Review paper

Legionnaires' disease: causation, prevention and control

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Summary

Legionnaires' disease, also termed Legionellosis, is a rare, potentially fatal form of pneumonia. It was first recognised in 1976 when an outbreak occurred in a hotel hosting a convention of the Pennsylvania Department of the American Legion.

Legionnaires' disease arises from inhalation deep into the lungs of contaminated water aerosols, mists or droplet nuclei. Common sources of contaminated stagnant water in this form include shower heads, whirlpool baths, evaporative condensers, cooling towers, air conditioning systems, humidifiers, industrial sprays. The commonest result of infection is an acute pneumonia, though many cases probably go undiagnosed and individual cases receive little publicity, with rare mass outbreaks attracting most attention.

The main strategy for prevention is to avoid conditions which allow legionella bacteria to thrive and to avoid creation of a spray or aerosol.

Preventing the release of water spray or aerosol may be achieved by using:

- dry cooling plant;
- adiabatic cooling systems;
- point of use heaters with minimal, or no, storage.

Strategies for preventing the proliferation of bacteria in the system include:

- Avoiding water temperatures between 20°C and 45°C.
- Designing pipework to prevent water from standing undisturbed for long periods, which may encourage biofilm growth.
- Avoiding materials that may harbour or provide nutrients for microbial growth.
- Regular maintenance of system cleanliness to avoid the build-up of sediments.
- Ensuring that the system is operated correctly and safely, and is well-maintained.

Keywords: Legionnaires' disease; Aerosol; Water

Introduction

Legionnaires' disease, also termed Legionellosis, is a rare, potentially fatal form of pneumonia. It was first recognised in 1976 when an outbreak occurred in a hotel hosting a convention of the Pennsylvania Department of the American Legion.[1] A total of 234 Legionnaires contracted the disease; 34 of them died. Despite a good understanding of the cause, prevention and treatment, many cases still occur and people die from the disease, often in healthcare institutions.

A large outbreak of Legionnaires' disease was associated with Stafford District General Hospital. [2]

A total of 68 confirmed cases were treated in hospital 22 of whom died. A further 35 patients, 14 of whom were treated at home, were suspected cases of Legionnaires' disease. All these patients had visited the hospital during April 1985. Epidemiological investigations demonstrated that there had been a high risk of acquiring the disease in the out-patient department, but none in other parts of the hospital. Water in a cooling tower and chiller unit which cooled the air entering the Department was contaminated with legionellae. Bacteriological and engineering investigations revealed how the chiller unit could have been contaminated and an aerosol containing legionellae could have been generated in the U-trap below it. These results, and epidemiological evidence, suggest that the chiller unit was the most likely major source of the outbreak. Nearly one third of hospital staff had legionella antibodies; they were likely to have worked in areas of the hospital served by the contaminated air conditioning plant.

Unfortunately, outbreaks of the disease in hospitals continue to be reported. In 2010 it was confirmed [3] that patients at a hospital severely criticised for high mortality rates and poor hygiene standards had contracted the disease.

Managers need to understand the hazard and risk control procedures in order to prevent employees, contractors, visitors and local communities from contracting the disease and also to avoid potential ensuing prosecution and civil litigation. Nowadays, a case of Legionnaires' disease can be linked to an environmental source by comparing the legionella strain found in the victim to the strain found in a water sample thereby enabling claimants to eliminate some water supplies, as in the victim's house, as the source of infection and implicate others, for example, in

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a defendant's building; c.f. DNA evidence in criminal cases. Legionnaires' disease lawsuits are not uncommon.

The hazard

In the UK Legionellosis is a reportable disease under RIDDOR.

Investigation of the Pennsylvania incident revealed the causative agent as a bacterium *L. pneumophila*, a previously unrecognised organism. Retrospective studies have since demonstrated that some earlier outbreaks of unattributed severe pneumonia were due to infection with legionella.

About 90% of cases of legionella infections are caused by *L. pneumophila*. This species has now been subdivided into smaller 'serogroups' (Figure 1). All may be capable of causing the disease but the commonest cause is serogroup 1. Over 37 different species have been isolated from environmental sources or patients and named to reflect either the place where they were found, or the person who discovered them, e.g. *L . bozemanii* and *L. longbeachae*.

Legionellae occur in low numbers in fresh waters e.g. ponds, rivers, springs, streams, lakes and river banks where they do not cause infections. However, multiplication is encouraged in warm stagnant conditions and it is inevitable that they will invade and colonise man-made water systems. Unlike most fresh-water aquatic bacteria they are slow growing with exacting nutritional requirements. They may live in association with other organisms such as amoebae which are frequently present in water including potable water, water tanks, showers, swimming pools, etc. A recent concern surrounds exposure to spray from warm stagnant water in windscreen washers not mixed with screenwash putting professional drivers at greatest risk.[4] One amoeba can contain 1000 legionellae. Whilst 0.4 mg/l chlorine kills free-living legionellae, amoeba-protected legionellae can survive normal drinking water disinfection and may require concentrations of $>$ 50 mg/l free chlorine.[5] Hence the legionellae may enter the mains water supply. In the distribution system, they may multiply, particularly if the water temperature is favourable, and form a biofilm or layer of thriving bacteria over artificial structures, excessive sediment, convoluted surfaces, etc. People may be subsequently exposed to the organism via sprays.

