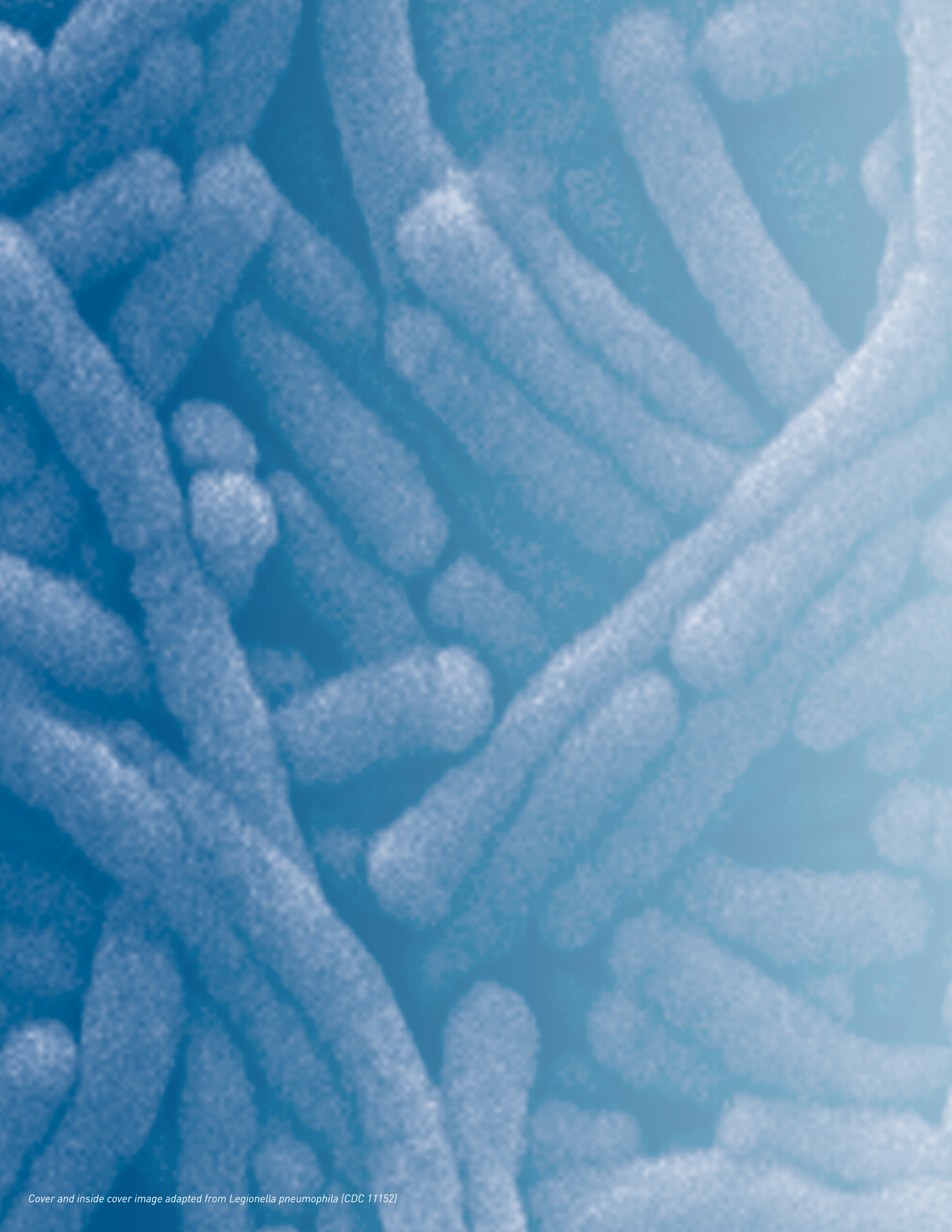
# Legionella

## Management in Building Water Systems: The Role of Chlorine Products

American Chemistry Council



*Cover and inside cover image adapted from Legionella pneumophila (CDC 11152)*

# Contents

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# Foreword

Drinking water contamination from regrowth of microorganisms is the most frequently reported cause of U.S. waterborne disease outbreaks in the last several years, according to the U.S. Centers for Disease Control and Prevention's (CDC) *Morbidity and Mortality Weekly Reports*. Microbial regrowth and recontamination occur during water's transit from a centralized treatment plant through distribution pipe networks to various facilities and in-building ("premise") plumbing systems. Among the numerous types of pathogens (i.e., disease-causing microorganisms) that can regrow, *Legionella pneumophila* bacteria that can cause Legionnaires' disease (hereafter legionellosis) are frequently found. Thousands of water-related cases and hundreds of deaths from legionellosis have been reported worldwide. Outbreaks associated with inhalation of aerosols containing *Legionella* from building plumbing water systems, blowdown from cooling towers, recreational spas and pools, and decorative water features like fountains are regularly reported in the science and mainstream news.

The May 2018 NSF International (NSFI) conference in Baltimore, Maryland, "Managing *Legionella* in Building Water Systems," provided comprehensive coverage of the technical, regulatory, and process issues. These included the role of water temperature, biofilms, and amoebas facilitating *Legionella* proliferation; analytical methods and monitoring; mitigation and water treatment technologies, including chlorine-based disinfectants; risk estimation approaches; plumbing system design factors; water system management (safety) plans; sources of guidance, regulatory approaches and policy issues; and potential liability consequences for not taking appropriate assessment and preventive actions. Three affiliated Water Research Foundation webinars followed in 2018 and focused on analysis and monitoring, technology and remediation, and management systems and guidelines, respectively. A September 2019 NSFI conference in Los Angeles, California, elaborated on some issues from the 2018 Baltimore conference.

A rapidly growing number of published reports on legionellosis cases, outbreaks, and mitigation technologies exists. This booklet is intended to provide an overview and summary of information to help managers and owners of at-risk facilities better understand and manage the risks of *Legionella pneumophila* in plumbing systems. It advocates for a proactive, preventative approach to mitigate legionellosis risks when appropriate, and includes examples of pertinent experiences focusing on currently available methods for assessment and the principal technologies that have been successful for mitigation and prevention. It also provides citations to key literature and guidance publications so interested readers can explore the relevant issues and technologies in greater detail before assessment or mitigation decisions are made and contractors engaged.

To date, the U.S. Environmental Protection Agency has not regulated nor has it provided detailed mitigation guidance for managing *Legionella* in distributed drinking water systems. For this reason, policies and procedures affecting implementation of location-specific mitigation measures continue to be determined by individual states.

Lastly, this booklet focuses primarily on chlorine-based *Legionella* control technologies because of their demonstrated effectiveness and affordability among currently available options.

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# Executive Summary

*Legionella* bacteria are widely distributed in water and soil environments. Legionellosis, also called Legionnaires' disease, as well as Pontiac fever are caused by different strains of these bacteria resulting from inhalation exposures. Legionellosis is a serious and potentially fatal pneumonia. In contrast, Pontiac fever is a flu-like illness that is usually self-limiting.

*Legionella pneumophila* are common environmental bacteria that can colonize and grow in plumbing, cooling towers, hot tubs, fountains, pools, and other building water features. They are also the cause of most recently reported U.S. waterborne disease outbreaks and all related deaths. Cases and outbreaks of the serious and sometimes deadly disease are often not diagnosed. Rather, water linkages are typically determined when identical bacterial strains are detected in patients and nearby water exposure sources, such as cooling towers.

*Legionella* bacteria grow in warm waters and can populate biofilms (slimy environments produced by microorganisms located on wet surfaces) and multiply in free-living amoebas within the biofilms. Many hot water tanks are deliberately set at lower temperatures to conserve energy (49 °C, 120 °F), resulting in the unintended consequence of providing favorable *Legionella* growth conditions. To maintain plumbing hot water tap and return temperatures of ~55 °C (~131 °F), hot water tank and system temperatures of 60 to 65 °C (140 to 149 °F) are widely recommended.

Inhalation of tiny drops of water called aerosols containing *Legionella* bacteria, but not ingestion, can lead to pneumonia. A portion of these cases are fatal. Individuals and groups most at risk for *Legionella* infection include occupants of healthcare and convalescent facilities, smokers, elderly, and immune-compromised individuals. Cooling heat exchangers and aerating wastewater treatment systems can also be a source of risk. However, millions of higher risk residents in generally lower risk home and work environments probably also contribute to numerous unidentified cases of sporadic (i.e., non-outbreak-related) legionellosis.

Numerous analytical methods exist and continue to be developed to evaluate plumbing and other facilities where exposure potential and risk exist. Infectious doses (i.e., the number of *Legionella* bacteria needed to cause an infection in an individual) can be relatively large compared to some pathogens. Further, individual susceptibility is a key factor in many exposure scenarios and adverse health outcomes.

Contracting legionellosis is a risk in any part of the world because of the ubiquitous environmental sources of *Legionella*, but it is likely to be more common in the developed world given the extent and density of indoor plumbing, water-based cooling towers, hot tubs and spas, elevated concentrations of high-risk patients in hospitals and nursing homes, and widespread travel.

Translating water and biofilm concentrations of *Legionella* bacteria into quantified infection risk from aerosol exposures is a complex undertaking. As with managing conventional (diarrheal) waterborne disease risks, conducting assessments and applying preventive mitigation technologies in at-risk situations and locations, when warranted, can help ensure public health protection. It is important to emphasize, however, that zero *Legionella* detections (total elimination) in building water systems is not necessarily the essential or achievable protective low-risk goal for legionellosis. Nonetheless, striving to achieve and maintain control to the fewest detections achievable is important.

The extent of colonization (% positive sampling sites) might also be indicative of risk. One thousand ($10^3$) colony forming units (CFU)/L has been suggested as a reasonable screening level for considering follow-up and possible mitigation. Practical experience suggests, though not without controversy, that legionellosis risk increases if >30% of building water system samples test positive.

The principal disinfection technologies for building water systems reviewed in this booklet are free chlorine, chloramine (monochloramine, also called combined chlorine), chlorine dioxide, and copper-silver ionization (CSI). *Legionella* prevention and mitigation processes include mitigating biofilms by shock heat and shock chlorination, possibly physically removing by *in situ* abrasive scouring, and continuous disinfection with measurable disinfectant residuals at end-use taps and showerheads. Several chlorine-based disinfectants have been shown to be effective in many applications.

Although a slower-acting disinfectant (high concentration × time [Ct]) compared to free chlorine, chloramine seems to be particularly effective as a secondary (residual) disinfectant in plumbing because it (1) survives longer in water systems, (2) its lower chemical reactivity facilitates enhanced penetration of biofilms prior to decomposing, and (3) it produces lower levels of regulated disinfection byproducts than free chlorine or chlorine dioxide. CSI systems are effective when maintained, not temperature sensitive, but are affected by pH and some water constituents such as anions. They are also not permitted in some states.

Biofilm control is a key challenge because they provide reservoirs where *Legionella* and other microorganisms, including amoebas, are protected from disinfectant residuals and can (re)colonize and proliferate. Microorganisms tend to accumulate in biofilms and are often aggregated on particulates. Although building water system assessments always involve water monitoring, some biofilm monitoring is appropriate, if feasible. Mitigation is frequently applied to only the hot water system; however, the cold water system should also be evaluated to determine if it is a significant risk factor for legionellosis—especially in summer months or warm climates.

Any prevention and mitigation process for *Legionella* and legionellosis risk in building water systems should be associated with the development, application, and periodic revision of a comprehensive Water Safety Plan (or the equivalent). It should incorporate a Hazard Assessment Critical Control Point (HACCP)-type management system for maintaining improved changes in building water system conditions. These can include the following components: (1) temperature management in hot water systems; (2) disinfection treatment, especially of warm and hot waters, but also possibly cold water; (3) continuous presence of residual disinfectants to all water taps or outlets; (4) periodic surveillance and monitoring to detect changing *Legionella* presence; and (5) verification and regular reassessments of prevention and mitigation practices to ensure continued *Legionella* control.

