Drinking Water Operator Certification Training
Instructor Guide

Module 26:
UV Disinfection

This course includes content developed by the Pennsylvania Department of Environmental Protection (Pa. DEP) in cooperation with the following contractors, subcontractors, or grantees:

The Pennsylvania State Association of Township Supervisors (PSATS)
Gannett Fleming, Inc.
Dering Consulting Group
Penn State Harrisburg Environmental Training Center

A Note to the Instructor

Dear Instructor:

The primary purpose of *Module 26: UV Disinfection* is to provide an understanding of the characteristics, benefits and operation of a UV disinfection system. This module has been designed to be completed in 7 hours but the actual course length will depend upon content and/or delivery modifications and results of course dry runs performed by the DEP-approved sponsor. The number of contact hours of credit assigned to this course is based upon the contact hours approved under the DEP course approval process. To help you prepare a personal lesson plan, timeframes have been included in the instructor guide at the Unit level and at the Roman numeral level of the topical outline. You may need to adjust these timeframes as necessary to match course content and delivery modifications made by the sponsor. Please make sure that all teaching points are covered and that the course is delivered as approved by DEP.

Web site URLs and other references are subject to change, and it is the training sponsor's responsibility to keep such references up to date.

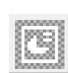
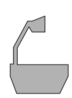
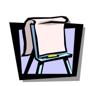
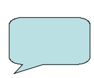
Delivery methods to be used for this course include:

- Lecture
- Exercises

To present this module, you will need the following materials:

- One workbook per participant
- Extra pencils
- Laptop (loaded with PowerPoint) and an LCD projector **or** overheads of presentation and an overhead projector
- Screen
- Flip Chart
- Markers

Icons to become familiar with include:

Participant Workbook		Instructor Guide	
	Exercise/Activity	Same icons for Participant Workbook apply to the Instructor Guide.	
	Case Study	**Ans:**	Answer to exercise, case study, discussion, question, etc.
	Discussion Question		PowerPoint Slide
	Calculation(s)		Overhead
	Exercise		Flip Chart
	Key Definition(s)		Suggested "Script"
	Key Point(s)		

Instructor text that is meant to be general instructions for the instructor is designated by being written in script font and enclosed in brackets. For example:

[*Ask participants if they have any questions on how to read the table. Answer any questions participants may have about how to read the table.]*

If your module includes the use of a PowerPoint presentation, below are some helpful controls that you may use within the Slide Show.

PowerPoint Slide Show Controls

You can use the following shortcuts while running your slide show in full-screen mode.

To	**Press**
Advance to the next slide	N, ENTER, or the SPACEBAR (or click the mouse)
Return to the previous slide	P or BACKSPACE
Go to slide <number>	<number>+ENTER
Display a black screen, or return to the slide show from a black screen	B
Display a white screen, or return to the slide show from a white screen	W
Stop or restart an automatic slide show	S
End a slide show	ESC
Return to the first slide	Both mouse buttons for 2 seconds
Change the pointer to a pen	CTRL+P
Change the pen to a pointer	CTRL+A
Hide the pointer and button temporarily	CTRL+H
Hide the pointer and button always	CTRL+L
Display the shortcut menu	SHIFT+F10 (or right-click)
Erase on-screen annotations	E
Go to next hidden slide	H
Set new timings while rehearsing	T
Use original timings while rehearsing	O
Use mouse-click to advance while rehearsing	M

INTRODUCTION OF MODULE: 5 minutes

Display Slide 1—Module 26: UV Disinfection.

[Welcome participants to "Module 26 – UV Disinfection." Indicate the primary purpose of this course is to provide an understanding of the characteristics, benefits and operation of a UV disinfection system.]

[Introduce yourself.]

[Provide a brief overview of the module.]

This module contains 5 units. On page i, you will see the topical outline for **Unit 1 – Introduction to Ultraviolet Disinfection** and **Unit 2 – UV Equipment**.

[Briefly review outline.]

On page ii, you will see the topical outline for **Unit 3 – UV Performance**.

[Briefly review outline.]

On page iii, you will see the topical outline for **Unit 4 – Operation**.

[Briefly review outline.]

If you turn the page, you will see the topical outline for **Unit 5 – Maintenance**.

[Briefly review outline.]

UNIT 1: <u>65 minutes</u>

Display Slide 2—Unit 1: Introduction to Ultraviolet (UV) Disinfection.

At the end of this unit, you should be able to:

- Explain what ultraviolet disinfection is and how it works.
- Indicate the removal or inactivation levels of *Cryptosporidium*, *Giardia*, and viruses during treatment of surface water or ground water under the direct influence of surface water for current disinfection regulations.

Display Slide 3—Unit 1: Introduction to Ultraviolet (UV) Disinfection.

The next three learning objectives are:

- State the relative effectiveness of UV in disinfecting for *Cryptosporidium*, *Giardia*, and viruses.
- Explain advantages/disadvantages of UV disinfection compared to other disinfectants.
- Indicate how UV is used with other disinfectants.

Display Slide 4—Unit 1: Introduction to Ultraviolet (UV) Disinfection.

The remaining learning objectives for this unit are:

- List the four categories of UV light.
- Explain how UV light is generated.
- Describe the four ways UV interacts with its surroundings.
- Perform absorbance and transmittance calculations.

WHAT IS ULTRAVIOLET DISINFECTION?: 10 minutes

Definitions

Let's begin the unit by looking at some terms that you will need to know.

[Review the definitions listed in the workbook.]

How UV Disinfection Works

Now that we've defined UV disinfection, let's take a quick look at how it works.

[Review the first bullet item in the workbook and then add the following:]

DNA is made up of four types of nucleotides, each with a different nitrogenous base. They are adenine, guanine, thymine, and cytosine. RNA is also made up of four types of nucleotides. They are the same as those for DNA, except RNA contains uracil in place of thymine.

[Review the second bullet item in the workbook. Add the following:]

In double-stranded DNA and RNA, adenine will always be paired with thymine (or uracil) and guanine will always be paired with cytosine. The nitrogenous bases are hydrogen-bonded together.

Display Slide 5—DNA.

