Guidance Manual for Determination of Disinfectant Contact Time and CT Requirements for Public Water Systems*

Tennessee Department of Environment and Conservation
Division of Water Supply

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*Note: This manual applies only to surface water systems and ground water under the direct influence of surface waters.

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Introduction

In response to the federally promulgated Surface Water Treatment Rule, the Tennessee Division of Water Supply has adopted Regulations pertaining to filtration and disinfection of public water supplies. The applicable regulations are found in Chapter 1200-5-1-.31 FILTRATION AND DISINFECTION, as well as Chapter 1200-5-1-.17 OPERATION AND MAINTENANCE-REQUIREMENTS paragraphs (27) & (30). These regulations apply to surface water systems and ground water under the direct influence of surface water (see definitions).

This manual is written to aid public water systems in determining the level of disinfection (CT value) required, the disinfectant contact time (T) for existing facilities, whether the system is in compliance with the requirements, and what needs to be reported to the State.

Definitions

(1) Conventional Filtration - this is a treatment system which typically utilizes chemical coagulation, mixing, flocculation, clarification and filtration. Most surface water treatment plants are of this type.

(2) CT or CT calc - this is the 'product of the -measured residual disinfectant concentration (C) in milligrams per liter at the end of a disinfection sequence and the corresponding disinfectant contact time (T) in minutes of the sequence (thus CxT = CT).

(3) CT 99.9 - this is the CT value required for 99.9% (3-log) inactivation of Giardia lamblia cysts. It is the CT value that must be met or exceeded to comply with the disinfection requirements of the Regulations.

(4) CT 99.99 - this is the CT value required for 99.99% (4-log) inactivation of viruses as required by the Regulations. Viruses are inactivated more quickly by disinfection than are Giardia lamblia cysts. A system which meets the CT 99.9 requirement for Giardia will also meet the CT 99.99 requirement for viruses.

(5) Direct Filtration - this is a treatment system which applies the raw water to the filters without prior sedimentation or clarification. Direct filtration may include chemical coagulation, mix ing and flocculation.

(6) Disinfection Sequence - this is the portion of the water system between the disinfectant application point and the first customer. For systems with multiple disinfectant application points a disinfection sequence is the portion of the system between one application point and the next.

(7) Ground Water Under the Direct Influence of Surface Water - any water beneath the surface of the ground with (a) significant occurrence of insects or other macroorganisms, algae, or large diameter pathogens such as Giardia lamblia; or (b) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions. A guidance manual for determination of direct surface _ water influence is available on request.

(8) Inactivation Ratio - This is the ratio of CT calc divided by the CT required. This ratio must be equal to or greater than 1.0 to meet the disinfection requirements of the Regulations. Systems with more than one disinfectant application point will calculate the inactivation ratio for each sequence and sum them to get the total inactivation ratio.

(9) Surface Water - water which is open to the atmosphere and subject to surface runoff. This includes lakes, rivers, streams, ponds and reservoirs.

(10) T - This is the disinfectant contact time in minutes of a disinfection sequence. T may be determined by calculation or by a tracer study.

PART I - CT Requirements

All public water systems using a surface water source or ground water under the direct influence of surface water must provide treatment to achieve 99.9% (3-10g) removal and/or inactivation of Giardia lambliacysts as well as 99.99% (4-10g) removal and/or inactivation of viruses. For compliance purposes, a water system that achieves 99.9% removal and/or inactivation of Giardia lamblia cysts will also achieve the required 99.99% removal or inactivation of viruses. The CT values in the following tables are the minimum required for 99.9% removal or inactivation of Giardia lamblia cysts. To obtain the required disinfectant contact time (T) for a particular disinfectant residual concentration (C) divide the CT value by the appropriate C value.

Conventional filtration systems are credited with a 2.5 log removal of Giardia lamblia cysts and must provide an additional .5 log inactivation through disinfection (2.5 log + .5 log = 3 log or 99.9%). Direct filtration systems are credited with a 2.0 log removal of Giardia and must provide an additional 1.0 log inactivation through disinfection. Unfiltered systems must provide the full 3.0 log inactivation by disinfection. Thus, the CT requirements will be highest for unfiltered systems and lowest for conventional filtration systems.

CT requirements are dependent on the temperature and pH of the water. The lower the temperature of the water, the higher the CT requirement. The higher the pH of the water, the higher the CT requirement. The worst case (highest CT requirement) for a public water system will be the coldest water temperature and highest pH. CT requirements will vary as frequently as the temperature and pH vary. To find a specific CT requirement, choose the proper table (Unfiltered, Direct Filtration, Conventional Filtration), temperature, pH and free chlorine residual. CT values between the indicated temperature and pH values may be determined by linear interpolation * or to be conservative, use the table for the lower temperature and the higher pH. Tables 1, 2, and 3 are for free chlorine as the disinfectant while Tables 4, 5, and 6 are for alternate disinfectants (chloramines, chlorine dioxide, ozone). Ozone is the fastest disinfectant followed by chorine dioxide, free chlorine and chloramines. Systems using alternate disinfectants must still provide a minimum .2 milligrams per liter free chlorine residual in the distribution system.

*<u>Example of Linear Interpolation</u>: Find the CT requirement for an unfiltered system (Table 1) with pH = 6.8. Temperature = 10·C and a free chlorine residual of 2.0 mg/l. From Table 1 we find that the CT requirement for pH = 6.5 is 104, and for pH = 7.0 it is 124. The CT required for the intermediate pH = 6.8 is interpolated as follows

$$CT = \frac{6.8 - 6.5}{7.0 - 6.5}(124 - 104) + 104 = 116$$

Public water systems must achieve an Inactivation Ratio of 1.0 or greater for compliance with the disinfection requirements. The Inactivation Ratio is the CT value achieved divided by the CT value required.

Table 1 - Unfiltered Systems
CT99.9 values to achieve 99.9% (3-109) inactivation of
Giardia lamblia cysts by Free Chlorine*

Water Temperature (0C)	Free Chlorine Residual mq/l	pH ≤ 6.0	6.5	7.0	7.5	8.0	8.5	≤9.0
	≤ .4	137	163	195	237	277	329	390
	.6	141	168	200	239	286	342	407
	.8	145	172	205	246	295	354	422
	1.0	148	176	210	253	304	365	437
	1.2	152	180	215	259	313	376	451
	1.4	155	184	221	266	321	387	464
	1.6	157'	189	226	273	329	397	477
≤ .5⁰C	1.8	162	193'	231	279	338	407	489
	2.0	165	197	236	286	346	417	500
	2.2	169	201	242	297	353	426	511
	2.4	172	205	247	298	361	435	522
	2.6	175	209	252	304	368	444	533
	2.8	178	213	257	310	375	452	543
	≥ 3.0	181	217	261	316	382	460	552
	< .4	97	117	139	166	198	236	279
	.6	100	120	143	171	204	244	291
	.8	103	122	146	175	210	252	301
	1.0	105	125	149	179	216	260	312
	1.2	107	127	152	183	221	267	320
	1.4	109	130	155	187	227	274	329
	1.6	111	132	158	192	232	281	337
	1.8	114	135	162	196	238	287	345
5°C	2.0	116	138	165	200	243	294	353
	2.2	118	140	169	204	248	300	361
	2.4	120	143	172	209	253	306	368
	2.6	122	146	175	213	263	312	375
	2.8	124	148	178	217	263	318	382
	≥ 3.0	126	151	182	221	268	324	389
	< .4	73	88	104	125	149	177	209
	.6	75	90	107	128	153	183	218
	.8	78	92	110	131	158	189	226
	1.0	79	94	112	134	162	195	234
	1.2	80	95	114	137	166	200	240
	1.4	82	98	116	140	170	206	247
	1.6	83	99	119	144	174	211	253
10°C	1.8	86	101	122	147	179	215	259
	2.0	87	104	124	150	182	221	265
	2.2	89	105	127	153	186	225	271
	2.4	90	107	129	157	190	230	276
	2.6	92	110	131	160	194	234	281
	2.8	93	111	134	163	197	239	287
	≥ 3.0	95	113	137	166	201	243	292