A comprehensive building water assessment process also requires examining the existing system and multiple water parameters, including water retention times, use rates, the presence and extent of "dead ends," and treated entry water supply, including seasonal variations. The latter includes parameters such as pH, disinfectant residuals, hardness, disinfection byproducts (DBPs), and the presence of other ions that could interfere with the efficacy of the mitigation technologies already in place or that are being evaluated.

The above considerations are complicated by the fact the existing water monitoring and compliance requirements often vary by state. This is because, to date, the U.S. Environmental Protection Agency (USEPA) has not regulated nor has it provided detailed mitigation guidance for managing *Legionella* in distributed drinking water systems. In this regard, there is a clear need for comprehensive and authoritative guidance from USEPA for the states so that they can provide consistent, science-based, and effective oversight as well as cost-effective controls for building water system treatment technologies where needed to protect the public. Such guidance should specifically encourage and facilitate the application of on-site supplemental technologies to reduce legionellosis risks. In contrast, designating a facility as a public water system creates regulatory barriers and associated costs that could adversely affect decisions on whether or not to apply supplemental water treatment to reduce legionellosis risks in building water systems.

The risk-benefit balance for reducing acute, potentially life-threatening, legionellosis risks in building water systems through supplemental disinfection is certainly greater than the largely hypothetical increased lifetime exposure and health risks resulting from some additional DBPs that might be produced—especially where affected populations are not residential.

Lastly, treatment of spas, decorative water features, and cooling tower water should not be subject to drinking water control requirements, but they should be disinfected and maintain a continuous effective disinfectant residual.

# 1 Introduction

*Legionella* bacteria are widely distributed in the water and soil environment. Legionellosis (also called Legionnaires' disease; see more below) and Pontiac fever are caused by inhalation—not ingestion—of a suspension of tiny droplets of water in air called aerosols containing different strains of the bacteria. Exposure can occur from showering, splashing, spa or therapeutic pool use, decorative water features such as cascades, as well as blowdown from cooling systems, heat exchangers, and "fugitive aerosols" from municipal and industrial waste treatment processes. Legionellosis is a serious and potentially fatal pneumonia; Pontiac fever is a milder, flu-like illness that is usually self-limiting.

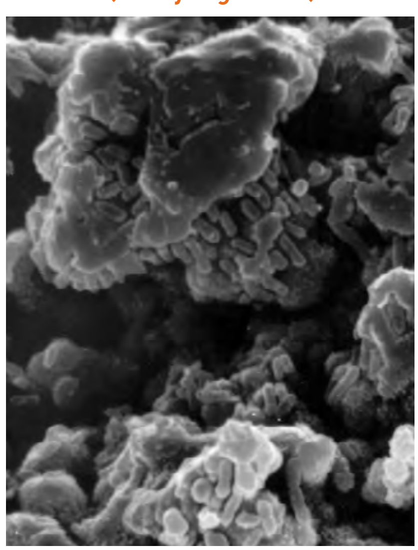
Inhalation of microbiologically contaminated water and drinking water system aerosols are likely the most significant waterborne disease risks in developed nations with managed, well-regulated drinking water systems. The conventional typhoid, cholera, and gastroenteritis ("diarrheal") diseases continue to be reduced and largely eliminated by better and more universal drinking water disinfection and filtration treatment and management (ACC, 2018; Cotruvo, 2019), but reported waterborne legionellosis (see more below) outbreaks are increasing—at least partly due to improved diagnoses and identification of *Legionella* in patients and associated building water systems.

Increased numbers of reports of legionellosis does not necessarily mean that actual cases or incidents are increasing compared to earlier years when medical awareness and applications of diagnostic procedures were much lower or nonexistent. It is likely that more cases and outbreaks are being detected, verified, and reported to the U.S. Centers for Disease Control and Prevention (CDC) and classified as to the source of exposure. On the other hand, as the population of older and immune-compromised individuals continues to increase, additional cases could also increase. Further, diagnostic DNA technology advancements allow matching of the specific disease-causing strain in the patient to strains detected in the plumbing system or other localized water exposure pathways.

*Legionella* bacteria are common in many environments, including soil and water, and at least 60 species and 70 serogroups have been identified (NASEM, 2019; WHO, 2007). *Legionella pneumophila*, in particular, is a significant and growing public health concern, accounting for about 90% of reported cases of legionellosis.

Many microorganisms can regrow or recontaminate after centralized drinking water treatment and colonize distribution, plumbing, and cooling water systems (see **Figure 1-1**). So-called opportunistic premise plumbing pathogens (OPPP) include *Legionella pneumophila* and non-pneumophila strains, *Mycobacterium avium*, *Pseudomonas aeruginosa*, *Naegleria fowleri*, and *Acanthamoeba* spp. (Lu et al., 2015; Wang et al., 2017). These and other microorganisms colonize biofilms, especially on warm water contact surfaces.

**Figure 1-1: Tuberculated Water Pipe Interior Containing Rod-Shaped Bacteria (Likely *Legionella*)**



*Source: USEPA.*

*Legionella* and other bacteria often survive and can thrive inside some free-living amoebas (single-celled protozoa) in biofilms (see **Box 1-1**) where they are protected from disinfectant residuals (Shaheen et al., 2019). Proliferation of protozoa in biofilms is a significant factor in *Legionella* regrowth to high colony forming unit (CFU) counts. Because not all of the regrowth (OPPP) microorganisms are impacted to the same extent by certain *Legionella* control treatments under different biofilm (microenvironment) and disinfection conditions, their presence needs to be examined separately or as part of an overall building water system assessment.

## What Is Legionellosis?

Legionellosis (Legionnaires' disease) is a severe pneumonia usually caused by the *Legionella pneumophila* bacterium; a milder, flu-like disease commonly called Pontiac fever is caused by *Legionella* spp. Legionellosis can be fatal and requires prompt medical attention and antibiotic treatment, but Pontiac fever is typically self-clearing and does not progress to pneumonia. Legionellosis and Pontiac fever have very distinct risk profiles. The World Health Organization (WHO, 2007, p. 43) states that:

> *Even when a source reaches a state at which it is infective, the proportion of people who acquire Legionnaires' disease is small (usually less than 5% of those exposed). Conversely, in outbreaks of Pontiac fever, a high percentage (about 95%) of those who are exposed become affected.*

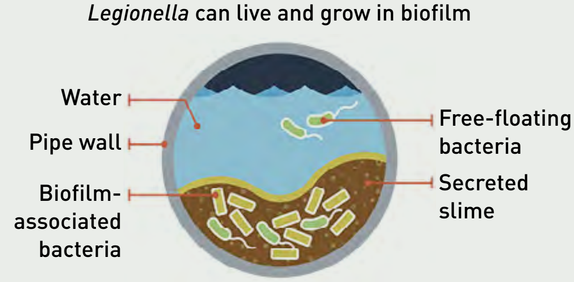
## Box 1-1: What Are Biofilms?

Biofilms are slimy environments produced by microorganisms located on wet surfaces (Biofilms, 2016). They are formed from extracellular polymeric substances, which are a network of sugars, proteins, and nucleic acids. Biofilms enable aquatic microorganisms to literally stick together and interact with one another. Biofilm communities can contain *Legionella* and other OPPP microorganisms, including bacteria, fungi, and protozoa. Microorganisms suspended in water and wet environments can deposit on and colonize suitable surfaces over time. Biofilms are common on virtually any water contact surface, including teeth, foods, submerged rocks in ponds and streams, and pipes. Over time, biofilms can increase in mass and surface area while providing a habitat suitable for microbial growth and are supported by accumulated nutrients.

Significantly, the depth and chemical composition of a particular biofilm, which can vary and evolve over time, can protect harbored microorganisms from antimicrobials, biocides, disinfectants, and even mechanical scouring. Because amoebas are more resistant to disinfectants than bacteria, *Legionella* that reproduce within amoebas are afforded additional protection. Free chlorine at typical residual levels in distributed water will chemically react with biofilm surface components, preventing or slowing the disinfectant's penetration to greater depths. Thus, typical disinfectant residuals might be insufficient to destroy many of the microorganisms located within the biofilm.

Microorganisms can detach from biofilms, and microbe-rich fragments of biofilms can become suspended in water and transported to "downstream" outlets such as taps and showerheads during normal use and flows. They also can be released in high amounts during water pressure changes (called "water hammer") and turbulence, such as resulting from local use of a fire hydrant.

**Figure 1-2: Illustration of a Pipe Cross-Section and Contents**




*Source: CDC, 2018e.*

Legionellosis is caused by inhaling the *Legionella pneumophila* bacterium. Symptoms typically develop in susceptible people 2 to 10 days after exposure to an infectious dose (i.e., the number of bacteria needed to result in an individual infection). Early symptoms include headache, muscle pain, chills, fever up to 104 °F (40.6 °C) or higher. Later symptoms include cough and shortness of breath. Deaths are typically caused by respiratory failure, septic shock, and kidney failure. Older adults, smokers, and people with weakened immune systems are most susceptible to legionellosis (Mayo Clinic, 2018).

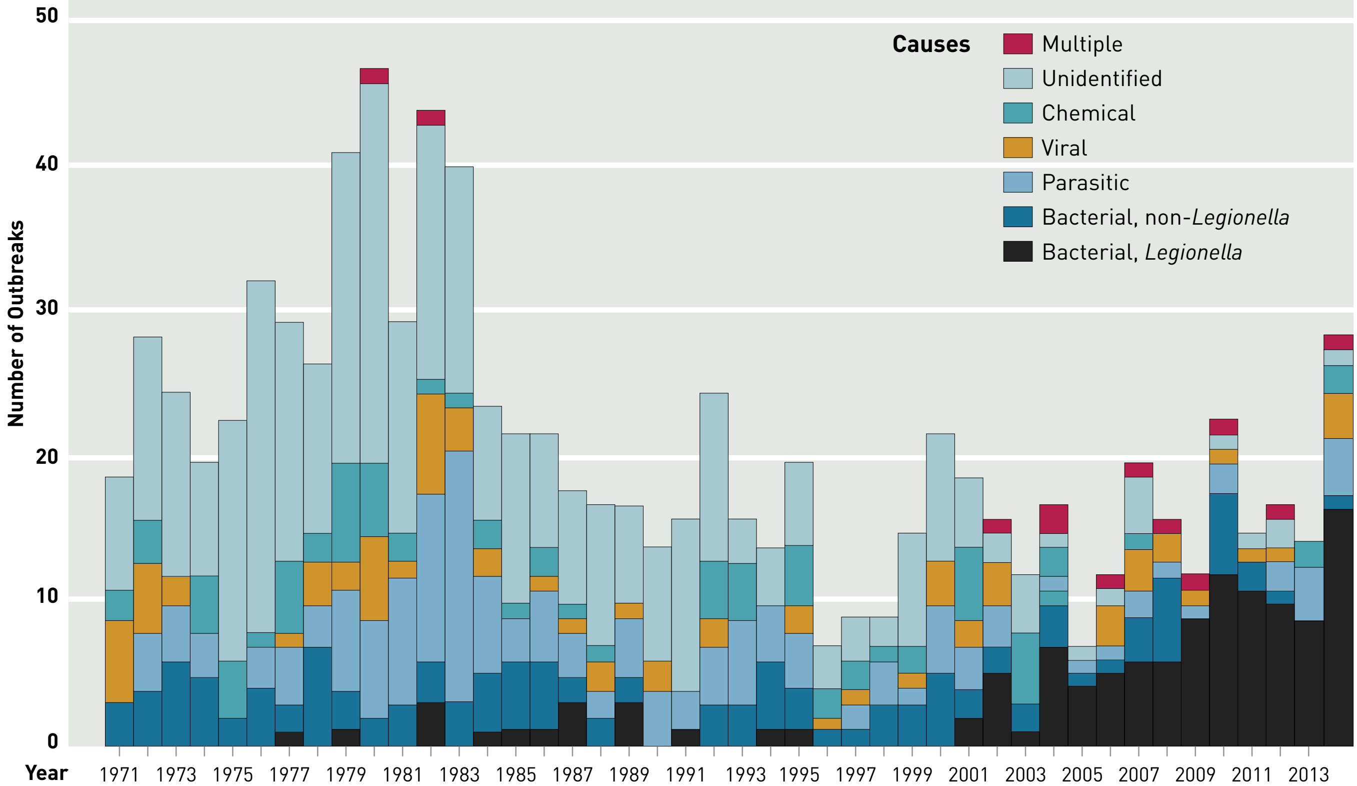
### Drinking Water Supplies as a Source of *Legionella pneumophila*

"Finished" water leaving a well-operated drinking water treatment plant that meets all USEPA and state regulations is likely to be virtually free of *Legionella* bacteria. However, once the treated water enters the distribution system the microbiological environment changes radically. For example, the treated water might encounter distribution pipes more than a century in age that are heavily "tuberculated" (see **Figure 1-1**) with accumulated biofilms, sediments, and established communities of microorganisms. These microenvironments are relatively inaccessible to residual disinfectants. Also, pipe leaks and breaks and water pressure drops can allow recontamination and colonization by external soil- and groundwater-associated microorganisms.

