3745-81-72 **Disinfection of water from surface water sources.**

"Disinfection practice" means the application of a disinfectant to the treatment flow for the purpose of meeting CT requirements of this rule. Significant changes to disinfection practice include any change which will affect the ability of a system to meet the CT requirements of this rule.

(A) A public water system that uses a surface water source, in whole or in part, shall provide the disinfection treatment specified in paragraph (B) of this rule. Failure to meet any requirement of this rule, excluding paragraph (E) of this rule, is a treatment technique violation for which public notification is required under rule 3745-81-32 of the Administrative Code. Failure to meet any requirement of paragraph (E) of this rule is a monitoring violation for which public notification is required under rule 3745-81-32 of the Administrative Code. A public water system that uses a surface water source, in whole or in part, and does not already provide filtration treatment shall comply with any interim disinfection requirements established by the director before filtration is installed.

(B) Each public water system that uses a surface water source, in whole or in part, shall provide disinfection treatment of the water as follows:

(1) The disinfection treatment shall be considered sufficient if the total treatment processes of that public water system would consistently and reliably achieve at least 99.9 per cent (3 log) inactivation and/or removal of Giardia lamblia cysts and at least 99.99 per cent (4 log) inactivation and/or removal of viruses, as determined from table A, and tables B-1 to B-13 of this rule or tables under paragraph (N) of rule 3745-81-68 of the Administrative Code. The inactivation by disinfection is calculated from the actual CT divided by the required CT during the peak hourly flow of each day that the public water system is in operation.

(2) Table A of this rule lists: the minimum requirement for inactivation and/or removal of Cryptosporidium, Giardia lamblia and viruses; the extent to which a properly operated conventional filtration treatment, direct filtration (once demonstrated in accordance with rule 3745-81-73 of the Administrative Code), and slow sand filtration are considered sufficient to remove Cryptosporidium, Giardia lamblia, and viruses; and the minimum disinfection needed to complete the required minimum inactivation and/or removal of Cryptosporidium, Giardia lamblia and viruses. Table A specifies the additional minimum log inactivation of Giardia lamblia and viruses by disinfection if filtration is properly operated and the turbidity treatment technique requirements of rule 3745-81-73 of the Administrative Code are satisfied. The filtration and disinfection treatment shall include disinfection that consistently and reliably achieves at least the minimum log inactivation by disinfection of Giardia lamblia and viruses as specified in table A.

(3) The residual disinfectant concentration in the water entering the distribution system shall not be less than 0.2 milligram per liter free chlorine or one milligram per liter combined chlorine for more than four consecutive hours.

(4) The residual disinfectant concentration in the distribution system shall not be less than 0.2 milligram per liter free chlorine or one milligram per liter combined chlorine in more than five per cent of the samples each month for any two consecutive months that the public water system serves water to the public.

(C) Disinfection treatment sufficiency determination.

(1) Paragraph (B)(1) of this rule requires a minimum percentage of inactivation and/or removal of Giardia lamblia and viruses in water obtained at least partly from a surface water source. Because of the difficulties in measuring the concentrations of viable Cryptosporidium, Giardia lamblia, and viruses, maximum contaminant levels are not practical and treatment technique requirements are used to ensure control of these contaminants in drinking water. For disinfectants other than UV, tables B-1 to B-13 of this rule shall be used to determine the sufficiency of disinfection. ~~This~~ For disinfectants other than UV, this determination is made at the peak hourly flow rate of each day the water system is in operation. Systems using UV to comply with the inactivation requirements of this rule shall meet the following: ~~paragraph (N) of rule 3745-81-68 of the Administrative Code and shall meet the reporting and record-keeping requirements of rule 3745-81-69 of the Administrative Code.~~

(a) Paragraph (N) of rule 3745-81-68 of the Administrative Code.

(b) The reporting and record-keeping requirements of rule 3745-81-69 of the Administrative Code.

(2) For disinfectants other than UV, the level of inactivation being provided by the system is determined by measuring actual CT values. The level of inactivation being provided by a system using UV is determined by the UV dosage. For systems using chlorine dioxide or ozone to comply with the additional Cryptosporidium treatment requirements in paragraph (E) of rule 3745-81-67 of the Administrative Code, unfiltered water flow may be used to achieve the additional treatment credit if approved by the director.

Only filtered water flow shall be used in the required CT calculations to meet the minimum log inactivation in table A of this rule, regardless of the disinfectant used.

Actual CT values are obtained by multiplying the residual disinfectant, C, by the disinfection contact time, T, giving the resultant, CT. The value of C in milligrams per liter is determined at a point before or at the first customer. The value of T in minutes is based on the time available for the disinfectant to work from the point at which ~~it~~ the disinfectant is added to the water until the point at which C is measured.

Values of T are determined based on the approved effective volume factor of the clearwell or contact tank. It may be appropriate to determine the value of C at more than one point of the water treatment flow, with the T associated with each C being estimated from the previous measurement point or the previous addition of disinfectant, whichever is closer. If more than one disinfectant concentration point is used, the products of each C and its associated T are added and the sum of these products is the actual CT value to compare with the appropriate value of the required minimum CT values for specified conditions and levels of inactivation in the following tables. Note that any disinfection after the last determination of C is not included in the actual CT value. Minimum required CT values for inactivation of Giardia lamblia and viruses by disinfection in relation to the disinfectant, the extent of inactivation, the disinfectant concentration, the pH, and the water temperature at the peak hourly flow rate for each day of operation are found in tables B-1 to B-13 of this rule. Applicable information for UV is found in paragraph (N) of rule 3745-81-68 of the Administrative Code.

(3) In tables B-1 to B-13 of this rule, the required CT between the indicated pH or residual disinfectant concentration may be determined by linear interpolation. The required CT between the indicated temperatures of different tables may be determined by linear interpolation.

If no interpolation is used, then the required CT shall be determined at the lower temperature, and at the higher pH, and at the higher residual disinfectant concentration. For Giardia lamblia inactivation at a pH greater than nine, the required CT shall be the same as the required CT at a pH equal to nine. For virus inactivation at a pH greater than nine, the required CT shall be the same as the required CT at a pH equal to ten.

