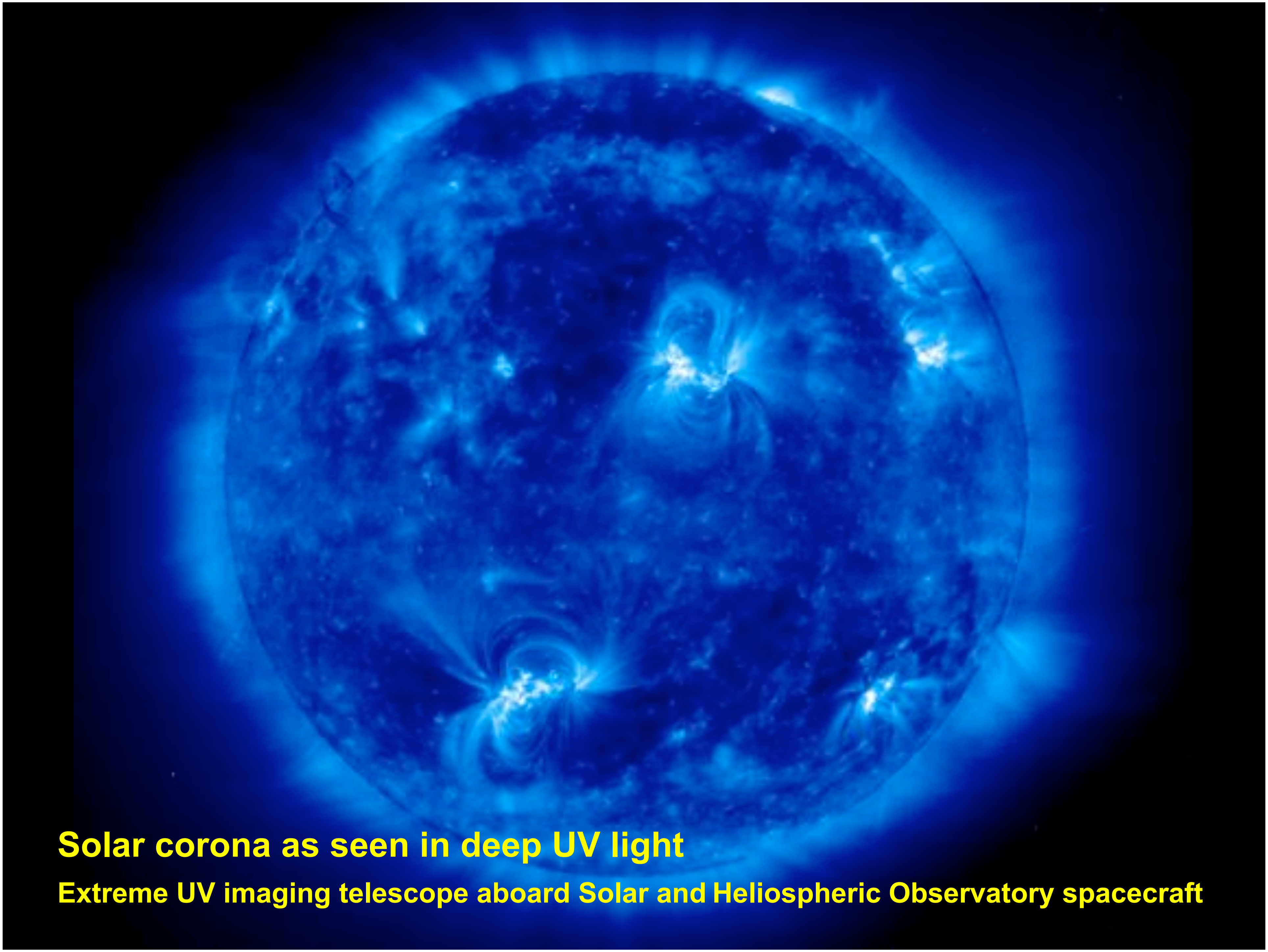
UV

Ultraviolet Light for Disinfection of Wastewater

Tom O'Connor, PE

H_2O'C Engineering



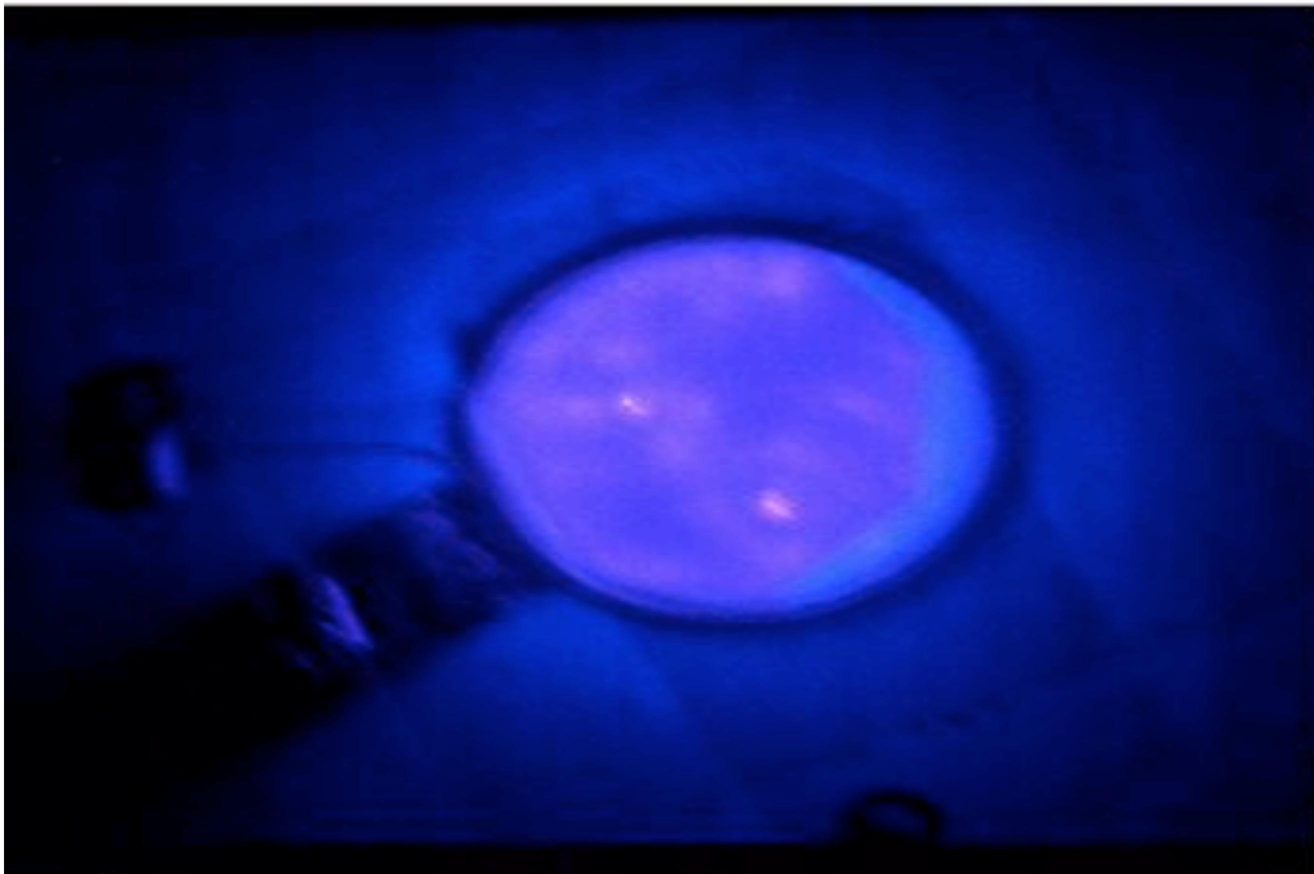
Solar corona as seen in deep UV light

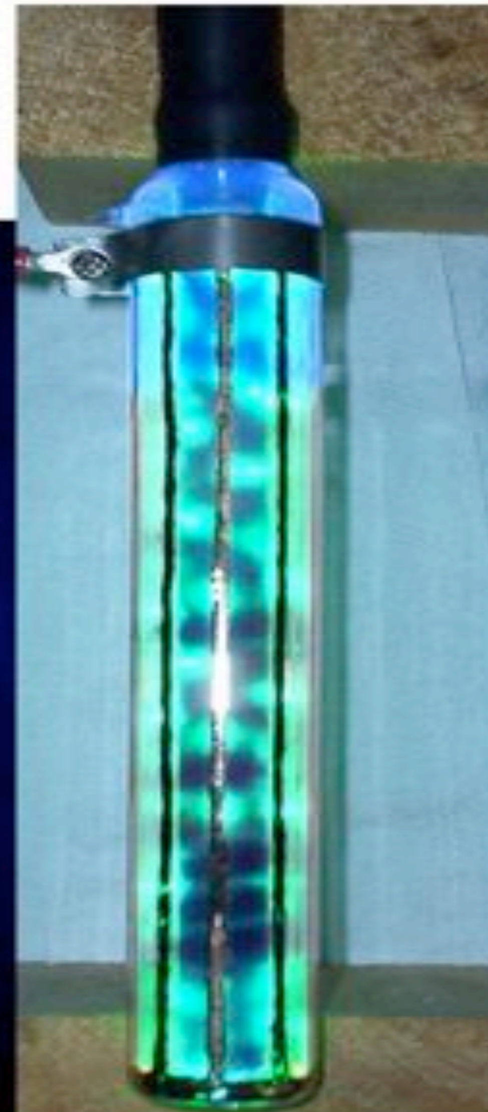
Extreme UV imaging telescope aboard Solar and Heliospheric Observatory spacecraft