Table 1 - con'd

15°C	< .4	49	59	70	83	99	118	140
	.6	50	60	72	86	102	122	146
	.8	52	61	73	88	105	126	151
	1.0	53	63	75	90	108	130	156
	1.2	54	64	76	92	111	134	160
	1.4	55	65	78	94	114	137	165
	1.6	56	66	79	96	116	141	169
	1.8	57	68	81	98	119	144	173
	2.0	58	69	83	100	122	147	177
	2.2	59	70	85	102	124	150	181
	2.4	60	72	86	105	127	153	184
	2.6	61	73	88	107	129	156	188
	2.8	62	74	89	109	132	159	191
	≥ 3.0	63	76	91	111	134	162	195
20°C	< .4	36	44	52	62	74	89	105
	.6	38	45	54	64	77	92	109
	.8	39	46	55	66	79	95	113
	1.0	39	47	56	67	81	98	117
	1.2	40	48	57	69	83	100	120
	1.4	41	49	58	70	85	103	123
	1.6	42	50	59	72	87	105	126
	1.8	43	51	61	74	89	108	129
	2.0	44	52	62	75	91	110	132
	2.2	44	53	63	77	93	113	135
	2.4	45	54	65	78	95	115	138
	2.6	46	55	66	80	97	117	141
	2.8	47	56	67	81	99	119	143
	≥ 3.0	47	57	68	83	101	122	146
≥ 25°C	< .4	24	29	35	42	50	59	70
	.6	25	30	36	43	51	61	73
	.8	26	31	37	44	53	63	75
	1.0	26	31	37	45	54	65	78
	1.2	27	32	38	46	55	67	80
	1.4	27	33	39	47	57	69	82
	1.6	28	33	40	48	58	70	84
	1.8	29	34	41	49	60	72	86
	2.0	29	35	41	50	61	74	88
	2.2	30	35	42	51	62	75	90
	2.4	30	36	43	52	63	77	92
	2.6	31	37	44	53	65	78	94
	2.8	31	37	45	54	66	80	9€
	≥ 3.0	32	38	46	55	67	81	91

*These CT values also achieve greater than 99.99% inactivation of viruses. CT values between the indicated pH and temperatures may be determined by linear interpolation or by using the lower temperature and higher pH values.

Table 2 - Direct Filtration Systems

CT Values to achieve 1.0 log inactivation of Giardia lamblia cysts by Free Chlorine* (these CT values in combination with direct filtration achieve 99.9% (3-log) inactivation of Giardia lamblia cysts).

Water Temperature °c	Free Chlorine Residual mall	pH						
		≤ 6.0	6.5	7.0	7.5	8.0	8.5	≤9.0
≤ .5°C	≤ .4	46	54	65	79	92	110	130
	.6	47	56	67	80	95	114	136
	.8	48	57	68	82	98	118	141
	1.0	49	59	70	84	101	122	146
	1.2	51:	60	72	86	104	125	150
	1.4	52	61	74	89	107	129	155
	1.6	52	63	75	91	110	132	159
	1.8	54	64	77	93	113	136	163
	2.0	55	66	79	95	115	139	167
	2.2	56	67	81	99	118	142	170
	2.4	57	68	82	99	120	145	174
	2.6	58	70	84	101	123	148	178
	2.8	59	71	86	103	125	151	181
	≥ 3.0	60	72	87	105	127	153	184
5°C	< .4	32	39	46	55	66	79	93
	.6	33	40	48	57	68	81	97
	.8	34	41	49	58	70	84	100
	1.0	35	42	50	60	72	87	104
	1.2	36	42	51	61	74	89	107
	1.4	36	43	52	62	76	91	110
	1.6	37	44	53	64	77	94	112
	1.8	38	45	54	65	79	96	115
	2.0	39	46	55	67	81	98	118
	2.2	39	47	56	68	83	100	120
	2.4	40	48	57	70	84	102	123
	2.6	41	49	58	71	86	104	125
	2.8	41	49	59	72	88	106	127
	≥ 3.0	42	50	61	74	89	108	130
10°C	.4	24	29	35	42	50	59	70
	.6	25	30	36	43	51	61	73
	.8	26	31	37	44	53	63	75
	1.0	26	31	37	45	54	65	78
	1.2·	27	32	38	46	55	67	80
	1.4	27	33	39	47	57	69	82
	1.6	28	33	40	48	58	70	84
	1.8	29	34	41	49	60	72	86
	2.0	29	35	41	50	61	74	88
	2.2	30	35	42	51	62	75	90
	2.4	30	36	43	52	63	77	92
	2.6	31	37	44	53	65	78	94
	2.8	31	37	45	54	66	80	96
	> 3.0	32	38	46	55	67	81	97

Table 2 - cont'd

	< .4	16	20	23	28	33	39	47
	.6	17	20	24	29	34	41	49
	.8	17	20	24	29	35	42	50
	1.0	18	21	25	30	36	43	52
	1.2	18	21	25	31	37	45	53
	1.4	18	22	26	31	38	46	55
15°C	1.6	19	22	26	32	39	47	56
	1.8	19	23	27	33	40	48	58
	2.0	19	23	28	33	41	49	59
	2.2	20	23	28	34	41	50	60
	2.4	20	24	29	35	42	51	61
	2.6	20	24	29	36	43	52	63
	2.8	21	25	30	36	44	53	64
	≥ 3.0	21	25	30	37	45	54	65
	< .4	12	15	17	21	25	30	35
	.6	13	15	18	21	26	31	36
	.8	13	15	18	22	26	32	38
	1.0	13	16	19	22	27	33	39
	1.2	13	16	19	23	28	33	40
	1.4	14	16	19	23	28	34	41
20°C	1.6	14	17	20	24	29	35	42
	1.8	14	17	20	25	30	36	43
	2.0	15	17	21	25	30	37	44
	2.2	15	18	21	26	31	38	45
	2.4	15	18	22	26	32	38	46
	2.6	15	18	22	27	32	39	47
	2.8	16	19	22	27	33	40	48
	> 3.0	16	19	23	28	34	41	49
	< .4	8	10	12	14	17	20	23
	.6	8	10	12	14	17	20	24
	.8	9	10	12	15	18	21	25
	1.0	9	10	12	15	18	22	26
	1.2	9	11	13	IS	18	22	27
	1.4	9	11	13	16	19	23	27
≥ 25°C	1.6	9	11	13	16	19	23	28
	1.8	10	11	14	16	20	24	29
	2.0	10	12	14	17	20	25	29
	2.2	10	12	14	17	21	25	30
	2.4	10	12	14	17	21	26	31
	2.6	10	12	15	18	22	26	31
	2.8	10	12	15	18	22	27	32
	≥ 3.0	11	13	15	18	22	27	32

* These CT values in combination with direct filtration also achieve greater than 9.99% inactivation of viruses. CT values between the indicated pH and temperature may be determined by linear interpolation or by using the lower temperature and higher pH values.

Table 3 - Conventional Filtration Systems

CT values to, achieve .5-log inactivation of Giardia lamblia cysts by Free Chlorine* (These CT values in combination with conventional filtration achieve 99.9% (3-log) inactivation of Giardia lamblia cysts.