(4) On each day when the actual CT value meets or exceeds the required minimum CT value in or linearly interpolated from tables B-1 to B-13 of this rule for chlorine, chlorine dioxide, ozone, or chloramines, or the table in paragraph (N) of rule 3745-81-68 of the Administrative Code for UV disinfection, then the water treatment plant is considered to be satisfying treatment technique requirements of this rule for disinfection of surface water sources. On each day when the actual CT value does not meet or exceed the required minimum CT value from tables B-1 to B-13 of this rule, then the water treatment plant is in violation of paragraph (B)(1) of this rule.

(5) For each clearwell, or contact tank, the approved effective volume factor shall be determined by the director based upon ~~its~~the design characteristics including: the average flow path length to channel width ratio; baffling; and the proximity of the outlet to the inlet using figures B-1 and B-2 of this rule. The approved effective volume factor shall be the preliminary effective volume factor obtained from figure B-1 of this rule multiplied by the reduction factor obtained from figure B-2 of this rule, rounded down to the nearest 0.05. A public water system may request that the

director approve an effective volume factor that was determined by tracer studies, hydraulic analysis or modeling, or an equivalent demonstration. For a tracer study to be acceptable, the net advection of the tracer shall be within ten per cent of the change in the tracer chemical storage within the clearwell system. Net advection means the amount of tracer convected out of the clearwell system minus the amount of tracer convected into the clearwell system over the duration of the tracer study.

[Note: Refer to the appendix to this rule for more information on how to determine disinfection sufficiency.]

(D) A public water system that serves a population of at least ten thousand persons and was required to develop a disinfection profile or benchmark under 40 CFR 141.172 or 40 CFR 141.170(d), or a community or nontransient noncommunity public water system that serves a population of less than ten thousand persons and was required to develop a disinfection profile or benchmark under 40 CFR 141.530, shall follow these requirements:

(1) Prior to making a significant change in ~~its~~the disinfection practice, the public water system shall submit the disinfection profile to the director for review and consultation. Such changes may require approval if determined substantial by the director as specified by rule 3745-91-02 of the Administrative Code. Significant changes to disinfection practice include any of the following:

(a) Changes to the point of disinfection~~;~~.

(b) Changes to the disinfectant used in the treatment plant~~;~~.

(c) Changes to the disinfection process~~; and~~.

(d) Any other modification identified by the director, including those identified and proposed in a general plan required by paragraph (A)(7) of rule 3745-81-24 of the Administrative Code.

[Comment: The 40 CFR 141.172, 40 CFR 141.170(d), and 40 CFR 141.530 refer to the "Code of Federal Regulations" published on July 1, 2012. At the effective date of this rule, a copy may be obtained from the "Superintendent of Documents, PO Box 371954, Pittsburgh, PA 15250-7954," (866) 512-1800, or http://bookstore.gpo.gov. This document is available for review at "Ohio EPA, Lazarus Government Center, 50 West Town Street, Columbus, OH, 43215-3425."]

(2) The public water system shall calculate ~~its~~the disinfection benchmark using the following procedure:

(a) The disinfection benchmark is the lowest monthly average value (for public water systems with one year of profiling data) or average of lowest monthly average values (for public water systems with more than one year of

profiling data) of the monthly logs of Giardia lamblia inactivation in each year of profiling data.

(b) For each year of profiling data collected and calculated, the public water system shall determine the lowest average monthly Giardia lamblia inactivation in each year of profiling data. The average Giardia lamblia inactivation shall be determined by dividing the sum of Giardia lamblia inactivation values by the number of values calculated for that month. For public water systems with a combined population of at least ten thousand persons, daily values shall be used. For public water systems with a combined population less than ten thousand persons, weekly values may be used. Values for each calendar month for each year of profiling data shall be used in the calculation.

(3) A public water system that uses chloramines, chlorine dioxide, or ozone for primary disinfection shall also calculate the disinfection benchmark for viruses using a method acceptable to the director.

(4) Prior to making a significant change, the public water system shall submit the following information for review by the director:

(a) A description of the proposed change~~;~~.

(b) The disinfection profile for Giardia lamblia (and, if necessary, viruses) and disinfection benchmark~~; and~~.

(c) An analysis of how the proposed change will affect the current levels of disinfection.

(5) The public water system shall retain the disinfection profile data in graphic form, as a spreadsheet, or in some other format acceptable to the director for review as part of a sanitary survey. The disinfection profile, disinfection benchmark, and all data and analysis used to complete the disinfection profile shall be retained by the public water system indefinitely.

(E) Disinfection profiling and benchmarking requirements for any system making a significant change to ~~their~~the disinfection practice.

(1) Following the completion of initial source water monitoring in accordance with paragraph (A) of rule 3745-81-65 of the Administrative Code, a system that plans to make a significant change to ~~its~~the disinfection practice, as defined in paragraph (E)(2) of this rule, shall develop disinfection profiles and calculate disinfection benchmarks for Giardia lamblia and viruses as described in paragraphs (E)(3) to (E)(7) of this rule. Prior to changing the disinfection practice, the system shall notify the director and shall include in this notice the following information:

(a) A completed disinfection profile and disinfection benchmark for Giardia lamblia and viruses as described in paragraphs (E)(3) to (E)(7) of this rule.

(b) A description of the proposed change in disinfection practice.

(c) An analysis of how the proposed change will affect the current level of disinfection.

(2) Significant changes to disinfection practices include any of the following:

(a) Changes to the point of disinfection~~;~~.

(b) Changes to the disinfectant used in the treatment plant~~;~~.

(c) Changes to the disinfection process~~; or~~.

(d) Any other modification identified by the director as a significant change to disinfection practice.

(3) Systems required to develop disinfection profiles in accordance with paragraphs (E)(1) and (E)(2) of this rule shall monitor at least weekly for a period of twelve consecutive months to determine the total log inactivation for Giardia lamblia and viruses. If systems monitor more frequently, the monitoring frequency shall be evenly spaced. Systems that operate for fewer than twelve months per year shall monitor weekly during the period of operation. Systems shall determine log inactivation for Giardia lamblia and viruses through the entire plant, based on CT99.9 values in tables B-1 to B-13 of this rule, as applicable. Systems shall determine log inactivation of viruses through the entire treatment plant based on a protocol accepted by the director.