This slide is a representation of what DNA looks like. Note the two sugar-phosphate backbone "strands" and the connections between them where nitrogenous bases are bonded. Replication of genetic material normally occurs by separating the two halves of the double strand. Because the nitrogenous base of each nucleotide will only bond to one other type of nitrogenous base, each half can be used as a template for a new double-strand.

[Review the first and second bullet items in the workbook and then add the following:]

The stronger bond cannot be broken during the normal replication procedure. Since the two DNA strands can no longer be separated, they cannot be replicated.

[Review the remaining information in the workbook.]

USING UV DISINFECTION TO MEET REGULATIONS: 30 minutes

Microbial and Disinfection By-Product Rules

Let's move on to how UV disinfection is used to treat drinking water.

Target Microorganisms for Disinfection

[Review the information in the workbook. Indicate that a protozoan is a single-celled animal.]

Regulatory Requirements

[Review the information in the workbook.]

[Review the formula for calculating log inactivation/removal.]

Example

[Use flipchart to work through the example in the workbook.]

The formula can be rearranged so that you would calculate for N, the concentration after disinfection. Remember this value is logarithmic. The log would be the exponent of 10 that equals the ratio of concentrations before and after disinfection. Now that we have reviewed an example of how to calculate log inactivation/removal, it's your turn to try a calculation. Take a minute to complete the calculation in your workbook and then we will review the answer.

Calculation

If you need to achieve 2.0- log inactivation of *Giardia* through UV disinfection and the active *Giardia* concentration before disinfection is 0.05 cysts/L, what is the maximum allowable concentration of active cysts remaining after the UV disinfection process?

Ans: Rearrange the formula in the following manner:

$N_0/N = 10^{(\text{log inactivation})}$

$N = N_0 / 10^{(\text{log inactivation})}$

Replacing 'N_0' with 0.05 cysts/L and 'log inactivation' with 2, we have:

$N = 0.05/(10^2)$
$N = 0.05/100$

$N = 0.0005 = 5 \times 10^{-4}$ active *Giardia* cysts/L.

[Review the remaining information in the workbook and then add the following:]

The DBPs regulated include total trihalomethanes (TTHM), five haloacetic acids (HAA5), bromate, and chlorite. TTHM and HAA5 are halogenated organics; both are groups of DBPs that are produced by the reaction of chlorine or other disinfectants with bromide and/or natural organic matter that are present in the source water. Bromate is formed as a byproduct of ozonation and chlorite is formed as a byproduct of disinfection with chlorine dioxide.

[Review the remaining bullet item on this page and then add the following:]

A running annual average is the average of data from the current sampling period and all sampling periods within the previous one-year time frame.

UV Disinfection Effectiveness

We've looked at what UV disinfection is, how it works, and how it is used. Now let's look at the effectiveness of using UV to disinfect drinking water.

Log Inactivation

[Review the information in the workbook and then add the following:]

The dose required for *Cryptosporidium* and *Giardia* is similar, although *Giardia* is slightly more easily disinfected. On the other hand, the dose for inactivation of viruses is much higher, indicating that UV is not as effective for use as a viral disinfectant.

Comparing UV to Other Disinfectants

Let's take a look at the effectiveness of other disinfectants.

Disinfection Effectiveness

[Review the information in the workbook, including Table 1.2, and then add the following:]

Ozone is effective at treating all three microorganisms with small CTs. Viruses are relatively easy to disinfect with all four chemical disinfectants, unlike UV light.

Chlorine and chloramine are not effective in inactivating *Cryptosporidium*. Chloramines are less effective than chlorine for all microorganisms. Chlorine dioxide is more effective than chlorine for *Cryptosporidium* and *Giardia*.

For all the chemical disinfectants, as temperature increases, disinfection effectiveness increases. However, temperature has only a minimal effect on UV light disinfection effectiveness. Chlorine is more effective as pH decreases, and more effective at low concentrations than high. pH has minimal or no effect on the disinfection effectiveness of other disinfectants, including UV light.

Disinfection Byproducts

When using disinfectants, you need to consider the creation of disinfectant byproducts.

[Review the information in the workbook.]

Disinfection Residual

Another facet of disinfectant effectiveness is disinfection residual.

[Review the information in the workbook.]

Pretreatment

Many disinfectants are also used as oxidants.

[Review the information in the workbook.]

Use of UV with Other Disinfectants

As we've seen, there are pros and cons to using each disinfectant. UV disinfection may be used in combination with others. Let's take a look at when and why.

[Review the information in the workbook.]

FUNDAMENTAL ASPECTS OF UV LIGHT: <u>25 minutes</u>

Now that we've gotten an overview/introduction of UV disinfection, let's take a closer look at UV light.

The UV Spectrum of Light

The first aspect of UV light we will look at is the UV spectrum of light.

[Review the first bullet item in the workbook.]

Display Slide 6—DNA Adsorption of UV Light.

[Review the second bullet item in the workbook. When reviewing the first sub-bullet, Slide 6.]

How UV Light is Generated

Another aspect of UV light that is important to understand is how it is generated.

[Review the first paragraph in the workbook.]

[Review the first bullet item in the workbook. After reviewing the third sub-bullet, add the following:]

Monochromatic literally means "one color" or in this case, one wavelength.

[Review remaining information in the workbook.]

Interaction of UV Light with its Surroundings

Yet another important aspect of UV light is how it interacts with its surroundings. Let's begin with adsorption.

[Review information in workbook.]

Another way that UV light interacts with its surroundings is through reflection.

[Review the first sub-bullet and then add:]

Transmit means "allow to pass through."

[Review the second sub-bullet and then add:]

Some surfaces will reflect a portion of the light and transmit some of the light (for example the lamp surface) and other surfaces do not transmit any light (for example the reactor walls).

[Review the remaining two bullet items.]

Display Slide 7—Reflection.

This slide shows both specular reflection and diffuse reflection. The next means of intereaction we will review is refraction. Let's take a few minutes to talk about refraction.

[Review the information in the workbook.]

Display Slide 8—Refraction.

This slide shows an example of refraction. As you can see, the light changes direction as it travels through the media.

The final means by which UV light interacts with its surroundings is through scattering.

[Review the information in the workbook.]

Display Slide 9—Scattering.