The organism can survive in wind-borne water droplets carried up to several km from its source. However, it is believed the disease may also be contracted by ingestion of legionella-contaminated water (e.g. drinking water) which may bypass the body's normal defences and enter the lungs by aspiration.[6] Most infections with legionellae are respiratory infections but wound infections may result from contact with contaminated water.[7] The commonest result of infection is an acute pneumonia, Legionnaires' disease.

Whichever species of legionella is involved, the pattern of illness is similar. After an incubation period of 2–10 days, usually 3–6 days, the victim may feel ill with flu-like symptoms e.g. malaise, muscle pain, and a headache. Within a couple of days a dry cough may develop followed by high fever with temperature rising to 40°C. Breathing difficulties, nausea, vomiting, and diarrhoea may occur. They may become confused and seriously ill. Some patients may develop pneumonia; complications may develop due to the organism spreading via the bloodstream. Overwhelming evidence suggests Legionnaires' disease is not contagious.

Pontiac Fever is a mild form of legionellosis resembling influenza so called because *L. pneumophila* was shown retrospectively to have been the cause of an outbreak in Pontiac, USA, in 1968. The incubation period is usually one or two days, and so is the illness. The patients develop a malaise, mild aches, some fever, chills and a headache, but within a couple of days resolves.[8]

The risk

Legionnaires' disease arises from inhalation deep into the lungs of contaminated water aerosols, mists or droplet nuclei. Common sources of contaminated stagnant water in this form include shower heads, whirlpool baths, evaporative condensers, cooling towers, air conditioning systems (although humidifiers in these have been referred to as unlikely sources for legionellae as the temperature is usually too low for growth), humidifiers, industrial sprays. Generally, a temperature range of 20°C to 45°C and the presence of sludge, scale, rust, algae or organic matter are critical factors.

Air-conditioning units, such as the type shown in Figure 2[9], represent the main danger. Colonisation of cooling towers may occur when bacteria are disturbed from nearby soil during building work and ploughing;[10] the organisms multiply in the water of the towers in which a cascade of water is used to cool air in pipes or vanes. This water does

