Disinfection: CT and Microbial Log Inactivation Calculations

Drinking Water Reference Guide: Colorado Department of Public Health and Environment
Water Quality Control Division - Engineering Section http://www.cdphe.state.co.us/wq/ 303-692-3500 May 2009

What do I need to know before I start calculating?

- **Peak Hourly Flow, Q (gpm)**
- **Residual Disinfectant Concentration, C (mg/L)**
- **Temperature (°C)**
- **pH (standard units, s.u.)**
- **Basin Geometry**
- **Baffle Configuration**
- **Disinfectant type**

Log Inactivation

- **1 log: 90% inactivation**
- **2 log: 99% inactivation**
- **3 log: 99.9% inactivation**
- **4 log: 99.99% inactivation**

Equation Summary

1. ***Giardia* Log Inactivation = 3 log × (CT_{CALC} / $CT_{99.9}$)**
2. **Virus Log Inactivation = 4 log × (CT_{CALC} / $CT_{99.99}$)**
3. **CT_{CALC} = C × T**
4. **T = TDT × BF**
5. **TDT = V / Q**

This reference guide takes you step by step through the CT and log inactivation calculation procedure, through an example calculation, and presents the disinfection segment concept.

What is Log Inactivation?

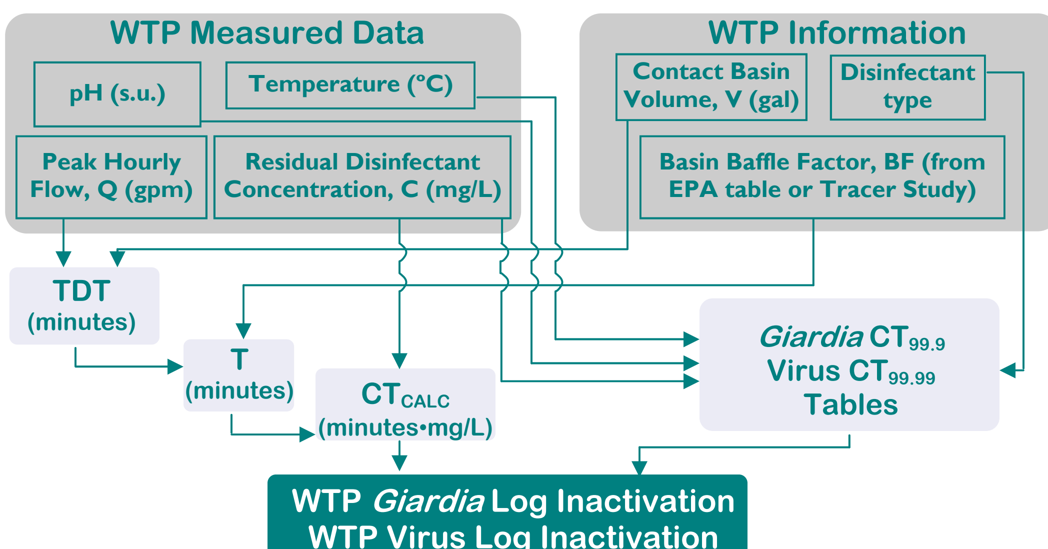
"Log inactivation" is a convenient way to express the number or percent of microorganisms inactivated (killed or unable to replicate) through the disinfection process. For example, a 3 log inactivation value means that 99.9% of microorganisms of interest have been inactivated. (See box at left.) Log inactivation measures the effectiveness of the disinfection process, which is influenced by variables including disinfectant concentration, temperature, pH and disinfectant type (e.g., lower temperature results in less inactivation since the reactions slow down as temperature decreases).

What is CT?

"CT" (minutes•mg/L) in the context of water treatment is defined as the product of: C, for "residual disinfectant concentration" in mg/L (determined before or at the first customer) and T, for the corresponding "disinfectant contact time" in minutes. CT is a measure of the disinfection process reaction time, but CT is only one of several variables that control the effectiveness of the disinfection process.

