NHS National Services Scotland

Scottish Health Technical Memorandum 04-01:

The control of *Legionella*, hygiene, 'safe' hot water, cold water and drinking water systems

Part D: Disinfection of Domestic Water Systems

Health Facilities Scotland
Engineering and Environment

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Disclaimer

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Acknowledgements

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Preface

About Scottish Health Technical Memoranda

Engineering Scottish Health Technical Memoranda (SHTMs) give comprehensive advice and guidance on the design, installation and operation of specialised building and engineering technology used in the delivery of healthcare.

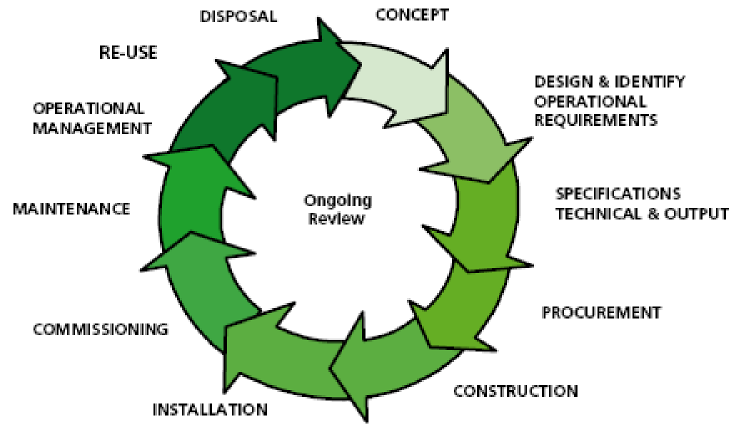
The focus of SHTM guidance remains on healthcare-specific elements of standards, policies and up-to-date established best practice. They are applicable to new and existing sites, and are for use at various stages during the whole building lifecycle: Healthcare providers have a duty of care to ensure that appropriate engineering governance arrangements are in place and are managed effectively. The Engineering Scottish Health Technical Memorandum series provides best practice engineering standards and policy to enable management of this duty of care.

It is not the intention within this suite of documents to repeat unnecessarily international or European standards, industry standards or UK Government legislation. Where appropriate, these will be referenced.

Healthcare-specific technical engineering guidance is a vital tool in the safe and efficient operation of healthcare facilities. Scottish Health Technical Memorandum guidance is the main source of specific healthcare-related guidance for estates and facilities professionals.

The core suite of eight subject areas provides access to guidance which:

- is more streamlined and accessible;
- encapsulates the latest standards and best practice in healthcare engineering;
- provides a structured reference for healthcare engineering.



Healthcare building life-cycle

Structure of the Scottish Health Technical Memorandum suite

The series of engineering-specific guidance contains a suite of eight core subjects:

Scottish Health Technical Memorandum 00: Policies and principles (applicable to all Scottish Health Technical Memoranda in this series)

Scottish Health Technical Memorandum 01: Decontamination

Scottish Health Technical Memorandum 02: Medical gases

Scottish Health Technical Memorandum 03: Heating and ventilation systems

Scottish Health Technical Memorandum 04: Water systems

Scottish Health Technical Memorandum 05: Reserved for future use

Scottish Health Technical Memorandum 06: Electrical services

Scottish Health Technical Memorandum 07: Environment and sustainability

Scottish Health Technical Memorandum 08: Specialist services

Some subject areas may be further developed into topics shown as -01, -02 etc and further referenced into Parts A, B etc.

Example: Scottish Health Technical Memorandum 06-02 Part A will represent: Electrical safety guidance for low voltage systems. In a similar way Scottish Health Technical Memorandum 07-02 will simply represent: Environment and Sustainability – EnCO2de.

All Scottish Health Technical Memoranda are supported by the initial document Scottish Health Technical Memorandum 00 which embraces the management and operational policies from previous documents and explores risk management issues.

Some variation in style and structure is reflected by the topic and approach of the different review working groups.

Health Facilities Scotland wishes to acknowledge the contribution made by professional bodies, engineering consultants, healthcare specialists and NHS staff who have contributed to the review.

Engineering guidance structure

1. Introduction

Background information

1.1 Health Facilities Scotland (HFS) Scottish Engineering and Technology Advisory Group raised concerns regarding a lack of information and guidance on the addition of chemicals to water in healthcare premises. In response to this, a Short-Life Working Group was formed and this eventually became the **National Water Services Advisory Group**. Part of the remit of this Group was to review available literature not only on the chemical treatment of water but also on processes used to treat water.

1.2 The use of any chemical in the treatment of potable water carries a risk and estates staff will need to call an independent party to review all paperwork and risk assessments before a treatment is implemented. This is of particular relevance when campaign or continuous treatment is contemplated but should also be implemented when shock treatment is proposed.

Group Membership

1.3 The group consisted of these members:

Tom Foley (Chair) NHS Tayside

Jim Alderton NHS Forth Valley

Iain McInally NHS Ayrshire & Arran

David Bennett NHS Tayside

Kenneth Walker NHS Grampian

Ged Mather NHS Borders

Alistair Johnstone NHS Dumfries & Galloway

Daniel Egan Golden Jubilee Hospital

Edward McLaughlan HFS Scotland

Ian Stewart HFS Scotland

Geraldine O'Brien HFS Scotland

Purpose of the Report

1.4 The purpose of this report has been to draw together peer reviewed information on potable water disinfection methods, in order to analyse them and identify the pros and cons associated with the use of each method

Report Layout

1.5 Supplementary to this report is a quick reference guide to each method, consisting of bullet points indicating the advantages, disadvantages and safety factors to be considered when using that method. This report will ultimately provide a review of published work on each of the disinfection systems available, how these chemicals/treatments affect NHSScotland estate and its occupants, and the main advantages and disadvantages associated with their uses, in order that the most appropriate system can be selected.

- Appendix 1 provides some case studies for further reading;
- Appendix 2 comprises a decision matrix, which has been arranged for use by estates staff during the decision-making process;
- Appendix 3 is provided to assess risks associated with the content/production of this document.

2. Disinfection of water systems

General Warning Regarding Chemical Disinfection of Hospital Water:

It has been found that the renal water plants do not filter out hydrogen peroxide, copper-silver ions, chlorine, chloramines and ozone. These disinfection systems should not be used where water serves a haemodialysis treatment area (SAN HAZ (SC) 08/07, 2008). Due to the extremely sensitive nature of renal water plants, no chemicals should be added to the water going to these units. If possible these units should be kept on a separate mains supply, or at least isolated when any shock or campaign treatment is planned.

Introduction

2.1 Opportunistic pathogens colonise water systems and can cause pulmonary, wound and bloodstream infections in healthcare patients. This contributes to approximately 25% of all healthcare-acquired infections (Anaisse et al., 2002). Papers published on nosocomial outbreaks in healthcare facilities have provided evidence that the source of contamination often originates from pathogens in the water supply. Bacteria, for instance, have been implicated in an estimated 1,400 deaths each year as a result of waterborne nosocomial pneumonias caused by *Pseudomonas aeruginosa* (Anaisse *et al*., 2002). Mucoid strains of *Pseudomonas aeruginosa* have been shown to have increased resistance to chlorine as a result of being protected by a biofilm (Grobe *et al*., 2001). These strains have been found to persist in swimming pool PVC pipework.

