Carson Dorn, Inc.
712 West 12th Street, Suite 1 Juneau, Alaska 99801

December 11, 2009

Mr. Liam Carnahan
CBJ Water Utilities Superintendent
City and Borough of Juneau
5433 Shaune Drive
Juneau, Alaska 99801

Re: Salmon Creek Water Source, EPA LT2 Treatment Requirement Evaluation

Dear Mr. Carnahan:

The City and Borough of Juneau (CBJ) water system has established water rights to withdraw about 3.5 million gallons per day of water to residents of Juneau from the Salmon Creek water source. This system has been in operation for approximately 25 years and over the years regulatory changes have periodically required upgrades to the treatment system. It is important to periodically review the performance of the water system to ensure its equipment and processes are still satisfactorily meeting the changing demands of a community and complying with State and federal regulations that ensure safe drinking water is being supplied.

Summary

Probably the most significant impact for Juneau's water system in terms of required capital construction and increased operating costs, will be complying with regulations adopted by the U.S. Environmental Protection Agency that govern unfiltered surface water sources like the Salmon Creek water source. All unfiltered surface water sources like Juneau's will need to provide additional treatment by October 1, 2013.

In 1989 the US Environmental Protection Agency adopted the Surface Water Treatment Rule (SWTR) to protect the public from waterborne diseases. The SWTR established standards for the removal or inactivation of *Giardia, Cryptosporidium* and viruses.

For CBJ's unfiltered Salmon Creek water source, inactivation of *Giardia* and viruses is currently being accomplished in accordance with the SWTR. This is done by keeping the disinfectant residual (chlorine) and contact times at concentrations and durations that are specified in the regulation. The contact times are met as the water transits a baffled water storage tank located above Salmon Creek. Water flow rates are carefully controlled to ensure sufficient contact time is achieved prior to the water reaching the distribution system and the first customer.

In 2006 the US Environmental Protection Agency adopted the Long Term 2 Enhanced Surface Water Treatment Rule, which specifically addresses inactivation of *Cryptosporidium*. *Cryptosporidium* is a parasitic protozoan that forms a protective cyst which makes it resistant to chlorine levels normally found in public water systems. *Cryptosporidium* and the disease it causes, *cryptosporidiosis*, was brought to the public's attention by an outbreak in 1993 in Milwaukee, Wisconsin. Up to 300,000 residents became ill during the outbreak and as many as 60 died. Several lawsuits were filed against the City of Milwaukee as a result of the outbreak.

The Long Term 2 Enhanced Surface Water Treatment Rule requires that Juneau and other unfiltered surface water systems (i.e. Unalaska, Ketchikan, Sitka and Kodiak) comply with the

Tel: 907 586 4447
Fax: 907 586 5917

treatment requirements for *Cryptosporidium* by either October 1, 2013 or October 1, 2014 depending on the size of the community served. For Juneau the compliance date is October 1, 2013.

Carson Dorn Inc. and its sub-consultants prepared an evaluation of alternatives for the City and Borough of Sitka to comply with the Long Term 2 Enhanced Surface Water Treatment Rule. This is a summary of that evaluation as it would apply to Juneau.

Three treatment processes have been found to be effective at inactivating Cryptosporidium, 1) UV Disinfection, 2) Ozone Disinfection, and 3) Chlorine Dioxide Disinfection. Each of these treatment processes were considered for Juneau along with two filtration options. The capital cost for each option and the annual operation, maintenance and labor were not developed as part of this evaluation of alternatives. However, the following table is a summary of a comparison of treatment alternative for a system capable of providing about 6.5 million gallons per day. While this comparison involves more infrastructure than that required by Juneau, it illustrates the clear cost advantage provided by UV disinfection for inactivation of *cryptosporidium*.

Sample Cost Comparison for Cryptosporidium Treatment
For a 6.5 MGD Water Source

Treatment Alternative	Capital Cost	Annual O&M and Labor Costs	25 Yr Life Cycle Cost
UV Disinfection	$6,450,000	$180,000	$9,100,000
Ozone Disinfection	$27,300,000	$1,270,000	$39,800,000
Chlorine Dioxide Disinfection	$34,900,000	$1,420,000	$48,900,000
High-Rate Granular Filtration	$24,100,000	$1,090,000	$34,700,000
Membrane Filtration	$46,600,000	$2,220,000	$68,300,000

EPA Surface Water Treatment Rule (SWTR)

The SWTR establishes treatment and monitoring requirements for all public water systems that use surface water. The SWTR requires that all surface water sources be treated to achieve a minimum 3-log removal of *Giardia* and 4-log removal of enteric viruses.

Juneau currently operates its Salmon Creek Water Source under the category of filtration avoidance. Because filtration is not provided, Juneau currently achieves all microbial inactivation required for SWTR compliance using chlorine disinfectant along with residence time in a baffled water storage tank located above the Salmon Creek Water Treatment Facility.

Filtration Avoidance

The SWTR requires filtration of all surface water supplies unless stringent source water quality, disinfection criteria, and site specific conditions are met. The following requirements pertain to public water systems operating under filtration avoidance (such as CBJ):

Source Water Quality Criteria

The source water prior to disinfection must have:

- Fecal coliforms ≤ 20/100 mL, or;
- Total coliforms ≤ 100/100 mL in at least 90 percent of the samples taken for the previous six months.

Furthermore, the turbidity level of the source water prior to disinfection must not exceed 5 NTU unless:

- The State determines that the event was caused by unusual or unpredictable circumstances, and;
- There have not been more than two events in the past twelve months or more than five events in the past 120 months, where an event is a series of consecutive days in which at least one turbidity measurement each day exceeds 5 NTU.

Disinfection Criteria

For filtration avoidance, CBJ's disinfection facilities must meet the following criteria:

- The calculated CT must meet or exceed the CT value stated in the SWTR.
- CBJ must have redundant disinfection components including an auxiliary power supply with automatic startup and alarm; or if approved by the State, automatic shutoff of the water supply when the residual drops below 0.2 mg/L for more than four hours.
- The chlorine disinfection concentration entering the distribution system must not be less than 0.2 mg/L for more than four hours.
- CBJ must maintain detectable disinfectant residual in the distribution system.
- Turbidity samples are to be taken at least once every 4 hours. If turbidity exceeds 1 NTU, one raw water sample must be collected for fecal or total coliform analysis.

Site-Specific Criteria

For filtration avoidance, site-specific criteria include:

- Maintenance of a watershed control program
- Subjection to an annual onsite inspection
- No history of waterborne disease outbreaks
- Compliance with the monthly MCL for total coliforms
- Compliance with disinfection by-product regulations

Watershed Protection

The SWTR also establishes watershed protection requirements for filtered and unfiltered systems. Source water protection is considered as the first barrier in a holistic approach toward reducing contaminant levels in drinking water. Because information on the inactivation of *Cryptosporidium* is still somewhat limited, watershed protection in unfiltered systems is a particularly important barrier for protection against this microbial pathogen.

Under the provisions of the SWTR, public water systems must maintain a watershed control program that minimizes the potential for source water contamination by viruses and *Giardia* cysts. The SWTR provisions state that a watershed control program must satisfy the following objectives:

- Characterize watershed ownership and hydrology;

- Identify characteristics of the watershed and activities within the watershed that might have an adverse effect on water quality, and;
- Minimize the potential for source water contamination by *Giardia lamblia* and viruses.

The public water system must demonstrate through ownership and/or written agreements with landowners within the watershed that it can control all human activities which may have an adverse impact on the microbiological quality of the source water. Both natural and human-caused sources of watershed contamination to be controlled are listed in the EPA Guidance Manual. These sources include wild animal populations, wastewater treatment plants, grazing animals, feedlots, and recreational activities.

The public water system must also undergo an annual on-site inspection to assess the watershed control program and disinfection process. A report of the on-site inspection summarizing all findings must be prepared on an annual basis.

Filtration

If Juneau is unable to maintain its filtration avoidance status as defined by the above-mentioned criteria, it will be required to install filtration facilities. Filtration technology alternatives that are currently available to Juneau include conventional granular media filters, pressure filters, and membrane filtration technology. Filtration was one of the alternatives considered.

Enhanced Surface Water Treatment Rules (ESWTRs)

The ESWTRs were issued as a supplement to the SWTR in order to provide additional microbial and disinfection controls for surface water systems. The ESWTRs were implemented in separate stages as the Interim Enhanced Surface Water Treatment Rule (IESWTR), and Stage 1 and Stage 2 Long-term Enhanced Surface Water Treatment Rules (LT1ESWTR and LT2EWSTR). These rules build upon the provisions set forth in the SWTR by providing improved public health protection against *Cryptosporidium*, while addressing risk tradeoffs with disinfection by-products (DBPs).

The ESWTRs added *Cryptosporidium* monitoring and inactivation to the watershed control requirements for unfiltered surface water systems. Other specific provisions that have an impact on Juneau include disinfection profiling and benchmarking provisions, and a requirement that unfiltered surface water systems conduct initial source water monitoring for *Cryptosporidium*.

Disinfection Profiling and Benchmarking

Juneau was required to develop a disinfection profile of the water system's disinfection practices by determining *Giardia* and virus log inactivations computed over a 1-year period based on daily operational data. The benchmark was developed by calculating average log inactivation of all the days for each calendar month, and determining the calendar month with the lowest average log inactivation. The lowest average month becomes the critical period or benchmark for that year.

Unfiltered Systems

The provisions for unfiltered systems in the LT2ESWTR are:

1) Continue to meet filtration avoidance criteria, and;
2) Provide 4-log virus inactivation, and;
3) Provide 3-log *Giardia lamblia* inactivation, and;
4) Provide 2 or 3-log *Cryptosporidium* inactivation depending on its presence in the source water. If the source water monitoring demonstrates a mean level of *Cryptosporidium*

above 1 oocysts/100 liters, then the system must provide at least 3-log *Cryptosporidium* inactivation. and;

5) Meet overall inactivation requirements using a minimum of two disinfectants.

Ongoing monitoring and any eventual reassignment to the level of additional *Cryptosporidium* inactivation requirement will be consistent with requirements for other systems of comparable size, with the provision that unfiltered systems must demonstrate that their mean *Cryptosporidium* occurrence level continues to be less than or equal to 1 count in 100 liters (or equivalent, using advanced methods), or provide a minimum 3-log *Cryptosporidium* inactivation.

In order to comply with federal regulations, the City and Borough of Juneau will be required to install additional treatment for removal and/or inactivation of *Cryptosporidium.* The primary regulatory drivers for additional water treatment are contained in the Long Term 2 Enhanced Surface Water Treatment Rule (LT2).