In this slide, you can see that the scattered light travels in many directions.

Water Quality as It Relates to UV Light

In describing water quality as it relates to UV light, two terms are commonly used—absorbance and transmittance. Let's talk about absorbance first.

Absorbance

[Review the first three bullet items and then add:]

"Pathlength" is the distance the light travels from the source to where it is measured.

[Review the information in the workbook.]

Transmittance

Now that we have discussed absorbance, let's spend a few minutes reviewing transmittance.

[Review the information in the workbook.]

Sample Calculation

Let's take a look at a sample calculation.

[Review the sample calculation by writing it on a flipchart or whiteboard.]

Now it's time for you to do a calculation on your own. Take a minute to complete the calculation in your workbook and then we will review the answer.

Calculation

1. The transmittance of some water that will be disinfected using UV light has been measured at 95%. The UV intensity 1 cm away from the UV lamp must be 25 mW/cm^2 to adequately disinfect the water. What must the UV intensity be at the surface of the lamp? What must the UV intensity be at the surface of the lamp if the UV intensity needs to be 25mW/cm^2 at a distance of 2 cm from the lamp?

Ans: Transmittance is typically reported for a pathlength of 1 cm, so for the first question, the distance from the lamp is the same as the pathlength the transmittance was measured at. To solve, rearrange the equation for transmittance to solve for the initial intensity:

$T = 100 * I/I_0$
$I/I_0 = T/100$
$I_0 = (100 * I)/T = (100 * 25)/95 = 26.3$ mW/cm^2

To determine how what the initial intensity would be 2 cm away, the transmittance (or absorbance) must be determined for a pathlength of 2 cm:

$A_1 = -\log(T/100) = -\log(95/100) = 0.0223$
$A_2 = A_1{*}P = 0.02228 * 2 = 0.0446$
$A = \log(I_0/I)$
$10^A = I_0/I$
$I_0 = I * 10^A = 25$ mW/cm^2 $* 10^{0.0446} = 27.7$ mW/cm^2

Note: This could also be solved by converting A back into T and then solving as was done for the first part of the question:

$T = 100{*}10^{-A} = 100 * 10^{-0.0446} = 90.24\%$
$I_0 = (100 * I)/T = (100 * 25)/90.24 = 27.7$ mW/cm^2

We have finished this unit of the module. Now it's time to take a few minutes and complete the exercise in your workbook. We will review the correct answers when you are finished.

[Allow participants 5 - 15 minutes to answer the questions. Then provide the answers to them, or ask for volunteers to share their answers. Be sure to clarify any misunderstood information.]

Unit 1 Exercise

T rue or False:

1. Ultraviolet Disinfection is one method of treatment that destroys or reduces the growth of harmful microorganism. T F **(TRUE)**

2. Ultraviolet light is measured with a volt-meter. T F **(FALSE)**

3. Ultraviolet light disinfects DNA or RNA. T F **(TRUE)**

4. Bacteria and Protozoan are made up of a single strand on DNA. T F **(FALSE)**

5. Ultraviolet light at wavelengths of 300nm will break the existing bond between the nitrogenous base. T F **(TRUE)**

Multiple Choice:

1. Disinfection regulations target three types of microorganisms for disinfection, which one does not apply.
   a. Cryptosporidium
   b. Filamentous Bacteria
   c. Giardia
   d. Viruses

   Answer: B

2. The log removal for Giardia is:
   a. 1-log
   b. 2-log
   c. 3-log
   d. 4-log

   Answer: C

3. Cryptosporidium is found in the:
   a. Surface water
   b. Ground water not under the direct influence of surface water
   c. After disinfection
   d. In the distribution system where the resident time is high.

   Answer: A

4. One benefit to UV disinfection is that it does not cause Disinfection Byproducts. Which statement is not correct:
   a. UV does not have a residual.
   b. UV is not an oxidant.
   c. UV can be used a sole source of disinfection in a plant that treat GUDI.
   d. UV is one option for providing additional inactivation required under the LT2ESWTR.

   Answer: C

5. Two common terms used to relate water quality to UV light are:
   a. Adsorption and Deflection
   b. Absorption and Transmittance
   c. Reflection and Refraction
   d. Pathlength and Pressure

   Answer: B

6. If the light intensity of a UV lamp is 20.0 mW/cm^2. Three centimeters away from the lamp, the UV intensity is measure as 15.2 mW/cm^2. What is the absorbance of the water for the pathlength of 3 cm?
   Where $A= \log (I_0/I)$
   $I_0 = 20$ mW/cm^2
   $I= 15.2$ mW/cm^2
   a. 0.76 for the measured pathlength of 3 cm
   b. 0.76 for the measure pathlength of 1 cm
   c. 0.1192 for the measure pathlength of 1 cm
   d. 0.1192 for the measured pathlength of 3 cm

   Answer: D

7. What is the absorbance for a pathlength of 1 cm above?
   Where $A_2=A_1*P$
   a. 0.0397
   b. 0.2533
   c. 0.3576
   d. 2.28

   Answer: A

8. If a lamp UV intensity out put is 35 mW/cm^2, what UV intensity will be measured for 1 cm from the lamp surface if the lamp is submerged in water with a UVT of 93%?
   Where $T(\%) = 100* I/I_0$
   a. 37.6 mW/cm^2
   b. 0.0266 mW/cm^2
   c. 32.55 mW/cm^2
   d. 0.0307 mW/cm^2

   Answer: C

[Point out that references and resources for the unit are listed on this page.]

We have now finished unit 1. Are there any questions about the material we have covered so far before we begin unit 2?

UNIT 2 – UV EQUIPMENT: <u>95 minutes</u>

Display Slide 10—Unit 2: UV Equipment.

At the end of this unit, you should be able to:

- Describe the two basic configurations for UV reactors.
- List the major components of a UV reactor.
- List the major components of a UV disinfection system.

UV REACTORS: 65 minutes

In this unit, we are going to discuss UV equipment. Specifically, we will talk about UV reactors and UV system components. This workbook focuses on closed channel reactors. Let's begin by talking about UV reactor configurations.

UV Reactor Configurations

[Review the information in the workbook.]

Display Slide 11—An Open Channel Reactor.

