Appendix C: INACTIVATION CALCULATIONS

Water systems using surface water, or groundwater under the influence of surface water, must achieve a 3.0-log reduction of *Giardia lamblia* cysts and a 4.0-log reduction of viruses. Given the treatment processes for physical removal at the plant, the disinfection process is required to achieve a minimum number of log inactivations of *Giardia lamblia* cysts and viruses.

As noted in our discussion of the disinfection process on page B-8, the effectiveness of the disinfection process for inactivating *Giardia lamblia* cysts and viruses depends on five factors:

- the type of disinfectant used
- the disinfectant residual concentration
- the time the water is in contact with the disinfectant
- the water temperature
- the water pH

The best way to be sure that the plant is meeting the disinfection requirements is to calculate the CT value for the plant and compare the result to the CT required to achieve effective disinfection. The SWMOR and SWMOR2 both have built-in functions to perform these calculations.

Nevertheless, it is possible to evaluate your disinfection process using other methods. For example, you can use the CT calculator that is built into the CT Study template or you can complete the evaluation manually. To complete this evaluation manually, you must:

1. calculate the current contact time in each disinfection zone
2. calculate the CT value for each disinfection zone
3. determine the value of $CT_{required}$ for each zone
4. calculate the inactivation ratio for each zone
5. add all of the inactivation ratios

The rest of this appendix describes the process you may use to evaluate your disinfection.

IMPORTANT

The SWMOR, SWMOR2, and CT Study spreadsheets use several complex mathematical equations to determine the value of $CT_{required}$. Consequently, under certain operating conditions, the procedure described in this section will give you slightly different results than the one you will get using the spreadsheets. Although the difference between the two readings is typically less than 5%, it can have a significant impact if you are operating very close to your minimum acceptable inactivation requirements—especially the one for viruses.

C.1 CALCULATING THE CONTACT TIME, T_{10}, FOR THE CURRENT FLOW RATE

Using the information from your CT-approval letter and the current flow rate through each disinfection zone, calculate T_{10}, in minutes, for each zone using Equation C-1.

$$T_{10\ Actual} = \frac{CT\ Study\ Flow\ Rate}{Actual\ Flow\ Rate} \times T_{10\ CT\ Study} \qquad \text{(Equation C-1)}$$

C.2 CALCULATING THE CT_{ACTUAL} VALUES FOR THE CURRENT OPERATING CONDITIONS

The CT value is the product of the residual concentration of a disinfectant, C, in milligrams per liter, and the contact time, T_{10}, in minutes. Using the T_{10} value you calculated above and the disinfectant residual you measured at the end of each disinfection zone, calculate the CT value for each zone using Equation C-2.

$$CT = C\ (mg/L) \times T_{10\ Actual}\ (minutes) \qquad \text{(Equation C-2)}$$

C.3 DETERMINING THE REQUIRED CT, $CT_{REQUIRED}$, FOR THE CURRENT OPERATING CONDITIONS

To find the value of $CT_{required}$, you can use either of two methods: approximation or interpolation.

- Approximation is much easier than interpolation, requires no mathematical calculations, and produces fewer errors. Although this method is convenient, it does not give you the exact value of $CT_{required}$. Approximation somewhat underestimates the actual effectiveness of your plant's disinfection process.
- To determine the exact value of $CT_{required}$, you may use interpolation. In this method, you use a series of mathematical calculations to find CT values under conditions that fall between adjacent values in a CT table.

Interpolation is particularly useful when the disinfectant is chlorine dioxide, ozone, or chloramine. Because the CT tables for these disinfectants apply to a wide range of disinfectant concentrations and pH values, you would need to interpolate between temperature values only. In one step, you can find the exact value of $CT_{required}$ for your disinfection zone.

Using interpolation for free chlorine is much more complicated. You must interpolate for each of three factors: temperature, pH, and concentration. Finding the exact $CT_{required}$ would take you as many as seven separate interpolations! Unless you are very comfortable with math, we don't recommend that you use interpolation for free chlorine.