2.2 Another example of opportunistic pathogens is mycobacteria, which can survive in potable water systems for several years due to having a moderate resistance to chlorine. These bacteria have been implicated in serious nosocomial outbreaks (Reyn et al. 1994), and *Mycobacteria avium* has been shown to be resistant to chloramination, chlorination, chlorine and ozone disinfectants (Taylor et al. 2000). Mycobacteria are common in the natural environment and can colonise water distribution systems (Wright et al., 1985). Taylor *et al*. (2000) state that *Mycobacterium avium* can be found in public water supply and can be the cause of infection in hospital patients. Some studies have shown mycobacteria colonizing only parts of hospital water systems (Fox et al., 1992; Fujita et al., 2002). This suggests that the source of the contamination in these cases is not necessarily the public supply. Fujita et al.'s (2002) results also show that the colonisation affected directly connected parts of the distribution system, suggesting that contamination can occur at a water outlet, and then travel throughout the system. Mycobacteria is one of the most common opportunistic infections in AIDS patients, and it has been reported that 20% to 40% are infected by mycobacteria (Horsburgh, 1991).

2.3 Other pathogens that may contaminate healthcare domestic water systems are Aeromonas, which are found in many types of water and have been shown to inhabit biofilms in distribution systems. Aeromonas symptoms include diarrhoea that can last a few days or weeks (Vila *et al*., 2003), and is generally not life threatening. However, high risk groups such as immuno-compromised, young, and old patients' lives may still be at risk from such an infection. Protozoa such as Cryptosporidium and Giardia can also be present in the domestic water system and although the main symptoms again include diarrhoea, they can present a more serious threat to patients (Freije, 2005).

2.3 A paper produced by Yu (2007), indicated that researchers have found 70 percent of hospital water systems tested in the US to be positive for *Legionella* species. Many of the standard hospital disinfection methods involve the use of chlorine, however Kuchta (1983) states that *Legionella* can survive low levels of chlorine for relatively long periods of time. Another factor that may promote the growth of *Legionella* is the temperature of the system, although Scottish guidance - SHTM 04-01 Part A, (2011) - specifies the flow and return temperature of a domestic hot water system in a healthcare environment should be no less than 60°C at the calorifiers with a return temperature of 55ºC, the minimum allowable return temperature is 50ºC. This temperature of 50ºC should not be designed for as it will not kill off, only inhibit *Legionella* growth. The optimum temperature for multiplication of *Legionella* strains in culture media is approximately 37°C (Kramer and Ford, 1994); this temperature should never be reached in a system unless there is a malfunction. However, contrary to common belief a healthcare institution's cold water supply may also be contaminated with *Legionella* (Hoebe 1998). Colbourne & Trew (1986) maintain that *Legionella* occurs in 52 to 54% of domestic and cooling water inside commercial, industrial and health care buildings, these types of water systems are now regarded as a normal habitat for *Legionella. Legionella* is commonly found in the public water supply, the public is not aware that *Legionella* is a common inhabitant of man-made water distribution systems (Stout and Yu, 2001).

2.4 The reason treated water systems continue to be colonised by these pathogens, is due to an inappropriate treatment regime. *Legionella* is ubiquitous in water systems unless treated, however, Zhang *et al*., (2009) states that infection can be prevented through using an appropriate water disinfection system. Chlorination, the traditional method, as mentioned above may not be the most efficient technique and, following growing evidence of a link between chlorination and mutagens in drinking water (Gopala *et al*., 2007), alternative disinfectants continue to be investigated. There are many disinfection systems currently available, examples of which include

- heat and flush;
- continuous chlorination;
- chlorine dioxide;
- Ultra Violet light (UV);
- copper silver ionisation;
- silver catalysed hydrogen peroxide;
- ozone and chloramines.

All of these decontamination processes have advantages and disadvantages and work at their optimal performance within different parameters. The main aim of this report is to investigate the different methods, analyse their advantages and disadvantages and determine the factors needed to ensure optimal results when using each system.

Physical Parameters

2.5 When considering the most suitable method of disinfection for a healthcare facility a number of parameters have to be taken into consideration, factors to be considered include the condition of estate, the health of the occupants, the quality of the public water supply, finance, and the availability of resources to implement a particular regime.

Parameters of Incoming Water

2.6 There are many factors concerning the incoming water supply that should be taken into consideration when selecting the most suitable disinfection method. These include aspects such as:

- pH - has no effect on Ozone or UV, however the disinfection power is reduced with a higher pH than 8 for continuous chlorination (See Appendix 2 for more details);
- temperature – has no effect on Ozone or UV, however the residual effect decreases for continuous chlorination and chlorine dioxide when temperature increases;
- taste and odour – if this is already a problem, chlorine dioxide can neutralise these odours. However some disinfectants may contribute to taste and odour, such as chlorination if used at a high dose (See Appendix 2 for more details);
- if systems or parts of systems are unused for long periods of time then it is essential that a full flushing regime is instigated. If the water is not used on a regular basis then a residual disinfectant will be required, the volume and pipework design should also be considered as this may also determine if a residual effect is required. Disinfectants such as UV and Ozone have no residual effect, whereas chlorine dioxide, copper – silver ionisation and silver catalysed hydrogen peroxide have a long-lasting residual effect.

Heat and Flush

2.7 This process is one similar to pasteurisation and is distinct from normal temperature control applied to DHWS; this is used as a means of disinfection causing the destruction of disease-causing microorganisms. Increasing the temperature of hot water was the first method used to control *Legionella* in a hospital distribution system (Fisher *et al*., 1981). This chemical-free method requires no additional equipment and is commonly used, particularly as an emergency decontamination procedure in hospital outbreak scenarios.

Method

2.8 As stated in L8, and SHTM 04-01 Part A this disinfection is carried out through raising the temperature of the entire contents of the calorifier, or hot water heater, followed by circulating the water throughout the system for at least an hour at 75ºC. The calorifier/heater temperature must be sufficiently high to ensure that the temperature in all parts of the circulating system, and at the return connection, do not fall below 75C (Zacheus and Martikainen, 1996). This can be used as a continuous process in a hot water system only but has a significant cost to sustain the high temperatures required. This form of disinfection can only be used as a shock treatment for an outbreak in a cold water system; therefore, it is not suitable for continuous disinfection. It must also be noted that when utilising this method for a cold water system particular attention must be made to the thermal expansion of the system and this must be accounted for.

Advantages

2.10 The main advantages to this form of disinfection are that it requires no specialist equipment and therefore can be implemented immediately after an outbreak has been detected. If also used to disinfect the cold water system an additional connection from the calorifier is required, this must be disconnected after flushing and any branch connections must *not* result in extended dead legs being formed.

Disadvantages

2.11 One of the main disadvantages to using this method of disinfection for treatment of a water distribution system is that disinfection may not eradicate *Legionella* fully and recolonisation may occur. This disinfection method is also labour intensive and numerous personnel are required to monitor water temperatures and flushing times. It can also prove ineffective for long-term *Legionella* infestation management (Zhang et al., 2009). Furthermore, the energy costs of maintaining a hospital hot water system above 60ºC are substantial and may not reliably prevent persistence at parts of the system where there is infrequent use and a lower temperature (Farr *et al*., 1998).

(See Appendix 1 on Case Studies for further information)

Continuous chlorination

2.12 Chlorination was the primary method of disinfection for drinking water from the early 1900s, however in the 1970s, it was discovered that chlorination caused a number of disinfection by-products that are known to be hazardous to human health (Moudgal *et al*. 2000). Also due to the risks inherent in the handling of chemicals to producing chlorine gas it is no longer as prominent in systems within UK healthcare facilities and has been replaced with Chlorine Dioxide.