Corrosion-related, mobilized biofilms and sediments can also be a direct cause of microorganism release and exposure. This was the case in the Flint, Michigan, corrosion-related events beginning in 2014. Two spikes of legionellosis were reported from 2014 to 2015 and contributed to 87 cases and 12 deaths from Legionnaires' disease (Zahran et al., 2018). *Legionella*

**Figure 1-3: Causes of 928 Reported U.S. Drinking Water-Associated Outbreaks, by Year**

Based on 1971–2014 CDC Data*




* Legionellosis outbreaks were first reported to CDC's Waterborne Disease and Outbreak Surveillance System in 2001; Legionellosis outbreaks before 2001 were added retrospectively during the 2007–2008 reporting period.

*Source: Adapted from CDC, 2017.*

*pneumophila* DNA markers were detected in both hot and cold water in two hospitals located in water system distribution zones with high-water age resulting from low use (and subsequently low or non-detectable disinfectant residuals). DNA markers were less frequent in nearby houses that were also tested. Reported *Legionella* counts and Legionnaires' disease cases in one hospital with supplemental chloramination (chlorine plus ammonia; see Chapter 2) were lower than in another hospital that did not use supplemental disinfection; however, only a portion of those cases of Legionnaires' disease could be attributed to hospital exposure (Schwake et al., 2016; Zahran et al., 2018).

## Plumbing and Other Systems as Sources of *Legionella pneumophila*

*Legionella* bacteria multiply readily in low nutrient, warm water environments. Growth rates are related to water temperature as well as presence of biofilms and host amoebas. Nutrients such as assimilable organic carbon (the fraction of dissolved organic carbon that is more easily metabolized by microorganisms than other types), nitrogen, phosphorous, calcium, and iron can also facilitate (re)growth. Building water systems include many microenvironments that are often conducive to microbial growth, including dead ends and other low-use regions as well as hot water tanks and hot water pipes where temperatures might accelerate *Legionella* regrowth (see **Figure 1-3** above).

**Many hot water tanks are deliberately set at lower temperatures to conserve energy (49 °C, 120 °F), resulting in the unintended consequence of providing favorable *Legionella* growth conditions.** Similarly, initially very hot water will cool in transit and storage during overnight hours and other non-use periods, such that distal (i.e., distant from the source of heated water) plumbing might also be within a temperature range conducive to *Legionella* (re)growth. Because residuals of reactive chemical disinfectants can be lost more rapidly in heated water through accelerated chemical and physical processes, as discussed later in this booklet, in-line disinfectant booster dosages (i.e., supplemental disinfection) might be necessary.

According to CDC (2018a), the optimal temperature growth range for *L. pneumophila* is between ~77 and 108 °F (~25° to 42 °C), but they can also grow below and above those temperatures. Two hours at 50 °C (122 °F) and 2 minutes at 60 °C (140 °F) will eliminate about 90% (called a 1-log reduction to one-tenth of the original concentration) of the bacteria. To maintain plumbing hot water tap and return temperatures of ~55 °C (~131 °F), hot water tank and system temperatures of 60 to 65 °C (140 to 149 °F) or above, are widely recommended (Legionella Control, 2019). However, because water has a scalding risk at high temperatures, adequate blending with cold water at the tap and in showers is important (WHO, 2007).

Hotel rooms that are not regularly occupied may represent an opportunity for *Legionella* regrowth in the underused plumbing during extended vacancy periods. In addition to hotels, hospital and long-term care facility exposures comprise a significant portion of reported legionellosis cases and deaths. This is because they house higher risk (susceptible) patients and often include showers, sinks, and related equipment that are not frequently used.

Commercial and industrial cooling towers often provide temperature and nutrient environments that support regrowth of *Legionella* and OPPP if an adequate disinfectant residual is not maintained. Human exposure risk is from blowdown from these tanks where *Legionella* and other microorganisms proliferate because of warm temperatures, often inadequate maintenance, and reduced or absent disinfectant residuals. The first reported Legionnaires' disease outbreak famously took place in 1976 at the American Legion Convention in Philadelphia and was caused by cooling water tower blowdown entering the hotel's ventilation system (Fraser et al., 1977). Other reported cases and outbreaks of legionellosis have resulted from people outside buildings inadvertently inhaling contaminated aerosols from rooftop tank heat exchangers.

Pools and heated spas are also a potential source of aerosol exposures to *Legionella* bacteria, particularly when swimmers inhale aerosols close to the surface of the water. Indoor pool and spa users may be at higher risk than those located outdoors. For example, spas are typically turbulent warm waters where disinfectants are quickly lost due to the high temperatures and volatilization that occurs (Legionella Control, 2019a,b).

Ice machines can be another source of legionellosis risk for susceptible hospital patients (Hamill, 2014). This can occur by patients chewing and aspirating (i.e., inhaling droplets into the lungs) melting ice. Further, ice machine water reservoirs are often located near compressors whose operating heat can warm the reservoir water to temperatures at which *Legionella* growth and entrainment in ice can occur during low-use periods.

### Waterborne Disease Outbreaks

CDC defines a waterborne disease outbreak as two or more persons (cases) linked epidemiologically by time, location of water exposure, and the illness characteristics of the cases. Water exposure must also be implicated as the probable source of the illness. Since the implementation of the U.S. Safe Drinking Water Act's (SDWA) National Primary Drinking Water Regulations in about 1980, there has been a general decline in reported conventional (diarrheal) waterborne disease outbreaks and those associated with lack of source water treatment. This decline is largely due to added regulatory monitoring, filtration, and disinfection requirements. However, a marked increase in U.S. "drinking-water associated outbreaks" of legionellosis associated with distributed water has been documented in recent years by CDC (**Figure 1-3**), indicating the importance of microbial regrowth or recontamination.

Reporting of legionellosis cases to CDC for their *Mortality and Morbidity Weekly Reports* (MMWRs) began in 2001; however, some data collection

*Bellevue-Stratford Hotel, Philadelphia, PA. Site of the first reported outbreak of Legionnaires' disease in 1976. (CDC)* was initiated earlier. Reported cases and deaths from legionellosis also continue to increase globally. As noted previously, *Legionella* bacteria-related respiratory diseases include legionellosis and Pontiac fever. The CDC reports are undoubtedly understatements of the actual numbers of outbreaks, cases, and deaths. This is due to underreporting and difficulties in diagnoses unless genotyping and serotyping of the disease organisms are undertaken, which is not always done.

Many cases of *Legionella*-associated respiratory disease have been reported in the United States and Europe since the first identified Legionnaires' disease outbreak was reported in 1976. CDC has estimated that about 8,000 to 18,000 people are hospitalized annually in the United States due to legionellosis-related diseases. A substantial portion of legionellosis cases has been directly associated with inhalation of aerosols from treated and distributed drinking water.

The CDC's MMWRs for 2013 to 2014 (CDC, 2017) demonstrate that water-related legionellosis remains the most significant waterborne disease in the United States (and probably in other developed nations as well). Twenty-four of the 42 reported U.S. drinking water-associated outbreaks were caused by *Legionella* and resulted in 130 cases and 13 deaths. Notably, legionellosis was the only cause of death among the recently reported waterborne outbreaks. Unpublished data from 2015 to 2017 in CDC's National Outbreak Reporting System (NORS) indicates 89 drinking water related outbreaks with 572 cases and 58 deaths (CDC, 2018g). See also **Boxes 1-2** and **1-3**.

## Box 1-2: Recent U.S. Legionellosis Cases and Outbreaks

CDC most recently reported a total of 6,140 cases of Legionnaires' disease in 2017 and 6,141 in 2016 (CDC, 2018a). Only a small portion is directly linked with an outbreak; that is, most cases are sporadic. A substantial portion is attributable to drinking water-associated sources. CDC's MMWR, 2017, covers the 2013 to 2014 period. In addition to drinking water system-related cases, public health officials from 11 states reported a total of 18 outbreaks associated with environmental or undetermined water exposures, causing 280 cases of illness, 67 hospitalizations (24% of cases), and 10 deaths. Of those 18 reports, 15 were Legionnaires' disease outbreaks that resulted in 254 cases and all 10 deaths. Five outbreaks had a known water source, including three from decorative fountains, a cooling tower, and a rooftop storage tank. The water source for 10 legionellosis outbreaks was undetermined. Among these, one outbreak had multiple implicated sources (drinking water, spa, and cooling system), while the remaining nine had insufficient data to implicate a particular source. Five of the 10 deaths caused by *Legionella* were healthcare facility-associated, including two with long-term care facilities and two with hospitals.

## Box 1-3: International *Legionella* Surveillance and Disease Outbreaks

Contracting legionellosis is a risk factor in any part of the world because of the ubiquitous environmental sources of *Legionella*, but it is likely to be more common in the developed world given the extent and density of indoor plumbing, water-based cooling towers, hot tubs and spas, elevated concentrations of higher-risk patients in health-care facilities and nursing homes, and widespread travel.

The European Center for Disease Prevention and Control (ECDPC) maintains two reporting systems for disease cases since 1995, but as in the United States, cases and outbreaks of legionellosis are likely underreported. In 2013, a total of 5,851 cases were reported by the 28 European Union (EU) states and Norway (ECDPC, 2015). Six countries (France, Spain, Italy, Germany, the Netherlands, and the UK) accounted for 83% of the reports, but that might be due to relatively poor reporting compliance in some of the other countries. Thus, actual case numbers are unknown and likely much greater. People over 50 years of age accounted for 81% of cases, with a median age of 63 years, and with a male to female ratio of 2.4 to 1. The latter might reflect higher smoking frequency among males in those countries. The death rate was about 10% of reported cases. Nineteen percent of cases of Legionnaires' disease were associated with travel. A total of 787 travel-associated cases were reported by 30 EU/European Economic Area (EEA) countries, Canada, Israel, Turkey, Thailand, and the United States.

The trending of reported EU/EEA cases began at about 4 per million population in 1995, rose steadily to about 12 per million in 2005, and has been relatively stable from 2005 to 2013. Cases were consistently more concentrated in the warmer months between August and October. That cycle has been repeated each year from 2008 to 2013. Mortality rates increased with age and were greater for cases acquired in winter months, peaking in February.

*Legionella pneumophila* (CDC 11152)

# 2 Overview of Principal *Legionella* Mitigation Technologies

Several currently available *Legionella* mitigation technologies have been shown to be effective in many, but not all, situations. Thus, each circumstance has unique elements that require targeted assessments, evaluations, and selection of one or more appropriate mitigation approaches (see review by USEPA, 2016a). All *Legionella*-related mitigation efforts should be managed using a Hazard Assessment Critical Control Point (HACCP)-type Water Safety Plan, or an equivalent management system for maintaining improved changes in building water system conditions. It should incorporate the following components (see CDC, 2018b,e; WHO, 2005, 2007, 2017; WHO and IWA, 2009):

- Understanding of the building plumbing configuration and locations and retention times to distant taps;
- Analytics to determine type and extent of contamination;
- Assessment of technology options;
- Implementation of the most suitable technology with consideration of safety and sustainability;
- Periodic monitoring of critical control points for microbial status and trends; and
- Management of the system to ensure continuous successful operations and modifications, if indicated.