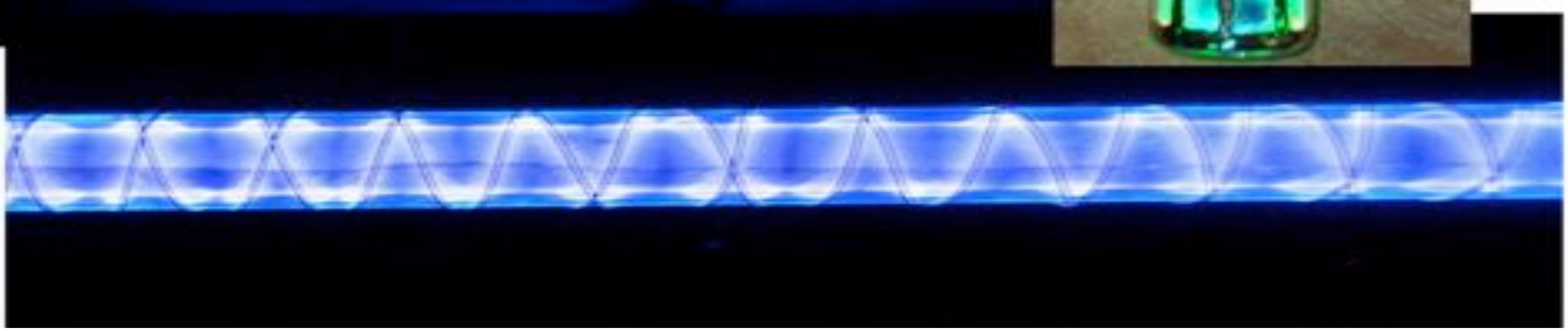
Outline

- What UV is
- How it Disinfects
- Dosage
- Equipment
- Operational Issues
- Wastewater Applications
  - Regulatory Issues
  - Design
  - Cost
  - Example Installation

