US Surface Water Treatment Rules (SWTR) for Drinking Water

Spartan Environmental Technologies, LLC

SAFE DRINKING WATER ACT (SDWA) 1974

- Authorizes EPA to set national standards
- Initially regulated quality at the tap
- 1996 amendment expanded to
  - source water
  - operator training
  - funding for improvements
  - public information

SURFACE WATER TREATMENT RULE (SWTR) -1989

- Protect against Giardia lamblia, virus, Legionella
- Inactivate 99.9% of Giardia and 99.99% of Virus
- Maintain disinfection residuals
- Filtration required unless avoidance criteria met
- Turbidity limits of 5 and 0.5 (95%) NTU
- Watershed control programs
- Water quality requirements unfiltered systems

STAGE 1 DISINFECTANTS & DISINFECTION BYPRODUCTS RULE (DBPR) - 1998

- Interrelate microbial pathogens & DBP
  - M-DBP - microbial/disinfection byproducts rules
- Enforce concurrent with IESWTR (next slide)
- Systems serving 10,000 or more
  - Surface water - comply by January 2002
  - All other sources - comply by January 2004
- Maximum contaminant levels - MCL
  - total trihalomethanes, haloacetic acids, bromate & chlorite
- Maximum residual disinfectant residuals - MRDL
  - chlorine, chloramines, chlorine dioxide

INTERIM ENHANCED SURFACE WATER TRATMENT RULE - (IESWTR) - 1998

- At least 10,000 people, surface water
- Remove 99% of Cryptosporidium
- 1 NTU Turbidity max, 0.3 NTU (95%)
- Continuous monitoring of Turbidity
- Benchmark microbial protection before meeting Stage 1 DBPR
- Comply by January 2002

LONG TERM 1 ENHANCED SURFACE WATER TREATMENT RULE (LT1ESWTR) - 2002

- Extended IESWTR to <10,000 people
- Enforcement beginning 2002

STAGE 2 DISINFECTANT AND DISINFECTION BYPRODUCT RULE (Stage 2 DBPR) -

- Phased along with LT2ESWTR
- Change monitoring to reduce DBP peaks
  - Location Running Annual Average LRAA instead of system-wide RAA
- Initial Distribution System Evaluation (IDSE)
  - Identify high TTHM and HAA5 monitoring locations
  - Standard Monitoring (SMP) or System-specific (SSS)
- Two phases - 2A and 2B

STAGE 2 DISINFECTANT AND DISINFECTION BYPRODUCT RULE (Stage 2 DBPR) - Cont'd

- Stage 2A
  - TTHM/HAA5 MCLs of 120/100 micrograms/L
    - LRAA at each Stage 1 DBPR monitoring site
    - Continue to comply with 80/60 micrograms/L at RAAs
- Stage 2B
  - TTHM/HAA5 MCLs of 80/60 micrograms/L
  - Locations identified under IDSE
- Significant Excursion Evaluation

LONG TERM 2 ENHANCED SURFACE WATER TREATMENT RULE (LT2ESWTR) - Proposed Draft 2003

- Requirements based on Cryptosporidium (or E-coli) occurrence in source water
- Systems classified into four bins that indicate treatment requirements
- Select from a “toolbox” of options
- Details in “Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual”

LONG TERM 2 ENHANCED SURFACE WATER TREATMENT RULE (LT2ESWTR) - Cont'd

If your *Cryptosporidium* concentration (oocysts/L) is...	Your bin classification is...	And if you use the following filtration treatment in full compliance with existing regulations, then your *additional* treatment requirements are...			
		Conventional Filtration Treatment (includes softening)	Direct Filtration	Slow Sand or Diatomaceous Earth Filtration	Alternative Filtration Technologies
< 0.075	1	No additional treatment	No additional treatment	No additional treatment	No additional treatment
≥ 0.075 and < 1.0	2	1 log treatment[2]	1.5 log treatment[2]	1 log treatment[2]	As determined by the State[2,4]
≥ 1.0 and < 3.0	3	2 log treatment[3]	2.5 log treatment[3]	2 log treatment[3]	As determined by the State[3,5]
≥ 3.0	4	2.5 log treatment[3]	3 log treatment[3]	2.5 log treatment[3]	As determined by the State[3,6]

[1] (40 CFR 141.709 and 40 CFR 141.720)

[2] Systems may use any technology or combination of technologies from the microbial toolbox.

