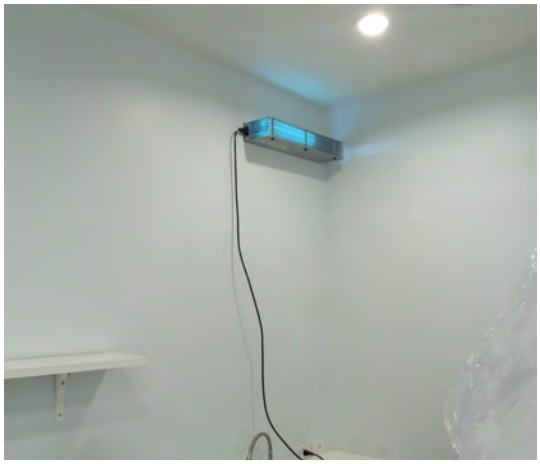
Ultraviolet Light Disinfection Data Sheet

UV has been used for disinfection since the mid-20th century, with beginnings even earlier when sunlight was investigated for bactericidal effects in the mid-19th century. It's used for drinking and wastewater treatment, air disinfection, the treatment of fruit and vegetable juices, as well as a myriad of home devices for disinfecting everything from toothbrushes to tablet computers. Within research facilities, UV has been an option when purchasing Biological Safety Cabinets for years, and can also be used within ductwork.



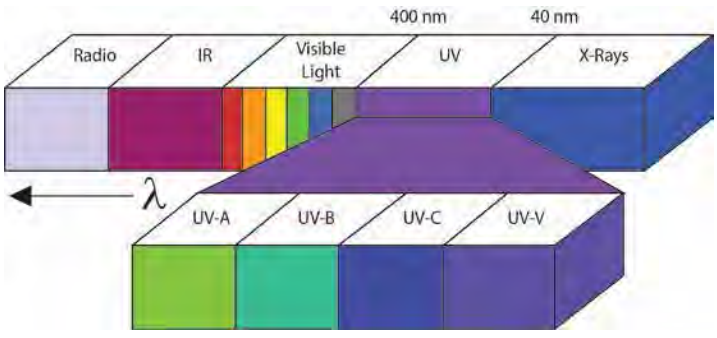
UV technology has advanced in recent years to become more reliable. Ballasts being used today are able to maintain the power output of UV bulbs for far longer than in the past. UV bulbs today have rated lifespans in the thousands of hours. This has allowed UV systems to become more viable for wide ranging use.

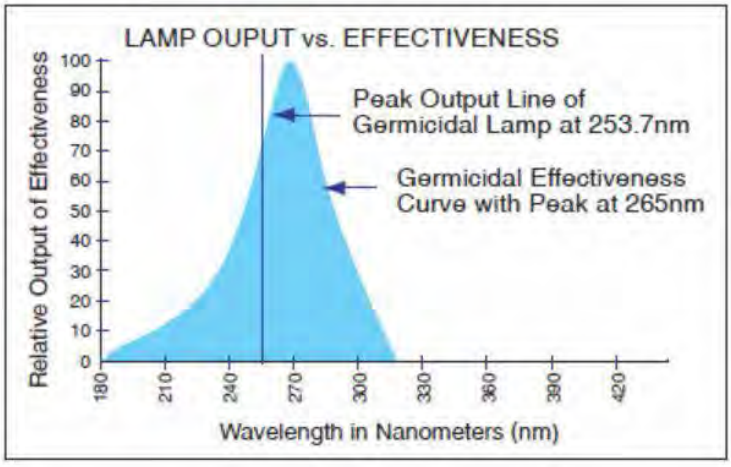
The use of UV has recently grown within the healthcare industry to provide disinfection of room surfaces in addition to existing cleaning methods. The use of ultraviolet light for surface disinfection within research facilities has started to increase as well due to its ease of use, short dosage times, and broad efficacy.

How Does UV Work?

Ultraviolet light exists within the spectrum of light between 10 and 400 nm. The germicidal range of UV is within the 100-280nm wavelengths, known as UV-C, with the peak wavelength for germicidal activity being 265 nm. This range of UV light is absorbed by the DNA and RNA of microorganisms, which causes changes in the DNA and RNA structure, rendering the microorganisms incapable of replicating. A cell that can't reproduce is considered dead; since it is unable to multiply to infectious numbers within a host. This is why UV disinfection is sometimes called ultraviolet germicidal irradiation (UVGI).