This letter examines the viability of five separate processes that are currently available to Juneau for treatment of *Cryptosporidium*.

Evaluation and Comparison of Treatment Options

In this letter, we evaluate five different alternatives as possible treatment methods that Juneau may consider in order to comply with the LT2 requirements for *Cryptosporidium* removal. Three of the treatment alternatives involve the incorporation of a second disinfectant to the treatment facilities for inactivation of *Cryptosporidium*. This additional disinfectant could be applied either prior to or after the chlorine injection point, and would be used in conjunction with chlorine. Two of the treatment alternatives involve the addition of filtration technology to the treatment facilities for removal of *Cryptosporidium*. The filtration methods could also be installed up or downstream of the chlorine injection point, and would be used in conjunction with existing chlorination facilities.

The treatment processes that are examined in this letter are:

1) Ultraviolet (UV) disinfection – To maintain filtration avoidance
2) Ozonation - To maintain filtration avoidance
3) Chlorine dioxide disinfection – To maintain filtration avoidance
4) Membrane filtration (MF) membrane treatment – To add a filtration process
5) High-rate granular media filtration – To add a filtration process

In order to maintain filtration avoidance status, Juneau will either be required to provide 2-log or 3-log *Cryptosporidium* inactivation in order to maintain its filtration avoidance status. Juneau has opted to install a system capable of 3-log inactivation of Cryptosporidium and forgo source water monitoring in anticipation of future events that may still require 3-log inactivation.

1-Ultraviolet (UV) Disinfection

Disinfection of drinking water using ultraviolet (UV) light has been practiced extensively in Europe and is now common throughout the United States. UV light disinfects water by rendering pathogenic microorganisms incapable of reproducing. This is accomplished by disrupting the genetic material in cells. The genetic material, namely DNA, will absorb light in the ultraviolet range—primarily between 200 nm and 300 nm in wavelength. If the DNA absorbs too much UV light it will be damaged to the point that it is unable to replicate. It has been found that the energy required to damage DNA is much less than that required to actually destroy the organism. The effect is the same however, since a microorganism cannot infect if it is unable to reproduce.

Ultraviolet light has been found to be particularly effective at inactivating the protozoans *Cryptosporidium* and *Giardia* in drinking water. In comparison, strong oxidants such as free chlorine, ozone, and chlorine dioxide are much less effective since *Cryptosporidium* and *Giardia* form cysts which are highly resistant to these chemicals. This effectiveness does not apply to viral disinfection, where chemical oxidants have been found to be much more effective for inactivation of viruses than UV light.

Properties of UV Light

UV disinfection uses electromagnetic radiation in the form of ultraviolet light to inactivate microorganisms, which is different from the mechanism that oxidant-based disinfectants use. UV disinfection is a physical process that uses photochemical energy to prevent cellular proteins and nucleic acids (i.e., DNA and RNA) from further replication. The germicidal effect of UV light is accomplished through its action on the DNA molecules to distort the normal helical structure and prevent cell replication. A cell that cannot replicate cannot infect. The range of UV electromagnetic rays covers 40 to 400 nm in wavelength. The germicidal UV wavelengths range from 200 to 300 nm with the optimum germicidal effect occurring at 253.7 nm.

UV electromagnetic energy is typically generated by the flow of electrons from an electrical source through ionized mercury vapor in the lamp. Several manufacturers have developed systems to align UV lamps in vessels or channels to provide UV light in the germicidal range for inactivation of bacteria, viruses, and protozoans. UV disinfection utilizes either low pressure lamps that emit maximum energy output at a wavelength of 254 nm, medium pressure lamps that emit energy at wavelengths from 180 to 1370 nm, or lamps that emit at other wavelengths in a high intensity "pulsed" manner.

UV light quickly dissipates into water to be absorbed or reflected off material within the water. As a result, no residual disinfectant is produced by UV light. This process is attractive from a disinfection by-product (DBP) formation standpoint; however, a secondary chemical disinfectant is required to maintain a residual within the distribution system.

Disinfection with UV Light

The inactivation of microorganisms by UV light is directly related to UV dose, a concept similar to CT used for oxidant-based disinfectants such as chlorine and ozone. The average UV dose is calculated as the product of the light intensity, I (units of milliwatts per square centimeter, mW/cm^2) and the exposure time, T (seconds). The product IT is typically expressed in units of energy per area as millijoules per square centimeter (i.e., mJ/cm^2). UV intensity is a function of

water UV transmittance and UV reactor geometry, as well as lamp age and fouling. Exposure time is estimated from the UV reactor specific hydraulic characteristics and flow patterns.
Since the UV dose is primarily based on the light intensity, water quality parameters that have the greatest effect on UV dose are turbidity and suspended solids, which have the ability to shield microorganisms from the UV light, and some organic and inorganic compounds that can absorb UV energy.

UV Disinfection Requirements for *Cryptosporidium* Inactivation

EPA published a table of required UV doses as part of the promulgated LT2ESWTR. The table specifies UV doses needed to achieve up to 4 log inactivation of *Giardia lamblia*, up to 4 log inactivation of *Cryptosporidium*, and up to 4 log inactivation of viruses.

The final LT2ESWTR provides dose requirements for inactivation of *Cryptosporidium*, *Giardia*, and viruses. The inactivation requirements contained in the dose table are as follows:

- *Cryptosporidium* inactivation: 2-log = 5.8 mJ/cm^2; 3-log = 12 mJ/cm^2
- *Giardia* inactivation: 3-log = 11 mJ/cm^2
- Virus inactivation: 4-log = 186 mJ/cm^2

Note that the dosages for virus inactivation are higher than original values listed in the Surface Water Treatment Rule because of resistance of certain viruses like Adenovirus to UV light. Although the current dose requirements for *Cryptosporidium* are less than originally anticipated (original doses in the 30 to 40 mJ/cm^2 range), the application of the Validation Factor (VF) for full-scale application means that, depending on the validation testing approach utilized for the selected equipment, the equipment size and power requirements for UV disinfection may be similar.

Disinfection By-products of UV Light

As a physical process, UV disinfection leaves no UV residual, and overdosing is not of environmental concern. Also, UV disinfection has a major advantage over chemical disinfectants in that it produces little or no disinfection by-products.

Studies have shown that there is no appreciable increase in trihalomethane (THM) or haloacetic acid (HAA) concentrations as a result of UV disinfection at doses that would be applicable in water treatment. However, low levels of formaldehydes and organic carbon may be produced in the finished water as a result of the UV treatment process at high UV doses.

UV Disinfection Process Variables

The UV process uses electromagnetic energy to inactivate microorganisms, and research indicates that typical water quality parameters such as pH, temperature, alkalinity, and total inorganic carbon do not appear to impact the overall effectiveness of UV disinfection. Hardness and iron and manganese concentrations affect the rate of lamp fouling, although automatic lamp cleaning systems incorporated in the current generation of UV equipment have minimized the impact of hardness on system design and operation.

The effectiveness of UV disinfection is mainly impacted by water quality parameters that prevent UV electromagnetic energy from reaching target microorganisms. Particles, turbidity, and

suspended solids may shield microorganisms from UV light or scatter UV light to prevent it from reaching target microorganisms. Recent studies indicate that turbidity levels up to 5 NTU (as has been allowed for unfiltered systems) do not adversely impact the effectiveness of UV disinfection. Some organic compounds (e.g., phenols, humic/fulvic acids) and inorganics (e.g., iron, manganese, nitrate) absorb energy and reduce the UV transmittance of the water being treated. Thus, UV transmittance (UVT) is commonly used as process controls at UV facilities.
UVT of water is measured by a spectrophotometer set at a wavelength of 254 nm using a 1-cm thick layer of water.

Continuous-wave UV light at doses and wavelengths typically employed in drinking water applications does not significantly change the chemistry of water, nor does it significantly interact with any of the chemicals commonly found in water. Therefore, no natural physicochemical features of the water are changed, and no chemical agents are introduced into the water.

UV Disinfection System Design

The main components of a UV disinfection system are mercury arc lamps, a reactor, and ballasts. The source of UV light is either low-pressure or medium-pressure mercury arc lamps with low or high intensities. Producing UV light requires electricity to power UV lamps. Ballasts control the power to the UV lamps.

UV Lamps

The lamps that are typically used in UV disinfection consist of a quartz tube filled with an inert gas, such as argon, and small quantities of mercury. The optimum wavelength range to effectively inactivate microorganisms is 250 to 270 nm. The intensity of the light emitted by the lamp dissipates as the distance from the lamp increases.

Both low-pressure and medium-pressure lamps are available for disinfection applications. Low-pressure lamps emit their maximum energy output at a wavelength of 253.7 nm, while medium-pressure lamps emit energy with wavelengths ranging from 180 to 1370 nm. The intensity of medium-pressure lamps is much greater than low-pressure lamps. Thus, fewer medium-pressure lamps are required for an equivalent dosage. Medium pressure lamps have approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps. The medium pressure lamp disinfects faster and has greater penetration capability because of its higher intensity. However, these lamps operate at higher temperatures with a higher energy consumption. The higher operating temperatures of medium pressure lamps compared to low pressure lamps results in a shorter lamp life.

Ballasts

Ballasts are transformers that control the power to the UV lamps. Ballasts must be kept in controlled environment in order to keep from overheating and prevent premature failure. Typically, the ballasts generate enough heat to require cooling fans or air conditioning.
Two types of transformers are commonly used with UV lamps; namely, electronic and electromagnetic. Electronic ballasts operate at a much higher frequency than electromagnetic ballasts, resulting in lower operating temperatures, less energy use, less heat production, and longer ballast life.

Reactors

Most conventional UV reactors are available in two types; namely, closed vessel and open channel. For drinking water applications, the closed vessel is generally the preferred UV reactor for the following reasons:

- smaller footprint
- no requirement for free water surface
- minimized pollution from airborne material
- minimal potential for personnel exposure to UV light
- modular design for installation simplicity

Instrumentation and Controls

Additional design features for conventional UV disinfection systems should include:

- UV intensity sensors to detect lamp output intensity
- UV transmittance sensor to monitor quality of raw water
- alarms and shut-down systems
- automatic or manual cleaning cycles.

