AN OVERVIEW OF THE UV DISINFECTION GUIDANCE MANUAL

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The UV Disinfection Guidance Manual was developed under the direction of EPA's Office of Water and was prepared by Malcolm Pirnie, Inc., Carollo Engineers, P.C., The Cadmus Group, Inc., Dr. Karl G. Linden, and Dr. James P. Malley, Jr. The purpose of the manual is to provide technical information relating to the application of UV light for disinfection of drinking water by public water systems. The manual supports two of EPA's upcoming drinking water regulations: the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), which would require certain systems to provide additional treatment for *Cryptosporidium*, and the Stage 2 Disinfection Byproducts Rule (DBP Rule), which places more stringent limits on certain disinfection byproducts.

The intended audience and objectives of the manual are:

- Provide utilities and designers with technical information and guidance on the selection, design, and operation of UV installations and the UV-related requirements for compliance with LT2ESWTR.
- Provide States with guidance and necessary tools to assess UV installations at the design, start-up, and routine operations phases.
- Provide manufacturers with testing and performance standards for UV components and systems for treating drinking water

The manual achieves these objectives through 6 Chapters and 16 Appendices. The key elements of the UVDGM are as follows:

1. Summary of LT2ESWTR and Stage 2 DBPR
2. Summary of the Principles of UV Disinfection
3. Planning and Design Aspects for UV Installations
4. UV Reactor Validation
5. Start-up and Operation of UV Installations
6. Bench-Scale and Pilot-Scale Testing
7. UV Lamp Breakage
8. Additional Reference Material

SUMMARY OF LT2ESWTR AND DBPR

Chapter 1 of the UVDGM begins with an overview of the manual and a description of each chapter and appendix. It then continues to summarize the two drinking water regulations the manual was designed to support: the LT2ESWTR and the Stage 2 DBPR. Information is presented in Chapter 1 that helps utilities determine how much treatment is required to remain in regulatory compliance. There are also several references to the complete rules for those instances when the summary information is not adequate to answer a detailed question. The regulatory information presented in Chapter 1 is supplemented by a regulations timeline in Appendix L. This timeline indicates the planning and implementation of tasks to achieve LT2ESWTR compliance for large systems (serving 10,000 or more people) and small systems (serving fewer than 10,000 people). The tasks listed include Rule Proposal, Rule Promulgation, source water monitoring, bin classification, process evaluation and planning, facility design, construction and startup, and the compliance deadline.

Chapter 1 also presents the UV dose requirements for filtered and unfiltered systems (Table 1). Note that the dose requirements presented only account for the uncertainty surrounding dose-response of microorganisms under highly controlled experimental conditions. As such, to account for other uncertainties associated with practical application of UV disinfection, the validation protocol assigns a safety factor to these dose requirements.

The methodology used to determine the UV dose requirements is presented in Appendix B. This appendix includes information on the data collected for statistical analysis, the qualitative review to determine what collected data should be included in the data sets, and the hierarchical Bayesian statistical approach used to analyze the data mathematically.

SUMMARY OF THE PRINCIPLES OF UV DISINFECTION

Chapter 2 of the UVDGM provides an overview of the UV disinfection fundamental concepts. It presents the fundamental aspects of UV disinfection with the goal of providing readers enough background information to understand the other sections of the manual.

The chapter begins with the history of UV disinfection and the fundamental aspects of how UV light is generated and propagated. Chapter 2 also presents information on the microbial response to UV light, including inactivation and repair. The basic components of UV reactors are presented with a focus on the differences between the various components (e.g., the differences between low-pressure and medium-pressure lamps and the differences between

***Table 1**. UV dose (in mJ/cm2) required by LT2ESWTR to inactivate target pathogens*

	Log Inactivation							
	0.5	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	-	-
Giardia	1.5	2.1	3.0	5.2	7.7	11	-	-
Virus	39	58	79	100	121	143	163	186

chemical and mechanical lamp sleeve cleaning). The chapter concludes with a discussion of the impacts of water quality on UV disinfection and the formation of by-products from UV disinfection. The information in Chapter 2 is supplemented by a more detailed discussion of these fundamental concepts in Appendix A.