CT and Log Inactivation Calculation Overview

Basically, log inactivation is a measurement of how effective a disinfection process is at killing microorganisms in a specific environment. Operationally, directly measuring log inactivation is not practical, but determining the microbial inactivation for an individual water treatment plant (WTP) can be achieved using the log inactivation calculations. The log inactivation calculation adjusts the WTP's CT value to account for the disinfection chemical reaction process variables that influence the disinfection process efficiency. The log inactivation calculations (Equations 1 and 2 in the left-hand bottom box) use the WTP's CT (CT_{CALC}) and the EPA-developed CT log inactivation tables ($CT_{99.9}$ for *Giardia lamblia* and $CT_{99.99}$ for viruses). (See box on Page 3 for the basis of CT log inactivation tables.) The flowchart below illustrates the log inactivation calculation process.



Where: TDT = Theoretical Detention Time
T = Detention Time
CT_{CALC} = Concentration Time Calculated Value for WTP
$CT_{99.9}$ = Concentration Time to inactivate 3 log of *Giardia* (from table)
$CT_{99.99}$ = Concentration Time to inactivate 4 log of virus (from table)

Source and for more information:

U.S. Environmental Protection Agency. 2003. *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual.* EPA 816-R-03-004
http://www.epa.gov/safewater/mdbp/pdf/profile/lt1profiling.pdf

CT and Log Inactivation Calculation Steps

Step 1: Calculate Detention Time

Step 1-A: Calculate Theoretical Detention Time (TDT)

TDT = V/Q

TDT = Theoretical Detention Time (minutes)

V = Volume, based on low water level (gallons)

Q = Peak hourly flow (gpm)

Step 1-B: Calculate Actual Detention Time (T)

T = TDT × BF

T = Actual Detention Time (minutes)*

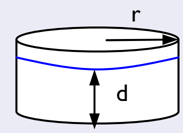
TDT = Theoretical Detention Time (minutes)

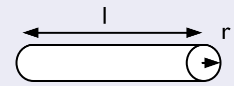
BF = Baffling Factor (measure of short circuiting)

Volume Equations:

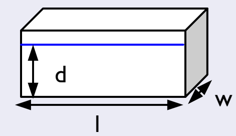
Cylindrical: $\pi \times r^2 \times d$

Pipeline: $\pi \times r^2 \times l$
Flowing full





Rectangular: l x w x d



d = minimum water depth
π = 3.1416

* The Actual Detention Time also may be available from site-specific tracer tests conducted at all possible flowrates.

Baffling Condition	Baffling Factor	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length-to-width ratio, high inlet and outlet flow velocities
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra basin baffles
Average	0.5	Baffled inlet or outlet with some intra basin baffles
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra basin baffles, outlet weir or perforated launders
Perfect (plug flow)	1.0	Very high length-to-width ratio (pipeline flow), perforated inlet, outlet, and intrabasin baffles

Step 2: Calculate CT_{CALC}

$CT_{CALC} = C \times T$

CT_{CALC} = Concentration Time, Calculated Value (minutes•mg/L)

C = Residual disinfectant concentration measured during peak flow (mg/L)

T = Actual Detention Time (minutes)

Conversion Factors:

1 cu-ft = 7.48 gallons

1 MGD = 694 gpm

1 gal water = 8.34 lbs

°C = 5/9 x (°F – 32)

Step 3: Calculate *Giardia lamblia* log inactivation

Step 3-A: Determine CT required for *Giardia lamblia* 3 log reduction ($CT_{99.9}$) using EPA tables and WTP information

The CT required for 3 log inactivation of *Giardia lamblia* (designated as $CT_{99.9}$) is available in tables for different disinfectants. (See Page 6, Table A for the free chlorine tables.) The $CT_{99.9}$ for *Giardia lamblia* depends on the residual disinfectant concentration (C), temperature, and pH. A section of "Table A: *Giardia lamblia* 3 log reduction ($CT_{99.9}$) for free chlorine" can be seen below.

