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 F: Chloramination of water supplies

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

Scottish Engineering 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.

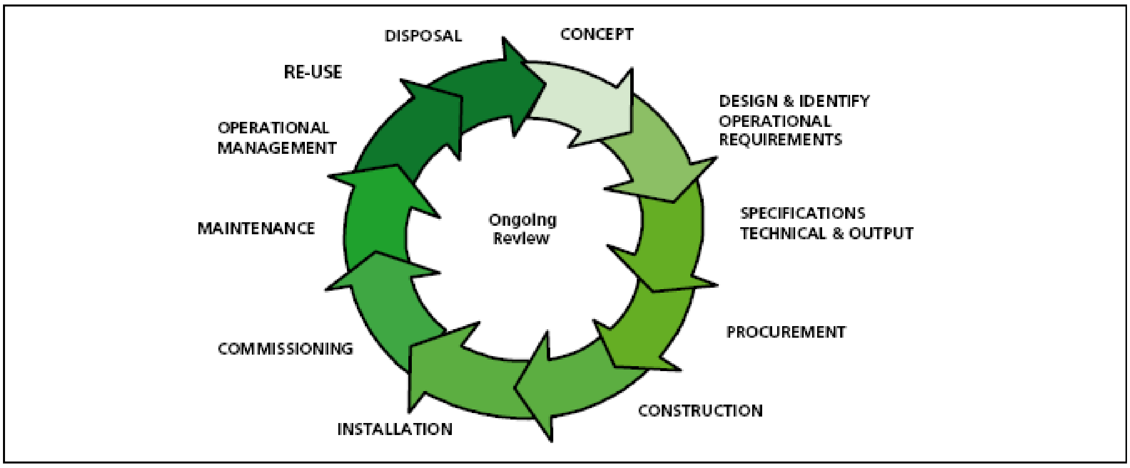
The focus of SHTM guidance remains on healthcare-specific elements of standards, policies and up-to-date established best practice. They are applicable to new and existing sites, and are for use at various stages during the whole building lifecycle. Healthcare providers have a duty of care to ensure that appropriate engineering governance arrangements are in place and are managed effectively. The Scottish Engineering 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 pending a re-assessment of Firecode SHTMs 81-86.

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.

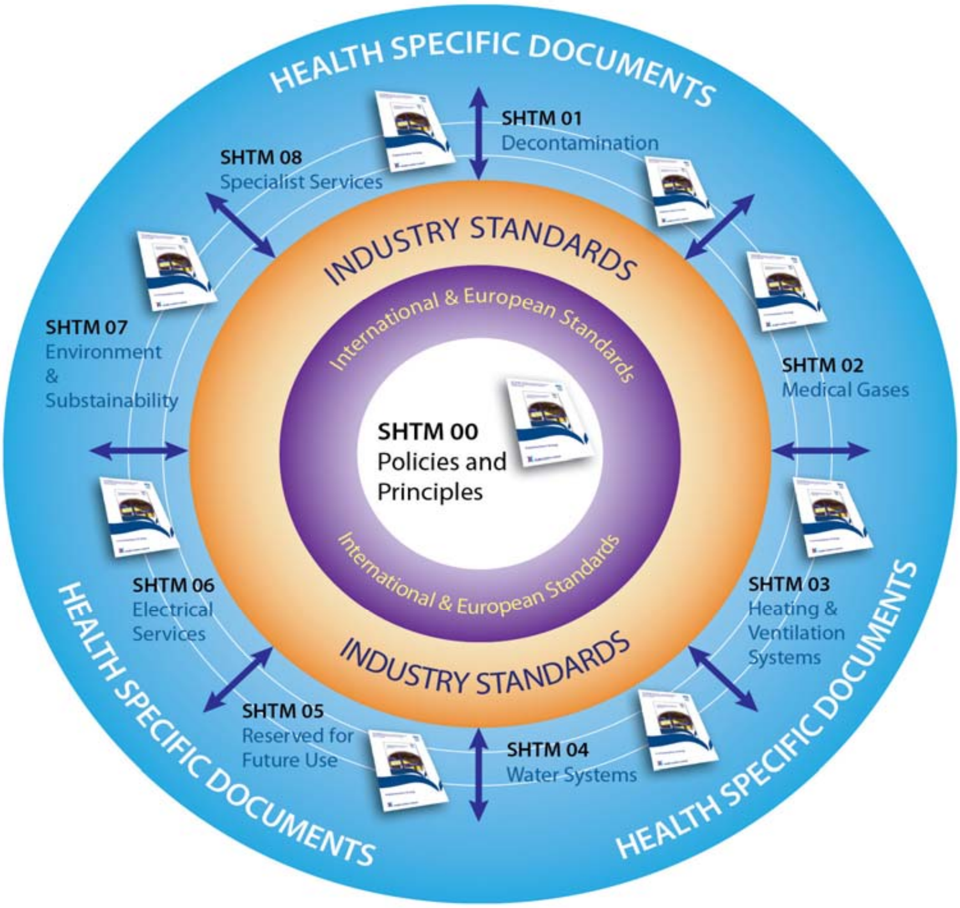
Example: Scottish Health Technical Memorandum 06-02 Part A will represent Electrical Services - Electrical safety guidance for low voltage systems.

In a similar way Scottish Health Technical Memorandum 07-02 will simply represent Environment and Sustainability – EnCO$_2$de.

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

Executive summary

Background information

Chloramine is increasingly replacing chlorine as the secondary disinfectant in water treatment systems primarily because it produces fewer dangerous disinfection by-products. Chloraminated water is already being introduced within some regions of Scotland and it is envisaged that most NHS Boards in Scotland will soon confront a change in their water supply disinfection regime.

This guidance provides information on the likely impact of the change backed up by relevant case studies.

1. Methodology

Aim of this SHTM

1.1 The aim of this SHTM is to assess the impact chloramination may have on patient safety and infrastructure within healthcare facilities provided by NHSScotland.

Factors examined

1.2 Following an outline of the relevant background detail, numerous factors have been examined including:

- those which will directly affect patients;
- those which may impinge upon the general populace;
- those which could concern estates staff.

Case studies undertaken

1.3 A series of case studies has been used to examine which lessons can be learned from water utilities which converted to chloramine disinfectant. The information contained within this SHTM was sourced from published technical papers and reports authorised by regulatory bodies in addition to material available online. The SHTM concludes with a series of observations and recommendations which have arisen from an appraisal of the relevant data and review of the literature.

Review questions

1.4 This SHTM seeks to verify if the introduction of chloramine into the common water supply enables a different maintenance regime to be developed in healthcare facilities without impacting on patient safety. Answers have been sourced to the following questions:

- what is chloramine?
- what is chloramination as it relates to water disinfection?
- what are the benefits and risks of using chloramine for water disinfection within a healthcare environment when compared with chlorine?
- are there any negative impacts that could occur when converting from chlorine to chloramine water disinfection and, if so, how can these be minimised?
- what has been the experience of other healthcare organisations which have changed to chloramine for their water disinfection needs? What can be learned from these past experiences?

Abbreviations

1.5 The following abbreviations have been used throughout this SHTM:

AWWARF	American Water Works Association Research Foundation
DBP	disinfectant by-product
HAA	haloacetic acids
HPC	heterotrophic
MWUA	Maine Water Utilities Association
NDMA	N-nitrosodimethylamine
NWSAG	National Water Services Advisory Group
PEFEx	Property & Advisory Forum Executive (Predecessor of Health Facilities Scotland)
SEDWQU	Scottish Executive Drinking Water Quality Unit
SFPUC	San Francisco Public Utilities Commission
THM	trihalomethane
USEPA	United States Environmental Protection Agency
UWRAA	Urban Water Research Association of Australia

2. Introduction

General

2.1 Reference is made in this SHTM to lead and copper pipework. It is believed that all lead pipework has been removed from NHS premises in Scotland and copper pipework is no longer routinely specified. Lead service pipes were phased out in the 1960s and proscribed in 1969, with lead-soldered joints being prohibited in 1987. Many existing installations still use copper pipework whereas some fittings may use alloys containing lead, therefore issues raised in case studies are still relevant.

2.2 Chloramination, whilst reducing the levels of *Legionella* in the water, may give rise to increased levels of other contaminants. Therefore, NHS Boards that are supplied with chloraminated water should be aware of the potential for incoming water to have increased levels of other contaminants; the types of contaminants likely to arise from this process are discussed within this document.

2.3 However, it should be noted that when water is supplied to Dialysis Units, Hydrotherapy Units and Manufacturing Pharmacies additional action should be taken at point of use. Further details on how to manage these areas are described in Parts A & B of this SHTM.

Secondary disinfection

2.4 The final step in water purification schemes within most developed countries involves the addition of disinfectant intended to persist within the distribution system. Known as ‘secondary disinfection’, this practice is intended to maintain water quality by inactivating pathogens or bacteria that may have entered the distribution network and is usually distinguished from a ‘primary disinfection’ stage which targets source water.

