinfection system can be created for many disinfection applications. These desired log reductions can be seen in the appendix referenced earlier.

UV Dose Response

The UV dose-response relationship determines what proportion of a specific microorganism is destroyed after a particular dose of UV radiation. This figure can be expressed as either the proportion of microorganisms inactivated or the proportion remaining as a function of UV dose. The UV dose-response is calculated using the following equation:

$$\textit{Log inactivation} = \log 10 (N_0/N)$$

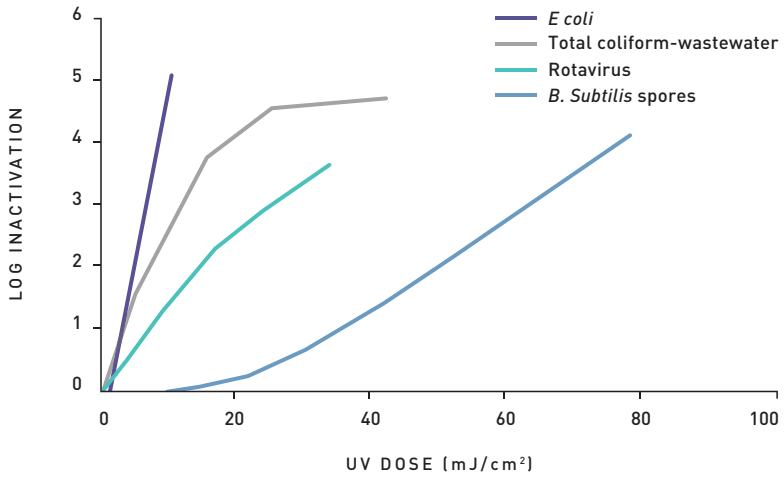
Where:

- N_0 = concentration of infectious microorganisms before exposure to UV light
- N = concentration of infectious microorganisms after exposure to UV light

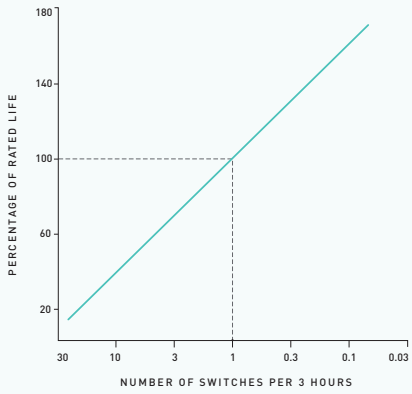
Each microorganism has a unique dose-response curve. The curve illustrates how different microorganisms respond to different doses of UV radiation.

Figure 4 shows several examples of UV dose-response curves. *B. Subtilis* requires a relatively high dose of UV radiation to reach higher log inactivations. *E. coli*, on the other hand, becomes inactivated with a relatively low dose of radiation.

FIGURE 4: SHAPES OF UV DOSE-RESPONSE CURVES



Unlike UVC LEDs, mercury lamps do not have an instant on/off feature. They require warm up and cool down cycles, which use time and energy. The overall lifetime of these mercury lamps decreases the more often they are switched on and off.



The Crystal IS Product for Your Disinfection Application

UV radiation can be an incredibly effective resource for disinfection applications, and Crystal IS has created a unique product that overcomes obstacles traditionally associated with UV light sources. Its lifetime expectancy and reliability can exceed other UV light sources, and the instant on/off feature which is inherent to solid state devices (unlike its plasma gas counterparts) can contribute to a lengthening of lifetime. The UVC LEDs are safe and eco-friendly, and offer design flexibility that other UV sources cannot match. The benefits of the Crystal IS LED product make UV disinfection a very efficient, cost-effective option in disinfection applications.

To learn more about Crystal IS ultraviolet LEDs for disinfection applications, visit our website at cisuvc.com.

