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ULTRAVIOLET RADIATION FOR DISINFECTION OF WASTEWATER EFFLUENT

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ULTRAVIOLET RADIATION FOR DISINFECTION OF WASTEWATER EFFLUENT

1. Purpose. The purpose of this Public Works Technical Bulletin (PWTB) is to transmit information on the use of ultraviolet radiation for disinfection of wastewater treatment plant effluent.

2. Applicability. This PWTB applies to all Corps of Engineers Districts and Department of the Army installations responsible for construction, and operation and maintenance (O&M) of wastewater treatment plants.

3. References.

a. Public Law 100-4, Clean Water Quality Act (CWA) of 1987.

b. AR 420-49, Utility Services, 28 May 1997.

c. MIL-HDBK-1138, Wastewater Treatment Systems Operations and Maintenance Augmenting Handbook, 31 October 1997.

4. Discussion.

a. AR 420-49 prescribes policy, responsibilities, and procedures for operating wastewater treatment facilities in a manner that protects public health and the environment.

b. Disinfectants most commonly used for wastewater treatment plant effluents include chlorine, ozone, chlorine dioxide, calcium hypochlorite, sodium hypochlorite, and ultraviolet (UV) radiation. Among these, chlorine is one of the most widely used disinfectants.

c. Public and environmental safety concerns have led to more stringent permit levels for chlorine and have resulted in an increasing interest in alternative disinfection methods for water and wastewater treatment. Lower operational costs, ease of operation, and no residual toxicity make UV disinfection a favorable alternative to conventional disinfection technologies. An increasing number of new wastewater treatment plants (WWTPs), existing plants with stringent permit requirements for chlorine residual, and plants where existing chlorine disinfection facilities have reached their useful life are opting for UV disinfection.

d. Installations are required to comply with increasingly stringent regulations for disposal of wastewater effluent. Part of the increased stringency is a need to provide disinfection and to reduce toxicity. Most Army WWTPs currently disinfect using chlorine, many without dechlorination. One characteristic of chlorine is its ability to increase toxicity of the effluent through chlorinated by products. This may even occur after dechlorination. Regulatory agencies are becoming more stringent in requiring total chlorine residuals near zero in new and renewed permits. Ultraviolet radiation can provide adequate wastewater effluent disinfection without increasing its toxicity, and can provide zero chlorine residual, at costs competitive with chlorination/dechlorination, currently the most widely used option. Appendix A provides more detailed information on the use of UV technology, system components, system design, and operational considerations.

5. Points of Contact. Questions and/or comments regarding this subject that cannot be resolved at the installation level should be directed to: U.S. Army Corps of Engineers, Installation Support Division, ATTN: CEMP-IS, 7701 Telegraph Road, Alexandria, VA 22315-3862, or: U.S. Army Construction Engineering Research Laboratories, PO Box 9005, Champaign, IL 61826-9005, ATTN: CECER-UL-T/Mr. Richard Scholze, Telephone: 1-800-USACERL, ext. 5590, or comm. (217) 398-5590, e-mail: r-scholze@cecer.army.mil, FAX: (217) 398-5564.

FOR THE DIRECTOR:

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APPENDIX A
Ultraviolet Light for Disinfection at Army Wastewater Treatment Plants

1. Background.

a. Disinfection. Disinfecting wastewater effluents kills disease-causing or "pathogenic" microorganisms found in wastewater effluent. Pathogenic organisms that most concern us are enteric bacteria, viruses, and intestinal parasites. These pathogens can cause such diseases as: salmonellosis, cholera, dysentery, gastroenteritis, infectious hepatitis, polio, giardiasis, cryptosporidiosis and many others.

(1) Disinfection improves water quality for subsequent downstream use (water supply, irrigation, swimming, growing shellfish, etc.). Adequate disinfection ensures that wastewater effluents are uncontaminated and safe for downstream water use.

(2) Regulatory agencies use a variety of methods to monitor the disinfection processes at wastewater treatment plants (WWTPs). Such methods help maintain adherence to design standards. In addition, the WWTP's National Pollutant Discharge Elimination System (NPDES) permit commonly requires compliance with specific water quality discharge or receiving water limitations. These limitations can vary depending on the different State regulations and on the characteristics of the particular receiving water body. The requirements may apply to average or peak flows, either in the present or the foreseeable future. Many regulatory agencies are increasing the requirement to use effluent coliform monitoring.

b. Disinfection Options. There are currently a number of alternatives for disinfection of wastewater effluents. Chlorination is the most common, primarily by application of chlorine gas. However, in recent years, alternative methods are more widely used. Ultraviolet (UV) radiation is one such disinfection agent currently coming into wider use.

c. Problems with Chlorination.

(1) The emergence of UV radiation as an important wastewater disinfection alternative may be attributed to the drawbacks of conventional chlorination, improvements in UV technology, and advances in understanding the UV process. The major problems associated with chlorination are effluent toxicity and safety. Residual chlorine may be effectively eliminated by

dechlorination (as is required in most new discharge permits), but, in some cases, effluent toxicity may remain.

(2) Chlorine is usually applied in a gaseous form, although other forms of chlorine are increasingly in use. Although few accidents have occurred with gaseous chlorine, it does represent a potential hazard to human health and the environment. As a result, the Uniform Fire Code (UFC) has been amended such that containment and scrubbing facilities are required in locations that use gaseous chlorine applications.

(3) Requirements for dechlorination and containment facilities have increased the cost of chlorine-based disinfection in comparison with UV disinfection (Table A1). At the same time, the development and application of open-channel, modular systems have reduced the cost of UV disinfection. Consequently, the costs of the two processes are comparable for new facilities. Cost calculations are discussed in more detail in Section 5

(4) The frequency of UV use has increased. By 1990, more than 500 WWTPs had adopted UV disinfection. Today, more than 1500 WWTPs in North America have chosen UV radiation for wastewater disinfection.

(5) Limitations on effluent chlorine residuals are becoming more common in many areas of the United States as new permits are being issued or reissued.

(6) Effluent toxicity may need to be evaluated at new and existing wastewater treatment plants. Chlorine disinfection without dechlorination typically produces a high level of acute toxicity in the receiving waters. Where dilution is inadequate to mitigate this effect, or where effluent standards require zero or near-zero chlorine residual at the point of discharge, UV or some other alternative is required.

(7) Chlorination of organic materials in effluents may produce carcinogenic compounds. Few regulatory agencies have established effluent limitations for these compounds. If the treated wastewater effluent enters a downstream potable water supply intake, the chlorination facility design should be optimized to minimize potential halogenated compounds from entering the intake. If there is a significant problem with effluents, the facility should compare the advantages of reducing concentrations of halogenated organic compounds by using alternative disinfectants to the monetary costs associated with the change in disinfection method.

Table A1

Capital Cost Comparison: UV Disinfection vs. Chlorination/Dechlorination System

Flow (MGD)		UV Disinfection System		Chlorination/Dechlorination System				
					Estimated Capital Costs			
ADWF**	PWWF***	No. of UV Lamps	Total Estimated Capital Cost †	Design Chlorine Dose	Chlorin-ation	Dechlorin-ation	Safety-Related Requirements †	Total Estimated Capital Costs
1	2.25	80	$115,000	5	$410,000	$290,000	$239,000	$1,127,000
10	20	704	$836,000	5	$1,804,000	$264,000	$264,000	$3,137,000
100	175	6048	$6,048,000	5	$10, 131,000	$1,031,000	$788,000	$14,340,000

* Source: Water Environmental Research Foundation (1995)
** Average dry weather flow
*** Peak wet weather flow
† Includes construction and ancillary equipment costs.
†† As mandated by the Uniform Fire Code

(8) Other important criteria include the reliability and effectiveness of both old and new methods. In general, risks to public health from a less-than-optimal disinfection system would probably be greater than risks associated with higher levels of halogenated compounds in the effluent.

2. Ultraviolet Radiation.

a. Ultraviolet radiation is a physical disinfection process with several characteristics that distinguish it from chemical disinfection processes. Disinfection is achieved by inducing photobiochemical changes within microorganisms. This requires two minimum conditions:

(1) Availability of radiation of sufficient energy to alter chemical bonds.