PLANNING AND DESIGN ASPECTS OF UV INSTALLATIONS

Chapter 3 of the UVDGM provides information on planning and designing a post-filter UV installation. The design process is presented in a flowchart that directs the reader to the appropriate section within the chapter. The chapter is organized to follow the design flowchart. The following list includes issues discussed in Chapter 3:

- UV installation goals
- Potential installation locations
- Key design parameters
- UV reactor validation issues to be considered in design
- UV installation footprint and elements to be considered in the process layout
- Hydraulic constraints
- Control strategy influence on design
- Electrical power and power quality implications on design
- Equipment specification
- State regulatory agency coordination and reporting

As previously noted, the information in Chapter 3 focuses on post-filter installations of UV disinfection. However, it is also possible to use UV disinfection for other applications such as unfiltered systems, groundwater systems, and small systems. The majority of the planning and design information is valid for other installations; however, supplemental information for each system type and how it differs from the design process and considerations outlined in Chapter 3 is included in the following appendices:

- Appendix G -- Supplemental Information for Unfiltered Systems
- Appendix H -- Supplemental Information for Groundwater
- Appendix I -- Supplemental Information for Small Systems

UV REACTOR VALIDATION

UV reactor validation is critical to ensuring UV reactor performance. Validation provides confidence that the UV reactor can produce the level of inactivation desired for a given disinfection application. The LT2ESWTR outlines the basic components of UV reactor validation. Chapter 4 of the UVDGM reviews the validation requirements in the rule and uses the requirements as a framework for recommended validation procedures. Additional approaches to UV reactor validation may be used at the discretion of the State regulatory agency. The draft EPA validation approach is summarized in more detail in the article entitled "An Overview of the UVDGM Validation Protocol" in this issue of IUVA News.

The validation protocol answers the following questions:

- How is the reduction equivalent dose related to log inactivation credit?
- Does validation take place on-site or off-site?
- How are reactor hydraulics considered in the validation protocol?
- How old should UV lamps be when the reactor is validated?
- Which organism should be used as the challenge organism during testing?
- What additives can be used to decrease the UV transmittance for testing?
- What are the procedures for microorganism preparation?
- What is the procedure for collimated beam testing?
- How is a full-scale biodosimetry test performed?
- How should the data be analyzed?

The validation protocol outlined in the UVDGM has two tiers. Tier 1 has a predetermined safety factor that is applied to the UV dose requirements listed in Table 1. Tables 2 and 3 present the resulting UV dose requirements when the required dose is multiplied by the safety factor for low and medium pressure UV lamps. The Tier 1 safety factors are based on assumed uncertainties and corrections. As such, the validation conditions should meet the criteria specified in the UVDGM in order for results to be practical. Tier 2 allows the user to calculate a reduced safety factor using site specific and detailed knowledge of the UV installation, its equipment, and the testing conditions. The derivation of the Tier 1 validation safety factor is presented in Appendix F along with the method for calculating the Tier 2 safety factor. EPA also developed a spreadsheet tool that can be downloaded from their website (www.epa.gov/safewater/lt2/) to assist the user in developing an appropriate Tier 2 safety factor.

Appendix C provides detailed examples of how to complete a validation with either a Tier 1 or Tier 2 approach. Other appendices that contain information related to validation are Appendix D (Microbiological Methods) and Appendix E (Collimated Beam Apparatus).

START-UP AND OPERATION OF UV INSTALLATIONS

Chapter 5 of the UVDGM provides information on the start-up activities and routine operating procedures associated with a UV disinfection installation. The chapter describes the final inspection and functional testing, including verification of mechanical operation, monitoring equipment, instrumentation and control systems, and flow distribution and headloss. The chapter also provides the requirements and recommendations for operating and maintaining UV facilities. The only operational requirement of the LT2ESWTR is that unfiltered systems using UV disinfection for *Cryptosporidium* inactivation credit must demonstrate that at least 95 percent of the water delivered to the public during each month must be from reactors operating within validated conditions. Although there is no specific requirement for filtered systems, it is recommended to minimize the water delivered by reactors that are operating outside of their validated limits.