Hydraulic Design Considerations

The major elements that should be considered in the hydraulic design of a UV closed vessel reactor are: dispersion, turbulence, effective volume, residence time distribution, and flow rate. These issues are addressed in the design of the reactor by the manufacturer. The upstream and downstream piping configuration is also important to minimize the impact of installation. Ideally, long straight lengths of pipe should be installed upstream and downstream of the reactors, on the order of as much as 10 pipe diameters upstream and 5 pipe diameters downstream. If a 90-degree bend was tested during validation upstream of the reactor, the US Environmental Protection Agency UV Design Guidance Manual recommends adding 5 pipe diameters of straight pipe upstream of the UV reactor.

Operational Considerations

UV disinfection facilities should be designed to provide flexibility in handling varying flow rates. For lower flow rates, a single reactor vessel should be capable of handling the entire flow rate. A second reactor vessel with equal capacity of the first reactor should be provided for redundancy. For higher flow rates, multiple reactor vessels can be provided with lead/lag operation and flow split capability to balance run time for each reactor vessel, and to avoid hydraulic overloading. If the plant flows do not vary significantly, then one reactor with a redundant unit may be sufficient.

For the flow rates being considered for Juneau, it appears that flows are low enough to use one online plus one redundant reactor to treat the entire range of system flow rates. For some manufacturers, two online plus one redundant may be required to meet the maximum design flow. The number and capacity of the reactors to be used is typically determined during the predesign phase.

The output of UV lamps diminishes with time. Two factors that affect their performance are: 1) solarization which is the effect UV light has on the UV lamp, causing it to become opaque, and 2) electrode failure which occurs when electrodes deteriorate progressively each time the UV lamp is cycled on and off. Frequent lamp cycling will lead to premature lamp aging. Guaranteed lamp life is determined by the manufacturer and varies for each system. Low-pressure lamps generally have a longer life than medium pressure, though specific vendor lamp life will vary.

Fouling of the quartz sleeve reduces the amount of UV light reaching the water. The quartz sleeve has a transmittance of over 90 percent when new and clean. Over time, the surface of the quartz sleeve that is in contact with the water starts collecting organic and inorganic debris (e.g., NOM, iron, manganese, calcium, silt), causing a reduction in transmittance.

Quartz sleeve cleaning may be accomplished by physical or chemical means. Physical alternatives include automatic mechanical wipers, ultrasonic devices, high water pressure wash, and air scour. Chemical cleaning agents include citric, sulfuric, or hydrochloric acid. A UV reactor vessel may contain one or more physical cleaning systems along with provisions for an occasional chemical cleaning. In low-hardness, low-iron waters such as CBJ's it is s till recommended that automatic cleaning devices be installed even though fouling potential may be relatively low. Low pressure UV systems are also less prone to fouling and may not require automated cleaning.

Standby Power

Producing UV light requires electricity to power the electronic ballasts, which in turn power the UV lamps. Since disinfection is of utmost importance in producing potable water, the UV system should remain in service during periods of primary power failure. A dual power feed system or essential circuitry powered by a standby generator are typical ways to achieve the desired reliability.

Loss of power or significant temporary disruptions in the power supply will cause the UV reactors to shut down. These systems can take several minutes to re-start. Utilities have addressed the issue in two primary ways to prevent untreated water from going to the distribution system: (1) provide an uninterruptible power supply (UPS), or (2) shut down the flow of water to the UV system upon power failure.

Final EPA guidance pertains to the amount of "off-specification operation" that is allowable, but the primacy agency will ultimately establish requirements. At this point off-specification requirements have not been established for the State of Alaska. The decision whether or not to include the design of a UV facility should be made during the predesign phase. Most UV systems in the US do not use a UPS, as it is not required by the US EPA. However for systems on power grids with any frequent power fluctuation, a UPS may be necessary. Power quality observations will provide additional data to determine the best approach for Juneau.

Advantages of UV Disinfection

The following advantages are realized when using UV light as a disinfectant for inactivation of *Cryptosporidium*:

- An effective disinfectant against both *Cryptosporidium* and *Giardia.*
- Little or no production of disinfectant byproducts.
- Unlike chemical disinfectants, efficiency does not depend upon typical water quality parameters such as pH and temperature.
- UV disinfection is a physical process rather than a chemical oxidant; thus eliminating the need to generate, handle, transport, or store toxic/hazardous or corrosive chemicals.

- There is no residual effect that can be harmful to humans or aquatic life.
- UV systems are easy to operate.
- UV disinfection requires a shorter contact time when compared to other disinfectants.
- UV disinfection equipment requires less space than other methods.

Limitations of UV Disinfection

The following limitations must be considered when using UV light as a disinfectant for inactivation of *Cryptosporidium*:

- Does not produce a residual. Must be followed by a secondary disinfectant (i.e., chlorine) for maintaining a disinfectant residual in the distribution system.
- Limited effectiveness against viruses. Must be used together with another chemical disinfectant (i.e., chlorine) for achieving viral inactivation CT requirements.
- Effectiveness can be compromised as turbidity increases.
- A preventive maintenance program is necessary to control fouling of lamp sleeves.
- There is no measurable residual to indicate the efficacy of UV disinfection.
- Validation testing is required to demonstrate the effectiveness of specific UV equipment. Validation testing introduces a great deal of complication into the evaluation and approval of UV disinfection systems. However, validation testing also provides the means of ensuring that an operating UV disinfection system is meeting the established performance targets at the water treatment facility.

2 - Ozonation

Ozone is one of the most powerful disinfectants available for use in water treatment, and has been used in Europe since the early 1900s. It has more recently found acceptance in the United States, with more than 250 plants currently using ozone. Most of these plants have a capacity of less than 1 mgd and use ozone as an oxidant for taste and odor control, as opposed to a disinfectant for regulatory compliance. Other types of disinfectants are usually used for *Cryptosporidium* and *Giardia* inactivation. This is primarily due to the high CT requirements for inactivation of *Cryptosporidium* and *Giardia* with ozone.

Properties of Ozone

Ozone is a tri-atomic form of oxygen (i.e., O_3). Ozone is a powerful oxidant, and is highly corrosive and toxic. The gaseous form is colorless with a pungent odor that is readily detectable at concentrations as low as 0.02 ppm.

Ozone gas is extremely unstable. Consequently, it must be manufactured onsite and used immediately. It has a very short half-life (less than 30 minutes) under normal conditions encountered in water treatment. The gas is manufactured by passing air or oxygen between two electrodes. A high potential (between 10,000 and 30,000 volts) is applied across the electrodes, which converts some of the oxygen to ozone.

Ozone is sparingly soluble in water. While ozone is more soluble than di-atomic oxygen (i.e., O_2), it is 12 times less soluble than chlorine. Consequently, typical concentrations of ozone residuals encountered during water treatment when the ozone generation system uses air as the source of oxygen range from less than 0.1 to 1 mg/L, although concentrations up to 4 mg/L are attainable when the ozone generation system uses liquid oxygen in place of air.

Ozone is used as a disinfectant because of its efficacy against bacteria, viruses, and protozoa at low doses. Ozone can be applied at various points in the treatment train, although it is usually applied early in the treatment process. Unlike chlorine, the disinfection effectiveness of ozone is not affected by pH.

Due to its short half-life, ozone decays quickly and does not maintain a residual for downstream processes. Therefore, ozonation can be used as a primary disinfectant but must be followed by a secondary disinfectant (i.e., chlorine) in order to establish a residual in the distribution system.

Ozone Disinfection

The calculation of CT for ozone is similar to other chemical disinfectants, with accurate determinations of residual concentration being a prerequisite for effective disinfection. Primary disinfection credit is achieved by the residual concentration and the effective contact time. Ample monitoring points should be included to allow close monitoring of residual concentrations. Ozone can only be used as a primary disinfectant because it cannot maintain a residual in the distribution system. Thus, ozone disinfection should be coupled with a secondary disinfectant, such as chlorine, for a complete disinfection system.

Ozone CT Requirements for *Cryptosporidium* Inactivation

The ozonation CT requirements for disinfection of *Cryptosporidium* are contained in the LT2ESWTR. The CT requirements are a function of water temperature (ranging from < 0.5 to 25 °C) and targeted level of *Cryptosporidium* inactivation (ranging from 0.5-log to 3-log inactivation).

For Juneau's Salmon Creek water treatment facilities, *Cryptosporidium* inactivation requirements will be determined by the LT2ESWTR, for unfiltered surface water systems the level of *Cryptosporidium* inactivation will most likely be 3-log. Sampling indicates that the minimum temperature for Juneau's raw water supply is 1 °C. According to the LT2, ozonation CT requirements for *Cryptosporidium* inactivation at 1 °C are 69 mg·min/L for 3-log inactivation. These CT values are for systems that measure both the initial and the final ozone residual in each cell of the contact chamber and use the geometric mean of the two values for the residual ozone concentration, C.

Ozone Demands and Ozonation By-products

Since ozone is such a powerful oxidant, it has been found to have many other uses than just for disinfection, such as iron and manganese oxidation and reduction, taste and odor removal, removal of color, reduction of disinfection by-product (DBP) precursors, and increasing the biodegradable dissolved organic carbon (BDOC) in the water. These reactions with organic and inorganic compounds cause an ozone demand in the water treated, which must be satisfied during the ozonation process prior to developing any measurable ozone residual.

In water, ozone demands are exerted by the following reactions:

- *Reactions with natural organic matter (NOM) contained in the raw water supply. The oxidation of NOM by ozone leads to the formation of various chemical by-products, including aldehydes, organic acids, and aldo- and ketoacids.*
- *Reactions with synthetic organic compounds (SOCs) present in the raw water supply. Some SOCs can be oxidized and mineralized under favorable conditions.*

- *Oxidation of bromide ion (Br^-). Oxidation of bromide leads to formation of hypobromous acid, hypobromite ion, bromate ion (a regulated DBP), brominated organics, and bromamines.*
- *Reactions with dissolved inorganics contained in the raw water supply. Inorganic reducing agents such as iron, manganese, and hydrogen sulfide will exert an ozone demand that must be satisfied before an ozone residual can be established in the ozonated water.*
- *Reactions with taste and odor compounds contained in the raw water supply. Taste and odor compounds, such as geosmin and methyl isoborneol (MIB) are oxidized by ozone.*

As noted above, the ozonation process does form DBPs, most notably brominated species. If bromide is detected in the raw water, the potential for bromate formation should be measured. Bromates are regulated with an MCL of 10 µg/L. Although the formation of bromate can be mitigated with pH depression or pre-chloramination, at the high CT values required at Juneau's cold water temperatures, bromate formation may be a potential fatal flaw for the use of ozone alone. Other DBPs that form during ozonation include aldehydes, ketones, and carboxylic acids.