This slide shows what an open channel reactor looks like.

Display Slide 12—A Closed Channel Reactor.

In this slide, we see an example of a closed channel reactor.

UV Reactor Components

Now that we understand the two basic UV reactor configurations, let's spend some time talking about UV reactor components. The components we will focus on include lamps, lamp sleeves, the lamp power supply, sleeve cleaning systems, UV intensity sensors, UV transmittance monitors, temperature sensors and hydraulic control baffles. Before we begin reviewing the individual components, let's take an overall look at a reactor.

Display Slide 13—The Inside of a Reactor.

[Review the different components that are labeled on the slide.]

UV Lamps

Now we are going to talk specifically about the UV lamps. Let's first see what a UV lamp looks like.

Display Slide 14—A UV Lamp.

[Review the first three bullet items in the workbook and then add:]

LP and LPHO lamps emit a peak of light at 185 nm. At this wavelength, UV light reacts with oxygen to form ozone. Ozone is a corrosive gas and absorbs UV light. For this reason, it is preferable to minimize transmittance of light at this wavelength. Low-wavelength light produced by MP lamps may also produce undesirable reactions.

[Review the remaining information in the workbook.]

Review Table 2.2, adding the following:

Higher electrical conversion to germicidal wavelengths means, in general, that LP/LPHO lamp reactors will use less electricity for an equivalent log-inactivation than MP lamp reactors.

Fewer lamps mean fewer lamps to replace, and thereby less maintenance time and less cost for new lamps. BUT fewer lamps of the same size also mean that you lose a greater percentage of disinfecting capability if one lamp fails.

Longer lamp life reduces lamp replacement frequency, which means less maintenance and less cost for new lamps.

Space requirements are especially important when adding UV to an existing plant.

Monochromatic output makes monitoring for the UV dose easier because only one wavelength needs to be measured and the UVT at only one wavelength is a concern. The wavelength of the LP/ LPHO lamps output is near the maximum of germicidal effectiveness.

In a water prone to fouling, the lower operating temperature of the LP/LPHO lamps may reduce cleaning frequency significantly.

Display Slide 15—UV Lamp Output: LP vs. MP.

This slide shows the difference in UV lamp output between low pressure and medium pressure lamps.

Lamp Sleeves

The next component we will review is the lamp sleeve.

[Review the information in the workbook. After the final bullet, add the following:]

Positioning of the lamp in the sleeve can affect the UV dose reaching the pathogens.

Lamp Power Supply

The next component is the lamp power supply, which consists of the ballasts, transformers and, frequency converters.

[Review the information in the workbook.]

Ballasts

[Review the information in the workbook.]

Review Table 2.3.

[Review the remaining bullet item in the workbook and then add:]

A capacitor is an electronic component that is used to temporarily store and then release an electric charge. The current is dependent upon the rating of the capacitor. An inductor is an electronic component that produces increasing resistance to current as the current increases. By doing so, the flow of current is limited.

Transformers

Another important component of the power supply is the transformer. Let's talk about transformers in more detail.

[Review the information in the workbook.]

Frequency Converters

The final component of the power supply that we will discuss is the frequency converter.

[Review the first bullet item and then add:]

Normal supply frequency is 60 hertz.

[Review the remaining information in the workbook.]

Sleeve Cleaning Systems

The next component of the UV reactor that we will discuss is the sleeve cleaning system.

[Review the information in the workbook.]

[Review the remaining information in the workbook.]

Display Slide 16—Lamp Wipers.

This slide shows an example of lamp wipers.

Display Slide 17—Lamp Wipers.

This is another example of the lamp wiper.

UV Intensity Sensors

So far we have reviewed several components of the UV reactor, including the UV lamps, the lamp sleeves, the lamp power supply, and sleeve cleaning systems. Now we will turn our attention to the UV intensity sensors.

[Review the information in the workbook.]

[Review the remaining information in the workbook.]

Display Slide 18—Intensity Sensor.

This is an example of what an intensity sensor looks like.

UV Transmittance Monitors

The next component is the UV transmittance monitor.

[Review the information in the workbook.]

Display Slide 19—UVT Monitor Drawing.

This drawing shows what a UVT monitor looks like. As you can see, there are three UV intensity sensors and each is located a different distance from the lamp.

Temperature Sensors

Next we will review the temperature sensors.

[Review the information in the workbook.]

[Review the remaining information in the workbook.]

Hydraulic Control Baffles

The hydraulic control baffles are the final component of the UV reactor we will review.

[Review the information in the workbook.]

UV SYSTEM COMPONENTS: 30 minutes

In this final section of the unit, we will learn about the UV system components. This includes the controls and instrumentation, the electrical system, and the piping components. Let's begin by talking about some control concepts.

Controls and Instrumentation

Control Concepts

[*Review the information in the workbook.]*

Indicators

Now let's talk about some of the indicators.

[Review the information in the workbook.]

Alarms

Now we will review some important points regarding alarms.

[Review the information in the workbook.]

System Interlocks

Next we will review system interlocks.

[Review the information in the workbook.]

Electrical System

The next component of the UV system we will learn about is the electrical system. We will focus on the power supply backup and the ground fault interrupters.

Power Supply Backup

[Review the information in the workbook.]

Ground Fault Interrupters

[Review the first two bullets information in the workbook.]

Never assume this or take anybody's word – check the circuit for voltage yourself before performing any work. Electrical shock occurs when your body becomes a path for current to flow. You can either be affected directly or indirectly from electrical shock. Never work around electricity when you are wet or in contact with water! Water is a good conductor of electricity. You can also become part of the circuit. De-energize the main source of power if possible or use a non-conducting safety rope to "lasso" the person off of the source.

[Review the last bullet information in the workbook.]

Piping Components

Now that we have reviewed the electrical system, let's turn our attention to the piping components. The first piping component we will talk about is the flow split.

Flow Split

[Review the information in the workbook.]

Meters

Meters are the next piping component we will highlight.

[Review the first bullet item in the workbook.]

[Review the second bullet item and after the first sub-bullet, share the following example:]

For example, filter rinse water or sludge removal from clarification basins.

[Review the second sub-bullet and then share the following example:]

For example, plant service water or filter backwash water.