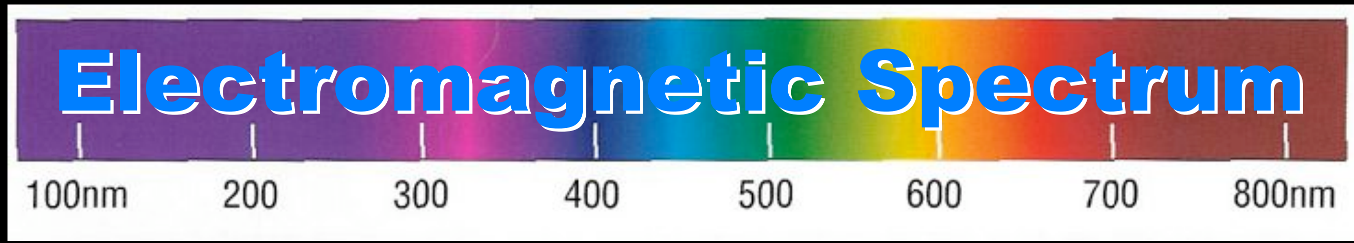
Ultraviolet Light

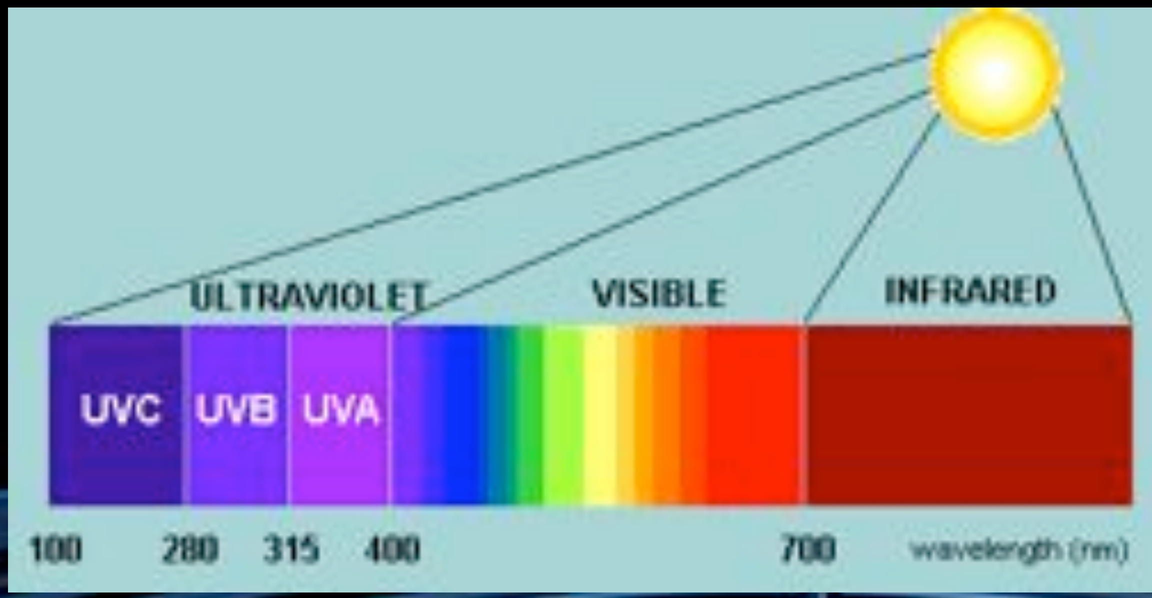


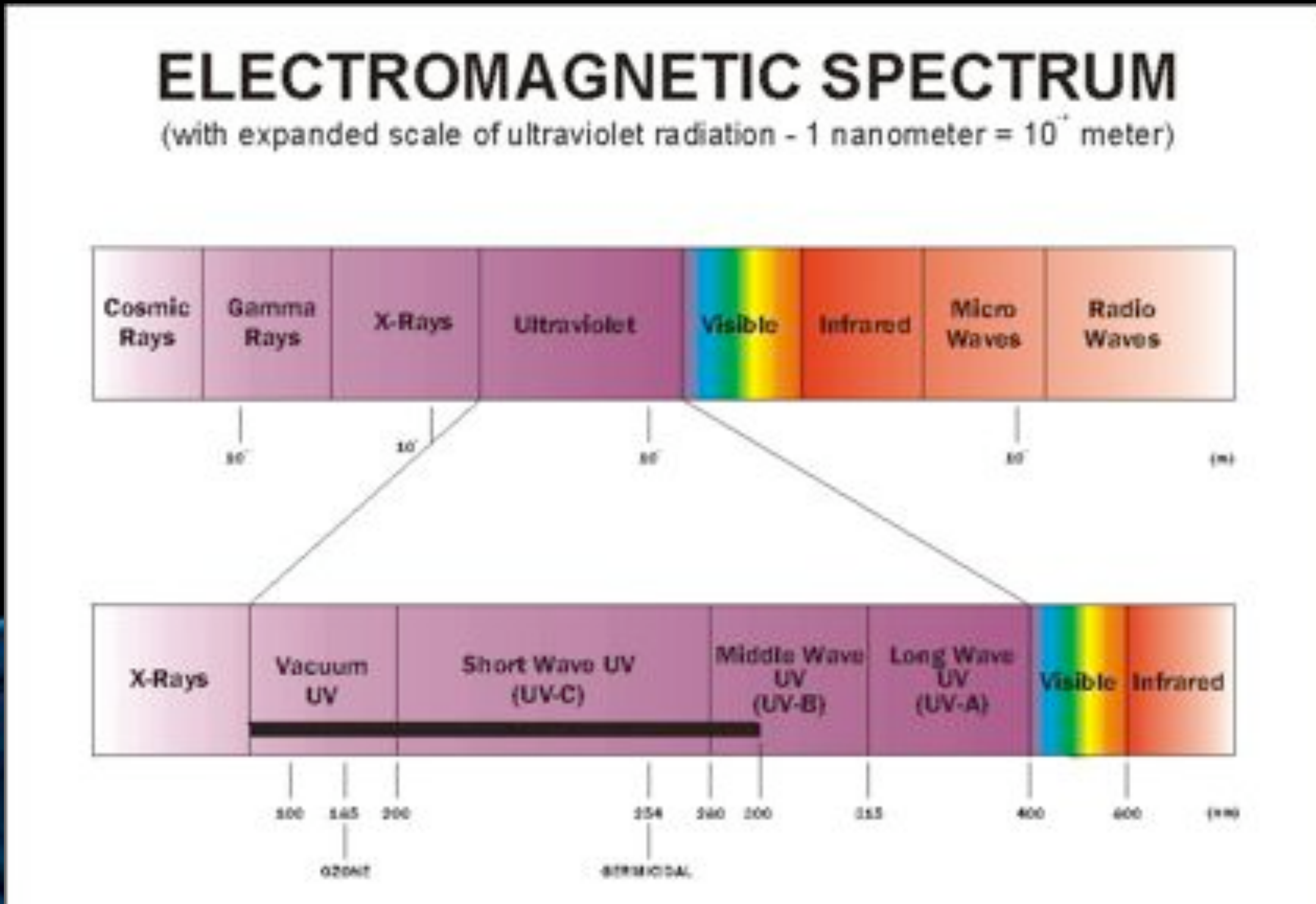




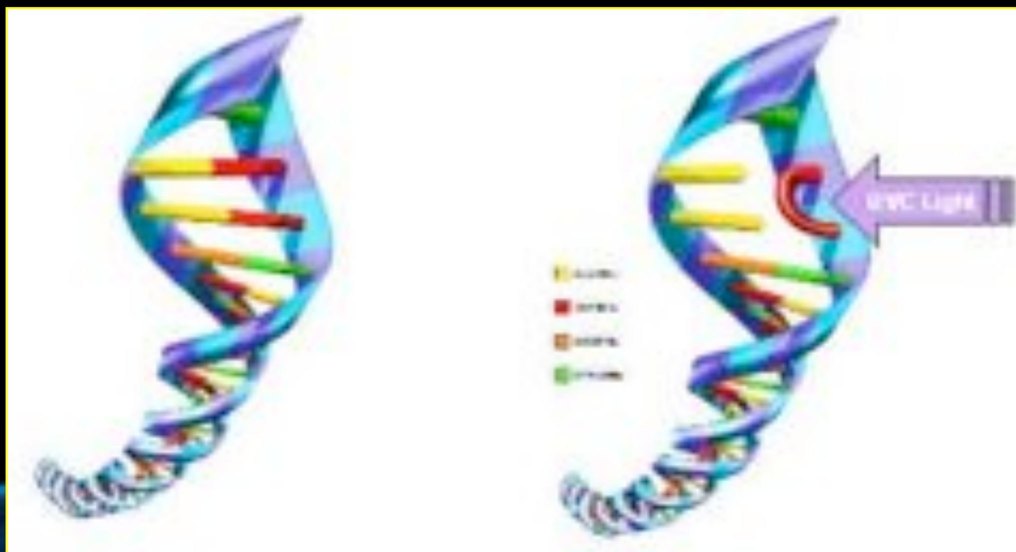
Electromagnetic Spectrum






ELECTROMAGNETIC SPECTRUM
(with expanded scale of ultraviolet radiation - 1 nanometer = 10 meter)
Cosmic Rays
Gamma Rays
X-Rays
Ultraviolet
Visible
Infrared
Micro Waves
Radio Waves
X-Rays
Vacuum UV
Short Wave UV (UV-C)
Middle Wave UV (UV-B)
Long Wave UV (UV-A)
Visible
Infrared
100
200
254
315
400
600

Method of Inactivation



- 250-270 nm wavelength
- Fuses DNA
- Prevents replication

H_2O'C ENGINEERING

UV Dose

Energy per unit area times contact time

UV Dose

Energy per unit area times contact time

Irradiance (mW/cm^2) x time (sec) = mWs/cm^2

(sometimes expressed as $\mu Ws/cm^2$)

1 mWs/cm^2 = 1 mJ/cm^2

UV Dose

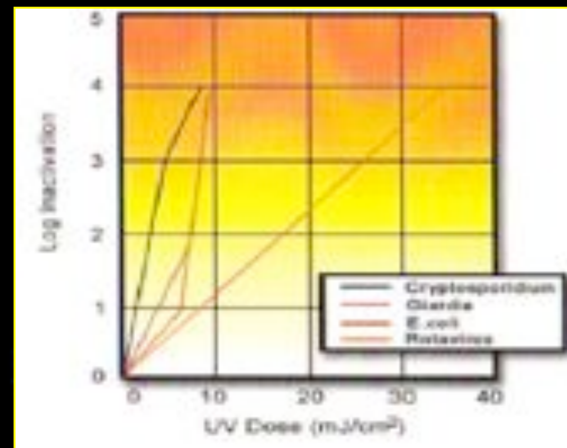
- Equipment Rating
- Lamp Age
- Lamp Fouling
- Water Quality
  - UV Transmittance, organic content, suspended solids, turbidity, iron

Inactivation

UV energy levels at 254 nanometer units wavelength required for 99.9% destruction of various organisms.

Microwatt-seconds per square centimeter.

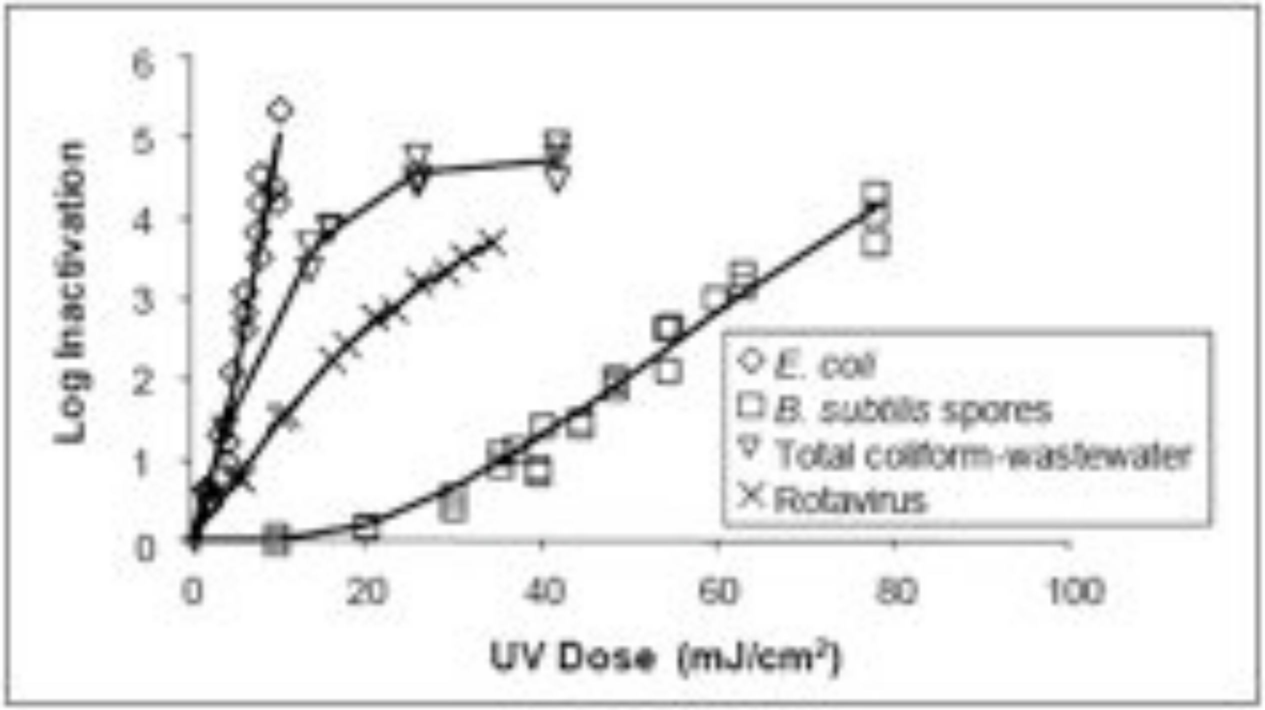
Bacteria	
Bacillus anthracis	8,700
Escherichia coli	6,600
Pseudomonas aeruginosa (lab)	3,900
P.aeroginosa (environmental)	10,500
Shigella dysenteriae (dysentery)	4,200
Staphylococcus aureus	7,000
Vibrio cholerae (cholera)	6,500
Protozoa	
Chlorella vulgaris (algae)	22,000
Paramecium	220,000
Virus	
Coliphage	6,600
Hepatitus virus (infectious)	8,000
Influenza virus	6,600
Poliomyelitis (polio virus)	21,000
Tobacco mosaic virus	440,000



H2O'C ENGINEERING

UV Dose-Response

Figure 2.8 Shapes of UV Dose-Response Curves
(adapted from Chang et al. 1985)



UV Pros and Cons

- No byproduct formation
- Effective disinfectant
- No chemicals
- No need to dechlorinate
- Low cost

- Lamp cleaning/replacement
- Solids can reduce effectiveness

Table A.2 UV Sensitivity of Pathogenic Microorganisms in Water[1]

Microorganism	Type	UV Dose (mJ/cm²) inactivation indicated				Reference
		1-log	2-log	3-log	4-log	
Aeromonas hydrophila	Bacteria	1.1	2.6	3.9	5	Wilson et al. 1992
Campylobacter jejuni	Bacteria	1.6	3.4	4	4.6	Wilson et al. 1992
Escherichia coli O157:H7	Bacteria	1.5	2.8	4.1	5.6	Wilson et al. 1992
Legionella pneumophila	Bacteria	3.1	5	6.9	9.4	Wilson et al. 1992
Salmonella anatum	Bacteria	7.5	12	15		Tosa and Hirata 1998
Salmonella enteritidis	Bacteria	5	7	9	10	Tosa and Hirata 1998
Salmonella typhi	Bacteria	1.8	4.8	6.4	8.2	Wilson et al. 1992
Salmonella typhimurium	Bacteria	2	3.5	5	9	Tosa and Hirata 1998
Shigella dysenteriae	Bacteria	0.5	1.2	2	3	Wilson et al. 1992
Shigella sonnei	Bacteria	3.2	4.9	6.5	8.2	Chang et al. 1985
Staphylococcus aureus	Bacteria	3.9	5.4	6.5	10.4	Chang et al. 1985
Vibrio cholerae	Bacteria	0.8	1.4	2.2	2.9	Wilson et al. 1992
Yersinia enterocolitica	Bacteria	1.7	2.8	3.7	4.6	Wilson et al. 1992
Adenovirus Type 40 [2]	Virus	30	59	90	120	Meng and Gerba 1996
Adenovirus Type 41 [3]	Virus	22	50	80		Meng and Gerba 1996
Coxsackievirus B5	Virus	6.9	14	21		Battigelli et al. 1993
Hepatitis A HM175	Virus	5.1	14	22	30	Wilson et al. 1992
Hepatitis A	Virus	5.5	9.8	15	21	Wiedenmann et al. 1993
Hepatitis A HM175	Virus	4.1	8.2	12	16	Battigelli et al. 1993
Poliovirus Type 1	Virus	4.0	8.7	14	21	Meng and Gerba 1996
Poliovirus Type 1	Virus	6	14	23	30	Harris et al. 1987
Poliovirus Type 1	Virus	5.6	11	16	22	Chang et al. 1985
Poliovirus Type 1	Virus	5.7	11	18	13	Wilson et al. 1992
Rotavirus SA11	Virus	7.6	15	23		Battigelli et al. 1993
Rotavirus SA11	Virus	7.1	15	25		Chang et al. 1985
Rotavirus SA11	Virus	9.1	19	26	36	Wilson et al. 1992
Cryptosporidium parvum [2]	Protozoa	< 2	< 3	< 5		Shin et al. 2001
Cryptosporidium parvum [2]	Protozoa		< 3	< 6		Clancy et al. 2000
Giardia lamblia [2]	Protozoa	<1			<2	Linden et al. 2002a
Giardia lamblia [2]	Protozoa	<1	< 3	< 6		Mofidi et al. 2002