Water Temperature °c	Free Chlorine Residual mg/l	pH						
		≤ 6.0	6.5	7.0	7.5	8.0	8.5	≤9.0
	< .4	23	27	33	40	46	55	65
	.6	24	28	33	40	48	57	68
	.8	24	29	34	41	49	59	70
	1.0	25	29	35	42	51	61	73
	1.2	25	30	36	43	52	63	75
	1.4	26'	31	37	44	54	65	77
	1.6	26	32	38	46	55	66	80
	1.8	27	32	39	47	56	68	82
≤ .5°C	2.0	28	33	39	48	58	70	83
	2.2	28	34	40	50	59	71	85
	2.4	29	34	41	50	60	73	87
	2.6	29	35	42	51	61	74	89
	2.8	30	36	43	52	63	75	91
	≥ 3.0	30	36	44	53	64	77	92
	< .4	16	20	23	28	33	39	47
	.6	17	20	24	29	34	41	49
	.8	17	20	24	29	35	42	50
	1.0	18	21	25	30	36	43	52
	1.2	18	21	25	31	37	45	53
	1.4	18	22	26	31	38	46	55
	1.6	19	22	26	32	39	47	56
	1.8	19	23	27	33	40	48	58
5°C	2.0	19	23	28	33	41	49	59
	2.2	20	23	28	34	41	50	60
	2.4	20	24	29	35	42	51	61
	2.6	20	24	29	36	43	52	63
	2.8	21	25	30	36	44	53	64
	> 3.0	21	25	30	37	45	54	65
	< .4	12	15	17	21	25	30	35
	.6	13	15	18	21	26	31	36
	.8	13	15	18	22	26	32	38
	1.0	13	16	19	22	27	33	39
	1.2	13	16	19	23	28	33	40
	1.4	14	16	19	23	28	34	41
	1.6	14	17	20	24	29	35	42
10°C	1.8	14	17	20	25	30	36	43
	2.0	15	17	21	25	30	37	44
	2.2	15	18	21	26	31	38	45
	2.4	15	18	22	26	32	38	46
	2.6	15	18	22	27	32	39	47
	2.8	16	19	22	27	33	40	48
	≥ 3.0	16	19	23	28	34	41	49

Table 3 - cont'd

	≤ .4	8	10	12	14	17	20	23
	.6	8	10	12	14	17	20	24
	.8	9	10	12	15	18	21	25
	1.0	9	11	13	15	18	22	26
	1.2	9	11	13	15	19	22	27
	1.4	9	11	13	16	19	23	28
15°C	1.6	9	11	13	16	19	24	28
	1.8	10	11	14	16	20	24	29
	2.0	10	12	14	17	20	25	30
	2.2	10	12	14	17	21	25	30
	2.4	10	12	14	18	21	26	31
	2.6	10	12	15	18	22	26	31
	2.8	10	12	15	18	22	27	32
	≥ 3.0	11	13	15	19	22	27	33
	≤ .4	6	7	9	10	12	15	18
	.6	6	8	9	11	13	15	18
	.8	7	8	9	11	13	16	19
	1.0	7	8	9	11	14	16	20
	1.2	7	8	10	12	14	17	20
	1.4	7	8	10	12	14	17	21
	1.6	7	8	10	12	15	18	21
20°C	1.8	7	9	10	12	15	18	22
	2.0	7	9	10	13	15	18	22
	2.2	7	9	11	13	16	19	23
	2.4	8	9	11	13	16	19	23
	2.6	8	9	11	13	16	20	24
	2.8	8	9	11	14	17	20	24
	≥ 3.0	8	10	11	14	17	20	24
	≤ .4	4	5	6	7	8	10	12
	.6	4	5	6	7	9	10	12
	.8	4	5	6	7	9	11	13
	1.0	4	5	6	8	9	11	13
	1.2	5	5	6	8	9	11	13
	1.4	5	6	7	8	10	12	14
≥ 25°C	1.6	5	6	7	8	10	12	14
	1.8	5	6	7	8	10	12	14
	2.0	5	6	7	8	10	12	15
	2.2	5	6	7	9	10	13	15
	2.4	5	6	7	9	11	13	15
	2.6	5	6	7	9	11	13	16
	2.8	5	6	8	9	11	13	16
	≥ 3.0	5	6	8	9	11	14	16

* These CT values *in* combination with conventional filtration also achieve greater than 99.99% inactivation of viruses. CT values between the indicated pH and temperatures may be determined by linear interpolation or by using the lower temperature and higher pH values.

TABLE 4

CT VALUES FOR

INACTIVATION OF GIARDIA CYSTS

BY CHLORAMINE pH 6-9

	Temperature (C)					
Inactivation	<1	5	10	15	20	25
0.5 log	635	365	310	250	285	125
1 log	1,270	735	615	500	370	250
1.5 log	1,900	1,100	930	750	550	375
2 log	2,535	1,470	1,230	1,000	735	500
2.5 log	3,170	1,830	1,540	1,250	915	625
3 log	3,800	2,200	1,850	1,500	1,100	750

TABLE 5

CT VALUES FOR

INACTIVATION OF GIARDIA CYSTS

BY CHLORINE DIOXIDE pH 6-9

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

TABLE 6

CT VALUES FOR

INACTIVATION OF GIARDIA CYSTS

BY OZONE pH 6-9

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

PART II - Determination of Disinfectant Contact Time

The disinfectant contact time (T) must be determined for each public water system in order to evaluate compliance with CT requirements. For a system with one disinfectant application point, T is the time in minutes that it takes water to move from the application point to the first water customer (for filtration plants the first customer is usually the plant itself). For a system with multiple disinfectant application points, T is the time in minutes that it takes water to move from one application point to the next. In the case of multiple disinfectant application points, a CT value will be calculated for each disinfection sequence (the last sequence being from the final application point to the first customer. The CT value of each sequence will be divided by the CT requirement (from Tables 1, 2, 3) for the sequence to get the Inactivation Ratio of the sequence. The Inactivation Ratio of all disinfection sequences will be summed to obtain the total Inactivation Ratio of the system' (must be greater>than or equal to 1.0 for compliance).

The value of T for a particular system can be determined by (1) calculations or (2) a tracer study. It is recommended that each public water system determine T by calculation. The calculation T can be used to estimate compliance with CT requirements. If, based on the calculated T values, there is doubt as to compliance (inactivation ratio close to or less than 1.0), a tracer study can be conducted to determine compliance. The Division of Water Supply may require a tracer study if there is doubt that CT requirements are being met by the public water system. The two methods of determining Tare discussed below (examples included).

A. Calculating T -

In calculating disinfectant contact time (T), the public water system shall use the peak flow rate or full capacity of the system. This rate should be expressed in gallons per minute (gpm). The CT requirement for each system must be based on worst case conditions (highest pH, lowest water temperature, and lowest disinfectant residual) • If the system meets or exceeds the CT requirement (achieves an Inactivation Ratio greater than 1.0) for worst case conditions, it is assumed that the system will be capable of compliance with CT requirements for all operating conditions.

1. Pipe Flow - T in pipe flow can be calculated on a "plug flow" basis. T is equal to the internal volume (V) of the pipe in gallons divided by the peak flow (Q) through the pipe in gpm.

$$V = \frac{\pi \left(\frac{d}{12}\right)^2}{4} L\ (7.48)$$

Where V is the volume in gallons, d is the internal pipe diameter in inches, L is the length of pipe in feet. After V is calculated, find T as follows:

$$T = \frac{V}{Q}$$

Example Problem 1: An unfiltered spring source is pumped at a peak rate of 100 gpm: The water is pumped through 1800 feet of 8-inch water line before reaching the first customers tap. Chlorine is fed at the pump discharge and the free chlorine residual at the first customers tap is maintained at 1.4 mg/l. The pH is 7.0 and water temperature is a constant 15^{0}C. Find the contact time (T) and the Inactivation Ratio. Is this system in compliance with $CT_{99.9}$ requirements?

Solution: Calculate the pipe volume in gallons.

$$V = \frac{\pi \left(\frac{8}{12}\right)^2}{4} (1800)\ (7.48) = 4700 \text{ gallons}$$

Calculate $T = \frac{V}{Q} = \frac{4700 \text{ gal.}}{100 \text{ gpm}} = 47$ minutes

Calculate CT = (1.4) (47) = 65.8

Find CT $_{99.9}$ requirement from Table 1 - unfiltered systems (pH = 7.0, temp. = 15°C, residual = 1.4)

$CT_{99.9} = 78$

Find Inactivation Ratio

Inactivation Ratio $= \frac{\text{CT calc}}{CT_{99.9}} = \frac{65.8}{78} = .84$

The Inactivation Ratio is less than 1.0, therefore, the system is not in compliance. If the system increases the chlorine residual to 2.0 mg/l then CT calc = (2.0) (47) = 94.