[3] Systems must achieve at least 1 log of the required treatment using ozone, chlorine dioxide, UV, membranes, bag/cartridge filters, or bank filtration.

[4] Total *Cryptosporidium* treatment must be at least 4.0 log.

[5] Total *Cryptosporidium* treatment must be at least 5.0 log.

[6] Total *Cryptosporidium* treatment must be at least 5.5 log.

LONG TERM 2 ENHANCED SURFACE WATER TREATMENT RULE (LT2ESWTR) - Cont'd

- SWTR use concentration and time (CT) methods to predict inactivation efficiencies
- Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources
  - App. O Guidelines to Evaluate Ozone Disinfection
- Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual
  - App. B Ozone CT Methods

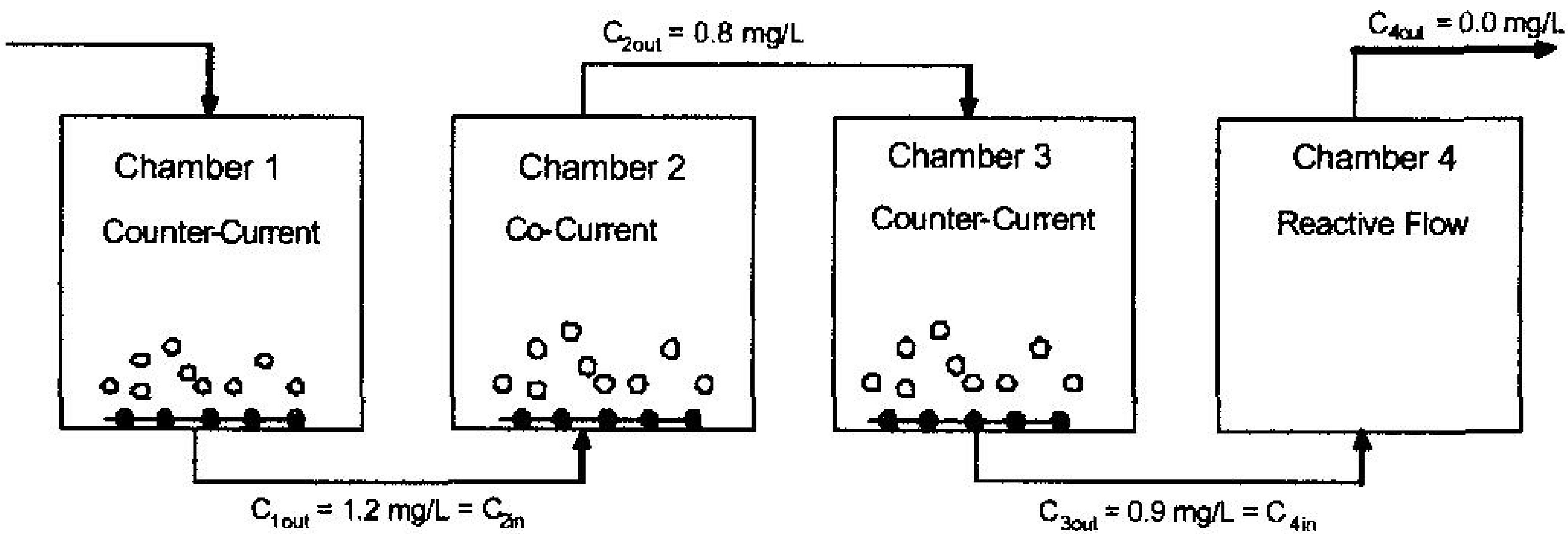
CT Methods for Log Inactivation

- T_{10} - Calculates CT assuming plug flow with tracer study
  - T_{10} time for 90% of water to pass through the contactor
  - T_{10} often less than 65% of Hydraulic Detention Time (HDT)
- CSTR - Calculates log inactivation using HDT
  - for significant back mixing or no tracer studies
- Extended CSTR - Calculates log inactivation using HDT
  - incorporates ozone decay rate
  - not applicable to chambers where ozone introduced
- Under Consideration
  - SFA (Segmented Flow Analysis), Log Integration and Geometric Mean