IMPORTANT
The SWMOR, SWMOR2, and CT Study template all use several complex mathematical equations to determine the value of $CT_{required}$. The approximation method will never give you the same $CT_{required}$ as the spreadsheets. Even if you use the interpolation method to get the more accurate $CT_{required}$ value, the result may still differ slightly from the value calculated by the spreadsheets. This discrepancy occurs because interpolation assumes a linear relationship between adjacent points on the CT tables. Unfortunately, the relationship between operating conditions and $CT_{required}$ is not truly linear.

Finding $CT_{required}$ by Approximation

Examples C-1 through C-3 show how to find the value of $CT_{required}$ using the approximation method.

Example C-1: Finding $CT_{required}$ for *Giardia lamblia* When Using Free Chlorine

Problem: Find $CT_{required}$ at 19°C, pH 7.2, and a chlorine concentration of 1.1 mg/L when a 0.5-log inactivation of *Giardia* is needed.

1. In Appendix D, find the CT tables for *Giardia* inactivation using free chlorine.

2. Find the table for the temperature that is equal to or slightly below the actual temperature of the water.
   For a temperature of 19°C, use the table for 15ºC: Table D-1.4.

3. Go to the section of this table for the pH that is equal to or slightly above the actual pH of the water.
   For a pH of 7.2, use the section for pH = 7.5.

4. Find the column for the log inactivations needed.
   This plant must achieve a 0.5-log *Giardia* inactivation, so use the “0.5-log” column.

5. Look at the far left side of the table and find the chlorine concentration that is equal to or slightly above the actual free chlorine concentration.
   In our example, the chlorine concentration is 1.1 mg/L, so use the “1.2 mg/L” row.

6. The value shown at the intersection of the concentration row and the inactivation column is the value of $CT_{required}$.
   In this example, $CT_{required}$ is 15.

Example C-2: Finding $CT_{required}$ for Viruses When Using Free Chlorine

Problem: Find $CT_{required}$ at 8°C and pH 7.2 when chlorine is used to obtain a 2.0-log inactivation of viruses.

1. Go to the CT table for viral inactivation using free chlorine (Table D-1.7).

2. Find the section of the table for the log inactivations needed.

   This plant is required to achieve a 2.0-log viral inactivation, so use one of the two columns under the 2.0-log inactivation section.

3. Go to the column for the pH range that is equal to or slightly above the actual pH of the water.

   For a pH of 7.2, use the “pH = 5.5–9.49” column.

4. Look at the far left side of the table and find the temperature that is equal to or slightly below the actual temperature of the water.

   For a temperature of 8°C, use the “5°C” row.

5. The value shown at the intersection of the temperature row and the pH column is the value of $CT_{required}$.

   In this example, $CT_{required}$ is 4.

Example C-3: Finding $CT_{required}$ When Using Chlorine Dioxide, Ozone, or Chloramine

The CT tables for chlorine dioxide, ozone, and chloramine are found in Appendix D (in Sections D-2, D-3, and D-4, respectively.) Because each of these tables has the same format, you can use the procedure described for chloramine below for any one of these three disinfectants.

Because these disinfectants are less sensitive than chlorine to the effects of pH, you will find no pH sections in these tables. Instead, each table applies to a broad pH range. Make sure the pH of the disinfection zone is within the pH range for the table you use.

Problem: Find $CT_{required}$ when using chloramine to obtain a 0.5-log inactivations of *Giardia* at 19°C.

1. Find the proper CT table for the disinfectant used in the zone. For example, use Table D-4.1 to determine the *Giardia* CT requirement when using chloramine.

2. Find the column for the temperature that is equal to or slightly below the actual temperature of the water.

   For a temperature of 19°C, use the "15°C" column.

3. Look at the far left side of the table and find the row for the required log inactivations.

   This plant is required to achieve a 0.5-log *Giardia* inactivation, so use the "0.5-log" row.