[Review the remaining sub-bullet item.]

Valves

The final piping component we will discuss is the valves.

[Review the information in the workbook.]

On the next page, you will find an end-of-unit exercise. Please spend a few minutes answering the questions and then we will review the answers.

[Allow participants 5- 15 minutes to answer the questions. Then provide the answers to them, or ask for volunteers to share their answers. Be sure to clarify any misunderstood information.]

Unit 2 Exercise

Fill in the blank:

1. Reactors are found in two basic configurations _________channel and ________channel.

   Answer: Open and Closed

2. UV lamps fall into three categories; low pressure, low pressure-high output and _________ pressure.

   Answer: Medium

3. All three use _____________ vapor to produce UV light.

   Answer: Mercury

4. Position the lamp in the ___________ ____________ can affect the UV does reaching the pathogens.

   Answer: Lamp Sleeves

5. UV lamps require power at specific ______________, ___________ and frequency to maximum the efficiency of UV light.

   Answer: Current, Voltage

6. Ballasts are used to limit the current flow through the lamp. The two classification of ballasts are: _________ and ____________.

   Answer: Magnetic, Electronic

7. A UV _________sensor measures the __________ of the UV light at some distance away form the UV lamp.

   Answer: Intensity

8. A UVT monitor measures the _____________________ of the water flowing through the reactor.

   Answer: Transmittance

9. The major components of a UV disinfection systems are: controls and _____________, the ____________system and the _____________ components and the UV ______________.

   Answer: Instrumentation, Electrical, Piping and Reactors.

We have now completed the second unit of this module. We have discussed UV reactor configurations, UV reactor components and UV system components. Are there any questions about the material we have covered before we move on to the third unit?

[Point out that resources are listed on this page.]

UNIT 3 – UV PERFORMANCE: 65 minutes

Display Slide 20—Unit 3: UV Performance.

At the end of this unit, you should be able to:

- Indicate the three parameters that affect UV dose.
- Explain what UV reactor validation is and how it is performed.
- Explain the difference between the required UV dose and the target RED value.

Display Slide 21—Unit 3: UV Performance.

The remaining learning objectives for this unit are:

- List six water quality characteristics that can affect the effectiveness of the UV disinfection system.
- Explain how lamp and sleeve aging can affect the UV disinfection system.

UV DOSE: <u>10 minutes</u>

This unit will begin with a discussion of UV dose. First, we will talk about target organisms and dose.

Target Organisms and Dose

[Review the information in the workbook. After the last bullet item, add the following:]

A milliwatt is a millijoule per second. Millijoule is a measurement of energy, so a milliwatt is energy per time, which is power. So intensity is a measurement of power per area, while dose is a measurement of energy (power times time) per area.

Operating Conditions Affecting Dose

Now we are going to discuss the operating conditions that affect dose. These include UV intensity, flowrate and UV transmittance.

[Review the information in the workbook.]

[Review the remaining information in the workbook.]

UV REACTOR VALIDATION: 20 minutes

Now that we have finished our discussion of UV dose, we are going to turn our attention to the topic of UV reactor validation. Let's begin by learning about hydraulics.

Hydraulics

[Review the information in the workbook.]

Display Slide 22—Reactor With Lamps.

This sketch shows a reactor with lamps and different paths organisms can take through the reactor. One path travels straight through, near lamps and another travels through along walls of reactor. One may go through faster than the other and one may see higher intensity of light because it is closer to the lamps.

Reactor Validation

Now let's discuss reactor validation.

[Review the information in the workbook.]

[Review the remaining information in the workbook.]

Uncertainty and Target RED Values

Another important topic when discussing UV reactor validation is the topic of uncertainty and target RED values. Let's delve further into this topic.

[Review the first paragraph in the workbook and then add the following:]

For example, an intensity sensor may have an uncertainty in the measurement of ±15%. So if the intensity measurement is 22 mW/cm^2, then the true intensity may be anywhere in the range of 18.7 to 25.3 mW/cm^2. (15% of 22 is 3.3, 22 - 3.3 = 18.7 and 22 + 3.3 = 25.3).

[Review the first two bullet items. After reviewing the first sub-bullet regarding the Tier 1 method, add the following:]

Take a look at these two tables. The difference in requirements for LP/LPHO systems and MP systems is due to the fact that MP lamps emit polychromatic light instead of monochromatic light. This introduces additional uncertainty since the doses presented in the LT2ESWTR are based on UV light at 254 nm.

[Review the second sub-bullet regarding the Tier 2 method and then add the following:]

In this way, if a system has lower uncertainty than assumed under the Tier 1 method, a lower target RED can be used. Or, if the system is unable to meet the Tier 1 criteria, an appropriate safety factor can be determined.

Off-Specification Water

The final topic we need to discuss in regards to UV reactor validation is off-specification water.

[Review the information in the workbook.]

IMPACTS OF WATER QUALITY: <u>15 minutes</u>

Our discussion of UV reactor validation is now complete. The next section of this unit focuses on the impacts of water quality. We are going to review several water quality parameters, including: fouling, transmittance, particles, upstream treatment, water temperature, and algae. Let's begin with fouling.

Fouling

[Review the information in the workbook.]

Transmittance

Next, we will discuss the impact of transmittance.

[Review the first two bullet items in the workbook and then add:]

Ozone is not likely to be in the water unless it is used as part of the treatment process upstream of the UV reactor.

[Review the remaining information in the workbook.]

Particles

Now let's take a look at the impact of particles.

[Review the information in the workbook.]

Upstream Treatment

Upstream treatment can also impact the effectiveness of UV disinfection. Let's take a look at how that happens.

[Review the information in the workbook.]

Water Temperature

Yet another parameter impacting UV effectiveness is water temperature.

[Review the information in the workbook and then add the following:]

Unlike chemical disinfectants such as chlorine, chloramines, chlorine dioxide, and ozone.

Algae

The final factor we need to review is algae.

[Review the first bullet item and then add:]

The visible light is not adsorbed as strongly by the water and so it travels farther than the germicidal UV light.

[Review the remaining information in the workbook.]