In many cases, the hot water system is the primary focus of the mitigation because *Legionella* regrowth is facilitated when the warmer water environment temperature drops to less than 55 °C (131 °F). However, the cold water system should also be examined, especially if the system water temperature will be elevated during warm months or from long retention in the building plumbing (i.e., increased "water age"). Mitigation will often begin with a shock thermal or chemical treatment to reduce accumulated biofilms and to rapidly reduce *Legionella* detections and concentrations. All currently available, active chlorine-based systems have been shown to be effective post-shock treatment in certain situations. However, chloramine secondary treatment is increasingly employed because of its (1) apparent ability to penetrate biofilms; (2) lower disinfection byproduct (DBP) production than free chlorine or chlorine dioxide; (3) and greater stability in hot water systems, which allows the residuals to persist at effective concentrations at distant taps.

Maintaining an adequate free chlorine residual in hot water typically requires booster doses (supplemental disinfection). This is because free chlorine is more reactive than the principal alternatives and will decompose more rapidly at warmer temperatures. Chlorine dioxide is

similar in that regard. Free chlorine addition for supplemental disinfection can produce additional regulated organic DBPs (trihalomethanes [THMs] and haloacetic acids [HAAs]). Chloramine use have lower regulated DBP formation potential compared to free chlorine (see Chapter 3). If the source of hypochlorite is fresh and contains low chlorate, which is an important degradation product, there would be less, if any, chlorite and chlorate than from addition of chlorine dioxide.

All three chlorine-based disinfectants (i.e., free chlorine, chloramine, and chlorine dioxide) have approximately equal ease of application and low cost compared to other currently available alternatives discussed in this booklet. Free chlorine can be applied by addition of sodium or calcium hypochlorite, whereas chloramine and chlorine dioxide must be produced on-site by mixing two reagents. Chloramine use can, however, affect the leaching of lead from solders and brass taps that could require water stabilization by pH adjustment and phosphate addition. However, that effect should not be a significant health issue when only the hot water system is being treated. Some states (see **Table 4-1**) require monitoring and drinking water standard compliance, even if only hot water is being treated.

The principal, currently available disinfection technologies for building water systems are chlorine, chloramine, chlorine dioxide, and copper-silver ionization (CSI). (Bromochlorodimethylhydantoin [BCDMH] is often used in hot tubs, which do not involve drinking water consumption; a residual of 4 to 6 mg/L of total bromine is recommended by WHO [2007]). Ozone is a potent biocide and ultraviolet (UV) light damages DNA preventing replication of *Legionella* bacteria and other microorganisms; however, neither leaves a significant disinfectant residual in the water. For this reason, those latter technologies may be mostly applicable for maintenance in recycle/return systems, and perhaps after biofilms have been cleared by using other disinfection systems. One older report of UV light success for *Legionella* maintenance followed thermal and chlorine shock treatments (Liu et al., 1995). However, ozone and UV light are not discussed in detail in this booklet because of their lack of residual disinfection.

Another common *Legionella* treatment approach in buildings is raising the hot water temperature to above 60 to 65 °C (140 to 149 °F) so that temperatures at distant taps are maintained above 55 °C (131 °F) (Lacointe et al., 2018). Successful *Legionella* mitigation strategies often involve a combination of methods that include temporary shock high-dose disinfection or shock high heat treatment with subsequent disinfection and disinfectant residual maintenance techniques to reduce regrowth (Cotruvo, 2014). A summary of characteristics of several *Legionella* management disinfection processes is provided in **Table 2-1** at the end of this chapter.

Because *Legionella* and other microorganisms, including amoebas, can colonize and proliferate in biofilms, a key element of mitigation and prevention is to manage and minimize biofilms—since permanent elimination is impossible—on water contact surfaces. Nevertheless, all mitigation procedures will include site-specific factors, costs, and considerations, so reported results must be evaluated on a case-by-case basis to determine whether a particular approach was successful for the specific facility. Further, because *Legionella* populations can gain resistance to biocides over time, periodic testing, and possibly applying alternative (supplemental) mitigation technologies and procedures may be appropriate (Flynn and Swanson, 2014).

### Shock Treatments: Heat, Flushing, and High-Dose Disinfectants

To reduce acute *Legionella* risks and prepare for longer-term maintenance and mitigation, it is often desirable to use shock treatments to rapidly reduce the presence of *Legionella* and biofilms in contaminated plumbing or other building water systems. Because these usually take several hours or more, they are often performed overnight with pre-notification alerts to residents and guests. Such warnings include use restrictions to minimize potential exposures to high disinfectant concentrations or scalding temperatures.

Thermal shock treatments over a range of temperatures and contact times have shown a variety of temporary benefits to microbial water quality. Typically, the temperature of water in the hot water heater is raised to at least 65 °C (149 °F) and perhaps up to 77 °C (171 °F) in conjunction with at least several hours retention time in the system and flushing from distant taps for 10 to 30 minutes so that temperatures at taps were at least 55 to 60 °C (131 to 140 °F). Results are site-specific, but generally achieve an immediate reduction of *Legionella* detections, but not always to zero. It is important to emphasize that zero detections are not necessarily the essential or achievable protective low-risk goal (Stout, 2018).

Chlorine is commonly used in shock chlorination to achieve rapid disinfection at levels in the range of 20 to 50 mg/L (parts per million or ppm); often as free chlorine for 1 or 2 hours or more contact time followed by flushing (Liu et al., 1998a). Shock disinfection followed by continuous chlorination was successfully demonstrated in hot water systems in healthcare facilities colonized by *L. pneumophila* (Cristino et al., 2012). In the latter example, although *Legionella* counts were significantly decreased, some remained positive; however, no hospital-acquired legionellosis cases occurred. In an older study of a hospital hot water system, heat flushing above 60 °C (140 °F) followed by continuous chlorination at 2 mg/L resulted in significant reduction of positive samples and no subsequent cases of legionellosis (Snyder et al., 1990). Other shock disinfectant dosing such as chlorine dioxide have been effectively applied to building water systems (Kaszyski and Gregory, 2019).

Without follow-up, continuous hot water system maintenance at ~55 °C (~131 °F) and addition of chlorine and other disinfectant residuals, *Legionella* detections and concentrations sometimes quickly rebound. Also, as noted previously, some *Legionella* bacteria have been shown to have the capacity to develop resistance to heat processes and disinfectants—especially if adequate temperatures, doses, and times were not maintained (Allegra et al., 2011).

**Chlorination—**Chlorination is a well-established and highly effective technique for killing or inactivating many waterborne microorganisms (see ACC, 2018). Free chlorine is also commonly used to manage *Legionella* and other bacteria and viruses in centralized water treatment plants as well as in premise plumbing, spas, cooling towers, and decorative water features. Supplemental chlorination in building water systems might not, however, always be an effective, long-term *Legionella* control technology in plumbing. This is due to accelerated corrosion, DBP formation, and limited biofilm penetration (Sidari et al., 2014).

Filtration to achieve and maintain low turbidity is a key component of treatment of surface water sources of drinking water. This reduces harboring of OPPP in particulates where they can be protected from the disinfectant. However, because of its chemical reactivity and decomposition, booster chlorination may be necessary—especially in hot water plumbing to maintain active residuals throughout the system. Premise plumbing concentrations, at least in cold water (Lin et al., 2011), should be temporarily in the 3 to 6 mg/L range (the USEPA drinking water standard, called a maximum residual disinfectant level or MRDL, for free chlorine is 4 mg/L) and reduced later to provide acceptable suppression of *Legionella* regrowth and to manage legionellosis risk. Efficacy is demonstrated by monitoring chlorine residuals and *Legionella* at distant tap locations, as well as hospital diagnostic case records (i.e., suspected or confirmed cases of legionellosis).

Several forms of chlorine are available for building water system applications, including aqueous solutions of sodium hypochlorite (chlorine bleach), calcium hypochlorite, and chlorine bleach generated onsite by the electrolysis of salt. Regardless of the form, when added to water, each initially forms *free chlorine* (see **Box 2-1**).

*Legionella* grow in warm water, so many if not most successful mitigation applications involve only the hot water portion of the building water system. Chlorine is a more active biocide at warmer temperatures and is more chemically reactive, so its concentrations will be diminished by reactions with any organic carbon present. This makes it more difficult to maintain a sufficient chlorine residual in hot water systems compared to cold water plumbing. Injecting chlorine in more than one location, especially in the hot water plumbing system, could be required to maintain a continuous effective residual throughout the entire plumbing system—particularly in low-use areas and dead ends. Booster chlorine additions may also be a necessary component of the building water safety or management plan (see discussion in Chapter 4). Periodic flushing and purging all taps and outlets is a good practice because it can remove some accumulated sediments and biofilm. It also reduces water age in low-use and dead end portions of the building water system.

Chlorine reacts with organic carbon in water and produces halogenated DBPs, including THMs and HAAs. Both groups are regulated in community drinking water. Because USEPA requires that the cold water and hot water in buildings both meet drinking water standards, facilities using supplemental disinfection with free chlorine—even if applied only to the hot water system—may be required to monitor for at least MRDLs. They may also have to meet maximum contaminant levels (MCLs; numeric, enforceable drinking water standards) for DBPs. Thus, such facilities may have difficulty maintaining both adequate disinfection for *Legionella* control and meeting various drinking water standards.

Dose selection considerations for long-term supplemental disinfection in building water systems using free chlorine should also be balanced against the increased potential for corrosion of copper plumbing (e.g., pinhole leaks resulting from higher chlorine residuals of 2 to 4 mg/L have been reported) as well as DBP occurrence. One study of 17

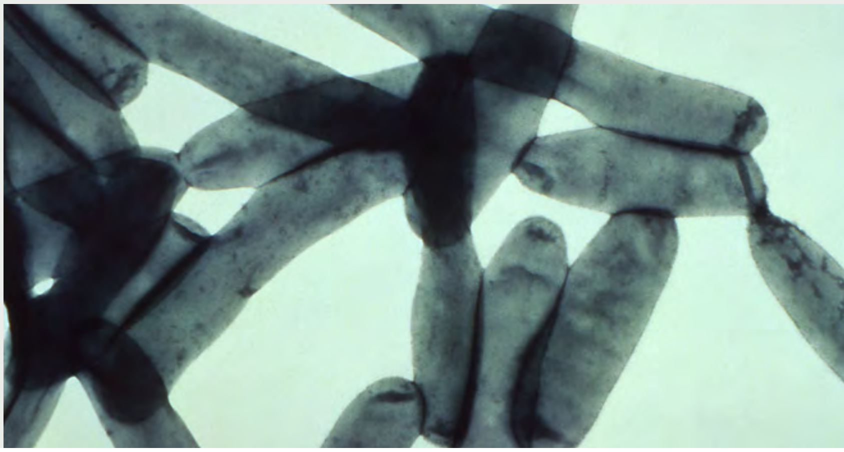
## Box 2-1: How Free Chlorine Kills *Legionella* and Other Pathogens

Water is disinfected because pathogens such as *Legionella* either die or are rendered incapable of reproducing (inactivated) so that they cannot infect humans. Upon addition of chlorine to water, two chemical species, hypochlorous acid and hypochlorite ion, collectively called free chlorine, are formed. The ratio of hypochlorous acid to hypochlorite ion in equilibrium in water is determined by the pH. At low pH (below 7.5) hypochlorous acid dominates while at higher pH hypochlorite ion dominates, and is almost exclusive at pH >9.5. Distributed water is commonly in the 6.5 to 8.5 pH range, although it is not unusual for water to be supplied at pH 9 or 10.

Hypochlorous acid is not only more reactive than the hypochlorite ion, but it is also a stronger disinfectant and oxidant. Although the hypochlorite ion is less reactive, somewhat longer contact times can provide sufficient biocidal activity and disinfection.

Fortunately, *Legionella* and other bacteria as well as most viruses are susceptible to chlorination over a wide range of pH.

