

COOLING TECHNOLOGY INSTITUTE

Legionellosis

Guideline: Best Practices for Control of Legionella



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This guideline document summarizes the best current state of knowledge regarding the specific subject. This document represents a consensus of those individual members who have reviewed this document, its scope and provisions. It is intended to aid all users or potential users of cooling towers.

Approved by the CTI Executive Board



This document has been reviewed and approved as part of CTI's Five Year Review Cycle. This document is again subject to review in 2013.

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Guideline: Best Practices for Control of Legionella

I. PURPOSE

The purpose of this guideline is to provide information and guidance in order to minimize Legionella in evaporative cooling water systems, specifically evaporative condensers, closed-circuit fluid coolers, and cooling towers.

II. SCOPE

This guideline provided specific environmental and operational guidelines that will contribute to the safe operation of cooling water systems to minimize the risk of occurrence of Legionellosis.

III. WHAT IS LEGIONNAIRES' DISEASE?

Following the 1976 American Legion Convention at the Bellevue Stratford Hotel in Philadelphia, 34 attendees died and 221 people became ill from pneumonia caused by the bacterium *Legionella pneumophila*. Although not recognized at the time, *Legionella* is not a new microorganism. It has since been found in many archived tissue samples at the US Centers for Disease Control and Prevention (CDC). These specimens were taken from persons with previously undiagnosed pneumonia-like illnesses.

This disease, now commonly known as Legionnaires' Disease, is a respiratory infection that strikes susceptible individuals exposed to *Legionella pneumophila*. Infection results from inhaling airborne water droplets or mist containing viable *Legionella pneumophila*, which are small enough to pass deep into the lungs and be deposited in the alveoli, the small pockets in the lungs. The dose of *Legionella pneumophila* required to infect humans is not definitively known. Ingesting *Legionella pneumophila* has not been shown to cause illness. Legionnaires' Disease can have an incubation period of two to ten days. Most reported cases have occurred in the 40- to 70-year old age group. Although healthy individuals may develop Legionnaires' Disease, people thought to be at increased risk of infection include smokers, patients with cancer, chronic respiratory diseases, kidney disease, and any immuno-suppressed condition. The fatality rate is estimated at 10 to 20% of those who contract the disease; but in immuno-suppressed persons or those with other underlying diseases, this figure can be much higher.

Legionella pneumophila is a ubiquitous organism. It appears in almost every ground and surface water. The organism survives typical chlorine disinfection for

potable water and consequently can appear in finished water distributed to homes and industry. It is important to keep the incidence of Legionellosis in perspective. For example, in the United States, the Technical Manual published by OSHA (Occupational Safety and Health Administration) estimates over 25,000 cases of the illness occur each year. More than 4,000 deaths are believed to occur, but only about 1,000 are reported. However, the CDC usually investigates less than ten community outbreaks per year (in 1995 there were three). An outbreak is considered to occur when two or more cases of the disease can be attributed to a work site.

IV. SYMPTOMS OF LEGIONNAIRES DISEASE

Initial symptoms of Legionnaires' Disease include high fever, chills, headache and muscle pain. A dry cough soon develops and most patients suffer breathing difficulty. Some patients also develop diarrhea or vomiting and can become confused or delirious. Legionnaires' Disease may not always be severe; in community outbreaks, mild cases may be recognized that would probably have escaped detection except for the increased awareness of the disease.

A common but less serious infection caused by *Legionella pneumophila* is an illness known as "Pontiac Fever." The symptoms of Pontiac Fever are similar to those of moderate to severe influenza: headache, fatigue, fever, arthralgia (joint pain), myalgia (muscle pain) and, in a small proportion of cases, nausea, vomiting and coughing. The incubation period is one to two days and the illness passes in five to ten days. No deaths have been attributed to Pontiac Fever. Since this illness generally escapes detection, statistical information about its occurrence is sparse.

V. MICROBIOLOGY

Legionella is the name given to a genus of bacteria for which at least 37 different species have been identified. *Legionella pneumophila*, for which fourteen serogroups have been identified, is the species most commonly associated with disease outbreaks. Serogroups 1, 4, and 6 are most commonly associated with human illness. *Legionella pneumophila* are rod-shaped bacteria and are widespread in natural water sources. They have been found in rivers, lakes, and streams; mud and soil samples; water and sludge from cooling towers; and in other man-made water systems. They have been

detected in many drinking water sources, including well water, resulting in the contamination of a variety of public and private systems using this water.