(2) Absorption of such radiation by the target molecule (organism).

b. UV light inactivates microorganisms by directly damaging the cellular nucleic acids (DNA/RNA). In simple terms, the UV rays literally kill the "bugs" by melting their vital internal organs into jelly. The following paragraph gives a more technical explanation.

c. Low-pressure mercury lamps are usually the source of UV radiation. About 85 percent of the lamp output is at a wavelength of 253.7 nm. This radiation causes an associated energy of 112.8 Kcal/einstein, which is sufficient to induce a photochemical change in many molecular bonds. For this change to be effective, the radiation must be readily absorbed. Nucleic acids, both DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) are strong absorbers over the 240 to 260 nm range. The majority of UV-induced damage is believed to be on the bases composing the nucleic acids. Dimerization of adjacent bases on nucleic acid strands has been identified as the predominant UV interaction mechanism.

3. Equipment.

a. General. Many types and sizes of equipment are used to disinfect with ultraviolet light. Discussing maintenance for each type of unit is not within the scope of this PWTB. Each manufacturer provides instructions for operation and maintenance of its equipment. This literature is prepared specifically for a certain make and model of equipment. All instructions or manuals should be filed and kept available for use by the operators. If such literature has been lost, it can be replaced by the manufacturer of the equipment.

b. Current Ultraviolet Equipment. Original systems offered by vendors in the early 1980s consisted of enclosed chambers using either a submerged-lamp system or a noncontact lamp system. The technology evolved to a modular, submerged-lamp system installed in an open channel, which significantly improved system maintenance and afforded better hydraulics. The modular, open-channel UV system using a conventional low-pressure mercury arc vapor lamp is currently the industry standard. (See Table A2 and Figure A1.) Nearly all recent and new installations of UV systems in operation today are open-channel, low-pressure lamp systems. A recent major improvement to these systems was the development of the electronic ballast, which has been available for approximately 5 years. The current market emphasis is research and development of alternate high-intensity UV sources, which fall into two basic categories: high-intensity low-pressure lamp systems and medium-pressure lamp systems. Changes in lamp physics allow each of the new systems to provide similar germicidal performance, with substantial reductions in the number of lamps (one-eighth to one-twentieth the number of lamps) compared to conventional low-pressure lamp systems.

c. Low-pressure Mercury Lamp Systems.

(1) The low-pressure mercury arc lamp principle is used both in germicidal and standard fluorescent lighting lamps. Both produce UV radiation by means of an electric discharge through a mixture of mercury vapor and argon at a controlled subatmospheric pressure (0.007 mm Hg). In ultraviolet lamps, this occurs in a transparent tube. Fluorescent lamps use a phosphor-coated tube that converts UV light to visible light.

(2) The low-pressure mercury vapor lamp is the most common lamp used for wastewater disinfection. It has the longest performance history of the three major lamp types. This lamp has been the industry standard since the introduction of UV disinfection systems. Low-pressure mercury vapor lamps account for almost all UV installations in the United States and Canada.

(3) Two standard lamp lengths are typically used in conventional disinfection systems: the 36-in. (30-in. arc length) and the 64-in. (58-in. arc length). Both are commonly used in vertical lamp systems, while the 64-in. lamp is typically used in horizontal lamp systems.

Table A2

Ultraviolet Light Components and Their Uses

Component	**Features**	**Function**
UV radiation chamber	Flow through stream Design for plug flow	UV light contactor provides sufficient detention time for UV germicidal dose to take effect.
Control box	Remote signals, UV lamp Ballasts	Control UV reactor electrical operation and Alarm.
Ultraviolet lamp	Three-pin plug Elapsed time meter, Nonresettable in hours	Generates UV light. Records elapsed time and keeps a permanent record.
Solenoid valve	Electrically actuates	Diverts flow to standby reactor if a problem occurs.
Flow control	Weir overflow box	Maintains maximum water level over UV lamp.
Alarm	Remote warning buzzer	Indicates overflow or low UV output.
Intensity monitor	Photocell and electronic circuit	Measures and monitors the UV energy through the Water or at the lamp surface.
Indicating light	Green	Safe condition.
	Amber	Warning, low UV output. Cleaning, or lamp replacement required.
	Red	Warning: falls below the safe level.

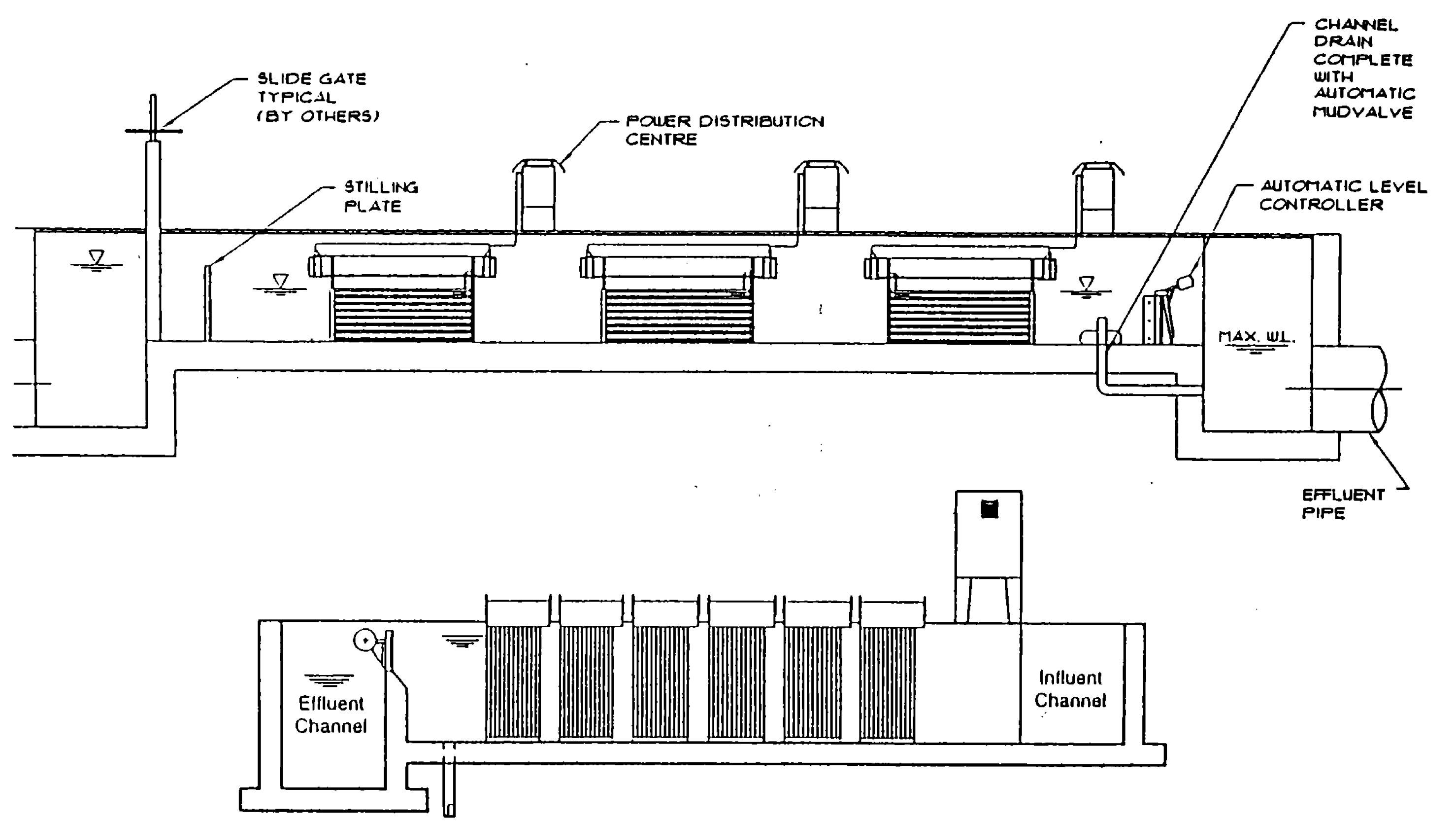

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Figure A1. Open-Channel Ultraviolet Disinfection System with Horizontal Lamp Configuration (Top); Open-Channel Ultraviolet Disinfection System with Vertical Lamp Configuration (Bottom).

