A RISK ASSESSMENT APPROACH TO CONTROLLING LEGIONELLA BACTERIA

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ABSTRACT
Legionella bacteria, the etiological agent of Legionellosis, are environmentally sourced organisms. The range of environmental sources associated with the bacteria is constantly increasing as new cases emerge, and epidemiology and environmental investigation techniques improve. As a system owner and operator it is incumbent upon you to identify the potential risk systems and take suitable action to minimize the risks. The level of action taken should of course be proportional to the risk, with the greatest level of resources being directed to the systems that present the highest risk. This paper presents some of the basics of risk assessment that have been learnt over several years applying the United Kingdom Health and Safety Commission’s Approved Code of Practice for the Prevention or Control of Legionellosis (L8) (Health and Safety Commission, 2000).

INDEX TERMS
Legionellosis, Legionnaires’ disease, Legionella, Pontiac fever

INTRODUCTION
Legionellosis is the term used to describe a number of respiratory diseases caused by the Legionella bacteria. The diseases range from a mild atopic influenza (Fields, 1997) that naturally self mediates to a severe, often fatal, pneumonia. Several people in the vicinity of the source may show an elevated antibody titer with no symptoms (MMWR, 2001, Buehler et al, 1985). This indicates that not all of those exposed to the bacteria will develop symptoms due to a lower dosage of the organism or a stronger immune system. The diseases covered under the generic heading of Legionellosis include:

- Legionnaires’ disease: a severe pneumonia with high fever, malaise, diarrhea, and dry cough. Pneumonia is confirmed by chest x-ray and the specific agent identified. Onset of symptoms is 2 to 14 days after exposure, with the norm in the 5 to 8-day range and extremis at 26 days (Boshuizen et al, 2000, Buehler et al, 1985).
- Pontiac fever: a flue like illness characterized by a high attack rate (95% plus) with rapid onset of symptoms (12 to 48 hours), which has never been shown to be fatal. There is some suggestion that a significant contributing factor to Pontiac fever could be the influence of endotoxin (Fields, 1997).
- Lochgoilphed fever: very similar to Pontiac fever and indeed the only recognized outbreak was in Lochgoilphed, Scotland. It is notable as a potentially separate disease due the causal agent Legionella micdadei rather than the more common Legionella pneumophila. (Goldberg et al, 1989)
- Non pneumophila Legionellosis: in part a political creation but is also an acknowledgement that many different species of Legionella are capable of causing infection. In particular the Australians report a far greater portion of the general

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population suffering from Legionnaires disease are infected by *Legionella Longbeachae*.

- Non-pneumonia Legionnaires’ disease: those individuals who show many of the characteristic indications of Legionnaires’ disease but do not have pneumonia. The individuals must also test positive for Legionella bacteria.

The common factor with all of these diseases is that the causal agent is one of the many species of Legionella bacteria.

**LEGIONELLA**

Legionellae are a genus of bacteria found in lakes, rivers, soil and composts. Legionella have been identified in both surface and ground waters, with wells up to 1,500 feet deep testing positive for the bacteria. The majority of these natural environments would not appear to provide the concentrated nutrients Legionellae in the laboratory are known to require for growth. The discovery by Rowbotham (Rowbotham, 1980) and Fields (Fields et al, 1984) of the parasitic relationship with amoebae and the protozoanosis exhibited provided insight into the true nature and ecology of the organism. The identification of viable Legionella bacteria in encysted protozoa is also critical in understanding the ecology of the organism.

There are over 54 named species of Legionellae in the literature with over sixty serogroups. Unnamed *Legionella*-like amoebal pathogens (LLAP), several of which were reclassified in 2001 as named Legionella species, and several strains of Legionellae awaiting identification as either new species or serogroups of existing species are known to exist possibly bringing the number of species to as many as 85 (Ratciliffe et al, 2002).

The two important points to note from this are that any potable water supply has the potential to contain Legionella bacteria regardless of its source, and even a chlorinated water supply may contain Legionella bacteria inside encysted protozoa protected from the effect of the oxidizing biocide. The *Legionella* bacteria may not be detectable in the potable water supply using standard analytical methods; a published study by the author (Hodgson et al, 1986) found detectable *Legionella* in only two of 817 city water samples. It would though be prudent when performing risk assessments to assume that all water supplies have the potential to contain *Legionella* (Health and Safety Commission, 2000, ASHRAE 2000).