4. The value shown at the intersection of the inactivation row and the temperature column is the value of $CT_{required}$.

   In this example, $CT_{required}$ is 250.

Finding $CT_{required}$ by Interpolation

Example C-4 shows how to determine the value of $CT_{required}$ using the linear interpolation method. Since the process is identical for all of the disinfectants, Example C-4 demonstrates the process for chlorine dioxide and the target organism *Giardia lamblia*.

It should be noted, however, that using this method for free chlorine requires you to repeat this process three times; once for temperature, once for pH, and once for residual. Because of the complexity of the process for free chlorine, we recommend that you use the approximation method when working with this disinfectant.

Example C-4: Finding $CT_{required}$ for *Giardia* When Using Chlorine Dioxide

Problem: Find the exact value of $CT_{required}$ to obtain a 0.5-log inactivations of *Giardia* when using chlorine dioxide at 17°C and a pH of 7.6.

Part 1: Selecting the Table to Use for Interpolation

1. Find the proper CT table or tables for the disinfectant used in the zone.

   For this example, use Table D-2.1 to determine the *Giardia* CT requirement when using chlorine dioxide.

   Once you have found this table, make sure that the pH of the zone is within the pH range of the table. If not, no inactivation credits can be given. A pH of 7.6 is within the range of Table D-2.1 (5.5 through 9.49).

2. Find the columns for the two temperatures that are immediately above and below the actual temperature of the water.

   For example, the temperature is 17°C, so use the "15°C" and "20°C" columns.

3. Look at the far left side of the table and find the row for the required log inactivations.

   This plant is required to achieve a 0.5-log *Giardia* inactivation, so use the "0.5-log" row.

4. The value shown at the intersection of the inactivation row and the temperature columns are the $CT_{required}$ values to be used in the interpolation.

   In this example, the two $CT_{required}$ values are 3.2 and 2.5.

Part 2: Calculating $CT_{required}$ by Linear Interpolation

1. Subtract the $CT_{required}$ value for the higher temperature from the $CT_{required}$ value for the lower temperature:

   3.2 – 2.5 = 0.7

2. Subtract the lower temperature from the higher temperature:

   20 – 15 = 5

3. Divide the result of step 5 by the result of step 6:

   0.7 / 5 = 0.14

4. Subtract the actual water temperature from the higher temperature:

   20 – 17 = 3

5. Multiply the result of step 7 by the result of step 8 and round to the same number of decimal places used in the CT table you are using:

   3 × 0.14 = 0.42 (which you then round to 0.4 since the CT values for chlorine dioxide are listed to the tenths decimal place)

6. Add the result of step 9 to the $CT_{required}$ value for the higher temperature:

   2.5 + 0.4 = 2.9

This is the value of $CT_{required}$ for the actual water temperature in this plant: 17°C.

C.4 CALCULATING THE INACTIVATION RATIO FOR EACH DISINFECTION ZONE

The inactivation ratio is a measure of how effective the disinfection has been under actual operating conditions. To find the inactivation ratio in a disinfection zone, divide the CT value achieved in that zone, or CT, by the CT value required for effective disinfection, or $CT_{required}$, as shown in Equation C-3.

$$Inactivation\ Ratio = \frac{CT_{Actual}}{CT_{Required}} \qquad \text{(Equation C-3)}$$

C.5 DETERMINING THE TOTAL INACTIVATION RATIO FOR THE PLANT

To find the overall inactivation ratio for the plant, you add up the inactivation ratios of the disinfection zones in the plant. Disinfection is sufficiently effective when this overall inactivation ratio is 1.00 or greater.

$$Total\ Inactivation\ Ratio = \sum_{Zone\ D1}^{Zone\ Dn} Inactivation\ Ratio_{Zone\ Dn} \qquad \text{(Equation C-4)}$$

$$= Inactivation\ Ratio_{D1} + Inactivation\ Ratio_{D2} + \ \ldots\ + Inactivation\ Ratio_{Dn}$$