2.5 For many years chlorine was the most widely used secondary disinfectant, although other substances were viewed as suitable (and in some cases preferable) alternatives. In one such instance, water authorities in Australia concerned with controlling the prevalence of the pathogenic amoeba *Naegleria fowleri* realised that chloramine was much more effective as a counter-measure (Urban Water Research Association of Australia [UWRAA], 1990).

2.6 However, the discovery that natural organic matter in water could react with chlorine to produce hazardous compounds known as disinfection by-products (DBPs), prominent among which were trihalomethanes (THMs) and haloacetic acids (HAAs), constituted the principal motivation for the use of chloramine.

2.7 During the 1970s and 1980s concern grew in the United States that exposure to THMs at high concentrations might increase the risk of some cancers. As a result, the United States Environmental Protection Agency (USEPA) began regulating THMs and developed the Stage 1 Disinfectants and Disinfection By-Products Rule, lowering the permissible total THM concentration to 80 µg/litre in

December 2001, with HAAs limited to 60 µg/litre (San Francisco Public Utilities Commission [SFPUC], 2004; Edwards *et al*., 2005).

2.8 It was known that using chloramine as an alternative to chlorine reduced the formation of these potentially carcinogenic THMs, ostensibly making the water safer for human consumption. Although chloramine had been used for disinfection in a small number of facilities within the US since the early 1900s, its popularity in recent years has soared, principally because it is a low-cost means of complying with the USEPA regulations (Edwards *et al*., 2005); 30% of water utilities in the US already used chloramine as a secondary disinfectant by 2004 (Flannery *et al*., 2006).

2.9 Notwithstanding Spain and Sweden's long established use of chloramine, European nations were generally slower to respond to the DBP issue (Lenntech, 2009). However, the number of water treatment plants in the EU using chloramine is expected to increase as utility companies seek to comply with more stringent regulatory requirements.

2.10 Scotland is bound to the EU Drinking Water Directive (98/83/EC) which limits total THM concentrations to100 µg/litre but does not specifically mention other DBPs. As part of its long term investment programme to improve water quality for customers, Scottish Water is gradually increasing the number of areas within Scotland that are supplied with chloraminated water (Scottish Water, 2010).

2.11 While chloramination appears to have several advantages in comparison with chlorination (these terms will be used henceforth to denote the relevant secondary disinfectant), its associated risks are still being determined. For example, a claim by Dr Michael J. Plewa of the University of Illinois that only 17% of DBPs associated with chloramination have been identified (see Barlow (2004)) has been given much publicity by campaign groups (such as 'Concerned Citizens about Chloramines') anxious about the purity of water supplies and companies which sell domestic purification equipment (exemplified by Aquavantage (see www.buyaquavantage.com/av-learnmore-epa.htm)).

Chloramination – possible risks?

2.12 Recent studies have found possible links between chloramination and blood lead levels (Miranda *et al*., 2007), nitrification, increased bacterial growth and the degradation or corrosion of pipe fittings (see, for example, Kirmeyer et al. (1993)). In addition, chloramine is known to be toxic in the bloodstream, thus posing significant risks for dialysis patients (Arrowsmith, 2002). Despite the well-known susceptibility of babies to nitrified water supplies (see, for example, Florida Department of Health, 2010), little detailed research work has focused on the impact chloramine might have on the healthcare environment and patient safety. In particular, there are no directly related literature surveys.

2.13 There exists a considerable body of literature that addresses chloramination from various other perspectives. A particularly comprehensive review of the topic was carried out by Kirmeyer et al. (1993) on behalf of the American Water Works Association Research Foundation (AWWARF) and this report draws heavily on the case studies contained therein. The AWWARF study was in fact supplemented more recently with the results of further research and practical experience of chloramination (Kirmeyer et al., 2004). Research focusing on some of the potential risks of chloramine is reasonably extensive (see, for example, Edwards *et al*. (2005), Miranda *et al*. (2007) and Weintraub et al. (2006)). While information on chloramine within a healthcare setting is sparse, Arrowsmith (2002) and Walker (2004) provide some foundation and several studies have associated chloramination with a *decreased* risk of Legionnaires' disease (Heffelfinger *et al*., 2003; Flannery et al., 2006; Kool *et al*., 1999). Additionally, there is anecdotal evidence that some NHSScotland Boards have had no reports of *Legionella* since their incoming water supplies were altered to being treated with chloramine.

Chloramination – advantages and disadvantages

2.14 This SHTM examines chloramination and discusses the various advantages and disadvantages of using chloramine as a disinfectant. It has also attempted to garner information from organisations that have converted from chlorine to chloramine and to determine the lessons that were learned in the process. Ultimately, it seeks to establish which problems Scotland's NHS Boards may encounter when faced with a changeover to a chloraminated water supply.

2.15 Following a detailed description of the chemical reactions and water treatment processes entailed, this SHTM discusses the advantages and disadvantages of chloramination. Attention subsequently focuses upon the main findings in respect of the impact chloramination may have, particularly with reference to patients and staff within NHSScotland healthcare facilities. The various issues involved are separated into

- those which have a direct impact on the NHS (dialysis, nitrification and the inactivation of pathogens);
- those which affect the populace, some of which may have a long-term impact upon the NHS (chloramine ingestion, cancer, disinfection by-products and aquatic life);
- those which will be primarily of concern to NHS estates staff (lead-leaching, metal corrosion and the degradation of rubber).

2.16 This SHTM proceeds to examine the experience of numerous water utilities following a conversion to chloraminated water. Finally, in light of the knowledge acquired in the literature survey, it concludes with a summary of the main observations and a list of recommended actions NHS Boards should consider.

3. Preparation of this SHTM

Sources of information

3.1 The initial review was carried out primarily as a literature survey with as systematic an approach as possible adopted given time and resource constraints. Information was obtained both from online sources and books, journals and guides. The researchers aimed to gather a wide range of information from many different sources, mostly from outside the UK. However, the case studies were as representative as possible.

3.2 In order to determine the key organisations in this field and the main sources of information, searches were carried out via general search engines such as Google. Search terms used included:

> Chloramine, chloramination, monochloramine, … + potable water, … + drinking water, + risks, … + benefits, … + healthcare, … + hospitals, … + pathogens, … + DBPs, … + toxicity, … + corrosion, … + materials degradation, … + lead-leaching, … + dezincification + bacteria.

3.3 Journal papers and articles were obtained from NHS libraries and databases, either online or in hard copy. Databases searched included Science Direct, MEDLINE and Cochrane. Several books on the topic were also sought from the NHS Library.

3.4 Source material which was deemed acceptable fulfils one or more of the following criteria: peer-reviewed scientific papers and articles, reliable information from reputable organisations, work carried out by or on behalf of governments and comprehensive case studies. Information from unknown organisations or agenda-driven websites was excluded as were case studies with insufficient details.

3.5 In published form as this SHTM it is expected to be used by NHSScotland managers, facilities management providers, designers and decision-makers to assist them in determining how chloramination could affect healthcare procedures and patient safety and enable them to take the steps necessary to minimise any negative impacts.

Note: This would include those responsible for home dialysis equipment.

Risk of bias

3.6 The information used in this SHTM came from a variety of sources, although there was a clear bias towards those from the United States. This has been largely unavoidable because the US has led the world in chloramination and possesses most expertise and experience. Nevertheless, there is not necessarily a bias within the US *per se*, since a wide spectrum of perspectives is reflected in the literature.

3.7 As chloramination becomes more widespread, particularly within United Kingdom, Europe and Australia, more case studies and information will become available. However, it will take time for lessons to be learned and shared. It is therefore anticipated that future updates of this SHTM will have a wider international slant.

4. Chemistry of chloramination

Basic Chemistry

4.1 This section follows UWRAA (1990) in describing the chemical reactions involved in the formation of chloramine.

- when gaseous chlorine is added to water it is said to hydrolyse or disproportionate as shown below:

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \qquad (1)$$

- a dissociation of the relatively weak hypochlorous acid HOCl into hypochlorite and hydrogen ions follows:

$$HOCl \rightarrow ClO^- + H^+ \qquad (2)$$

- the hypochlorite ion ClO- very rapidly establishes equilibrium with hypochlorous acid. The reaction between HOCl and ammonia NH_3 forms monochloramine NH_2Cl:

$$HOCl + NH_3 \rightarrow NH_2Cl + H_2O \qquad (3)$$

- the reaction between monochloramine and hypochlorous acid forms dichloramine NHCl2:

$$HOCl + NH_2Cl \rightarrow NHCl_2 + H_2O \qquad (4)$$

- while the reaction between dichloramine and hydrochlorous acid forms trichloramine NCl_3:

$$HOCl + NHCl_2 \rightarrow NCl_3 + H_2O \qquad (5)$$

Definitions

4.2 Monochloramine, dichloramine and trichloramine are sometimes collectively known as combined chlorine (or combined available chlorine). However, depending on whether the context involves water treatment or chemistry, the term ’chloramine’ is used to denote both the compound monochloramine alone as well as the mixture of compounds, monochloramine, dichloramine and trichloramine. Monochloramine predominates at ratios of chlorine to ammonia-nitrogen of 3:1 to 5:1, while the formation of dichloramine and trichloramine are favoured by higher ratios (Hankin, 2001).