Method

2.13 Chlorination is the process of adding chlorine to water as a means of water purification. This is accomplished by continuous injection through calcium hypochlorite, sodium hypochlorite, or gas chlorination. The effectiveness of chlorine as a disinfectant is determined by the chlorine concentration, contact time, the pH level, temperature, the concentration of organic matter, and the number and types of microorganisms in the water.

Advantages

2.14 Continuous chlorination provides a residual disinfectant concentration throughout the entire distribution system (Fass et al., 1998). Nearly 100 years of chlorination for the disinfection of drinking water has demonstrated the effectiveness of this process for the inactivation of microbial pathogens, with the notable exception of *Cryptosporidium* where very high concentrations of chlorine are required (Korich *et al*., 1990).

Disadvantages

2.15 There are several disadvantages to using chlorine as a disinfectant:

- it is highly corrosive and causes damage to pipework (Lin *et al*., 1998);
- needs monitoring due to the fact that once added and circulating freely within the water the chlorine combines with organic compounds and produces carcinogenic chloroform and carbon tetrachloride. It is the combination of chlorine and organic materials already in the water that produces cancer-causing by products. The more organic matter in the water, the greater is the accumulation of Trihalomethanes (THMs) (Waller *et al*., 1998). Also studies in Belgium have related development of malignant melanoma to consumption of chlorinated water (Douglass, 1994). The residual chlorine levels should be below 5 mg/litre as stated in the drinking water quality guideline (WHO Drinking Water Guidelines, 2004);
- Chlorine may only suppress *Legionella* and not kill it and rarely can *Legionella* be eradicated from a system using this method alone. Moreover, the inactivation of *Cryptosporidium* requires high chlorine dosages, thereby resulting in higher by-product concentrations and increased rates of corrosion. One of the main side effects to using chlorination as a disinfectant is that it reacts with natural organic matter to produce halogenated disinfection by-products i.e. THMs;
- Chlorine reacts with organic materials and creates carcinogenic by-products called (THMs), and numerous studies have linked the consumption of chlorinated water with cancer (Lin *et al*., 1998). This in turn has led to guidelines by international organisations such as the World Health Organisation to be revised to lower the THMs in drinking water;
- Chlorine has no detergent cleansing powers; therefore it is essential that slime and debris are removed by thoroughly cleansing before chlorine is used. However, chlorine should not be used with some other biocides, since they may neutralise each other unless they are known to be compatible. Such as ammonia which reacts with chlorine to form harmful THMs.

Chlorine Dioxide (ClO_2)

2.16 Chlorine dioxide must be manufactured on site because it decomposes readily and presents toxicity hazards when stored (Kim *et al*., 2002).

Method

2.17 The chemical is a gas that is generated mechanically or electrolytically from a sodium chlorite solution which is then introduced into the water distribution system.

Advantages

2.18 Chlorine dioxide is a very selective oxide, allowing lower dosages to be used to obtain the same results as chlorine or ozone (Gates, 1998). Radziminski et al. (2002) state that chlorine dioxide is superior to chlorine in the destruction of spores, bacteria, viruses, protozoan cysts, biofilm, and waterborne pathogens. There are also only minimal corrosion issues associated with using chlorine dioxide, and although biofilm in the pipework can protect *Legionella* from disinfection system such as heat and flush and chlorine, chlorine dioxide can remove biofilm and kill these bacteria, spores and viruses. ClO_2 is also an effective biocide over a wide pH range and is useful for removing iron and manganese to control taste and odour (Zhang *et al*., 2009). However taste problems can become an issue from chlorine dioxide at high dosage levels.

Disadvantages

2.19 There are some dangers to using this disinfectant in potable water, as chlorine dioxide and its by-products, (THMs), chlorate and chlorite ions, do have toxic properties and pose health risks to consumers (Zhang et al., 2009). Chlorine dioxide generally forms less THMs, haloacetic acids (HAAs), and total organic halogen (TOX) than free chlorine. However, chlorine dioxide forms more iodinated DBPs when iodide is present in the source water. The WHO's recommended guideline for chlorite in drinking water is less than 0.2 mg/litre, while the Secretary of State for the Environment's legal requirement is that the combined concentration of chlorine dioxide, chlorite and chlorate should not exceed 0.5 ppm.

(See Appendix 1 on Case Studies for further information).

UV light

2.20 Disinfection using UV light differs considerably from chemical disinfectants such as chlorine and ozone, which inactivate microorganisms by destroying or damaging cellular structures, interfering with metabolism, and hindering biosynthesis and growth (Snowball and Hornsey, 1988). UV on the other hand, inactivates microorganisms by damaging their nucleic acid, thereby preventing the microorganism from replicating.

Method

2.21 This disinfection method involves exposing contaminated water to radiation from UV light. The most efficient and widely used device for this purpose is the mercury arc lamp, as approximately 85% of its energy output is of the 253.7 nm wavelength, which is within the optimum germicidal range of 250–270 nm (Chen *et al*., 2006). This can be used at the entry to the domestic water system where all of the water is disinfected or can be used as a point of use system which Kim *et al*. (2000) suggest is the most effective use of this type of filtration system. The use of a point of use system may not be feasible in a healthcare setting as this would not be economical on a large scale system.

Advantages

2.22 UV light can inactivate pathogenic microorganisms without forming the by-products that other chemical treatments create, and it has proven effective against some pathogens, such as *Cryptosporidium*, that are resistant to commonly used disinfectants like chlorine (USEPA, 2003). In particular, several studies have confirmed the efficacy of UV light for disinfecting *Legionella* in laboratory water settings (Muraca *et al*., 1987).

2.23 Some other advantages of ultraviolet light include its easy installation, and its lack of adverse effects on water or plumbing systems. Studies suggest that the efficacy of UV light is only minimally affected by high water temperature (Severin *et al*., 1983; Malley, 2000). Studies also indicate that UV disinfection at doses of up to 200 mJ/cm^2 do not change the pH, turbidity, dissolved organic carbon level, UV transmittance (UVT), colour, nitrate, nitrite, bromide, iron, or manganese of the water being treated (Malley *et al*., 1995).

2.24 Lin *et al.* (1998) state that if UV light is used to disinfect an entire system, as it is only effective immediately after disinfection, and it should be combined with another systemic disinfection method such as hyperchlorination or thermal eradication. Filters are also required prior to UV filtration to remove particles from the water system (Kim *et al*., 2002). The recommended pre-filter for each UV model depends on the turbidity of the local water supply this filter size can range from 20-5 microns.

Disadvantages

2.25 The main disadvantage to this form of disinfection is its lack of residual protection. If used at the point of entry to a domestic water system, levels of contamination would have to be measured at outlets, as *Legionella* re-growth in the biofilm layers of scale and accumulated debris still allows for recolonisation. Maintenance of the water system is necessary and important to reduce this biofilm formation and *Legionella* recolonisation (Franzin *et al*., 2002).

