CHLORAMINES

HUMAN PHYSIOLOGICAL QUESTIONS

Q: What is the position of the regulatory agencies on the use of chloramine for drinking water disinfection?

A: Chloramine is a more effective distribution system disinfectant than chlorine. It has been used extensively in the U.S. and around the world for decades. Using chloramine as a distribution system disinfectant allows MAWC to comply with the USEPA regulations regarding levels of disinfection by-products in drinking water

Q: What happens when chloramine is ingested?

A: When people ingest chloramine, the chloramine is broken down quickly in the digestive system to chloride and ammonia. The chloride is eliminated through the urine, and the ammonia is transformed to urea in the urea cycle. Whether it comes from the breakdown of chloramine or the breakdown of proteins in foods like hamburger or tofu, ammonia is transformed to urea in the urea cycle. Ammonia does not bioaccumulate.

Q: Is there an impact of chloramine on human metabolism?

A: There is evidence that chloramine in the concentrations that are present in drinking water has no effect on human metabolism. A study conducted in 1993 and published in the peer-reviewed journal Environmental Health Perspectives showed no effects of chloramine ingestion at levels of 2mg/L. Healthy men were randomized to consume 1.5 liter per day of either distilled water, water containing 2mg/L chloramine, or water containing 15 mg/L chloramine for four weeks. At the end of the study, the men who were drinking 2mg/L chloramine, showed no difference in total cholesterol, triglycerides, HDL cholesterol, LDL cholesterol, apolipoproteins A1, A2, or B, compared to the men drinking distilled water. The 2 mg/L study group had no difference in thyroid metabolism compared to the distilled water group. The men who drank 15 mg/L had no differences except that their plasma apolipoprotein B levels, (a protein associated with LDL cholesterol) had risen by about 10%, whereas the men drinking distilled water and the men drinking water with 2 mg/L chloramine had their plasma apolipoprotein B levels drop slightly. The authors suggested that this finding may be due to chance (Wones et al., 1993).

Another study found that 10 healthy male volunteers experienced no biochemical or physiochemical response after drinking water treated with chloramine at concentrations up to 24mg/L and compared to a control group (Lubbers et al., 1981). Typical levels of chloramine in drinking water in the MAWC system are between 1 and 2 mg/L Total Cl_2.

Q: What happens when chloramine is inhaled?

A: Monochloramine is preferentially created in the MAWC disinfection process, and this compound is soluble and stable in the water. Monochloramine does not volatilize to any significant extent in a shower or bathing environment.

Vikesland et al (2001) showed that at $35°C$ and pH 7.5 monochloramine has a half-life of 75 hours. With this long half-life, the concern about inhalation exposures is unwarranted. The half-life of chloramine can be even longer (several weeks) in high quality waters at lower temperatures and slightly alkaline pH values typical for drinking water distribution systems (Wilczak et al., 2003b).

The Occupational Safety and Health Administration (OSHA) documents for concentrated chemicals and studies investigating exposure to chlorine and trichloramine at swimming pools in Europe are not relevant to drinking water. Monochloramine is highly soluble in water and loss to evaporation is minimal. Dichloramine is a little more volatile but it is not present in MAWC drinking water—based on the presence of ammonia, the pH range, and the extent of loss of disinfectant due to aeration. It is impossible for highly volatile trichloramine to exist in a chloraminated drinking water system without free chlorine (White, 1999). There is no record of inhalation concerns in the water industry.

Chloramine loss in the shower or bath is minimal as compared with chlorine, which was more volatile at all tested temperatures. At shower temperature of $100°F$ ($38°C$), which is typical for bathing, less than 8% of chloramine was lost from the water in the bath or shower, which is consistent with the literature. In chlorinated water, 12 to 94% of the chlorine was lost in the shower at $100°F$, depending on pH. In cold water ($67°F$, $20°C$), the loss of chloramine in the shower or bath was within the measurement error (i.e., insignificant). Relatively less chloramine was lost in the shower compared with chlorine.

Q: Can chloramine be absorbed through skin during bathing?

A: There have been no published studies on the absorption of chloramine through the skin, in either animals or humans (USEPA 1994). This is likely because there is no evidence that chloramine would come out of solution in the water to enter through the skin.