From Table 1 (pH = 7.0, temp. = 15°C, residual = 2.0)

$CT_{99.9} = 83$

Inactivation Ratio $= \frac{\text{CT calc}}{CT_{99.9}} = \frac{94}{83} = 1.13$

Increasing the chlorine residual to 2.0 has increased the inactivation ratio to 1.13 and the system is in compliance.

2. Basins, Tanks, Clearwells - The disinfectant contact time (T) in basins, tanks and clearwel1s may not be calculated as "plug flow" by dividing total volume by peak flow rate. No basin achieves 100% effective contact time. The effective contact time depends on flow distribution, flow velocities and baffling conditions. The actual volume of the basin should be based on lowest typical operating water level, not the overflow level of the basin. Sedimentation basin volume

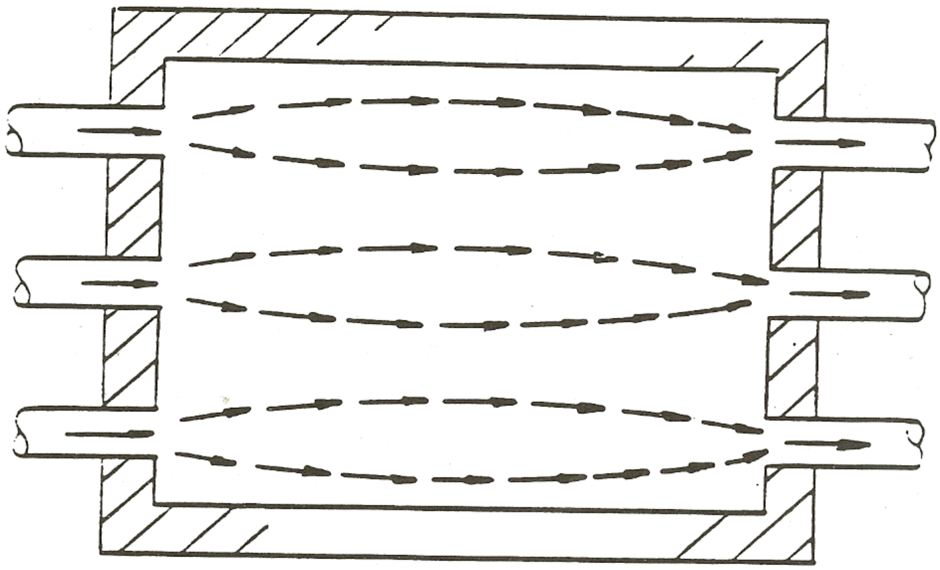
should account for sludge in the basin by subtracting the sludge volume. Distribution storage tanks are generally not constructed (piping etc.) to provide contact time. Contact time may only be counted up to the first customer. For most filter plants, the first .customer is the plant itself, therefore no distribution lines or tanks may be included to meet CT requirements. Effective volume in tanks and basins will generally vary between 30% and 70% of the total volume of water in the basin. Some basins (clearwells for example) may be as low as 10% due to turbulence, lack of baffles and location of high service pump intakes. The following table should be used as guidance for determining effective volume of basins. Diagrams are included as examples.

Table 7

Baffling Condition	Effective Volume / Actual Volume	Description
None	.10	turbulent basin, low length to width ratio, high inlet and outlet velocities, no baffling
Poor	.30	unbaffled inlet or outlet, poor flow distribution, no intermediate baffles
Average	.50	baffled inlet and outlet with no intermediate baffles, baffled inlet or outlet with some intermediate baffles
Superior	.70	Superior inlet and outlet flow distribution such as perforated baffles and long weirs, intermediate baffles and/or serpentine flow pattern included.

In choosing the proper baffling condition, be conservative (use the lower number) if you are unsure which category best fits the basin in question. Intermediate values (.2, .4, .6) may be used if conditions appear to be characterized by two categories (i.e. poor to average use .4). Filters may be counted as a basin with superior baffling (.7). The volume of media, gravel and underdrains must be subtracted from the volume of the~ filter bay or-vessel.

Example Problem 2: A conventional surface water filtration plant has a capacity of 2.0 million gallons per day (MGD). Filtered water enters a square, unbaffled 250,000 gallon clearwell at high velocity through a single filter effluent line. Chlorine is injected in the filter effluent line and maintained at 2.0 mg/l residual through the clearwell. Temperature of the water is 10^{0}C and pH is 7.5. Water leaves the clearwe1l through a single high service pump suction line. The water level in the clearwell drops no lower than 80% full.



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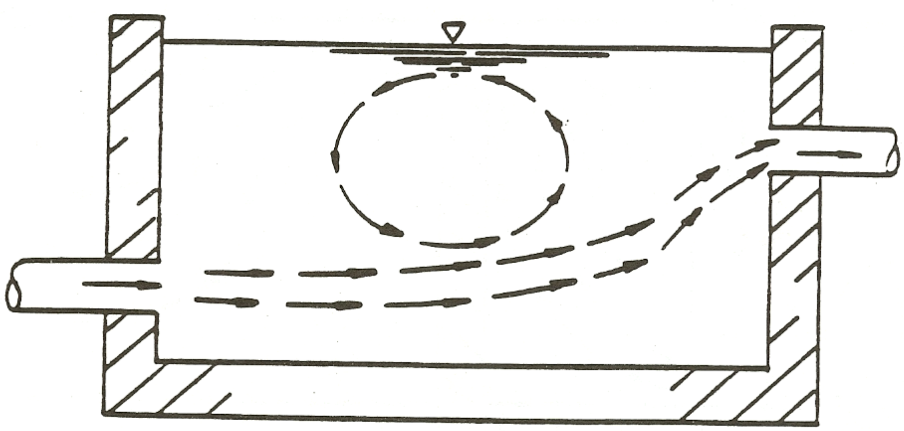
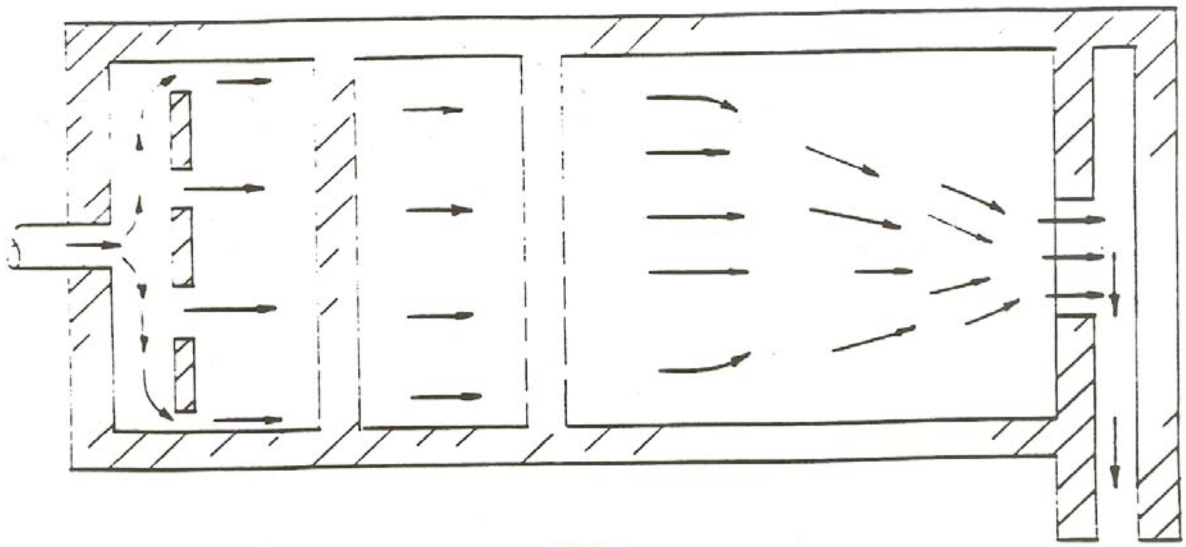