4.3 Collectively, Cl_2 (the chlorine molecule), HOCl (hydrochlorous acid) and the hypochlorite ion (ClO-) are known as free chlorine or freely available chlorine.

Chloramination – a Brief Summary

4.4 Chloramination is a water management practice that uses chloramine to treat and deliver public water supplies in compliance with water supply regulations

(Flannery et al., 2006), while apparently producing fewer potentially dangerous DBPs than chlorine (SFPUC, 2004).

4.5 Municipal drinking water disinfection generally occurs in two phases, the first being an initial disinfection to kill organisms in the water, while a residual disinfection agent maintains biocidal activity throughout the water distribution system (Kool *et al*.,1999). Chloramination is known to provide a lasting residual disinfectant in the water system (Flannery *et al*., 2006) and, consequently, a typical chloramine water treatment plant uses chlorine for the initial disinfection and monochloramine for the residual disinfection (Kool *et al*., 1999).

4.6 The process of chloramination usually introduces chloramine at a concentration of 1.5 to 2.5 mg/litre, although it can be as low as 0.2 mg/litre and as high as 3.0 mg/litre based on World Health Organisation (WHO) recommendations (Hankin, 2001). It is known that because chloramine is a weaker agent a higher disinfectant residual will be needed to produce the same results as chlorine (MWUA, 2010). Therefore, a residual of 2.0 mg/litre of chloramine is relatively equivalent to a residual of 0.5 mg/litre of free chlorine.

4.7 Monochloramine is the most active chloramine compound and forms preferentially at the ratios of chlorine to ammonia-nitrogen defined above and at a pH value in the range 7.5 – 9.0 (Kim et al., 2002). At ratios of chlorine to ammonia-nitrogen between 5:1 and 7:1 and a pH ranging from 4 to 7 dichloramine tends to form, while the corresponding values favouring trichloramine are 7:1 and above and pH levels lower than 3.0.

4.8 Both trichloramine and dichloramine can cause taste and odour problems (Lenntech, 2009; Kool et al., 1999). It should be noted that the chloramine compounds can be broken down into free chlorine relatively easily and have a half-life ranging from one minute to 23 days (Lenntech, 2009). One major reaction leading to chloramine loss is initiated by the disproportionate of monochloramine, namely (see UWRAA (1990)):

$$NH_2Cl + NH_2Cl \rightarrow NHCl_2 + NH_3 \qquad (6)$$

The subsequent decomposition of dichloramine results in the loss of chloramine:

$$NHCl_2 + NH_2Cl \rightarrow N_2 + 3Cl- + 3H+ \qquad (7)$$

4.9 Although it will ultimately decay, chloramine is more stable than free chlorine and persists for longer periods, thereby enabling the disinfectant to reach more remote areas of a distribution system (SFPUC, 2004) and facilitating a potential reduction in costs (Kool et al., 1999). However, it is also a less effective (Kim et al., 2002), less reactive (American Society of Microbiology, 2007) and slower disinfectant (Kool et al., 1999) than chlorine and is weak at inactivating certain viruses (Hankin, 2001). Its slow reaction means that if there is contamination after water leaves a treatment plant, monochloramine may not be as effective as chlorine, since there is little control over its contact time with the contaminant (American Society of Microbiology, 2007). On the other hand, chloramines provide antibacterial activity with lower total chlorine (namely, the chlorine content of free chlorine and combined chlorine) levels (Arrowsmith, 2002) and seem to penetrate biofilm more thoroughly than free chlorine, enabling them to kill sessile biofilm bacteria (Kool *et al*., 1999). According to Walker (2010), a distinct benefit of chloramines in comparison with chlorine is that they have no significant odour or taste provided the levels of dichloramine and trichloramine are insignificant, which water utilities usually can ensure by the appropriate manipulation of variables such as pH and chlorine: ammonia-nitrogen ratios.

4.10 It is believed that monochloramine produces fewer dangerous DBPs (such as THMs and HAAs) since the contact time of the initial chlorine is shorter (Hankin, 2001) and this is the main factor driving the changeover in the US and elsewhere.

4.11 The USEPA states that THM reductions of 40-80% are usually experienced when a utility company switches from free chlorine to chloramines (Water Research Foundation, 1999). The THM by-products are chemical compounds that form when chlorine mixes with naturally occurring organics in source water. Many THMs are carcinogenic in laboratory animals and therefore expected to be so in humans (Kool et al., 1999). It is also suspected that they are associated with reproductive problems (Guay, Rodriguez & Serodes, 2004), although more research is needed to confirm this possible finding.

4.12 The EU currently has set a standard of 100 parts per billion as the safe level of THMs in drinking water although Scottish Water aims to reduce THM levels significantly lower. Since monochloramine produces fewer DBPs and is in contact with the water for a longer period, thereby shortening the time that free chlorine is in the system, it is believed that a chloramination regime poses less of a cancer risk than disinfection by free chlorine (Kool *et al*.,1999).

5. Issues Arising from Chloramination

Factors Directly Affecting NHSScotland Healthcare Staff:

Dialysis (including home dialysis)

5.1 Chloramines are known to be particularly harmful when they directly enter the bloodstream and because they persist in a water system longer than chlorine they pose a particular danger during dialysis. However, dialysis patients can use chloraminated water for drinking, cooking and bathing (Hankin, 2001).

5.2 The Renal Association currently sets limits of 0.1 mg/litre for chloramine (and 0.5 mg/litre for total chlorine) in dialysis water because excess amounts can cause haemolysis in patients (Arrowsmith, 2002).

5.3 Many dialysis patients also suffer from anaemia or methaemoglobinaemia, since they lack the natural hormone erythropoietin (EPO) which stimulates bone marrow to produce red blood cells. In these patients EPO is not produced in sufficient quantities and although synthetic EPO can be provided it is accompanied by unpleasant side effects. When chlorine or chloramine exist in dialysis water the need for EPO increases and transfusions may be necessary in severe cases (Hankin, 2001). Consequently, it is important to ensure that all chlorine and chloramines are eliminated from water used for dialysis treatment in order to minimise required EPO dosages (Arrowsmith, 2002). Furthermore, during the dialysis process the water comes into contact with the blood through a permeable membrane. This membrane does not remove the chloramines but can be damaged by them and therefore the chloramines need to be removed before the water passes through any reverse osmosis membrane system (Hankin, 2001).

5.4 Chloramine removal can be achieved through several processes. One possibility is deionisation, although this practice is inconsistent. Another is chemical reduction by the use of ascorbic acid (Vitamin C); a concern in this case is the acid’s toxicity for dialysis patients.

5.5 The most common solution is to use filters containing granular activated carbon (GAC) which is made mostly from bituminous coal. The resulting charcoal is pulverised and activated by exposure to superheated steam which increases its surface area for absorption and provides filtration down to 2 μm (Arrowsmith, 2002). In order that the life of the carbon filters is optimised, monitoring of the water is essential and sampling must be carried out using the DPD test or a simple drop test for total oxidant. Small photometers are also available as an alternative (Arrowsmith, 2002).

5.6 Currently, all NHS equipment used for renal care treatments is required to be modified with GAC filtration in compliance with SAN (SC) 03/10. The size of carbon filter required in chloraminated systems, however, is approximately 10 times that required for chlorine systems, implying an increase in cost. Although an economic solution might save on testing and monitoring costs by having a central facility serving the renal dialysis unit, this would conflict with NHS policy which encourages patients to dialyse at home (Scottish Executive Drinking Water Quality Unit [SEDWQU], 2002).

5.7 The main issue with respect to home dialysis equipment is ‘chloramine-proofing’ the units since a substantial number of carbon filters would be required and protocols introduced to ensure that patients test and monitor their own water. While it was proposed by NHSScotland that Scottish Water contributes to the cost of chloramine-proofing the units, there is currently no provision in the Scottish Water investment plan for this funding (SEDWQU, 2002). In order that the home dialysis units are monitored adequately, one solution would be a programme that includes routine visits to change carbon filters.

5.8 Arrowsmith (2002) suggests that dialysis filtration can be continued based on the assumption that the carbon filters can remove 1.0 mg/litre total chlorine (free chlorine or monochloramine). Levels of total chlorine in the water supply remain relatively constant aside from a small reduction in winter or during public water mains work where disinfection is carried out afterwards. It is essential therefore that the water authority is notified of dialysis patients in its area so that they can be included on the ‘sensitive client’ list and notified when chlorine or chloramine levels will be high. It is noted that this process is the NHS Boards’ responsibility (Arrowsmith, 2002).