Example Calculation for the T_{10} Method

- Calculate Log Inactivation Credit for Cryptosporidium for the following System:
  - Four chamber contactor with ozone injection in chamber 1, 2 & 3.
  - Chambers each have a volume of 1,000 gals.
  - Chambers 1 & 3 have counter-current flow while Chamber 2 has co-current flow. Chamber 4 has reactive flow.
- Example taken from Chapter 11 LT2ESWTR Toolbox

T10 EXAMPLE - BLOCK DIAGRAM



Example Calculation for the T_{10} Method

- System Description Continued:
  - Water temperature is 5 degrees C
  - T_{10} for all chambers based on tracer study was 24 minutes
  - Ozone residual from Chamber 1 = 1.2 mg/l
  - Ozone residual from Chamber 2 = 0.8 mg/l
  - Ozone residual from Chamber 3 = 0.9 mg/l
  - Ozone residual from Chamber 4 = 0.0 mg/l

Example Calculation for the T_{10} Method

- Step 1 is to determine concentration in each chamber – USEPA does not recommend credit for chamber 1 therefore:
  - Chamber 2 $C = (C_{in} + C_{out})/2 = (1.2 + 0.8)/2 = 1$ mg/l
  - Chamber 3 $C = C_{out}/2 = 0.9/2 = 0.45$ mg/l
  - Chamber 4 $C = C_{out} = 0.0$ mg/l

Example Calculation for the T_{10} Method

- Step 2 is to Calculate T for each Chamber by dividing T_{10} proportionally among the four chambers.
  - T_{10} for each Chamber = $T_{10}(V_{1-4}/V_T)$
  - T_{10} for each Chamber = 24 minutes (1000 gal/4000 gals) = 6 minutes

Example Calculation for the T_{10} Method

- Step 3 is to Calculate CT for Each Chamber
  - Chamber 1 (not calculated)
  - Chamber 2 CT = 1 mg/l * 6 min = 6 mg-min/l
  - Chamber 3 CT = 0.45mg/l * 6 min = 2.7 mg-min/l
  - Chamber 4 CT = 0.0 mg/l * 6 min = 0.0 mg-min/l

Example Calculation for the T_{10} Method

- Step 4 Identify the CT_{table} for the log inactivation credit desired for each chamber. Calculate the ratio of CT_{calc} to CT_{table}, and sum the ratios to get a total log inactivation ratio.

	CT Calculated	CT for 0.5 Log Inactivation	Ratio of CT Calc/CT Table
Chamber 2	6 mg-min/l	7.9	0.76
Chamber 3	2.7 mg-min/l	7.9	0.34
Chamber 4	0.0 mg-min/l	7.9	0.00
		Total Ratio	1.10

CT TABLE

Table 11.1 CT Values for *Cryptosporidium* Inactivation by Ozone (40 CFR 141.730)

Log credit	Water Temperature, °C[1]									
	<=0.5	1	2	3	5	7	10	15	20	25
0.5	12	12	10	9.5	7.9	6.5	4.9	3.1	2.0	1.2
1.0	24	23	21	19	16	13	9.9	6.2	3.9	2.5
1.5	36	35	31	29	24	20	15	9.3	5.9	3.7
2.0	48	46	42	38	32	26	20	12	7.8	4.9
2.5	60	58	52	48	40	33	25	16	9.8	6.2
3.0	72	69	63	57	47	39	30	19	12	7.4

[1]CT values between the indicated temperatures may be determined by interpolation.