LAMP AND SLEEVE AGING: <u>20 minutes</u>

So far we have covered UV dose, UV reactor validation, and the impacts of water quality. The final topic we will cover in this unit is lamp and sleeve aging.

Lamp Intensity

The first topic related to lamp and sleeve aging is lamp intensity. Let's explore this topic further.

[Review the information in the workbook.]

UV Transmittance

UV transmittance is also affected by lamp and sleeve aging.

[Review the information in the workbook.]

Please take a few minutes to complete the exercise on the next page of your workbook. After you have completed the exercise, we will review the answers.

[Allow participants about 5-15 minutes to answer the questions. Then provide the answers to them, or ask for volunteers to share their answers. Be sure to clarify any misunderstood information.]

Unit 3 Exercise

Multiple Choice:

1. UV _____________ increases the dose will increase, as ____________________ increase, the dose will decrease. As UV ______________________decreases, dose will decrease.

   a. flowrate, transmittance, intensity,
   b. intensity, flowrate, transmittance
   c. transmittance, flowrate, intensity

   Answer: B

2. When a reactor is tested at various UV intensities and flowrates is called a ________ ____________.

   a. reactor validation
   b. reactor calibration
   c. reactor standardization

   Answer: A

3. ________ will scatter the UV light, decreasing the intensity of the UV light reaching the pathogen.

   a. Algae
   b. Coagulates
   c. Particles

   Answer: C

4. When particles and substances dissolve in the water deposit onto the surface of the lamp sleeve is called ___________________________.

   a. fouling
   b. deposition
   c. lamp coating

   Answer: A

5. Improving operations of the UV system by increasing the UVT of the water can be accomplished by ________________ __________________.

   a. upstream treatment
   b. water treatment
   c. taking off-line

   Answer: A

6. Water _________________ has little effect on the disinfection effectiveness of the UV light but can affect the fouling rates.

   a. pH
   b. temperature
   c. color

   Answer: B

7. Algae growth can be ___________; it can cause taste and odors problems in the finished water.

   a. beneficial
   b. overlooked
   c. a nuisance

   Answer: C

8. The intensity of the UV light and UVT _________________ as a lamp and lamp sleeve age.

   a. decrease
   b. increase
   c. remain the same

   Answer: A

We have now finished unit 3. Are there any questions about the material we have covered so far before we begin unit 4?

UNIT 4 – OPERATION: 140 minutes

Display Slide 23—Unit 4: Operation.

At the end of this unit, you should be able to:

- Given the appropriate data, determine the UV intensity setpoint.
- Describe the three control strategies used to ensure an adequate UV dose is applied to the water.
- Indicate the advantages and disadvantages for each of the following operational strategies—single setpoint, variable setpoint, and setpoint interpolation.

Display Slide 24—Unit 4: Operation.

The remaining learning objectives for this unit are:

- List the operational tasks associated with a UV system.
- Describe potential problems that may occur in the UV disinfection process, including their possible causes and solutions.
- Indicate which items must be monitored, recorded, and reported for each UV reactor under the proposed LT2ESWT.
- Specify safety issues pertaining to UV disinfection.

INITIAL STARTUP: 10 minutes

We will begin this unit by discussing items that need to be checked during initial startup of a UV disinfection system. The first item we will discuss is verification that the system components are operating properly.

Verification

[Review the information in the workbook.]

[Review the remaining information in the workbook.]

Performance Testing

Performance testing is another key aspect of initial startup. Let's discuss performance testing further.

[Review the information in the workbook.]

OPERATIONS: 90 minutes

We have just finished reviewing some key points regarding initial startup of a UV disinfection system. Now let's spend some time talking about the actual operation of the system, beginning with control strategies.

Control Strategies

[Review the first bullet item. After the third sub-bullet, add the following:]

For example, the UV intensity setpoint for flows from 25 to 100 gpm may be 1.6 mW/cm^2, for 100 to 200 gpm it may be 2.3 mW/cm^2, and for 200 to 300 gpm it may be 3.0 mW/cm^2.

[Review the remaining information in the workbook.]

Operational Strategies

We have completed our discussion of control strategies and will now turn our attention to operational strategies.

[Review the information in the workbook.]

Determining the UV Intensity Setpoint

Let's take a look at how the UV intensity setpoint is determined.

[Review the information in the workbook.]

Example 1

Let's take a look at an example.

[*Review the information in the workbook. After the second bullet item, add the following:]*

Because the control strategy used with this reactor was UV Intensity Setpoint, changes in the UVT are taken into account in the intensity measurement.

[Review the remaining information the workbook.]

[Review the first bullet item in the workbook while referring to Figure 4.1. Add the following:]

EXCEL is one tool that can be used to calculate an equation for the relationship. Please note that actual field data is not likely to be as easy to interpolate as this example and will probably have more scatter. The resulting equation will not necessarily be linear.

[Review the remaining information in the workbook.]

Example

Let's review a second example.

[Review the information in the workbook.]

[Review the remaining information in the workbook.]

Advantages and Disadvantages

We have discussed three different control strategies: single setpoint, variable setpoint, and setpoint interpolation. Now we will review the advantages and disadvantages of each of these strategies.

[Review Table 4.1 in the workbook.]

Automation

Our discussion of control strategies is now complete. Now let's spend a few minutes talking about automation of system controls.

[Review the information in the workbook.]

[Review the remaining information in the workbook.]

Operational Tasks

Next we will review some of the operational tasks that need to be completed daily, weekly, monthly, and semi-annually.

[Review the information in the workbook.]

Reactor Startup and Shutdown

Startup and shutdown of a UV disinfection system are another important aspect of its operation. We will now review some of the procedures for both of these tasks, beginning with startup.

Startup

[Review the information in the workbook.]

Shutdown

Now we will review some of the shutdown procedures.

[Review the information in the workbook.]

Winterization

The final operational issue we need to discuss is winterization.

[Review the information in the workbook.]

Troubleshooting

We have now finished reviewing the operational tasks associated with a UV disinfection system. Now we are going to talk about problems that you may encounter during the operation of a UV disinfection system and how to troubleshoot those problems.

[Review the information in the workbook.]

Low UV Intensity or UV Dose

The first problem we are going to review is low UV intensity or UV dose.

[Review the information in the workbook.]