Nitrification

5.9 Another potential problem with the use of monochloramine is nitrification, which is caused by a reaction between ammonia-oxidising bacteria and excess ammonia from an incorrect dosing (MWUA, 2010) or from the decay of chloramine due to water ageing and temperature increases. The nitrifying bacteria can be found on the inside of water pipes, protected by biofilms, and nitrification can occur if there are low disinfectant residuals to combat it. Currently two-thirds of medium and large water distribution systems in the US that use chloramines experience nitrification to some degree (MWUA, 2010).

5.10 During the nitrification process, the bacteria oxidise the ammonia and produce nitrite, which is subsequently converted to nitrate and organic carbon in the form of biomass and soluble microbial products. The health concerns of excess nitrate in water relate to the capacity of blood to carry oxygen; short-term exposure to excessive levels of nitrate or nitrite can lead to potential problems, the most serious of which in a healthcare context is ‘blue baby disease’.

5.11 Consequently, drinking water standards for nitrite and nitrate have been set within the United States at 1 mg/litre and 10 mg/litre, respectively (MWUA, 2010). In comparison, the permitted concentration values in Scotland are 0.5 mg/litre (nitrite) and 50 mg/litre (nitrate) in accordance with the EU Drinking Water Directive 98/83/EC.

5.12 There appear to be no studies that address the use of chloraminated water within maternity wards and as a result no definitive relevant conclusions or recommendations can be made within this survey. Nonetheless, it might be reasonable to suggest that caution should be the watch-word. The presence of nitrification in water is relatively straightforward to ascertain and several manufacturers sell test strips at low cost which can detect the relative level of both nitrates and nitrites.

5.13 With regard to chloramine, it must also be considered that the levels of organic carbon created by nitrifiers may be sufficient to support the growth of heterotrophic (HPC) bacteria. In one study (MWUA, 2010), the levels of HPC bacteria were 1,000 times more than they would have been had chlorine been used as the disinfectant. A significant advantage of chlorine is that it does not release nutrients for bacterial growth.

5.14 During nitrification, chloramine residuals are consumed faster than those of nitrate due to an increase in demand and a system with no chloramine residuals is vulnerable to future bacterial contamination. The numbers of nitrifying bacteria increase markedly during periods of accelerated chloramine decay, although the causality of this relationship is not fully clear (UWRAA, 1990).

5.15 Nitrification is also usually accompanied by a reduction in pH and dissolved oxygen; under certain conditions nitrifying bacteria can potentially accelerate lead and copper corrosion due to the release of nitric acid (Kirmeyer et al., 1993). It should be noted that Scottish Health Technical Memorandum (SHTM) 04-01 Part E ‘Alternative materials and filtration’ states copper is no longer routinely specified for use in NHSScotland premises (HFS 2011). This repeats the statement in the superseded Scottish Hospital Technical Note (SHTN) 2 (PEFEx, 1999). However, these publications have not gone as far as to state that existing copper within systems had to be removed. As a result some older healthcare premises still contain large amounts of copper pipework.

5.16 The Water Research Foundation (1999) states that nitrification and its methods of control depend on water quality factors:

- pH;
- temperature;
- chloramine residual;
- ammonia concentration;
- chlorine-to-ammonia ratio;
- concentrations of organic compounds and distribution factors;
- detention time;
- reservoir design and operation;
- sediment;
- tuberculation in piping;
- biofilm;
- the absence of sunlight.

5.17 There is no consensus within the literature concerning the relative significance of nitrification in relation to chloramination. According to MWUA (2010), nitrification alone may negate the benefits of using chloramine, although full consideration of its suitability should include the source water type and quality and the overall treatment process required to produce potable water.

5.18 The UWRAA (1990) report into chloramination asserts that nitrification is the major problem facing operators of chloraminated systems. On the other hand, SFPUC (2004) states:

‘nitrification is more of a nuisance and operational a health issue since nitrification is due to metabolism and growth of harmless non-pathogenic nitrifying bacteria that are ubiquitous in soils and water’.

5.19 To minimise nitrification, treatment plants must ensure that sufficient disinfection residual is maintained at all times and particularly during the winter months. Additionally, free ammonia entering the system should be limited and the distribution network flushed periodically to prevent water ageing in areas of low circulation. In the US, several utilities have rid their systems of nitrifying bacteria by temporarily converting to chlorine (Kirmeyer *et al*., 2004). Lastly, booster stations should be established and supplemental treatment applied at storage and pumping stations to increase monocholoramine concentrations (MWUA, 2010).

Note:

Piping Materials

Feedback obtained during the preparation of this SHTM raised the topic of the effect different piping materials might have on biofilm formation and thereby nitrification. There is thus a link other than corrosion between the issues of chloramination and piping material, albeit indirectly.

Kerr *et al*.(1999) carried out a lengthy experiment which examined the relative resistance of cast iron, Thermanox (a trademark name for a polymer widely used in laboratory equipment), medium-density polyethylene (MDPE) and unplasticised polyvinyl chloride (PVC-U) to biofilm accumulation. Potable water was pumped at a rate of 3 ml/minute past specimens of the various materials and measurements taken of the numbers of viable heterotrophs (organisms that cannot fix carbon and use organic carbon for growth). Bacteria built up exponentially during an initial phase of 2-3 weeks and then tended to level off, with the exception of cast iron which showed a slower, but steady, increase. A year or so later, it was apparent that the plastics resisted biofilm formation to a much greater extent than cast iron, with both MDPE and PVC-U superior to Thermanox in this regard. Park et al. (2007) performed a similar experiment and discovered little difference between stainless steel, galvanised steel and PVC in resisting biofilm formation.

Yu *et al*. (2010) analysed the capability of 6 different piping materials (copper, chlorinated PVC, (PVC-C), polybutylene (PB), polyethylene (PE), stainless steel and zinc-coated steel) in resisting biofilm formation in drinking water, a mix between drinking water and river water and drinking water inoculated with *E. coli.* This experiment differed from those above in not simulating water flow. The material which exhibited the most resistance to bacteria formation was copper with the steels faring worst while the plastics were fairly indistinguishable. Silhan et al. (2006) was concerned with the formation of biofilm in galvanised steel, PEX (cross-linked polyethylene), MDPE and copper. These researchers were also looking at the survival of *E. coli* in both biofilm and water within each of these piping materials. Once again, steel fared less well with copper being most resistant to biofilm formation. *E. coli* was not detected within biofilm on any material. It was noted that biofilm formation was very significantly increased at very warm temperatures (35ºC) in the plastics but relatively unaffected in the metals.

There are some discrepancies between results within the literature and the papers referred to above only report a series of experiments. The general picture appears to be that plastic piping is increasingly favoured by water utilities which view the rough surfaces of old cast iron pipes as encouraging biofilm growth (Water Quality and Health Council).

5.20 Recent research has investigated the role nitrification may have in the corrosion of plumbing systems (Zhang *et al*., 2008). The research group concerned has also been examining whether pipe corrosion may induce or exacerbate nitrification. This work was motivated by fears of copper and lead dissolution caused by nitrification, the risk of which is considered likely to increase with a chloraminated water supply. It is important to note that the experiment was laboratory-based and no recommendations were made with respect to piping materials.

Inactivation of Pathogens

5.21 Chloramine is a less effective biocide than agents such as hypochlorous acid, hypochlorite, ozone or chlorine dioxide. This was verified in Kirmeyer *at al*. (1993) which tabulated research by Olivieri *et al*. (1985) recording CT values (dosage concentration x time taken to inactivate various percentages of pathogens present) for a variety of biocides in relation to *E. coli* and Poliovirus1. The same source also records data obtained by the USEPA that established the CT values of chloramine and other agents for various inactivation levels of *Giardia lamblia* and what were known generically as 'viruses'; again, the values associated with chloramine are very much larger than those of other agents, including chlorine. It is also known that chloramine is ineffective in removing *Cryptosporidium parvum*, although this applies to chlorine too.

5.22 Nonetheless, it is important to note that chloramine is intended to be a secondary disinfectant and its comparatively large related CT values should not preclude it from this role. The Australian experience of a changeover from chlorine to chloramine (UWRAA, 1990) was positive in terms of microbiological quality. One paramount concern was to control the growth of *Naegleria fowleri*, the causative agent of an invariably fatal disease which attacks the central nervous system.

5.23 In this regard, chloramination was found to be highly successful, with only 1 sample out of a total of 580 containing this amoeba after chloramination – the corresponding figure before the changeover was 40 positive samples from a total of 701. The Australian authorities also carried out surveys at various locations to ascertain the impact on the traditional indicators of microbiological quality: total coliforms, *E. coli* and plate count organisms; HPC iron bacteria, *Aeromonas* spp. and fungi were also examined.