A cooling tower system can present an ideal environment for growth of *Legionella pneumophila*. Cooling tower drift in the form of aerosols can be easily inhaled. Showers, wash stands, sinks, air scrubbers and air washers / handlers can also provide a good growth environment and possible means of transmission of *Legionella pneumophila* bacteria.

VI. ECOLOGY

The ecology of *Legionella pneumophila* in water systems is not fully understood; however, the following conditions have been found to affect its growth rate:

- Sediment, sludge, scale and organic materials can harbor the bacterium and promote growth. The formation of a biofilm within a water system is thought to play an important role in harboring and providing favorable conditions in which *Legionella pneumophila* can grow. A biofilm is a layer of microorganisms contained in a matrix that may form a thin layer of slime on surfaces in contact with water. *Legionella pneumophila* grows within biofilms and within protozoa acting to shield *Legionella pneumophila* from concentrations of biocides that would otherwise kill or inhibit *Legionella pneumophila* when freely suspended in water.
- Water temperatures in the range of 68°F (20°C) to 113°F (45°C) favor growth. It is uncommon to find proliferation below 68°F (20°C), and it does not survive above 140°F (60°C). The optimum laboratory temperature for the growth of the bacterium is 99°F (37°C). Organisms may, however, remain viable and dormant in cool water, multiplying only when the temperature reaches a suitable level and when growth and reproduction are not inhibited by adequate bio-control.
- *Legionella pneumophila* have been shown to colonize certain types of water systems that may have stagnant areas, e.g., water heaters, tanks, reservoirs, and basins. Fittings, piping, and various gasket materials used in these systems can also be colonized. Stagnant conditions promote growth of *Legionella pneumophila* and make eradication difficult.
- Commonly encountered microorganisms (such as algae, amoebae and other bacteria) in untreated or ineffectively treated water may promote *Legionella pneumophila* growth. Some protozoa serve as hosts for *Legionella pneumophila*, which can enable rapid proliferation of *Legionella*.

VII. BEST PRACTICES AND RECOMMENDATIONS FOR MINIMIZATION OF RISKS ASSOCIATED WITH LEGIONELLA

The following best practices for microbiological control are recommended to promote and maintain clean heat transfer surfaces and a healthy work environment around open recirculating cooling systems. The practices outlined in this document are a description of the consensus of existing best practices as recommended by various authoritative bodies worldwide. Halogen oxidizers have been proven to control *Legionella* when applied properly. Evidence exists that other compounds, such as ozone, peroxides, and non-oxidizing biocides are effective against *Legionella* bacteria in limited circumstances. Treatment techniques such as ultraviolet light or ultrasonics have also shown the ability to kill *Legionella* bacteria in limited circumstances.

The CTI reviewed publications and interviewed representatives from authorities such as OSHA, CDC, ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers), the UK HSE (United Kingdom Health and Safety Executive), the UK BACS (British Association of Chemical Specialties), and the health & safety agencies of Japan, Australia, Singapore, and Taiwan, among others. *In no way, however, should these recommendations be interpreted to guarantee the absence of Legionella bacteria or any other particular pathogen, and consequently that these measures will prevent illness (e.g. Legionellosis).*

Nevertheless, we believe these measures can be effective in fostering the safety of cooling systems. This is accomplished directly by destruction of planktonic (free-swimming) bacteria including *Legionella*, and indirectly by eliminating conditions that favor *Legionella* amplification (multiplication), i.e. the elimination of biofilms and amoebae and other protozoa that feed on biofilms and which serve as *Legionella* hosts. Research continues on effective means for control of protozoan cysts, which can also harbor and protect *Legionella* for extended periods.

These best practice recommendations focus on chemical control parameters. Halogens serve as the primary disinfectants in these recommendations. Sources of halogens include chlorine gas, hypochlorites, chlorine dioxide and stabilized halogen donors. It must be recognized, however, that chemical treatment is only one aspect of risk minimization. Design, operation, and maintenance practices are also crucial to reducing health risks associated with cooling systems.

Monitoring *Legionella* in Cooling Water Systems

Evaluate system cleanliness and the effectiveness of microbial control by visual inspection as well as through regular monitoring of bulk water (planktonic) and surface (sessile) microbial populations.