(4) Systems with a single point of disinfectant application prior to the entrance to the distribution system shall conduct the monitoring in this paragraph. Systems with more than one point of disinfectant application shall conduct the monitoring in this paragraph for each disinfection segment. Systems shall monitor the parameters necessary to determine the total inactivation ratio, using analytical methods in accordance with paragraph (C) of rule3745-81-27 of the Administrative Code.

(a) For systems using a disinfectant other than UV, the temperature of the disinfected water shall be measured at each residual disinfectant concentration sampling point during peak hourly flow or at an alternative location accepted by the director.

(b) For systems using chlorine, the pH of the disinfected water shall be measured at each chlorine residual disinfectant concentration sampling point during peak hourly flow or at an alternative location accepted by the director.

(c) The disinfectant contact ~~time(s)~~time, T, shall be determined during peak hourly flow.

(d) The residual disinfectant ~~concentration(s)~~concentration, C, of the water before or at the first customer and prior to each additional point of disinfectant application shall be measured during peak hourly flow.

(5) In lieu of conducting new monitoring under paragraph (E)(4) of this rule, systems may elect to meet ~~the requirements of paragraph (E)(5)(a) or (E)(5)(b) of this rule.~~the following:

(a) Systems that have at least one year of existing data that are substantially equivalent to data collected under the provisions of paragraph (E)(4) of this rule may use these data to develop disinfection profiles as specified in this rule if the system has neither made a significant change to the treatment practice nor changed sources since the data were collected. Systems may develop disinfection profiles using up to three years of existing data.

(b) Systems may use disinfection ~~profile(s)~~profile developed in accordance with paragraph (D) of this rule in lieu of developing a new profile if the system has neither made a significant change to the treatment practice nor changed sources since the profile was developed. Systems that have not developed a virus profile under paragraph (D) of this rule shall develop a virus profile using the same monitoring data on which the Giardia lamblia profile is based.

(6) Systems shall calculate the total inactivation ratio for Giardia lamblia as ~~specified in paragraphs (E)(6)(a) to (E)(6)(c) of this rule~~follows:

(a) Systems using only one point of disinfectant application may determine the total inactivation ratio for the disinfection segment based on either of the following:

(i) Determine one inactivation ratio ($CT_{calc}/CT_{99.9}$) before or at the first customer during peak hourly flow.

(ii) Determine successive $CT_{calc}/CT_{99.9}$values, representing sequential inactivation ratios, between the point of disinfectant application and a point before or at the first customer during peak hourly flow. The system shall calculate the total inactivation ratio by determining ($CT_{calc}/CT_{99.9}$) for each sequence and then adding the ($CT_{calc}/CT_{99.9}$) values together to determine ($\Sigma(CT_{calc}/CT_{99.9})$).

(b) Systems using more than one point of disinfectant application before the first customer shall determine the CT value of each disinfection segment immediately prior to the next point of disinfectant application, or for the

final segment, before or at the first customer, during peak hourly flow. The ($CT_{calc}/CT_{99.9}$) value of each segment and (Σ ($CT_{calc}/CT_{99.9}$)) shall be calculated using the method in paragraph (E)(6)(a)(ii) of this rule.

(c) The system shall determine the total logs of inactivation by multiplying the value calculated in paragraph (E)(6)(a) or (E)(6)(b) of this rule by 3.0.

(d) Systems shall calculate the log of inactivation for viruses using a protocol approved by the director.

(7) Systems shall use the following procedures to calculate a disinfection benchmark:

(a) For each year of profiling data collected and calculated under paragraphs (E)(3) to (E)(6) of this rule, systems shall determine the lowest average monthly level of both Giardia lamblia and virus inactivation. Systems shall determine the average Giardia lamblia and virus inactivation for each calendar month for each year of profiling data by dividing the sum of daily or weekly Giardia lamblia and virus log inactivation by the number of values calculated for that month.

(b) The disinfection benchmark is the lowest monthly average value (for systems with one year of profiling data) or the average of the lowest monthly average values (for systems with more than one year of profiling data) of Giardia lamblia and virus log inactivation in each year of profiling data.

Table A
Minimum Requirements For Inactivation Or Removal of Cryptosporidium, Giardia Lamblia, and Viruses

Type of Filtration	Required Minimum Log Removal/Inactivation			Expected Log Removal by Filtration			Minimum Log Inactivation by Disinfection	
	Cryptosporidium (Log Removal Only)	Giardia	Viruses	Cryptosporidium	Giardia	Viruses	Giardia	Viruses
Conventional	2	3	4	2	2.5	2.0	0.5	2.0
Direct	2	3	4	2	2.0	1.0	1.0	3.0
Slow Sand	2	3	4	2	2.0	2.0	1.0	2.0

Comment: Log removal and log inactivation refer to the negative logarithm of the quotient of the concentration of an impurity after treatment divided by the concentration before treatment. For instance, a 99.9 per cent decrease in viruses has a post treatment concentration 0.001 times the pretreatment concentration and a 3 log removal designation. Common conversions include:

Removal designation	Concentration decrease	Quotient after/before
0.5 log	70%	0.3
1 log	90%	0.1
1.5 log	97%	0.03
2 log	99%	0.01
2.5 log	99.7%	0.003
3 log	99.9%	0.001
4 log	99.99%	0.0001

Table B-1
Required CT For Inactivation Of Giardia Cysts By Free Chlorine At 0.5° Celsius Or Less

Chlorine Concentration (mg/L)	pH≤6 Log Inactivations						pH=6.5 Log Inactivations						pH=7.0 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	23	46	69	91	114	137	27	54	82	109	136	163	33	65	98	130	163	195
0.6	24	47	71	94	118	141	28	56	84	112	140	168	33	67	100	133	167	200
0.8	24	48	73	97	121	145	29	57	86	115	143	172	34	68	103	137	171	205
1	25	49	74	99	123	148	29	59	88	117	147	176	35	70	105	140	175	210
1.2	25	51	76	101	127	152	30	60	90	120	150	180	36	72	108	143	179	215
1.4	26	52	78	103	129	155	31	61	92	123	153	184	37	74	111	147	184	221
1.6	26	52	79	105	131	157	32	63	95	126	158	189	38	75	113	151	188	226
1.8	27	54	81	108	135	162	32	64	97	129	161	193	39	77	116	154	193	231
2	28	55	83	110	138	165	33	66	99	131	164	197	39	79	118	157	197	236
2.2	28	56	85	113	141	169	34	67	101	134	168	201	40	81	121	161	202	242
2.4	29	57	86	115	143	172	34	68	103	137	171	205	41	82	124	165	206	247
2.6	29	58	88	117	146	175	35	70	105	139	174	209	42	84	126	168	210	252
2.8	30	59	89	119	148	178	36	71	107	142	178	213	43	86	129	171	214	257
3	30	60	91	121	151	181	36	72	109	145	181	217	44	87	131	174	218	261