Ozonation System Design

Ozone is expensive to install and dangerous to handle. Therefore, separate facilities are required for the production of ozone and also for storage of liquid oxygen (LOX) if used as the feed gas. The production and feed systems for ozone, as well as monitoring systems require extensive training in order for operators to effectively operate the system.

When designing an ozonation system as the primary means of *Cryptosporidium* inactivation, the following design criteria must be considered:

- ozone target dose
- ozone demand and residual decay rates
- CT requirements to meet the regulatory guidelines for inactivation of *Cryptosporidium*.

Ozonation System Components

Ozone water treatment systems have four basic components:

1) a gas feed system
2) an ozone generator
3) an ozone contactor
4) an off-gas destruction system.

The gas feed system provides a clean, dry source of oxygen to the generator. The ozone contactor transfers the ozone-rich gas into the water to be treated, and provides contact time for ozonation reactions to occur. The final process step, off-gas destruction, is required as ozone gas is toxic in the concentrations present in the off-gas. Some ozonation systems include an off-gas recycle system that returns the ozone-rich off-gas to the first contact chamber to reduce the ozone demand in the subsequent chambers. Some systems may also include an optional quench chamber to remove any ozone residual that remains in solution.

Gas Feed System

Gas feed systems used in the ozonation process are classified as using air, high purity oxygen, or a combination of the two. High purity oxygen can be purchased and stored as a liquid, or it can be generated on-site through either a cryogenic process, with vacuum swing adsorption, or with pressure swing adsorption. Cryogenic generation of oxygen is a complicated process that is only feasible for large water systems.

Liquid oxygen feed systems are relatively simple, consisting of a storage tank, evaporators to convert the liquid to a gas, filters to remove impurities, and pressure regulators to limit the gas pressure to the ozone generators.

Air feed systems for ozone generators are fairly complicated as the air needs to undergo proper conditioning to prevent damage to the generator. Air that is fed to the generator must be clean and dry, with a maximum dew point of –60 °C, and free of contaminants. Air preparation systems typically consist of air compressors, filters, dryers, and pressure regulators.

Particles and moisture cause arcing within the generator, which damages generator dielectrics. Particles greater than 1 μm and oil droplets greater than 0.05 μm should be removed by filtration. Moisture removal can be achieved by either compression or cooling, which lowers the moisture holding capacity of the air, and by desiccant drying, which strips moisture from the air. Desiccant dryers are required for all air preparation systems.

Ozone Generator

Two different geometric configurations for the electrodes are used in ozone generators: (1) concentric cylinders, and (2) parallel plates. The parallel plate configuration is commonly used in small generators, and can be air-cooled.

Most of the electrical energy input to an ozone generator (about 85 percent) is lost as heat. Because of the adverse impact of temperature on the production of ozone, adequate cooling should be provided to maintain generator efficiency. For the concentric cylinder configuration, excess heat is usually removed by water flowing around the electrodes. The cylindrical tubes are usually arranged in either a horizontal or vertical configuration in a stainless steel shell, with cooling water circulated through the shell.

Ozone generators are classified by the frequency of the power applied to the electrodes. Low frequency (50 to 60 Hz) and medium frequency (60 to 1,000 Hz) generators are the most common found in the water industry. Medium frequency generators are efficient and can produce ozone economically at high concentrations, but they generate more heat than low frequency generators and require more complicated power supply to step up the frequency supplied by the power utility.

Ozone Contactors

Once ozone gas is transferred into water, the dissolved ozone reacts with the organic and inorganic constituents, including any pathogens. Ozone not transferred into the process water during contacting is released from the contactor as off-gas. Transfer efficiencies of greater than 80 percent typically are required for efficient ozone disinfection.

Common ozone transfer mechanisms that are used in the water industry include: (1) bubble diffusers, (2) injectors, and (3) turbine mixers.

Bubble diffuser contactors use ceramic or stainless steel diffusers that are either rod-type or disc-type to generate fine gas bubbles. Contactor volume is determined in conjunction with the applied ozone dosage and residual concentration to satisfy the disinfection CT requirements. Bubble-diffuser contactors are typically constructed with 20-foot water depths to achieve 85 to 95 percent ozone transfer efficiency. Since all of the ozone is not transferred into the water, the contactor chambers are covered to contain the off-gas. Off-gas is routed to an ozone destruction unit, usually catalysts, thermal, or thermal/catalysis.

For the injector method, ozone is injected into the water stream under negative pressure. A venturi section is used to generate the negative pressure on the ozone gas, which pulls the ozone into the water stream. The gas-to-liquid ratio is a key parameter in the design of injector contacting systems. This ratio should be less than 0.067 cfm/gpm in order to optimize ozone transfer efficiency. Meeting this criterion typically requires relatively low ozone dosages and ozone gas concentrations greater than 6 percent. High concentration ozone gas can be generated using a medium-frequency generator and/or liquid oxygen as the feed gas. To meet the CT disinfection requirements, additional contact time is required after the injector, typically in a plug flow reactor. The additional contact volume is determined in conjunction with the applied ozone dosage and estimated residual ozone concentration to satisfy the disinfection CT requirement. Since all of the ozone is not transferred into the water, the contactor chamber is covered to contain the off-gas. Off-gas is then routed to an ozone destruction unit.

Off-gas Destruction System

The concentration of ozone in the off-gas from a contactor is usually well above the permissible discharge limit. Thus, off-gas that is collected from the ozone contactors must be treated for destruction of the remaining ozone prior to its release to the atmosphere. The off-gas ozone destruction system is designed to reduce the ozone concentration to less than 0.1 ppm, the current limit set by OSHA for worker exposure in an eight hour shift. This is accomplished by elevating the temperature of the off-gas to 100 °C in the presence of a catalyst. A blower is used on the discharge side of the destruct unit to pull the air from the contactor, placing the contactor under a slight vacuum to ensure that no ozone escapes.

Instrumentation

Ozone technology requires careful monitoring for ozone leaks which pose a health hazard. Instrumentation should be provided for ozone systems to protect both personnel and the equipment. Gas phase ozone detectors should be provided in spaces such as generator and destruct rooms where ozone gas may be and personnel are routinely present. An ozone detector is also needed on the outlet from the off-gas destruct unit to ensure that the unit is working properly. These units should be interlocked with the ozone generator controls to shut down the ozone generation system should excess ozone be detected. A dew point detector on the feed gas supply just upstream of the generator is required to protect the generator from moisture in the feed gas. Flow switches on the cooling water supply are needed to protect the generator from overheating and a pressure switch to prevent over-pressurization.

Other instrumentation can be used to monitor and control the ozone process, although manual control is adequate for small systems, but most small systems are designed to operate automatically, particularly in remote areas. Ozone monitors can be used in conjunction with process flow meters to match ozone dose to process demands and control ozone generation. Sophisticated control schemes can be implemented to minimize the cost of dosing with ozone and reduce operator attention requirements. Many systems include residual monitoring at various points in the contactor to maintain a desired ozone residual and prevent energy-wasting overdosing.

Operation and Maintenance of Ozonation System

Even though ozone systems are complex, using highly technical instruments, the process is highly automated and very reliable. The production and feed systems require extensive training for operators to effectively run the system. Maintenance on ozone generators requires skilled technicians. If trained maintenance staff are not available at the plant, the work can be done by the equipment manufacturer.

Ozone generators should be checked on a daily basis when in operation. After a shutdown, dry air or oxygen should be allowed to flow through the generator to ensure that any moisture has been purged prior to energizing the electrodes. At initial start up and after long down times, this process may take up to 12 hours and usually longer when air is the feed gas.

Filters and desiccant air preparation systems should be changed periodically, with the frequency depending on the quality of the inlet air and the number of hours in operation. Compressors require periodic service, depending on the type and operating time. Piping and contact chambers should be inspected periodically to check for leaks and corrosion.

Dielectric tubes require cleaning when the generator efficiency drops by 10 to 15 percent. Cleaning is usually required every 4 to 5 years. Cleaning the tubes is usually performed by the manufacturer since it is a delicate operation and the tubes are fragile and expensive. Adequate space should be provided for the cleaning operation and for storage of spare tubes.

Advantages of Ozonation

The following advantages are realized when using ozone to treat water for *Cryptosporidium* inactivation:

- Produces no taste or odors in finished water.
- Used to control taste and odor problems associated with raw water.
- Oxidation of iron, manganese, and color.
- May reduces levels of DBP precursors in raw water.
- Disinfection efficacy is not significantly affected by pH.
- Provides a barrier for removal of contaminants of potential concern (CPCs), including synthetic organic chemicals (SOCs).
- Ozonation systems are highly automated and easy to operate.
- Decays rapidly in water.

Limitations of Ozonation

The following limitations must be considered when using ozone to treat water for *Cryptosporidium* inactivation:

- Ozone is highly toxic.
- Expensive to generate, and must be produced on-site.
- Much less soluble in water than chlorine; thus, special mixing devices are necessary.
- Ozone destroying device is needed at the exhaust of the ozone reactor to prevent toxicity and fire hazards.
- May produce undesirable ozonation by-products such as aldehydes and ketones when reacting with NOM present in the raw water supply. Also produces bromate when raw water contains the bromide ion.
- Provides no residual, and therefore, must be used in conjunction with a secondary disinfectant.
- Increases assimilable organic carbon (AOC) and BDOC, so ozone is often coupled with biological filtration to ensure biological stability through the distribution system
- The ozonation process produces high dissolved oxygen levels in the finished water supply, thereby increasing the finished water corrosivity and potential for microbial regrowth in the distribution system.

3 - Chlorine Dioxide

Chlorine dioxide has uses both as an oxidant and a primary disinfectant in water treatment. Currently, there are over 500 public water systems world-wide that use chlorine dioxide to treat potable water. It is produced by the reaction of sodium chlorite with chlorine, and must be generated on-site at the treatment plant.

Properties of Chlorine Dioxide

Chlorine dioxide (ClO_2) is a powerful chemical oxidant. It is a relatively small, volatile, and highly energetic molecule that reacts strongly with reducing agents. Despite its volatility, chlorine dioxide does remain fairly stable in dilute solution in the absence of light.

One of the most important physical properties of chlorine dioxide is its high solubility in water. In contrast to the hydrolysis reactions of chlorine gas in water, chlorine dioxide does not hydrolyze when added to water; instead, it remains in solution as a dissolved gas. Chlorine dioxide is approximately 10 times more soluble in water than chlorine, even though its volatility allows for easy removal with a minimal amount of aeration. Unlike ozone, chlorine dioxide can be used for post-CT disinfectant credit to establish a disinfectant residual for the distribution system.