Chlorine Conc. (mg/L)	Temperature <= 0.5°C						
	pH						
	<=6.0	6.5	7	7.5	8	8.5	9
<=0.4	137	163	195	237	277	329	390
0.6	141	168	200	239	286	342	407
0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437

Log reduction tables for other disinfectants (e.g., UV, chloramine, chlorine dioxide, ozone) are available in the 2003 EPA LT1ESWTR Guidance Manual.

Step 3-B: Calculate *Giardia lamblia* Log Inactivation

$$\textit{Giardia} \text{ Log Inactivation} = 3 \log \times (CT_{CALC} / CT_{99.9})$$

CT_{CALC} = Concentration Time, Calculated Value (minutes•mg/L)

$CT_{99.9}$ = Concentration Time to inactivate 3 log of *Giardia* (minutes•mg/L) from table

Step 4: Calculate virus log inactivation

Step 4-A: Determine CT required for Virus 4 log reduction ($CT_{99.99}$)

The CT required for 4 log inactivation of viruses (designated as $CT_{99.99}$) for free chlorine is presented in the table below. The virus $CT_{99.99}$ is dependent on temperature and pH.

Temperature °C	pH	
	6-9	10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

Step 4-B: Calculate Virus Log Inactivation

$$\text{Virus Log Inactivation} = 4 \log \times (CT_{CALC} / CT_{99.99})$$

CT_{CALC} = Concentration Time, Calculated Value (minutes•mg/L)

$CT_{99.99}$ = Concentration Time to inactivate 4 log of virus (minutes•mg/L) from table

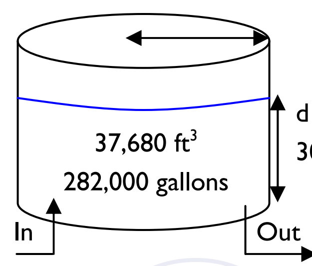
Example Log Inactivation Calculation

Measured at Peak Flow:

- Peak Flow, Q = 347 gpm
- Free chlorine residual, C = 0.8 mg/L
- pH = 6 s.u.
- Temperature = 0.5°C

Cylindrical basin Information:

- Inner tank diameter, D = 40 ft
- Inner tank radius, r = 20 ft
- Minimum tank water level, d = 30 ft
- No baffling, BF = 0.1



Background - Calculate Basin Volume, V

$V = \pi \times d \times r^2$, Cylindrical Basin Volume Equation

$V = 3.1416 \times 30 \text{ ft} \times (20 \text{ ft})^2 = 37{,}680 \text{ ft}^3$

$V = 37{,}680 \text{ ft}^3 \times 7.48 \text{ gallons/ft}^3$

V= 282,000 gallons

Step 1: Calculate Detention Time

Step 1-A: Calculate Theoretical Detention Time

$$TDT = V / Q$$

TDT = V / Q

TDT = 282,000 gals / 347 gpm

TDT = 813 minutes

Step 1-B: Calculate Actual Detention Time

$$T = TDT \times BF$$

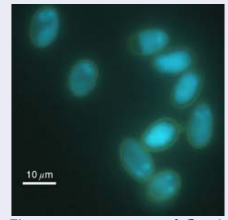
T = TDT × BF

T = 813 minutes × 0.1

T = 81.3 minutes

What is *Giardia*?

Giardia lamblia **is a flagellated protozoan, which is shed during its cyst-stage within the feces of humans and animals. When water containing these cysts is ingested, the protozoan causes a severe gastrointestinal disease called giardiasis.**



Fluorescence image of *Giardia lamblia* cysts
Photo Credit: H.D.A Lindquist, U.S. EPA

Where did the CT tables come from?

The $CT_{99.9}$ and $CT_{99.99}$ tables were developed by the EPA, based on experimental data, to account for the impact of major variables (e.g., temp, pH, concentration) on disinfection reaction efficiency. For example, the $CT_{99.9}$ value in the EPA table is the CT required to achieve a 3 log reduction of *Giardia lamblia* for a given disinfectant type and concentrations under various temperature and pH conditions.