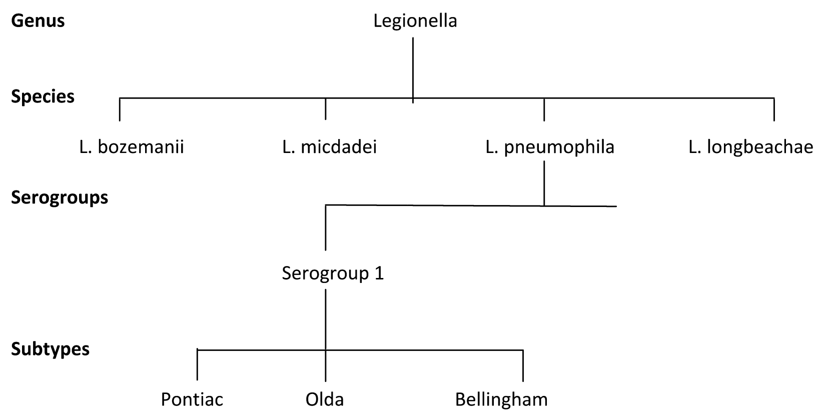

Figure 1: Legionella taxonomy

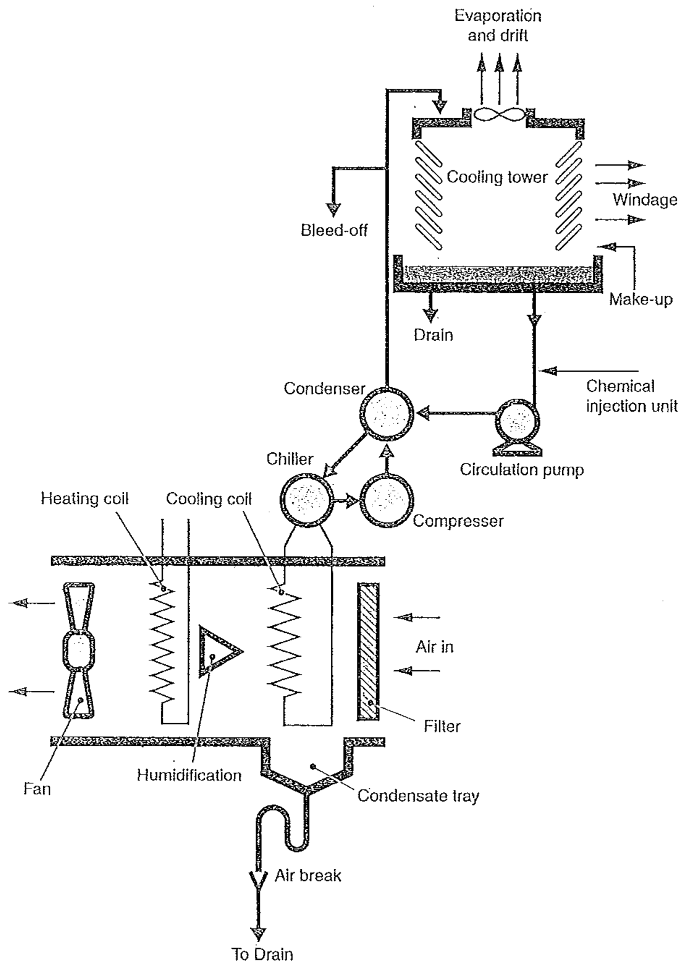

Figure 2: Typical air conditioning system

not come into direct contact with the air but much escapes by evaporation or as spray. Since smaller cooling towers are usually located in the roofs of buildings contaminated droplets may enter air intakes of the building or descend onto people passing by.

In 1988 an outbreak of Legionnaires' disease, traced to the cooling towers at a corporation's headquarters in central London, culminated in three fatalities.[11] One patient had been working on the fifth floor of the building, and another had been working as a roofer 200 metres away.

In all 58 people were affected, of whom 18 were employees. The retirement of one man who performed a regular water treatment programme, was followed by a period of confusion over requirements and duties. The company was prosecuted and fined.

A taxi driver, who also contracted the disease due to exposure when driving past the headquarters, was awarded £26,000 in damages.[12] A naval officer who was in the vicinity at the time of the outbreak subsequently suffered severe pneumonia and neurological symptoms.[13]

Several factors influence the risk. The most vulnerable populations include males, cigarette smokers, elderly patients, those with pre-existing lung disease and patients with deficient immune systems. Subjects suffering from cancer or chronic kidney diseases are less able to fight infections, and diabetics and sufferers of liver cirrhosis have increased vulnerability — hence the outbreaks in health care institutions. Healthy people, however, can also be infected.

Many cases of Legionnaires' disease probably go undiagnosed and individual cases receive little publicity, with rare mass outbreaks attracting most attention.

A large outbreak of Legionnaires' disease occurred in Murcia, Spain, in July 2001. More than 800 suspected cases were reported; 449 of these were confirmed. This was the world's largest outbreak of the disease at the time. The epidemiologic investigation implicated the cooling towers at a city hospital. An environmental isolate from these towers had an identical molecular pattern to the clinical isolates which supported that epidemiologic conclusion.[14]

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When an outbreak of Legionnaires' disease occurred during a flower exhibition in Bovenkarspel, The Netherlands, in March 1999, 230 people became ill with at least 32 fatalities. More people probably died and were buried before legionella infection was recognised. The source of the bacteria was two bubbling hot-tub displays at the centre of the exhibition area. At least 100 victims were still suffering debilitating effects some 10 years later. Dutch officials admitted that 90% of the legionella controls in the country were not carried out properly and were not followed up with inspections.[15]

About half the cases occurring in the UK arise from foreign travel. Reviews[15] have shown shipping to pose a problem with over 50 incidents of Legionnaires' disease, involving over 200 cases, associated with ships in three decades.

An outbreak of Legionnaires' disease occurred on a single cruise ship in 1994. Fifty passengers were affected on nine different cruises and one passenger died. The disease was linked to a whirlpool spa on the ship.[16]

The problem extends to other ships including tankers, etc. Serological surveys of seafarers on cargo ships have shown a high proportion have antibodies to *L. pneumophila* suggesting crew are at increased risk compared with onshore communities. Surveys carried out on general cargo vessels have also shown drinking water and air-conditioning systems to be contaminated with *L. pneumophila.*

Many of the cases which originate in the UK are associated with urban areas particularly industrial estates; possibly due to the greater concentration of water cooling towers in those areas and the higher population density.

Excluding travel exposure, the majority of cases and clusters of Legionnaires' disease in Europe are associated with community sources, involving large buildings e.g. hospitals, hotels, museums, office blocks etc because they have larger, more-complex water supply systems which facilitate spread of legionella contamination via air conditioning units, spa pools, hot water systems, etc. However, industry, including the chemical and process industries, possesses many of the potential sources of the disease such as cooling towers, air conditioning units, offices, canteens, shower amenities, spray systems, frequent-travelling employees, shipping (for transportation of raw-materials and finished goods), etc. Whilst direct links with industrial manufacturing processes are less common many use cooling towers intensively and continuously, and inspection of wet cooling towers at 22 chemical manufacturing sites in the Midlands revealed[17] that at 25% there was build-up of slime, algae, scale and corrosion; ponds were poorly covered and exposed to light and fouling; and equipment was broken or damaged.