Chlorine dioxide cannot be compressed or stored commercially as a gas because it is explosive under pressure. Therefore, it is never shipped, and must be generated on-site. Most commercial generators use sodium chlorite ($NaClO_3$) as the common precursor feedstock chemical to generate chlorine dioxide for drinking water application. Conventional systems generate chlorine dioxide by reacting sodium chlorite with an acid and either chlorine (gaseous or aqueous), or hydrogen peroxide (otherwise known as purate).

Chlorine dioxide generation and addition to water produces by-products of chlorite and chlorate, both of which can be harmful to humans. The Stage 1 Disinfectants and Disinfection By-products Rule regulates both chlorine dioxide and chlorite levels in drinking water. The maximum residual disinfectant level (MRDL) for chlorine dioxide is 1.0 mg/L, and the maximum contaminant level (MCL) for chlorite is 0.8 mg/L. The formation of chlorite greatly limits the dose that can be applied to water. If the oxidant demand of the water to be treated with chlorine dioxide is greater than 1.4 mg/L, the formation of chlorite in the water may exceed the chlorite MCL. Chlorine dioxide can also produce distribution system related taste and odor at residual levels above 0.4 mg/L. Typical doses in water treatment vary between 0.07 and 2.0 mg/L.

As an oxidant, chlorine dioxide can be used to treat taste and odors in the raw water. Chlorine dioxide destroys phenolic compounds that cause taste and odors, as well as the compounds associated with decaying vegetation and algae. Chlorine dioxide can also be used to remove dissolved iron and manganese from water by reacting with the soluble ions to form insoluble precipitates.

Chlorine Dioxide Disinfection

The calculation of CT for chlorine dioxide is similar to other chemical disinfectants, with accurate determinations of residual concentration being a prerequisite for effective disinfection. Primary disinfection credit is achieved by the residual concentration and the effective contact time. It has been found in practice that because of the volatile nature of the gas, chlorine dioxide works extremely well in plug flow reactors such as pipelines. It can be easily removed from dilute aqueous solution by turbulent aeration in rapid mix tanks or purging in recarbonation basins. For post-CT disinfection credit, chlorine dioxide can be added before clearwells or transmission pipelines. Ample monitoring points should be included to allow close monitoring of residual concentrations.

Chlorine Dioxide CT Requirements for *Cryptosporidium* Inactivation

The chlorine dioxide CT requirements for disinfection of *Cryptosporidium* are contained in the LT2ESWTR. The CT requirements are a function of water temperature (ranging from < 0.5 to 25 °C) and targeted level of *Cryptosporidium* inactivation (ranging from 0.5-log to 3-log inactivation).

For Juneau's water treatment facilities, *Cryptosporidium* inactivation requirements will be 3-log. Sampling indicates that the minimum temperature for Juneau's raw water supply is 1 °C. According to the Final LT2, chlorine dioxide CT requirements for *Cryptosporidium* inactivation at 1 °C is 1,830 mg·min/L for 3-log inactivation. These CT values are for systems that measure both the initial and the final chlorine dioxide residual in the contact chamber and use the geometric mean of the two values for the residual concentration, C. These CT values, combined with the realistic limits on chlorine dioxide dose to remain in compliance with the chlorite MCL, mean that a contact basin with a contact time on the order of 1,800 minutes (30 hours) would be required.

Chlorine Dioxide Disinfection By-products and Oxidation Demands

Chlorine dioxide produces chlorite and chlorate as byproducts in water, both of which are regulated under the Stage 1 Disinfectants/Disinfection By-products Rule. Chlorine dioxide does not produce halogenated DBPs, and can be used as one mechanism for the reduction of DBP precursors (by oxidation of organic material) in water. However, the possibility does exist for the production of nonhalogenated DBPs that are not currently regulated, but may be regulated in the future.

Chlorite and chlorate are produced in varying ratios as end products during chlorine dioxide treatment and subsequent degradation. The primary factors affecting the concentrations of chlorine dioxide, chlorite, and chlorate in finished drinking water involve:

- dosage applied/oxygen demand ratio
- blending ratios of sodium chlorite and chlorine during the generation process
- exposure of water containing chlorine dioxide to sunlight
- reactions between chlorine and chlorite when free chlorine is used for distribution system residual maintenance
- levels of chlorate in sodium chlorite feedstock.

Numerous inorganic and biological materials found in raw water will react with chlorine dioxide. Chloride, chlorite, and chlorate ions are the dominant degradation species arising from these reactions. Chlorite is the primary product of chlorine dioxide reduction. Approximately 50 to 70 percent of the chlorine dioxide consumed by oxidation reactions is converted to chlorite under conditions typical in water treatment. The application of 2 mg/L chlorine dioxide produces between 1 and 1.4 mg/L of chlorite.

Chlorite is relatively stable in the presence of organic material but can be oxidized to chlorate by free chlorine if added as a secondary disinfectant. Chlorate is therefore produced through the reaction of residual chlorite and free chlorine during secondary disinfection.
EPA recommends that the total concentration of chlorine dioxide, chlorite, and chlorate be less than 1.0 mg/L as Cl_2. In addition, chlorine dioxide concentrations exceeding 0.4 to 0.5 mg/L may contribute to taste and odor problems in finished water. Due to these issues, the use of chlorine dioxide to provide a disinfectant residual is somewhat limited in moderate to high TOC water. In low oxidant-demand water, chlorine dioxide residuals may last several days.

Design of ClO_2 Disinfection System

Major equipment that is required for a chlorine dioxide disinfection system includes stock chemical storage and feed systems, chlorine dioxide generators, and feed piping and injection equipment. When designing a disinfection system that utilizes chlorine dioxide as the primary means of *Cryptosporidium* inactivation, the following design criteria must be considered:

- chlorine dioxide contact concentrations
- competing oxidation demands
- managing chlorine dioxide dose to maintain compliance with chlorite MCL
- CT level to meet the regulatory requirements for inactivation of *Cryptosporidium*.

System Components

Chlorine dioxide disinfection systems have two basic components:

1) chlorine dioxide generator

2) contactor basins.

Chlorine dioxide generators are relatively simple mixing chambers. The chambers are frequently filled with media (Teflon chips, ceramic or raschig rings) to generate hydraulic turbulence for mixing. The generators require careful monitoring of the chemical feed rates and mixture to ensure the most efficient production of chlorine dioxide. If not carefully monitored, chlorine dioxide generation can produce excess chlorine, as well as excessive concentrations of chlorites that cannot be easily removed from the process stream.

Contactor basins should be designed to optimize hydraulics and minimize short circuiting, with sufficient detention time to meet the CT requirements for *Cryptosporidium* removal.

Operational Considerations and Monitoring Requirements

Chlorine dioxide systems typically include the following operational considerations and monitoring requirements:

- Storage and feeding in a designated space.
- Storage in clean, closed, non-translucent containers. Exposure to sunlight, UV light, or excessive heat will reduce product strength.
- Avoid storage and handling of combustible or reactive materials, such as acids or organic materials, in the sodium chlorite area.
- Secondary containment for storage and handling areas to accommodate the worst case spill with sumps provided to facilitate recovery.
- A water supply near storage and handling areas for cleanup.
- Adequate ventilation and air monitoring.
- Flow monitoring on all chemical feed lines, dilution water lines, and chlorine dioxide solution lines.
- Air contact with chlorine dioxide solutions should be controlled to limit the potential for explosive concentrations building up within the generator. Chlorine dioxide concentrations greater than 10 percent should be avoided.
- The MRDL for chlorine dioxide is 0.8 mg/L and the MCL for chlorite is 1.0 mg/L. This means that if the oxidant demand is greater than about 1.4 mg/L, chlorine dioxide may not be used as a disinfectant because the chlorite/chlorate ion by-products might exceed the maximum allowable level.
- Daily monitoring for chlorite and chlorine dioxide is required at the entrance to the distribution system. For any daily sample that exceeds the chlorine dioxide MRDL of 0.8 mg/L or the chlorite MCL of 1.0 mg/L, the system must take additional samples in the distribution system the following day at the locations specified in the Disinfectants/Disinfection By-products Rule.

Advantages of Chlorine Dioxide Use

The following advantages may be realized when using chlorine dioxide as a disinfectant for *Cryptosporidium* inactivation:

- Taste and odors resulting from algae and decaying vegetation, as well as phenolic compounds, are controlled by chlorine dioxide.
- Chlorine dioxide is easy to generate.
- Oxidation of iron, manganese.
- Provides plant control over algae growth.
- Does not produce halogenated DBPs.

Limitations of Chlorine Dioxide Use

The following limitations must be considered when using chlorine dioxide as a disinfectant for *Cryptosporidium* inactivation:

- Requires an extremely long reaction time for inactivation of *Cryptosporidium.*
- The process forms chlorite and chlorate as by-products.
- Costs associated with training, sampling, and laboratory testing for chlorite and chlorate are high.
- The cost of sodium chlorite is high.
- The chlorine dioxide dose cannot exceed 1.4 mg/L in order to limit the total combined concentration of chlorine dioxide, chlorite, and chlorate to a maximum of 1.0 mg/L.
- Chlorine dioxide gas is explosive, so it must be generated on-site.
- Chlorine dioxide can produce noxious odors in some systems. Dialysis patients may be adversely affected by the presence of chlorine dioxide in water.
- The process of producing chlorine dioxide includes the storage and use of multiple hazardous chemicals

4 - Membrane Filtration

A membrane, or more properly, a semipermeable membrane, is a thin layer of material capable of separating substances when a driving force is applied across the membrane surface. Membrane processes can be separated into four basic categories—reverse osmosis, nanofiltration, ultrafiltration, and microfiltration. Reverse osmosis (RO) and nanofiltration (NF) are used to remove dissolved inorganic compounds such as sodium, calcium, and magnesium ions, or dissolved organic compounds such as humic and fulvic acids that make up the primary source of DBP precursors. They operate at transmembrane pressures of about 80 to 1,200 psi. Ultrafiltration (UF) and microfiltration, on the other hand, cannot remove dissolved materials, and are limited to the removal of particulate material. UF membranes have a nominal pore size of between 0.003 and 0.03 µm, whereas MF membranes have a nominal pore size of between 0.05 and 0.5 µm. UF and microfiltration operate at transmembrane pressures of about 5 to 100 psi.

Microfiltration membranes, because of pore size, are generally limited to removal of bacteria and protozoans like *Giardia* and *Cryptosporidium*, while UF membranes have the added feature of removing not only protozoans and bacteria, but also viruses. Some microfiltration membranes are also credited with virus removal though.