5.24 UWRAA (1990) reports that by each of the aforementioned criteria, chloramination of a previously chlorinated supply improved microbiological quality. For example, in two river systems the frequency of isolation of total coliforms was reduced from values of 45.9% and 32.3% to 1.7% and 4.8% respectively. Kirmeyer *et al*. (1993) confirms that chloramine has been very successful in practice in terms of reducing coliform organisms. Moreover, as mentioned previously, chloramine also seems to be more effective than chlorine for controlling biofilm in pipes (LeChevallier et al. as cited in Kirmeyer et al. (1993)). While chloramine's mechanism of action make it a weak primary disinfectant, Kirmeyer *et al*. (1993) describes research suggesting that the very same properties may account for its ability to penetrate biofilm. A detailed discussion of the processes involved is beyond the scope of this SHTM.

5.25 One key advantage of chloramination in a healthcare context may be a reduced risk of the outbreak of Legionnaires' disease, a community-acquired and nosocomial type of pneumonia caused by the inhalation of aerosols or the microaspiration of water containing *Legionella* bacteria (see, for example, Flannery *et al*. (2006) and Heffelfinger *et al*. (2003)). Each year in the US there are 8,000 to 18,000 cases of Legionnaires' disease, of which 10-20% occur from outbreaks (Kool *et al*., 1999).

5.26 Prevention of this disease currently focuses mainly on preventing or limiting the colonisation of *Legionella* bacteria in water pipe systems by increasing temperature in hot water pipes and employing 'heat and flush' to cold water pipes or supplementing with extra chlorine. However, both of these treatments are generally unsuitable, due to practical constraints in the former instances while extra chlorine may quicken the development of corrosion and leaks in plumbing systems (Heffelfinger *et al*., 2003).

5.27 In one study (Flannery *et al*., 2006), a two-year trial during which water and biofilm were collected from 53 buildings during six intervals, it was found that *Legionella* colonized 60% of the hot water systems before chloramine was introduced, at which point colonization decreased to only 4%. These authors therefore concluded that "increasing use of monochloramine in water supplies throughout the United States may reduce *Legionella* transmission and incidence of Legionnaires' disease".

5.28 Another study (Heffelfinger *et al*., 2003) was conducted through a survey of 459 members of the Society for Healthcare Epidemiology of America that addressed hospital features, endemic- and outbreak-related, hospital-acquired Legionnaires' disease, water supply sources and methods of disinfection used by the hospitals and water treatment plants. Results from the 166 hospitals that responded found that hospitals supplied with drinking water disinfected with chloramine were less likely to have sporadic cases or outbreaks of hospital-acquired Legionnaires' disease.

5.29 Kool *et al*. (1999) also discovered that hospitals supplied with drinking water containing free chlorine were more likely to have a reported outbreak of Legionnaires' disease than those which used chloraminated water. In Kool's study, 32 hospitals that had experienced outbreaks of Legionnaires' disease were compared with 48 control hospitals selected for their hospital characteristics and water treatment factors. It was suggested that 90% of the outbreaks associated with drinking water may not have occurred had chloramine been used for disinfection rather than free chlorine, although these authors recommended that further studies be conducted to confirm this finding.

5.30 In addition to research in the form of case studies, an in vitro experiment that measured the effect of disinfectants on *Legionella* growth showed monochloramine to be more effective at killing the bacteria in biofilm than chlorine (Donlan *et al*. as cited in Heffelfinger *et al*., 2003).

5.31 Finally, another study of a hospital's water system indicated that monochloramine generated on site and used as a supplemental disinfectant could lead to the rapid and sustained reduction of *Legionella* growth (Shelton et al., as cited in Heffelfinger et al. 2003). The relative ability of monochloramine to inactivate *Legionella* bacteria is thought to arise from its property of penetrating biofilm more aggressively than free chlorine. Nevertheless, although these studies suggest that monochloramine reduces the risk of Legionnaires' disease, it cannot be concluded that monochloramine will kill *Legionella* bacteria in all instances.

Factors Indirectly Affecting NHSScotland:

Chloramine Ingestion

5.32 Surprisingly little data exist on the health effects of monochloramine ingestion despite its long history in water disinfection. According to Hankin (2001), ingested monochloramine would reach the stomach intact and rapidly decay in stomach acid. No studies were found that suggest chloramines could have any negative impact in respect of stomach ulcers, although this is an area that warrants more research. It can be only tentatively suggested that chloramine is not expected to enter the systemic circulation intact.

5.33 In one past study, the short-term exposure to a maximum of 24 mg/litre of monochloramine in drinking water did not produce any adverse effects (Lubbers *et al*., 1981). International guidelines for drinking water quality suggest that no short-term or long-term health effects have been associated with chloramines in water (Hankin, 2001).

Cancer

5.34 Hankin (2001) states that to date the International Agency for Research on Cancer has not fully evaluated the cancer-causing potential of chloramines. Although a number of studies have found chlorinated drinking water to be associated with bladder and colon cancer, few of these involved chloraminated drinking water. In research conducted by Zierler *et al*. (as cited in Health Canada, 1995), it was found that the incidence rate of pneumonia and influenza leading to deaths in a Massachusetts community was slightly higher among those who had their water disinfected with chloramine rather than chlorine. On the other hand, the bladder cancer mortality rate was more excessive among residents using chlorinated water in comparison with those supplied with chloraminated water.

5.35 There is little other information available indicating any link between cancer and chloramine. The USEPA (1992)) has not classified chloramine/monochloramine as carcinogenic because there are inconclusive human data and equivocal evidence from laboratory animal assays. However, Edwards *et al*. (2005) states that '*the switch to chloramine immediately reduces the concentration of potentially carcinogenic disinfectant by-products in water*' (p.2). Bull and Kopfler (as cited in Kirmeyer *et al*. (1993)) believe this reduction in cancer risk could be as much as 80%, assuming that the chloramine used produces similar by-products to chlorine, but rather at lower levels. In conclusion, further research is needed to determine if any associations may exist between chloramine and cancer.

Disinfection By-Products

5.36 As stated previously, chloramine is known to produce fewer dangerous DBPs in comparison with chlorine, (see, for example, SFPUC (2004)). However, there are two particular DBPs produced to a greater degree during chloramination than chlorination which give cause for concern: cyanogen chloride and N-nitrosodimethylamine (NDMA). NDMA in particular can develop at higher concentrations in areas where precursor amines exist in the water from man-made sources, thereby necessitating enhanced monitoring and controlling of existing amines. Further research is being conducted on this by-product and progress has been made within the United States to limit its formation.

5.37 In 2004, there was another worrying development when iodoacid, the most toxic and DNA-damaging to mammalian cells of DBPs discovered to date, was discovered in chloraminated water within Texas. This may have been a rare occurrence due to the area’s high levels of bromide and iodide (Barlow, 2004). It has been claimed that scientists currently have only been able to identify 50% of the DBPs in chlorine-treated water and only 17% of those in chloramine-treated water. In addition, the Water Research Foundation (1999) states that DBP formation decreases as the pH increases and the chlorine-to-ammonia ratio decreases and that a change in either of these variables can significantly impact DBP formation, suggesting that there is still a long way to go in determining the full effects and impacts of chloramination (Hankin, 2001).

Factors Affecting NHSScotland Estates Staff:

Lead-Leaching and Corrosion

5.38 Some research has revealed that the conversion from chlorine to chloramine can cause an increase in blood lead levels due to corrosion, a new and unexpected finding both for regulators and the water industry (SFPUC, 2004). In general, most childhood lead uptake occurs from exposure to degrading lead paint, although 14-20% of childhood lead exposure in the United States is estimated to originate from drinking water (USEPA, as cited in Miranda et al., 2007). Surprisingly, Edwards et al. (as cited in Edwards *et al*., 2005) state that there are no maximum contaminant levels enforced ‘at the tap’ in the United States, although an ‘action level’ of lead concentration is given as 15 µg/litre. In comparison, in accordance with the EU Drinking Water Directive (98/83/EC) Scotland imposes an upper limit on lead concentration of 10 µg/litre.

5.39 Several studies have proved that the introduction of chloramines to water systems containing lead-based pipes, fixtures or solder may increase the amount of lead in the water due to changes in the resulting water chemistry (Edwards & Dudi; Mass *et al*.; Schock; Shock *et al*.; Switzeret *et al*.; as cited in Miranda *et al*. (2007)).

5.40 Miranda *et al*., (2007) also discovered that a change to chloramine disinfection in the Goldsboro Water System in North Carolina was associated with an increase in children’s blood lead levels. However, this particular study noted that the impact of the change was progressively mitigated in newer housing and in houses built after 1950, with the age of the house constituting a stronger influence on blood lead than the use of chloramines as a disinfectant (Miranda *et al*., 2007).

5.41 Variables such as the location of a potential lead source, the timing of sample collection and small changes in water chemistry can affect measured water lead levels considerably. In addition '*numerous factors can contribute to metal corrosion including water quality, biofilms, the pipe manufacturing process, and the design and installation methods of piping systems*' (SFPUC, 2004, p.15). In two studies (North Carolina and Washington, DC) this unpredictability caused the increased levels of lead as a result of chloramination to remain undetected until almost a year after the conversion had taken place (Miranda *et al*., 2007). It has been suggested that the dissolving of lead from pipes into water following chloramination may only be a transient process as a new film may subsequently develop inside the pipe, thereby creating a barrier between the water and lead source (Miranda *et al*., 2007). Evidently, there is still much to learn about the association between chloramine and lead-leaching.