Furthermore clusters of Legionnaires' disease have been reported from a variety of industrial sectors with workers exposed to contaminated sources of aerosolised water.

A major drinks manufacturer and a contractor pleaded guilty to contraventions of the Health and Safety at Work etc Act 1974, following an outbreak of Legionnaire's disease in Hereford in 2003. At inquests the Coroners' court had directly related the deaths of two people to the outbreak and the Health Protection Agency had originally attributed 28 cases of Legionnaire's disease. This figure was later revised to 26.

An investigating inspector explained that there had been a failure to institute and maintain an effective cleansing treatment and disinfectant regime for two cooling towers at the company, and that inadequate management, by neglecting such an obvious duty of care, resulted in the health and lives of the public or employees being endangered. The fact that building users engage a specialist contractor does not ensure compliance with the law; they must work with the contractor and ensure they are receiving the service required. Equally, specialist contractors and sub-contractors must provide their clients with the expertise for which they have been engaged.[18]

In mid-June 1996, the first reports of a flu-like illness affecting workers at an abattoir came to the notice of a Public Health Unit.[19] The fact that all those affected worked at an abattoir, and none was from the general community caused no concern since the symptoms were sufficiently non-specific to represent any one of a number of community-acquired viral infections. Two workers were transferred to hospital for investigation of a sudden onset of brain complaints. Both subsequently developed neurological complications one week after the onset of their symptoms.

Other workers manifested symptoms, predominantly swinging fever, headache, profound myalgia and dry cough; some lasted 2–3 days. Others workers required hospitalisation of up to a week. It is believed that between 12 and 13 people were affected at this stage. From the onset, serology was sent for leptospirosis, Q fever, brucellosis and psittacosis as well as legionellosis and respiratory infections (adenovirus, parainfluenzae, influenza).

In the last week of June, serology from the initial case showed a convincing rise in titre to L. pneumophila serogroup 4. One week later, the second patient exhibited serological evidence of exposure to legionella, but with concurrent rises to mycoplasma, parainfluenzae 1, and Q fever. The broad reactivity was confusing, but there was sufficient evidence to consider an outbreak. Water samples were taken from cooling towers, storage tanks and hose reservoirs, and from the bores that supplied the plant with all of its water. A third case involving a trainee meat inspector was subsequently notified.

Of the 82 workers at that stage, 22 (27%) eight 'possible cases' were identified, in addition to the three already notified. The approximate dates of onset of

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illness did not follow any pattern indicative of continued transmission of the organism(s) over at least two months. There was no apparent social connection between any of the cases, and no other cases of the same definition outside the abattoir.

The three confirmed cases all worked in the 'wet' areas of the abattoir where they would be most likely to be exposed to water (the slaughter floor, meat meal shed and by-products section). The water supply was considered to be the most probable source as the air-conditioning system was ammonia-based. Initial water testing failed to isolate a causative organism. A fourth worker on the slaughter floor seroconverted to *L. pneumophila* serogroup 4. A number of workers subsequently became ill, with little or no time off work and symptoms that suggested influenza, which was prevalent in the community at that time. It was concluded that this episode was probably a legionella outbreak, spread via a contaminated water supply.

Several reports suggest the risk of Legionnaires' disease may exist in injection moulding processes.

During an inspection *L. Pneumophila* were found at high concentrations in water used to cool the metal moulds and the process equipment used in the manufacture of plastic parts, suggesting workers engaged in injection moulding may be at an increased risk of Legionnaires' disease.[20] Unconfirmed cases of Legionnaires' disease were also identified among the workers. Water samples from the mould outlet (37°C) were shown to contain the presence of high concentrations of *L. Pneumophila* (<1,000 organisms/ml). Water samples from the cooling tower, which had been poorly maintained but had received some biocide treatment, contained legionella genus bacteria or legionella-like bacteria but low concentrations of *L. Pneumophila* (ca 10 organisms/ml). Because other species of legionella, in addition to *L. Pneumophila*, are capable of causing Legionnaires' disease and other respiratory illnesses, exposure to this water source also presented a health risk.

Five employees were confirmed to have developed the disease, one of whom died. Three other cases of pneumonia were identified. Although the initial laboratory evaluation of these cases did not confirm Legionnaires' disease, additional antibody testing was pursued. *L. Pneumophila* had been isolated from non-potable water samples collected at the facility.