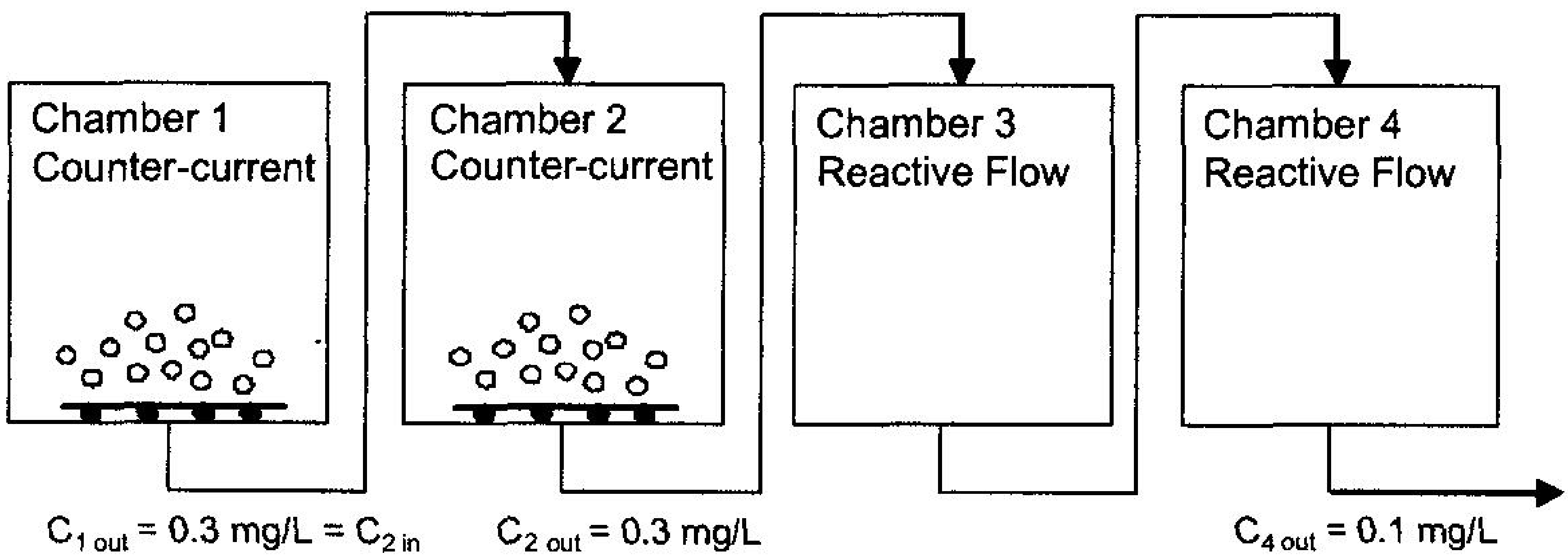
Example Calculation for the T_{10} Method

- Step 5 Determine if Ratio of CT Calculated to CT Table is Equal to One or Greater
  - The CT ratio = 1.1
  - Therefore the process receives a 0.5 log credit for inactivation of Cryptosporidium.

Example Calculation for CSTR Method

- Calculate Log Inactivation Credit for Cryptosporidium for the following System:
  - Four chamber contactor with ozone injection in chamber 1 & 2. Chambers each have a volume of 1,000 gals.
  - Chambers 1 & 2 have counter current flow while Chambers 3 & 4 have reactive flow.
- Example taken from Chapter 11 LT2ESWTR Toolbox

CSTR EXAMPLE - BLOCK DIAGRAM



Example Calculation for CSTR Method

- System Description Continued:
  - Water temperature is 10 degrees C
  - HDT (Hydraulic Detention Time) for all chambers is 20 minutes
  - Ozone residual from Chamber 1 = 0.3 mg/l
  - Ozone residual from Chamber 2 = 0.3 mg/l

Example Calculation for CSTR Method

- System Description Continued:
  - Ozone residual from Chamber 3 not measured, but assumed to equal measured value from Chamber 4
  - Ozone residual from Chamber 4 = 0.1 mg/l

Example Calculation for CSTR Method

- Step 1 Determine C Values for Each Chamber:
  - Chamber 1 No inactivation credit recommended
  - Chamber 2 $C = C2_{out}/2 = 0.3 / 2 = 0.15$ mg/L
  - Chamber 3 $C = C_{out} = 0.1$ mg/L
  - Chamber 4 $C = C4_{out} = 0.1$ mg/L

Example Calculation for CSTR Method

- Step 2 Calculate the Log Inactivation for each Chamber
  - Inactivation credit = Log (1 + 2.303k_{10} x C x HDT)
  - $k_{10} = 0.0397 \times (1.09757)^T$ based on tabular data from US EPA. K_{10} is the inactivation coefficient and T is the temperature.