5.42 Lead piping within Scottish houses and infrastructure is highly unusual nowadays and the main problem is likely to stem from lead-tin solder or degradation of brass fittings. Brass components can also experience dezincification, although the correlation between this phenomenon and chloramination is as yet unclear. Ideally, brass in taps and other appurtenances should be of a composition that is dezincification-resistant (DZR) and relatively immune to the leaching of copper (and lead, if present at all).

5.43 Miranda et al. (2007) summarised the current state of knowledge on general metal corrosion from chloramine by stating that 'the details of all the related environmental chemistry are not fully understood and are highly dependent on the particular chemical interactions found in each water treatment and distribution system'. The most comprehensive field study covering the impact of chloramination and materials deterioration is contained within Kirmeyer et al. (2004). This report confirms that both chlorine and chloramine can increase water's corrosiveness towards copper and its alloys (brass, bronze, cupronickel, etc), especially at low pH levels. There are two distinct manifestations of copper corrosion: a uniform, gradual thinning and a more destructive form, known as 'pitting'. Kirmeyer et al. (2004) details a survey of 31 utilities which converted from chlorination to chloramination after 1980. 13 of the respondents found there had been no increase in pipe erosion, 17 did not know and only 1 thought there had been an increase in the corrosion of galvanised pipes. Biocorrosion of copper piping was mentioned by Kirmeyer et al. (2004), although an evaluation of the influence of water disinfectant in controlling it requires further investigation.

5.44 There is little available data on the relative degradation of plastic piping fittings and associated equipment by chlorinated and chloraminated water. Kirmeyer et al. (2004) reports only one issue related to the possible impact of chloramination on plastic components, namely, hot water propylene dip tube heaters in Chesterfield, Virginia, and does not confirm that this was a result of the changeover. Chung *et al*., (2006) carried out a series of tests on ½" standard SDR-9 PEX tubing and found no discernible difference between the degradation induced by water containing representative concentrations of chlorine, chloramine and chlorine dioxide.

5.45 Carrying out research for the Urban Water Research Association of Australia (UWRAA), Moore (1998) concluded that the long term testing of a variety of materials at chloramination levels of 4 mg/litre and lower indicated:

- increased de-alloying of copper-based alloys, particularly in non-DZR materials (DZR alloys showed some corrosion but well within limits);
- increased corrosion of copper;
- negligible effect on stainless steel and plastic materials.

Moore (1998) accordingly recommended that the use of DZR materials in Australian water supplies should be mandatory.

Effect on Rubber

5.46 According to SFPUC (2004), the use of chloramine in a water system can have deleterious effects on distribution system plumbing fixtures, particularly natural rubber products and their derivatives commonly used in household appliances. Indeed, Kirmeyer et al. (2004) places this factor (after concerns about dialysis patients and aquaculture and ahead of those related to nitrification) as the second most serious hazard related to chloramination.

5.47 Practical experience has revealed that the severity of the effect of chloramine exposure on rubber has varied widely and is dependent on the material used, the amount of chloramine present and the temperature of the operating environment (Kirmeyer et al., 2004; Ashtabula Rubber Co., 2010). For example, one study found that 23% of utilities surveyed experienced an increase in the materials degraded after chloramination. In another case, after Austin, Texas, converted a portion of its water system to chloramine a number of complaints were received from customers concerning black specks in the water which were the result of the degradation of nitrile rubber material within the system (SFPUC, 2004). Moore (1998) stated that both natural rubber and neoprene suffered from significant attack in chloraminated water.

5.48 To examine the impact of chloramine on rubber products, the American Water Works Association Research Foundation (AWWARF) – see Kirmeyer et al. (1993) – studied seven elastomer formulations including natural rubber, nitrile, Styrene Butadiene Rubber (SBR), Neoprene, Ethylene propylene butadiene Monsoner (EPDM), silicone, and fluorocarbon and subjected them to a number of tests to determine their life cycle when exposed to chloramine. It was found that natural rubber subjected to chloramine exposure tended to crack, exhibit severe swelling and lose elasticity and tensile strength; chloramine attacked the polymers which significantly degraded rubber’s physical properties. Furthermore, it was verified that the rate of decay was positively associated with increased temperatures.

5.49 Nitrile, SBR, neoprene and EPDM fared better in these tests but still showed significant degradation, whereas the considerably more expensive options silicone and fluorocarbon performed well. Custom, chloramine-resistant EPDM and nitrile materials are now available and are increasingly being used within the US potable water industry (Ashtabula Rubber Co., 2010). NHSScotland should therefore ensure that any rubber components within their facilities, which can be found in kitchen fixtures, bathroom shower heads and taps, bathroom toilets, drinking fountains, irrigation, systems, ice makers, fire suppression systems, sprinklers, water pipes and water meters contain chloramine-resistant components.

Notes:

Safety Action Notice:

A Safety Action Notice published by Health Facilities Scotland in 2009 looked at the risk of flexible hoses harbouring Legionella and other potentially harmful micro-organisms, it stated that HFS had received reports that high levels of Pseudomonas and *Legionella* bacteria had been found in water samples taken from water outlets fed by flexible hoses, this was confirmed by testing of the hoses which revealed colonisation of the lining. The lining material in these reports was EPDM. However, it is possible that other lining materials (and washers within the couplings) could have been similarly affected. Due to this, in situations where flexible hoses must be used they should be lined with an alternative to EPDM and be WRAS approved.

Aquatic Life:

Chloramines are harmful to fresh and saltwater fish and aquatic reptiles and amphibians, easily passing through the gills and directly entering the bloodstream (SFPUC, 2004). Here the compounds bind to iron in red blood cell haemoglobin and reduce each cell's capacity to carry oxygen. Care must therefore be taken to ensure that water courses are discharged neutrally or water-conditioning agents are added to remove the ammonia and chlorine (Walker, 2010). Specifically, SFPUC (2004) suggests that to remove or neutralise chloramine, a GAC filtration system or an additive that contains a dechloraminating chemical for both ammonia and chlorine, should be used. In addition, water tests should be completed frequently to ensure that chloramine has been sufficiently reduced (SFPUC, 2003). Consultation with the Water Authority may be required to ensure that any WRAS arising from processes introduced by them are not unreasonably borne by the consumer as they can be underwritten by savings achieved by the utility company.

Conversion from Chlorination to Chloramination

5.50 An appreciable body of information has now been established documenting the experiences of water authorities which have converted from chlorine to chloramine disinfection. A study conducted by Flannery *et al*. (2006) in California showed that the conversion to a monochloramine disinfection system resulted in higher concentrations of total chlorine and lower concentrations of THM components. While the average temperature and pH measured in building water samples remained relatively constant, the conversion resulted in a 10-fold increase in total chlorine concentrations in the hot-water systems.

5.51 As a result, it was concluded that monochloramine in drinking water provides better control of Legionella growth in building plumbing systems than free chlorine, although the Group also state that the potential use of supplemental monochloramine in hospitals to prevent Legionnaires' disease still needs to be evaluated. In addition, the increased stability of monochloramine ensured higher disinfectant concentrations in potable hot water systems, since chlorine dissipates rapidly at higher temperatures.

5.52 Another conversion from chlorine to chloramine, completed by the Regional Municipality of Ottawa-Carleton in Canada in 1992, resulted in an average chloramine concentration of 0.92 mg/litre (95% of which was monochloramine) leaving the plant and 0.71 mg/litre in the distribution system. The changeover to chloramine produced no observable changes in the bacteriological quality of the drinking water (Health Canada, 1995), although the municipality has increased its average concentration to 1.0 mg/litre in order to achieve higher residual amounts at the end of the distribution system. According to SFPUC (2004), many water agencies that have converted to chloramine from chlorine have reported that customers note an improvement to taste and odour of the water.

Scottish experience

5.53 In a Scottish context, NHS Dumfries & Galloway recently completed a pilot scheme to measure and assess the impact of the changeover to chloramine, and noted no observable changes during or after the process, although it did start with a 'clean' water system in a new facility. NHS Lothian has also converted and likewise reported little noticeable change to water quality and operational maintenance (Walker, 2010). However, NHS Grampian, which has been supplied with chloraminated water for 7 years, noticed a considerable improvement in quality much cleaner water pipework and tank systems. Moreover, laboratory personnel who have been unable to culture Legionellae in supply and secondary system samples suggest that chloramination has the potential to reduce operational maintenance requirements.

5.54 On the other hand, NHS Grampian observed that the conversion introduced manganese in granular form, most likely originating from leaching of Scottish Water pipework (Walker, 2010). Anecdotally it has been suggested that differing distances from the reservoir to the point of use may account for differences in quality of water, this has not been proven.