Chlorine Concentration (mg/L)	pH=7.5 Log Inactivations						pH=8.0 Log Inactivations						pH=8.5 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	40	79	119	158	198	237	46	92	139	185	231	277	55	110	165	219	274	329
0.6	40	80	120	159	199	239	48	95	143	191	238	286	57	114	171	228	285	342
0.8	41	82	123	164	205	246	49	98	148	197	246	295	59	118	177	236	295	354
1	42	84	127	169	211	253	51	101	152	203	253	304	61	122	183	243	304	365
1.2	43	86	130	173	216	259	52	104	157	209	261	313	63	125	188	251	313	376
1.4	44	89	133	177	222	266	54	107	161	214	268	321	65	129	194	258	323	387
1.6	46	91	137	182	228	273	55	110	165	219	274	329	66	132	199	265	331	397
1.8	47	93	140	186	233	279	56	113	169	225	282	338	68	136	204	271	339	407
2	48	95	143	191	238	286	58	115	173	231	288	346	70	139	209	278	348	417
2.2	50	99	149	198	248	297	59	118	177	235	294	353	71	142	213	284	355	426
2.4	50	99	149	199	248	298	60	120	181	241	301	361	73	145	218	290	363	435
2.6	51	101	152	203	253	304	61	123	184	245	307	368	74	148	222	296	370	444
2.8	52	103	155	207	258	310	63	125	188	250	313	375	75	151	226	301	377	452
3	53	105	158	211	263	316	64	127	191	255	318	382	77	153	230	307	383	460

Chlorine Concentration (mg/L)	pH=9.0 or pH>9.0 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	65	130	195	260	325	390
0.6	68	136	204	271	339	407
0.8	70	141	211	281	352	422
1	73	146	219	291	364	437
1.2	75	150	226	301	376	451
1.4	77	155	232	309	387	464
1.6	80	159	239	318	398	477
1.8	82	163	245	326	408	489
2	83	167	250	333	417	500
2.2	85	170	256	341	426	511
2.4	87	174	261	348	435	522
2.6	89	178	267	355	444	533
2.8	91	181	272	362	453	543
3	92	184	276	368	460	552

[Comment: $CT_{99.9}$ = CT for 3 log inactivation.]

Table B-2
Required CT For Inactivation Of Giardia Cysts By Free Chlorine At 5° Celsius

Chlorine Concentration (mg/L)	pH≤6 Log Inactivations						pH=6.5 Log Inactivations						pH=7.0 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	16	32	49	65	81	97	20	39	59	78	98	117	23	46	70	93	116	139
0.6	17	33	50	67	83	100	20	40	60	80	100	120	24	48	72	95	119	143
0.8	17	34	52	69	86	103	20	41	61	81	102	122	24	49	73	97	122	146
1	18	35	53	70	88	105	21	42	63	83	104	125	25	50	75	99	124	149
1.2	18	36	54	71	89	107	21	42	64	85	106	127	25	51	76	101	127	152
1.4	18	36	55	73	91	109	22	43	65	87	108	130	26	52	78	103	129	155
1.6	19	37	56	74	93	111	22	44	66	88	110	132	26	53	79	105	132	158
1.8	19	38	57	76	95	114	23	45	68	90	113	135	27	54	81	108	135	162
2	19	39	58	77	97	116	23	46	69	92	115	138	28	55	83	110	138	165
2.2	20	39	59	79	98	118	23	47	70	93	117	140	28	56	85	113	141	169
2.4	20	40	60	80	100	120	24	48	72	95	119	143	29	57	86	115	143	172
2.6	20	41	61	81	102	122	24	49	73	97	122	146	29	58	88	117	146	175
2.8	21	41	62	83	103	124	25	49	74	99	123	148	30	59	89	119	148	178
3	21	42	63	84	105	126	25	50	76	101	126	151	30	61	91	121	152	182

Chlorine Concentration (mg/L)	pH=7.5 Log Inactivations						pH=8.0 Log Inactivations						pH=8.5 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	28	55	83	111	138	166	33	66	99	132	165	198	39	79	118	157	197	236
0.6	29	57	86	114	143	171	34	68	102	136	170	204	41	81	122	163	203	244
0.8	29	58	88	117	146	175	35	70	105	140	175	210	42	84	126	168	210	252
1	30	60	90	119	149	179	36	72	108	144	180	216	43	87	130	173	217	260
1.2	31	61	92	122	153	183	37	74	111	147	184	221	45	89	134	178	223	267
1.4	31	62	94	125	156	187	38	76	114	151	189	227	46	91	137	183	228	274
1.6	32	64	96	128	160	192	39	77	116	155	193	232	47	94	141	187	234	281
1.8	33	65	98	131	163	196	40	79	119	159	198	238	48	96	144	191	239	287
2	33	67	100	133	167	200	41	81	122	162	203	243	49	98	147	196	245	294
2.2	34	68	102	136	170	204	41	83	124	165	207	248	50	100	150	200	250	300
2.4	35	70	105	139	174	209	42	84	127	169	211	253	51	102	153	204	255	306
2.6	36	71	107	142	178	213	43	86	129	172	215	258	52	104	156	208	260	312
2.8	36	72	109	145	181	217	44	88	132	175	219	263	53	106	159	212	265	318
3	37	74	111	147	184	221	45	89	134	179	223	268	54	108	162	216	270	324

Chlorine Concentration (mg/L)	pH=9.0 or pH>9.0 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	47	93	140	186	233	279
0.6	49	97	146	194	243	291
0.8	50	100	151	201	251	301
1	52	104	156	208	260	312
1.2	53	107	160	213	267	320
1.4	55	110	165	219	274	329
1.6	56	112	169	225	281	337
1.8	58	115	173	230	288	345
2	59	118	177	235	294	353
2.2	60	120	181	241	301	361
2.4	61	123	184	245	307	368
2.6	63	125	188	250	313	375
2.8	64	127	191	255	318	382
3	65	130	195	259	324	389

[Comment: $CT_{99.9}$ = CT for 3 log inactivation.]