Table A.3 UV Sensitivity of Non-Pathogenic Bacteria, Bacteriophage, and Spore-Forming Bacteria in Water[1]

Microorganism	Type	UV Dose (mJ/cm^2) inactivation indicated				Reference
		1-log	2-log	3-log	4-log	
Escherichia coli	Bacteria	2.5	3	3.5	5	Harris et al. 1987
Escherichia coli	Bacteria	3	4.8	6.7	8.4	Chang et al. 1985
Escherichia coli	Bacteria	4.0	5.3	6.4	7.3	Sommer et al. 1998
Escherichia coli	Bacteria	4.4	6.2	7.3	8.1	Wilson et al. 1992
Streptococcus faecalis	Bacteria	6.6	8.8	9.9	11	Chang et al. 1985
Streptococcus faecalis	Bacteria	5.5	6.5	8	9	Harris et al. 1987
MS-2	Phage	4	16	38	68	Wiedenmann et al. 1993
MS-2	Phage	16	34	52	71	Wilson et al. 1992
MS-2	Phage	12	30			Tree et al. 1997
MS-2	Phage	21	36			Sommer et al. 1998
MS-2	Phage	17	34			Rauth 1965
MS-2	Phage	14	29	45	62	Meng and Gerba 1996
MS-2	Phage	19	40	61		Oppenheimer et al. 1993
ϕX174	Phage	2.2	5.3	7.3	10	Sommer et al. 1998
ϕX174	Phage	2.1	4.2	6.4	8.5	Battigelli et al. 1993
ϕX174	Phage	4	8	12		Oppenheimer et al. 1993
PRD-1	Phage	9.9	17	24	30	Meng and Gerba 1996
B-40	Phage	12	18	23	28	Sommer et al. 1998
Bacillus subtilis spores	Spores	36	49	61	78	Chang et al. 1985
Bacillus subtilis spores	Spores	29	40	51		Sommer et al. 1998

[1] Adapted from Wright and Sakamoto 1999.

Technology Performance and Availability:

An EPA Perspective

Dan Schmelling, USEPA

UV can inactivate high levels of waterborne pathogens at feasible doses and is effective against bacteria, viruses, Giardia, and Cryptosporidium.

Typical UV doses for water disinfection range from 30 - 140 mJ/cm^2. Log inactivation of bacterial pathogens is reported at doses of 3 - 34 mJ/cm^2.

Technology Performance and Availability:

An EPA Perspective

Dan Schmelling, USEPA

	inactivation	dosage *mJ/cm²*
Viruses	4-log	7 - 50
Giardia	3-log	20
Crypto	3-log	20
bacterial pathogens	1-log	3 - 34

The Gear

- Mercury lamps
- Ballasts and power supplies
- Lamp sleeves
- Cleaning systems
- UV intensity sensors
- UV transmittance monitors
- Temperature sensors

Ballasts-Magnetic & Electronic

Ballasts-Magnetic & Electronic

	Magnetic Ballast	Electronic Ballast
Comparative Advantages	• Less potential for power interference due to stored energy • More resistant to power surges • More resistant to high temperatures. • Less prone to interference with electronic devices • Less prone to sputtering (inductive less than capacitive) • Proven technology (in use for nearly 70-years) • Less expensive	• More efficient • Lighter weight • Smaller size • Less potential for heat generation • Less potential for noise • Continuous power adjustment • Longer lamp operating life
Comparative Disadvantages	• Less efficient (capacitive more efficient than inductive) • Heavier weight • Larger size • More potential for heat generation • More potential for noise. • Step-function power adjustment (number of steps proportional to number of inductors/capacitors) • Shorter lamp operating life	• More potential for power interference due to stored energy (can be minimized by incorporating a capacitor) • Less resistant to power surges • Less resistant to high temperatures • More prone to interference with electronic devices • More potential for sputtering • Newer technology (limited operating experience, especially in larger sizes) • More expensive

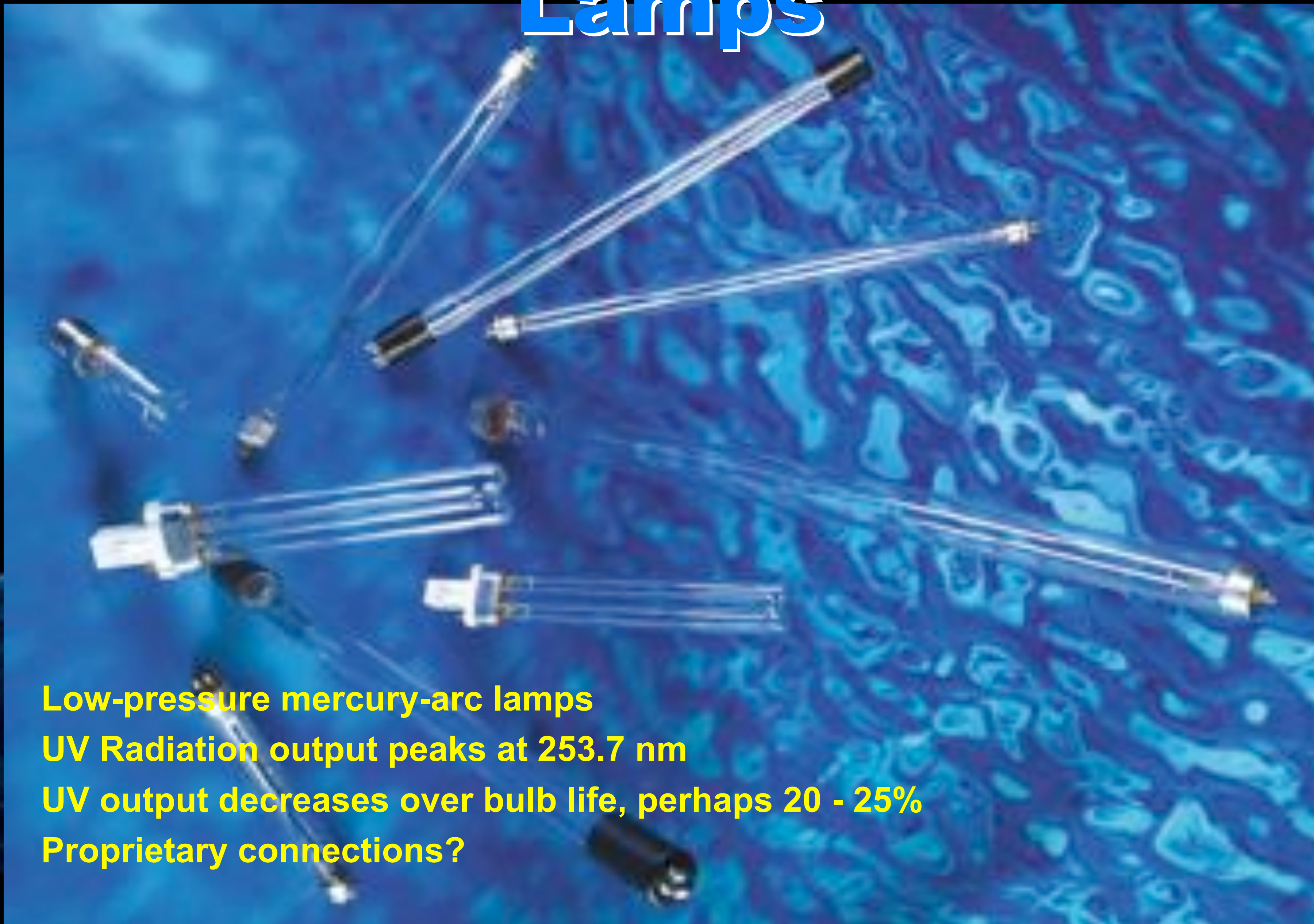
Measuring UV Intensity

InternationalLight
NIST Traceable Light Measurement Systems

IL77
Germicidal Radiometer
Preliminary Specifications

- NIST – traceable certification
- ± 2% accuracy
- 4 ½ - digit readout
- Spectral response 214 – 360 nm (10% pts.)
- Calibration at 254 nm
- Visible blind
- Simple 1 – button operation, auto shut down
- 9 – volt battery operated
- Designed for measurement of low-pressure mercury lamps