Low UV Transmittance

Now let's see what you should do if the problem you encounter is low UV transmittance.

[Review the information in the workbook. After reviewing the first item under bullet two, sub-bullet two (Check upstream processes to ensure ….), add the following:]

For example, if filter effluent turbidity is high, this would decrease the UVT.

[Review the next two items under the sub-bullet and then add:]

Increasing the coagulant dose will often improve the removal of natural organic matter. NOM absorbs UV light, decreasing the UVT.

[Review the next item and then add:]

Oxidants may include chlorine, chlorine dioxide, chloramines, ozone, hydrogen peroxide, and potassium permanganate. Be aware that increasing the dose of some of these oxidants may increase production of disinfection byproducts, so the likelihood of exceeding disinfection byproduct maximum contaminant limits should be evaluated.

[Review the remaining item under the sub-bullet and then add:]

Iron, ozone, and potassium permanganate will all absorb UV light, so if an excess of one of these chemicals were to remain in the water at the UV reactor, they may cause a low UVT.

[Review the remaining information in the workbook.]

Unreliable UV Intensity Sensor Readings

Another potential problem you may encounter is unreliable UV intensity sensor readings.

[Review the information in the workbook.]

High or Low Flow

High or low flow is another possible problem. Let's talk about that in further detail.

[Review the information in the workbook.]

Power Quality Problems

The next type of problem we are going to review is power quality.

[Review the information in the workbook. After the second sub-bullet, add the following:]

Normal power is 60 Hz, or 60 cycles per second. With a frequency converter, the frequency may increase to as many as 100,000 cycles per second (100 kHz). So the length of the voltage sag only needs to be fractions of a second to affect the lamp arc.

[*Review the remaining information in the workbook.]*

Monitoring, Recording, and Reporting

Now that we have completed our review of troubleshooting, we are going to spend some time discussing the monitoring, recording, and reporting requirements for UV reactors.

[Review the information in the workbook.]

Parameters

Now let's look at some of the parameters that need to be monitored.

[Review the information in the workbook.]

[Review the remaining information in the workbook.]

Examples of Off-Specification

Sometimes water will be considered off-specification. Let's look at some of the causes for this.

[Review the information in the workbook.]

On page 4-20, you will see information about additional parameters that have not been discussed yet. These parameters include power usage, water temperature, UV lamp on/off cycles, turbidity, pH, iron, hardness, alkalinity, UV intensity sensor calibration check, UVT monitor calibration check, the age of lamps, ballasts, sleeves and UV intensity sensors, the flowmeter calibration check, and failure of any equipment. Your workbook provides information regarding the recommended monitoring frequency, recommended recording frequency, and additional notes for each of these parameters. Due to time constraints, we will not review this information in detail, but it is available for you in your workbook.

SAFETY: <u>40 minutes</u>

In this final section of the unit, we will review some of the safety issues related to UV disinfection systems, beginning with UV exposure.

UV Exposure

[Review the information in the workbook.]

Electrical

Next we will discuss electrical safety issues.

[Review the information in the workbook.]

Remember the warning back in Unit 2. It can not be stressed enough, be very cautious working around electricity.

High Temperature

Next we will highlight safety issues pertaining to high temperature.

[Review the information in the workbook.]

Lamp Breakage

Lamp breakage is another safety concern. Let's examine the hazards associated with lamp breakage.

[Review the information in the workbook.]

Causes and Prevention of Lamp Breakage

Now let's spend some time talking about the causes of lamp breakage and what can be done to prevent it.

[Review the information in the workbook.]

On this page you will see a table that summarizes the possible causes of on-line lamp failure. The table also lists preventative measures that can be taken. Some of the possible causes included in this table are debris, overheating, water pressure, procedural errors, electrical issues, the cleaning mechanism, and material selection. While we do not have enough time to review this table in detail, please be aware that the information is available for your reference in your workbook.

Broken Quartz or Glass

[Review the information in the workbook.]

Mercury Release

The final safety issue we will examine is the issue of mercury release.

[Review the information in the workbook.]

We have finished this unit of the module. Now it's time to take a few minutes and complete the exercise in your workbook. We will review the correct answers when you are finished.

[Review the remaining information in the workbook. After the last sub-bullet, add the following:]

Note that for typical mercury amounts of 0.005 to 0.4 grams of mercury per lamp, anywhere from 1,100 to greater than 90,000 lamps would have to break to release one pound of mercury.

We have finished this unit of the module. Now it's time to take a few minutes and complete the exercise in your workbook. We will review the correct answers when you are finished.

[Allow participants 5 - 15 minutes to answer the questions. Then provide the answers to them, or ask for volunteers to share their answers. Be sure to clarify any misunderstood information.]

Unit 4 Exercise

1. The following data is collected during validation testing of a reactor using UV Intensity Setpoint control. What would the UV intensity setpoint be for a flowrate of 7 mgd and 2.5-log inactivation using:

Flowrate (mgd)	UV Intensity (mW/cm^2)	Log Inactivation Credit
6	3.6	2.0
6	5.3	2.5
6	6.7	3.0
8	4.9	2.0
8	7.3	2.5
8	9.7	3.0
10	6.1	2.0
10	9.3	2.5
10	13.0	3.0

a) A Single Setpoint operational strategy. ___________________________

b) A Variable Setpoint operational strategy ___________________________

Answer: a) 9.3 (max dose for 2.5 log inactivation for all flow rates)
b) 7.3 (max dose for flowrate range 6 to 8 mgd and 2.5 log inactivation)

2. Assuming a linear interpolation, the Setpoint Interpolation Operational Strategy would be:

Where: $y_2 = (y_1 + slope)(x_2 - x_1)$
Slope= 1 mW/cm2 per mgd
The liner interpolation = 6.3
The Flowrate (x_2) = 7 mgd

Answer: Rearrange to solve for y_1, which is the required UV intensity:
$y_2 = (y_1 + slope)(x_2 - x_1)$
$y_2 = (5.3 + 1)(7-6)$
$y_2 = (6.3)(1)$
$y_2 = 6.3\ mW/cm^2$

3. Match the UV control/operational strategies with their definitions.

___**E**_ 1. A UV intensity or dose setpoint is used for all flowrates and UVTs within the validated ranges. — A. UV Intensity Set point