(4) The introduction of electronic ballasts to drive UV lamps was a significant improvement to conventional low-pressure lamp systems. The older, conventional electromagnetic ballasts, although reliable, were inefficient and susceptible to overheating. They did not allow modulation of the power supplied to the lamps. The electronic ballasts, which have become standard and are used in most new systems today, are solid state. The electronic ballasts are significantly lighter, more compact, modular (plug-in design), energy efficient, and allow modulation of the power supply to the lamps. The electronic ballast's ability to dim lamps allows better and more cost-effective flow pacing of the UV system. However, specification and selection of electronic ballasts are not standard. Systems can vary by manufacturer. The alternate lamp systems have not, as a rule, incorporated these ballasts into their system designs. Such systems are being developed, though, and one medium-pressure lamp system has recently been introduced with an electronic ballast.

(5) While the low-pressure lamp is efficient at producing effective germicidal radiation, its output intensity is relatively low. The UV output is 0.46 W/in. of arc length. This yields standard outputs (at 254 nm) from new 36-in. (30-in. arc length) and 64-in. (58-in. arc length) lamps of 13.8 and 26.7 W, respectively. Systems require relatively large numbers of these lamps in fairly densely packed lamp banks (2- to 5-in. spacings).

(6) Low-pressure lamp systems have become increasingly reliable from both an operations and a performance standpoint, to the point where reliability is generally not a factor in comparison with other disinfection technologies. Lamps are widely available at a relatively low cost. Initially, and with the first-generation closed-shell reactors, lamp life was estimated at approximately 7,500 hours. Today, with actual operating experience and the advances in open-channel, full-submergence systems, effective lamp lives have been shown to be greater than 13,000 hours. This results in an 85 percent longer relamping interval than originally needed, yielding a significant reduction in operating costs.

(7) Low-pressure lamp systems are available in several open-channel modular configurations. However, closed-shell and noncontact low-pressure lamp systems are not manufactured for wastewater applications. Open-channel systems fall into two major categories: horizontal and vertical. A good "rule of thumb" is to allow 40 to 60 lamps per MGD.

d. Horizontal Ultraviolet Systems.

(1) Open-channel, modular, horizontal UV lamp configurations (Figure A1) are the most prevalent systems in the municipal wastewater industry. In 1990, more than half of all systems in operation were horizontal. When open-channel systems alone were considered, they outnumbered vertical systems eight to one. Although alternate lamp systems are receiving increasing consideration (especially at large installations), the low-pressure lamp configurations are usually specified, and the ratio of horizontal-to-vertical lamp placements for new systems may currently be more than 10:1.

(2) Horizontal lamp systems consist of lamp bundles suspended from modular racks in planes parallel to the channel floor. Most suppliers in the category provide systems with lamps that are parallel to the direction of process flow. Lamp bundles, referred to as "banks," consist of a number of modules that span the channel width. Because of its modular nature, a bank of lamps may contain any number of modules. The module consists of a metal support frame through which the lamp wiring runs to any number of evenly spaced quartz-jacketed lamps. In large systems, the modules typically hold either 8 or 16 lamps, and smaller systems hold as few as 4 to 6 lamps per module. Large systems are offered with UV banks mounted in "cages" so that a whole bank can be removed for cleaning. Conversely, in most smaller systems, the individual modules are removed for cleaning or maintenance. Horizontal systems are generally of multibank and multichannel design. This allows the economic use of semiautomatic to fully automatic flow pacing, and provides system flexibility to allow cleaning and maintenance tasks without a loss in system performance.

(3) The UV lamp is housed in a quartz tube in either a double, open-ended tube, or a single, open-ended test-tube-like shell. The lamp/quartz assembly is secured to the module rack by an o-ring and socket connector. Today's systems are designed with individually isolated lamps; this maintains system integrity in the event of individual lamp failure or breakage. Currently, the industry standard lamp spacing is 3 in. arranged in a uniform lamp array. Early systems were supplied with lamp spacings varying from approximately 1.5 to 4 in.

(4) Liquid level control is an important concept in horizontal systems. Level-control devices currently in use are designed to maintain a target level within approximately 0.25 in. The target level is generally the height to the top lamp plus half the height of the lamp spacing. This promotes the

distribution of a relatively uniform dose to all fluid elements being treated. The level-control device also prevents the liquid level from dropping below the top set of lamps, which would result in both safety and operating problems. The most common liquid-level-control device is the counterbalanced flap gate. Fixed and motorized weirs have also been used.

(5) Lamp cleaning of the horizontal system is accomplished by either bank or module removal to a mobile or dedicated cleaning station. The level of cleaning complexity can range from a drained area equipped with a holding rack, hose, and cleaning solution to automatic air sparging or an ultrasonic dip tank for large banks accessed with overhead hoists.

e. Vertical Ultraviolet Systems.

(1) Open-channel, modular, vertical UV systems (Figure A1) have been operating in the municipal wastewater field since 1987. Vertical systems were brought to the market as an alternative to modular, horizontal, open-channel systems, which saw their first full-scale operation at a WWTP in Canada in 1982.

(2) Vertical lamp systems consist of lamp bundles that are secured in an open rectangular frame. The frame rests on the channel bottom in an upright position (lying on one of its short faces), such that the lamps are perpendicular to the channel floor. A vertical lamp system module typically consists of 40 lamps mounted in a frame unit in an eight-by-five lamp array. Traditionally, these modules have employed a staggered lamp array, in which alternating rows of lamps are parallel to one another, but are essentially "out of phase" by one-half of the lamp spacing distance. In theory, this design should result in increased radial turbulence with minimal added axial turbulence. More recently, vertical system manufacturers have been using uniform lamp arrays.

(3) Lamp modules may be placed side by side and/or front to back to form banks. The modules require an overhead crane for removal from the channel. An important feature is that the unit can be relamped with the module in place, unlike the horizontal lamp modules. However, the entire module would necessarily need to be de-energized to permit safe servicing. Vertical systems generally use the shorter 36-in. lamps, although the 64-in. lamps have been used for larger systems. The lamp length sets the required liquid depth, which is substantially deeper than that used with the horizontal systems.

(4) Liquid-level control and system monitoring and control are similar to those found in the horizontal lamp systems. Fixed and motorized weirs are essentially the same, although the tendency toward deep, generally narrower channels would require longer fixed weirs and more active motorized weirs. The difference in counterbalanced flap gate systems is that the system generally provides a base wall. Early vertical systems afforded better flow-pacing potential because lamp rows could be turned off without reducing the areal dose of UV radiation. To maximize this advantage, vertical system manufacturers offer rapid-start lamps that allow more frequent on-off cycles than the instant-start lamps used in horizontal systems. Horizontal system flow pacing required shutting down whole lamp banks to effect energy savings. Current systems offer electronic ballasts that allow lamp dimming. Lamp dimming improves flow-pacing ability in both vertical and horizontal lamp systems.

f. Medium-Pressure Mercury Lamp Systems.

(1) Alternative sources of UV radiation are also being investigated for disinfection processes. In particular, medium-pressure mercury arc lamps have been used for some applications. The output spectrum of these lamps is substantially different from the spectrum of conventional low-pressure lamps. Radiation is emitted from these lamps over a large fraction of the UV spectrum.

(2) Medium-pressure lamps employ the same basic principle as low-pressure lamps. The major difference is that the mercury vapor emission is carried out at significantly higher lamp pressures and temperatures. The medium-pressure lamp operates in the 10^2 or 10^4 mm Hg range, which is at or near atmospheric pressure. Lamp operating temperatures range from 600 to 800 °C, which is 10 to 20 times higher than the standard operating temperature range of 40 to 60 °C for low-pressure lamps. Unlike with the low-pressure lamp, the wastewater temperature has no impact on the medium-pressure lamp operating temperature.

(3) Physical differences characterizing medium-pressure lamps include a thin molybdenum foil that connects the electrodes and external connections, and external coating of the lamp ends with a reflective, heat-resistant material. The external coating is used to maintain lamp temperature, thereby preventing mercury condensation. This is critical because, in contrast with low-pressure lamps (in which only a portion of the mercury is vaporized), all of the mercury in a medium-pressure lamp is vaporized. The pressure remains constant and is fixed by the amount of mercury in the lamp.