Membrane processes have become more attractive for potable water treatment in recent years due to the increased stringency of drinking water regulations. In this document, we will focus on the microfiltration/ultrafiltration membrane process as it applies to *Cryptosporidium* removal.

Membrane Filtration (MF) Process

Membrane filtration (MF) is loosely defined as a membrane separation process using membranes with a 0.1-µm (or smaller) nominal pore size, and a relatively low feedwater operating pressure of 15-60 psi. Representative materials removed by MF include sand, silt, clays, *Giardia lamblia*, *Cryptosporidium*, cysts, algae, and most bacterial species. MF is not an absolute barrier to viruses in all cases; however, when used in combination with disinfection, it is an effective means of eliminating viruses.

The primary impetus for the more widespread use of MF has been the increasingly stringent requirements for removing particles and microorganisms from drinking water supplies. Additionally, there has been a growing emphasis on limiting concentrations and number of chemicals that are applied during water treatment. By physically removing pathogens, membrane filtration can significantly reduce chemical addition as compared to conventional filtration technology.

MF membranes provide absolute removal of particulate contaminants from a feed stream by separation based on retention of particulates on the membrane surface. In the simplest design, the MF process involves pumping of raw feed water under pressure onto a membrane. For municipal-scale drinking water applications, the commercially available membrane geometries that are the most commonly employed are spiral wound, tubular, and hollow capillary fiber. However, spiral-wound configurations are not normally employed for MF due to the flat-sheet nature of the membrane, which presents difficulties in keeping the membrane surface clean. Unlike spiral-wound membranes, hollow-fiber and tubular configurations allow the membrane to be backwashed, a process by which fouling due to particulate and organic materials is controlled. The components of most commercially-available MF membrane plants include feed pumps, cleaning tanks, automatic backwash system, and membrane modules. Product water recovery (ratio of finished water flowrate to raw water flowrate) for MF technology ranges from 85 to 95 percent, and can be even higher in cases where the raw water has low levels of suspended solids.

Operational and Maintenance Considerations

In Membrane Filtration, there are two methods for maintaining or re-establishing permeate flux after membranes are fouled: (1) membrane backwashing, and (2) chemical cleaning.

Membrane Backwashing

In order to prevent the continuous accumulation of solids on the membrane surface, the membrane is periodically backwashed. Unlike backwashing for conventional media filtration, the backwashing cycle for MF takes only a few minutes. Both liquid and gas backwashing are employed with MF technology. For most systems, backwashing is fully automatic.

Chemical Cleaning

If backwashing is incapable of restoring the flux, then membranes are chemically cleaned. The variables that should be considered in cleaning MF membranes include frequency and duration of cleaning, chemicals and their concentrations, cleaning and rinse volumes, temperature of cleaning, recovery and reuse of cleaning chemicals, neutralization and disposal of cleaning chemicals.

Residuals Handling Facilities

Residuals handling facilities for treatment of waste streams are often a major component of the MF process. Waste streams that are generated as part of the MF process include high-turbidity water from routine backwash operations, and chemical solutions that are used to remove foulants from the membrane surfaces. Waste stream volumes generated during routine backwash operations can amount to between 5 and 15 percent of the total finished water production, depending on the raw water quality. For most applications, backwash water can be discharged to a sewer with no additional treatment. Spent chemical solutions may require neutralization before being discharged to a sewer. If there is no sewer connection available, the treatment plant will need to install residuals handling facilities. These facilities may include such devices as clarifiers, solids thickeners, neutralization tanks, and solids drying beds.

Advantages of Membrane Filtration

The following advantages are realized when using membrane filtration to treat water for removal of *Cryptosporidium*:

- Very effective for removal of protozoa and bacteria, with greater than 5-log (99.999%) removal.
- Reliability of consistent effluent quality.
- Automation provides ease of operation.

Limitations of Membrane Filtration

The following limitations must be considered when using membrane filtration to treat water for removal of *Cryptosporidium*:

- Does not provide residual disinfection. Must be followed by a secondary disinfectant (i.e., chlorine) for maintaining a disinfectant residual in the distribution system.
- Need to clean membranes using acids, oxidants, and caustic solutions.
- Produces a waste stream that will likely require treatment.
- Post-filter disinfection required for viral inactivation.

The final method to be considered in this letter for removal/inactivation of *Cryptosporidium* is high-rate gravity granular media filtration.

5 - High-Rate Granular Filters

High-rate granular media filtration process contains the following basic elements:

1) Coagulant addition and mixing, with alum as the coagulant.
2) Gravity filtration through granular media filters.
3) Backwash waste facilities.

For Juneau's water treatment plant, the likely location of conventional filtration facilities in the process train is upstream of the existing chlorine feed system. The conventional filtration system would be used to provide the necessary removal of suspended solids and microorganisms, whereas chlorine would be used as a primary disinfectant and for establishing a residual disinfectant concentration in the distribution system.

The following assumptions were used to generate facility requirements:

- Alum and polymer used for coagulation of raw water.
- Rapid mix system consisting of an in-line static mixer.
- Flocculation with 15 minutes of retention time
- Dual media filters consisting of 60-inches of anthracite over 12-inches of sand.
- Filter backwash consisting of bed fluidization and air scour.
- A post-filtration pump station is required to pump filtered water into the distribution system.

- Process waste is discharged to a backwash equalization and decant facility and then recycled upstream of the filtration plant
- Filter loading rate of 10 gpm/sf
- Filter run time prior to backwashing of 12 hours, minimum
- Additional Labor: 1 Full Time Equivalent (more or less may be required based on operational strategy and current staff workload.

Space requirements are frequently a limiting factor when considering gravity filters. The space estimate includes a chemical storage building, rapid mix facilities, blower building, filters, and post-filtration pump station.

Space Requirements for Gravity Filters

Unit Process	Structure Space Requirement
Flocculation	1,070 sf
High-Rate Granular Filtration	5,530 sf
Polymer System	340 sf
Alum System	5,740 sf
Backwash Recycle Basin	1,430 sf
Finished Water Pump Station	640 sf
Backwash Supply Pump Station	540 sf
Total Building Area	14,750 sf (0.34 ac)
Approximate Structure Footprint	100' W x 150' L

The results indicate that the gravity filters and pump station will require 0.34 acres of land. Note that this applies only to the building footprints, and does not include land requirements for roads, driveways, loading/unloading zones, parking, etc.

Due to site constraints at the existing Salmon Creek facility, it would likely not be possible to locate gravity filtration systems there. Another site would need to be determined for location of a gravity filtration system.

Recommended Alternative

An examination of the five treatment options reveals that UV disinfection is the most cost effective alternative for treatment of *Cryptosporidium* from both a capital and life cycle cost perspective. While each alternative will meet the treatment requirements of the LT2ESWTR, we recommend planning for UV disinfection facilities at the City and Borough of Juneau Salmon Creek Water Source in order to comply with EPA's requirements for *Cryptosporidium* treatment.

Conceptual Level Cost Estimate

The existing site layout of the Salmon Creek Water Treatment Facility was evaluated and it appears that the most cost effective approach to adding UV disinfection equipment at that facility would be to intercept existing underground piping adjacent to the existing treatment building and add the UV equipment in an underground vault. Following is a conceptual level cost estimate of this arrangement that will be refined as more detailed design decisions are made.

The cost estimate is based on an ultraviolet disinfection unit manufactured by Trojan Technologies, the TrojanUVSwift Model D12, which has the capacity to treat approximately 2,555 gallon per minute (3.6 MGD). A manufactures catalog cut of the TrojanUVSwift is provided at the end of the letter report.

We have assumed two UV disinfection units will be necessary to reliably supply the design flow rate at the Salmon Creek facility. This way if one unit is off-line for maintenance or repairs, the other unit can still handle the design flows.
\

Preliminary Salmon Creek Water System Cost Estimate
Ultraviolet Light Disinfection System

Site Work	$50,000
Underground Concrete Vault, approximately 24' x 16'	$150,000
2- UV Disinfection Units each with the capacity to treat plant design capacity (3.5 MGD)	$320,000
Piping and valving modifications to accommodate each unit	$75,000
Electrical, Instrumentation and Controls	$150,000
Estimated Construction Cost	**$745,000**
Contingency (~30% of Const. Cost)	$225,000
Design, Inspection, CBJ Administration (~40% of Const Cost.)	$300,000
Total Estimated Project Cost	**$1,270,000**

This letter summarizes the changes that have occurred in the federal drinking water regulations with regards to surface water sources such as the Salmon Creek Source and the options available to CBJ as it proceeds with improvements needed to comply with these regulations. If you have any questions about any of the items in this letter report, please let me know and I would be happy to discuss them with you in more detail.

Sincerely yours,

James L. Dorn P.E.
Principal

TROJANUVSWIFT™SC

DRINKING WATER TREATMENT

TROJANUVSWIFT™SC

Water Confidence for Communities Large & Small

Trojan's proven UV solutions provide validated, cost-effective disinfection

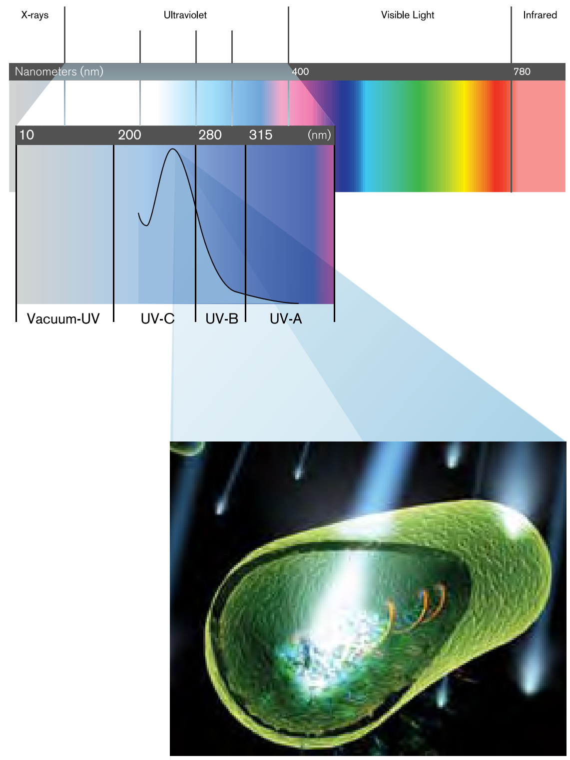
Trojan Technologies is an ISO 9001: 2000 registered company and for more than 25 years has set the standard for proven UV technology and ongoing innovation. With unmatched scientific and technical expertise, and a global network of specialists, representatives and technicians, Trojan is trusted more than any other firm as the best choice for municipal UV solutions – worldwide. The TrojanUVSwift™SC is one of the reasons why. With units designed to treat flow rates of 15 GPM to 15.4 MGD (0.6 to 2430 m^3/hr), these compact, robust UV systems offer communities an efficient, economical solution for drinking water disinfection. Like all Trojan drinking water products, the TrojanUVSwift™SC is bioassay validated, having undergone rigorous DVGW and USEPA certification to ensure verified dose delivery, maximum public safety and peace of mind.