Findings from the Case Studies

5.55 The case studies reviewed for this report are restricted to North America. Nevertheless, the experiences they provide are diverse and, as such, they still represent a valid basis for determining the possible effects of chloramine disinfection in other situations. The key point emerging from the case studies is that the impact of chloramination depends very much on the raw water quality, surrounding soil, pipe fittings and combinations of other chemicals.

5.56 Most of the case study organisations experienced one or more of the negative characteristics associated with chloraminated water and, consequently, the successful implementation of chloramination may rely heavily on the experimental abilities of individual water treatment plants to manipulate variables such as pH levels or the ratio of chlorine to ammonia-nitrogen appropriately.

5.57 However, bearing in mind the strict requirements of healthcare facilities, the risks already highlighted in this report warrant a degree of caution before chloramine can be recommended as a completely safe choice for NHSScotland and its patients. Some thoughts with regards to these case studies, in conjunction with relevant findings from the literature, are given below:

- the theoretically-oriented literature states that, being a more stable and persistent disinfectant than chlorine, chloramine has associated cost reductions. This principle was borne out by the case studies, with Brown Deer finding chloramine to be the best cost/benefit option and Massachusetts being able to eliminate booster stations by using a 5:1 chloramine to ammonia-nitrogen ratio, thereby saving $100,000 each year. However, when used, chloramine booster stations decreased service pipe failures for Brown Deer;
- a decrease in DBPs after switching to chloramine was observed by Gulf Coast, Massachusetts, Ann Arbor, Hackensack and Tampa Water Departments, indicating that this is also a reliable benefit of chloramine use. Moreover, the use of chloramine provided increased residual in water distribution systems for Brown Deer, Massachusetts, Vancouver and Tampa, thereby helping to decrease HPC and coliform bacteria levels. In Ann Arbor, however, where a decreased residual resulted in increased HPC levels in dead-end areas, free chlorination was used for control measures before re-conversion to chloramination;
- taste and odour results were more mixed: Philadelphia found chloramine to decrease taste and odour effects, whereas Vancouver found the opposite occurred. Vancouver attributes this result to chloramine residual being more widespread within the test area and its presence more detectable to customers than the chlorine previously used;
- of the 14 case studies, lead corrosion from chloramine was evident in Brown Deer, North Carolina, Washington and Maui, while in Massachusetts chloramination actually helped to decrease iron corrosion. Affecting 29% of the case studies in this report, lead-leaching is a dangerous characteristic and its possible link with chloramine requires substantial future analysis;
- Nitrification is described alternatively as ‘more of a nuisance and operational problem than a health issue’ (SFPUC, 2004, p.8) and a factor that may negate the benefits of using chloramine (MWUA, 2010). Reports of nitrification in the case studies were not very common although when they did occur they were dealt with by experimenting with different solutions. Ann Arbor, for instance, managed to decrease nitrification by changing its ratio of chlorine to ammonia-nitrogen and increasing pH before temporarily switching to free chlorine. Portland, however, employed the use of booster stations to decrease its nitrification;

- although chloramine is known to have increased residuals and reached outer-most areas of their distribution systems, Washington and Maui both noticed that during stagnation periods there was an increase in bacteria levels. In Maui's case, the chloramine was being mixed with phosphate and causing a slime-forming bacteria at a pH of 7.7;
- nitrification falls within the remit of water utility organisations and NHSScotland has little leeway in controlling the amounts of excess ammonia within a water distribution system. As noted in the recommendations, however, it is possible to take action to minimise the formation of nitrification within NHS facility water systems by ensuring through the regular flushing of pipes and the avoidance of dead-legs that no stagnation of water occurs. Provided UK and NHS regulations and procedures concerning these practices are complied with, stagnation and its possible associated bacterial growth should not prove a significant issue within Scottish healthcare premises;
- the link between chloramine use and general health is still not known with absolute confidence. North Carolina experienced a number of health complaints after conversion to chloramine, although none of the skin disorders discovered was found after investigation to be fully attributable to chloramine;
- several of the case studies, including Vancouver and Tampa, noted the importance of a public education and notification programme when implementing chloramine treatment. Philadelphia in particular worked to understand customer perceptions and sensitivities with regard to chloraminated water and realised that direct communication with the public was the best option. Through its education programme, the organisation also attempted to develop a link between chloramine and safe, clean water, so that if the public detected a change in the taste of their water when the system converted from chlorination to chloramination, they would make this educated association rather than complain or panic. The water department noted that a public survey was a useful tool for gathering the required information and the populace can provide reliable information on water-related concerns;
- the Hackensack Water Authority initially avoided the public notification and education stage, believing that since it had already used chloramine in the (relatively distant) past the changeover would be trouble-free. However, the conversion caused substantial problems with aquatic life and several dialysis patients required transfusions. The conversion to chloramine was conducted successfully four years later following the launch of a proper information campaign;
- in the case of Scotland, an educational program on chloramination would generally be the responsibility of Scottish Water. However, if needed, a smaller campaign could be developed by the NHS Boards in Scotland to inform staff about the changeover;
- a monitoring programme before, during and after a change to a chloramine system is an important component for success. In particular, Portland states that an understanding of chloramine chemistry is vital for a monitoring strategy to be useful. It continued a monitoring programme with

the objective of limiting free ammonia and ensuring high residuals in their system;

- several of the organisations in the case studies reported the use of chlorine to treat particularly difficult cases of bacteria, even though they may have implemented a chloraminated system; these include Ann Arbor and Maui. (Gulf Coast successfully combined chloramine with chlorine dioxide.) In all cases, the use of chlorine was successful, whether the aim was to decrease lead concentration, bacteria or nitrification. However, in Maui the chlorine residual decayed significantly while in Ann Arbor, there was an increase in HPC, coliform bacteria and THMs. The eventual outcome was that chloramine remained the preferred choice for these organisations, with chlorine simply on hand in future if needed for temporary treatments. Ann Arbor stated that future chlorination treatments would need to be accompanied by improved measures to minimise any negative effects.

6. Conclusions and Implications

6.1 This SHTM has investigated the advantages and disadvantages entailed in a changeover from chlorinated to chloraminated water supplies, with particular focus on the bearing this might have on healthcare facilities. Chloramination is being adopted by water utility companies primarily because of the requirement to find a cost-effective means of complying with increasingly stringent regulations covering quality.

6.2 There are certainly advantages associated with using chloramine as a disinfectant, especially in terms of its long-lasting presence within the supply network and its generation of fewer dangerous by-products. Nevertheless, it is clear that the addition of chloramine to water is not entirely risk-free and, given the American experience, there are concerns over possible nitrification and materials degradation.

6.3 Scottish Water supplies the vast majority of Scotland’s healthcare facilities, although a small number have their own private water source. Consequently, most NHS Boards have little control over the water within their domains and must adopt a reactive policy based on planning and monitoring. This review has identified the chief areas of concern in a medical context to be the safety of dialysis patients and small babies, while materials degradation in water distribution systems may become a problem in respect of physical infrastructure. It is important that these issues are addressed and there are some steps that can be taken by NHS Boards in regions of Scotland where chloramination is envisaged.

7. Recommendations

Communication

7.1 Direct communication should be developed between NHSScotland Health Boards, healthcare and estates staff and Scottish Water (or the relevant water treatment organisation) to ensure all are fully briefed on issues concerning chloramination and aware of the actions needed from their side to ensure a successful change and the maintenance of patient safety. It is essential that unilateral changes from chlorination to chloramination of incoming water supplies do not occur without consultation. This has happened in the past.

Monitoring Water

7.2 NHSScotland Health Boards must give serious consideration to monitoring for possible nitrification the water supplied to wards with young babies and relatively inexpensive testing kits are available for this purpose. NHS Boards should also have an action plan in place to account for any sudden increase in nitrate levels. Additionally, a line of communication must be established between Scottish Water and NHSScotland Health Boards which would raise an early alarm in the event of a problem arising in the water supply. This will also help to ensure that unilateral decisions are not taken (see paragraph 7.1, above).

Dialysis Equipment

7.3 In advance of chloramination, NHS healthcare and estates staff must ensure that provision is made for the supply, installation and regular replacement of the appropriate granulated activated carbon (GAC) filters for dialysis machines. Previously, Safety Action Notice (SAN) (SC) 03/10 recommended that a notice of 12 months was required before changeover.

Distribution Infrastructure

7.4 The estates staff responsible for overseeing water networks within healthcare facilities must be informed as to the possible impact of chloramination on pipes and appurtenances. In particular, components containing rubber or vulnerable elastomers should be replaced when necessary by equivalents which are chloramine-resistant. In certain cases, it may be necessary to effect these changes in advance of chloramination.

7.5 Additionally, when pipes and fittings are being replaced they should be inspected for corrosion and other problems. Brass fittings should be dezincification-resistant (DZR). Due attention must be given to the need to avoid stagnation and dead-ends, although this is standard practice.