(4) The UV output of a medium-pressure lamp is 50 to 80 times higher than the output of a low-pressure lamp. Ultraviolet output is typically on the order of 23 to 36 W/in. arc length. However, the radiation produced is polychromatic and ranges from the lower end of the germicidal range (200 nm) to red visible light (approximately 700 nm). While the 30 to 40 percent conversion of input energy to radiation is similar to that of low-pressure lamps, only approximately 25 percent of the energy is in the germicidal range. The net effect is that the conversion of input energy to germicidal energy is 5 to 7 percent for medium-pressure lamps, compared to 30 to 35 percent for low-pressure lamps.

(5) The typical arc length of a medium-pressure lamp is roughly one-fifth that of the standard 64-in. (58-in. arc length) low-pressure lamp. When accounting for the shorter lamp length, higher intensity, and lower conversion to germicidal energy, the theoretical UV output is 8 to 16 times greater than that of a low-pressure lamp.

(6) Medium-pressure lamps have a rated life of 4,000 hours, although experience has shown an expected life exceeding 8,000 hours. The actual lamp life depends on lamp operating power. A higher operating power results in higher lamp temperatures and lower lamp life. Because of their currently limited market, the lamps are significantly more expensive, and their availability is limited (from manufacturers only).

(7) The major advantage of the medium-pressure system is the lower capital cost of installation. The expense of facility requirements for a medium-pressure system is 10 to 20 percent that of a low-pressure system. The cost savings are realized through reduced construction and installation costs. Equipment costs vary from marginally lower to marginally higher. (Medium-pressure lamp costs range from $300 to $500 per lamp.) As the number of applications increases, lamp price discounts can be expected. A second advantage is the decreased requirement for lamp cleaning resulting from the significantly reduced number of lamps. Additionally, manufacturers of these systems provide automatic lamp-cleaning systems that further reduce cleaning efforts. Medium-pressure systems are attractive to facilities with peak flows above 10 mgd, where lamp cleaning is a concern.

(8) The major disadvantage to medium-pressure systems is their high operation and maintenance costs (exclusive of lamp cleaning). These systems cost more in energy to operate because of their inefficient energy conversion. Maintenance costs relating to lamp replacement are high. Actual relamping costs

are marginal, but the medium-pressure lamp replacement cycle is 10 to 40 percent shorter than that of conventional low-pressure lamp systems. However, when relamping labor is considered, the cost difference may well be minimal.

(9) Experience with medium-pressure lamp systems is limited, but increasing. More than 50 such systems have been installed in the past 4 years. However, these systems are being considered for installation in ever-increasing numbers. Army applications are possible, and should be considered on a case-by-case basis. In general, medium-pressure systems are most appropriate for larger systems (greater than 10 mdg). Army systems are commonly much smaller.

(10) Lamp replacement in the second system requires removal of the lamp module from the reactor. This would require taking the unit out of service. Lamp replacement in the first system can be accomplished with the system on line. Lamps are accessed through watertight ports in the chamber wall, with all electrical connections made outside the chamber. Monitoring and control of medium-pressure lamp systems are similar to those employed in low-pressure systems. The lamps have more than one power setting, which allows added flow-pacing capability and increased lamp life.

g. Low-Pressure, High-Intensity Systems.

(1) The aim of the low-pressure, high-intensity lamp is to incorporate the beneficial features of the conventional low-pressure and medium-pressure lamp systems, specifically, the nearly monochromatic germicidal light produced by conventional low-pressure lamps and the high-intensity levels characteristic of medium-pressure lamps. The low-pressure, high-intensity lamp uses a high-current discharge technique that allows operating pressures in the 10^{-2} to 10^{-3} mm Hg range. The actual operating pressure is as much as 40 percent higher than that of its conventional counterpart. Operating temperatures for high-intensity lamps are in the 180 to 200 °C range, five times higher than those of conventional lamps. The high-intensity lamp is driven by currents as high as 5 amps, 10 to 15 times higher than those of conventional low-pressure lamps.

4. Design.

a. Overview.

(1) The majority of UV disinfection systems today use an open-channel, modular design. Two principal lamp geometries have

been adopted: horizontal, uniform arrays with flow directed parallel to lamp axes, and vertical, staggered arrays with flow directed perpendicular to lamp axes (See Figure A1). The horizontal lamp orientation has been adopted in the majority of applications, although both can provide acceptable levels of disinfection.

(2) Ultraviolet disinfection units, with their high length-to-width ratios, are designed to closely follow a plug-flow pattern (where liquid particles pass through the tank and are discharged in the same sequence in which they enter). Inlet and outlet conditions for these reactors are important because of relatively short detention times in the reactor unit. Maximization of radial mixing (mixing perpendicular to flow) is a desirable feature of these disinfection units. This is unique to UV radiation reactors because radiation dose is proportional to the distance from the radiation source. Monitoring UV dose is therefore difficult.

(3) From the perspective of hydraulic behavior, the critical issues in UV system design are promotion of "plug-flow-like" conditions and minimization of head loss. Mixing and head loss behavior will both be governed by the geometry and hydraulic loading of the system. Therefore the optimal design should achieve acceptable levels of longitudinal dispersion and head loss.

(4) Lamp arrays dominate mixing behavior within the irradiated zone. In terms of facility design, the most critical factor in minimizing short-circuiting may be the geometry of inlet and outlet structures. These structures should be designed to promote uniform velocity profiles (plug flow) both upstream and downstream of the irradiated zone (Figure A2). In multichannel systems, these structures must also serve the purpose of facilitating uniform flow distribution between channels.

(5) A number of strategies have been used to achieve these performance goals. Inlet flow conditioning is achieved through the application of hydraulic structures, such as stilling plates (Figure A3) and submerged dams. These structures impose a controlled energy loss on the system influent and are effective in achieving an even distribution of momentum throughout the channel. By positioning the inlet structures far enough upstream from the irradiated zone, flow irregularities caused by the inlet structure can dissipate, allowing a uniform velocity profile to reach the first bank of UV lamps.

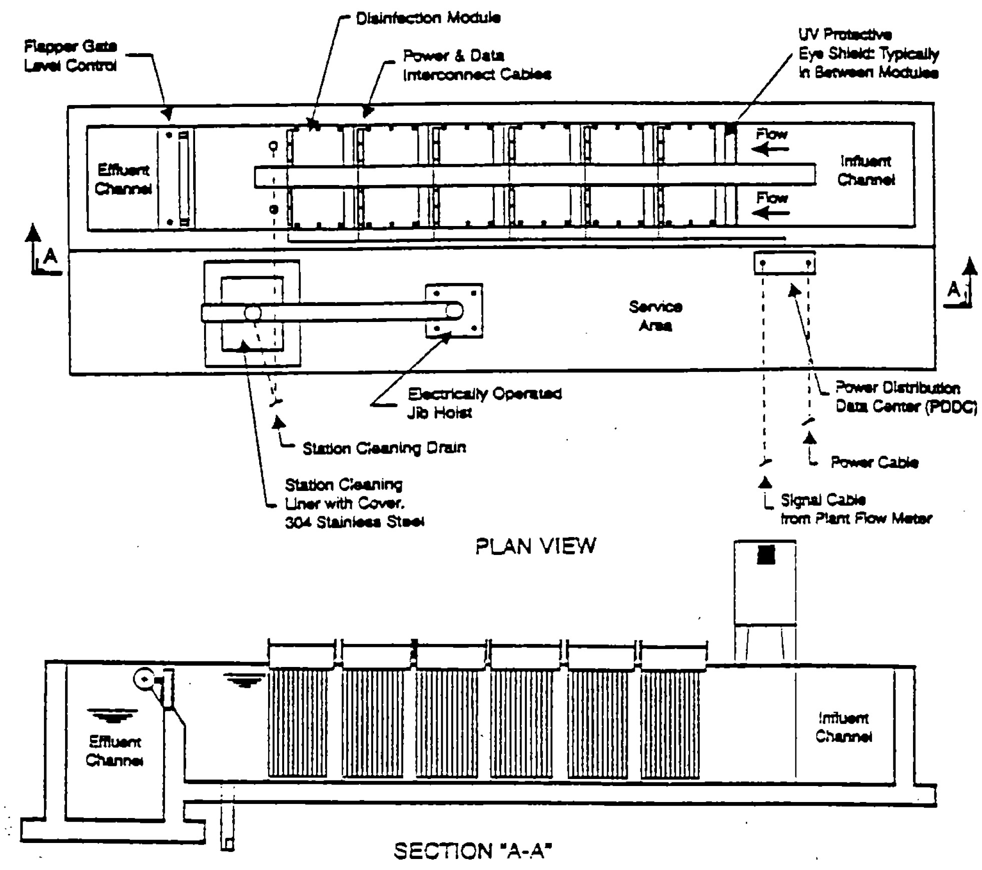

Figure A2. Lamp Modules Relative to Inlet and Outlet Structures; Lamp Modules Are Placed Far Enough Away From Flow Structures to Ensure Uniform Flow at the Entrance to and Exit From the Irradiated Zone.