Check the cooling tower deck and tower fill for gross evidence of biofouling. When operations permit, the mist eliminator section of the cooling tower should also be inspected for biological deposits. Collect suspected biological deposits for microscopic examination to confirm biological content and the presence or absence of amoebae and ciliated protozoa. When performed by a trained microscopist, this approach can provide valuable, same-day information on system cleanliness and associated health risk since some protozoans can serve as host organisms for *Legionella* allowing amplification of *Legionella* to dangerous levels. High numbers of protozoa therefore represent an increased risk for multiplication of *Legionella* and consequent increase in the risk of Legionnaires' disease for susceptible individuals.

Use dipslides, PetriFilm™, or other culturing techniques to quantify total aerobic heterotrophic bacteria populations in bulk water and on sur-faces. Alternatively, ATP-based biomonitoring can be used. This technique has the advantage of eliminating the 2-day delay in results imposed by incubation requirements of culture-based methods.

Most professional and government agencies that have issued *Legionella* position statements and guidelines do not recommend testing for *Legionella* bacteria on a routine basis. These reasons derive from difficulties in interpreting *Legionella* test results and in using test results as a basis for control. Note the following aspects:

- An infectious dose level for *Legionella* has not been established and in any case, (given variations in strain virulence and wide differences in individual susceptibility) the concept of a fixed infectious dose level may be misleading. Since no fixed “danger” level can be assigned, it also follows that no specific level of the organism can be assigned as “safe.”
- *Legionella* may be “non-detectable” in bulk water samples collected on one day but can repopulate and be found within a few days. *Legionella* can be released from biofilms or from host life forms associated with these films. *Legionella* are reported to be capable of rapid recolonization of previously cleaned systems, especially if conducive conditions are present.
- Simple detection of the organism in a cooling system does not necessarily mean there is a risk of disease, in part because not all *Legionella* serogroups are associated with Legionellosis.

- Culture-based techniques used by testing labs to quantify *Legionella* have a 10 to 14 day turnaround for results. This period is too long for *Legionella* monitoring to serve as an effective tool for treatment control.

Various studies have shown that some 40 to 60% of cooling towers tested contained *Legionella*. Therefore, it is best to assume that any given system can harbor the organism, and that routine, continuous microbiological control practices should be implemented to minimize the risk of *Legionella* amplification and associated disease.

Testing for *Legionella* is recommended in the event of an outbreak (to identify potential sources of the organism) and to evaluate the effectiveness of disinfection procedures. Testing is also recommended whenever process intrusions into the cooling water occur or other factors mitigate a loss of microbiological control for an extended period of time. There have been reports of vary rapid increases in *Legionella* concentrations in a short period of time under these circumstances.

If testing is required, contact a laboratory experienced in performing *Legionella* analyses on environmental samples. Also, concurrent sampling should be performed on the bulk water and surface deposits for microscopic detection of higher life forms, along with total aerobic heterotrophic counts. Collect bulk water samples from several locations within the system (e.g., makeup water, hot return water, basin water, and from sample taps on heat exchangers remote from the cooling tower if available). Where evident, collect deposit samples from the basin walls, tower fill, and distribution decks. The following three scenarios are possible:

- A low *Legionella* count with an undetectable or small population of amoebae/protozoa (higher life forms) and low biofilm counts (low sessile bacteria numbers) is a good indication of a clean, well-maintained system with low risk to health.
- A low bulk water *Legionella* count along with low numbers of higher life forms in deposits, but with high biofilm counts may indicate a low present health risk but suggests the potential for future problems if steps are not taken to reduce biofilm levels. Since protozoa that promote *Legionella* amplification graze on bacteria in biofilms, the presence of significant biofilm can promote the development of higher, and thus potentially more dangerous, levels of *Legionella*.

- A low bulk water *Legionella* count associated with a large number of higher life forms indicates a strong potential for amplification, and the low *Legionella* count cannot therefore be interpreted to indicate a system with a low health risk.