2.26 As discussed above, another way UV treatment can be utilised is as a point of use system. Although this system seems to be effective, in the case of a large hospital it would be uneconomical as there are many points of use. Another possible drawback to using UV light as a disinfectant is that some of the microorganism cells damaged by the UV light can be repaired, either in the presence of light, termed ‘photoreactivation’, or through a ‘dark repair’ in the absence of light (Jagger, 1967). As a result, the strategy in UV disinfection has been to provide a sufficiently high dosage to ensure that nucleic acid is damaged beyond repair. UV disinfection costs will vary depending on size and difficulty of installation. The Water Research Foundation carried out a case study on a water treatment works in Arizona, and found that running costs were $0.004 per 1,000 gallons.
(http://www.waterresearchfoundation.org/research/TopicsandProjects/Resource

s/caseStudies/caseStudyFlagStaff.aspx. It is impossible to convert this into a UK equivalent figure, but this illustrates the relatively low cost of treatment by volume. Small scale systems are available from several manufacturers. One example of these is a 430 litres/minute system costing £4,499, with lower priced systems for lower water demand, going down to 40 litres/minute (http://www.eastmidlandswater.com/products2.asp?CategoryID=18&SubcategoryID=30).

The intensity of the lamps declines over time; therefore they need to be replaced in most units every 8,000 to 9,000 hours for optimum unit performance (Srikanth, 1995).

Copper-Silver Ionisation

2.27 Metals such as copper and silver ions are known as bactericidal agents. Most studies on the use of copper-silver ionisation as a disinfection method have suggested good efficacy for *Legionella* control in water systems (Liu *et al*., 1994). A laboratory study by Huang *et al*. (2008) of copper and silver ions in combination provided evidence to suggest that bactericidal efficiencies are greater than 99.99% against the most significant clinical waterborne microbes; *P. aeruginosa*, *Acinetobacter baumannii*, and *S. maltophilia*, including *Legionella*. Silvestry-Rodriguez et al. (2007) summarises the disinfectant properties of copper-silver ionisation for large building water distribution systems, stating that this method has an appreciable impact on levels of coliform bacteria, iron-related bacteria, sulphate-reducing bacteria and slime producing bacteria. This has led to the conclusion that copper–silver ionisation may have the potential to eradicate major waterborne pathogens in hospital distribution systems. However the eradication efficacy of ionisation under field conditions in UK institutional water systems and its significance in reducing hospital-acquired infections are still to be determined. Studies in the United States have shown copper-silver ionisation to be effective at controlling *Legionella* in hospitals (Lin *et al*., 1998; Stout *et al*., 1998).

Method

2.28 This disinfection method is brought about by electrolysis, positive copper and silver ions are created from electrodes made of copper and silver, these ions are then distributed throughout water systems to eradicate bacteria. Copper ions penetrate the cell wall and as a result they will create an entrance for silver ions. Silver ions bond to various parts of the cell, such as the DNA and RNA, causing all life support systems in the cell to be immobilized. The ions remain active until they are absorbed by a microorganism.

Advantages

2.29 Copper-silver ionisation systems have many advantages in that they are easily installed and maintained, and their efficacy is not affected by high water temperature, unlike chlorine and ultra-violet light (Lin Yu *et al*., 1998). Additionally, *Legionella* is killed through this disinfection method rather than suppressed, which minimises the possibility of recolonisation (Lin *et al*., 1996). This was demonstrated in Liu Z *et al*'s study in 1994 where recolonisation was delayed by six to twelve weeks, even after the ionisation was shut down in one hospital. This factor provides a safety margin if the system malfunctions, unlike chlorination through which *Legionella* can rapidly re-appear.

Disadvantages

2.30 Some of the disadvantages to copper-silver ionisation are that silver ions react easily with chlorines and nitrates that are present in the water, causing them to no longer be effective, therefore to ascertain the level of ionization required the levels of chlorines and nitrates present in the water must be established. This may cause a problem if the water has very high levels of chlorines and nitrates as a very high level of copper and silver ions would be required to disinfect the entire system properly. Furthermore, some microorganisms can become resilient to silver and it is suggested that *Legionella* could develop resistance to copper and silver ions (Mietzner *et al*., 2005). This form of disinfection is also expensive to install, and the electrodes must be cleaned regularly to reduce scale build up, and replaced annually to give optimal performance. High concentrations of silver in the water can also stain porcelain (Lin *et al*., 1998). The only obvious sign of silver overload to humans is Argyria, a condition in which skin and hair are heavily discoloured by silver in the tissues. The amount of silver required to develop Argyria is estimated (by the EPA) to be 3.8 grams per day.

2.31 The pH of water is an important factor in the efficacy of copper and silver (Lin *et al*., 2002), as elevated pH levels (>8.0) reduce the effectiveness of copper ions against *Legionella*. Although pH has little effect on silver ions, a higher pH can alter the positively charged copper ions to become negatively charged, and therefore less effective at eradicating *Legionella*. Sensors would have to be provided in order to maintain accurate concentrations throughout the system. In terms of these concentrations in water, the European Union does not dictate any standards concerning silver. However copper has a maximum value of 0.02mg/litre (EU Drinking water directive, 98/83/EC1998).The WHO also does not dictate any standards; they believe the available data is insufficient for recommending a concentration limit (WHO Guidelines for Drinking Water Quality, 2004). The United States however, dictates a maximum value of 1 mg/litre for copper and a maximum value of 0.1 mg/litre for silver (EPA National Secondary Drinking Water regulations, 2002). Industry leaders who manufacture copper silver ionisation technology recommend a copper concentration of 0.4 to 0.8 mg/litre and a silver concentration at 40 to 60 µg/litre, to be compliant with EPA drinking water standards (Shields, 2002).

2.32 The Health and Safety Executive issued an Approved Code of Practice and guidance on the control of *Legionella* bacteria (L8, 2000) in water systems, below is the statement made in clause 176 of the document:

"The application of ionisation will need to be properly assessed, designed and maintained as part of an overall water treatment program. The Water Supply (Water Quality) Regulations and Private Supply Regulations prescribe a maximum value for the level of copper and silver ions in drinking water supplies. It is important that installers of ionisation systems are aware of the need to avoid any breach of these Regulations and maintain copper and silver levels

below the maximum allowable concentration. The local water company may need to be consulted to check that the installation complies with the requirements of the Water Regulations. "

http://www.hse.gov.uk/pubns/priced/l8.pdf

2.33 The Scottish Government issued a formal document stating that silver is not to be used continuously as a disinfectant for a public water supply. Below is what the Drinking Water Quality Division - List of Approved Products, December 2007 states:

"Current approval for the use of products containing silver salts in relation to emergency disinfection of water intended for human consumption is subject to the following conditions of approval:

- the concentration of silver in the water does not exceed 80 µg/litre; and
- consumers are exposed to water containing silver for only as long as necessary to restore conventional treatment, and for no more than a total of 90 days in any period of a year.

These conditions ensure that there is only a limited exposure of the consumer to silver". http://www.scotland.gov.uk/Publications/2008/03/04152957/9

2.34 For a public water supply indicated by The Water Supply (Water Quality) (Scotland) Regulations (2001), the inclusion of silver is not contained in the document as no product has been approved for this application and would have to be assessed for this purpose.
http://www.opsi.gov.uk/legislation/scotland/ssi2001/20010207.htm

2.35 In contrast to this if a hospital has its own private water supply then, The Private Water Supplies (Scotland) Regulations (2006) should be adhered to, schedule 3 in these regulations state that:

"Silver may be used in some water treatment devices where it is used for disinfection purposes"

Table B part II states that a concentration of 10µg/litre is allowed and if used in a water treatment process, 10µg/litre may be substituted for 80µg/litre.

http://www.opsi.gov.uk/legislation/scotland/ssi2006/20060209.htm#4

2.36 The above Scottish regulations do not imply that silver is any safer to be used in a private supply than a public supply, only that silver is more likely to be used in a private water supply due to the smaller quantities involved, for public supplies the economics of using silver would not stand up against cheaper alternatives such as chlorine.