It's engineered and built to provide reliable performance, simplified maintenance, and reduced operating costs with innovative features like a hydraulically optimized, "L-shaped" reactor, high-intensity amalgam lamps and optional automatic or manual sleeve wiping.

The Benefits of UV

Broad-spectrum, cost-effective protection that offers unparalleled safety

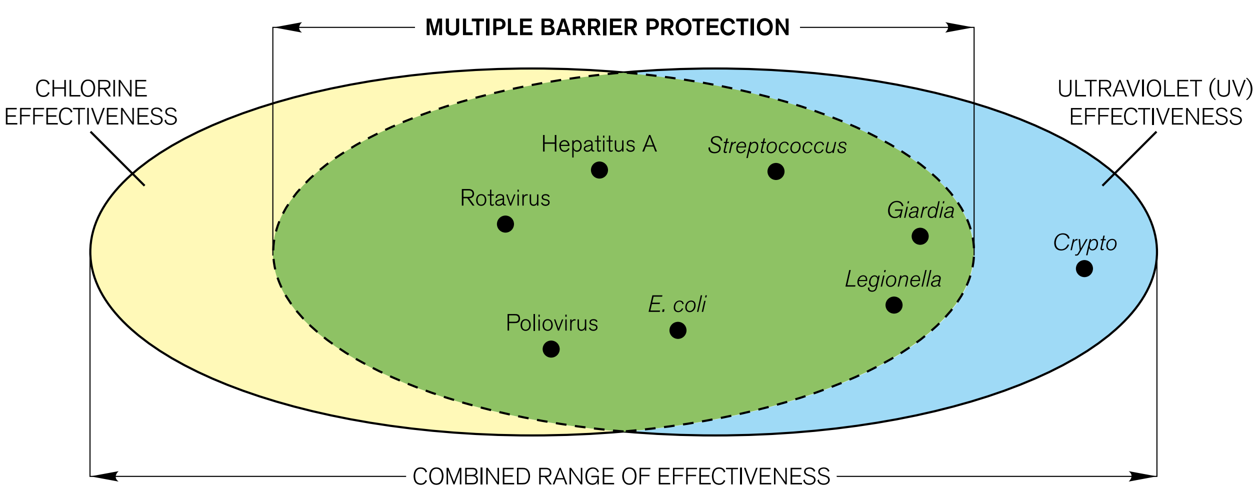
- UV light is an environmentally-friendly, chemical-free way to safeguard water against harmful pathogens
- Proven in thousands of installations, UV is widely accepted and endorsed worldwide for disinfection of drinking water
- UV offers broad-spectrum protection against a wide range of pathogens, including bacteria, viruses, and chlorine-resistant protozoa
- UV treatment provides *Cryptosporidium* and *Giardia* inactivation of up to 4-log at low doses
- UV is a reliable, cost-effective part of a multi-disinfectant treatment strategy often used in conjunction with chlorine to provide a dual barrier
- UV does not create disinfection by-products (DBPs) and does not affect taste
- At approximately 1/5 the cost of ozone disinfection and 1/10 the cost of membrane filtration, UV is the most cost-effective approach for multi-barrier treatment strategies



Ultraviolet light is invisible to the human eye, but a highly effective, chemical-free way of inactivating microorganisms in water. UV light penetrates the cell wall of the microorganism and alters its DNA so it can no longer reproduce or cause infection.

Benefits of a Multiple Barrier Treatment Approach

- UV offers a cost-effective, secondary barrier of protection to safeguard drinking water against virtually all microorganisms treated by chlorine – as well as proven inactivation of chlorine-resistant protozoa, including *Cryptosporidium* and *Giardia*. Dual barrier treatment using UV provides significantly greater community safety and reduced liability risk for municipalities



TROJANUVSWIFT™SC

Designed for efficient performance

Amalgam Lamps

Utilizes high-output amalgam lamps. Each is located within its own protective quartz sleeve and supported by a removable, sleeve holder assembly. Designed for easy lamp replacement.

UV Reactor

Type 316L stainless steel. Can be installed vertically or horizontally. Reactor configurations are available with multiple inlet/outlet diameters. Rated to 150 PSI (10 BAR). A drain port is located opposite the outlet flange.

Control Panel (CP)

Epoxy-painted, carbon steel cabinet is designed for indoor, wall-mount installation. Houses a microprocessor-based controller with I/O connection points, and electronic power supplies. Distributes power to the UV reactor as well as the UV sensor and optional automatic wiping system. UV intensity, lamp elapsed time and lamp status are continuously monitored and displayed on the operator interface, located on the control panel door.

UV Sensor

Highly accurate, DVGW approved, photodiode sensor monitors UV output within the reactor. Mounted within the sensor port on the side wall of the reactor for easy access.

Sleeve Wiping System

Optional manual or automatic systems available; both operate online, without interrupting disinfection. Fluorocarbon wipers are mounted in stainless steel yoke around the quartz sleeve of each lamp. The manual system is driven by hand using an external handle. The automatic system allows cleaning at preset intervals using a motor driven wiper assembly.

Remote Monitoring & Control

Robust microprocessor-based controller provides standard input/out signals for on/off control from a remote location. Programmable digital and analog I/O capabilities can generate unique alarms for individual applications, and send signals to operate valves and pumps. All units feature optional SCADA communication via ModBus for remote monitoring and control, and D-Series systems offer dose pacing.

Key Benefits
TrojanUVSwift™SC

Proven performance – full bioassay validation. TrojanUVSwift™SC systems meet the stringent, internationally-recognized standards of DVGW and USEPA – having undergone comprehensive validation at a wide range of flow rates and UV transmittance levels.

Assurance of NSF 61 compliance. TrojanUVSwift™SC systems meet the stringent standards of NSF International.

Compact footprint for installation flexibility. The TrojanUVSwift™SC can handle maximum flow capacity in minimal space. Its compact design allows it to be installed vertically or horizontally in restrictive spaces, thereby lowering installation costs. The system can even be installed immediately after a 90° elbow and other upstream piping configurations.

Fewer lamps required to treat a given flow. Trojan's use of efficient, high-intensity amalgam lamps minimizes the lamps, seals, and maintenance to meet dose delivery requirements.

Sleeve wiping system reduces maintenance costs. The TrojanUVSwift™SC can be equipped with a highly effective manual or fully automated sleeve wiping system to minimize the frequency and costs of cleaning. Both options work while the UV unit is online and disinfecting.

Designed for maximum operating efficiency. High-efficiency, electronic ballasts ensure cost-effective operation. Trojan's high-capacity D-Series models can be equipped with optional dose pacing that adjusts lamp output to match dose to actual disinfection requirements – minimizing operating costs and extending lamp life.

Local service. Global support. Trojan's comprehensive network of certified service providers offers ongoing maintenance programs and fast response for service and spare parts.

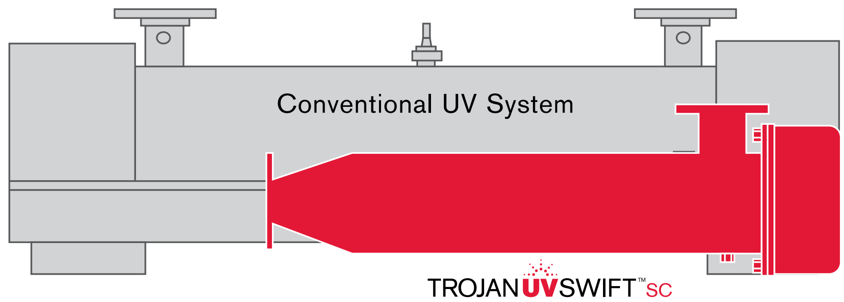
Guaranteed performance and comprehensive warranty. Trojan systems include a Performance Guarantee and comprehensive protection for your investment. Ask for details.

Compact Reactor for Installation Flexibility

Efficient, cost-saving design can be installed vertically or horizontally

Benefits:

- Compact footprint simplifies installation and minimizes related capital costs – making it ideal for retrofit applications into existing water treatment plants
- Engineered to fit into restrictive pipe galleries
- Designed for horizontal or vertical installation to allow maximum flexibility
- Lamps and sleeves are fully serviceable from one side – allowing the system to be installed tight to walls, other equipment or piping
- Validated with a 90° elbow installed immediately before the reactor to ensure consistent dose delivery – even under challenging hydraulic conditions created by upstream piping
- “L-shaped” reactor design is 40% more efficient than “U-shaped” systems
- Low head-loss design simplifies integration into existing processes, and minimizes the need for additional pumps and their associated capital and operating costs
- Compact wall-mounted control panel can be located up to 82' (25 m) from the reactor



The highly efficient "L-shaped" design and LPHO amalgam lamps result in an extremely compact footprint, as shown in the size comparison with a conventional "U-shaped" low-pressure system – both of which are capable of treating approximately 175 GPM (40 m^3/hr) at 90% UVT.