**Recommended Target Values
Routine Treatment of Cooling Water Systems**

Parameter	Dipslides	Agar Pour Plate or Petrifilm	Microscopic Exam
Planktonic Counts (Bulk Water)	<10,000 CFU/mL	<10,000 CFU/mL	No higher life forms
Sessile Counts (Surfaces)	<100,000 CFU/cm ²	<100,000 CFU/cm ²	No higher life forms
Deposits	NA	NA	No higher life forms

Note: Results from dipslides, agar pour plates, or Petrifilm are colony forming units (CFU per milliliter or per square centimeter) of total aerobic heterotrophic bacteria. *Legionella* bacteria are not detected by these conventional plate count media. Microscopic examination for the presence of higher life forms requires a trained microscopist and specialized microscopy equipment.

**Routine Treatment
Continuous Application of Halogens**

- For relatively clean systems or where clean potable water makeup is used, feed a source of halogen (chlorine or bromine) continuously and maintain a free residual. Continuous free residuals of 0.5 to 1.0 ppm (as Cl₂) in the cooling tower hot return water have been recommended by many agencies¹. Periodic monitoring of the residual at sample points throughout the cooling water system is needed to insure adequate distribution. The effectiveness of either halogen decreases with increasing pH; bromine is relatively more effective at a higher pH (8.5 to 9.0).
- Stabilized halogen products should be added according to the label instructions, and sufficient to maintain a measurable halogen residual.
- Discharge of system water directly to surface water may require dehalogenation.

¹ UK Publication “The Control of Legionella in Water Systems” Approved Code of Practice & Guidance. Third Edition

- A biodispersant/biodetergent may aid in the penetration, removal, and dispersion of biofilm and often increases the efficacy of the biocide.
- Continuous halogen programs may require periodic use of nonoxidizing biocides. These may be required to control biofilm and planktonic organisms in systems that use makeup water from other than potable water sources, and those with process leaks or contamination. The choice of nonoxidizing biocides should be based on the results of toxicant evaluations. Reapply as dictated by results of biomonitoring.

Intermittent Use of Halogens

Continuous halogenation is always preferred for *Legionella* risk minimization; however, if this is not possible, intermittent use of halogen is necessary.

- As a minimum control program for relatively clean systems or where clean, potable water is used for makeup, establish a free halogen residual of 1.0 up to 2.0 ppm (as Cl₂) and hold this residual for no less than one hour each day. Free residual must be monitored throughout the distribution system.
- Stabilized halogen products should be added according to the label instructions and to achieve a measurable halogen residual. This residual should be held for no less than one hour each day.
- Bulk water and sessile counts, along with microscopic examination of deposit samples, will be necessary to ensure that the concentration and duration of halogen residuals are adequate.
- A biodispersant may aid in penetrating the biofilm and may increase the efficacy of the biocide.
- Discharge of system water directly to surface water may require dehalogenation.
- Nonoxidizing biocides are critical to the cleanliness of systems treated intermittently with halogens and are recommended. The choice of nonoxidizing biocide should be based on the results of toxicant evaluations. Reapply as dictated by the results of biomonitoring.

Routine On-Line Disinfection

Hyperhalogenation

Hyperhalogenation as practiced is the maintenance of a minimum of 5 ppm free halogen residual for at least 6 hours. Periodic on-line disinfection may be necessary for systems:

- That have process leaks
- That have heavy biofouling
- That use reclaimed wastewater as makeup
- That have been stagnant for a long time
- When the total aerobic bacteria counts regularly exceed 100,000 CFU/ml
- When *Legionella* test results show greater than 100 CFU/ml

Periodic hyperhalogenation will discourage development of large populations of *Legionella* and their host organisms. Consequently, periodic hyperhalogenation may eliminate the need for conducting more complicated and higher risk off-line emergency disinfection procedures.

Other Treatment Approaches:

Because of the interest in controlling *Legionella*, a number of products have been promoted as a control of Legionellosis in Cooling Systems. Some of them are electronic water treatment devices, material coatings and bio-static components. At the date of this publication, there is little application data to support these approaches. While these technologies may have some benefit, they should not distract your attention from the key issues of:

- Eliminating stagnant water areas
- Eliminating controllable sources of nutrient to the Cooling Water system.
- Maintain overall system cleanliness and provide good biological control.
- Use the best technology in Drift Elimination (lowest drift rate).

Emergency Disinfection

The following emergency disinfection procedure is based on OSHA and other governmental recommendations. This procedure may require modification based on system volume, water availability and wastewater treatment capabilities.