Our UV systems use low-pressure, mercury-arc germicidal lamps which are designed to produce the highest amounts of UV radiation - where 90% of energy is typically generated at 254nm. This radiation is very close to the peak of the germicidal effectiveness curve of 265nm, the most lethal wavelength to microorganisms.





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What is UV Effective Against?
UV has been proven effective against a broad spectrum of microorganisms. Viruses contain RNA or DNA and are thus susceptible to irradiation. Bacteria and fungi both contain DNA and are similarly vulnerable to UV light. Spores are also susceptible to UV. With the longstanding use of UV for disinfection, there is a plethora of information regarding dosages necessary to inactivate different microorganisms. Bacteria are generally easier to inactivate than viruses, with fungi and spores being even harder to inactivate with UV. Please see Appendix 2 for a list of microorganisms which UV-C is effective against.

Safety
As UV-C provides radiation, it is not safe to be in the room while UV-C disinfection is taking place. UV-C is classified as "reasonably anticipated to be a human carcinogen" by the National Toxicology Program. It presents a hazard to skin and eyes, so direct exposure to UV-C is always to be avoided. UV-C is blocked by a number of materials, including glass (but not quartz glass) and most clear plastics, so it is possible to safely observe a UV-C system if you are looking through a window. UV-C provides residue free disinfection, so there is no concern over dangerous residues that need to be wiped down or neutralized after the disinfection occurs. The process is environmentally friendly in that there are no dangerous or toxic chemicals that require specialized storage or handling. Since no chemicals are added to the air/water there are no process byproducts to be concerned with. The UV bulbs do not require special handling or disposal either, making the system a green alternative to chemical disinfectants.

Benefits
While there are definite limitations to UV-C disinfection technologies, there are many benefits as well. Disinfection times are fast, with a typical disinfection cycle lasting about 15 minutes. This allows for extremely fast turnover times for rooms or other spaces being disinfected. Due to its simplicity, UV-C disinfection is extremely easy to understand. All surfaces within a certain distance will observe an assured level of disinfection in a certain amount of time as long as the light is not blocked from shining on that surface. It becomes very easy to plan the use of a UV-C disinfection system when the parameters and limitations are easily established and understood.

There is no need to establish air flow patterns with UV-C as you would with a fogging system. Nor is there a need to isolate rooms from HVAC systems or seal doors. This, along with the lack of chemical mixture, makes the preparation time quick to setup and start a UV-C disinfection cycle.

The cost to run UV systems is very low, as systems are powered by regular wall outlets. With that, a typical UV-C treatment costs under 2 cents. UV systems also require little maintenance and upkeep due to their simplistic nature. UV bulbs last thousands of hours at their peak output, limiting the need for routine consumable change out and maintenance.

Drawbacks
While UV is effective at inactivating a wide range of microorganisms, there are limitations for its use. As it involves light waves, UV operates in a "line of sight" fashion, only irradiating surfaces within its sightlines. Surfaces can be blocked from the light if objects are in the way, much like a beach umbrella offering protection from the sun. These areas that become blocked from the UV light are commonly referred to as shadow areas. Surfaces in these shadow areas do not receive adequate disinfection as UV light does not have the ability to reflect well off surfaces. Shadow areas are typically dealt with by moving the UV light source to a second position to accommodate disinfection of the surfaces blocked from UV disinfection the first time.

Distance also plays a factor into the efficacy of UV light. The strength of the UV-C light decreases the further away it gets from the light source, following the inverse square law. This means that at twice the distance, the UV-C will have ¼ of its power that was present at the original reference point. This relationship limits how far a single source of UV light is effective before it is too weak to provide adequate disinfection. Most systems deal with this by quantifying their UV-C output at a given distance, and using that distance to generate treatment times. Sensors are available which can measure the UV-C output of the UV systems at any location, such that adequate treatment times can be interpreted for that specific location.

UV light does not penetrate well into organic materials, so for best results UV-C should be used after a standard cleaning of the room to remove any organic materials from surfaces.