Note: It can be concluded that there is no clear decision to be made on the use of silver in domestic water systems, however the Opinion of Counsel have put forward ANY form of treatment to domestic water systems that causes a change to the condition supplied by the Water Authority leaves the User of that Treatment open to legal challenge. Due to this, the Counsel recommends that an independent assessment is carried out of all Risk Assessment and Method Statement documentation prior to treatment being initiated. This documentation should be supplied to Scottish Water and to the Drinking Water Inspectorate.

Silver Catalysed Hydrogen Peroxide

2.37 There is very little research within the UK on the use of silver catalysed hydrogen peroxide as it is a relatively new form of decontamination and at present is only implemented in a small number of water distribution systems within the UK (it is widely used in Europe). Available research suggests that combined Sliver and Hydrogen Peroxide has a moderate bactericidal effect on *E. coli* and only a mild virucidal effect (Pedahzur *et al*., 2000).

Method

2.38 A silver catalysed hydrogen peroxide solution is added to a water system by injecting it directly into the water.

Advantages

2.39 In some instances, the combined bactericidal effects of silver and hydrogen peroxide are 1,000-fold higher than the sum of them being introduced on their own. Another benefit to using this disinfectant is that the biocidal action of silver catalysed hydrogen peroxide generally increases with rising temperature and pH levels (Pedahzur *et al*., 2000). In addition, the slow and moderate bactericidal effect, and the prolonged stability and efficacy at relatively low concentrations, point to its use as a secondary long-acting residual disinfectant for good quality drinking waters (Pedahzur *et al*., 2000).

Disadvantages

2.40 One area of concern is the level of silver contained in the water. As discussed previously in this document under the copper-silver ionisation section. There are Scottish Government guidelines indicating levels of silver allowed in a water supply, which should be adhered to in this instance. As also stated in the previous section on Copper/Silver ionisation, the Private Water Regulation Act (2006) allows the use of silver for disinfection. However there is no mention of Hydrogen peroxide in this document. The Drinking Water Quality Division - List of Approved Products, December 2007 states in relation to Hydrogen peroxide:

"Hydrogen peroxide containing silver or its compounds should not be used continuously as a disinfectant for public water supply".

http://www.scotland.gov.uk/Publications/2004/02/18931/33327

Levels of silver must also adhere to the documents produced by Scottish water as stated in the previous section on copper-silver ionisation.

Ozone

2.41 Ozone is a similar disinfectant to UV light as it decomposes quickly in potable water and is therefore normally used as a secondary disinfectant at point of use. Ozone is an unstable compound and because of its instability, it cannot produce a persistent disinfectant residual in distribution systems (Singer, 1994).

Method

2.42 Ozone disinfects water by damaging the DNA of microorganisms (Kim et al., 2002). Ozone in aqueous solutions may react with microbes either by a direct reaction with molecular ozone or by an indirect reaction with the radical species formed when ozone decomposes.

Advantages

2.43 Ozone is one of the strongest and fastest acting disinfectants, and its high efficiency may have significant advantages in water treatment processes (Wojtenko, 2001). The bactericidal activity of ozone is much less prone to variation in pH and ammonia content than chlorine, and is more effective at low temperatures (Ingrams & Barnes, 1954), however ozone does react with ferrous and manganous salts to produce a scum that must be filtered off. The use of ozone in the removal of colour and odour has been well documented, and this use may be combined with the disinfection process (O'Donovan, 1965).

Disadvantages

2.44 One of the main disadvantages to using ozone as a disinfectant is that it has been shown that mutagenic and possibly carcinogenic by products may be produced under certain conditions of ozonation (Charmichael et al., 1982). Ozone is not a widely used disinfectant mainly due to its cost, and many hospitals choose to use chlorine, chloramines and chlorine dioxide which are cheaper to set up and run. Kim *et al*. (2002) state that one of the main reasons ozone on its own is not suitable as a disinfectant is that it has a very short life and carries no residual disinfectant into the water mains. This confirms previous reports in which ozone alone was found to be inefficient for controlling *Legionella* in water systems (Blanc *et al*., 2005). Charmichael *et al*. (1982) state that a more effective disinfection method would be to disinfect water by ozonation and then add small amounts of another disinfectant to give a residual effect in the piped supply. Chlorine would form (THMs) when combined with ozone which also carry risks; these are discussed in the section on Continuous Chlorination.

Chloramines

2.45 There has been an increasing interest in using chloramines as a secondary disinfectant to maintain a residual disinfectant effect throughout the distribution system (Seidel *et al*., 2005). Chloramines provide a similar protection to

Chlorine and, although they have weaker bactericidal properties, they are more persistent in the water supply, lasting from 10 – 14 days.

Method

2.46 Adding ammonia to water containing free chlorine, hypochlorous acid (HOCl) and hypochlorite ions (OCl-), can, depending on the pH, produce chloramines. The ideal pH value for this reaction is 8.4, at which point the water is slightly alkaline.

Advantages

2.47 There are advantages to using this form of disinfectant. Primarily, chloramine technology is easily installed and maintained and it is among the less expensive disinfectant alternatives to chlorine that has a residual effect (USEPA, 2007). Chloramine is also not as reactive as chlorine, and forms fewer disinfection by-products, which, as discussed previously (Continuous Chlorination), may be harmful to humans (Hua, 2007). However, it should be noted that chloramines form more iodinated DBPs when iodide is present in the source water (Hua, 2007). In addition, as chloramine is more stable and longer lasting than chlorine, and provides better protection against bacterial re-growth. Chloramine is also effective in controlling biofilm, as shown by a study conducted by LeChevallier (1988) in which chloramines were more effective at inactivating biofilm organisms than free chlorine.

Disadvantages

2.48 There are some drawbacks to using chloramines, mainly because it can lead to the production of excess ammonia present in the water and leads to taste and odour problems. This can however be prevented by maintaining a pH level above seven which must be tested for prior to implementation for this disinfection system to be deemed suitable, and keeping the chlorine to ammonia ratio at 5:1 (USEPA Water Disinfection, 2007) these levels must be continually observed and the dose rate must be constantly adapted to maintain the specified ratio. Additionally, there are some potential problems with chloramines in relation to the corrosion of copper pipes and elastomer gaskets (USEPA Water Disinfection, 2007). Estates staff have also found that in the UK and the rest of Europe, this disinfection system is only available on large scale installations and at present it is not accessible to most NHSScotland healthcare settings.

3. Disinfecting agents: Pros and cons

Chlorine

H&S: Chlorine gas - Very dangerous

Hypochlorite liquid, etc - Dangerous/Moderate

Chlorine release tablets - OK

Cost: Low

Advantages: Well-established technology.

Readily available as gas, liquid or powder.

Inexpensive.

Relatively simple and flexible dosing control.

Well-known taste, if present.

Can eliminate certain noxious odours during disinfection.

Liquid chemical can be prepared off or on site.

Available as tablets for ease of handling.

Can be generated from salt and electricity.

More cost-effective than either UV or ozone disinfection.

The residual that remains in the water can prolong disinfection even after initial treatment and can be measured to evaluate the effectiveness.

Reliable and effective against a wide spectrum of pathogenic organisms.

Effective in oxidising certain organic and inorganic compounds.

Toxic to most microorganisms.