Conduct emergency disinfection:

- When very high *Legionella* counts exist (i.e., >1000 CFU/ml).
- In cases where Legionnaires disease are known or suspected and may be associated with the cooling tower.
- When very high total microbial counts (>100,000 CFU/mL) reappear within 24 hours of a routine disinfection (hyperhalogenation).

Emergency Disinfection Procedure

1. Remove heat load from the cooling system, if possible.
2. Shut off fans associated with the cooling equipment.
3. Shut off the system blowdown. Keep makeup water valves open and operating.
4. Close building air intake vents in the vicinity of the cooling tower (especially those downwind) until after the cleaning procedure is complete.
5. Continue to operate the recirculating water pumps.
6. Add a biocide sufficient to achieve 25 to 50 ppm of free residual halogen.

7. Add an appropriate biodispersant (and antifoam if needed).
8. Maintain 10 ppm free residual halogen for 24 hours. Add more biocide as needed to maintain the 10 ppm residual.
9. Monitor the system pH. Since the rate of halogen disinfection slows at higher pH values, acid may be added, and/or cycles reduced in order to achieve and maintain a pH of less than 8.0 (for chlorine-based biocides) or 8.5 (for bromine-based biocides).
10. Drain the system to a sanitary sewer. If the unit discharges to a surface water under a permit, dehalogenation will be needed.
11. Refill the system and repeat steps #1 through 10.
12. Inspect after the second drain-off. If a biofilm is evident, repeat the procedure.
13. When no biofilm is obvious, mechanically clean the tower fill, tower supports, cell partitions, and sump. Workers engaged in tower cleaning should wear (as a minimum) eye protection and a ½ face respirator with High Efficiency Particulate (HEPA) filters, or other filter capable of removing >1 micron particles.
14. Refill and recharge the system to achieve a 10 ppm free halogen residual. Hold this residual for one hour and then drain the system until free of turbidity.
15. Refill the system and charge with appropriate corrosion and deposit control chemicals, re-establish normal biocontrol residuals and put the cooling tower back into service.

VIII. RECORDKEEPING

To ensure that adequate information is available to describe tower operations, records should be kept of precautionary measures and treatments, monitoring results and remedial work. Some government agencies specify the type and level of detail for these records. In any case, sufficient information should be recorded to show the particular measures taken, including but not limited to: instances of mechanical cooling tower cleaning, the frequency and amount of biocide addition, halogen residual levels, results of biomonitoring, and other significant aspects of the tower operation.

If there are any complaints or safety, health or environmental audit findings regarding tower operations, they should be documented, as should any corrective actions taken.

A records retention policy should be developed and adhered to, and should be in reasonable conformance to any general records retention policy at the facility, utility or corporation. Records retention should not be

any shorter than any minimum regulatory requirement that may have been established.

IX. MECHANICAL DESIGN CONSIDERATIONS FOR MINIMIZING LEGIONNAIRE'S DISEASE

Any new or retrofit tower or component design should include consideration of the issues discussed below.

Drift Eliminators (DE)

- State-of-the-art high-efficiency nesting type eliminators, if not already present to minimize drift mass flow, are suggested [reference CTI ATC-140].
- Tower designers should use these eliminators within their design air velocity requirements as set and tested by the manufacturer. Drift eliminators are intended to prevent escape of entrained water droplets that might contain LD bacteria from the tower.

Plenum

- Tower designers should avoid locally elevated exit air velocities at the eliminators, designing the plenum to maintain airflow within the tolerances of design throughout, particularly at the center of the eliminator bank in counterflow towers and at the upper portions of the eliminator bank in crossflow towers.
- Tower designers should supply effective eliminator air seals, covering all open area beyond the eliminators themselves. Small gaps allow elevated local velocities and can lead to substantial water droplet formation and leakage.
- Proper installation of the eliminators and air seals is critical to minimize the drift rate.

Water Distribution, Falling Water, and Fill

- Tower designers should provide distribution components to minimize the creation of very small droplets which are more likely to escape through the drift eliminators.
- Tower designers should provide distribution components to minimize masses of water at louver or eliminator locations that might by-pass air-seals allowing circulating water to enter the exit airstream.
- Tower designers should provide tower air inlet and rain zones that minimize splash-out and aerosol droplet creation.