In addition, a case of Legionnaires' disease involving plastic injection moulding operations had been reported in the literature[21] where two workers employed in the plastic injection moulding industry contracted pneumonia and one later died of Legionnaires' disease. A positive culture taken from the victim identified the organism as *L. Pneumophila*). High concentrations of *L. Pneumophila* organisms [3,000 colony forming units (cfu)/ml] were detected in the chilled water used to cool the moulds.

The cases demonstrate the need for plastic injection moulding manufacturers to follow good industry practices to minimise the potential for proliferation of these organisms in water systems. Water sources for cooling purposes may be chilled water from a mechanical refrigeration unit or cooled water supplied directly from a cooling tower. It may be delivered at relatively-high pressure (80 psi), thus enhancing the potential for aerosol release into the workplace in the event of leaking lines or during mould change outs. These water sources can present a hazard if operating conditions do not minimise the growth of the micro-organism in the water.

In May 2008, two workers from a construction and agricultural-equipment manufacturing plant in the West Midlands were admitted to hospital with Legionnaires' disease.[22] Both were middle aged men, heavy smokers, and with no travel, leisure or other common community exposure to legionella sources. They lived in different towns (9 miles apart) and drove to work using different routes. They worked on different stages of the production line approximately 20 metres apart. The plant contained no wet cooling or air conditioning systems and there were no cooling towers in the town or in the immediate vicinity of the plant with no adjacent industries or office buildings. No increase in respiratory disease or worker absenteeism occurred at the plant during the preceding month. Alerts to hospitals and medical practitioners yielded no further cases. The two men responded well to standard treatment and were discharged from hospital after eight days.

The plant's water systems comprised:

1. Two independent domestic-type hot and cold water systems supplying the restroom and changing facilities. These had been drained in April 2008, were regularly monitored, and had no stagnant water sections.
2. A paint mist trap in an unheated spray paint booth. Here, a below-ground water-jet trapped paint mist from exhaust under negative pressure to an extraction stack. The water was at ambient temperature.
3. An aqueous metal pre-treatment tunnel through which steel parts on a monorail moved through - degreasing and rinsing stages. The system had a complex network of pipelines and tanks providing jet spraying of parts with solutions (including alkaline degreaser and an acidic phosphate solution) and water (which has a pH neutralising effect) at successive stages inside a tunnel.

Different solutions and water were drawn from their respective tanks by pumps and fed to spray nozzles inside the tunnel. There were six pre-treatment stages: a cleaning stage followed by two water rinses, then a 'keying chemical' stage with two water rinses. Each stage had its respective supply and collection tank. The chemical tanks were heated to 55–60°C. The water for rinsing was mains-fed and supplied four unheated water tanks at 25–38°C. The brushes covering the conveying railing were missing and there was no local extraction for the tunnel. Aerosols visibly leaked from the gap between the conveying railing and the large openings at the entrance and exit of the tunnel.

Prior to this incident, the aqueous pre-treatment process had not been risk-assessed as a source of legionella organisms and potential human exposure. No management protocol for monitoring (including legionella sampling), disinfecting and cleaning the water systems was in place.

No legionella was isolated from the domestic hot and cold water system or the paint mist water trap system. Water samples from the aqueous pre-treatment system contained *L. pneumophila* serogroup 1 at a count of <30 cfu/ml. Furthermore, this system posed the greatest risk due to aerosolisation. Drainage, cleaning and biocide treatment using thiazalone eliminated legionella from the system.

Aqueous pre-treatment systems are subject to legionella growth due to the presence of nutrients (rust and dirt from metal parts), favourable water temperature, convoluted surfaces that encourage formation of biofilm, and recirculation of water. Indeed since the West Midlands' incident five similar aqueous pre-treatment systems have been inspected by the UK Health and Safety Executive, and legionella has been isolated in four. Further growth of the bacterium was prevented by introduction of cleaning and disinfection practices.

HSE inspectors visited a metal finishing company in the West Midlands in September 2008 to examine controls for legionella in two cooling towers. There was no management system in place to control the bacterium and no regular monitoring and testing. Earlier in the year the company had engaged the services of two water-treatment specialists to conduct surveys, one of which showed high levels of bacteria. However, the company failed to implement any of the recommendations. The inspectors issued a Prohibition Notice to halt operation of the towers and an Improvement Notice requiring the introduction of a management system. Although the company ceased trading in October 2008 the managing director was judged to have been neglectful in his role and in February 2010 was fined £2000 with £1000 costs after pleading guilty to contravening S 37(1) of the UK 1974 Health and Safety at Work Act.[23]

In the mid-1989 a routine check on the bacterial infection revealed the presence of *L. pneumonium* serogroup 6 in a shower head in an amenity building in Scotland.[24] This was not the virulent strain but can cause flu-like symptoms when inhaled in droplet form. Since neither the hot water system (85°C) nor the cold water (17°C) would promote bacterial growth the infection was deduced to have been localised to the shower head. A system of routine sterilisation of the shower heads was subsequently introduced based on the methods summarised in Table 1.