Lamps



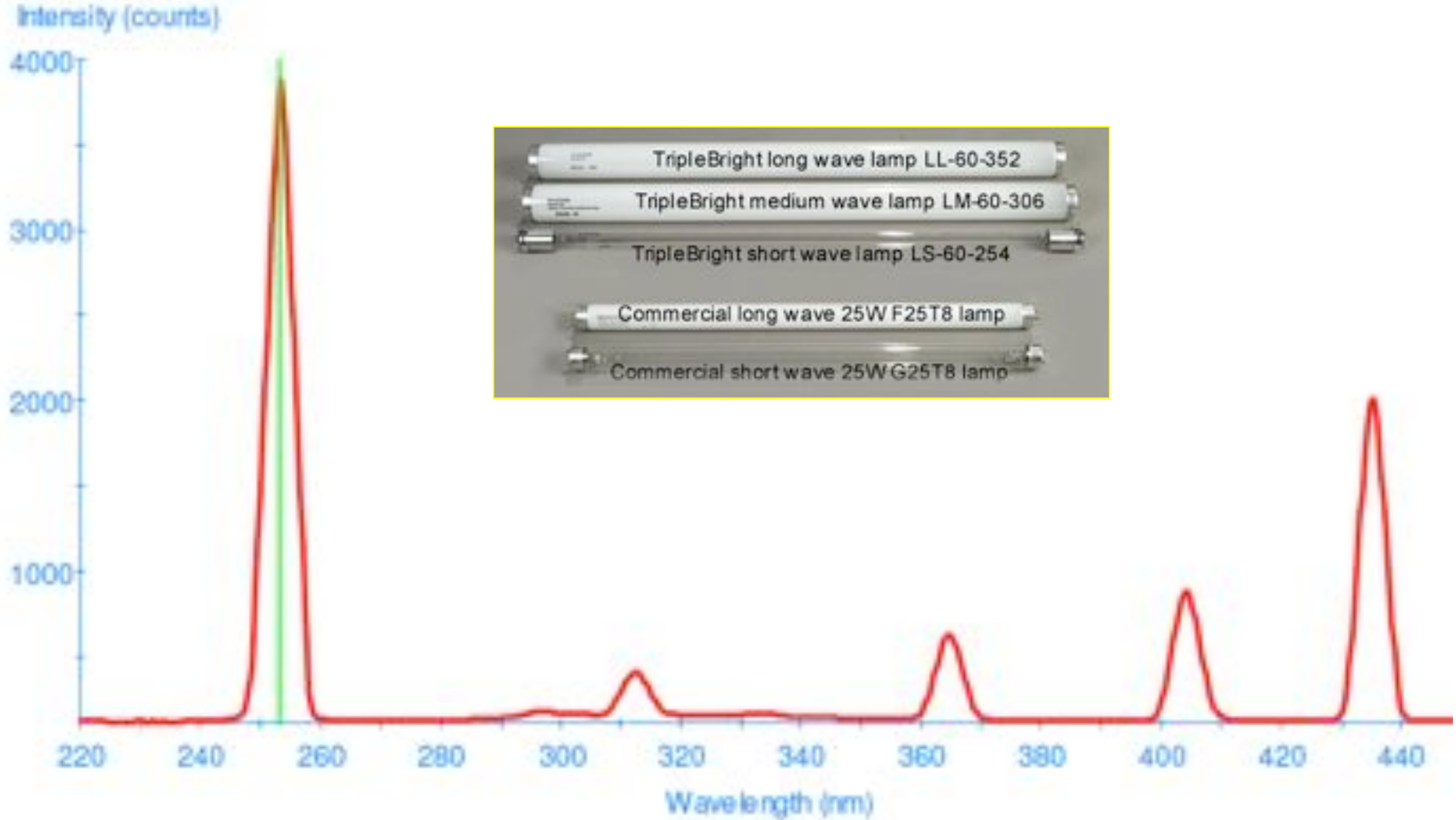
Low-pressure mercury-arc lamps

UV Radiation output peaks at 253.7 nm

UV output decreases over bulb life, perhaps 20 - 25%

Proprietary connections?

Lamp Intensity



uv-technik

Germany

types	geometry[3] (values in mm)			electrical data				UV-power[1]	
	arc length BL	total length GL with wires/base	tube diameter D	lamp wattage W	working current A	working voltage* V	ballast[2]	total power W	@ 1m in $\mu W/cm^2$
UVI 40	240	290/300	15	35	1.2	30	EB-D 200C	12,5	80
UVI 60	370	425/435	15	50	1.2	43	EB-D 200C	15	150
UVI 70	440	495/505	15	70	1.2	70	EB-D 200C	20	200
UVI 120	785	850/860	15	110	1.5	75	EB-D 200C	35	340
UVI 201	1473	1540/1554	15	200	1.5	150	EB-D 200B	72	550
UVI 130	770	830/840	19	110	1.85	68	EB-D 200A	35	330
UVI 160	930	990/1000	19	130	1.85	80	EB-D 200A	43	390
UVI 200	1040	1113/1120	19	170	1.85	100	EB-D 200A	46	400
UVI 240	1220	1300/1310	19	190	2.0	100	EB-D 400D	60	500
UVI 260	1470	1540/1554	19	225	2.0	115	EB-D 400C	78	600
UVI 300	1920	1990/2000	19	265	2.1	155	EB-D 400C	90	600
UVI 100	480	540/550	25	78	2.2	36	EB-D400C	22	220
UVI 140	810	870/880	25	125	2.1	60	EB-D 400C	34	310
UVI 200	1130	1190/1200	25	205	2.9	75	EB-D 400B	80	690
UVI 300	1430	1490/1500	25	260	2.9	92	EB-D 400B	110	860
32 mm diameter lamps are being developed; ballasts (EB-D 400 A) for these are already available									

USHIO Ordering Code	USHIO Lamp Code	Dimensions Length (A) (mm)	Length (A) (in)	Diameter (B) (mm)	Diameter (B) (in)	Watts (W)	Current (A)	Volts (V)	Spectral Peak (nm)	UV Output (W)	Avg Life (h)	Base
	E17 BASE											
3000022	GTL3	63.0	2.48	20.0	0.79	3.0	0.300	10.5	253.7	0.16	3000	E17
	T5 - MINIATURE BI PIN G5 BASE											
3000013	G4T5	134.5	5.30	15.5	0.61	4.5	0.170	29.0	253.7	0.8	6000	G5
3000015	G6T5	210.5	8.29	15.5	0.61	6.0	0.160	42.0	253.7	1.8	8000	G5
3000309	G7T5	165.0	6.50	15.5	0.61	6.3	0.230	30.0	253.7	1.6	8000	G5
3000016	G8T5	287.0	11.30	15.5	0.61	7.2	0.145	57.0	253.7	2.2	8000	G5
3000310	G11T5	210.5	8.29	15.5	0.61	11.0	0.330	37.0	253.7	2.2	8000	G5
3000311	G16T5	287.0	11.30	15.5	0.61	16.0	0.350	50.0	253.7	3.2	8000	G5
3000344	G20T5	400.0	15.75	15.5	0.61	20.0	0.400	62.0	253.7	5.5	8000	G5
	T8 - MEDIUM BI PIN G13 BASE											
3000006	G10T8	330.0	12.99	25.5	1.00	9.5	0.230	46.0	253.7	2.7	8000	G13
3000007	G15T8	436.0	17.16	25.5	1.00	15.0	0.305	55.0	253.7	4.9	8000	G13
3000008	G25T8	436.0	17.16	25.5	1.00	25.0	0.600	46.0	253.7	6.9	8000	G13
3000009	G30T8	893.0	35.16	25.5	1.00	30.5	0.355	99.0	253.7	13.9	8000	G13
3000316	G55T8	893.0	35.16	25.5	1.00	55.0	0.770	83.0	253.7	18.0	8000	G13
	T10 - G13 BASE											
3000314	G20T10	588.5	23.17	32.5	1.28	19.0	0.360	58.0	253.7	7.5	8000	G13
3000315	G40T10	1198.0	47.17	32.5	1.28	39.5	0.420	106.0	253.7	19.8	8000	G13
	T5 - SINGLE PIN											
3000345	G14T5L (GPH287)	287.0	11.30	15.5	0.61	14.0	0.400	40.0	253.7	3.0	8000	Single Pin
3000338	G10T5L	357.0	14.06	15.5	0.61	16.0	0.425	55.0	253.7	5.3	9000	Single Pin
3000347	G22T5L (GPH436)	436.0	17.16	15.5	0.61	22.0	0.420	62.0	253.7	7.0	8000	Single Pin
3000312	G36T5L	846.0	33.31	15.5	0.61	39.0	0.425	115.0	253.7	13.0	9000	Single Pin
3000313	G64T5L	1553.6	61.17	15.5	0.61	65.0	0.425	250.0	253.7	27.0	9000	Single Pin
	T5 - 4-PIN BASE											
3000348	G14T5L/4P (GPH287)	287.0	11.30	15.5	0.61	14.0	0.400	40.0	253.7	3.0	8000	4-Pin
3000355	G10T5L/4P	357.0	14.06	15.5	0.61	16.0	0.425	55.0	253.7	5.3	9000	4-Pin
3000350	G22T5L/4P (GPH436)	436.0	17.16	15.5	0.61	22.0	0.420	62.0	253.7	7.0	8000	4-Pin
3000343	G36T5L/4P	846.0	33.31	15.5	0.61	39.0	0.425	115.0	253.7	13.0	9000	4-Pin
3000351	G64T5L/4P	1553.6	61.17	15.5	0.61	65.0	0.425	250.0	253.7	27.0	9000	4-Pin

Dimensions				Watts	Current	Volts	Spectral Peak	UV Output	Avg Life
Length (A)		Diameter (B)							
(mm)	(in)	(mm)	(in)	(W)	(A)	(V)	(nm)	(W)	(h)
846.0	33.31	15.5	0.61	39.0	0.425	115.0	253.7	13.0	9000

First Light USA

Instant-Start Lamps

Lamp Type	Base Face Base to Base*	Arc Length	Lamp Diameter	Lamp Wattage	Lamp Current mA	Lamp Voltage V@ 50 or 60Hz	UV Output UVC Watts	UV Output @ 1m µWatts/cm^2	Rated Life Hours
G10T5L/C	357mm	281mm	15mm	17	425mA	51	5.7	56	9000
G36T5L/C	843mm	767mm	15mm	42	425mA	100	14.4	150	9000
G36T5L/HO/C	843mm	767mm	15mm	75	800mA	95	25.0	240	9000
G64T5L/C	1554mm	1478mm	15mm	75	450mA	175	30.0	260	9000
G64T5L/HO/C	1554mm	1478mm	15mm	145	800mA	180	48.0	385	9000

Note * UV output is measured at 253.7nm at 100 hours under laboratory conditions.