As with all disinfectants, chlorine's efficacy is a function of concentration, contact time and temperature. Ct values (concentration in mg/L × time in minutes) at specific temperatures and pH values are a common way of quantifying the comparative biocidal efficacy of disinfectants in solution. Chlorine laboratory Cts for a 99% (2-log) reduction of *Legionella* in tap water at 21 °C (70 °F) at pH 6 were 0.5 min-mg/L, 1 to 6 min-mg/L at pH 7, and 3 to 9 min-mg/L at pH 7.6 (Kuchta et al., 1983). The lower the Ct value, the more effective the disinfectant in solution. Simulated solution testing and Ct values, however, may not always be directly convertible to effects for killing or inactivating *Legionella*, OPPP, and other microorganisms in biofilms.



*Legionella pneumophila (CDC/Francis Chandler)*

hospitals using supplemental chlorination in 1990, but no longer using it in 2011, concluded that for the reasons above, "supplemental chlorination is not considered an effective permanent disinfection method for *Legionella* in building water systems" (Sidari et al., 2014, p. 26).

Free chlorine residual concentrations in regulated community drinking water distribution systems should be at least 0.2 mg/L (WHO, 2017). Although those levels may be capable of controlling heterotrophic (bacteria) plate count (HPC) regrowth in building water systems, regrowth of *Legionella* and other OPPP may not be controlled—especially if biofilms are present. HPC bacteria are not generally considered to be pathogenic, but rather serve as a general, overall indicator of the cleanliness and maintenance of the system. These bacteria (re) grow in the absence of a residual disinfectant.

Although free chlorine is an established and effective biocide for microbial contaminants in solution, because of its chemical reactivity at the biofilm surface, it does not appear to be an effective disinfectant when microbes are harbored in biofilms. This is especially the case for *Legionella* and other microorganisms living within amoebas inhabiting biofilms (Shaheen et al., 2019). **Thus, biofilm management and minimization in building water systems are essential in *Legionella* and legionellosis risk mitigation.**

**Free Chlorine Examples—**Applications of free chlorine in building water systems are primarily as part of shock disinfectant treatments at concentrations on the order of 20 to 50 mg/L or greater concentrations for 2 to 12 hours (Kim et al., 2002). As noted above, following shock treatment, chlorine concentrations should be temporarily maintained in the 3 to 6 mg/L range and reduced later to 2 to 4 mg/L as acceptable performance for suppressing *Legionella* regrowth and managing legionellosis risk (Lin et al., 2011).

Orsi et al. (2014) tracked the performance of shock and continuous hyperchlorination and showed significant reductions of *Legionella* in hospital buildings over 5 years of follow up. The reductions improved with time and were related to the chlorine concentrations. Cold as well as hot water systems should be maintained, and especially when the pH in the approximate 7 to 8 range allows for significant hypochlorite ion presence (see **Box 2-1**).

As noted previously, residual maintenance is more difficult to maintain at warm and hot water temperatures and often requires booster chlorine additions. Corrosion associated with higher chlorine residuals, reduced efficacy managing biofilms, and formation of regulated DBPs are considered drawbacks to long-term free chlorine disinfection in premise plumbing. Cooling tower and spa disinfection may be more applicable and are typically less restricted. Freije (2015) recommends maintaining a free chlorine residual in the cooling tower water of 5 mg/L for 6 hours, although corrosion can still be an issue associated with its extended use. CDC (2018f) recommends maintaining chlorine levels of 2 to 4 mg/L at pH of 7.2 to 7.8 in hot tubs. For further information, see Muraca et al. (1987), Saby et al. (2005), and Sidari et al. (2014).

**Chloramine—**Chloramination (monochloramine, also called combined chlorine) is a common technique for secondary disinfection in drinking water systems (see ACC, 2018). It is widely used for maintaining residual disinfection in piped water in building water systems. Chloramine is commonly generated following primary, centralized disinfection by a more potent biocide. This is achieved by the rapid reaction of chlorine and added ammonia in a dilute water solution or through the addition of preformed chloramine before the water leaves the water treatment plant. Chloramine can also be produced using ammonium salts as the ammonia source in small applications. Chloramine generators for building premise plumbing applications are commercially available. The ammonia quenches the free chlorine thus reducing DBP formation and providing a more stable residual disinfectant to reduce regrowth of *Legionella* and other bacteria as well as amoebas in the distribution system. Because this secondary, residual disinfection process produces smaller amounts of chlorinated (and regulated) DBPs, chloramination continues to be widely used by U.S. community water systems (ACC, 2018).

The ratios and additions of the reagents must be managed carefully. Chlorine or hypochlorite are added to ammonia, or an ammonium salt, with a chlorine to ammonia weight ratio of ~5:1 to produce monochloramine ($NH_2Cl$), the more active and desired form for disinfection. Excess chlorine will produce dichloramine and trichloramine, which are undesirable, eye irritants, and ineffective disinfectants. Monochloramine forms above pH 7, with an optimum pH of about 8.4 (Water Treatment, 1985).

Because monochloramine is chemically less reactive than free chlorine, it will persist and disinfect longer in distribution and plumbing systems. Numerous laboratory studies have established Ct values for 2- (99%) or 3-log (99.9%) reductions for chloramine and *Legionella* that vary depending upon water temperature (e.g., Dupuy et al., 2011). The higher Ct is not a concern because the contact time can be very long (hours) during continuous chloramination in building water systems.

Although chloramine is a less potent biocide and is less chemically reactive than free chlorine, a growing body of research has shown that it is apparently more capable of penetrating biofilms in its active form. Thus, chloramine has a greater opportunity to contact and reduce *Legionella* bacteria and amoebas that may reside in the biofilm (LeChevallier et al., 1988; Wang et al., 2017). In one study, monochloramine penetrated biofilm 170-times faster than free chlorine, although chlorine more effectively inactivated microorganisms near the biofilm surface (Lee et al., 2011).

Rapid primary disinfection by potent disinfectants such as free chlorine is important in a municipal water system where high water volumes are moving rapidly through the treatment plant. The time (t) factor is much less significant in building plumbing applications because contact of the disinfectant in the water and biofilm in plumbing is continuous (and perhaps cumulative). Also, overnight low-flow contact times in hours are typical, providing an ideal environment for reducing *Legionella* and possibly other OPPPs. This combination of survival as a disinfectant residual and ability to penetrate biofilms has made chloramine an increasingly attractive choice for treated water distribution and building water system maintenance in the United States.

Studies in pilot and pipe loops and premise plumbing have demonstrated the efficacy of chloramine under a variety of conditions (e.g., Coniglio et al., 2015; Marchesi et al., 2012, 2013). Further, there are indications that even the relatively small chloramine residual in municipal drinking water reduces *Legionella* detection frequencies and concentrations and the likelihood of water supply-related legionellosis cases (Heffelfinger et al., 2003; Marchesi et al., 2012; Melada and Coniglio, 2015; Weintraub et al., 2008). For example, San Francisco's water distribution system converted to monochloramine from free chlorine in 2004. Mean total chlorine (monochloramine plus trace free chlorine) measurements were 0.13 mg/L before and 1.10 mg/L after the conversion. In a 2-year study of hot water systems in 53 buildings, *Legionella* colonization detections were reduced from 60% to 4% following conversion to chloramine (Flannery et al., 2006).

The MRDL for chloramine is 4 mg/L (as chlorine)—the same as for free chlorine—and the typical target dosing is commonly 2 to 4 mg/L, at least initially. Concurrent corrosion management is required because changing from free chlorine to chloramine has been shown to result in increased leaching of lead from pipes and water fixtures (Guidotti et al., 2008). Adjusting water quality (pH and alkalinity) and adding phosphate, however, can be effective in controlling lead corrosion associated with chloramine use.

Chloramine has also been used to control the deadly amoeba *Naegleria fowerli* (Cunliffe, 1990), but some other pathogenic hot water system bacteria beyond *Legionella* (e.g., *Mycobacterium avium*) may not be significantly affected (Melada and Coniglio, 2015).

**Chloramine Examples—**The Marchesi et al. (2013) mitigation study was conducted in a 765-bed hospital setting. The building was 9 stories high and 40 years old. Prior to treatment, *Legionella* in all 22 plumbing hot water samples were positive while 16 of the 22 exceeded $10^4$ (10,000) CFU/L. Notably, the study included a plumbing network treated with chloramine and others treated with chlorine dioxide (see more below). Chloramine was generated using a stabilized chlorine precursor and an ammonium salt. Residual concentrations were maintained initially at between 2 and 3 mg/L and later reduced to ~1 to 1.5 mg/L. Chloramine concentrations were maintained in the recirculation hot water loop at temperatures as high as 60 °C (140 °F) by an electronic system that automatically increased disinfectant output as needed.

The authors decided to sample sites at locations where higher risk patients were housed. A total of 428 samples were collected from storage tanks, return loops, distant showers, and some tap outlets after 1 minute of flushing. Some of the samples (68) were collected without flushing. Sampling was conducted at one remote point location per 50 beds and at least every 3 to 4 months. The chloramine treated network was monitored after one week, and the first, third, and fourth month during the first year, then every two months in the second year, and every 4 months during the third year of the study.

Chloramine levels were measured as total chlorine using the standard N,N-diethyl-*p*-phenylenediamine method (APHA/AWWA/WPCF, 1992). Sodium thiosulfate was added to eliminate residual chloramine for bacteriological analyses. *Legionella* were cultured and identified using ISO 11731. (Additional analytical methods are available as listed in Chapter 3) Samples were also analyzed for THM and HAA DBPs.

After chloramine treatment was initiated, 8 of 84 samples were positive for *L. pneumophila*, but none exceeded $10^4$ CFU/L. Four detections occurred during the first month, three more within 8 months, and one in the 15th month, after chloramine was reduced to ~1 mg/L. No additional positive samples were detected in the subsequent 21 months of the study. Chloramine levels of 2 mg/L at distant outlets were needed to maintain *Legionella* concentrations below the detection limit of 25 CFU/L. Concentrations between 1 and 2 mg/L were sufficient to maintain *Legionella* concentrations below 1,000 CFU/L.

It was essential to use a first draw sample collection procedure rather than prior flushing. Of 68 chloramine and chlorine dioxide treated samples collected without flushing, 23 were positive for *Legionella* with a geometric mean of 2,700 CFU/L, with a 2-log difference between samples taken with and without flushing. However, only 7.3% of chloramine treated waters were positive without flushing.

**Chlorine Dioxide—**Chlorine dioxide is a potent biocide and an effective primary disinfectant for drinking water applications. It exists as a gas and has different physical, chemical, and disinfection properties than free chlorine's hypochlorous acid or hypochlorite ions (see **Box 2-1**). Chlorine dioxide is manufactured on-site in commercially available devices by the reaction of chlorine, or an acid, and sodium chlorite. It can also be produced by reacting sodium chlorate with an acid, but chlorine is a byproduct. Because it is inherently unstable, chlorine dioxide cannot be stored or compressed in gaseous form. It has low Ct performance comparable to free chlorine, but might penetrate biofilms better than free chlorine as a result of its lower and more selective chemical reactivity (Loret et al., 2005).

Chlorine dioxide's biocidal efficacy is less sensitive to pH than free chlorine because it is a dissolved, non-ionized neutral gas. It produces oxidized organics in water from reactions with the organic carbon that is present; pure chlorine dioxide does not react with ammonia to produce chloramine or with organic carbon to produce halogenated DBPs. Its oxidation-reduction products are chlorite and chlorate, both of which are included in WHO's (2017) *Guidelines for Drinking-water Quality*, each with Guideline values of 0.7 mg/L. They are regulated in some jurisdictions. The USEPA MCL for chlorite is 1 mg/L, so dosages should be managed to prevent formation of excess residues of those anions. Its chemistry and biocidal activity are temperature-related and can also result in a more noticeable taste and odor than other disinfectants (Gates et al., 2009).