Table 1: Procedure for sterilisation of shower heads

- For metal shower heads: remove from shower, place in a heated oven at 150°C for one hour. Switch off oven and leave shower head to cool. Refit.
- For plastic shower heads: remove and soak in 5–10% household bleach (hypochlorite) for one hour (or overnight if convenient). Rinse with hot water and refit.
- When the head is removed, flush the piping feed to the head at full bore for a few minutes.
- This procedure can be repeated at three-monthly intervals.

Following investigation of an outbreak of Legionnaires' disease at a wallpaper company in 1990 in the UK the HSE concluded that the company had not taken all reasonable precautions to ensure measures were properly carried out to control the legionella bacterium by application of biocide to the water of a cooling tower system.[25] The company required chemicals to be added but failed to ensure they were used. They were fined for a breach of Reg 8(1) of the Control of Substances Hazardous to Health Regulations 1988. This was the first prosecution under the COSHH Regulations.

In 2003–2004 bacteria carried by the wind from cooling towers on a petrochemical plant site in France resulted in the deaths of 17 people and 69 non-fatal cases of Legionnaires' disease amongst members of the public. Some of those infected lived 6 km from the plant. The incident attracted considerable attention by regulatory agents and the site was permanently closed as a direct result.[26]

A more unusual case involved a 59 year old man who contracted *L. longbeachae*, one of the rarest forms of Legionnaire's disease, just days after opening a bag in his garden in Scotland.[27] He was hospitalised and spent seven weeks in intensive care on a ventilator. The legionella exposure was believed to have occurred by inhaling compost dust.

The strain of the bacterium is most common in Australia and there have been only a few cases in Scotland. Environmental health workers showed no trace of the organism.

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Two days after returning to work after a temporary closure of sections of a car assembly plant in Canada, an outbreak of Pontiac fever developed amongst the workforce.[28] *L. feeleii* was isolated from an oil-water mixture used as a coolant during machining processes. About 50% of the employees developed the disease, most of whom were in the vicinity of the incriminated coolant system; the incidence reduced with distance from the source.

During June and July 2008, five cases of Legionnaires' disease were reported to the local health authorities and the Norwegian Institute of Public Health.[29] In the same area, a large outbreak of the disease with 56 cases and ten deaths had occurred in 2005.[30] The source at the time had been traced to an industrial air scrubber at the factory of a leading supplier of wood-based chemicals. During this outbreak patients were infected up to 10 km away from the source.

The age of the five patients in the 2008 cluster was in the range 51–84. Two patients died. No obvious indoor common source was identified. However, four of the five patients had been in the vicinity of the production plant. The investigation concluded that there was a link between three of the five patients and the detection of legionella at the company. However, it was not clear how the bacteria spread from the production plant. The aeration ponds of the biological treatment plant probably played an important role in the growth and spread of the bacteria, either directly through the air or indirectly by contaminating the air scrubbers or the river. The purpose of these ponds was degradation of organic material by means of microbiological decomposition. The temperature was around 37°C and 30,000 L/h air was pumped into the ponds to provide optimal conditions for microbiological activity. It was known from previous investigations that the conditions in such ponds are favourable for the growth of legionella. Samples taken from the recipient river in August 2008 showed high concentrations of *L. pneumophila* serogroup 1 at the outlet of the production plant and more than 10 km downstream. No legionella could be cultured from samples taken upstream of the outlet.

After the 2005 outbreak, new regulations were introduced to minimise the risk of spread of legionella bacteria from aerosol-generating equipment. These emphasised the responsibility of owners and operators to inspect, maintain and monitor aerosol-generating equipment possessing conditions suitable for the growth of legionella. Investigation of the 2008 incident confirmed, however, the company had complied with the requirements indicating the need for the authorities to review the original guidelines and regulations.

During a hot, humid summer workers fell ill with fever and flu-like symptoms typical of Pontiac fever after repairing a decanter for sludge concentration at a sewage treatment plant in the food industry.[31] The work had taken ten days in a small closed room. Another decanter was in operation at the time and releasing aerosol into the work environment. Positive antibody titres to *L. pneumophila* serogroup *1* were found in blood from all five patients. It was also cultured in high amounts from sludge from the decanter. This led to the conclusion that the fever was caused by *L. pneumophila* emitted to the environment by the uncovered decanter. Procedures to prevent new cases included:

- enclosure of the decanter,
- installation of room ventilation, and
- mandatory wearing of air-line equipment by workers inside the decanter house.