Education and Notification

7.6 All staff should be informed of the changeover to chloraminated water beforehand. This will hopefully prevent any unnecessary alarms over unfamiliar tastes and odours and encourage vigilance.

References

American Society for Microbiology (2007). ***Monochloramine Treatment Not As Effective In Protecting Drinking Water.*** Retrieved November 22, 2010 from http://www.sciencedaily.com/

Arrowsmith, L. W. M. (2002). ***Chloramine in Public Water Supplies and Implications for Healthcare***. Commissioned report.

Ashtabula Rubber Co. (2011). ***Chloramine in Potable Water Systems Causes Rapid Elastomer Deterioration.*** Retrieved Jan 8, 2011 from http://www.ashtabularubber.com/

Barlow, J. (2004). ***By-product of water disinfection process found to be highly toxic*****.** Retrieved Nov 29, 2010 from http://www.medicalnewstoday.com/

Chung, S., K. Oliphant, K., Vibien, P. and Zhang, J. (2006). **An Examination of the Relative Impact of Common Potable Water Disinfectants (Chlorine, Chloramines and Chlorine Dioxide) on Plastic Piping System Components.** Presented at the *2006 Plastic Pipes XIII Conference*, Washington, DC. Retrieved Jan 26, 2011 from http://www.janalab.com/research_knowledge.php

Edwards, M., Marshall, B., Zhang, Y. and Lee, Y. (2005). **Unintended Consequences of Chloramine Hit Home**. *Proceedings of the Water Environment Federation, Disinfection 2005*, 17, 240-256.

Flannery, B., Gelling, L. B., Vugia, D. J., Weintraub, J. M., Salerno, J. J., Conroy, M. J., Stevens, V. A., Rose, C. E., Moore, M. R., Fields, B. S. and Besser, R. E. (2006). **Reducing *Legionella* Colonisation of Water Systems with Monochloramine.** *Emerging Infectious Diseases*, 12, 588-596.

Florida Department of Health (2010). ***Risks to Small Water Systems – Nitrate*****.** Retrieved Jan 7, 2011 from http://www.doh.state.fl.us/

Guay, C., Rodriguez, M., Serodes, J. (2005). **Using ozonation and chloramination to reduce the formation of trihalomethanes and haloacetic acids in drinking water.** *Desalination*, 176, 229-240.

Hankin, S. (2001). ***Chemicals in Drinking Water: Chloramines*****.** Scottish Centre for Infection and Environmental Health.

Health and Safety Executive (2010). ***Control of*** **Legionella** ***bacteria in hot and cold water systems.*** Retrieved Jan 7, 2011 from http://www.hse.gov.uk/safetybulletins/*legionella*.htm

Health Canada (1995). ***Chloramines*****.** Retrieved Nov 17, 2010 from http://www.hc-sc.gc.ca/

Heffelfinger, J. D., Kool, J. L., Fridkin, S., Fraser, V. J., Hageman, J., Carpenter, J. and Whitney, C. G.; Society for the Healthcare Epidemiology of America (2003). **Risk of Hospital-Acquired Legionnaires' Disease in Cities Using Monochloramine Versus Other Water Disinfectants.** *Infection Control and Hospital Epidemiology*, 24, 569-574.

Kerr, C.J., Osborn, K.S., Robson, G.D. and Handley, P.S. (1998). **The relationship between pipe material and biofilm formation in a laboratory model system.** *Journal of Applied Microbiology* 85 (1), 29-38.

Kim, B. R., Anderson, J. E., Mueller, S. A., Gaines, W. A. and Kendall, A. M. (2002). **Literature review – efficacy of various disinfectants against *Legionella* in water systems.** *Water Research*, 36, 4433-4444.

Kirmeyer, G. J, Foust, G. W., Pierson, G. L., Simmler, J. J. and LeChevallier, M. W. (1993). ***Optimising Chloramine Treatment*.** AWWA Research Foundation and American Water Works Association.

Kirmeyer, G. J., Martel, K., Thomson, G. and Radder, L. (2004). ***Optimising Chloramine Treatment Second Edition**.* AWWA Research Foundation and American Water Works Association.

Kool, J. L., Carpenter, J. C. and Fields, B. S. (1999). **Effect of monochloramine disinfection of municipal drinking water on risk of nosocomial Legionnaires' disease.** *The Lancet*, 353, 272-277.

Lenntech. (2009). ***Disinfectants - Chloramines.*** Retrieved Jan 7, 2011 from http://www.lenntech.com/

Lubbers, J. R., Chauhan, S. and Bianchine, J. R. (1981). **Controlled clinical evaluations of chlorine dioxide, chlorite and chlorate in man.** *Fundamental and Applied Toxicology,* 1, 334-338.

Miranda, M., Kim, D., Hull, A. P., Paul, C. J. and Overstreet, M. A. (2007). **Changes in Blood Lead Levels Association with Use of Chloramines in Water Treatment Systems***.* *Environmental Health Perspectives,* 115 (2), 221-225.

Moore, G.C. (1998). ***Effects of Chloramination of Potable Water on the Performance of Materials.*** (ed.), Urban Water Research Association of Australia (UWRRA) Research Report No. 141, July 1998.

Raloff (2008). ***Lead-free? Faucets are anything but****.* Retrieved Nov 18, 2010 fromhttp://www.sciencenews.org/view/generic/id/38190/title/Science%2B_thePublic__Lead-free%3F_Faucets_are_anything_but

San Francisco Public Utilities Commission (2004). ***In Depth Chloramination Q&A: Statistics and General Information*.** Retrieved Nov 18, 2010 from http://www.westboroughwater.com/Documents/In%20Depth%20Chloramination%20Q.pdf

Scottish Executive Drinking Water Quality Unit (2002). **Note of Chloramination Meeting Held at 10:00 on Wednesday 24 July 2002 in Scottish Executive Victoria Quay Edinburgh.** Meeting Notes for SEDWQU, 24 July, 2002.

Silhan, J., Corfitzen, C.B. and Albrechtsen, H.J. (2006). **Effect of temperature and pipe material on biofilm formation and survival of Escherichia coil in used drinking water pipes: a laboratory-based study.** *Water Science Technology* 54(3), 49-56.

University Gazette (2010). ***Elfland takes on lead levels in plumbing as public health issue*.** Retrieved Nov 18, 2010 from http://gazette.unc.edu/archives2/10nov17/file.4.html

United States Environmental Protection Agency, Washington, DC, (1992). Integrated Risk Information System**:** ***Monochloramine*** *(CASRN 10599-90-3).* Retrieved on Feb 1, 2011 from http://www.epa.gov/iris/subst/0644.htm

Urban Water Research Association of Australia (1990). ***Chloramination of Water Supplies.*** Thomas, P.M. (ed.), Urban Water Services Association of Australia (UWRAA) Research Report No. 15, July 1990.

Walker, K. (2004). ***Chloramine – Impact for the NHS in Scotland*.** NHS Grampian Meeting Notes, 22 May 2004.

Walker, K. (2010). ***SBAR Report – Management of Chloramine Water Supply Regime*.** Meeting Notes for NWSAG, 9th November, 2010.

Water Quality and Health Council (no date). Retrieved on Feb 10, 2011 from http://www.waterandhealth.org/drinkingwater/safewater.html

Water Research Foundation (1999). ***How chloramines improve water quality.*** Retrieved Nov 16, 2010 from http://www.waterresearchfoundation.org/research/TopicsAndProjects/Resources/caseStudies/researchappsChloram.aspx

Water Research Foundation (2010a). ***Case Study: Philadelphia Tracks Customer Perceptions to Confirm Its Taste and Odour Practices*.** Retrieved Nov 23, 2010 from http://www.waterresearchfoundation.org/research/TopicsAndProjects/Resources/caseStudies/caseStudyPhilly.aspx

Water Research Foundation (2010b). ***Case Study: Brown Deer Water Utility's Booster Chloramine Station.*** Retrieved Jan 28, 2011 from http://www.waterresearchfoundation.org/research/TopicsAndProjects/Resources/caseStudies/caseStudyBrownDeer.aspx

Water Services Association of Australia (1990). ***Chloramination of Water Supplies*.** UWRRA Research Report 15.

Weintraub, J. M., Berger, M., Bhatia, R. (2006). **Heterogeneous dermatitis complaints after change in drinking water treatment: a case report.** *Environmental Health: A Global Access Science Source*, 5 (18).

Yu, J., Kim, D., Lee, T. (2010). Microbial **diversity in biofilms on water distribution pipes of different materials.** *Water Science Technology,* 61(1), 163-71.

Zhang, Y., Griffin, A., Edwards, M. (2008). **Nitrification in Premise Plumbing: Role of Phosphate, pH and Pipe Corrosion**. *Environmental Science and Technology*, 42 (12), 4280-4284. Retrieved on Feb 17, 2022 from http://pubs.acs.org/doi/abs/10.1021/es702483d