Applications
UV light can safely be used for a variety of disinfection applications. Systems are available to disinfect rooms and high touch areas, ambulances and other emergency service vehicles, ductwork, tools equipment inside a disinfection chamber, continuous UV-C passthrough conveyors, and many other applications. It has long been available for Biological Safety Cabinet disinfection and home water treatment as well. It provides a chemical free method of disinfecting soundproofing materials that are traditionally chemically incompatible.

Appendix 1 – Historical Use of UV Light for Disinfection

For the past 100 years science has recognized the bactericide effects of the ultraviolet area of the electromagnetic spectrum. Below are some key contributions over the years:

1855 Arloing and Daclaux demonstrated sunlight killed Bacillus anthracis and Tyrothrix scaber

1877 Downes and Blunt reported bacteria were inactivated by sunlight – violet blue spectrum most effective

1889 Widmark confirmed UV rays from arc lamps were responsible for inactivation

1892 Geisler used a prism and heliostat to show sunlight and electric arc lamps are lethal to Bacillus Typhosus

1903 Banard and Morgan determined UV spectrum 226-328 nm is biocidal

1932 Ehris and Noethling isolated biocidal spectrum to 253.7 nm

1957 Riley proves effectiveness for Tb control

1994 CDC acknowledges UV effectiveness for Tb control

1999 WHO recommends UVGI for Tb control

Appendix 2 – Ultraviolet Light Exposure Dosage

The degree of inactivation by ultraviolet radiation is directly related to the UV dose applied. The UV dose is the product of UV intensity [I] (expressed as energy per unit surface area) and exposure time [T].

Therefore: DOSE = I x T

This dose, sometimes referred to as fluence, is commonly expressed as millijoule per square centimeter (mJ/cm^2). The units "J/m^2" are used in most parts of the world except for North America, where "mJ/cm^2" are used.

The reduction of micro-organisms is classified using a logarithmic scale. A single log reduction is a 90% reduction of organisms. A two log reduction is a 99% reduction of organisms, followed by a three log reduction (99.9%), etc. The UV-C exposure dosage needed for each level of reduction is shown in the table along with the published reference where the data came from.

UV Dose (mJ/cm^2) Needed For a Given Log Reduction

	Log Reduction						
	1	2	3	4	5	6	Reference
Spore							
Bacillus anthracis spores - Anthrax spores	24.32	46.2					Light Sources Inc. 2014
Bacillus magaterium sp. (spores)	2.73	5.2					Light Sources Inc. 2014
Bacillus subtilis ATCC6633	24	35	47	79			Mamane-Gravetz and Linden 2004
Bacillus subtilis WN626	0.4	0.9	1.3	2			Marshall et al., 2003
Bacillus subtilis spores	11.6	22.0					Light Sources Inc. 2014
Bacterium							
Aeromonas salmonicida	1.5	2.7	3.1	5.9			Liltved and Landfald 1996
Aeromonas hydrophila ATCC7966	1.1	2.6	3.9	5	6.7	8.6	Wilson et al. 1992
Bacillus anthracis - Anthrax	4.52	8.7					Light Sources Inc. 2014
Bacillus magaterium sp. (veg.)	1.3	2.5					Light Sources Inc. 2014
Bacillus paratyphusus	3.2	6.1					Light Sources Inc. 2014
Bacillus subtilis	5.8	11.0					Light Sources Inc. 2014
Campylobacter jejuni ATCC 43429	1.6	3.4	4	4.6	5.9		Wilson et al. 1992
Citrobacter diversus	5	7	9	11.5	13		Giese and Darby 2000
Citrobacter freundii	5	9	13				Giese and Darby 2000
Clostridium tetani	13.0	22.0					Light Sources Inc. 2014
Corynebacterium diphtheriae	3.37	6.51					Light Sources Inc. 2014

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UV Dose (mJ/cm^2) Needed For a Given Log Reduction