Risk assessment

Factors to be considered in a risk assessment include[9]:

- source of system supplying water e.g. mains or other;
- possible sources of contamination of it on site prior to a cold water storage cistern, calorifier, cooling tower, etc, that may present a risk of legionella exposure;
- normal plant operating characteristics;
- unusual, but reasonably-foreseeable operating conditions, such as breakdowns.

The assessment should be reviewed regularly, for example at $<$2 yearly intervals, and if there is reason to suspect its validity, such as:

- changes to the water system or its use;
- changes to the use of the building concerned;
- new information about risks or control measures;
- any case of Legionnaires' disease or legionellosis related to the system.

In the UK the duty imposed under S3(1) of the Health and Safety at Work Act 1974 for an employer to ensure, so far as is reasonably practicable, that persons not in his employment are not exposed to risks to their health, covers risks due to *L. pneumophila*. It has been held that the public outside a museum had been exposed to such risks by reason of an inadequate maintenance of the air conditioning system. It was not necessary to prove that members of the public had actually inhaled the bacterium or that it had been present, it was sufficient to show that there had been a risk of it being present.[32]

Prevention, control and treatment

Prevention

The main strategy for prevention is to avoid conditions which allow legionella bacteria to thrive and to avoid creation of a spray or aerosol. Legionellae in the water supply or in air conditioning systems may be almost impossible to eradicate, but a series of control measures is recommended including, where appropriate [after 9]:

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Preventing the release of water spray or aerosol, for example by using:

- dry cooling plant, for example, evaporative cooling towers in hospitals in the West Midlands, UK have been replaced by air-cooling units;
- adiabatic cooling systems;
- point of use heaters with minimal, or no, storage.

Prevention of proliferation of bacteria in the system by:

- Avoidance of water temperatures between 20°C and 45°C . Hot water should be stored at 60°C, although this may be difficult to achieve in older hot water systems. Cold water should be stored at 20°C or less, but with very large storage tanks this may not be possible at all times of the year.
- Cisterns and pipe-work should be designed to prevent water from standing undisturbed for long periods, for example, avoidance of water stagnation which may encourage biofilm growth. They should also be covered to stop dirt, debris and vermin from entering, i.e. proper control of dissolved solids and the minimization of organic material in the water. Organic-based materials such as decaying leaves and other organic matter will consume the oxidizing capability of biocides resulting in insufficient bacterial control.
- Avoidance of materials that may harbour or provide nutrients for microbial growth. Water fittings and washers should not be made of material which encourages the growth of the organisms (e.g. leather, some rubbers and plastics); local water authority bylaws may stipulate materials and fittings to be used. Water distribution systems should avoid dead-ends which causes water stagnation and encourages multiplication of the organism.
- Regular maintenance of system cleanliness to avoid the build-up of sediments.

Frequent visual inspection and periodic maintenance of the water system and its mechanical components are essential.

- Use of appropriate water treatment. For hot and cold water systems the cold water received from utility suppliers usually contains a trace of chlorine disinfectant but this cannot be relied upon for the hot water system. Water from other sources requires pre-treatment. A rigorous temperature control regime is common. Where biocide treatments, or ionisation i.e. electrolytic generation of copper and silver ions, are permissible then routine inspection and maintenance are essential. Periodic cleaning and disinfection of cooling towers may require use of alternation of biocides, one of which is an oxidizing-type to prevent the proliferation of the organism in the water during operation. For example, in an induced-draught cooling tower (Figure 3) biocides are routinely added to the sump or at the suction side of the recirculation pump. Active forms of chlorine, bromine, or organic chemicals which release active chlorine or bromine are often alternated with other types of biocides. Proper control of pH. Alkaline pH conditions reduce the efficacy of both chlorine and bromine as biocidal agents, although bromine is more tolerant of high pH than chlorine.
- Ensuring that the system is operated correctly and safely, and is well-maintained.

In addition, the following specific recommendations should be considered for air conditioning plants, including cooling towers and humidifiers.

- Cooling towers may need to be registered with the local authority. In the UK it is a legal requirement for local Environmental Health Departments to be notified of all wet cooling towers and/or evaporative condensers.