Disadvantages: May dissipate quite rapidly (12 to 24h), especially in distribution due to reacting with organic matter and other oxidizable contaminants. For this reason it may not reach the end of the water system, even if high doses applied.

Dosing equipment requires regular maintenance.

Can create taste and odour problems in poor quality water.

Can create carcinogenic compounds Trihalomethanes (THMs) in poor quality water. When considering the water from the utility provider, although it is of a potable standard there is still organic matter in the water that reacts with Chlorine to create THMs.

Simple neutralisation may be required before discharge to the environment. Any chemical discharge to a drain needs to be sanctioned by the Water Authority, who may then impose conditions on the discharge.

Long-term effects of discharging dechlorinated compounds into the environment are unknown.

Does not penetrate into centre of established biofilms.

All forms of chlorine are highly corrosive and toxic. Thus, storage, shipping, and handling pose a risk, requiring increased safety regulations.

Some parasitic species have shown resistance to low doses of chlorine, including oocysts of *Cryptosporidium parvum*, cysts, of *Endamoeba histolytica* and *Giardia lamblia*, and eggs of parasitic worms.

Potentially dangerous in case of a leak of chlorine gas.

System corrosion causes pipe leaks.

Workers must have access to a wash down hose, chemical eyewash, and shower. Operators must also wear the proper safety equipment, including carrying an Acid Gas escape respirator.

Must be removed from water prior to dialysis.

Chloramine (monochloramine)

H&S: Chlorine: Gas - Very dangerous

Liquid - Dangerous/Moderate

Tablets - OK

Ammonia: Gas - Very dangerous

Solutions - OK

Cost: Low

Advantages: Less potent disinfectant, but more persistent (residual can last 10 to 14 days).

Less prone to creating taste or odour problems, if correctly applied.

Low residuals can be effective.

Will generally not create carcinogenic compounds (THMs).

Some effect on biofilms.

Chloramines may provide a less obnoxious taste and smell than chlorine.

Few disinfection by-products are formed.

Chloramines remain active for a long time, longer than chlorine.

Disadvantages: Weak disinfectant and oxidation agent compared to chlorine. Ineffective against viruses and cysts (*Giardia, Cryptosporidium*).

High dosage and prolonged contact time required in comparison to the other disinfectants. Must be removed from water prior to dialysis.

Requires careful, precise mixing and dosing regime. Can create bad tastes, due to creation of dichloramine or trichloramine, if dosing is inaccurate or if pH unsuitable.

Has to be mixed and dosed on site. Not available as package plant. Dosing equipment requires regular maintenance. More difficult to remove from water than chlorine or chlorine dioxide, needs to be removed using active carbon. May not penetrate into biofilm. Can cause corrosion to copper. Workers must have access to a wash down hose, chemical

eyewash, and shower. Operators must also wear the proper safety equipment, including carrying an Acid Gas escape respirator.

Must not be used in water systems supplying dialysis machines.

Chlorine Dioxide

H&S: Dangerous - When chlorine dioxide concentrations reach 10% or more in air, chlorine dioxide becomes explosive.

Cost: Moderate

Advantages: Chlorine dioxide is more effective than chlorine and chloramines for inactivation of viruses, *Cryptosporidium* and *Giardia*.

Required contact time and concentration is low.

Generally good at controlling bad tastes and odours.

Available as package plant.

More effective at a high pH level.

Will remove biofilm, over a period of time.

Oxidizes iron, manganese, and sulphides.

May enhance the clarification process.

Is easy to generate. Provides residuals.

No formation of bromides from bromates.

At the concentrations required for disinfection, chlorine dioxide is not corrosive.

Must not be used in water systems supplying dialysis machines.

Disadvantages: Unstable, generally must be dosed immediately after manufacture - has to be made on site.

Requires careful, precise mixing and dosing regime, low pH needed.

May cause precipitation of iron and manganese.

Dosing equipment requires regular maintenance.

Can lead to production of noxious odours in some systems, may need to be neutralised before discharge to the environment. Any chemical discharge to a drain needs to be sanctioned by the Water Authority, who may then impose conditions on the discharge.

The chlorine dioxide process forms the specific by-products chlorite and chlorate.

Costs associated with training, sampling, and laboratory testing for chlorite and chlorate are high.

Cost of the sodium chlorite is high.

Chlorine dioxide decomposes in sunlight.

Workers must have access to a wash down hose, chemical eyewash, and shower. Operators must also wear the proper safety equipment, including carrying an Acid Gas escape respirator.

Chlorine dioxide is generally effective for the deactivation of pathogenic microorganisms. It is less effective for the deactivation of rotaviruses and E. coli bacteria.

5 to 10 times more expensive that chlorine.

Can form THMs at lower levels than chlorine, forms more iodinated DBPs in relation to the other disinfection methods when iodide is present in the source water.

Ozone

H&S: Dangerous

Cost: High

Advantages:

Rapid and strong disinfectant and oxidation agent.

Been used for several decades for disinfection, colour elimination, taste and odour control.

Does not form Trihalomethanes (THMs).

Very effective against Giardia, Cryptosporidium and any other pathogenic microflora.

Facilitates removal of turbidity from water.

Can improve the palatability of the water.

Package plants are available.

Disadvantages:

Disinfects only at the point of injection.

Specialised equipment required to generate ozone.

Decomposes quickly.

Hard to hold effective concentration.

Ground level ozone is an air pollutant with harmful effects on lung function.

Bromite mutagenic and carcinogenic by-products may be produced under certain conditions.

Must use biologically active filters to remove by products.

No residual disinfection.

Expensive for initial equipment.

May cause precipitation of iron.

Plant and equipment require regular maintenance.

When reacting with organic compounds, ozone disintegrates them into smaller components, which could become a feeding media for microorganisms growth in water distribution systems.

Requires high voltage equipment.

Training and installation support required.

Silver Catalysed Hydrogen Peroxide

H&S: Dangerous

Cost: Moderate

Advantages: Hydrogen peroxide is catalysed with silver for increased activity.

Rapid and effective disinfectant.

Will remove biofilm.

Works in all temperatures.

Silver has curative properties against disease.

Disinfects drinking water for long periods of time.

Will not corrode pipes.

Easy to install and maintain.

Disadvantages: Residual Silver may need to be neutralised before discharge to the environment. Any chemical discharge to a drain needs to be sanctioned by the Water Authority, who may then impose conditions on the discharge. Expensive chemicals but overall system is cost effective. Not approved for continuous dosing, except in emergencies. See http://www.scotland.gov.uk/Publications/2008/03/04152957/9

Maintenance of plant is simple and straightforward but there is a need to maintain close control over the sensor used to monitor dosage rates.

Requires the inclusion of a filter on the inlet to the sensor and regular inspection of it to ensure a clean sensor electrode.

Biocidal efficacy of silver may be compromised by high concentrations of chloride.

High pH may affect efficacy.

Not equally effective for all pathogens.

Must not be used in water systems supplying dialysis machines.

Silver/copper ionisation

H&S: Can be dangerous to dialysis patients

Cost: Low

Advantages: Works in all temperatures. High doses will remove biofilm. Silver has curative properties against disease. Disinfects drinking water for long periods of time. Will not corrode pipes. Easy to install and maintain.

Disadvantages: Monitoring the silver levels is difficult and expensive. Can stain porcelain. May need to be neutralised before discharge to the environment. Any chemical discharge to a drain needs to be sanctioned by the Water Authority, who may then impose conditions on the discharge.

High pH may affect efficacy.