UV DOSES FOR BACTERIA

BACTERIUM	LAMP TYPE	UV DOSE (FLUENCE) (MJ/CM²)*							REFERENCE
		1	2	3	4	5	6	7	
Halobacterium elongata ATCC33173	LP	0.4	0.7	1					Martin et al. 2000
Halobacterium salinarum ATCC43214	LP	12	15	17.5	20				Martin et al. 2000
Klebsiella pneumoniae	LP	12	15	17.5	20				Giese & Darby 2000
Klebsiella terrigena ATCC33257	LP	4.6	6.7	8.9	11				Wilson et al. 1992
Legionella pneumophila ATCC43660	LP	3.1	5	6.9	9.4				Wilson et al. 1992
Legionella pneumophila ATCC33152	LP	1.6	3.2	4.8	6.4	8.0			Oguma et al. 2004
Legionella pneumophila ATCC33152	MP	1.9	3.8	5.8	7.7	9.6			Oguma et al. 2004
Pseudomonas stutzeri	UVB	100	150	195	230				Joux et al. 1999
RB2256	UVB	175	>300						Joux et al. 1999
Salmonella spp.	LP	<2	2	3.5	7	14	29		Yaun et al. 2003
Salmonella anatum (from human feces)	N/A	7.5	12	15					Tosa & Hirata 1998
Salmonella derby (from human feces)	N/A	3.5	7.5						Tosa & Hirata 1998
Salmonella enteritidis (from human feces)	N/A	5	7	9	10				Tosa & Hirata 1998
Salmonella infantis (from human feces)	N/A	2	4	6					Tosa & Hirata 1998
Salmonella typhi ATCC19430	LP	1.8	4.8	6.4	8.2				Wilson et al. 1992
Salmonella typhi ATCC6539	N/A	2.7	4.1	5.5	7.1	8.5			Chang et al. 1985
Salmonella typhimurium (from human feces)	N/A	2	3.5	5	9				Tosa & Hirata 1998
Salmonella typhimurium (in act. sludge)	LP	3	11.5	22	50				Maya et al. 2003
Salmonella typhimuirium	UVB	50	100	175	210	250			Joux et al. 1999
Shigella dysenteriae ATCC29027	LP	0.5	1.2	2	3	4	5.1		Wilson et al. 1992
Shigella sonnei ATCC9290	N/A	3.2	4.9	6.5	8.2				Chang et al. 1985
Staphylococcus aureus ATCC25923	N/A	3.9	5.4	6.5	10.4				Chang et al. 1985
Streptococcus faecalis ATCC29212	N/A	6.6	8.8	9.9	11.2				Chang et al. 1985
Streptococcus faecalis (secondary effluent)	N/A	5.5	6.5	8	9	12			Harris et al. 1987
Vibrio anguillarum	LP	0.5	1.2	1.5	2				Liltved & Landfald 1996
Vibrio cholerae ATCC25872	LP	0.8	1.4	2.2	2.9	3.6	4.3		Wilson et al. 1992
Vibrio natreigens	UVB	37.5	75	100	130	150			Joux et al. 1999
Yersinia enterocolitica ATCC27729	LP	1.7	2.8	3.7	4.6				Wilson et al. 1992
Yersinia ruckeri	LP	1	2	3	5				Liltved & Landfald 1996

**UV dose is for a given Log Reduction without photo-reactivation*

UV DOSES FOR PROTOZOA

PROTOZOAN	LAMP TYPE	UV DOSE (FLUENCE) (MJ/CM²)*							REFERENCE
		1	2	3	4	5	6	7	
Cryptosporidium hominis	LP & MP	3	5.8						Johnson et al. 2005
Cryptosporidium parvum, oocysts, tissue culture assay	N/A	1.3	2.3	3.2					Shin et al. 2000
Cryptosporidium parvum	LP & MP	2.4	<5	5.2	9.5				Craik et al. 2001
Cryptosporidium parvum	MP	<5	<5	<5	~6				Amoah et al. 2005
Cryptosporidium parvum	MP	<10	<10	<10					Belosevie et al. 2001
Cryptosporidium parvum	LP	1	2	<5					Shin et al. 2001
Cryptosporidium parvum	MP	1	2	2.9	4				Bukhari et al. 2004
Cryptosporidium parvum	LP	<2	<2	<2	<4	<10			Clancy et al. 2004
Cryptosporidium parvum	MP	<3	<3	3-9	<11				Clancy et al. 2000
Cryptosporidium parvum	LP	<3	<3	3-6	<16				Clancy et al. 2000
Cryptosporidium parvum	LP	0.5	1	1.4	2.2				Morita et al. 2002
Cryptosporidium parvum	LP	2	<3	<3					Zimmer et al. 2003
Cryptosporidium parvum	MP	<1	<1	<1					Zimmer et al. 2003
Encephalitozoon cuniculi, microsporidia	LP	4	9	13					Marshall et al. 2003
Encephalitozoon hellem, microsproidia	LP	8	12	18					Marshall et al. 2003
Encephalitozoon intestinalis, mircosporidia	LP & MP	<3	3	<6	6				Huffman et al. 2002
Encephalitozoon intestinalis, mircosporidia	LP	3	5	6					Marshall et al. 2002
Giardia lamblia, gerbil infectivity assay	LP	<0.5	<0.5	<0.5	<1				Linden et al. 2002b
Giardia lamblia	LP	<10	~10	<20					Campbell et al. 2002
Giardia lamblia	LP	<2	<2	<4					Mofidi et al. 2002
Giardia lamblia, excystation assay	N/A	>63							Rice & Hoff 1981
Giardia lamblia, excystation assay	N/A	40	180						Karanis et al. 1992
Giardia muris, excystation assay	N/A	77	110						Carlson et al. 1985
G. muris, cysts, mouse infectivity assay	N/A	<2	<6	10 + tailing					Craik et al. 2000
Giardia muris	MP	1	4.5	28 + tailing					Craik et al. 2000
Giardia muris	MP	<10	<10	<25	~60				Belosevic et al. 2001
Giardia muris	LP	<1.9	<1.9	~2	~2.3				Hayes et al. 2003
Giardia muris	LP	<2	<2	<4					Mofidi et al. 2002
G. muris, cysts	MP	<5	<5	5					Amoah et al. 2005