Example Log Inactivation Calculation (continued)

Step 2: Calculate CT_{CALC}

$CT_{CALC} = C \times T$

$CT_{CALC} = C \times T$

$CT_{CALC} = 0.8$ mg/L × 81.3 minutes

$CT_{CALC} = 65$ minutes•mg/L

Step 3: Calculate *Giardia lamblia* log inactivation

Step 3-A: Determine CT required for *Giardia lamblia* 3 log reduction

Determine *Giardia* $CT_{99.9}$ from CT Table given Temperature = 0.5°C, pH = 6 s.u., Free chlorine residual = 0.8 mg/L

Chlorine Conc. (mg/L)	Temperature <= 0.5°C pH						
	<=6.0	6.5	7	7.5	8	8.5	9
<=0.4	137	163	195	237	277	329	390
0.6	141	168	200	239	286	342	407
0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437

$CT_{99.9} = 145$ minutes•mg/L

Step 3-B: Calculate *Giardia lamblia* Log Inactivation

Giardia Log Inactivation = 3 log × (CT_{CALC} / $CT_{99.9}$)

Giardia Log Inactivation = 3 log × (CT_{CALC} / $CT_{99.9}$)

Giardia Log Inactivation = 3 log × (65 minutes•mg/L / 145 minutes•mg/L)

***Giardia* Log Inactivation = 1.34 log**

Step 4: Calculate virus inactivation

Step 4-A: Determine CT required for Virus 4 log reduction

Determine virus $CT_{99.99}$ from CT Table given Temperature = 0.5°C and pH = 6 s.u.

Temperature °C	pH 6-9	10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

$CT_{99.99} = 12$ minutes•mg/L

General relationships:

- **As C ↓ log inactivation ↓**
- **As pH ↑ log inactivation ↓**
- **As BF ↓ log inactivation ↓**
- **As Peak Q ↑ log inactivation ↓**
- **As Temp ↓ log inactivation ↓**
- **As Contact Volume ↓ log inactivation ↓**

Step 4-B: Calculate Virus Log Inactivation

Virus Log Inactivation = 4 log × (CT_{CALC} / $CT_{99.99}$)

Virus Log Inactivation = 4 log× (CT_{CALC} / $CT_{99.99}$)

Virus Log Inactivation = 4 log × (65 minutes•mg/L / 12 minutes•mg/L)

Virus Log Inactivation = 21.67 log

Alternatively: What is the CT, *Giardia* and virus inactivation if the free chlorine residual concentration is 0.4 mg/L vs. 0.8 mg/L?

Answer: $CT_{CALC} = C \times T = 0.4$ mg/L × 81.3 minutes = 32.5 minutes•mg/L

Giardia Log Inactivation = 3 log × (CT_{CALC} / $CT_{99.9}$) = 3 × (32.5 minutes•mg/L / 137 minutes•mg/L) = 0.72 log

Virus Log Inactivation = 4 log× (CT_{CALC} / $CT_{99.99}$) = 4 × (32.5 minutes•mg/L / 12 minutes•mg/L) = 10.83 log

Disinfection Segments

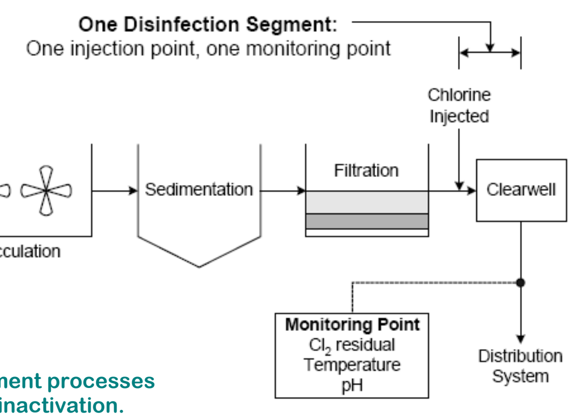
What is a Disinfection Segment?

- **A disinfection segment is a section of a treatment system beginning at one disinfection injection or monitoring point.**
- **Every disinfectant injection point is the start of a new disinfection segment.**
- **Every injection point has an associated monitoring point.**

Total inactivation is the sum of log inactivation for each disinfection segment (if the system has multiple disinfection segments).