Table B-3
Required CT For Inactivation
Of Giardia Cysts By Free Chlorine
At 10° Celsius

pH≤6

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	12	24	37	49	61	73
0.6	13	25	38	50	63	75
0.8	13	26	39	52	65	78
1	13	26	40	53	66	79
1.2	13	27	40	53	67	80
1.4	14	27	41	55	68	82
1.6	14	28	42	55	69	83
1.8	14	29	43	57	72	86
2	15	29	44	58	73	87
2.2	15	30	45	59	74	89
2.4	15	30	45	60	75	90
2.6	15	31	46	61	77	92
2.8	16	31	47	62	78	93
3	16	32	48	63	79	95

pH=6.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	15	29	44	59	73	88
0.6	15	30	45	60	75	90
0.8	15	31	46	61	77	92
1	16	31	47	63	78	94
1.2	16	32	48	63	79	95
1.4	16	33	49	65	82	98
1.6	17	33	50	66	83	99
1.8	17	34	51	67	84	101
2	17	35	52	69	87	104
2.2	18	35	53	70	88	105
2.4	18	36	54	71	89	107
2.6	18	37	55	73	92	110
2.8	19	37	56	74	93	111
3	19	38	57	75	94	113

pH=7.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	17	35	52	69	87	104
0.6	18	36	54	71	89	107
0.8	18	37	55	73	92	110
1	19	37	56	75	93	112
1.2	19	38	57	76	95	114
1.4	19	39	58	77	97	116
1.6	20	40	60	79	99	119
1.8	20	41	61	81	102	122
2	21	41	62	83	103	124
2.2	21	42	64	85	106	127
2.4	22	43	65	86	108	129
2.6	22	44	66	87	109	131
2.8	22	45	67	89	112	134
3	23	46	69	91	114	137

pH=7.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	21	42	63	83	104	125
0.6	21	43	64	85	107	128
0.8	22	44	66	87	109	131
1	22	45	67	89	112	134
1.2	23	46	69	91	114	137
1.4	23	47	70	93	117	140
1.6	24	48	72	96	120	144
1.8	25	49	74	98	123	147
2	25	50	75	100	125	150
2.2	26	51	77	102	128	153
2.4	26	52	79	105	131	157
2.6	27	53	80	107	133	160
2.8	27	54	82	109	136	163
3	28	55	83	111	138	166

pH=8.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	25	50	75	99	124	149
0.6	26	51	77	102	128	153
0.8	26	53	79	105	132	158
1	27	54	81	108	135	162
1.2	28	55	83	111	138	166
1.4	28	57	85	113	142	170
1.6	29	58	87	116	145	174
1.8	30	60	90	119	149	179
2	30	61	91	121	152	182
2.2	31	62	93	124	155	186
2.4	32	63	95	127	158	190
2.6	32	65	97	129	162	194
2.8	33	66	99	131	164	197
3	34	67	101	134	168	201

pH=8.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	30	59	89	118	148	177
0.6	31	61	92	122	153	183
0.8	32	63	95	126	158	189
1	33	65	98	130	163	195
1.2	33	67	100	133	167	200
1.4	34	69	103	137	172	206
1.6	35	70	106	141	176	211
1.8	36	72	108	143	179	215
2	37	74	111	147	184	221
2.2	38	75	113	150	188	225
2.4	38	77	115	153	192	230
2.6	39	78	117	156	195	234
2.8	40	80	120	159	199	239
3	41	81	122	162	203	243

pH=9.0 or pH>9.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	35	70	105	139	174	209
0.6	36	73	109	145	182	218
0.8	38	75	113	151	188	226
1	39	78	117	156	195	234
1.2	40	80	120	160	200	240
1.4	41	82	124	165	206	247
1.6	42	84	127	169	211	253
1.8	43	86	130	173	216	259
2	44	88	133	177	221	265
2.2	45	90	136	181	226	271
2.4	46	92	138	184	230	276
2.6	47	94	141	187	234	281
2.8	48	96	144	191	239	287
3	49	97	146	195	243	292

[Comment: $CT_{99.9}$ = CT for 3 log inactivation.]

Table B-4
Required CT For Inactivation
Of Giardia Cysts By Free Chlorine
At 15° Celsius

pH≤6

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	8	16	25	33	41	49
0.6	8	17	25	33	42	50
0.8	9	17	26	35	43	52
1	9	18	27	35	44	53
1.2	9	18	27	36	45	54
1.4	9	18	28	37	46	55
1.6	9	19	28	37	47	56
1.8	10	19	29	38	48	57
2	10	19	29	39	48	58
2.2	10	20	30	39	49	59
2.4	10	20	30	40	50	60
2.6	10	20	31	41	51	61
2.8	10	21	31	41	52	62
3	11	21	32	42	53	63

pH=6.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	10	20	30	39	49	59
0.6	10	20	30	40	50	60
0.8	10	20	31	41	51	61
1	11	21	32	42	53	63
1.2	11	21	32	43	53	64
1.4	11	22	33	43	54	65
1.6	11	22	33	44	55	66
1.8	11	23	34	45	57	68
2	12	23	35	46	58	69
2.2	12	23	35	47	58	70
2.4	12	24	36	48	60	72
2.6	12	24	37	49	61	73
2.8	12	25	37	49	62	74
3	13	25	38	51	63	76

pH=7.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	12	23	35	47	58	70
0.6	12	24	36	48	60	72
0.8	12	24	37	49	61	73
1	13	25	38	50	63	75
1.2	13	25	38	51	63	76
1.4	13	26	39	52	65	78
1.6	13	26	40	53	66	79
1.8	14	27	41	54	68	81
2	14	28	42	55	69	83
2.2	14	28	43	57	71	85
2.4	14	29	43	57	72	86
2.6	15	29	44	59	73	88
2.8	15	30	45	59	74	89
3	15	30	46	61	76	91

pH=7.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	14	28	42	55	69	83
0.6	14	29	43	57	72	86
0.8	15	29	44	59	73	88
1	15	30	45	60	75	90
1.2	15	31	46	61	77	92
1.4	16	31	47	63	78	94
1.6	16	32	48	64	80	96
1.8	16	33	49	65	82	98
2	17	33	50	67	83	100
2.2	17	34	51	68	85	102
2.4	18	35	53	70	88	105
2.6	18	36	54	71	89	107
2.8	18	36	55	73	91	109
3	19	37	56	74	93	111