	Log Reduction						
	1	2	3	4	5	6	Reference
Ebertelia typhosa	2.14	4.1					Light Sources Inc. 2014V
Escherichia coli O157:H7 CCUG 29193	3.5	4.7	5.5	7			Sommer et al. 2000
Escherichia coli O157:H7 CCUG 29197	2.5	3	4.6	5	5.5		Sommer et al. 2000
Escherichia coli O157:H7 CCUG 29199	0.4	0.7	1	1.1	1.3	1.4	Sommer et al. 2000
Escherichia coli O157:H7 ATCC 43894	1.5	2.8	4.1	5.6	6.8		Wilson et al. 1992
Escherichia coli	3.0	6.6					Light Sources Inc. 2014
Escherichia coli ATCC 11229	7	8	9	11	12		Hoyer 1998
Escherichia coli ATCC 11303	4	6	9	10	13	15	Wu et al. 2005
Escherichia coli ATCC 25922	6	6.5	7	8	9	10	Sommer et al. 1998
Escherichia coli K-12 IFO3301	2.2	4.4	6.7	8.9	11.0		Oguma et al. 2004
Escherichia coli O157:H7	<2	<2	2.5	4	8	17	Yaun et al. 2003
Halobacterium elongate ATCC33173	0.4	0.7	1				Martin et al. 2000
Halobacterium salinarum ATCC43214	12	15	17.5	20			Martin et al. 2000
Klebsiella pneumoniae	12	15	17.5	20			Giese and Darby 2000
Klebsiella terrigena ATCC33257	4.6	6.7	8.9	11			Wilson et al. 1992
Legionella pneumophila ATCC33152	1.9	3.8	5.8	7.7	9.6		Oguma et al. 2004
Legionella pneumophila ATCC 43660	3.1	5	6.9	9.4			Wilson et al. 1992
Legionella pneumophila ATCC33152	1.6	3.2	4.8	6.4	8.0		Oguma et al. 2004
Leptospiracanicola - Infectious Jaundice	3.15	6.0					Light Sources Inc. 2014
Micrococcus candidus	6.05	12.3					Light Sources Inc. 2014
Micrococcus sphaeroides	1.0	15.4					Light Sources Inc. 2014
Mycobacterium tuberculosis	6.2	10.0					Light Sources Inc. 2014
Neisseria catarrhalis	4.4	8.5					Light Sources Inc. 2014
Phytomonas tumefaciens	4.4	8.0					Light Sources Inc. 2014
Proteus vulgaris	3.0	6.6					Light Sources Inc. 2014
Pseudomonas stutzeri	100	150	195	230			Joux et al. 1999
Pseudomonas aeruginosa	5.5	10.5					Light Sources Inc. 2014
Pseudomonas fluorescens	3.5	6.6					Light Sources Inc. 2014
Salmonela paratyphi - Enteric fever	3.2	6.1					Light Sources Inc. 2014
Salmonella anatum (from human feces)	7.5	12	15				Tosa and Hirata 1998
Salmonella derby (from human feces)	3.5	7.5					Tosa and Hirata 1998
Salmonella enteritidis (from human feces)	5	7	9	10			Tosa and Hirata 1998
Salmonella infantis (from human feces)	2	4	6				Tosa and Hirata 1998
Salmonella spp.	<2	2	3.5	7	14	29	Yaun et al. 2003
Salmonella typhi ATCC 19430	1.8	4.8	6.4	8.2			Wilson et al. 1992
Salmonella typhi ATCC 6539	2.7	4.1	5.5	7.1	8.5		Chang et al. 1985
Salmonella typhimurium (from human feces)	2	3.5	5	9			Tosa and Hirata 1998
Salmonella typhimurium	50	100	175	210	250		Joux et al. 1999
Salmonella enteritidis	4.0	7.6					Light Sources Inc. 2014
Salmonella typhimurium	8.0	15.2					Light Sources Inc. 2014
Salmonella typhosa - Typhoid fever	2.15	4.1					Light Sources Inc. 2014
Sarcina lutea	19.7	26.4					Light Sources Inc. 2014
Serratia marcescens	2.42	6.16					Light Sources Inc. 2014
Shigella dysenteriae ATCC29027	0.5	1.2	2	3	4	5.1	Wilson et al. 1992
Shigella dyseteriae - Dysentery	2.2	4.2					Light Sources Inc. 2014
Shigella flexneri - Dysentery	1.7	3.4					Light Sources Inc. 2014
Shigella paradysenteriae	1.68	3.4					Light Sources Inc. 2014
Shigella sonnei ATCC9290	3.2	4.9	6.5	8.2			Chang et al. 1985
Spirillum rubrum	4.4	6.16					Light Sources Inc. 2014