Biocidal efficacy of silver may be compromised by high concentrations of chloride. Level of silver required for effectiveness is eight times greater than for silver catalysed hydrogen peroxide. Not equally effective for all pathogens. Must not be used in water systems supplying dialysis machines.

Ultra Violet

H&S: UV radiation is not suitable for water with high levels of suspended solids, turbidity, colour, or soluble organic matter. UV light can cause serious damage to the retina if viewed directly through the viewing port.

Cost: High

Advantages: Requires no chemical handling. Effective in clean, low turbidity waters. No special requirements for storage and transportation. No formation of by-products. Not effected by pH or temperature.

Disadvantages: Only works at point of entry. Leaves no residual disinfectant in the water. Can be ineffective in turbid waters. Expensive in equipment and maintenance. Actually, the UV generator is quite inexpensive, relatively speaking. The cost increases, though, when serious filtration is needed to allow the process to work.

Power supply deviations effect wavelength. Requires pre filtration. May require frequent cleaning of tubes and chamber. Water velocity is critical so may require special chamber to provide appropriate dwell time. Poor penetrating power of UV light in established biofilms. Turbidity makes it difficult for radiation to penetrate water. These materials can react with UV radiation, and reduce disinfection performance.

Appendix 1

Case Studies

Heat and Flush

Colville *et al* (1993) stated that following a heat and flush treatment at Nottingham University Hospital, new cases of hospital-acquired Legionnaires' disease were reported. Chen *et al*., (2005) also reported recolonisation in a Taiwanese hospital where heat and flush was used for the treatment of Legionella. It should be noted that when adhering to the recommendations of two authoritative bodies, namely the Centers for Disease Control and Prevention (CDC) and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), the heat and flush method was shown to be ineffective in eradicating *Legionella* from this hospital's water system. The paper puts forward that this failure may have been due to the flush time, which is recommended by ASHRAE to be greater than five minutes. The author suggests that a flush time of thirty minutes would have been required to eliminate Legionella in this system. Zhang *et al*. (2009) maintains that the heat and flush method is labour intensive and numerous personnel are required to monitor water temperatures and flushing times and can prove ineffective for long-term Legionella infestation management.

Chlorine Dioxide

Pavey and Roper (1997) have published results indicating that chlorine dioxide concentrations of 0.1 ppm to 0.2 ppm were shown to be effective in decontaminating a cold water system, whilst higher concentrations up to 0.35 ppm were needed for the hot water system.

Other studies have shown that temperature and high levels of total organic carbon in drinking water would cause deterioration of the chlorine dioxide levels in the water, therefore affecting the efficiency to control contaminants (Zhang *et al*., 2008). Maintaining a sufficient residual level of chlorine dioxide in the hot water system is a difficult task as an elevated water temperature accelerates the conversion of chlorine dioxide to chlorite, through reactions with organic compounds in the water distribution system. This finding is consistent with Zhang et *al*'s. (2007) study observation where the mean chlorite concentration in hot water was higher than that in cold water. Additionally, results from Pavey and Roper's (1997) study showed that more chlorine dioxide was used in the soft water than hard water systems to achieve the same concentration.

Zhang *et al*'s. (2007) study also showed that chlorine dioxide did not completely eliminate Legionella organisms from a hospital's hot and cold water system, given a target feed concentration of 0.5-0.7 mg/litre in the cold water.

UV

Abbaszadegan *et al*. (1997) completed an experiment to evaluate the microbial disinfection efficacy of a point-of-use water treatment system comprised of a pressed activated carbon block filter followed by an ultraviolet (UV) light reactor. This method of filtration was found to effectively remove and/or inactivate more than 99.9999% of the bacterial pathogens, more than 99.99% of the viruses and more than 99.9% of the protozoan cysts and oocysts, tested to 150% of the water treatment capacity of the point of use water treatment system. These findings suggest that a properly designed and operated point of use water treatment may be adopted as an approach to removing microbiological waterborne pathogens from potable water (Abbaszadegan *et al*., 1997). This system would probably not be considered on a large scale as it has a high capital and revenue costs compared to other disinfectant methods as many disinfection points would be required as UV has no residual effect. Also there may be problems in retro fitting a UV system if there is limited space.

Appendix 2

Traditional forms of water treatment for the disinfection of potable water systems in healthcare premises

Biocide comparison chart

Parameters	Heat and flush	Continuous chlorination	Chlorine dioxide	Ultra violet light (U.V.)	Copper – silver ionisation	Silver catalysed hydrogen peroxide	Ozone	Chloramines
Concentration required at outlets during continuous use	Continuously above 55°C	2-4 mg/l as free chlorine (Zhang, 2007)	0.5 mg/l as CL02 (Zhang, 2007)	300 nm (Chen *et al*., 2006)	Cu=0.2-0.4 mg/l	H202=15 mg/l	0.1 to 5.0 mg/l over a contact time ranging from 5 minutes to 15 minutes	WHO maximum allowable concentration is 3.0 mg/l based on the NOAEL level
	70-80°C for 30 min (Zacheus and Martikainen, 1996)				Ag=0.02-0.04 mg/l (Kim *et al*., 2002)	Ag=0.008 mg/l (Pedahzur *et al*., 2000)	(Kim *et al*., 2002)	1.0 mg/l for design purposes (Kim, 2002)
On-site efficacy documented in literature	Yes (Zacheus and Martikainen, 1996)	Yes (Korich et al., 1990)	Yes (Gates, 1998)	Yes (Maraca *et al*., 1987)	Yes (Blanc, 2005)	Yes (Kim *et al*., 2002)	Yes (Kim *et al*., 2002)	Yes (Kim *et al*., 2002)
Residual effect	No	Yes (WHO, 2004)	Yes (Thomas, 2004)	No (Chen et al., 2006)	Yes (Blanc, 2005)	Yes (Kim et al., 2002)	No (Kim et al., 2002)	Yes (Kim et al., 2002)
Time to re-colonisation after treatment stopped	Varies but usually a few months (Zacheus and Martikainen, 1996)	1-2 Weeks (Fiehn & Henriksen, 1988)	Some residual protection until biofilm is re-established (Gates, 1998)	Only works at point of entry (Maraca *et al*., 1987)	6-12 weeks (Liu *et al*., 2004)	Long lasting residual effect in water (Pedahzur *et al*., 2000)	No residual disinfectant (Kim *et al*., 2002)	A few days, far less effective than chlorine (Kim et al., 2002)
Temperature	N/A	Residuals decrease as temperature increases (Kim *et al*., 2002)	Residuals decrease as temperature increases. Bacterial kill rate increases with increase in water temperature (Kim *et al*., 2002)	Temperature effects are minimal (Mally, 2000)	Residuals unaffected by high temperature (Lin *et al*., 1996)	No reported degradation at up to 90 degrees, centigrade. Poor disinfectant below 10 degrees (Pedahzur *et al*., 2000)	Unaffected by temperature (Kim *et al*., 2002)	Unaffected by temperature (Hua, 2007)
PH	No effect (Neurener, 2002)	PH>8 Disinfection power is reduced (Neurener, 2002)	Effective over normal range of PH values for drinking water below pH of 10 (Kim *et al*., 2002)	No effect (Mally, 1995)	Elevated pH (>8) may effect efficacy (Blanc, 2005)	Biocidal action generally increased with increased pH (Pedahzur *et al*., 2000)	No effect (Kim *et al*., 2002)	Quantities of ammonia and chlorine depend on the acidity of the water (USEPA, 2007)
Disinfection by-product	None (Neurener, 2002)	Trihalomethane (THMs) (Hua, 2007)	Can form (THMs) lower levels than chlorine. Forms more iodinated DBPs when iodide is present in the source water (Hua, 2007)	Ozone (Jeong, 2005)	None known but residual levels of Cu and Ag (Neurener, 2002)	Residual levels of Ag. Primary compound breaks down into water and oxygen (Pedahzur *et al*., 2000)	Bromite mutagenic and carcinogenic by-products may be produced under certain conditions (Charmichel *et al*., 1982)	Can form (THMs) lower levels than chlorine. Forms more iodinated DBPs when iodide is present in the source water (Hua, 2007)