**RISK ASSESSMENT**

One of the requirements of the United Kingdom Health and Safety Commissions’ Legislation (Health and Safety Commission, 2000) is that all building owners and operators perform a risk assessment of all water systems on site to determine those likely to be the cause of an outbreak of Legionellosis. To accomplish this it is recommended that a competent individual is retained to perform the evaluation, however, minimal guidance is provided in how to perform the evaluation. The quality of many early risk assessments was often poor with chemical vendors often determining that cooling towers were low risk systems purely on the basis of their own treatment products being used. Industry concern over the quality of risk assessment resulted in the introduction of a voluntary code of conduct in 1999 in part to prevent further government regulation (British Association of Chemical Specialties, 2000).

To accomplish the risk assessment the author recommends that the following factors be considered:

Potential for the system to support amplification of Legionella bacteria
Potential for the system to produce an aerosol in the breathing zone. Case history of previous outbreaks associated with similar systems.

For each of these three factors that indicate a positive response the risk factor associated with the piece of equipment is increased. Generally four levels of risk are considered:

High risk: all three parameters are positive
Medium risk: two of the three parameters are positive
Low risk: one of the three parameters is positive
Negligible risk: none of the three parameters are positive.

The susceptibility to Legionnaires’ disease of the local population due to age and immune system condition is an important consideration. Hospitals, aged persons accommodation and institutional accommodations have populations susceptible to Legionellae.

CONDITIONS REQUIRED FOR LEGIONELLA AMPLIFICATION
The following characterize the primary considerations when looking at the potential for Legionella amplification in a water system:

Temperature, pH, dissolved oxygen concentration, and the presence of biofilm or deposits

When considering temperature there is both agreement and disagreement on the required temperature for amplification. One issue is that most of the early research concentrated on culture grown *Legionella pneumophila*, rather than the other species or *Legionella* in conjunction with its natural host organism. Widely quoted figures (Health and Safety Commission, 2000, ASHRAE, 2000) have suggested that the bacterium is dormant below 20 or 25°C and that above 45°C the bacterium is killed with time. The optimum temperature for growth of *L. pneumophila* is quoted by the CDC and reflected in the ASHRAE Guidelines (ASHRAE 2000) at 37°C.

Work recently published by Berk (Berk et al, 1998) suggests that for some species of Legionella the optimum temperature may be as low as 25°C when grown in association with protozoa. Additional data indicates that some growth can be “kick started” by a short period at 30°C followed by continual growth at 25°C. All of this complicates the picture considerably particularly as we are just starting to learn of different relationships between *Legionella* bacteria and various species of protozoa. The one thing that does not appear to change significantly is the effect of elevated temperatures on Legionella bacteria. Once the temperature rises above 45 °C the bacteria starts to die off with time. At 50 °C it takes approximately 2 hours to attain a 90 percent kill, at 60 °C it takes approximately 2 minutes to attain a 90 percent kill, and at 70°C an almost instantaneous kill to 100 percent is attained.

When performing a risk assessment it is important to know the operating temperature of the system under consideration. It is also prudent to consider the range of potential temperatures in a system. Measuring the temperature of a system at a single location on that system and determining that there is minimal risk may not reflect all of the conditions in a system. Consideration should also be given to temperature fluctuations during variable load conditions and shut down procedures.
*Legionella* bacteria are acid fast and capable of survival at 4.5 pH for short periods and also capable of surviving at pHs of up to 10.5 for a few minutes. For growth of the organism the optimum pH at 6.6 to 7.2 though growth can be observed at a broader range.

*Legionella* bacteria prefer lower dissolved oxygen concentrations than are typically found in systems but is certainly not anaerobic. These conditions are typically found in low flow or stagnant areas of a system or within biofilms and under deposits.

The roll of biofilm in *Legionella* amplification is still not fully understood however the presence of biofilm provides a food source for the protozoa host and also an area where some protection is afforded from the effect of biocides. Heavy fouling with Algae was reported by one investigator to have an association with *Legionella* but this may be an indirect association, as there is no direct interaction between the *Legionella* bacteria and algae, the algae certainly provides a habitat that shelters other bacteria and protozoa.

Heavy fouling from inorganic salts such as calcium carbonate will also provide an environment that is conducive to *Legionella* growth. Eradication of *Legionella* bacteria from heavily fouled systems is close to impossible until the deposits have been removed. When performing a risk assessment a thorough visual assessment of accessible areas of the system and review of the water chemistry is required.

**AEROSOL PRODUCTION AND TRANSMISSION**

Establishing if a process produces an aerosol would at least initially appear to be reasonably straightforward. Visual observation will tell us if a process is open to atmosphere and if it will produce an aerosol at that point. What is less clear is the quantity of aerosol produced and how much of the aerosol will enter the breathing zone of an individual.