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UV Dose (mJ/cm^2) Needed For a Given Log Reduction	Log Reduction						
	1	2	3	4	5	6	Reference
Staphylococcus aureus ATCC25923	3.9	5.4	6.5	10.4			Chang et al. 1985
Staphylococcus albus	1.84	5.72					Light Sources Inc. 2014
Staphylococcus aureus	2.6	6.6					Light Sources Inc. 2014
Staphylococcus hemolyticus	2.16	5.5					Light Sources Inc. 2014
Staphylococcus lactis	6.15	8.8					Light Sources Inc. 2014
Streptococcus faecalis (secondary effluent)	5.5	6.5	8	9	12		Harris et al. 1987
Streptococcus faecalis ATCC29212	6.6	8.8	9.9	11.2			Chang et al. 1985
Streptococcus viridans	2.0	3.8					Light Sources Inc. 2014
Vibrio anguillarum	0.5	1.2	1.5	2			Liltved and Landfald 1996
Vibrio cholerae ATCC25872	0.8	1.4	2.2	2.9	3.6	4.3	Wilson et al. 1992
Vibrio comma - Cholera	3.375	6.5					Light Sources Inc. 2014
Vibrio natriegens	37.5	75	100	130	150		Joux et al. 1999
Yersinia enterocolitica ATCC27729	1.7	2.8	3.7	4.6			Wilson et al. 1992
Yersinia ruckeri	1	2	3	5			Liltved and Landfald 1996
Yeasts							
Brewers yeast	3.3	6.6					Light Sources Inc. 2014
Common yeast cake	6.0	13.2					Light Sources Inc. 2014
Saccharomyces carevisiae	6.0	13.2					Light Sources Inc. 2014
Saccharomyces ellipsoideus	6.0	13.2					Light Sources Inc. 2014
Saccharomyces spores	8.0	17.6					Light Sources Inc. 2014
Molds							
Aspergillius flavus	60.0	99.0					Light Sources Inc. 2014
Aspergillius glaucus	44.0	88.0					Light Sources Inc. 2014
Aspergillius niger	132.0	330.0					Light Sources Inc. 2014
Mucor racemosus A	17.0	35.2					Light Sources Inc. 2014
Mucor racemosus B	17.0	35.2					Light Sources Inc. 2014
Oospora lactis	5.0	11.0					Light Sources Inc. 2014
Penicillium digitatum	44.0	88.0					Light Sources Inc. 2014
Penicillium expansum	13.0	22.0					Light Sources Inc. 2014
Penicillium roqueforti	13.0	26.4					Light Sources Inc. 2014
Rhisopus nigricans	111.0	220.0					Light Sources Inc. 2014
Protozoan							
Chlorella Vulgaris	13.0	22.0					Light Sources Inc. 2014
Cryptosporidium hominis	3	5.8					Johnson et al. 2005
Cryptosporidium parvum	2.4	<5	5.2	9.5			Craik et al. 2001
Cryptosporidium parvum, oocysts, tissue culture assay	1.3	2.3	3.2				Shin et al. 2000
Encephalitozoon cuniculi, microsporidia	4	9	13				Marshall et al. 2003
Encephalitozoon hellem, microsporidia	8	12	18				Marshall et al. 2003
Encephalitozoon intestinalis, microsporidia	3	5	6				Marshall et al. 2003
G. muris, cysts	<5	<5	5				Amoah et al. 2005
G. muris, cysts, mouse infectivity assay	<2	<6	10 + tailing				Craik et al. 2000
Giardia lamblia	<10	~10	<20				Campbell et al. 2002
Giardia muris	<1.9	<1.9	~2	~2.3			Hayes et al. 2003
Nematode Eggs	45.0	92.0					Light Sources Inc. 2014
Paramecium	11.0	20.0					Light Sources Inc. 2014

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The following table shows the required UV-C exposure dosages necessary for various log reductions of viruses.