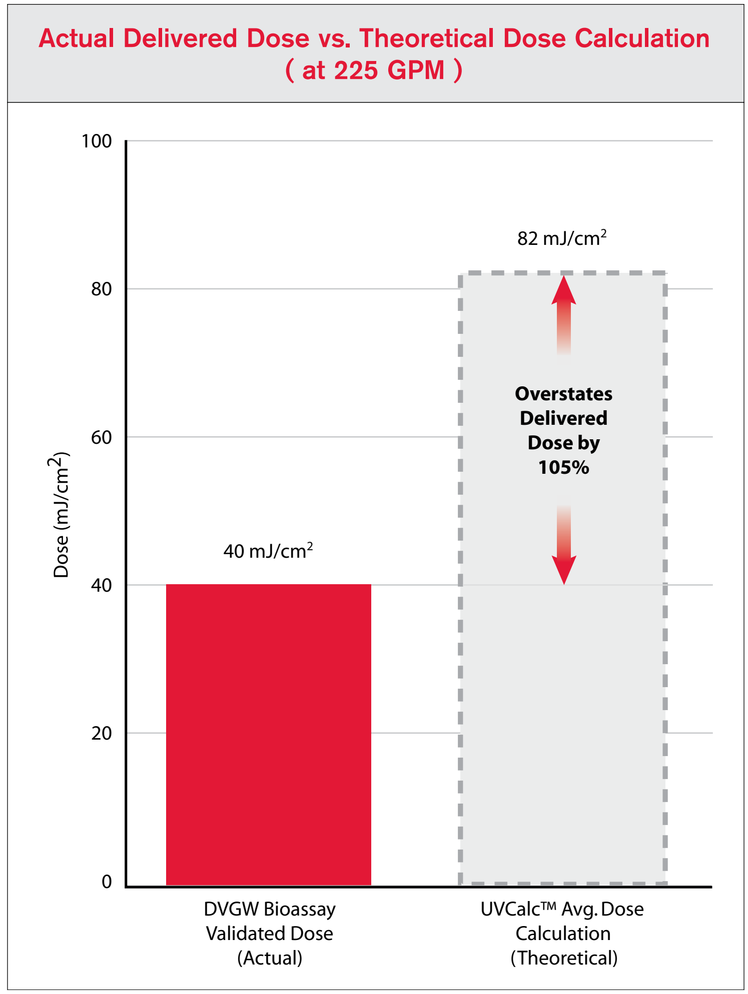
Developed using advanced Computational Fluid Dynamic (CFD) modeling, and incorporating high-output amalgam lamps, the TrojanUVSwift™SC is extremely space efficient. Its compact footprint allows the system to be integrated into restrictive pipe galleries of water treatment facilities – vertically or horizontally – reducing installation costs and eliminating the need for additions to buildings.

Bioassay Validated Performance

In-field testing ensures public safety over wide range of operating conditions

Benefits:

- All TrojanUVSwift™SC units are certified for source water of various qualities, having been DVGW bioassay tested under a range of UV transmittances (UVT) and flow rates
- The stringent standards of Deutsche Vereinigung des Gas und Wasserfaches e.v. – German Association of Gas and Water (DVGW) are recognized by the USEPA and internationally
- Bioassay performance data for the TrojanUVSwift™SC line was generated under the worst-case orientation – with a 90° elbow at the inlet
- Bioassay validation is widely endorsed as the evaluation standard for UV technologies because it provides the most accurate assessment of equipment sizing needs to ensure public health protection
- Theoretical calculations can significantly overstate dose, jeopardizing water quality and community safety
- Trojan systems meet the stringent standards of NSF International, fully complying with NSF 61



The graph above highlights an actual comparison of DVGW bioassay validation results with theoretical dose calculations using UVCalc™ for a TrojanUVSwift™SC at a flow rate of 225 GPM. The theoretical calculation overstates the delivered dose by 105%. Had a drinking water system been selected based on the results of the calculated dose, public safety could be seriously compromised.

DVGW

NSF International

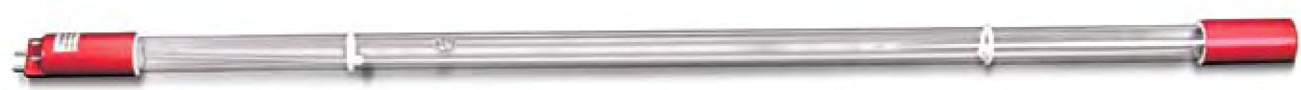
Energy Efficient, High-Output Amalgam Lamps

Need for fewer lamps reduces capital and O&M costs

Efficient, low-pressure, high-output amalgam lamps allow TrojanUVSwift™SC systems to deliver the required UV dose with fewer lamps and lower operating costs.

Benefits:

- The TrojanUVSwift™SC requires 1/2 to 1/3 fewer lamps to deliver the required dose compared to traditional UV systems using low-pressure lamps
- With fewer lamps, the TrojanUVSwift™SC is very compact and can be located in small spaces, reducing installation costs
- Trojan high-efficiency, amalgam lamps draw less energy than competitive high-output systems – minimizing operating costs
- Fewer lamps means reduced annual maintenance costs for lamp change-outs



Robust Sleeve Wiping Systems

Optional manual or automatic wiping ensures consistent dose delivery

The optional wiping systems reduce maintenance costs. Operators have a choice of the manual system that is operated by hand, or motorized system (shown above) which can be programmed to wipe automatically at preset intervals.

Benefits:

- Wiping systems minimize fouling of the quartz sleeves
- Ensure consistent UV dose delivery for maximum public safety
- Systems operate online while the lamps are disinfecting, reducing downtime
- Automatic wiping system can be programmed to wipe lamp sleeves at preset intervals

User-Friendly Digital Controller

Intuitive system provides at-a-glance system status and allows remote operation

The TrojanUVSwift™SC controller and high efficiency electronic ballasts have been proven in thousands of installations. The Control Panel features a user-friendly digital interface, and can be mounted up to 82 ft (25 m) from the reactor.

Benefits:

- Robust, microprocessor-based controller combines extensive functionality with an operator-friendly, digital interface
- Display provides at-a-glance, real-time system status information
- Programmable digital and analog I/O capabilities allow remote on/off control and alarm code differentiation for fast identification of changes in system status
- Optional dose pacing on high capacity D-Series systems minimizes energy use while maintaining required dose
- Optional ModBus protocol communicates with plant SCADA system for centralized monitoring of UV performance, lamp status, power levels and other parameters

Designed for Easy Maintenance

Operator-friendly design for easy routine maintenance

The TrojanUVSwift™SC design simplifies maintenance procedures. For example, lamp changeovers require no tools and take less than five minutes per lamp.

Benefits:

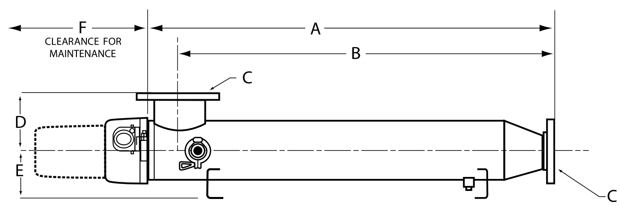
- Single-ended UV lamps simplify annual replacement
- Lamps require less than 5 minutes each to change – without tools or need to drain the reactor
- Externally mounted sensor allows easy access
- Optional automatic or manual sleeve wiping system reduces the frequency, inconvenience and cost of manual cleaning

TROJANUVSWIFT™SC

System Specifications

Model #	A02	B03	B04	B06	B08	D06	D12	D30
Maximum Validated Disinfection Flow Rate (98% UVT 40 mJ/cm^2): GPM (m^3/hr)	57 (13)	132 (30)	185 (42)	330 (75)	577 (131)	1190 (270)	2555 (580)	10695 (2430)*
UVT Range	Nominal range of 80% to 98%					70% to 98%		
Number of Lamps:	2	3	4	6	8	6	12	30
Electrical Requirements:								
Standard Voltage	120	208 to 240 Volt, single phase, 2 wire + GND, 60 Hz L-L, 50 Hz L-N						
Connected / Operating Power (W) Single Phase	320 / 320	1060 / 510	1310 / 660	1810 / 960	2310 / 1260	1810 / 1560	3300 / 3060	7810 / 7560
Ballast Type	Electronic, Constant Power					Electronic, Variable Power		
Sensors:								
Sensors Per Reactor (1 per 10 lamps, as per DVGW)	1						2	3/1*
Control Panel:								
Materials of Construction	Painted Mild Steel (Gray)							
Dimensions: inches	16 x 14 x 6	24 x 16 x 10	24 x 16 x 10	24 x 16 x 10	24 x 24 x 10	24 x 16 x 10	24 x 24 x 10	48 x 36 x 10
cm	41 x 36 x 15	61 x 42 x 25	61 x 42 x 25	61 x 42 x 25	61 x 61 x 25	61 x 42 x 25	61 x 61 x 25	122 x 91 x 25
Rating	Type 12 (IP54)							
Remote ON/OFF (24V - 280V) / Analog Output	Standard/ 4 Optional Outputs (model dependent)							
Intensity Pacing & SCADA Comm, Optional	Not Available					✔		
Panel Weight — lbs (kg)	40/18	70/32	75/34	80/36	100/45	80/36	110/50	300/136
Water Chamber – Engineered Materials/Options:								
Materials of Construction, Stainless Steel	316L (1.4404 / Europe)							
Max Operating Pressure PSI (BAR)	150 (10)							
Max Fluent Temp °F (°C)	104 (40)							
Sleeve Cleaning Mechanism, Optional	Manual	Manual /Automatic				Automatic		
Reactor Weight (Wet/Dry) (lbs)	65/34	149/72	149/75	160/81	162/85	551/275	839/400	2382/1200
Mounting Feet	Optional					Standard		
Dimensions – Inches (cm)								
A:	33 (84)	47 (119)	47 (119)	47 (119)	47 (119)	66 (170)	68 (173)	70 (178)
B:	30 (75)	43 (109)	43 (109)	43 (109)	43 (109)	60 (152)	59 (150)	56 (142)
Flange Size / Alternate Flange Orientation (✔) C:	3 (80DN)	4 (100DN)	4 (100DN)	6 (150DN)	6 (150DN)	8 (200DN) /✔	12 (300DN) /✔	20 (500DN) /✔
D:	6 (15)	8 (20)	8 (20)	8 (20)	8 (20)	11 (27)	14 (35)	21 (53)
E:	6 (15)	7 (18)	7 (18)	7 (18)	7 (18)	9 (23)	12 (30)	18 (45)
F:	50 (127)	60 (152)	60 (152)	60 (152)	60 (152)	70 (178)	70 (178)	70 (178)

* per USEPA protocols, D30 only



Find out how your drinking water treatment plant can benefit from the TrojanUVSwift™SC – call us today.

Head Office (Canada)
3020 Gore Road
London, Ontario
Canada N5V 4T7
Telephone: (519) 457-3400
Fax: (519) 457-3030

Trojan UV Technologies UK Limited (UK): +44 1905 77 11 17
Trojan Technologies (The Netherlands): +31 70 391 3020
Trojan Technologies (France): +33 1 6081 0516
Trojan Technologies Espana (Spain): +34 91 564 5757
Trojan Technologies Deutschland GmbH (Germany): +49 6024 634 75 80
Hach/Trojan Technologies (China): 86-10-65150290

www.trojanuv.com

Products in this brochure may be covered by one or more of the following patents:
U.S. 5,504,335; 6,500,346; 6,872,954
Other patents pending.

TROJANUV
WATER CONFIDENCE™

MDW-003 (0907) TROD-1033