SECTION

FIGURE C-5 POOR BAFFLING CONDITIONS --
RECTANGULAR CONTACT BASIN



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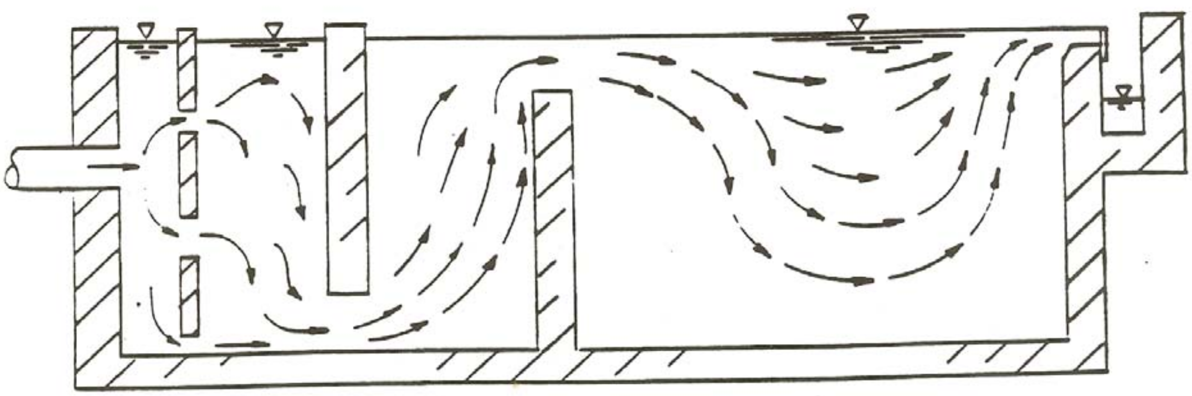
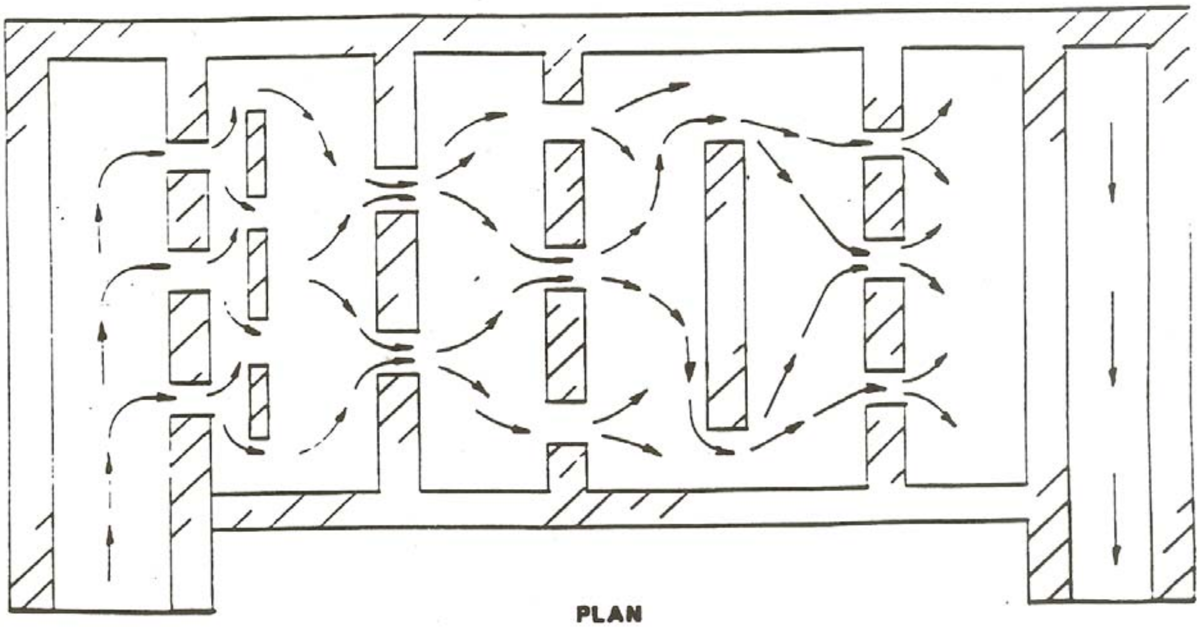


SECTION

FIGURE C-6 AVERAGE BAFFLING CONDITIONS -- RECTANGULAR CONTACT BASIN



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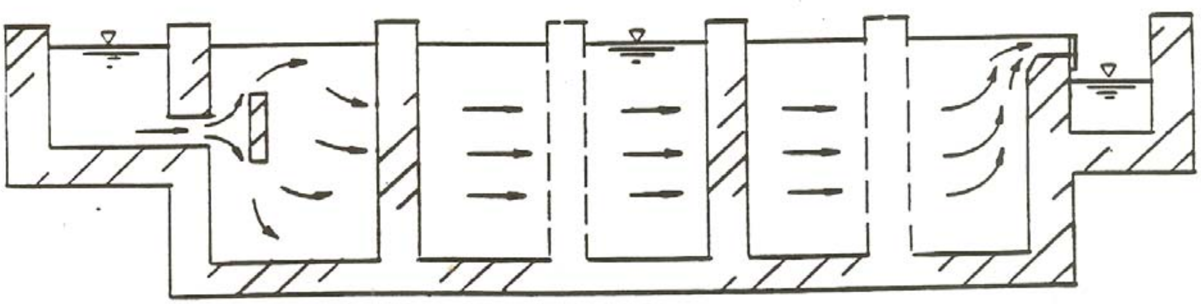
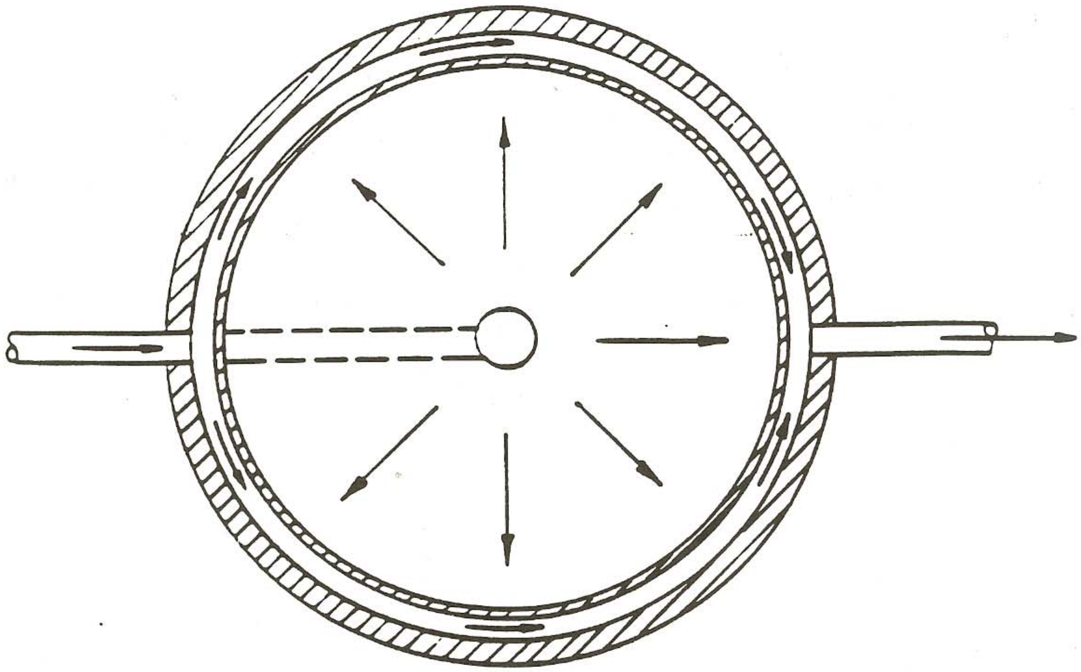