**Chlorine Dioxide Examples—**As discussed above, Marchesi et al. (2013) included parallel studies using chlorine dioxide in three different hospital plumbing networks. Results were somewhat different in each plumbing segment tested, demonstrating that site-specific factors should be considered in any *Legionella* mitigation process. Sampling was conducted at one remote point location for each 50 beds, at least every 3 to 4 months. Prior to chlorine dioxide application, 27 of 28 samples were positive with a geometric mean of $10^4$ *Legionella* spp.

Chlorine dioxide was generated by reacting a mix of sodium chlorite and hydrochloric acid and injecting it into the recirculating hot water system. Chlorine dioxide oxidant levels were measured using the N,N-diethyl-*p*-phenylenediamine method (APHA/AWWA/WPCF, 1992). Dosages of chlorine dioxide concentrations were maintained such that at least 0.3 mg/L were obtained at distant taps while not exceeding 0.8 mg/L, the USEPA MRDL.

Positive detections of *Legionella* for all three systems were 96 of 209 (45.9%). Nine of 96 post-treatment positive samples exceeded 104 CFU/L. The geometric mean of the positives was 550 CFU/L. Chlorine dioxide concentrations between 0.50 mg/L and 0.70 mg/L reduced *Legionella* detections to less than about 100 CFU/L. Increased chlorite and chlorate concentrations were detected. Of 68 chloramine and chlorine dioxide treated samples collected without flushing, 23 were positive for *Legionella*. However, only 7.3% of chloramine treated waters were positive without flushing compared to a parallel set of chlorine dioxide treated networks that had 50% positive samples without flushing.

## Copper-Silver Ionization

CSI technologies have been applied successfully for *Legionella* mitigation and management for many years. CSI systems use copper and silver alloy anodes and a direct electrical current to cause both ions to enter the building water system. Copper and silver positive ions (cations) are biocides or "biostats" that suppress replication of *Legionella* and other microorganisms. Concentrations used in water plumbing are typically maintained at 200 to 400 µg/L copper ion and 20 to 40 µg/L silver ion, but higher concentrations have been recommended (200 to 800 µg/L copper and 10 to 80 µg/L silver; Lin et al., 2011). These levels must be maintained in distant taps (Liu et al., 1998a,b).

**Table 2-1: Summary of *Legionella* Management Disinfection Processes and Characteristics**

| | Free Chlorine | Monochloramine | Chlorine Dioxide | Copper-Silver | Thermal (°C) | Ozone | UV Light |
|---|---|---|---|---|---|---|---|
| **Typical Concentrations (mg/L)** | 2–4, initial | 2–4, initial | 0.1–0.8 | Cu: 0.2–0.8<br>Ag: 0.02–0.08 | 55–77 | Low dosage ranges | Varied |
| **pH Effect on Efficacy** | Reduced above 8–9 | None in 7–9 range | None in 6–10 range | pH >8.5 | None | Not at normal pH | None expected |
| **Temperature** | Increased decay rate | Minimal | Increased decay rate | None | >55 | Increased decay rate | None expected |
| **Major Byproducts** | Halogenated DBPs (THMs and HAAs) | Less THMs | Chlorite and chlorate | None besides Cu and Ag residues | None | Transient oxygenated organics | None expected |
| **Standards and Guidelines (mg/L)** | **USEPA:** 4<br>THMs: 0.08<br>HAAs: 0.06<br>**WHO:** 5<br>**Can:** No guideline<br>THM: 0.1<br>HAAs: 0.08 | **USEPA:** 4 as $Cl_2$<br>**WHO:** 3 as $Cl_2$<br>**Can:** 3 as $Cl_2$ | **USEPA:**<br>$ClO_2$: 0.8<br>$ClO_2$-: 1<br>**WHO:**<br>$ClO_2$: 0.7<br>$ClO_3$-: 0.7<br>**Can:**<br>$ClO_2$-: 1<br>$ClO_3$-:1 | **USEPA:**<br>Cu: 1.3<br>Ag: 0.1 (SMCL)<br>**Can:**<br>Cu: 2<br>Ag: No guideline | None | None | None |

Where: Ag = silver; Can = Canadian Drinking Water Guideline; $Cl_2$ = chlorine; $ClO_2$ = chlorine dioxide; $ClO_2$- = chlorite; $ClO_3$- = chlorate; Cu = copper; HAAs = haloacetic acids; SMCL = secondary MCL; THMs = trihalomethanes; UV = ultraviolet light; USEPA = U.S. Environmental Protection Agency maximum residual disinfectant level; WHO = World Health Organization Guideline. Note: all concentrations are reported in mg/L (ppm).

The concentrations of the ions are readily controllable to below the USEPA action levels for lead (0.015 mg/L, 15 µg/L) in a stagnant first draw 1 L sample and for copper (1.3 mg/L) under the Lead and Copper Rule (LCR). Secondary esthetic standards (secondary MCLs or SMCLs) and MCL goals (MCLGs) for copper and silver are 1.0 mg/L and 0.1 mg/L, respectively. The current Canadian drinking water guideline for copper is 2 mg/L with an esthetic value of 1 mg/L. Notably, Canada does not have a silver guideline value after concluding that none was required. The WHO (2017) guideline value for copper is 2 mg/L; there is no esthetic guideline.

Regulatory monitoring requirements for CSI applications should reflect the chemistry of the metals and not regulated organic DBPs, which would not be formed. Tap water measurements for copper for CSI applications should be distinguished from the USEPA LCR, which is intended to gauge the water's corrosivity. Thus, monitoring methods and locations should be designed to reflect that important distinction for proper interpretations, which can differ from state to state. This is particularly true for hot water system applications, which are not included in LCR compliance determinations. Numerous successful applications as well as exceptions for the use of CSI systems for *Legionella* control in premise plumbing of healthcare facilities and other buildings have been reported in the literature (e.g., Chen et al., 2008; Dziewulski et al., 2015; Lin et al., 2011).

CSI stability in solution is not affected by water temperature and does not produce regulated chemicals other than copper. Water quality factors such as pH and anion concentrations (which can precipitate-out as copper or silver salts), however, might affect the availability and biocidal activity of the copper and silver cations (Rohr et al., 1999). Although the electrical operating system is passive, regular maintenance and monitoring are required to ensure consistent performance. As with other biocides, there are indications that microorganisms can develop resistance to CSI over time, and that disinfection efficacy can be impeded by the presence of biofilms and amoebas.

# 3 Factors Affecting *Legionella* Mitigation Technology Applications

Legionellosis risks are a function of dose (inhalation exposure) as well as individual susceptibility, and are not fully understood. The risks are particularly difficult to quantify due to complexities of exposure type and time from aerosol production and inhalation, intermittent *Legionella* releases, and the range of individual susceptibilities. Concentrations in water and biofilms—and corresponding individual risks—can be highly variable within the same building water system as a result of changing temperatures, stagnation times, water flow rates, lengths of showers, and many other factors. Individual susceptibilities vary widely and are affected by current physical condition and disease state, age, immune system conditions, and smoking status and history.

### Goals

Although not essential for successful risk reduction, in the ideal case it would be desirable to eliminate all detectable *Legionella* in premise plumbing, cooling towers, and other sources by applying appropriate mitigation technologies and management practices. **Not achieving zero detection (total elimination) of *Legionella* should not be considered to be failure, but striving to achieve and maintain control to the fewest detections achievable is important.**

As discussed throughout this booklet, to maintain reduction of *Legionella* counts, continued water monitoring system surveillance and management are essential. Total eradication is not necessary, however, and may not always be achievable over the long-term to protect against significant legionellosis risks (Stout, 2018). Significant *Legionella* reductions in concentrations and detection frequencies after treatment processes often result in no new hospital-acquired cases—even while positive counts are still detectable in building water system samples. The presence of 1 microorganism per mL (1,000 CFU/L) is a practical, common action and evaluation level target used throughout Europe (Legionella, 2018). In contrast, a recent NASEM (2019) report recommended 50,000 CFU/L as an initial (urgent) action level, with lower CFU levels to be determined in case-by-case evaluations reflecting susceptible population exposures and other factors based on quantitative microbial risk assessment (QMRA).

Several countries have recommended action levels for *Legionella* maintenance and immediate actions in both general population and high-risk population environments. Maintenance-level recommendations for the general population are usually in the range of <100 to 1,000 CFU/L and <100 CFU/L in high-risk environments. Immediate action recommendations are often 1,000 CFU/L or more for high-risk populations, but can sometimes exceed 1,000 CFU/L for general populations (LeChevallier, 2020a,b).

The 1,000 CFU/L action level represents a practical and protective action trigger that would not require complex, costly, time-consuming, and difficult to interpret results of QMRA evaluations prior to applying management and possibly mitigation technology. It has also been suggested that reductions of *Legionella* detections to <30% of samples in a facility usually results in no (additional) cases of legionellosis (ACHD, 2014; Stout, 2018).

### Corrosion Management Issues

Using oxidizing chemicals such as chlorine, chloramine, and chlorine dioxide can cause pipe corrosion or seal degradation. In such cases, corrosion refers to the extraction of plumbing-related metals such as iron, copper, and lead from pipes resulting in degradation of water quality, metallic taste, discoloration, pitting, leaks, and pipe deterioration. Disinfectant-based corrosion can also lead to non-compliance with drinking water regulations—especially USEPA's LCR. Corrosion inhibitors such as phosphates may be appropriate additives along with pH adjustments. Changes in the water's corrosivity can also result in disturbance of biofilms and suspension of contaminated deposited sediment pipe coatings, as happened in Flint, Michigan.

In general, different piping materials have not been found to be remarkably different with respect to their influence on *Legionella* (re) growth over extended periods. Similar levels of corrosion were reported on galvanized steel coupons (i.e., immersing a piece of metal in a stream of water to observe surface chemistry) by free chlorine, chloramine, chlorine dioxide, CSI, and ozone (see Loret et al., 2005). Greater copper corrosion associated with free chlorine compared to chloramine was reported by Kirmeyer et al. (2004). Increased leaks have been reported as a result of hyperchlorination. Leaks and deterioration were reported in a hot water system prior to introducing silicate corrosion inhibitors (Grosserode et al., 1993).

Degradation was noted in high density polyethylene (HDPE) pipe exposed to 3 mg/L chlorine at 105 °C (221 °F) (Hassinen et al., 2004), which greatly exceeds normal hot water system temperatures. However, Castagnetti et al. (2011)

reported no HDPE pipe failure after 2,000 hours exposure to 2.5 mg/L chlorine. A more recent study found that chlorine dioxide was more aggressive than chlorine toward HDPE degradation (Castagnetti et al., 2019). Although chloramine has been reported to be more aggressive than free chlorine for elastomer degradation, chloramine-resistant seals and polymers are widely used in drinking water plumbing (Reiber, 1993). As noted previously, chloramine use without stabilization can result in increased lead leaching from pipe and fixtures (Guidotti et al., 2008).

### Disinfection Byproduct Formation and U.S. Drinking Water Regulations

Drinking water disinfectants provide well-recognized protection from microbial contaminants and waterborne disease in public drinking water supplies (ACC, 2018). Treated water delivered to a building from a community water system should already meet USEPA (and state) drinking water standards. Nevertheless, additional disinfection may provide a valuable public health benefit by reducing acute *Legionella* and other OPPP risks. One factor to be considered in supplemental applications of disinfectants in building water systems is the potential for increased DBP formation. In this regard, the WHO (2017, p. 173) continues to emphasize that

*In attempting to control DBP concentrations, it is of paramount importance that the efficiency of disinfection is not compromised and that a suitable residual level of disinfectant is maintained throughout the distribution system.*

**The risk-benefit balance for reducing acute legionellosis risks in building water systems is certainly greater than the largely hypothetical increased lifetime exposure and health risks resulting from additional DBPs that might be produced, especially in non-residential populations.**

Clearly, meeting drinking water standards is not an important issue for ornamental fountains, pools, spas, and cooling towers. Further, it should not be an important issue for treated hot water systems in a building since hot water is not intended to be nor is it typically consumed as drinking water.