___**F**_ 2. UV intensities would be set at a different intensity for — B. Setpoint Interpolation each flowrate.

___**B**_ 3. An equation would be developed that describes the relationships between flowrate and UV intensity.	C. UV Transmittance (UVT)
___**A**_ 4. Control method to make sure the UV intensity sensors control the reactors.	D. UV Dose
___**C**_5. Water quality parameter that has the greatest impact on the operated of the UV system. It is monitored to control the reactor.	E. Single Setpoint
___**D**_ 6. UV intensity, UVT and flowrate are used to calculate this.	F. Variable Setpoint

Multiply choice:

4. Potential problems in the UV disinfection process are: (may be more than one correct answer)
    a. Low UV intensity
    b. Low UVT
    c. Split flow
    d. Validated limits
    e. Unreliable sensor readings
    f. Power Interruptions

Answer: A, B, E, F

5. UV intensity, flow rate and _______________ must be monitored and recorded every four hours as proposed by the LT2ESWT.
    a. UV Dose
    b. Lamp outage
    c. UV Residual
    d. Lamp Breakage

Answer: B

6. Working with UV disinfection has it share of safety related issued to be concerned with. Which of the below does not apply to UV disinfection:
    a. UV exposure
    b. Chlorine Feed line leakage
    c. High temperatures
    d. Lamp Breakage

Answer: B

We have now finished unit 4. Are there any questions about the material we have covered so far before we begin unit 5?

UNIT 5 – MAINTENANCE: <u>55 minutes</u>

Display Slide 25—Unit 5: Maintenance.

At the end of this unit, you should be able to:

- Identify eight components of a UV disinfection system that should be inspected.
- Describe calibration methods for flow meters, intensity sensors, and UVT monitors.
- List three components of a UV disinfection system that require cleaning and describe how they should be cleaned.
- Identify the pertinent issues to consider when replacing lamps and sleeves.

EQUIPMENT INSPECTION: 15 minutes

In this last unit, we will discuss maintenance. Maintenance of the UV disinfection system is essential to ensure the equipment continues to provide the required level of disinfection. Maintenance includes calibration of the instruments, cleaning, inspecting mechanical and electrical components, and replacing or repairing components that have failed. Before any maintenance is performed on any component of a UV disinfection system, the power to the component should be disconnected and lockouts and tagouts put in place according to specific site procedures. Before maintenance on reactors is performed, lamps should be allowed to cool for at least 5 minutes after power is disconnected. Let's start by talking about equipment inspection. We will begin with inspection of the UVT monitor.

UVT Monitor

[Review the information in the workbook.]

UV Intensity Sensors

The UV intensity sensors also require inspection.

[Review the information in the workbook.]

Flow Meters

Next are the flow meters.

[Review the information in the workbook.]

Pressure Gauges

The pressure gauges should also be inspected.

[Review the information in the workbook.]

Leak Check

The UV disinfection system also needs to be inspected for leaks.

[Review the information in the workbook.]

Sleeves

There are several important issues regarding sleeve inspection. Let's take a look at those now.

[Review the information in the workbook.]

Cleaning System

Several aspects of the cleaning system require inspection.

[Review the information in the workbook.]

Electrical Components

Like the cleaning system, there are several components of the electrical system that should be inspected.

[Review the information in the workbook.]

EQUIPMENT CALIBRATION: 10 minutes

In this next section, we are going to talk about equipment calibration, beginning with calibration of the flow meters.

Flow Meters

[Review the information in the workbook.]

Intensity Sensors

[Review the information in the workbook.]

UVT Monitor

Another component of the system that requires calibration is the UVT monitor.

[Review the information in the workbook.]

CLEANING: <u>10 minutes</u>

So far, we have talked about inspecting the equipment and calibrating it. Next we are going to review cleaning the equipment, starting with cleaning the sleeves.

Sleeves

[Review the information in the workbook.]

Sensors

Sensors also require some cleaning.

[Review the information in the workbook.]

UVT Monitor

Like the sleeves and sensors, the UVT monitor will also need to be cleaned.

[Review the information in the workbook.]

PART REPLACEMENT: 20 minutes

We have just finished a discussion regarding cleaning of several components of the UV disinfection system. Now let's spend a few minutes discussing the replacement of parts.

[Review the information in the workbook.]

Lamps

Now let's talk specifically about replacing lamps.

[Review the information in the workbook.]

Sleeves

Next we will talk about replacing sleeves.

[Review the information in the workbook.]

Spare Parts

We will complete this section with a discussion about spare parts.

[Review the information in the workbook.]

We have finished this unit of the module. Now it's time to take a few minutes and complete the exercise in your workbook. We will review the correct answers when you are finished.

[Allow participants 5 - 15 minutes to answer the questions. Then provide the answers to them, or ask for volunteers to share their answers. Be sure to clarify any misunderstood information.]

Unit 5 Exercise

True of False:

1. Calibrating of the UVT monitors should be increased if performance records indicate consistent weekly results. T F **(False)**

2. Intensity sensors do not have to be calibrated monthly but can wait for the annual manufactures calibration. T F **(False)**

3. Pressure gauges may confirm spilt flow when individual flow meter to the reactors are not installed. T F **(True)**

4. Discoloration of the sleeves is one indicator of fouling. T F **(True)**

5. The cleaning system includes the wiper blades, drive mechanism, cleaning fluid reservoir and flow meter. T F **(False)**

6. A GFI circuit breaker will trip when there is a problem with the ballast cooling system. T F **(False)**

7. Flow meters should be taken off-line if the uncertainty of the flow meter is less than the uncertainty of the validation testing of the UV reactor. T F **(False)**

8. UVT monitors should be check against a laboratory spectrophotometer. T F **(True)**

9. When manually cleaning the sleeves, you should not use latex gloves because the latex will melt on the sleeve. T F **(False)**

10. After replacing the lamp, you will be able discard the old lamp in the regular municipal trash it you roll it in bubble wrap or heavy paper so it does not break in handling. T F **(False)**

That completes our look at UV Disinfection. Are there any questions on what we have discussed?

{Remind them of references and resources for the module.]