SECTION

FIGURE C-7 SUPERIOR BAFFLING CONDITIONS -- RECTANGULAR CONTACT BASIN



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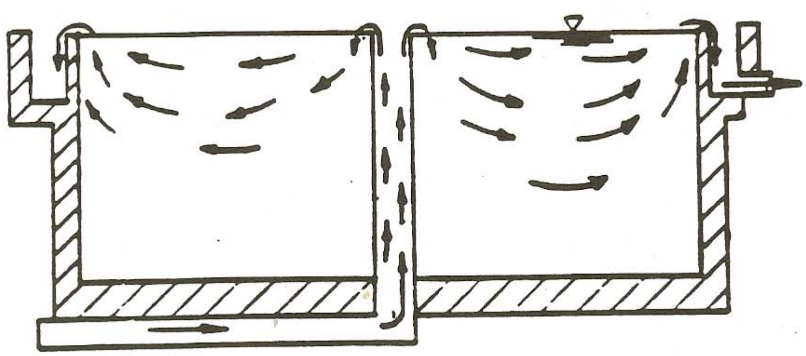
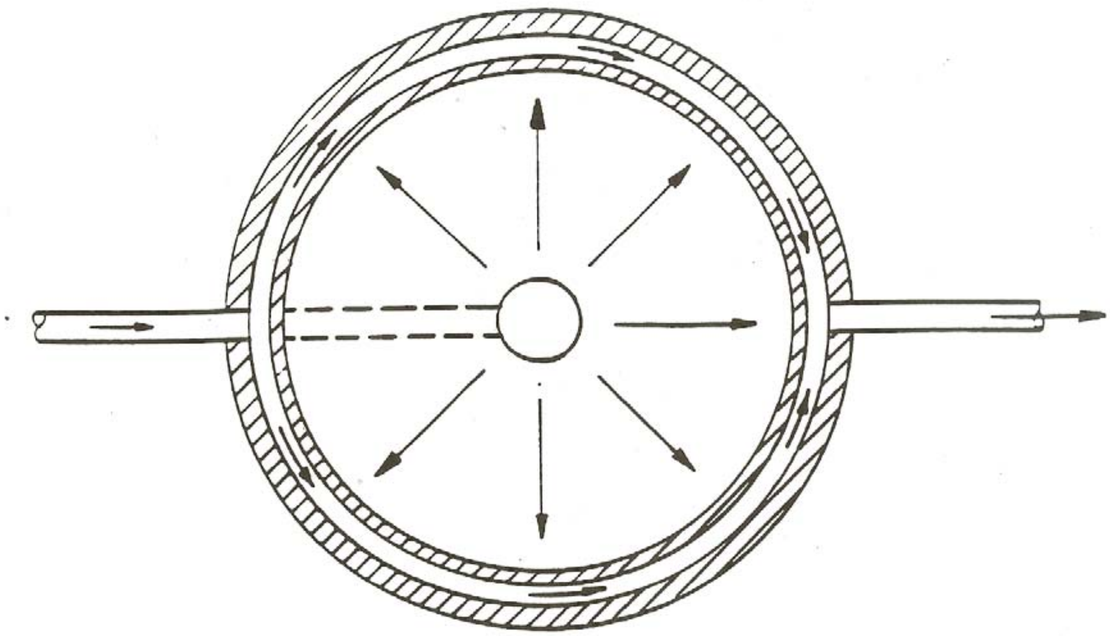


SECTION

FIGURE C-8 POOR BAFFLING CONDITIONS --
CIRCULAR CONTACT BASIN



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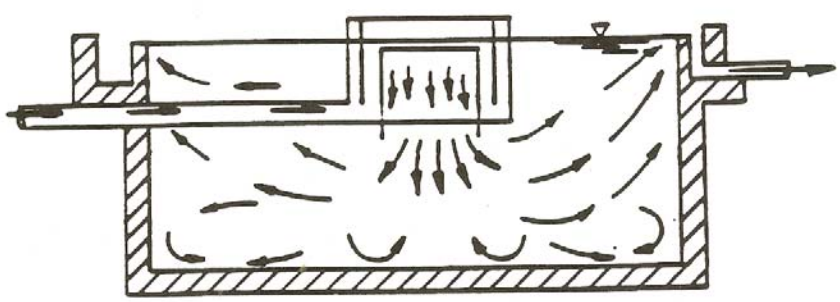
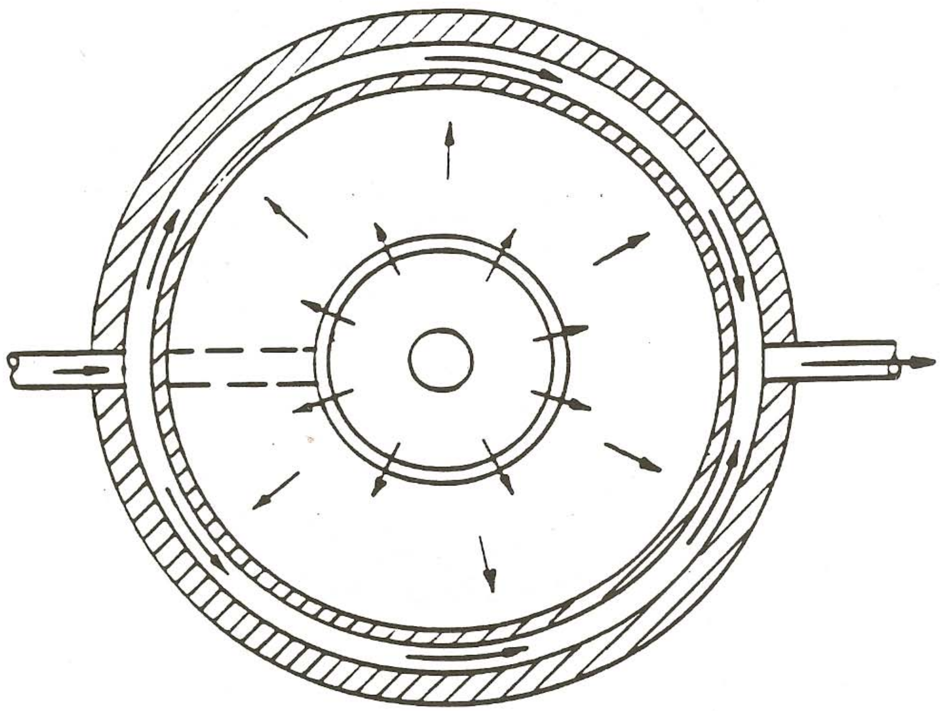


SECTION

FIGURE C-9 AVERAGE BAFFLING CONDITIONS - - CIRCULAR CONTACT BASIN



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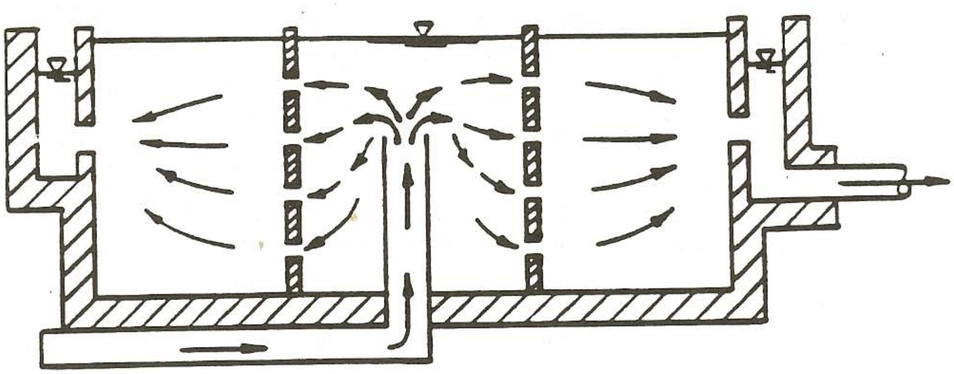


SECTION

FIGURE C-10 SUPERIOR BAFFLING CONDITIONS - -
CIRCULAR CONTACT BASIN

Find the effective contact time in the clearwell, the CT value achieved, the CT requirement for the clearwell, and the Inactivation ratio. Is this clearwell meeting the disinfection requirement for the water plant?