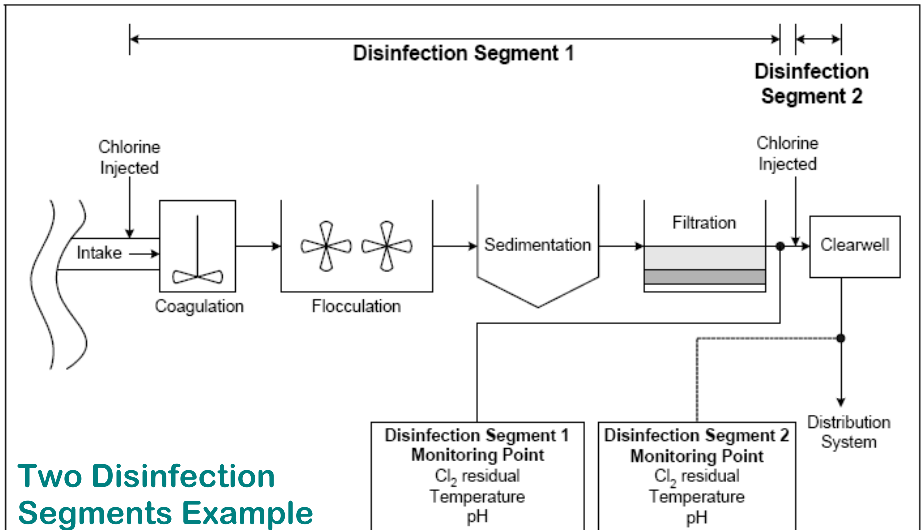
Therefore, calculate log inactivation for each segment and add together to determine total system inactivation.

One Disinfection Segment Example



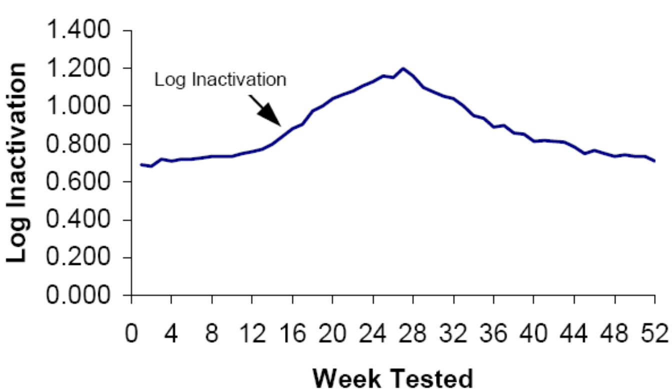
Note: Removal credits for treatment processes are independent of disinfection inactivation.

Two Disinfection Segments Example



Total inactivation = ∑ log inactivation from each disinfection segment

Disinfection Profile



Almost all community and non transient, non community public water systems that use Surface Water or Ground Water Under the Direct Influence of Surface Water sources are required to develop a disinfection profile. Systems are required to retain the disinfection profile in graphic form and it must be available for review by the state as part of a sanitary survey.

What is a Disinfection Profile and Benchmark?

- **A disinfection profile is a graphical representation of a system's level of *Giardia lamblia* or virus inactivation measured, at least weekly, during the course of a year.**
- **A benchmark is the lowest monthly average microbial inactivation during the disinfection profile time period.**

EPA Disinfection Profile Spreadsheet Calculator

The EPA has developed a disinfection profile spreadsheet calculator that calculates and graphs the disinfection profile for *Giardia* and viruses. The spreadsheet can be downloaded from: http://www.epa.gov/safewater/mdbp/lt1eswtr.html.