Cooling towers have been shown to spread aerosols over considerable distances, in one instance over 3 kilometers form the source. Certainly it is not uncommon to look at bioaerosol transmission distances from this type of equipment of over 500 meters (Health and Safety Commission, 2000, ASHRAE 2000).

Potable water systems are less likely to spread aerosol over long distances, the use of items such as showers provides a direct exposure to the individual. Even where there are no showers in the system, a water stream from a faucet striking a porcelain surface under pressure will produce an aerosol, the greater the pressure the more aerosol produced.

Care should also be taken to consider failure and abnormal operating conditions, with special attention paid to exposure for maintenance personnel. Personnel involved in maintenance activities are often subject to far greater concentrations of aerosol than the general population, in such instances appropriate respiratory protection should be recommended from the risk assessment.

**CASE HISTORY**

Some commonly used water systems such as cooling towers, potable hot water systems, recirculating water humidifiers, whirlpool spas baths, and ornamental water features have well researched and established histories as the sources of multiple outbreaks. Other less widely used applications have fewer case histories associated with them, often of a lesser quality in terms of investigation and reporting, with reports appearing in news papers and trade journals rather than peer reviewed articles.
It is often difficult to establish a strong or reliable case history for particular types of equipment especially process operations, which may be unique to particular industries. Even commonly used processes can be a cause for heated debate an example of this being metal working fluids. With one published outbreak of Pontiac fever associated with metal working fluids from 1981 (Herwalde et al, 1984), and several suspected cases or unpublished investigations, however manufacturers of metal working fluids point to changes in product formulations since the 1981 outbreak as suggesting such data is no longer pertinent.

The Roll of Sampling in Risk Assessment
Collection and analysis of water samples from a water system as part of a risk assessment is often used to establish if a system is capable of supporting Legionella growth. The sample results may not provide the answer the researcher is looking for. A positive test result will confirm the potential of a specific system to support the growth of Legionella bacteria, however, a negative result does not prove that the system can not support Legionella growth. A more accurate description of the sample result can be summarized as “Legionella bacteria are not present above the limit of detection for the analytical method used”.

The first concern is to look at the analytical method and test results to determine what a result of not detected really means, which may not be that the bacteria is not present. A sample analyzed by the Centers for Disease Control and Prevention (CDC) (Centers for Disease Control and Prevention, 1994) published method, that has not been concentrated, has a theoretical limit of detection of 33 cfu/mL. It has been suggested that the centrifuge concentration and heat treatment approach of ISO 11731 (International Standards Organization, 1998) provides a lower limit of detection than the filter and acid treatment approach from the CDC, but that recovery rates for the CDC method were greater than those for the ISO method.

One thing that neither analytical method considers is the potential undercounting of Legionella concentration due to the bundling effect of vesicles released from protozoa. A common tenant of microbiology is that a single bacterium on a culture plate multiplies and grows to form a single colony. Berk (Berk et al, 1998) reports there may be several thousand viable bacteria in single vesicle. When plated on to agar these bacteria will form a single colony, in effect our colony forming unit is the vesicle with numerous bacteria packaged together, but the plate count is unable to differentiate vesicle bound bacteria from free swimming individual cells.

UK Health and Safety Commission mandates routine testing of all high-risk systems with quarterly testing of cooling towers and six monthly testing of potable hot water systems (Health and Safety Commission, 2000). The analytical method used must be capable of attaining a limit of detection of less than 100 cfu/L (0.1 cfu/mL), with the only acceptable analytical result being that Legionella is not detected in the sample.

CONCLUSIONS AND IMPLICATIONS
Risk assessment can be a useful tool in determining which water systems present the greatest potential for causing legionnaires disease, and hence warrant the application of the most stringent control procedures. Probably the single most important factor in determining if a system has the potential to amplify Legionella is the overall operating temperature with tepid water system in the range of 20 to 45°C presenting the greatest risk.
The overall system operating condition and the presence of fouling due to biofilm or organic salt deposition increase all of the risk factors and make control of *Legionella* more difficult. Overall there are significant opportunities for intervention to prevent infection of personnel by *Legionella* by preventing amplification, interrupting the passage of aerosols containing the bacteria, or as a final resort providing personal protective equipment to personnel working in areas associated with high risk of infection. Risk assessment is a valuable tool in determining which approach is most appropriate for intervention.

REFERENCES


British Association for Chemical Specialties and the water Management Society; The Control of Legionellosis, A Recommended Code of Conduct for Service Providers.