**UV dose is for a given Log Reduction without photo-reactivation*

UV DOSES FOR VIRUSES

VIRUS	HOST	LAMP TYPE	UV DOSE (FLUENCE) (MJ/CM²)* PER LOG REDUCTION						REFERENCE
			1	2	3	4	5	6	
PRD-1 (Phage)	*S. typhimurium* Lt2	N/A	9.9	17.2	23.5	30.1			Meng & Gerba 1996
B40-8 (Phage)	*B. fragilis*	LP	11	17	23	29	35	41	Sommer et al. 2001
B40-8 (Phage)	*B. fragilis* HSP-40	LP	12	18	23	28			Sommer et al. 1998
MS2 (Phage)	*Salmonella typhimurium* WG49	N/A	16.3	35	57	83	114	152	Nieuwstad & Havelaar 1994
MS2 DSM 5694 (Phage)	*E. coli* NCIB 9481	N/A	4	16	38	68	110		Wiedenmann et al. 1993
MS2 ATCC15977-B1 (Phage)	*E. coli* ATCC15977-B1	LP	15.9	34	52	71	90	109	Wilson et al. 1992
MS2 NCIMB 10108 (Phage)	*Salmonella typhimurium* WG49	N/A	12.1	30.1					Tree et al. 1997
MS2 (Phage)	*E. coli* K-12 Hfr	LP	21	36					Sommer et al. 1998
MS2 (Phage)	*E. coli* CR63	N/A	16.9	33.8					Rauth 1965
MS2 (Phage)	*E. coli* 15977	N/A	13.4	28.6	44.8	61.9	80.1		Meng & Gerba 1996
MS2 (Phage)	*E. coli* C3000	N/A	35						Battigelli et al. 1993
MS2 (Phage)	*E. coli* ATCC15597	N/A	19	40	61				Oppenheimer et al. 1993
MS2 (Phage)	*E. coli* C3000	LP	20	42	69	92			Batch et al. 2004
MS2 (Phage)	*E. coli* ATCC15597	LP	20	42	70	98	113		Lazarova & Savoye 2004
MS2 (Phage)	*E. coli* ATCC15977	LP	20	50	85	120			Thurston-Enriquez et al. 2003
MS2 (Phage)	*E. coli* HS(pFamp)R	LP		45	75	100	125	155	Thompson et al. 2003
MS2 (Phage)	*E. coli* C3000	LP	20	42	68	90			Linden et al. 2002a
MS2 (Phage)	*E. coli* K-12	LP	18.5	36	55				Sommer et al. 2001
MS2 (Phage)	*E. coli* NCIMB 9481	N/A	14						Tree et al. 2005
PHI X 174 (Phage)	*E. coli* WG5	LP	2.2	5.3	7.3	10.5			Sommer et al. 1998
PHI X 174 (Phage)	*E. coli* C3000	N/A	2.1	4.2	6.4	8.5	10.6	12.7	Battigelli et al. 1993
PHI X 174 (Phage)	*E. coli* ATCC15597	N/A	4	8	12				Oppenheimer et al. 1993
PHI X 174 (Phage)	*E. coli* WG 5	LP	3	5	7.5	10	12.5	15	Sommer et al. 2001
PHI X 174 (Phage)	*E. coli* ATCC13706	LP	2	3.5	5	7			Giese & Darby 2000
Staphylococcus aureus phage A 994 (Phage)	*Staphylococcus aureus* 994	LP	8	17	25	36	47		Sommer et al. 1989
Calicivirus canine	MDCK cell line	LP	7	15	22	30	36		Husman et al. 2004
Calicivirus feline	CRFK cell line	LP	7	16	25				Husman et al. 2004
Calicivirus feline	CRFK cell line	N/A	4	9	14				Tree et al. 2005