Output may vary under actual operating conditions.

* - Base face measurement is from base to base, not including pins.

** - Lamps are also available in both Pure Quartz (VH) or Synthetic Quartz (VHS)

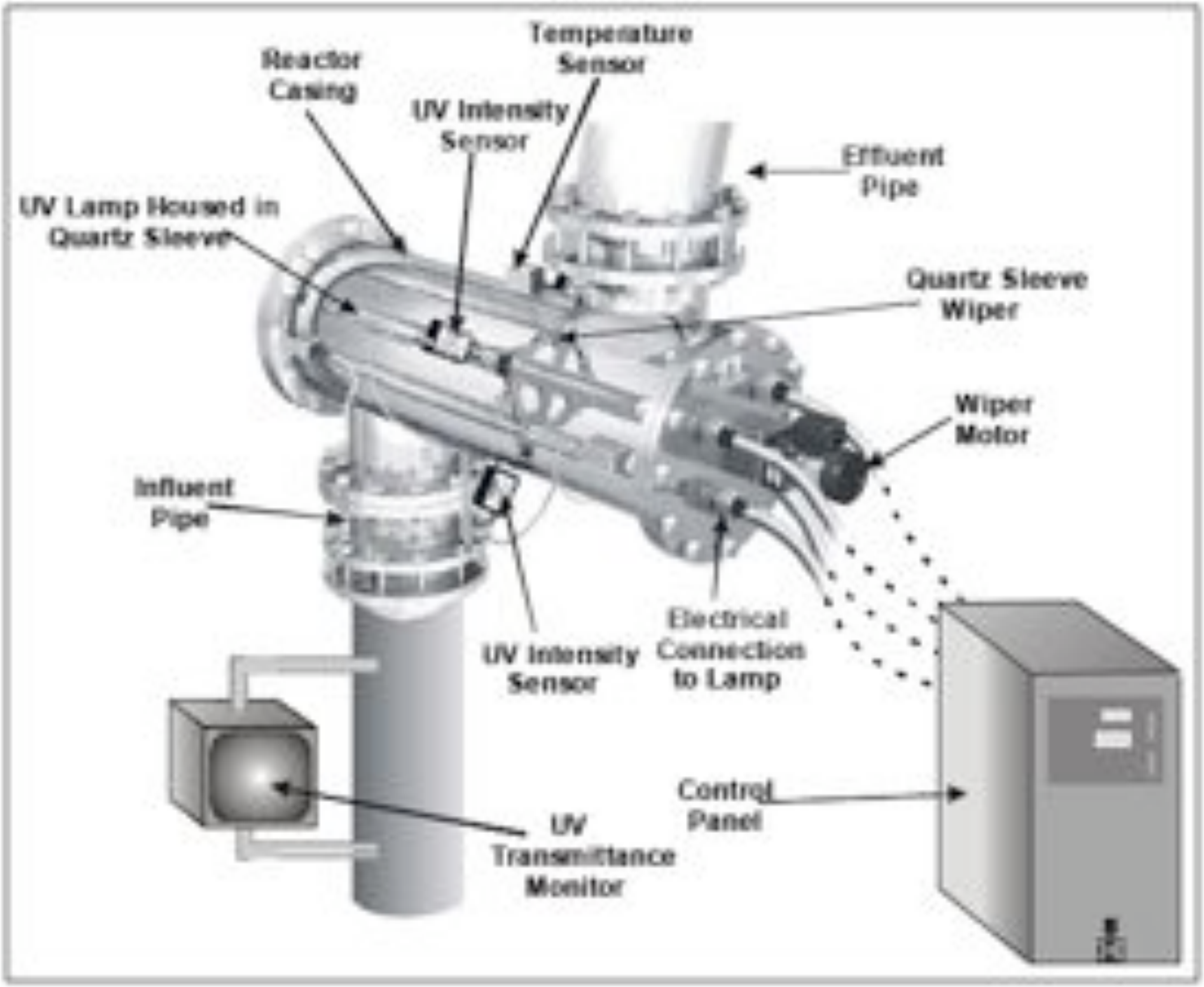
First Light USA

Instant-Start Lamps

Lamp Type	Base Face Base to Base*	Arc Length	Lamp Diameter	Lamp Wattage	Lamp Current mA	Lamp Voltage V@ 50 or 60Hz	UV Output UVC Watts	
G10T5L/C	357mm	281mm	15mm	17	425mA	51	5.7	$29
G36T5L/C	843mm	767mm	15mm	42	425mA	100	14.4	$33
G36T5L/HO/C	843mm	767mm	15mm	75	800mA	95	25.0	$41
G64T5L/C	1554mm	1478mm	15mm	75	450mA	175	30.0	$43
G64T5L/HO/C	1554mm	1478mm	15mm	145	800mA	180	48.0	$51

H2O'C ENGINEERING

Figure 2.10 UV Disinfection System Schematic
(courtesy of Severn Trent Services)



SteriPen

$150


VECTON


A2
A1

UV Equipment

- Single-vessel
- Multiple-lamp
- 200 - 500 watts
- 200 - 700 gpm*
- $2,000 - 4,000

* at 15,000 μWs/cm^2

H2O'C ENGINEERING

UV Equipment

- High-output
- 450 - 2,000 watts
- 400 - 2,000 gpm*
- $4,000 - 13,000

* at 15,000 $\mu Ws/cm^2$

H2O'C ENGINEERING

UV Equipment

- TMC
- 110 - 660 watts
- 15 - 100 gpm*
- $350 - 2,600

* at 30,000 μWs/cm^2

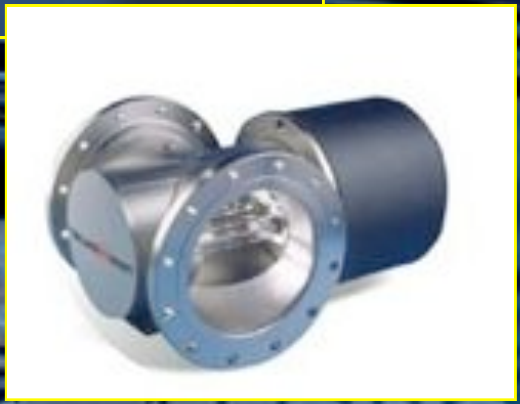
H2O'C ENGINEERING

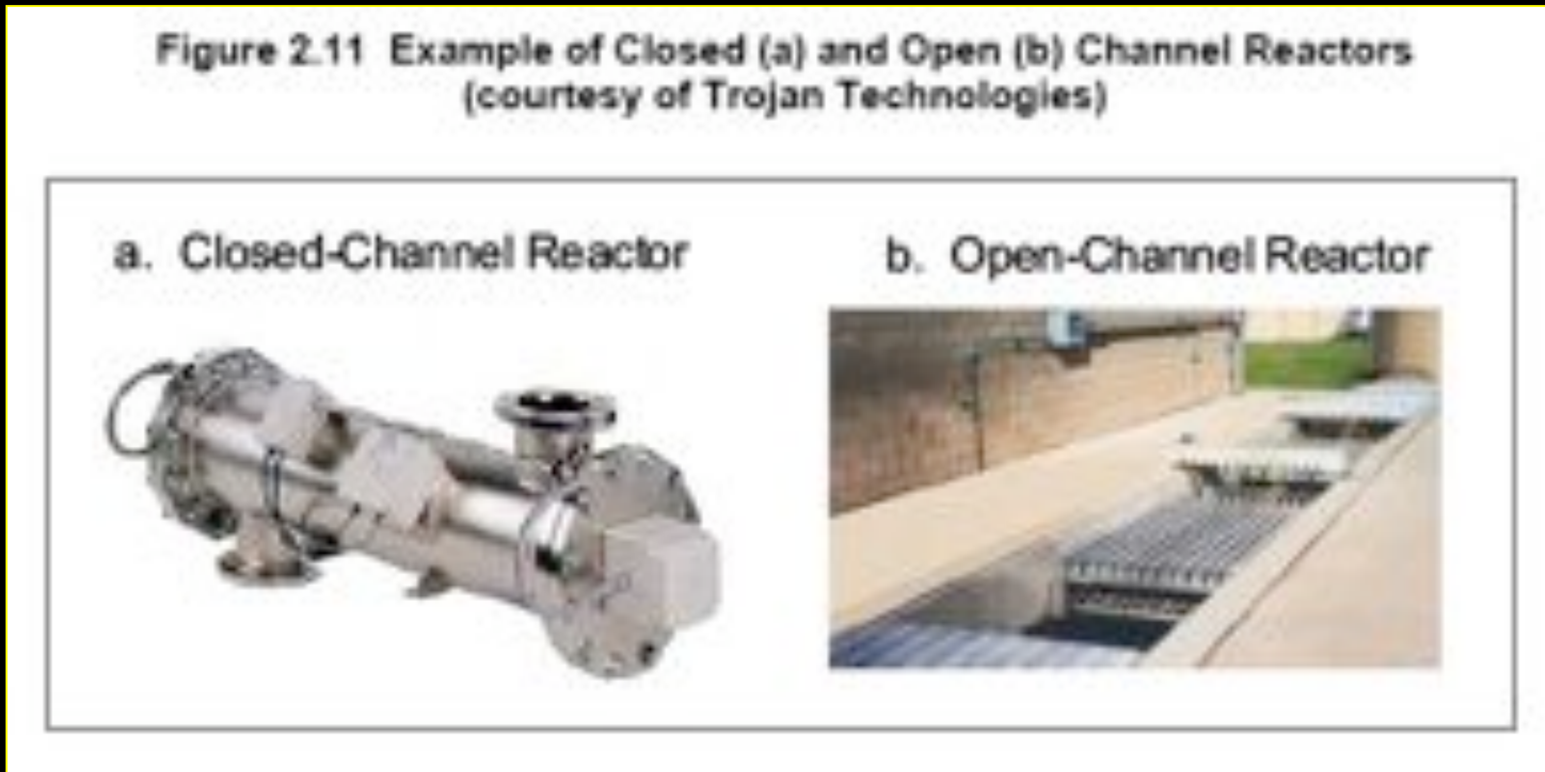
UV Equipment

- Pentair Aquatics
- 8 - 240 watts
- 4 - 150 gpm*
- $140 - 1,300

* at 15,000 μWs/cm^2

Trojan UV





Closed Channel for Drinking Water

Open Channel for Wastewater

Design: Wastewater

MDNR's Design Standards for Wastewater Systems

Rules of Department of Natural Resources
Division 20—Clean Water Commission, Chapter 8—Design Guides

(3) Forms of Disinfection. Chlorine is the most commonly used chemical for wastewater disinfection. The forms most often used are liquid chlorine and calcium or sodium hypochlorite. Other disinfectants, including chlorine dioxide, ozone or bromine, may be accepted by the agency in individual cases.