UV Dose (mJ/cm^2) Needed For a Given Log Reduction								
		Log Reduction						
Virus	**Host**	**1**	**2**	**3**	**4**	**5**	**6**	
Adenovirus type 15	A549 cell line (ATCC CCL-185)	40	80	122	165	210		Thompson et al. 2003
Adenovirus type 2	A549 cell line	20	45	80	110			Shin et al. 2005
Adenovirus type 2	Human lung cell line	35	55	75	100			Ballester and Malley 2004
Adenovirus type 2	PLC / PRF / 5 cell line	40	78	119	160	195	235	Gerba et al. 2002
Adenovirus type 40	PLC / PRF / 5 cell line	55	105	155				ston-Enriquez et al. 2003
Adenovirus type 41	PLC / PRF / 5 cell line	23.6	ND	ND	111.8			Meng and Gerba 1996
B40-8 (Phage)	B. Fragilis	11	17	23	29	35	41	Sommer et al. 2001
Bacteriopfage - E. Coli	N/A	2.6	6.6					Light Sources Inc. 2014
Calicivirus canine	MDCK cell line	7	15	22	30	36		Husman et al. 2004
Calicivirus feline	CRFK cell line	5	15	23	30	39		ston-Enriquez et al. 2003
Coxsackievirus B3	BGM cell line	8	16	24.5	32.5			Gerba et al. 2002
Coxsackievirus B5	Buffalo Green Monkey cell line	6.9	13.7	20.6				Battigelli et al. 1993
Coxsackievirus B5	BGM cell line	9.5	18	27	36			Gerba et al. 2002
Echovirus I	BGM cell line	8	16.5	25	33			Gerba et al. 2002
Echovirus II	BGM cell line	7	14	20.5	28			Gerba et al. 2002
Hepatitis A	HAV/HFS/GBM	5.5	9.8	15	21			Wiedenmann et al.
Hepatitis A HM175	FRhK-4 cell	5.1	13.7	22	29.6			Wilson et al. 1992
Hepatitis A HM175	FRhK-4 cell	4.1	8.2	12.3	16.4			Battigelli et al. 1993
Infectious Hepatitis	N/A	5.8	8.0					Light Sources Inc. 2014
Influenza	N/A	3.4	6.6					Light Sources Inc. 2014
MS2 (Phage)	Salmonella typhimurium WG49	16.3	35	57	83	114	152	Nieuwstad and Havelaar
MS2 (Phage)	*E. coli* ATCC 15597	20	42	70	98	133		Lazarova and Savoye 2004
MS2 (Phage)	*E. coli* HS(pFamp)R		45	75	100	125	155	Thompson et al. 2003
MS2 ATCC 15977-B1 (Phage)	*E. coli* ATCC 15977–B1	15.9	34	52	71	90	109	Wilson et al. 1992
MS2 DSM 5694 (Phage)	*E. coli* NCIB 9481	4	16	38	68	110		Wiedenmann et al. 1993
MS2 NCIMB 10108 (Phage)	*Salmonella typhimurium* WG49	12.1	30.1					Tree et al. 1997
PHI X 174 (Phage)	*E. coli* C3000	2.1	4.2	6.4	8.5	10.6	12.7	Battigelli et al. 1993
PHI X 174 (Phage)	*E. coli* WG 5	3	5	7.5	10	12.5	15	Sommer et al. 2001
Poliovirus - Poliomyelitis	N/A	3.15	6.6					Light Sources Inc. 2014
Poliovirus 1	BGM cell line	5	11	18	27			Tree et al. 2005
Poliovirus 1	CaCo2 cell-line (ATCC HTB37)	7	17	28	37			Thompson et al. 2003

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UV Dose (mJ/cm^2) Needed For a Given Log Reduction								
		Log Reduction						
Virus	**Host**	**1**	**2**	**3**	**4**	**5**	**6**	
Poliovirus Type Mahoney	Monkey kidney cell line Vero	3	7	14	40			Sommer et al. 1989
Poliovirus Type 1 LSc2ab ()	MA104 cell	5.6	11	16.5	21.5			Chang et al. 1985
Poliovirus Type 1 LSc2ab	BGM cell	5.7	11	17.6	23.3	32	41	Wilson et al. 1992
PRD-1 (Phage)	S. typhimurium Lt2	9.9	17.2	23.5	30.1			Meng and Gerba 1996
Reovirus Type 1 Lang strain	N/A	16	36					Harris et al. 1987
Reovirus-3	Mouse L-60	11.2	22.4					Rauth 1965
Rotavirus	MA104 cells	20	80	140	200			Caballero et al. 2004
Rotavirus SA-11	MA-104 cell line	9.1	19	26	36	48		Wilson et al. 1992

Application

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