pH=8.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	17	33	50	66	83	99
0.6	17	34	51	68	85	102
0.8	18	35	53	70	88	105
1	18	36	54	72	90	108
1.2	19	37	56	74	93	111
1.4	19	38	57	76	95	114
1.6	19	39	58	77	97	116
1.8	20	40	60	79	99	119
2	20	41	61	81	102	122
2.2	21	41	62	83	103	124
2.4	21	42	64	85	106	127
2.6	22	43	65	86	108	129
2.8	22	44	66	88	110	132
3	22	45	67	89	112	134

pH=8.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	20	39	59	79	98	118
0.6	20	41	61	81	102	122
0.8	21	42	63	84	105	126
1	22	43	65	87	108	130
1.2	22	45	67	89	112	134
1.4	23	46	69	91	114	137
1.6	24	47	71	94	118	141
1.8	24	48	72	96	120	144
2	25	49	74	98	123	147
2.2	25	50	75	100	125	150
2.4	26	51	77	102	128	153
2.6	26	52	78	104	130	156
2.8	27	53	80	106	133	159
3	27	54	81	108	135	162

pH=9.0 or pH>9.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	23	47	70	93	117	140
0.6	24	49	73	97	122	146
0.8	25	50	76	101	126	151
1	26	52	78	104	130	156
1.2	27	53	80	107	133	160
1.4	28	55	83	110	138	165
1.6	28	56	85	113	141	169
1.8	29	58	87	115	144	173
2	30	59	89	118	148	177
2.2	30	60	91	121	151	181
2.4	31	61	92	123	153	184
2.6	31	63	94	125	157	188
2.8	32	64	96	127	159	191
3	33	65	98	130	163	195

[Comment: $CT_{99.9}$ = CT for 3 log inactivation.]

Table B-5
Required CT For Inactivation Of Giardia Cysts By Free Chlorine At 20° Celsius

pH≤6

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	6	12	18	24	30	36
0.6	6	13	19	25	32	38
0.8	7	13	20	26	33	39
1	7	13	20	26	33	39
1.2	7	13	20	27	33	40
1.4	7	14	21	27	34	41
1.6	7	14	21	28	35	42
1.8	7	14	22	29	36	43
2	7	15	22	29	37	44
2.2	7	15	22	29	37	44
2.4	8	15	23	30	38	45
2.6	8	15	23	31	38	46
2.8	8	16	24	31	39	47
3	8	16	24	31	39	47

pH=6.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	7	15	22	29	37	44
0.6	8	15	23	30	38	45
0.8	8	15	23	31	38	46
1	8	16	24	31	39	47
1.2	8	16	24	32	40	48
1.4	8	16	25	33	41	49
1.6	8	17	25	33	42	50
1.8	9	17	26	34	43	51
2	9	17	26	35	43	52
2.2	9	18	27	35	44	53
2.4	9	18	27	36	45	54
2.6	9	18	28	37	46	55
2.8	9	19	28	37	47	56
3	10	19	29	38	48	57

pH=7.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	9	17	26	35	43	52
0.6	9	18	27	36	45	54
0.8	9	18	28	37	46	55
1	9	19	28	37	47	56
1.2	10	19	29	38	48	57
1.4	10	19	29	39	48	58
1.6	10	20	30	39	49	59
1.8	10	20	31	41	51	61
2	10	21	31	41	52	62
2.2	11	21	32	42	53	63
2.4	11	22	33	43	54	65
2.6	11	22	33	44	55	66
2.8	11	22	34	45	56	67
3	11	23	34	45	57	68

pH=7.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	10	21	31	41	52	62
0.6	11	21	32	43	53	64
0.8	11	22	33	44	55	66
1	11	22	34	45	56	67
1.2	12	23	35	46	58	69
1.4	12	23	35	47	58	70
1.6	12	24	36	48	60	72
1.8	12	25	37	49	62	74
2	13	25	38	50	63	75
2.2	13	26	39	51	64	77
2.4	13	26	39	52	65	78
2.6	13	27	40	53	67	80
2.8	14	27	41	54	68	81
3	14	28	42	55	69	83

pH=8.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	12	25	37	49	62	74
0.6	13	26	39	51	64	77
0.8	13	26	40	53	66	79
1	14	27	41	54	68	81
1.2	14	28	42	55	69	83
1.4	14	28	43	57	71	85
1.6	15	29	44	58	73	87
1.8	15	30	45	59	74	89
2	15	30	46	61	76	91
2.2	16	31	47	62	78	93
2.4	16	32	48	63	79	95
2.6	16	32	49	65	81	97
2.8	17	33	50	66	83	99
3	17	34	51	67	84	101

pH=8.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	15	30	45	59	74	89
0.6	15	31	46	61	77	92
0.8	16	32	48	63	79	95
1	16	33	49	65	82	98
1.2	17	33	50	67	83	100
1.4	17	34	52	69	86	103
1.6	18	35	53	70	88	105
1.8	18	36	54	72	90	108
2	18	37	55	73	92	110
2.2	19	38	57	75	94	113
2.4	19	38	58	77	96	115
2.6	20	39	59	78	98	117
2.8	20	40	60	79	99	119
3	20	41	61	81	102	122

pH=9.0 or pH>9.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	18	35	53	70	88	105
0.6	18	36	55	73	91	109
0.8	19	38	57	75	94	113
1	20	39	59	78	98	117
1.2	20	40	60	80	100	120
1.4	21	41	62	82	103	123
1.6	21	42	63	84	105	126
1.8	22	43	65	86	108	129
2	22	44	66	88	110	132
2.2	23	45	68	90	113	135
2.4	23	46	69	92	115	138
2.6	24	47	71	94	118	141
2.8	24	48	72	95	119	143
3	24	49	73	97	122	146

[Comment: $CT_{99.9}$ = CT for 3 log inactivation.]