Ten-State Standards for Wastewater Systems

Design standards, operating data, and experience are not well established… prototype testing… ask reviewing authority…

- **open-channel designs**
- **modular UV units**
- **two banks in series**
- **consider safety, operation, and maintenance**
- **water level control**
- **closed-chamber units reviewed on a case-by-case basis**
- **ask reviewing authority**

Ten-State Standards for Wastewater Systems

EFFLUENT WATER QUALITY CHARACTERISTICS

Parameter	*Maximum*
UV 254 transmittance	**65% at 1 cm (35% absorbance)**
BOD	**30 mg/l**
TSS	**30 mg/l**

H2O'C ENGINEERING

Ten-State Standards for Wastewater Systems

GENERAL GUIDE TO UV DOSAGE BASED ON DESIGN PEAK HOURLY FLOW

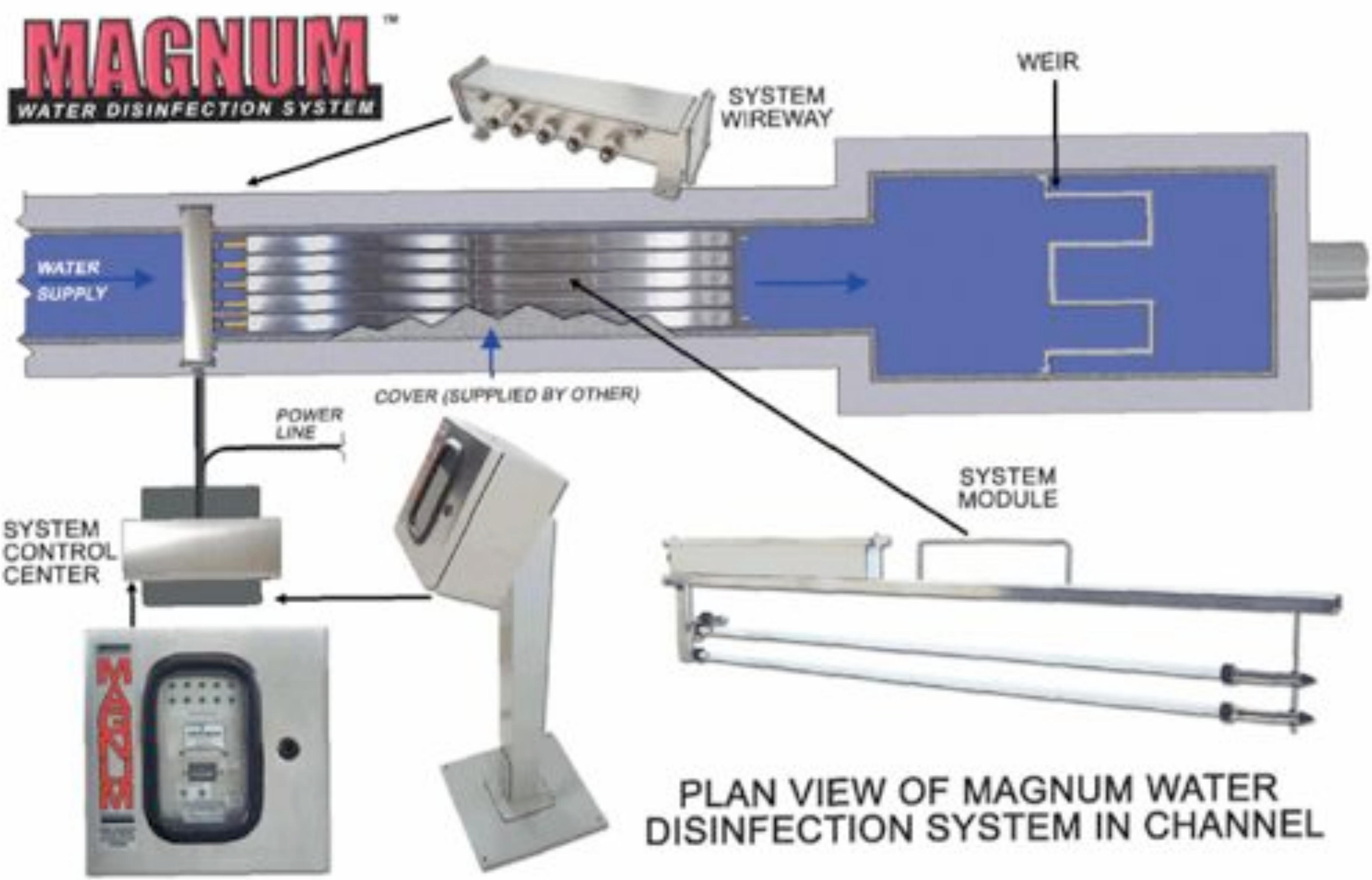
UV dosage > 30,000 µWs/cm^2 (30 mJ/cm^2)

AFTER adjustments for:

- maximum tube fouling
- lamp output reduction after 8,760 hours of operation
- other energy absorption losses

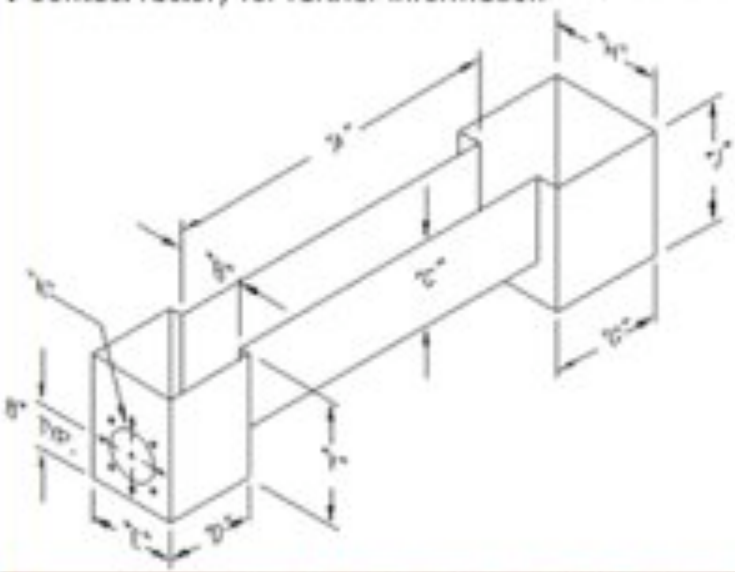
H2O'C ENGINEERING

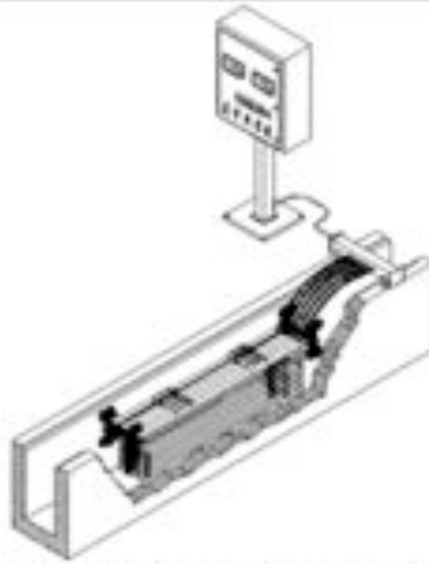
Atlantic Ultraviolet



Model	Peak Flow Rate (GPM)	Peak Flow Rate (GPD)	Quantity Of Lamps	Channel Size "A"x"B"x"C" (inches)	Transition Box Size "D"x"E"x"F"	Weir Box Size "G"x"H"x"J" (inches)	Inlet/Outlet Flange Size "K"	Channel Width	Effluent Depth
HC2-64/2WC	69.4	100,000	4	96"x6"x15"	16"x14"x22"	20"x14"x22"	6"	6"	6"
HC2-64/3WC	104.2	150,000	6	96"x9"x15"	16"x16"x22"	20"x16"x22"	8"	9"	6"
HC2-64/4WC	138.9	200,000	8	96"x12"x15"	16"x16"x22"	20"x20"x22"	8"	12"	6"
HC2-64/5WC	173.6	250,000	10	96"x15"x15"	16"x22"x22"	20"x25"x22"	8"	15"	6"
HC2-64/6WC	208.3	300,000	12	96"x18"x15"	16"x22"x22"	20"x30"x22"	8"	18"	6"
HC2-64/7WC	243.0	350,000	14	96"x21"x15"	16"x28"x22"	20"x35"x22"	8"	21"	6"

1 Channel, Transition Box & Weir Box are Stainless Steel.
2 Lamp Modules and Electronic Enclosure omitted for clarity.
3 Flow rates are based on:
- Maximum Total Suspended Solids (TSS) of 30mg/l
- Maximum Biological Oxygen Demand (BOD) of 30 mg/l
- Minimum Ultraviolet Transmission of 65% per centimeter
4 Contact factory for further information





1 Ultraviolet system does not include concrete channels.
2 Lamp Modules and Electronic Enclosure omitted for clarity.
3 Flow rates are based on:
- Maximum Total Suspended Solids (TSS) of 30mg/l.
- Maximum Biological Oxygen Demand (BOD) of 30 mg/l.
- Minimum Ultraviolet Transmission of 65% per centimeter.
4 Contact factory for further information.