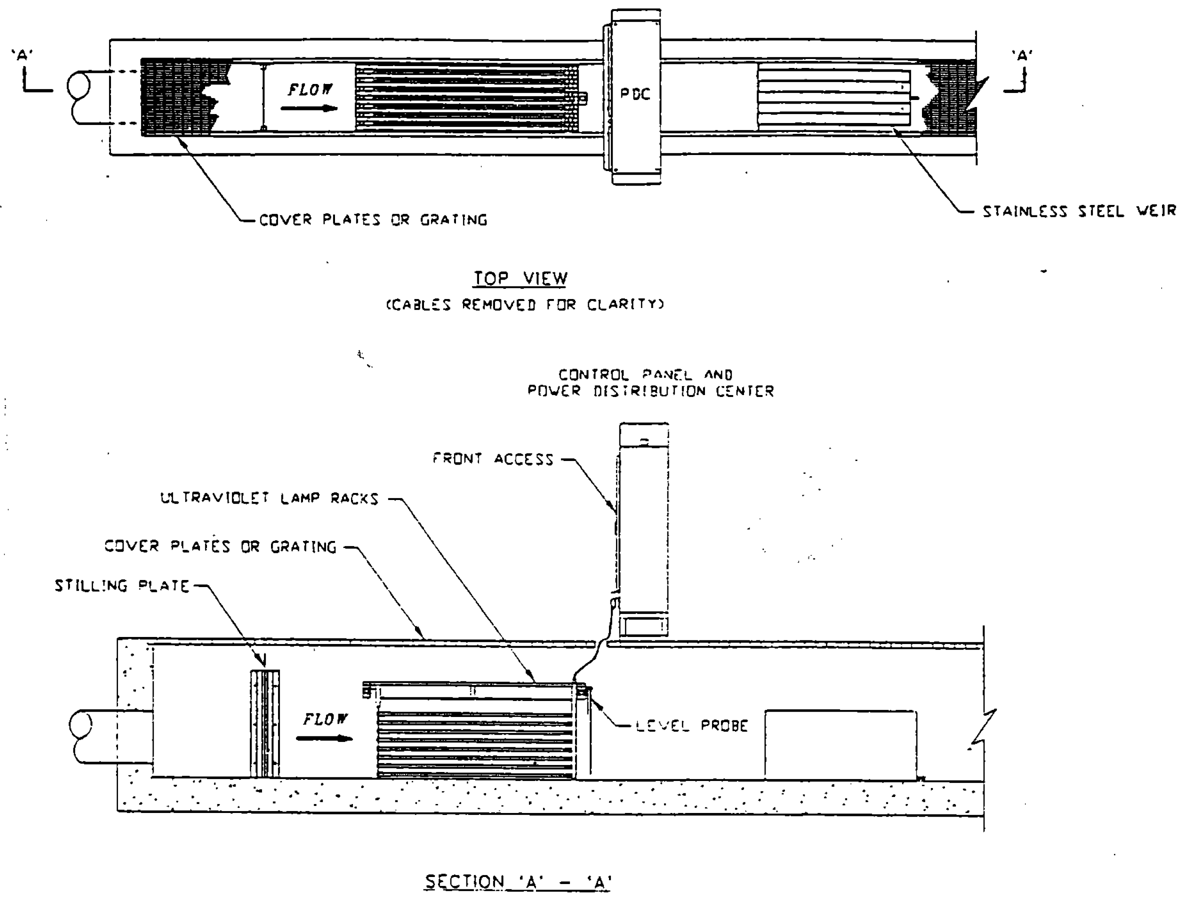

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Figure A3. Ultraviolet Disinfection System with Stilling Plate for Flow Conditioning and Elongated Weir for Level Control.

(6) Outlet structures follow a similar approach: flow patterns leaving the irradiated zone should be uniform. Outlet structures must also allow liquid level control over the range of expected flow conditions. Several alternatives have been used to achieve these performance objectives, including elongated weirs and flap gates. Flap gates are usually used on larger systems. Elongated weirs have the advantage of containing no mechanical components. They are often used on smaller systems. Elongated weirs also have potential advantages for systems with low

overnight flows because they are less likely to allow channel draining than flap gate systems.

(7) The placement of inlet and outlet structures relative to lamp arrays is critical to achieving uniform flow.

b. Head Loss.

(1) Head loss in open-channel UV systems is manifested as a drop in the free water surface through the system. In terms of power consumption, the energy loss in these systems is inconsequential compared with other losses in a WWTP. However, the drop in the free surface can induce operational problems in the disinfection process. If the liquid level is set such that the downstream free surface is coincident with the top of the irradiated zone, then some liquid on the upstream end of the system will pass through a region of low intensity. Conversely, if the liquid level is set such that the upstream free surface is coincident with the top of the irradiated zone, then a portion of the downstream lamps will not be immersed. With the diurnal fluctuations in flow experienced at most WWTPs, this allows some lamps to experience alternate conditions of immersion and dryness, which can lead to fouling of the quartz jackets surrounding the lamps.

(2) Head loss measurements have been taken at UV facilities. Empirical observations indicate that acceptable performance can be achieved by maintaining total head losses of less than 4 in. In some cases, construction of a stepped channel can minimize effects of head loss. Designers should use caution in adopting this practice for facilities where wide diurnal variations take place because of the possibility of flooding under low-flow conditions, when head losses are relatively small.

(3) Energy (head) losses in UV systems are a strong function of approach velocity. Selection of an appropriate approach velocity represents an optimization problem. The optimum design condition will correspond to a situation in which head loss is minimized while achieving an adequate intensity of turbulence. Conventional systems with approach velocities of 5 to 50 cm/sec appear to satisfy these criteria.

c. Factors Affecting Lamp Output.

(1) For a given set of operating conditions, lamp output will govern microbial inactivation. Although the processes that govern lamp output are largely beyond the control of WWTP operators, a discussion is presented for understanding.

(2) Ultraviolet output from mercury arc lamps changes as a function of time. In general, lamps begin with a relatively high output power. Lamp output falls sharply in the first 1,000 to 2,000 hours of operation, followed by a more gradual decline up to the point of failure. The recommended operating life of a mercury arc lamp was generally in the range of 7,500 to 8,000 hours. However, lamps have been operated effectively for considerably longer than this (Figure A4). The decision as to when to replace a UV lamp should consider the price of lamp replacement compared to the increased cost associated with operating aged lamps. Lamp lives have been effective for over 13,000 hours. Considering the small size of Army plants, and the relatively small number of lamps, it makes sense to replace bulbs "as needed," and to maintain a 10-20 percent supply in storage.

(3) System output can be kept relatively uniform if a schedule of staged lamp replacement is implemented. If lamps are replaced in a staged, logical, orderly manner, the system should provide relatively consistent UV output.