Table B-6
Required CT For Inactivation Of Giardia Cysts By Free Chlorine At 25° Celsius And Greater

pH≤6

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	4	8	12	16	20	24
0.6	4	8	13	17	21	25
0.8	4	9	13	17	22	26
1	4	9	13	17	22	26
1.2	5	9	14	18	23	27
1.4	5	9	14	18	23	27
1.6	5	9	14	19	23	28
1.8	5	10	15	19	24	29
2	5	10	15	19	24	29
2.2	5	10	15	20	25	30
2.4	5	10	15	20	25	30
2.6	5	10	16	21	26	31
2.8	5	10	16	21	26	31
3	5	11	16	21	27	32

pH=6.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	5	10	15	19	24	29
0.6	5	10	15	20	25	30
0.8	5	10	16	21	26	31
1	5	10	16	21	26	31
1.2	5	11	16	21	27	32
1.4	6	11	17	22	28	33
1.6	6	11	17	22	28	33
1.8	6	11	17	23	28	34
2	6	12	18	23	29	35
2.2	6	12	18	23	29	35
2.4	6	12	18	24	30	36
2.6	6	12	19	25	31	37
2.8	6	12	19	25	31	37
3	6	13	19	25	32	38

pH=7.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	6	12	18	23	29	35
0.6	6	12	18	24	30	36
0.8	6	12	19	25	31	37
1	6	12	19	25	31	37
1.2	6	13	19	25	32	38
1.4	7	13	20	26	33	39
1.6	7	13	20	27	33	40
1.8	7	14	21	27	34	41
2	7	14	21	27	34	41
2.2	7	14	21	28	35	42
2.4	7	14	22	29	36	43
2.6	7	15	22	29	37	44
2.8	8	15	23	30	38	45
3	8	15	23	31	38	46

pH=7.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	7	14	21	28	35	42
0.6	7	14	22	29	36	43
0.8	7	15	22	29	37	44
1	8	15	23	30	38	45
1.2	8	15	23	31	38	46
1.4	8	16	24	31	39	47
1.6	8	16	24	32	40	48
1.8	8	16	25	33	41	49
2	8	17	25	33	42	50
2.2	9	17	26	34	43	51
2.4	9	17	26	35	43	52
2.6	9	18	27	35	44	53
2.8	9	18	27	36	45	54
3	9	18	28	37	46	55

pH=8.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	8	17	25	33	42	50
0.6	9	17	26	34	43	51
0.8	9	18	27	35	44	53
1	9	18	27	36	45	54
1.2	9	18	28	37	46	55
1.4	10	19	29	38	48	57
1.6	10	19	29	39	48	58
1.8	10	20	30	40	50	60
2	10	20	31	41	51	61
2.2	10	21	31	41	52	62
2.4	11	21	32	42	53	63
2.6	11	22	33	43	54	65
2.8	11	22	33	44	55	66
3	11	22	34	45	56	67

pH=8.5

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	10	20	30	39	49	59
0.6	10	20	31	41	51	61
0.8	11	21	32	42	53	63
1	11	22	33	43	54	65
1.2	11	22	34	45	56	67
1.4	12	23	35	46	58	69
1.6	12	23	35	47	58	70
1.8	12	24	36	48	60	72
2	12	25	37	49	62	74
2.2	13	25	38	50	63	75
2.4	13	26	39	51	64	77
2.6	13	26	39	52	65	78
2.8	13	27	40	53	67	80
3	14	27	41	54	68	81

pH=9.0 or pH>9.0

Chlorine Concentration (mg/L)	Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
≤0.4	12	23	35	47	58	70
0.6	12	24	37	49	61	73
0.8	13	25	38	50	63	75
1	13	26	39	52	65	78
1.2	13	27	40	53	67	80
1.4	14	27	41	55	68	82
1.6	14	28	42	56	70	84
1.8	14	29	43	57	72	86
2	15	29	44	59	73	88
2.2	15	30	45	60	75	90
2.4	15	31	46	61	77	92
2.6	16	31	47	63	78	94
2.8	16	32	48	64	80	96
3	16	32	49	65	81	97

[Comment: $CT_{99.9}$ = CT for 3 log inactivation.]

Table B-7
Required CT For Inactivation
of Viruses by Free Chlorine

	..... Log Inactivation					
	2.0 Log		3.0 Log		4.0 Log	
Temperature (Celsius)	pH 6-9	pH 10	pH 6-9	pH 10	pH 6-9	pH 10
0.5	6	45	9	66	12	90
5	4	30	6	44	8	60
10	3	22	4	33	6	45
15	2	15	3	22	4	30
20	1	11	2	16	3	22
25	1	7	1	11	2	15

Table B-8
CT Values for Inactivation of Giardia Cysts
by Chlorine Dioxide pH 6-9

	····· Temperature (Celsius) ·····					
Log Inactivation	≤1	5	10	15	20	≥25
0.5	10	4.3	4	3.2	2.5	2
1	21	8.7	7.7	6.3	5	3.7
1.5	32	13	12	10	7.5	5.5
2	42	17	15	13	10	7.3
2.5	52	22	19	16	13	9
3	63	26	23	19	15	11

Table B-9
CT Values for Inactivation of Viruses
By Chlorine Dioxide pH 6-9

	····· Temperature (Celsius) ·····					
Log Inactivation	≤1	5	10	15	20	≥25
2	8.4	5.6	4.2	2.8	2.1	1.4
3	25.6	17.1	12.8	8.6	6.4	4.3
4	50.1	33.4	25.1	16.7	12.5	8.4

Table B-10
CT Values for Inactivation of Giardia Cysts
By Ozone pH 6-9

Log Inactivation	Temperature (Celsius) ≤1	5	10	15	20	≥25
0.5	0.48	0.32	0.23	0.16	0.12	0.08
1	0.97	0.63	0.48	0.32	0.24	0.16
1.5	1.5	0.95	0.72	0.48	0.36	0.24
2	1.9	1.3	0.95	0.63	0.48	0.32
2.5	2.4	1.6	1.2	0.79	0.60	0.40
3	2.9	1.9	1.43	0.95	0.72	0.48

Table B-11
CT Values for Inactivation of Viruses by Ozone

Log Inactivation	Temperature (Celsius) ≤1	5	10	15	20	≥25
2	0.9	0.6	0.5	0.3	0.25	0.15
3	1.4	0.9	0.8	0.5	0.4	0.25
4	1.8	1.2	1.0	0.6	0.5	0.3