Solution: Convert the plant flow rate to gpm

$$Q = \frac{2{,}000{,}000 \text{ gal/day}}{1440 \text{ min/day}} = 1389 \text{ gpm}$$

Find the effective volume of the clearwell.

Volume at low water level = (.80) (250,000)   200,000 gallons

From Table 7 use .10 for turbulent basin with high velocities and no baffles

Veff = (.10) (200,000 gal.) = 20,000 gal.

Find the effective contact time

$$T = \frac{\text{Veff}}{Q} \quad \frac{20{,}000 \text{ gal.}}{1389 \text{ gpm}} = 14.4 \text{ minutes}$$

CT calc   (2.0 mg/l) (14.4 min.) = 28.8

From Table 3 for conventional filtration, the required CT = 25

$$\text{Inactivation Ratio} - \frac{\text{CT calc}}{\text{CT required}} = \frac{28.8}{25} = 1.15$$

Despite the short circuiting, this clearwell meets the CT requirement for the plant because conventional filtration is credited with a 2.5 log removal of Giardia. Pre-chlorination was not included in this example but would also count toward meeting the required CT values and Inactivation Ratio for the plant.

3. <u>Multiple Disinfectant Application Points</u> -

Systems which have multiple disinfection point s will calculate the CT value of each sequence (from one disinfection point to the next). Find the CT required (from tables 1, 2, 3) for each sequence and calculate the Inactivation Ratio (CT achieved divided by CT required) for each sequence. The final sequence is from the 1 a st disinfectant application point to the first customer. The total Inactivation Ratio is the sum of the Inactivation Ratios of each sequence. Temperature , pH and disinfect residual values must be measured at the end of each sequence. Remember to use the lowest temperature, highest pH and lowest disinfectant residual.

Example Problem 3: Water is pumped from a spring at a rate of 500 gpm. The water travels through 1000 feet of 12-inch raw water line to a treatment facility which injects a coagulant aid and applies the raw water directly to a filter. Chlorine is injected at the source to produce a minimum residual of .8 mg/l entering he filter. The filter effluent enters a 40,000 gallon clearwell with "poor" baffling conditions. Water is pumped out of the clearwell at the same 500 gpm rate. Raw water temperature is 10°C and pH is 6.5. Chlorine is injected in the filter effluent to boost the residual to 1.8 mg/l in the clearwell and the pH is adjusted up to 7.5 in the clearwell. Find the CT values and CT requirements for each disinfection sequence. What is the Inactivation ratio of each sequence and the Total Inactivation Ratio. Is this system in compliance?

Solution: This system has two disinfectant application points (at the source and the filter effluent) and therefore, has two disinfection sequences to consider. Also the pH and disinfectant residual have been altered in the system. The first sequence is from the source to the f il ter plant. To find T for the first sequence, find volume of pipe (1000 feet of 12-inch line)

$$V = \frac{\pi \left(\frac{12}{12}\right)^2}{4} (1000)\ (7.48) = 5875 \text{ gallons}$$

$$T = \frac{V}{Q} = \frac{5875 \text{ gal.}}{500 \text{ gpm}} = 11.7 \text{ minutes}$$

Then find CT calc = (.8) (11.7) = 9.4

Find CT required from Table 2 (Direct Filtration)
For temp. = 10°C, pH = 6.5 and residual = .8
CT required = 31

The Inactivation Ratio for the first Sequence is

$$\frac{\text{CT calc}}{\text{CT required}} = \frac{9.4}{31} = .3$$

For the second disinfection sequence (clearwell) the effective volume is

V_{eff} = (.30) (40,000 gal.) = 12,000 gal.

$$T = \frac{V_{eff}}{Q} = \frac{12{,}000 \text{ gal}}{500 \text{ gpm}} = 24 \text{ minutes}$$

CT calc = (1.8 mg/l) (24 min.) = 43.2
From Table 2 for temp: = 10°C, pH = 7.5
residual = 1.8, CT required = 49

The Inactivation Ratio for the second sequence

$$= \frac{43.2}{49} = .88$$

The Total Inactivation Ration = .3 + .88 = 1.18

The Total Inactivation Ratio is greater than 1.0 and the system is in compliance.

Note: the volume of the filter was not given in this problem but filter vessels can be counted as contact basins with "superior" (.7-) baffling." Volume of media, Gravel, underdrains etc., must subtracted from the filter volume.

B. Tracer Studies

A public water system may conduct a tracer study to determine disinfectant contact time (T). A tracer study is conducted by adding a known dose of tracer chemical to the flow stream and tracing the time and concentration of the chemical at various points. The Division of Water Supply may require a tracer study if previously discussed calculation methods are inconclusive or if there is a doubt that CT requirements are being met by the public water system. The tracer study should be conducted during peak flow rate conditions and must be conducted during at least 90% of peak flow conditions. A system may wish to conduct several tracers at varying flow rates to establish T over a range of flow conditions. However, only one tracer is required if it is conducted at 90% or greater of the peak flow rate. Once T is determined at a specific flow rate, T for other flow rates can be estimated as follows:

$$T_X = T_T \frac{Q_T}{Q_X} \quad \text{where}$$

Tx = Contact time at any assumed flow rate
T_T = Contact time determined in tracer study
Q_T = flow rate during tracer study
Qx = any assumed flow rate

Systems which have parallel treatment schemes which are identical, may conduct a tracer study on one section and assume the same" results from other identical sections. Likewise, systems with identical units in series may conduct a tracer study on one unit and assume the same results for the identical units.

The disinfectant contact time (T) in a tracer study is defined as the contact time at which 90% of the water passing through the unit is retained in the unit. The tracer study can be done with one trace across the entire system (from the first disinfectant application point to the first customer) or by tracing each disinfection sequence individually. The tracer chemical· must be added at a constant dosage at poiI!ts corresponding to the disinfectant application points for the particular system. This may require some temporary chemical feed set-ups. The contact times derived from the tracer studies are then used in determining CT values and inactivation ratios for compliance with disinfection requirements.

1. Tracer Chemicals - Chloride and fluoride are the most commonly used :tracer chemicals in public water supplies. Consult with the Division of Water Supply before using any other tracer chemicals. ' Fluoride should be fed to produce a 1 to 2 milligram per liter (mg/1) dosage in the tracer study and chloride to produce a 10 to 20 mgll dosage. The Secondary Maximum contaminant Level (MCL) is 2 mg *11* for fluoride and 250 mg/l for chloride. The chemicals must be fed at a constant- rate to produce-the desired dosage and must be fed at the same point as the disinfectant. If one tracer across the entire system is conducted, the tracer chemical is fed at the first disinfection point and concentrations of the tracer are measured at each subsequent disinfection point and at the first customer. Tracer concentration levels are measured and recorded at each point at set time intervals (every 3 minutes for example). If separate tracer studies are to be conducted for each disinfection sequence, start with the last disinfection sequence. This will prevent residual tracer chemicals from interfering with subsequent tracers. The contact time (T) for a tracer study is the time that it takes to detect a concentration of the tracer chemical which is 10% of the dosage added. Remember, -the contact time is the time at which 90% of the water passing through the unit is retained in the unit. By determining when 10% of the dosage has been achieved, we are approximating when 10% of the water has passed through the unit.