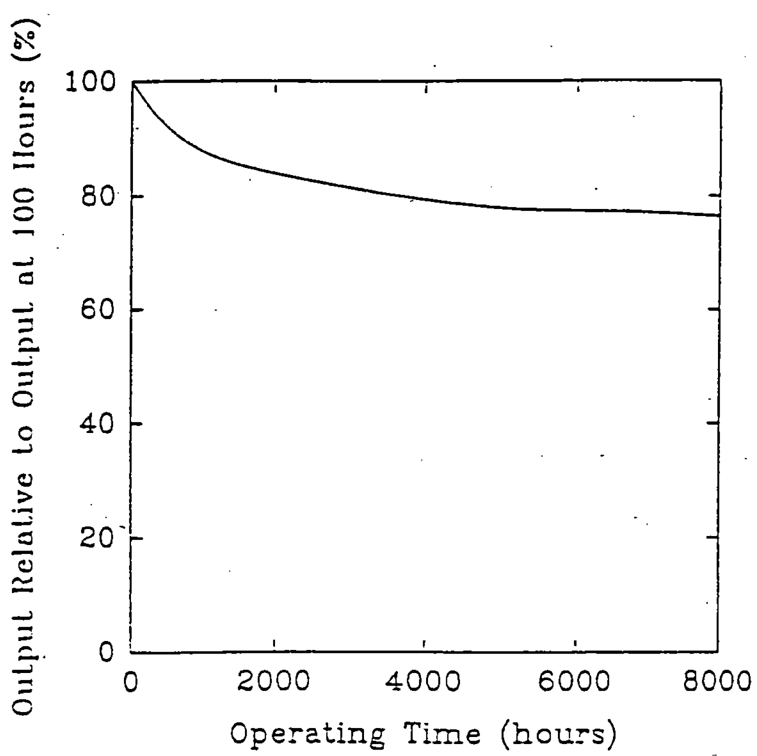

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Figure A4. Typical Ultraviolet Lamp Output as a Function of Time.

(4) Lamp wall temperature is also known to affect output with an optimal level of 35 to 50 °C. Generally, holding lamp wall temperatures between 45 and 50 °C will maintain maximum output from the lamp. This will be a function of the quartz sleeve diameter (e.g., the thickness of the air gap between the quartz sleeve wall and the lamp wall), the liquid temperature, and the power driving the lamp. The smaller the quartz diameter, the cooler the lamp will run over the typical liquid temperature operating range (5 to 30 °C). Liquid temperatures between 15 and 25 °C will typically result in lamp temperature conditions that are near optimum (greater than 85 percent maximum output), with outputs falling significantly at liquid temperatures above or below this range.

(5) The electronic ballasts currently being installed with all new systems (instead of the standard 430-mA electromagnetic ballasts) can provide variable power input to the lamps, which can affect the lamp operating temperature. (Manufacturers offer a range of ballast designs.) If liquid temperatures remain constant, higher currents will drive the lamp temperatures up, and vice versa. Therefore, the impact of liquid temperature on lamp output can be offset by the ballast input. This suggests that the lamp output can be held near optimum over a wide range of operating conditions.

d. System Sizing and Configuration Considerations.

(1) Final design of a full-scale UV system will include establishing the number of lamps required to meet disinfection requirements under design conditions. Equally critical is the manner in which lamps are configured in the full-scale design. Typically, lamp banks are arranged in series, usually two or three for horizontal lamp systems, and three to six for conventional vertical lamp systems. Both horizontal and vertical flow options are acceptable. Traditionally, most installations have been horizontal. Preference is up to the user or designer. Furthermore, it is preferable to design the system with relatively long, narrow channels to encourage plug flow and avoid any degree of short-circuiting. As a screening guideline, an average design sizing of 37 conventional 1.5 m lamps per million gallons per day of peak design flow may be used (USEPA, 1992). Note that this average is based on a wide range of applications. Any specific WWTP size will depend on conditions and effluent quality.

(2) Hydraulic design is a critical factor to consider when laying out the full-scale system. Ineffective hydraulic design can cause the system to fail to meet disinfection requirements.

Closed-shell systems using conventional lamps, which were widely used in earlier UV installations, often experienced performance problems because of poor hydraulic behavior. The current practice of designing long and narrow open channels mitigates these concerns.

(3) In designing the channel to house the UV modules, it is important to include proper inlet and outlet structures and to consider approach and exit conditions. Upstream, a perforated stilling plate can be installed if sufficient head is available. This distributes the flow and equalizes the velocities across the cross section of the channel. The stilling plate should be placed at least 5 ft in front of the first lamp bank. Otherwise, the channel should have an undisturbed straight-line approach of two to three lamp lengths. There should be sufficient distance allowed between lamp banks (2 to 4 ft) and two to three lamp lengths between the last bank and the downstream level control device.

(4) Proper design practice, particularly for large systems, entails the consideration of multichannel configurations. Under these circumstances, the inlet structure must satisfy the dual requirements of inducing uniform flow and allowing even distribution of flow among operational channels. Channel inlet structures should also allow for hydraulic isolation of individual channels during low flow and routine maintenance. Operationally, the multichannel design should be controlled to maintain a minimum velocity through any one channel.

(5) In conventional low-pressure lamp systems, wastewater within the channel must be maintained at a constant level, with little fluctuation. Most designs use a mechanical counterbalance gate downstream of the lamp batteries. These are successful when operated within a specific flow range. Problems have occurred, however, when there is little or no flow. These systems are most appropriate at WWTPs where these conditions can be avoided. Larger, multichannel systems are applicable when the proper flow range can be maintained by opening and closing channels as needed. In smaller WWTPs, fixed or adjustable weir length must be provided to avoid excessive water level fluctuation.

(6) System control should be a function of the system type and the size of the WWTP. Controls should be simple. The objective of such controls is to ensure that system loading is maintained and disinfection accomplished while conserving the operating life of the lamps. This becomes increasingly important in larger systems. In smaller systems, it may be best to have the full unit in operation at all times, excluding the redundant

units incorporated into the design. Manual control and flexibility should be available as the system increases in size, enabling the operator to bring portions of the system (such as channels and banks) into and out of operation as needed to adjust for changes in flow or water quality. Automating this activity is increasingly beneficial as the system becomes larger and incorporates multiple channels.

(7) Mechanical wipers, with and without chemical cleaning capability, are provided with some systems.

(8) The reactors, channels, and related tankage should be equipped with drains to allow for complete and rapid dewatering. Drainage should be directed back to the headworks of the WWTP. A clean-water system should be permanently available for rinsing and cleaning needs. Consideration should be given to providing a bypass around the UV system, particularly in WWTPs that have seasonal disinfection requirements.

(9) Screening should be considered upstream of the UV units to remove any debris from the wastewater. Algae, in particular, have caused problems when sloughing from the upstream clarifiers and channels. Leaves and plastic debris have also been observed. These materials tend to catch on the lamps and can cause difficulties. Cleaning can present a maintenance problem. The screens can range from simple mesh inserts that are manually removed and maintained, to self-cleaning, mechanical, moving screens.

e. Retrofit Considerations.

(1) Many WWTPs are abandoning chlorination and switching to UV disinfection. Existing chlorine contact chambers offer an opportunity to cost-effectively install the equipment. The channels are simply modified with a false floor and interchannel walls to accept the equipment. Often, only a portion of the contact chamber is needed for this purpose, while the remaining portion can be used for future expansion.

(2) The most significant hydraulic constraint often encountered in retrofit applications is the available hydraulic head. This factor should be carefully considered in the design of the system. Additionally, chlorine contact tanks are relatively wide. They should be split into multiple channels to provide a high length-to-width ratio conducive to plug flow.

5. Cost Considerations.

a. A WERF report (Darby et al. 1995) compared UV radiation with chlorination. As part of that investigation, cost estimates were developed for capital and O&M of comparable systems for three different size plants, with secondary effluents at average daily wet flow (ADWF) rates of 1, 10, and 100 Mgal/day. Cost estimates were based on design and construction of new facilities only. Retrofit savings were not considered. Chlorination/dechlorination costs included provisions for Article 80 of the 1991 UFC, which requires treatment systems to handle the accidental release of chlorine and sulfur dioxide gas, as well as emergency power sufficient to operate the chemical scrubbing equipment. Costs were annualized over 20 years at 8 percent interest. Table A3 lists capital costs for UV disinfection systems. Table A4 lists O&M costs for UV systems. Note that costs presented in these tables represent estimates based on the design and construction of new disinfection facilities.

b. Capital and O&M costs for chlorination/dechlorination systems were also developed in the report (Table A5) for comparison with UV system costs. The range reflects the variety of variables that enter the considerations: wastewater quality, bacterial discharge criterion, and flow rate. Table A6 lists unit costs for chlorination/dechlorination facilities for ADWF of 1.0 and 10 mgd.