Model	Peak Flow Rate (GPM)	Peak Flow Rate (GPM)	Peak Flow (Cu. Meters/Day)	Quantity Of Lamps	No. of Modules	Channel Width	Effluent Depth
HC4-64/4	277.7	400,000	1503	16	4	12"	12"
HC4-64/5	347.2	500,000	1879	20	5	15"	12"
HC4-64/6	416.6	650,000	2255	24	6	18"	12"
HC4-64/7	486.1	700,000	2631	28	7	21"	12"
HC4-64/8	555.5	800,000	3006	32	8	24"	12"
HC4-64/9	625.0	900,000	3382	36	9	27"	12"
HC4-64/10	694.4	1,000,000	3758	40	10	30"	12"

Operation and Maintenance

Power consumption

- similar to fluorescent lighting

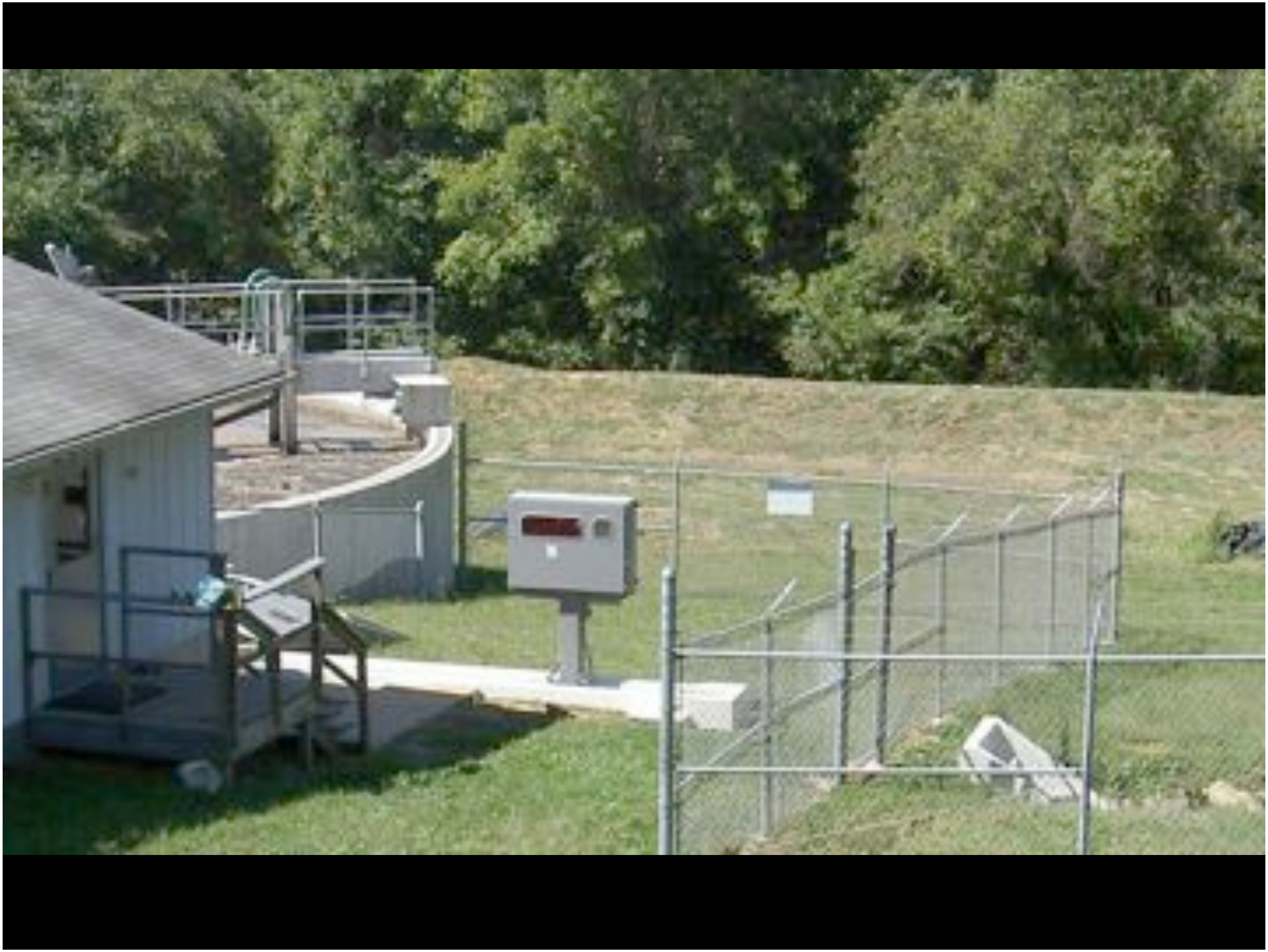
Lamp and sleeve cleaning

- important to maintain UV dosage
- automatic / manual
- chemical / mechanical

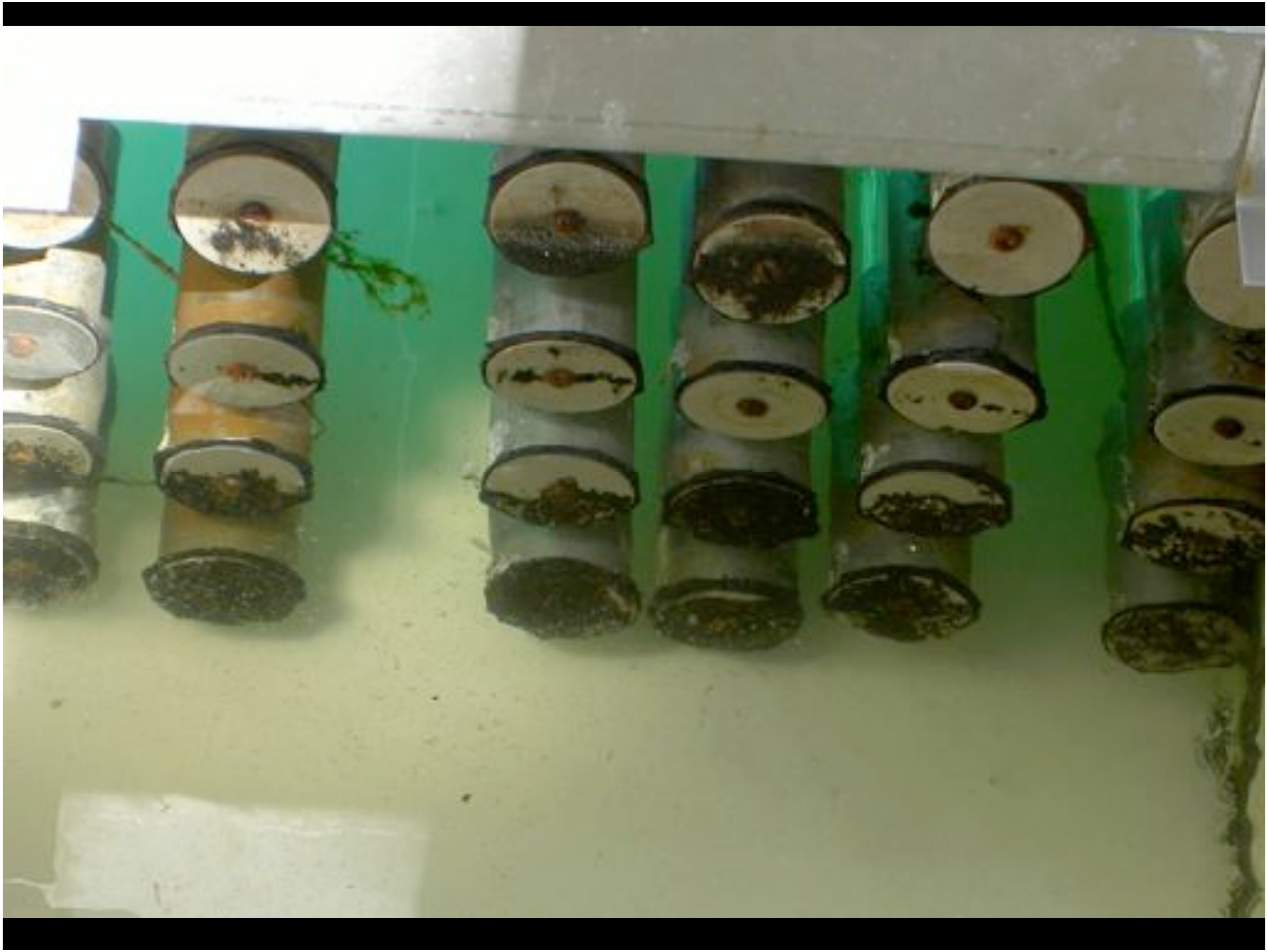
Lamp replacement (7,500 to 20,000 hours)

Performance monitoring (temp, UV intensity, coliform)

Example Installation




3
4
5
6




X
Suddenly required replacement
~ $14,000

So there you have it

- What UV is
- How it Disinfects
- Dosage
- Equipment
- Operational Issues
- Wastewater Applications

Tom O'Connor, PE
H_2O'C Engineering
877-22-WATER
tom@h2oc.com