Table 1. *UV dose (in mJ/cm2) required by LT2ESWTR to inactivate target pathogens*

	Log Inactivation							
	0.5	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**
Cryptosporidium	6.8	11	15	21	28	36	-	-
Giardia	6.6	9.7	13	20	26	34	-	-
Virus	55	81	110	139	169	199	227	259

Table 3. Tier 1 RED targets for UV reactors with MP Lamps (in mJ/cm2)

	Log Inactivation							
	0.5	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**
Cryptosporidium	7.7	12	17	24	32	42	-	-
Giardia	7.5	11	15	23	30	40	-	-
Virus	63	94	128	161	195	231	263	300

The following operational and maintenance tasks are described in Chapter 5:

- Routine start-up
- Routine shutdown
- Calibration of UVT monitors, UV intensity sensors, and flow meters
- Checking the reactor, lamp sleeves, and wiper seals for leaks
- Checking the cleaning efficiency
- Checking the cleaning fluid reservoir (if applicable)
- Replacing UV lamps and disposing used lamps
- Replacing lamp sleeves

Chapter 5 concludes with a section that describes the monitoring, recording, and reporting of UV installation operational data. According to the LT2ESWTR, utilities must monitor each reactor to determine whether it is operating within validated conditions and calculate the percentage of flow that was treated within validated limits. Monthly monitoring of UV intensity sensor calibration also is required. The monitoring parameters required depend on the dose control strategy used and the validation results. It is recommended that all required monitoring parameters be monitored continuously for each UV reactor and recorded at least once every four hours. For installations in which this frequency is not practical, the utility should work with the State to develop an approved monitoring plan. Reports must be submitted to the State on a monthly basis. The reports must include the percentage of off-specification flow and the percentage of UV intensity sensors that were checked for calibration. Example monthly compliance forms are included in Appendix M of the UVDGM.

BENCH-SCALE AND PILOT-SCALE TESTING

In addition to providing information for full-scale design, validation, and operation of UV disinfection installations,

the UVDGM also provides information on preliminary evaluation of UV disinfection. The most carefully controlled experiment for evaluating UV disinfection effectiveness for a given microorganism and water quality is to perform bench-scale collimated beam testing. A protocol for performing this test is presented in Appendix E. This protocol outlines the design of the collimated beam test stand, how to calculate UV dose delivered to the test organism, quality assurance and control recommendations, and the components of the collimated beam testing report.

Pilot-and demonstration-scale testing can be used to achieve the following objectives as described in Appendix J:

- Gain operational experience
- Assess lamp sleeve fouling
- Evaluate cleaning systems
- Measure headloss
- Determine the effects of lamp aging
- Evaluate controls and alarm systems

UV LAMP BREAKAGE

The last key element of the UVDGM is a discussion of the issues associated with UV lamp breakage. There are concerns relating to lamp breakage because most of the commercially available UV lamps contain mercury. Appendix N addresses regulations that may apply to breaking UV lamps in water treatment plants, including the maximum contaminant level for mercury established by the Safe Drinking Water Act, operator exposure limits as defined by the Occupational Safety and Health Administration, and disposal considerations for UV lamps as defined in the Universal Waste Rule. The appendix also discusses the amount of mercury in lamps and the potential fate of mercury after lamp breakage. Lastly, the differences between on-line and off-line lamp breakage is presented along with causes of lamp breakage and clean-up procedures.

ADDITIONAL REFERENCE MATERIAL

In addition to the major chapters and appendices, the UVDGM provides additional reference material. Chapter 6 of the manual contains a list of nearly 50 articles, books, and references cited in Chapters 1 through 5 of the manual. In addition, each appendix contains its own reference list. The introduction to the UVDGM contains a glossary for UV disinfection related terminology and also a list of acronyms and abbreviations used throughout the manual.