Table A3

Capital Costs for UV Disinfection Systems

		Value*	
Item	**Unit**	**Range**	**Typical**
UV lamps			
1 - 5 Mgal/d	$/UV lamp	397-1365	575
5 - 10 Mgal/d	$/UV lamp	343-594	475
10 - 100 Mgal/d	$/UV lamp	274- 588	400
> 100 Mgal/d	$/UV lamp		375
Construction cost for physical facilities	% of UV lamp cost	75-200	150

* Based on an ENRCC Index of 5,210
From :"Comparison of UV radiation to Chlorination: Guidance for Achieving Optimal UV Performance," Water Environment Research Foundation Final report, Darby et al., 1995, p 5-3.

Table A4

Operation and Maintenance Costs for UV Disinfection Systems

Item	**Unit**	**Unit Cost**	**Cost per Year ($/Lamp *)**
Electrical power	kWhr	0.08	29.78
Lamp replacement	Each	40.00	14.60
Ballast replacement	Each	80.00	4.00
Sleeve replacement	Each	40.00	4.00
Chemicals, etc.	Per lamp/yr	5.00	5.00
Staffing	Per hour	36.00	18.00-27.00
Misc. Equipment			10.00-14.38
Repair			
Total			85.38-98.76

* Based on 1993 ENRCC Index of 5,210
From "Comparison of UV Radiation to Chlorination: Guidance for Achieving Optimal UV Performance," Darby et al., Water Environment Research Foundation Final Report, 1995. p 5-4.

Table A5

Comparison of Total Annualized Costs for UV Radiation and Chlorination/Dechlorination Disinfection Systems

Flow Rate (ADWF Mgal/d)	Range in Total Annualized Costs ($1000)*	
	UV Radiation	Chlor./Dechlor.
1	19.6 - 106	164 - 206
10	153 - 827	478 -781
100	1,132 - 6,228	2,120 - 2,820

* Costs are planning/reconnaissance estimates with +50/-30 percent range of variability in accordance with the American Association of Cost Engineers.
Source: "Comparison of UV Radiation to Chlorination: Guidance for Achieving Optimal UV Performance," Darby et al., Water Environment Research Foundation Final Report, 1995, p 5-11.

Table A6

Unit Costs for Chlorination/Dechlorination Facilities for Average Dry Weather Flows of 1.0 and 10 mgd (2.25 and 20 Peak Wet Weather Flow)

Item	Unit	Unit Cost, $1000*					
		1.0 (2.25) mgd			10 (20) MGD		
		Chlorine dose (mg)/L					
		5	10	20	5	10	20
Chlorine storage building (no evaporators)	sq ft sq ft	0.18	0.18	0.18	0.20	nr	nr
Chlorine storage building	sq ft	nr	nr	nr	nr	0.22	0.22
Sulphur dioxide storage building	each	0.18	0.18	0.18	0.20	0.22	0.22
1-ton Cl_2/SO_2 scrubber	each	189	189	189	189	189	189
25-ton Cl_2/SO_2 scrubber	each	nr	nr	nr	nr	nr	nr
RR tank car unloading facilities		nr	nr	nr	nr	nr	nr
RR tracks	each	nr	nr	nr	nr	nr	nr
Offload towers	each	nr	nr	nr	nr	nr	nr
Scales	each	10.5	10.5	10.5	10.5	10.5	10.5
Automatic switchover system	each	8.8	8.8	8.8	8.8	8.8	8.8
Bulk storage tank and accessories	each	nr	nr	nr	nr	nr	nr
Chlorine evaporators	each	nr	nr	nr	27.3	27.3	27.3
Sulphur dioxide evaporators	each	nr	27.3	27.3	27.3	27.3	27.3
Gas feed room (under vacuum)	sq ft	0.18	0.18	0.18	0.20	0.22	0.22
Chlorinators and sulphonators	each	19	19	19	19	19	19
Vacuum piping to injector (Cl_2 and SO_2)		23	30	38	45	75	95
Remote Cl_2 and SO_2 injectors	each	26.3	26.3	26.3	26.3	26.3	26.3
Flow metering system	each	15	15	15	75	75	75
Control system - Cl_2 and SO_2	each	10	10	10	20	20	20
Residual sampling systems	each	12.6	12.6	12.6	12.6	12.6	12.6
Chlorine contact basin	1000 gal/d (ADWF) unit	0.12	0.12	0.12	0.12	0.12	0.12
Emergency power generator	Unit	50	50	50	75	75	75

Based on an ENROCC Index Value of 5210.
nr = Equipment not required for facility.

c. In summary, the WERF authors

(Darby et al. 1995) state that there is a large range in UV costs for a particular treatment plant flow rate, which is influenced by the particular design scenario. Chlorination/dechlorination costs are relatively insensitive to water quality. The range of costs shown indicates that UV radiation is substantially less expensive than chlorination/dechlorination, except when unusually stringent discharge criteria (23 MPN/100mL) must be met with poorer quality effluents.

d. The USEPA also sponsored an investigation that included cost analyses (USEPA 1992). Table A7 summarizes the data. The USEPA divided systems into those of less than 100 lamps and those with more than 100 lamps. As a basis, they used 1 KW of total available UV output as equivalent to 37 standard long lamps. In 1990, equipment costs for small systems were $29,700 per UV KW. Larger systems averaged $22,000 per UV KW. Capital costs were developed by adding construction costs of $29,100 per UV KW to the equipment costs for a total of $58,800 per UV KW for small systems. Large systems had a construction component of $17,000 per UV KW totaling $39,000 per UV KW for capital costs. Lamp estimate costs were $60 each, quartz sleeves $50 each, and ballasts $80 each. The report also developed O&M cost figures of $3,265 to $3,745 per UV KW per year. The caveat was also presented that there is a substantial range, dependent on site-specific conditions.

Table A7

Cost Comparison of Large and Small UV Disinfection Systems

Parameters	Small Systems (<=100 lamps)	Large Systems (>100 Lamps)
Equipment Costs per UV KW (1990)	$29,700	$22,000
Construction Costs	$29,100	$17,000
Capital Costs	$58,800	$39,000

* 1 KW of total available output = 37 standard long lamps.
Lamp costs estimated at $60 each
Quartz sleeve costs estimated at $50 each
Ballast costs estimated at $80 each
O&M costs estimated at $3265 to 3745 / UV KW / year
The USEPA notes that a substantial range in costs depend on site-specific conditions.

e. Cost information on a medium-pressure system was presented for a 27 mgd facility for 1997. Annual operating cost was $38,000, or $21.50 per million gal of secondary effluent disinfected. Power consumption was $41/day, or $8.13 per million gal treated. Lamp cost was $16,000 for 80 new lamps.

6. Operation and Control. System control varies from minimal to fully automatic. Fully automatic systems enable system control from a remote location such as a central operations center. System controls usually provide, at a minimum, system power, system hours, and lamp status indicators. Fully automatic designs can integrate flow and wastewater conditions and pace the UV system by either dimming lamps, shutting down banks, or taking channels out of service.

7. Maintenance Considerations.

a. An overriding concern in the proper maintenance of the UV reactor is to keep all surfaces through which the radiation (light intensity) must pass, clean and fully transparent. Prevention of surface fouling is critical. Insufficient cleaning can often be the primary reason for improper system performance. Proper design should include easy access to lamp modules for cleaning and maintenance. The installation should consist of an area large enough for working conditions and for handling modules taken out of the channels.

b. Current UV systems provide various methods of cleaning. Manual cleaning is sufficient for small, conventional low-pressure units. Dip tanks and racks for the individual module should be provided for manual cleaning. In larger systems, the modules are removed in banks and cleaned in a dip tank. In this case, a traveling hoist is needed for removing and handling the modules. Ultraviolet systems are designed to reduce bacteria counts to a certain allowable level depending on the receiving water quality and permit requirements. Killing effectiveness of UV light depends on intensity of the light and time in contact with the organism. Any condition that reduces either the light intensity or contact time will decrease the performance of the UV disinfection system.

c. Lamp cleaning for vertical systems is generally accomplished in a manner similar to that of the horizontal systems. Early systems offered two in-place cleaning systems, one involving the introduction of a cleaning solution into the channel followed by subsequent agitation, the other employing a mechanical wiping system. The cleaning system would require taking the unit off line to accomplish lamp cleaning. Current options include an air-scouring system that is engaged in place and under process conditions. This system is used to increase the interval between chemical lamp-cleaning cycles, which can either be done *in situ* (isolating the channel), or by transferring the module to a dip tank.