Currently regulated THMs are not carcinogenic in recent bioassays conducted in drinking water (Cotruvo and Amato, 2019). However, some increased inhalation and dermal exposures to DBPs can occur from use of booster chlorine-based disinfectants in building water systems. Hot water sampling is not required for any drinking water regulation compliance, including USEPA's LCR. However, if a state determines that a given facility is a community or non-transient, non-community water supply,[1] it may require designation as a public water system and require monitoring and reporting for certain DBPs. Even without that designation, some additional water quality monitoring may be required. Other specifications, such as requiring certified water operators, may also be imposed.

**Designating a building as a public water system creates regulatory barriers and associated costs that could adversely affect decisions on whether or not to apply supplemental water treatment to reduce legionellosis risks** (Cotruvo, 2014). Numerous countries such as the UK, Germany, Canada, and Australia do not have such requirements for supplemental disinfection of building water systems, but may require professional management and some reporting of disinfectant residuals.

THMs and HAAs are regulated under the SDWA with MCLs of 0.08 mg/L and 0.06 mg/L, respectively. These enforceable standards for community water systems are based on an assumed lifetime water consumption of 2 L/day for 70 years. There are also MRDLs of 4 mg/L for chlorine and chloramine, 0.8 mg/L for chlorine dioxide, and MCLs of 1 mg/L for chlorite and 1.3 mg/L for copper (see also **Table 2-1**).

Under the LCR, there is a corrosion-related action level of 0.015 mg/L (15 µg/L) for lead and a copper action level of 1.3 mg/L. Each has specific sampling and interpretation requirements. Regarding copper monitoring and compliance issues under the LCR, building water system sampling should be designed to differentiate copper contributions resulting from CSI disinfection versus from conventional lead and copper corrosion. Although USEPA proposed revisions to the LCR in October 2019, maintaining the same actions levels, but with some other different provisions, the proposal has not yet been finalized and the requirements remain unknown. Therefore, building managers as well as state and local regulators may need outside assistance to resolve these and other potential regulatory issues in a particular location based on evolving federal and state requirements.

### Analyses for *Legionella* in Water and Biofilms

About half of U.S. healthcare facilities and 30 to 50% of cooling towers that were tested in a recent study

[1]Non-transient, non-community supplies are those that have regular users who are not residents, such as manufacturing plants that provide their own drinking water because they are not connected to a public water supply.

were positive for *Legionella* (Stout, 2018), but again—**a positive detection does not necessarily equal high-risk of legionellosis. It does, however, indicate the need for monitoring and surveillance, and possibly additional preventive corrective actions for *Legionella* mitigation and management.** The extent of colonization (% positive sampling sites) might be more indicative of risk than the number of CFUs in a given sample (ACHD, 2014; Stout, 2018), but there is controversy about using any rule of thumb.

Sampling procedures are described in several guidelines and differ for cooling towers and building premise plumbing. Because hot water plumbing is the most likely primary reservoir for *Legionella* bacteria, it (and ideally biofilm samples, if possible) should be included as part of any building water system surveillance or mitigation project. Cold water systems should also be checked, but again, facilities that apply supplemental disinfection generally only do so for hot water systems. Biofilm samples are usually difficult to obtain without opening pipes, so water samples are the norm for *Legionella* screening. Biofilms samples would, however, be an important part of a legionellosis outbreak investigation.

Because all of these issues are managed at the state level, it is essential to communicate with the most appropriate state agency for *Legionella* mitigation advice and direction. Such analyses may include first draw tap or showerhead hot water, and possibly biofilms.

Currently available analytical methods for detecting *Legionella* bacteria in water include: standard culture-based methods requiring 3 to 7 days that are widely considered to be more reliable than rapid tests; ISO 11731, 2nd edition, 2017-05 (CDC, 2018b,c); IDEXX Legiolert®; molecular-based methods, including qPCR and microarray; cellular-based methods; and "Next Generation Sequencing" (see Boczek and Buse, 2018; Stout, 2018). Notably, CDC recommends methods capable of detecting all members of the *Legionella* genus, not just *Legionella pneumophila* (ASTM D 5952; HSE L8 ACP 2013).

## Costs and Other Considerations

Assessment and management costs of *Legionella* control and mitigation continue to be highly dependent on site-specific circumstances and the technologies selected, the extent and depth of upfront assessments, evaluation, and maintenance monitoring (Hosein et al., 2005; Zhang et al., 2009). It is important to emphasize that a poorly understood cost dependence on specific state requirements and considerations exists because states do not have uniform requirements. Costs may depend on:

- Size and complexity of configurations of facilities as well as purchase and installation costs;
- Contracted service providers or turnkey rentals, including chemicals and electric power;
- Whether (or not) public water system designation is required with associated monitoring and reporting requirements;
- Which constituents must be monitored and at what frequency;
- Whether or not certified water operators must be employed; and
- Exclusion of some mitigation technologies such as CSI by some states (e.g., Pennsylvania).

Thus, annual building water system monitoring and mitigation costs could easily exceed $50,000, not including initial evaluation and startup costs (Zhang et al., 2009). For example, one recent mitigation effort was reported to have cost over $1 million in a psychiatric hospital setting with 700 staff and 270 patients. That unusual effort (which was not associated with any reported cases of legionellosis) included the costs of providing bottled water for drinking and cooking, portable showers and toilets, and wipes for bathing for nearly a month (Washington Post, 2019).

# 4 Overview of *Legionella*-Related Regulations and Guidelines

There is no MCL for *Legionella* in distributed water from community water systems. This is primarily because most *Legionella* growth and regrowth occurs in premise plumbing (usually hot water systems) after the centrally treated water has already been delivered to consumers, and which is likely beyond SDWA purview (Cotruvo, 2014). USEPA has not yet determined whether additional regulations for *Legionella pneumophila* in distributed water are appropriate, but it continues to be listed on drinking water Contaminant Candidate Lists and was designated as a candidate for revision as part of USEPA's most recent Six-Year Review of Drinking Water Standards (USEPA, 2016b, 2017).

The MCLG for *Legionella* in treated drinking water at the water plant is zero (i.e., no detections). There is also a treatment technique requirement for *Legionella* under the Surface Water Treatment Regulations that applies at the water treatment plant. A disinfectant residual of at least 0.2 mg/L in treated surface waters is required to be maintained in the distribution system (40 CFR 141.72(a)(3) & (b)(2)). More specifically, the residual disinfectant concentration in the distribution system cannot be undetectable in more than 5% of the samples each month for any 2 consecutive months. However, many small U.S. groundwater systems are not disinfected.

The current treatment technology requirements for the protozoan intestinal parasites *Giardia* and *Cryptosporidium* and virus removals are expected to also remove *Legionella* bacteria. However, as discussed throughout this booklet, *Legionella* and other regrowth microorganisms are primarily present in higher numbers due to site-specific conditions in the plumbing and distribution systems. "Reseeding" and regrowth of microorganisms including *Legionella* in the distribution system might occur from any microorganisms that survive water treatment, and as a result of water line breaks, plumbing repairs, and new construction—especially where the plumbing system has not been properly disinfected prior to placing the facility (back) into service.

Some nations require *Legionella* testing and mitigation in some building environments. They often have limited compliance requirements when a facility provides supplemental treatment (disinfection). USEPA's opportunities to regulate *Legionella* in plumbing systems are likely to remain limited because its authority under the SDWA is limited on private property beyond the public water system (e.g., monitoring under LCR).

In 2016, USEPA released a report titled *Technologies for Legionella Control: Scientific Literature Review* (EPA 810-R-16-001), regarding water supplies and *Legionella* treatment. Although the report is a fairly comprehensive technical resource, it is generally regarded to be a literature review and does not provide specific regulatory guidance to states, water system operators, and building owners/managers. Existing USEPA drinking water regulations require that if any facility having more than 15 service connections or 25 users adds water treatment to the public water entering the facility, it becomes a public water system. Thus, any facility that adds supplemental disinfection after receiving water from a public water system could be regulated as a "consecutive water system" under the SDWA. As noted previously, that designation adds additional responsibilities and could adversely affect decisions on whether or not to add supplemental disinfection in plumbing systems. However, USEPA has left that interpretation to the states.

**Treatment of spas, decorative water features, and cooling tower water should not be subject to drinking water control requirements, but they should be disinfected and maintain a continuous effective residual.**

Because USEPA essentially delegates the interpretation and application of public water system designations to the states, wide differences among states has resulted. These range from not requiring notification or reporting if a facility adds supplemental disinfection to placing minimal to substantial reporting and monitoring requirements on affected facilities, such as disinfectant residuals, corrosion indicators, and some MCLs. A consecutive water system designation could also lead to broader monitoring, requiring certified water operators, and formal compliance reporting, including public notifications of MCL exceedances.

## State Perspectives on Technologies Triggering Regulation of a Building as a Consecutive Water System

A recent white paper commissioned by the Association of State Drinking Water Administrators (ASDWA) surveyed state positions regarding implementation of *Legionella* management actions in building water systems (ESPRI, 2019). Some decisions could lead to state-specific and possibly site-specific monitoring, reporting, and certified water operator qualification requirements, as well as legal status concerns. The purpose of state oversight and regulation would be to ensure that public health risks from water consumption or exposure to the building drinking water system are managed.

As is evident in **Table 4-1**, the results are not always logical or consistent. About 85% of surveyed states would trigger consecutive water system requirements under the SDWA for the addition of supplemental chemical disinfection. Except for shock chlorination, which only one state currently regulates, the state responses varied for most processes, and split almost evenly on UV light applications. Twelve out of 28 states would include regulatory requirements for treatment of hot water only, which as discussed previously, is not intended nor should be considered to be drinking water for regulatory purposes. Notably, none of the surveyed states explicitly included temperature controls where scalding risks occur. In

**Table 4-1: State Building Water System Regulations/Requirements**

| Process | No | Yes |
|---|---|---|
| **Chlorine/chloramine** | 5 | 29 |
| **Chlorine dioxide** | 5 | 28 |
| **Shock chlorination** | 31 | 1 |
| **Copper-silver ionization** | 7 | 23 |
| **Hot water system only** | 16 | 12 |
| **UV light** | 17 | 16 |

*Source: ESPRI, 2019.*

addition, 7 of 31 states included coverage of point-of-use devices such as end-of-tap microbial filters.

## Guidelines and Mandates for *Legionella* Control

Since 2017, the U.S. Department of Health and Human Services, Center for Medicare and Medicaid Services (CMS) has mandated that all covered medical facilities "must develop and adhere to policies and procedures that inhibit microbial growth in building water systems that reduce the risk of growth and spread of *Legionella* and other opportunistic pathogens in water" (CMS, 2017). The mandate applies to hospitals, critical access hospitals, and long-term care facilities. It requires actions but does not dictate the specific preventive and mitigation approaches.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) issued several building water system standards, including ASHRAE Standard 188-2015, ANSI (American National Standards Institute)/ASHRAE Standard 188-2018 et seq., and Guideline 12:2000, Legionellosis: Risk Management Standard for Building Water Systems. Their adoption and implementation should provide some level of risk reduction for legionellosis.

CDC has also provided several online resources, including a toolkit called "A Practical Guide for State and Local Public Health Laboratories" (CDC, 2018d), Developing a Water Management Program (CDC, 2018b), as well as numerous documents and guidelines to assist *Legionella* assessment and mitigation applications. Additional information is available from the American Industrial Hygiene Association (AIHA, 2015) as are directives from the Veterans Health Administration of the Department of Veterans Affairs for recertification of their facilities (VHA, 2014).

CDC has also provided recommendations for managing *Legionella* in hot tubs and spas (CDC, 2018f). Similar advice and requirements exist in Europe, such as the detailed Code of Practice and Guidance for control of *Legionella* bacteria in water from the UK Health and Safety Executive (HSE, 2013).

# 5 Conclusions

Understanding and managing *Legionella* colonization of building water systems, including premise plumbing, cooling towers, and biofilms, is a complex but important undertaking. Contracting legionellosis is a risk factor in any part of the world because of the ubiquitous environmental sources of *Legionella*, but it is likely to be more common in the developed world given the extent and density of indoor plumbing, water-based cooling towers, hot tubs and spas, concentrations of higher-risk patients in healthcare facilities and nursing homes, and widespread travel.