   Background levels of the tracer must be determined before the test and taken into account. For instance, a tracer dosage of 1.5 mg/l is added to water with a background fluoride level of .1 mg/l producing a fluoride concentration of 1.6 mg/l. The detention time is determined when 10% of the added dosage is detected. In this case:

   (.10) (1.5 mg/l) + .1 background = .25 mg/l

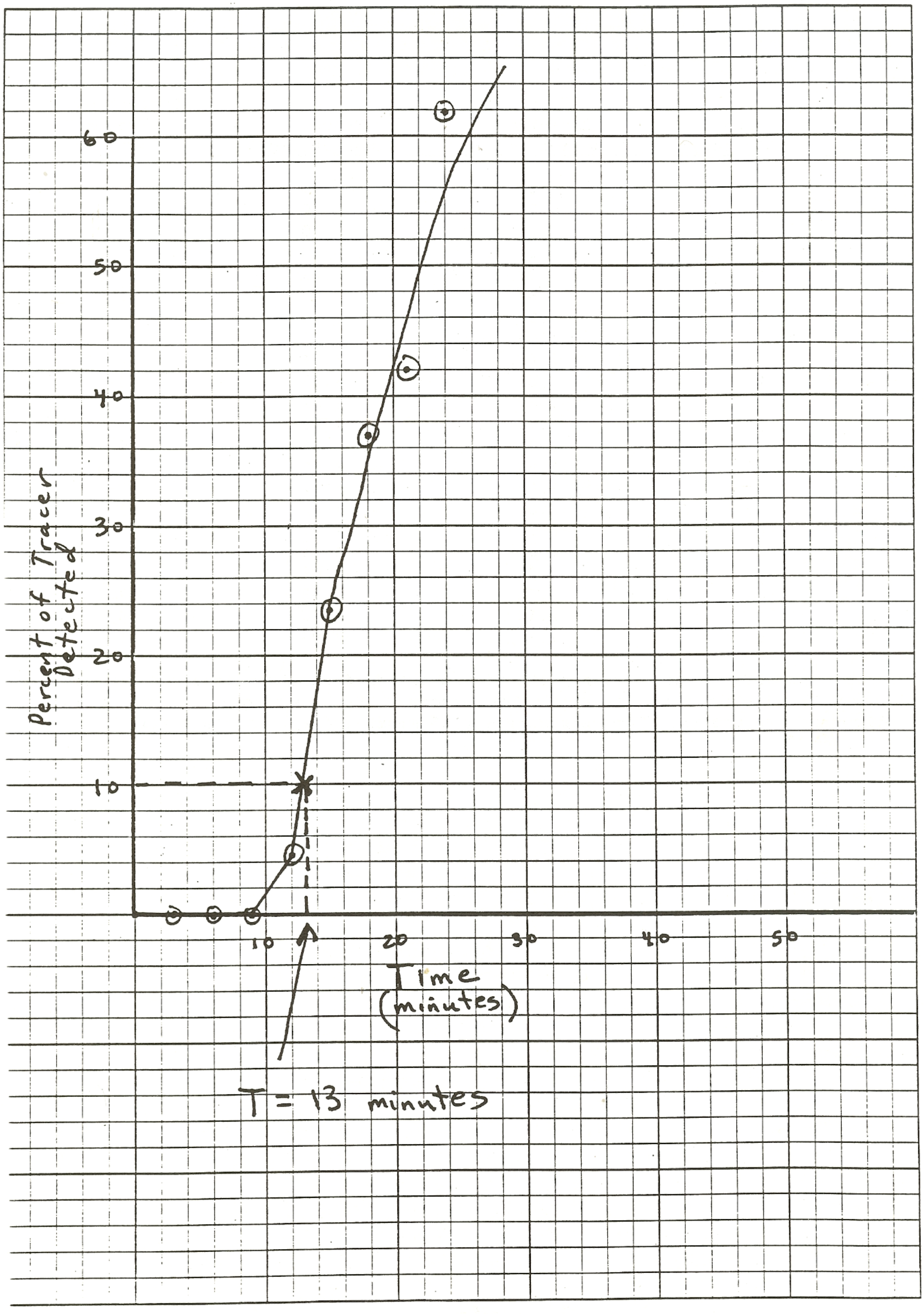
   The time at which .25 mg/l fluoride is measured is the detention time.

   Tracers conducted in treatment processes (sedimentation basins, solids contact clarifiers, filters etc.) may result in the removal of a portion of the tracer chemical. To account for this, the tracer study must be continued until the tracer concentration reaches a steady state level. For example, a 2.0 mg/l fluoride tracer dose is added prior to a sedimentation basin. The fluoride level leaving the basin reaches 1.6 mg/l and stays at that concentration (.4 mg/l of your tracer dose has been removed in the basin). The dosage added would be 1.6 mg/l in this case and 10% of the dosage added would be .16 mg/l for determination of contact time.

2. Example Tracer Study - A 2.0 mg/l fluoride dose is added to the influent of a clearwell. The water has a background fluoride level of .2 mg/l. Fluoride levels in the effleunt are measured every 3 minutes with the results tabulated below. What is the contact time in this clearwell?

Time (minutes)	Effluent Fluoride (mg/l)	Tracer Fluoride (mg/l)	Percent of Tracer Detected
0	.2	0	0
3	.2	0	0
6	.2	0	0
9	.2	0	0
12	.29	.09	4.5
15	.67	.47	23.5
18	.94	.74	37
21	1.04	.84	42
24	1.44	1.24	62
27	1. 55	1. 35	67.5
30	1. 52	1. 32	66
33	1. 73	1. 53	76.5
36	1.93	1. 73	86.5
39	1.85	1.65	82.5
42	1. 92	1.72	86
45	2.02	1.82	91
48	1.97	1. 77	88.5
51	1.84	1.64	82
54	2.06	1.86	93
57	2.05	1.85	92.5
60	2.10	1.90	95
63	2.14	1.94	97

From the results we can see that 10% of the tracer dosage was detected between 12 and 15 minutes after starting the tracer. By plotting the results as follows we can see that T = approximately 13 minutes for this clearwell.


60
50
40
30
20
10
Percent of Tracer Detected
10
20
30
40
50
Time (minutes)
T = 13 minutes

After the appropriate T value(s) have been determined by the tracer study, the CT values can be calculated by knowing the disinfectant residual (C) at the end of each disinfection sequence. These calculated CT values are compared to the CT requirements from tables 1, 2, & 3 to determine inactivation ratios and compliance.

PART IV - Reporting Requirements

The reporting requirements will vary according to whether the system is filtered or unfiltered. Requirement 'for each type of system are described below. The following describes reporting requirements for CT compliance only. Complete reporting requirements for chlorine residual, turbidity, coliform, and Well Head Protection are found in Regulation 1200-5-1-.31 paragraph (6).

A. Filtered Systems (Conventional or Direct Filtration) - Systems that filter will be required to demonstrate by calculation or tracer study that a 99.9% (3 log) removal and inactivation of Giardia lamblia cysts is achieved prior to the first customer. This demonstration must assume peak flow rates (full plant capacity) if calculations are used. Tracer studies should also be conducted at peak flow rates. CT requirements for filtering systems should be based on "worst case conditions" (lowest water temperature, highest pH and lowest disinfectant residual). If the demonstration shows that an inactivation ratio of 1.0 or greater is achieved at the peak flow and "worst case conditions," then it is assumed the system is in compliance for all other operating conditions. The system shall submit results of the calculations or tracer study for the Divisions review.

Further demonstrations of compliance will only be necessary if the system modifies or expands its facilities, increasing the peak flow rate, changes disinfectants, 'or modifies the disinfection process so as to decrease the contact times or residuals concentrations. Addition of new sources will also necessitate a demonstration of compliance.

B. Unfiltered Systems - Unfiltered systems must monitor and report compliance with CT requirements on a daily basis. The disinfectant residual (C), contact time (T), pH, and water temperature must be recorded daily for each disinfection sequence. The $CTcalc_c$ and CT99.9 of each disinfection sequence must be recorded daily as well **as** the total Inactivation Ratio. All of the above information is to be recorded daily and submitted to the State within 10 days after the end of each month.

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