Parameters	Heat and flush	Continuous chlorination	Chlorine dioxide	Ultra violet light (U.V.)	Copper – silver ionisation	Silver catalysed hydrogen peroxide	Ozone	Chloramines
Taste and odours at nmo	No (Neurener, 2002)	Yes taste and odour problems (Kim *et al*., 2002)	Minimal at high concentrations, Neutralises odours (Kim *et al*., 2002)	Only if High intensity, ozone lamps are used (Froese *et al*,m 1999)	None (Lin *et al*,m 1998)	None (Pedahzur *et al*., 2000)	Could allow formation of odorous, aldehydes (Frose *et al*., 1999)	Depends on acidity of the water or ratio of ammonia (USEPA, 2007)
Pipe corrosion	Old pipes may be affected (Neurener, 2002)	Highly corrosive (Lin *et al*., 1998)	Minimal potential of corrosion problems (Sinnivasan *et al*., 2003)	Potential corrosion problems if high intensity ozone lamps are used (USEPA, 2007)	Copper concentrations above 1 mg/l can corrode iron and steel (HTM 04-01)	None observed at normal concentrations (O'Donnell, 2007)	Corrosive for specific materials and in certain circumstances. Particularly attacks rubber products and causes degradation of metals (USEPA, 2007)	Corrosive for specific materials and in certain circumstances. Particularly attacks rubber and Elastomeric products (USEPA. 2007)
Maintenance issues		COSHH applies	COSHH applies		COSHH applies	COSHH applies	COSHH applies	
	Scalding possible	Concentration control and monitoring	Concentration control and monitoring (Neurener, 2002)	Must be proceeded by filtration, which required replacement.	Routine ion monitoring	Routine monitoring of Ag content	System required to be filtered to remove metallic components precipitated out	Routine monitoring of chlorine and ammonia levels
			Chlorine dioxide must be handled with great care, requires trained workers for operation and maintenance					
	Labour intensive (Neurener, 2002)	Corrosion control (Lin *et al*., 1998)	Corrosion control (USEPA, 2007)	Routine cleaning (USEPA, 2007)	Routine inspection of electrodes (Neurener, 2002)	Routine inspection of electrodes (Kim, 2002)	(Odonovan, 1965)	(USEPA, 2007)
Maintenance issues	Does not penetrate biofilm (Chen *et al*., 2005)	Does not penetrate biofilm (Kim *et al*., 2002)	Presents toxicity hazards when stored (Kim *et al*., 2002)	Can only be effective at point of entry (Mally *et al*., 2002)	Electrodes must be replaced annually (Kim *et al*., 2002)	Can be lethal to dialysis patients if the hydrogen peroxide is not filtered out properly (SAN, HAZ(SC) 08/07)	None identified (Kim *et al*., 2002)	Chloramines can remain in the water for a long period of time posing problems for dialysis patients (USEPA, 2007)
Efficacy issues	*Legionella* bacteria only lie dormant below 20°C and are killed above 60°C	Loses efficacy at elevated pH. Decays at elevated temperature and over distance (SHTM 2040 Part 5)	Decays at elevated temperature and over distance	Particle filtration required	Can be lethal to dialysis patients if the silver is not filtered out properly (SAN, HAZ(SC) 08/07)			Filtration to remove chloramine is expensive and complex (USEPA, 2007)
	Time dependent (Chen *et al*., 2005)		Efficacy reduces with an increase in the organic content of the water	Does not work with shadows (Abbaszadegan, 1997)				
			Decays when in contact with corrosion products deposited in iron and copper pipe work (USEPA, 2007)					

Parameters	Heat and flush	Continuous chlorination	Chlorine dioxide	Ultra violet light (U.V.)	Copper – silver ionisation	Silver catalysed hydrogen peroxide	Ozone	Chloramines
Other issues		Concerns raised about long-term health implications from by-products (Frose 1989)	Concerns raised about long-term health implications from by-products (Vischetti 2004)	Concerns raised about chemical degradation arising out of some UV treatments (Corin *et al.*, 1996)	Argyria possible from prolonged exposure to very high silver levels (typically 100 times the recommended dosing concentration) (Butkus 2005)	Argyria possible from prolonged exposure to very high silver levels (typically 1000 times the recommended dosing concentration) (Butkus 2005)	Suitable fro use in dialysis units but decomposition products include small quantities of hydrogen peroxide, which produces an adverse affect on renal patients (AAMI/ANSI 1992)	At high dosage rates (500mg/l), will degrade RO membranes (USEPA 2007)
		Adverse affect on neonates (Magnus 1999)	Adverse affect on neonates (Tuthill *et al.*, 1982)	UV can form Nitrite (Sharpless *et al.*, 2003)	Recommended silver concentration may lead to discolouration of sanitary ware, porcelain, etc. (lin et al., 1998)	Adverse affect on renal dialysis systems. Maximum allowable silver concentration of 0.005 mg/l (AAMI/ANSI 1992)	Low concentrations of ozone may produce mutagenicity in the water (0.5 to 1.5 mg/l) (Bourbigot *et al.*, 1986)	Can cause nitrite levels in the water to rise, which may be harmful to children under 5 (Pintar & Slawson 2003)
			Adverse affect on renal dialysis systems (Zhang 1999)		For dialysis systems, maximum allowable concentration are copper at 0.1 mg/l and silver at 0.005 mg/l (AAMI/ANSI 1992)	Some microorganisms can become resilient to silver (Lin *et al.*, 1998)		Monochloramine vapours released into the atmosphere may give rise to asthma attacks in susceptible individuals (Emanuel 1998)
			Adverse affect on renal water treatment plants (Zhang 1999)		Some microorganisms can become resilient to silver (Lin *et al.*, 1998)			Must be filtered before dialysis (USEPA 2007)

Appendix 3

Risk register

Ref No	Description of risk	Date and person raised	Issue owner	Resolution date	Impact	Probability	Rusk status based on 5*5 matrix	Comment: Progress: Resolution:
1	Risk of implementing a water management strategy that does not meet users requirements		Group		Major	10%	Low	The group are experienced and proficient in water systems. Outside consultation is also an option.
2	Financial risk		HFS		Low	10%	Low	The financial implications are currently low. This may increase if outside consultations sought
3	Resource risk		HFS		Low	10%	Low	Discussions are ongoing with regard to increasing the size of the group
4	The project becomes a data collection exercise and is not an effective management tool		Group		High	10%	Low	
5	Risk that the quality of data is not sufficient to enable a proper assessment of disinfection of water systems		HFS		High	10%	Low	A great deal of data has already been gathered and vetted
6	Non co-operation from Water Management companies with regard to access to test results		Group		Medium	30%	Medium	
7	Lack of specialist advice i.e. Medical/Microbiology		HFS		High	10%	Low	Advice is available at individual Board level

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