	Water Temperature, °C									
	<=0.5	1	2	3	5	7	10	15	20	25
k_{10}	0.0417	0.0430	0.0482	0.0524	0.0629	0.0764	0.101	0.161	0.254	0.407

Example Calculation for CSTR Method

- Calculations:
  - Chamber 1 no credit by rule
  - Chamber 2 Log inactivation = Log(1 + 2.303×0.1005×0.15×20) = 0.23
  - Chamber 3 Log inactivation = Log(1 + 2.303×0.1005×0.1×20) = 0.17
  - Chamber 4 Log inactivation = Log(1 + 2.303×0.1005×0.1×20) = 0.17

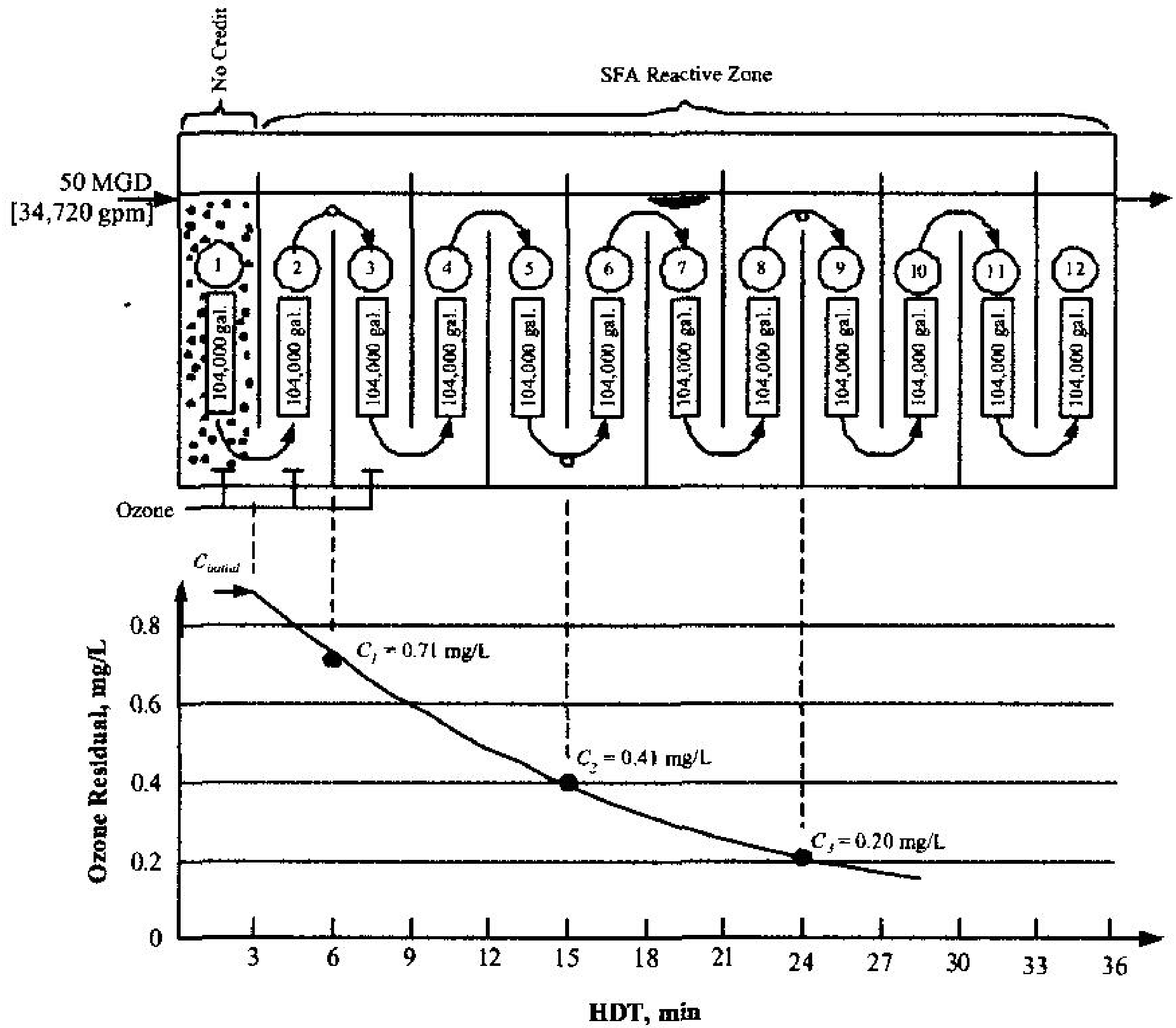
Example Calculation for CSTR Method

- Step 3 Sum the log inactivations to determine the log credit achieved:
  - The total log-inactivation across the contactor is 0.23 + 0.17 + 0.17 = 0.57 log inactivation, therefore 0.5 log credit achieved.