d. Two systems are currently available. Both provide automatic in-place cleaning systems. One supplies dual cleaning consisting of a mechanical wiping system and a chemical in-channel cleaning system. The mechanical wiping system provides routine physical cleaning while the chemical cleaning system accomplishes more effective cleaning (which is required less frequently). The chamber is taken out of service during chemical cleaning operations. The second system incorporates mechanical and chemical cleaning in one unit. It operates while the system is in operation without affecting disinfection performance. This is accomplished by a 2-in. wiper mechanism that circulates cleaning solution under pressure within the wiper as it moves along the lamp length.

e. Flow rate affects the contact time. Increasing the water flow rate across the UV lamps decreases the contact time and lowers the kill rate. Most UV systems are designed to disinfect at the peak flow rate. If the contact channel is short-circuited, the duration of contact will be reduced.

f. The characteristics of the wastewater passing through the disinfection channel affect disinfection performance. The quality that most affects performance is the UV ability to penetrate the water, which is defined as the percentage of UV light not absorbed after passing 1 cm of water, and which depends on dissolved and suspended matter and color. Reduced transmission lowers the intensity of the light reaching the bacteria, resulting in a decreased kill. Suspended solids can lower the UV transmission by scattering and absorbing the light. Suspended solids can also reduce the kill by encapsulating the bacteria and protecting them from exposure to the UV light. The visual clarity of the water is not always a good indicator of UV transmission since water appearing clear in visible light may actually absorb invisible UV wavelengths.

g. UV is generally considered as an alternative where the permit requires very low or no chlorine residual due to toxicity, and where UV treatment is usually compared with chlorination plus dechlorination. UV radiation most efficiently disinfects advanced treatment effluent because of this effluent's low suspended solids concentrations and low turbidities.

h. The UV light process includes several components (Table A1). Basic operation of UV systems can be found in Water

Environment Federation (WEF) Manual of Practice 11. However, the manufacturer should provide detailed individualized O&M guidance.

i. Process control variables and UV reactor efficiency depend on:

(1) Intensity of UV lamps at 254 nm

(2) Hydraulic characteristics of the reactor

(3) Exposure time

(4) Wastewater effluent quality

(5) Age of the UV lamps.

j. Lamp output should be monitored and recorded as part of the lamp history record.

k. The UV system needs a control capable of turning lamps on and off to maintain a UV intensity proportional to the flow. Operation of a secondary lamp enables checking of effluent absorbance. Other elements of a control system include:

(1) In-place intensity monitors

(2) Power meters

(3) Lamp operation indicators

(4) Elapsed time meters

(5) Lamp temperature indicators

(6) Ballast panel temperature indicators

(7) Appropriate alarms and instrumentation.

l. Conditions that the operator controls are:

(1) Output of the UV lamps

(2) Coating formation on the lamps jacket

(3) Ultraviolet transmission of the effluent.

m. The operator monitors the lamp output by measuring the intensity of the UV light. The sensor probe, located on the UV module, sends a signal to a meter on the control panel. The operator simply reads the meter to check the intensity. Correlating the indicator bacteria counts (based on laboratory analyses) with the intensity reading will indicate the degree of disinfection obtained at a given UV dosage.

n. Interfering parameters, such as color, suspended solids, turbidity, iron, organics, chlorine, and nitrates in high levels, will affect UV transmission and cause low UV lamp intensity monitor readings, but should be accounted for in system design. If turbidity or suspended solids exceed normal levels, the operator should take the necessary steps to reduce those parameters. Should any of the components of the UV system fail to operate properly, the operator needs to check the equipment and repair it promptly. A properly operating UV disinfection system must remain on-line continuously 24 hours per day. Therefore, the secondary unit should operate during maintenance of the primary unit. If the system lacks a secondary unit, the main unit must re-enter service promptly following maintenance to minimize any adverse impacts of undisinfected water on receiving waters. The permit may require State review for this option as it may be a permit violation. Redundant systems may be required, not just an option. Table A8 lists routine operational checks and possible remedies for UV equipment.

o. The reactor should be equipped with a system drain and have the capability of isolating modules. A complete backup capability is needed to avoid impairing system efficiency during either preventive or corrective maintenance. Lamps and ballasts must be accessible. A spare parts inventory needs to include lamps, quartz sheaths, ballasts, and other spare parts necessary to maintain the system. Records and documentation should be kept on lamp use, lamp life, and equipment replacement cycles.

p. Biological scaling of the UV surface contacting the wastewater effluent poses a severe and continuing maintenance problem. Coatings may form on the lamps of all UV systems. To ensure proper disinfection, these coatings must be removed from all surfaces including quartz jackets, inspection sight ports, and the walls of the disinfection chamber.

q. Good maintenance calls for regular inspections and cleaning.

Table A8

Routine Operational Checklist and
Troubleshooting Guide for UV Disinfection

Item	**What To Check**	**Potential Problem**	**Corrective Action**
Ultraviolet Purifier	Lamp indicators	Burned out bulb Wrong sequence	Replace as needed respective lamps indicate sequence of individual components
Intensity Meter	Indicates chamber UV intensity	Build-up on quartz jacket	Clean routinely as deemed necessary
Ultraviolet Lamps	Lamps	Burned out	Replace as necessary
Intensity Monitor	Photocell and electronic circuit, indicating meter alarm condition, and pilot lights	Nonfunctional	Repair or replace
Control Box Indicator Lights	Amber bulb	Low UV output	Clean chamber or replace
	Red Bulb	Poor water quality Check processes	Clean chamber or replace
Gland Seal Assembly	o-ring	Water leaks	Tighten the gland nut to compress o-ring or replace
Electrical Service	AC volts, DC volts, Ohms AC	Over range	Use multimeter and set ranges according to Manufacturer's Recommendation
Lamp out Warning System	Circuit board	Defective	Replace
	Indicator bulb	Burned out	Replace
	Pilot Light	Burned out	Replace

r. Other preventive tasks are:

(1) Because UV lamps have limited effective lives, replace them periodically to ensure maximum performance.

(2) Use the "push to test" feature to test the accuracy of the UV intensity monitor. Observe the full-scale, midpoint, and zero response by pushing the corresponding switches. The UV photocell can be easily unplugged and removed for replacement or testing.

8. Personnel Safety Considerations. Safety centers on electrical hazards and protection from exposure to UV radiation Safety is important in the design and operation of the UV process. A human exposure risk is generally minimal as long as the operating lamps are submerged and the lamp batteries are shielded. It is generally not necessary to operate lamps in the air except under extraordinary circumstances. The advanced high-intensity lamps must not be operated unshielded in the air. All systems must be equipped with safety interlocks that shut down the modules if they are moved out of their operating positions or if the wastewater level falls, leaving any or all lamps exposed to air. Electrical hazards are minimized by including ground-fault-interruption circuitry with each module. This should be a specified feature of all systems.

9. Summary

a. UV radiation is becoming the disinfection process of choice for many municipal and military wastewater treatment plants. Costs of UV treatment are competitive with those of chlorination/dechlorination. Reliability and effectiveness of UV systems have also increased with the newer generations of equipment and the use of electronic ballasts. Among the advantages of UV treatment is freedom from hazardous gases. This can be a motivating factor for conversion, especially in highly populated areas. The ability to reduce toxicity associated with chlorine compounds for areas requiring zero effluent chlorine residual is another advantage. Other reasons for switching to UV from chlorine are that:

(1) UV systems require minimal maintenance.

(2) UV systems discharge no residuals or chemical byproducts.

(3) UV systems do not chemically or physically alter treated effluent.

(4) UV systems require no transport, storage, or handling of chemicals.

(5) UV light is generated on-site.

(6) Safety considerations for UV systems are not as intensive as for chlorination systems.

(7) UV systems are effective in treating some microorganisms that are resistant to chlorine.

b. Additional problems with chlorine systems may occur where outdated equipment and requirements for dechlorination combine to result in overdosage due to variations in flow rates.

c. Disadvantages of UV systems include the potential fouling of sleeves by wastewater, and attendant cleaning requirements. UV systems are also less flexible than chlorine systems because maximum dosage is proportional to the number of bulbs available. There is also a sensitivity to water quality characteristics. The ability of UV light to penetrate through effluent can vary with effluent suspended solids content and other factors. This ability may also vary from plant to plant, and by season.

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