- Tower designers should select the fill for proper air and water management to control the drift rate and splash-out.
- Fill selection should be based on expected water quality and treatment, to minimize fouling and poor water distribution of water that might encourage *Legionella* propagation.

Fan and Fan Cylinder

- Tower designers should provide fan cylinder seal integrity such that no extraneous water can make its way to the fan even if the hot water basin (HWB) overflows (crossflow towers).

Siting and Flow

- System design engineers should place cooling towers away from building air intakes in such a manner that cooling tower drift or splash-out is not fed into the building air supply system.
- The tower should be designed to provide good continuous water flow through and out of the tower to move water effectively. There should be no dead flow locations in the basins.
- System design engineers should provide discharge piping and equalizers to move water effectively with no dead flow locations. Special attention should be paid to equalizer piping to ensure these areas are not stagnant.

Side Stream Filtration

- When suspended solids in the cooling tower water are excessive, side stream filtration may be considered for reduction of these solids. Side stream filtration has been shown to control suspended solids in cooling tower circulating water. Particulate solids are suitable surfaces for the growth of bacterial films that provide a safe haven for *Legionella* bacteria. The exact design of this equipment is site specific; it will consider makeup water quality, design of tower fill, recirculation rate, and total system volume.

X. COOLING TOWER INSPECTIONS AND PHYSICAL MAINTENANCE

It is important to visually inspect the cooling tower frequently to maintain the tower and its components in good working order. During maintenance and inspection operations, plant safety procedures must always be followed. Organic fouling, dirt or debris must be removed. Defects in the components or their installation, which may lead to emission of excessive drift or spray, should be corrected.

Inspection should also be performed on the outside of the unit for general cleanliness, leaks, or any evidence

of biomass. Pools of water or small droplets emanating from the tower may be a sign of excessive drift. The appearance of heavy deposits on the outside of the unit may be an indication of excessive water loss due to windage or other factors. During maintenance and inspection operations appropriate plant safety procedures should always be followed.

Water Treatment System

Inspect the water treatment system for proper operation of all components.

Louvers

Inspect louvers and surrounding area for biomass and scale. Louvers should be undamaged and positioned as designed to prevent spray from splashing or blowing out of the tower. Missing or damaged louvers should be replaced. Out of position louvers should be properly placed back in position, making sure retaining hardware is also correctly placed.

Piping dead legs

Inspect circulating water piping system for deadlegs. Any deadlegs which cannot be removed or replaced with a circulating line should be bled frequently. Bleed equalizer piping between adjacent cooling tower cells frequently.

Cold water basins

Inspect the cold water basin for build-up of organic matter, dirt, and debris. If any significant accumulation of debris or sludge is found, the accumulation should be removed.

If the tower is taken out of service, the basin should be cleaned.

Crossflow hot water basin

Leaks from the hot water basin that might lead to droplets becoming entrained in the air-stream should be repaired. Missing or broken nozzles should be replaced. Basin covers that may be missing or broken should be replaced or repaired. Water overflowing the basin should be corrected.

Counterflow spray system

The spray system should be properly positioned and free of fouling. Missing nozzles should be replaced. Misaligned nozzles may spray water up into the eliminators and should be correctly re-positioned. Leaks at piping joints or nozzles that spray water into the eliminators should be repaired.

Eliminators

The eliminator system is critical for controlling the water droplets leaving the cooling tower. Drift eliminators should be inspected for build-up of organic and inorganic material and for deterioration or damage.

Eliminators should be cleaned as needed.

Missing or damaged eliminators should be replaced. Any gaps in or between eliminators or between eliminators and casing, structural elements, air seals, or plenum framework should be corrected.

Fill

Fill air entrance and exit surfaces should be thoroughly inspected. Evidence of fouling should lead to a more extensive inspection and review of water treatment and maintenance procedures. Damaged or deteriorated fill should be replaced.

XI. SUMMARY

To minimize the proliferation of *Legionella pneumophila* and the associated risk of Legionnaires' disease, the consensus recommendations are:

- Minimize water stagnation
- Minimize process leaks into the cooling system that provide nutrients for bacteria
- Maintain overall system cleanliness. This will minimize the buildup of sediments that can harbor or provide nutrients for bacteria and other organisms.
- Apply scale and corrosion inhibitors as appropriate.
- Use high-efficiency mist eliminators on cooling towers.
- Control the overall microbiological population.

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