Table A: 3 Log CT ($CT_{99.9}$) Values for *Giardia* Cysts by free chlorine

Chlorine Conc. (mg/L)	Temperature <= 0.5°C							Temperature = 5°C							Temperature = 10°C						
	pH							pH							pH						
	<=6.0	6.5	7	7.5	8	8.5	9	<=6.0	6.5	7	7.5	8	8.5	9	<=6.0	6.5	7	7.5	8	8.5	9
<=0.4	137	163	195	237	277	329	390	97	117	139	166	198	236	279	73	88	104	125	149	177	209
0.6	141	168	200	239	286	342	407	100	120	143	171	204	244	291	75	90	107	128	153	183	218
0.8	145	172	205	246	295	354	422	103	122	146	175	210	252	301	78	92	110	131	158	189	226
1.0	148	176	210	253	304	365	437	105	125	149	179	216	260	312	79	94	112	134	162	195	234
1.2	152	180	215	259	313	376	451	107	127	152	183	221	267	320	80	95	114	137	166	200	240
1.4	155	184	221	266	321	387	464	109	130	155	187	227	274	329	82	98	116	140	170	206	247
1.6	157	189	226	273	329	397	477	111	132	158	192	232	281	337	83	99	119	144	174	211	253
1.8	162	193	231	279	338	407	489	114	135	162	196	238	287	345	86	101	122	147	179	215	259
2.0	165	197	236	286	346	417	500	116	138	165	200	243	294	353	87	104	124	150	182	221	265
2.2	169	201	242	297	353	426	511	118	140	169	204	248	300	361	89	105	127	153	186	225	271
2.4	172	205	247	298	361	435	522	120	143	172	209	253	306	368	90	107	129	157	190	230	276
2.6	175	209	252	304	368	444	533	122	146	175	213	258	312	375	92	110	131	160	194	234	281
2.8	178	213	257	310	375	452	543	124	148	178	217	263	318	382	93	111	134	163	197	239	287
3.0	181	217	261	316	382	460	552	126	151	182	221	268	324	389	95	113	137	166	201	243	292

Chlorine Conc. (mg/L)	Temperature = 15°C							Temperature = 20°C							Temperature = 25°C						
	pH							pH							pH						
	<=6.0	6.5	7	7.5	8	8.5	9	<=6.0	6.5	7	7.5	8	8.5	9	<=6.0	6.5	7	7.5	8	8.5	9
<=0.4	49	59	70	83	99	118	140	36	44	52	62	74	89	105	24	29	35	42	50	59	70
0.6	50	60	72	86	102	122	146	38	45	54	64	77	92	109	25	30	36	43	51	61	73
0.8	52	61	73	88	105	126	151	39	46	55	66	79	95	113	26	31	37	44	53	63	75
1.0	53	63	75	90	108	130	156	39	47	56	67	81	98	117	26	31	37	45	54	65	78
1.2	54	64	76	92	111	134	160	40	48	57	69	83	100	120	27	32	38	46	55	67	80
1.4	55	65	78	94	114	137	165	41	49	58	70	85	103	123	27	33	39	47	57	69	82
1.6	56	66	79	96	116	141	169	42	50	59	72	87	105	126	28	33	40	48	58	70	84
1.8	57	68	81	98	119	144	173	43	51	61	74	89	108	129	29	34	41	49	60	72	86
2.0	58	69	83	100	122	147	177	44	52	62	75	91	110	132	29	35	41	50	61	74	88
2.2	59	70	85	102	124	150	181	44	53	63	77	93	113	135	30	35	42	51	62	75	90
2.4	60	72	86	105	127	153	184	45	54	65	78	95	115	138	30	36	43	52	63	77	92
2.6	61	73	88	107	129	156	188	46	55	66	80	97	117	141	31	37	44	53	65	78	94
2.8	62	74	89	109	132	159	191	47	56	67	81	99	119	143	31	37	45	54	66	80	96
3.0	63	76	91	111	134	162	195	47	57	68	83	101	122	146	32	38	46	55	67	81	97

Table B: 4 Log CT ($CT_{99.99}$) Values for viruses by free chlorine

Temperature °C	pH	
	6-9	10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

Tables reproduced from

U.S. EPA. 2003. *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual.* EPA 816-R-03-004, http://www.epa.gov/safewater/mdbp/pdf/profile/lt1profiling.pdf

For more information

EPA's LT1ESWTR web site: http://www.epa.gov/safewater/mdbp/lt1eswtr.html

CDPHE WQCD web site: http://www.cdphe.state.co.us/wq/