UV DOSES FOR VIRUSES (CONTINUED)

VIRUS	HOST	LAMP TYPE	UV DOSE (FLUENCE) (MJ/CM²) PER LOG REDUCTION						REFERENCE
			1	2	3	4	5	6	
Calicivirus feline	CRFK cell line	LP	5	15	23	30	39		Thurston-Enriquez et al. 2003
Adenovirus type 2	A549 cell line	LP	20	45	80	110			Shin et al. 2005
Adenovirus type 2	Human lung cell line	LP	35	55	75	100			Ballester & Malley 2004
Adenovirus type 2	PLC / PRF / 5 cell line	LP	40	78	119	160	195	235	Gerba et al. 2002
Adenovirus type 15	A549 cell line (ATCC CCL-185)	LP	40	80	122	165	210		Thompson et al. 2003
Adenovirus type 40	PLC / PRF / 5 cell line	LP	55	105	155				Thurston-Enriquez et al. 2003
Adenovirus type 40	PLC / PRF / 5 cell line	LP	30	ND	ND	124			Meng & Gerba 1996
Adenovirus type 41	PLC / PRF / 5 cell line	LP	23.6	ND	ND	111.8			Meng & Gerba 1996
Poliovirus Type 1 ATCC Mahoney	N/A	N/A	6	14	23	30			Harris et al. 1987
Poliovirus Type 1 LSc2ab ()	MA104 cell	N/A	5.6	11	16.5	21.5			Chang et al. 1985
Poliovirus Type 1 LSc2ab	BGM cell	LP	5.7	11	17.6	23.3	32	41	Wilson et al. 1992
Poliovirus 1	BGM cell line	N/A	5	11	18	27			Tree et al. 2005
Poliovirus 1	CaCo2 cell line (ATCC HTB37)	LP	7	17	28	37			Thompson et al. 2003
Poliovirus 1	BGM cell line	LP	8	15.5	23	31			Gerba et al. 2002
Poiovirus Type Mahoney	Monkey kidney cell line Vero	LP	3	7	14	40			Sommer et al. 1989
Coxsackievirus B5	BGM cell line	N/A	6.9	13.7	20.6				Battigelli et al. 1993
Coxsackievirus B3	BGM cell line	LP	8	16	24.5	32.5			Gerba et al. 2002
Cocksacievirus B5	BGM cell line	LP	9.5	18	27	36			Gerba et al. 2002
Reovirus-3	Mouse L-60	N/A	11.2	22.4					Rauth 1965
Reovirus Type 1 Lang strain	N/A	N/A	16	36					Harris et al. 1987
Rotavirus SA-11	Monkey kidney cell line MA 104	LP	8	15	27	38			Sommer et al. 1989
Rotavirus SA-11	MA-104 cell line	N/A	7.6	15.3	23				Battigelli et al. 1993
Rotavirus SA-11	MA-104 cell line	N/A	7.1	14.8	25				Chang et al. 1985
Rotavirus SA-11	MA-104 cell line	LP	9.1	19	26	36	48		Wilson et al. 1992
Rotavirus	MA-104 cells	LP	20	80	140	200			Caballero et al. 2004
Hepatitis A HM175	FRhK-4 cell	LP	5.1	13.7	22	29.6			Wilson et al. 1992
Hepatitis A	HAV / HFS / GBM	N/A	5.5	9.8	15	21			Wiedenmann et al. 1993
Hepatitis A HM175	FRhK-4 cell	N/A	4.1	8.2	12.3	16.4			Battigelli et al. 1993
Echovirus 1	BGM cell line	LP	8	16.5	25	33			Gerba et al. 2002
Echovirus 2	BGM cell line	LP	7	14	20.5	28			Gerba et al. 2002

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We invite you to learn more about our UVC LEDs.

Crystal IS™
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