A significant level of knowledge and expertise is required to successfully evaluate and effectively manage the issues and problem. Detailed information and literature reviews on *Legionella* in building water systems are available (NASEM, 2019; USEPA, 2016a; WRF 2018a,b,c). Some consultants tend to focus on using certain technologies based on their own familiarity; however, it would be beneficial to choose mitigation and prevention technology providers who have broad successful experience and are capable of objectively evaluating the available options to select the optimum technological and cost-effective solution for each situation. Costs and implementation requirements to control legionellosis risks in a particular location, however, are inherently site- and technology-specific.

Because the optimal temperature growth range for *L. pneumophila* is between 25 and 42 °C (77 to 108 °F), to maintain plumbing hot water tap and return temperatures of ~55 °C (~ 131 °F), hot water tank and system temperatures of 60 to 65 °C (140 to 149 °F) are typically recommended.

Any prevention and mitigation process for *Legionella* and legionellosis risk in building water systems should be associated with the development, application, and periodic revision of a comprehensive Water Safety Plan (or the equivalent) in accordance with CDC and WHO guidance. It should incorporate a HACCP-type management system for maintaining improved changes in building water system conditions and considering all relevant factors to help ensure the best chance for long-term success. These should include the following components: (1) temperature management in hot water systems; (2) disinfection treatment, especially of warm and hot waters, but also possibly cold water; (3) continuous presence of residual disinfectants to all water taps or outlets; (4) periodic surveillance and monitoring to detect changing *Legionella* presence; and (5) verification and regular reassessments of prevention and mitigation practices to ensure continued *Legionella* control.

A comprehensive building water assessment process also requires examining the existing system and multiple water parameters, including water retention times, use rates, the presence and extent of dead ends, and treated entry water supply, including seasonal variations. The latter includes parameters such as pH, disinfectant residuals, hardness, and the presence of other ions that could interfere with the efficacy of the mitigation technologies already in place or that are being considered. The above factors and components for *Legionella* control in building water systems are complicated by the fact the existing drinking water monitoring and compliance requirements vary by state.

Zero *Legionella* detections in building water systems are not necessarily the essential or achievable protective low-risk goal for legionellosis, but striving to achieve and maintain control to the lowest detections achievable is important. More specifically, the extent of colonization (% positive sampling sites) might be more indicative of risk than an action level based on a specific amount of CFUs in a given sample. Practical experience suggests that legionellosis risk increases if >30% of building water system samples test positive (ACHD, 2014; Stout, 2018), although there is some controversy about using such a rule of thumb.

Biofilm control is a key challenge because they provide reservoirs where *Legionella* and other OPPP microorganisms, including amoebas, (re)colonize and proliferate. Because microorganisms tend to accumulate in biofilms and are often aggregated on particulates, some biofilm monitoring should be included, when possible.

Maintaining an adequate disinfectant residual in drinking water systems as well as in building premise plumbing are critical to protect public health. The efficacy of any disinfectant used for *Legionella* management is often related to the presence and extent of amoebas in biofilms that provide protection from contact with the disinfectant. The latter is especially critical for healthcare facilities with high-risk inhabitants. It is also important in cooling towers, and in hotels and other facilities that have intermittent use of showers and other facilities where the flushing time lag allows stagnant water to collect and cool, potentially leading to increased populations of *Legionella* and other OPPP microorganisms.

Several technologies have demonstrated their effectiveness in specific application environments. Successful mitigation plans often combine initial (temporary) thermal or disinfectant shock treatments and residual disinfectant dosing and maintenance. Chlorine-based systems are versatile in regard to residual disinfection; ozone and UV light do not provide disinfectant residuals. CSI systems are effective when maintained and are not temperature sensitive, but are affected by pH and some water constituents such as anions. The latter can precipitate-out as copper or silver salts. They are also not currently permitted in some states. Both high and low temperature water management and communications are important where scalding risks exist.

Chlorine-based systems, which include free chlorine, chloramine, and chlorine dioxide, as well as CSI technologies have important applications in building water systems; ozone and UV light may have some applications in recirculating systems if maintaining a residual disinfectant is not essential. Each technology has its strengths and limitations that should be considered according to the specific circumstances and applications; some disinfection combinations may be appropriate in the treatment train. Because chlorine-based products are commonly used as water disinfectants, their application conditions are readily understood. Free chlorine and chlorine dioxide are primary disinfectants while chloramine is a secondary disinfectant in municipal drinking water plants.

The risk-benefit balance for reducing acute legionellosis risks in building water systems through disinfection is greater than the hypothetical increased lifetime exposure risk resulting from additional DBPs that might be produced by the addition of chlorine-based disinfectants. This is particularly the case where affected populations are not residential.

Free chlorine and chlorine dioxide (and heat) are also used in shock treatments in building water systems, but increasingly, post chloramine application has been shown to be effective for biofilm penetration and long-term plumbing and system-wide residual maintenance. Free chlorine and chlorine dioxide are temperature sensitive because of their chemical reactivities, so it can be difficult to maintain an adequate residual in hot water systems that are primary sources of *Legionella*. Chloramine is more stable and persistent at warmer temperatures. However, chlorine dioxide and chloramine are less pH-sensitive than free chlorine. Again, the efficacy of a disinfectant for *Legionella* management is often related to the presence of amoebas in biofilms that provide protection from contact with the disinfectant.

Several sources of guidelines are available to help building owners and managers implement corrective measures for *Legionella* control, including: ASHRAE Standard 188-2015, ANSI/ASHRAE Standard 188-2018 et seq., CDC (2018a), AIHA (2015), and directives from the Veterans Health Administration. CDC has provided recommendations for managing *Legionella* in hot tubs and spas. Although spas, decorative water features, and cooling tower water should not be subject to drinking water control requirements, they should be disinfected and maintain a continuous effective residual. Similar guidance and requirements exist in Europe for *Legionella* management and mitigation.

Lastly, there is a clear need for comprehensive and authoritative guidance for the states so that they can provide consistent, science-based, and effective oversight and cost-effective controls for building water system treatment technologies where needed to protect the public. Such guidance should specifically encourage and facilitate the application of on-site supplemental technologies to reduce well-known legionellosis risks. In contrast, designating a facility as a public water system can create regulatory barriers and associated costs that could adversely affect decisions of whether or not to apply supplemental water treatment to reduce legionellosis risks in building water systems.

# Acronyms and Abbreviations

| | |
|---|---|
| **ACC** | American Chemistry Council |
| **AIHA** | American Industrial Hygiene Association |
| **ANSI** | American National Standards Institute |
| **ASDWA** | Association of State Drinking Water Administrators |
| **ASHRAE** | American Society of Heating, Refrigerating and Air Conditioning Engineers |
| **BCDMH** | Bromochlorodimethylhydantoin |
| **CCD** | Chlorine Chemistry Division (of ACC) |
| **CDC** | U.S. Centers for Disease Control and Prevention |
| **CFU** | Colony forming units |
| **CMS** | Department of Health, Education and Welfare, Center for Medicare & Medicaid Services |
| **CSI** | Copper-silver ionization |
| **Ct** | Concentration in mg/L × time in minutes |
| **DBP** | Disinfection byproducts |
| **ECDPC** | European Center for Disease Prevention and Control |
| **EU/EEA** | European Union/European Economic Area |
| **HACCP** | Hazard assessment critical control point(s) |
| **HAAs** | Haloacetic acids (DBPs) |
| **HDPE** | High density polyethylene |
| **HPC** | Heterotrophic plate count bacteria |
| **LCR** | USEPA Lead and Copper Rule for corrosion control |
| **MCL** | Maximum contaminant level |
| **MCLG** | Maximum contaminant level goal |
| **MMWR** | CDC's *Morbidity and Mortality Weekly Report* |
| **MRDL** | Maximum residual disinfectant level |
| **NORS** | CDC's National Outbreak Reporting System |
| **NSFI** | NSF International |
| **OPPP** | Opportunistic premise plumbing pathogens |
| **QMRA** | Quantitative microbial risk assessment |
| **SDWA** | U.S. Safe Drinking Water Act |
| **SMCL** | Secondary MCL |
| **THMs** | Trihalomethanes (DBPs) |
| **UK** | United Kingdom |
| **U.S.** | United States |
| **USEPA** | U.S. Environmental Protection Agency |
| **UV** | Ultraviolet light |
| **WHO** | World Health Organization |
| **WRF** | Water Research Foundation |

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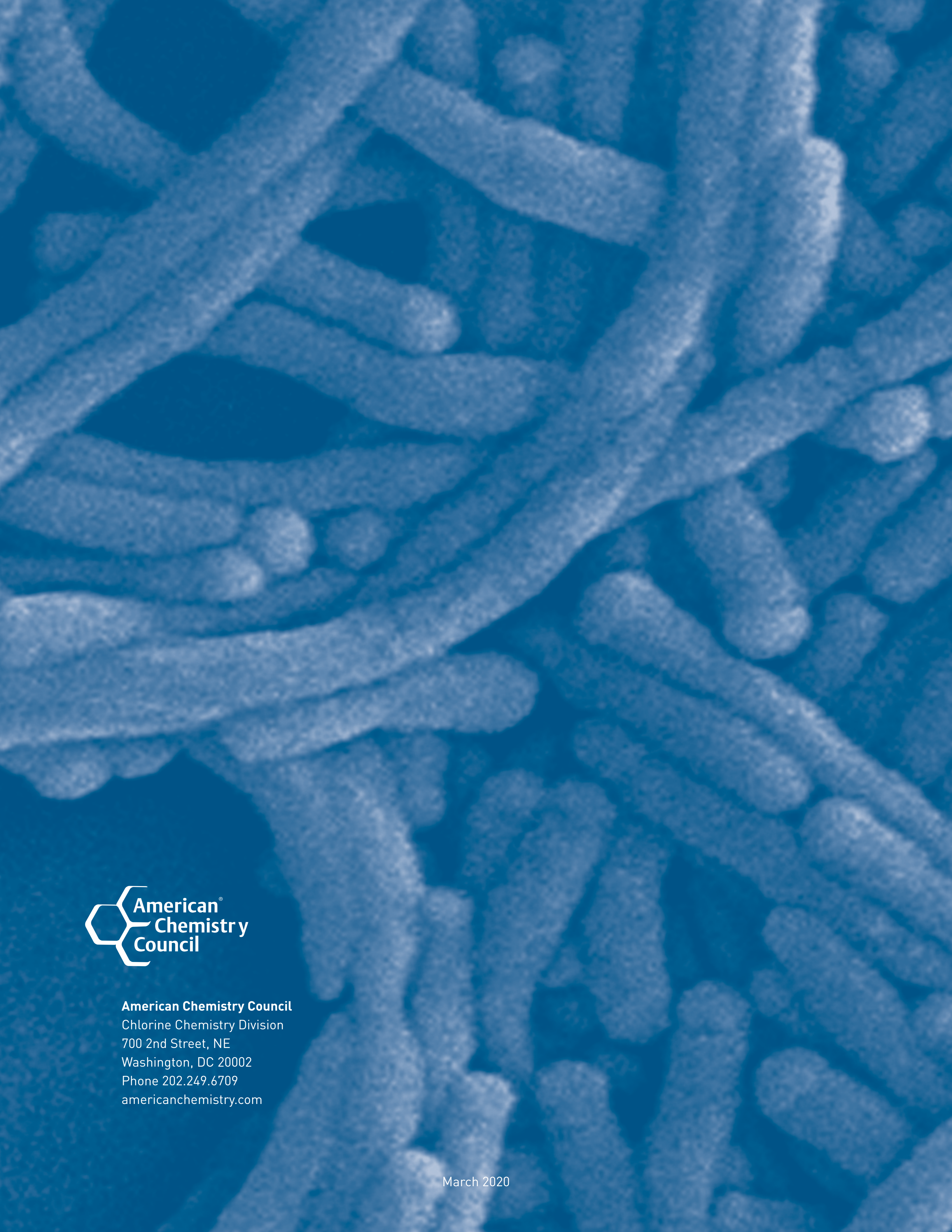

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