Table B-12

Required CT Values for Inactivation of Giardia Cysts by Chloramine, pH 6.0-9.0																									
Temperature (Celsius)																									
Log Inactivation	≤1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0.5	635	568	500	433	365	354	343	332	321	310	298	286	274	262	250	237	224	211	198	185	173	161	149	137	125
1	1270	1136	1003	869	735	711	687	663	639	615	592	569	546	523	500	474	448	422	396	370	346	322	298	274	250
1.5	1900	1700	1500	1300	1100	1066	1032	998	964	930	894	858	822	786	750	710	670	630	590	550	515	480	445	410	375
2	2535	2269	2003	1736	1470	1422	1374	1326	1278	1230	1184	1138	1092	1046	1000	947	894	841	788	735	688	641	594	547	500
2.5	3170	2835	2500	2165	1830	1772	1714	1656	1598	1540	1482	1424	1366	1308	1250	1183	1116	1049	982	915	857	799	741	683	625
3	3800	3400	3000	2600	2200	2130	2060	1990	1920	1850	1780	1710	1640	1570	1500	1420	1340	1260	1180	1100	1030	960	890	820	750

Table B-13

Required CT for Inactivation of Viruses by Chloramine[1]																									
Temperature (Celsius)																									
Log Inactivation	≤1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2	1243	1147	1050	954	857	814	771	729	686	643	600	557	514	471	428	407	385	364	342	321	300	278	257	235	214
3	2063	1903	1743	1583	1423	1352	1281	1209	1138	1067	996	925	854	783	712	676	641	605	570	534	498	463	427	392	356
4	2883	2659	2436	2212	1988	1889	1789	1690	1590	1491	1392	1292	1193	1093	994	944	895	845	796	746	696	646	597	547	497

[1]These required CT may be assumed to achieve greater than 99.99 per cent inactivation of viruses only if chlorine is added and mixed in the water prior to the addition of ammonia. If this condition is not met, the public water system must demonstrate, based on onsite studies or other information, as approved by the director, that the public water system is achieving at least 99.99 per cent inactivation of viruses.

Figure B-1

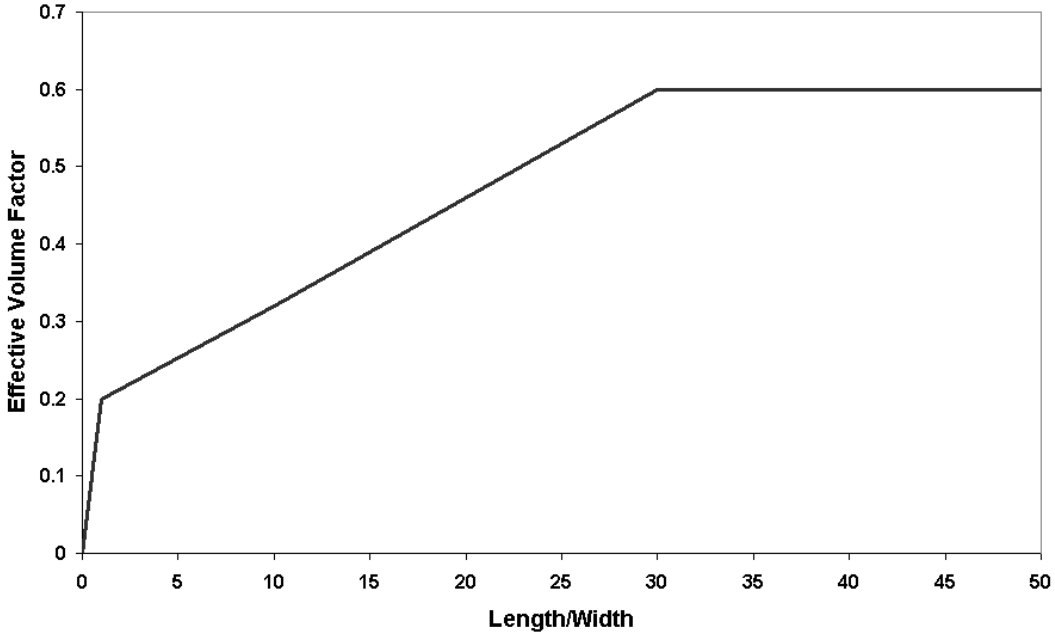
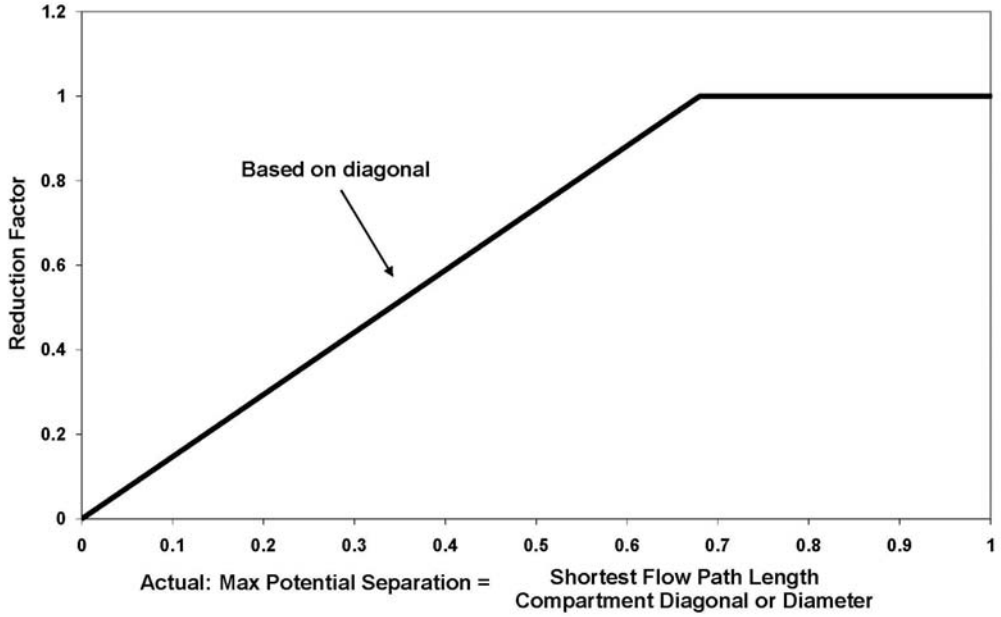


Figure B-2



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CERTIFIED ELECTRONICALLY

Certification

03/13/2020

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