Example Calculation for Extended CSTR Method

- Description of System:
  - 12 chamber over and under contactor
  - Each Chamber is 104,000 gals
  - Total flow is 50 MGD
  - Water Temperature is 20 degrees C
  - Ozone added only to chamber 1
  - Residual measurements at outlet of chambers 2, 5 & 8
- Example taken from Appendix B LT2ESWTR Toolbox

EXTENDED CSTR - BLOCK FLOW DIAGRAM



Example Calculation for Extended CSTR Method

- Methods
  - No Credit is given cryptosporidium inactivation in chamber 1
  - Chambers 2-12 evaluated using Extended CSTR model

Example Calculation for Extended CSTR Method WHERE DOES 104,000 COME FROM?

- Step 1 calculate k*, the ozone decay rate:
- $k^*_{1\text{-}2} = (N_{1\text{-}2} \times Q/V_{1\text{-}2}) \times ((C1/C2)^{(1/N1\text{-}2)} - 1)$
- $k^*_{1\text{-}2} = (3 \times 34{,}720/(3 \times 104{,}000)) \times ((0.71/0.41)^{1/3} - 1) = 0.067\ \text{min}^{-1}$
- $k^*_{1\text{-}3} = (6 \times 34{,}720/(6 \times 104{,}000)) \times ((0.71/0.2)^{1/6} - 1) = 0.0785\ \text{min}^{-1}$
- N = Number of Chambers, V = Volume, Q=Flow Rate & C = Ozone residual concentration

Example Calculation for Extended CSTR Method

- Calculate k*
  - $k^* = (k^*_{1\text{-}2} + k^*_{1\text{-}3})/2$
  - $k^* = (0.067+0.0785)/2 = 0.0728\ min^{-1}$
  - k* must be in a maximum range of variability of 20%, in this example it is within a range of 8%

Example Calculation for Extended CSTR Method

- Calculate $C_{initial}$
  - $C_{initial,1} = C_1 \times (1 + k^* \times V_{0-1}/N_{0-1}/Q)^{N0-1}$
  - $C_{inital,1} = 0.71 \times (1 + 0.728 \times 104{,}000/1/34{,}720)^1 = 0.865$ mg/l
  - $C_{initial,2} = 0.41 \times (1 + 0.728 \times (4 \times 104{,}000) / 4 / 34{,}720)^4 = 0.902$ mg/l

Example Calculation for Extended CSTR Method

- Calculate $C_{initial}$ Continued
  - $C_{initial,3}$ = 0.20 x (1 + 0.728 x (7 X 104,000) / 7 / 34,720)^{7} = 0.796 mg/l
  - $C_{initial}$ = ($C_{inital,1}$ + $C_{inital,2}$ + $C_{initial,3}$)/3
  - $C_{initial}$ = (0.865 + 0.902 + 0.796) / 3 = 0.854 mg/l

Example Calculation for Extended CSTR Method

- Step 3 Calculate the Inactivation constant k_{10} at 20 degrees C:
  - This number can be taken from Tables supplied by the US EPA

	Water Temperature, °C									
	<=0.5	1	2	3	5	7	10	15	20	25
k_{10}	0.0417	0.0430	0.0482	0.0524	0.0629	0.0764	0.101	0.161	0.254	0.407

- $k_{10} = 0.0397 \times (1.09757)^T$
- $K_{10} = 0.0397 \times (1.09757)^{20} = 0.255$

Example Calculation for Extended CSTR Method

- Step 4 Calculate the Ozone Residual at the Effluent of Each Chamber:
  - $C_X = C_{initial} / (1 + k^* \times V_{0-X} / N_{0-X} / Q)^{N0-X}$
  - In this the extended CSTR region begins with the effluent of Chamber 1, so for C_4 the subscripts for V and N would be 1-4.
  - $C_4 = .854/(1 + 0.0728 \times 3 \times 104{,}000 / 3 / 34{,}720)^3 =$ 0.473 mg/l
  - This procedure is continued for all chambers except chamber 1.

Example Calculation for Extended CSTR Method

- Step 5 Calculate Log Inactivation of Each Chamber:
  - Log Inactivation = Log (1 + 2.303 x k_{10} x C_X x V_X / Q)
  - = Log (1 + 2.303 x 0.246 x 0.473 x 104,000 /34,720) = 0.26 Logs
  - The sum of the log inactivation values for all chambers is the log inactivation of the entire contactor
  - In this case 1.9 Logs