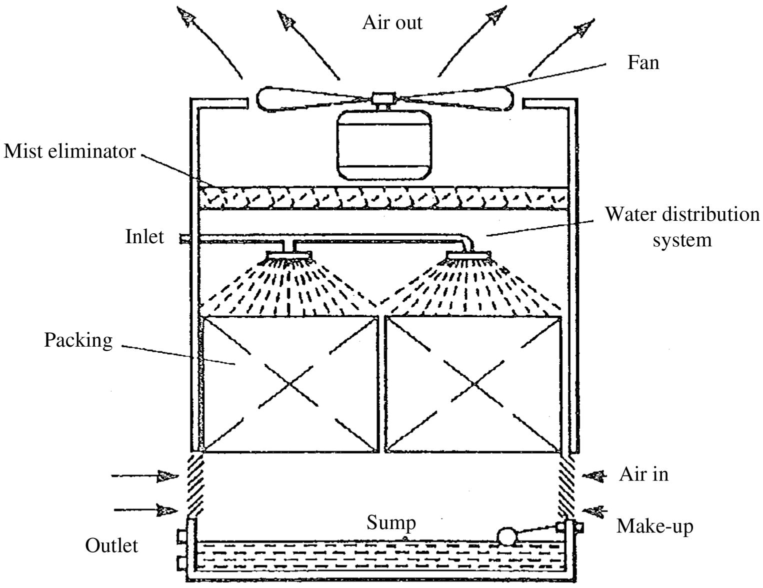

Figure 3: Induced draught cooling tower

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- Systems should be designed to operate with low sump- or basin-water temperature to reduce the potential for bacterial growth. Proper sizing of the cooling tower to ensure that the system has adequate cooling capacity to meet heat removal demands. Insufficient cooling capacity will result in warmer water temperatures in the cooling tower, a condition which encourages the growth of legionella.
- Control of the amount of water mist, or drift, is also an important design feature for cooling towers. Drift eliminators installed prior to the exhaust of a cooling tower will reduce the amount of aerosolized water lost to the environment and also reduce the risk of infection if this water source is contaminated with legionella.
- Frequent examination and cleaning are essential. Cooling towers and evaporative condensers should be inspected and thoroughly cleaned and disinfected at least six-monthly intervals. Corroded parts, such as drift eliminators, should be replaced. Algae and accumulated scale should be removed. Cooling water should be treated regularly. Ideally, an automatic water treatment system should be used to continuously control the quality of circulating water. Fresh air intakes to buildings should not be located close to cooling towers since contaminated water droplets may enter the ventilation system.
- Where reasonably practicable, cooling towers should be replaced with dry cooling systems.

Unfortunately, adherence to industry practice may in itself provide inadequate assurance that legionella proliferation in a water system will not occur; sampling water for the organisms may be the only method of verifying that the operating and maintenance practices are working effectively.

Additional considerations to reduce the risk of legionellosis on ships generally include:

- Proper disinfection, filtration and storage of source water, avoidance of dead ends in pipes and regular cleaning and disinfection of spas .
- Preventative environmental health management including water supply at port, water production, treatment and distribution on ship, swimming and spa pools, waste disposal, food safety and vermin and vector control; and
- Provisions for disease surveillance, outbreak investigation, and routine inspection and audit.

Control

As 'biological agents' the prevention or control of exposure to the causative bacteria are regulated in the UK by the Control of Hazardous Substances to Health Regulations 2002 (as amended).

Detailed practical guidance on the prevention and control of the risk from legionella bacteria is provided in reference 8. This should be consulted in any specific situation.

Treatment

Legionnaires' disease can be detected and cured with appropriate and timely procedures. Whilst the legionella organism is susceptible to a range of antibiotics under laboratory conditions, once in the human body it thrives and multiplies within the lung alveolar macrophages where it is protected from many, though not all, antibiotics. Should any case of Legionnaires' disease be suspected it is crucial to report the incident(s), and to investigate to identify the cause, those likely to be infected, and to institute rapid treatment of the contaminated water system.

Monitoring

With cooling towers, a check on the effectiveness of water treatment, the composition of make-up and cooling water should be monitored routinely. Typical checks and their recommended frequency are summarised in Table 2.[9] Identification of significant changes in the water chemistry then allows corrective measures to be taken with the operating conditions and treatment: with hot and cold water systems routine monitoring should cover temperature, water demand, cleanliness and use. A detailed annual check and monitoring for legionella in specific cases are also recommended.

Table 2: Typical on-site monitoring checks recommended for good operating practice

Parameter	Timing	
	Make up-water	**Cooling water**
Calcium hardness as mg/l $CaCO_3$	Monthly	Monthly
Magnesium hardness as mg/l $MgCO_3$	Monthly	Monthly
Total hardness as mg/l $CaCO_3$	Monthly	Monthly
Total alkalinity as mg/l $CaCO_3$	Quarterly	Quarterly
Chloride as mg/l Cl	Monthly	Monthly
Sulphate as mg/l SO_4	Quarterly	Quarterly
Conductivity us (Total dissolved solids)	Monthly	Weekly
Suspended solids mg/l	Quarterly	Quarterly
Inhibitor(s) level mg/l	–	Monthly
Oxidising biocide mg/l	–	Weekly
Temperature°C	–	Quarterly
pH	Quarterly	Weekly
Soluble iron as mg/l Fe	Quarterly	Quarterly
Total iron as mg/l Fe	Quarterly	Quarterly
Concentration Factor	–	Monthly
Microbiological activity	Quarterly	Weekly
Legionella	–	Quarterly

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