Q: What is the damage to blood cells by chloramine?

A: If chloramine enters the blood stream directly, it combines with hemoglobin (red blood cells) so it can no longer carry oxygen. This can occur if chloramine is not removed from water used in dialysis machines but cannot happen by drinking chloraminated water. Both chlorine and chloramine need to be removed from kidney dialysis water.

Q: Can one safely wash an open wound with chloraminated water?

A: Yes. It is safe to use chloraminated water in cleaning and open wound because virtually no water can enter the bloodstream that way (Kirmeyer et al., 2004).In dialysis patients, blood may come into direct contact (via a semi-permeable membrane) with between 90 and 190 liters of water in a single session. Even if a person soaked a bleeding wound in one liter of water at the typical concentration of 2mg/L for several hours the wound would be exposed only to the 2 milligrams of chloramine in the liter. Not all of that would be absorbed into the bloodstream via the wound, and even if it were, it would still not be enough to make any difference in the usual level of hemoglobin that is available to carry oxygen in the bloodstream.

Q: Can chloramine and ammonia bioaccumulate in the body?

A: Chloramine and ammonia do not bioaccumulate in the body. Chloramine is broken down quickly in the digestive system and eliminated through the urine. The breakdown product ammonia is converted to urea in the urea cycle. All proteins that people ingest are broken down into ammonia and converted to urea in the same way. These products do not bioaccumulate. Chloramine is not a persistent chemical and is neutralized rapidly by common drinks (e.g. tea, coffee, juices) or foods (e.g. chicken stock).

Q: Is ammonia toxic and/or digestible?

A: Ammonia, in the concentrations used for drinking water disinfection, is not toxic. Whether it comes from the breakdown of chloramine or the breakdown of proteins in foods like hamburger or tofu, ammonia is transformed to urea in the urea cycle. Ammonia does not bioaccumulate.

Many foods contain ammonia, and the exposure via drinking water is a small fraction of that in other foods. Water typically contains about 2 mg/L chloramine and less than 1 mg/L ammonia, typically 0.5 mg/L NH_3-N, so ingesting 1 liter of water results in ingestion of less than 1 mg NH_3. By comparison, a one-ounce serving of cheddar cheese contains about 31 mg NH_3 (derived from Rudman et al.,1973).

Q: What types of evidence are taken into account when evaluating the toxicity of drinking water disinfectants?

A: Three different kinds of evidence are available with regard to the potential adverse effects of disinfectants in drinking water: (1) information from animal testing; (2) information from feeding studies in humans: and (3) information from epidemiologic studies. The Integrated Risk Information System (IRIS) provides a summary of the USEPA's risk assessment of chloramine. The summary includes information on oral

toxicity, chronic exposure and carcinogenicity of chloramine, based on human and animal studies.

Q: What is the evidence that drinking or bathing in chloraminated water does not cause health problems? Why haven't there been long-term studies of the health effects of chloraminated water?

A: The Integrated Risk Information System (IRIS) provides a summary of the USEPA's risk assessment of chloramine. The summary includes information on oral toxicity, chronic exposure and carcinogenicity of chloramine, based on human and animal studies. The oral reference dose for chloramine of 0.1 mg/kg/day is based principally on the National Toxicology Program studies in rats and mice that were published in 1992. (US DHHS, 1992) The rat studies found "no clinical changes attributable to consumption of chloraminated water" and "no non-neoplastic lesions after the 2-year treatment with chloraminated water." The mouse studies had similar results (USEPA, 1992). One study in humans found no acute effects on lipid and thyroid metabolism associated with ingestion of chloraminated water at 2mg/L concentration (Wones et al., 1993).

Both chlorination and chloramination result in the formation of disinfection by-products, although fewer halogenated by-products are formed with chloramine. Some studies have looked at the relationships between different health outcomes and the use of the chloraminated water compared to water that is not chloraminated. One study (Zierler et al., 1988) showed that people that consumed water disinfected with chloramine had lower risk of bladder cancer compared to people who consumed chlorinated water. This result is likely due to the fact that chloraminated water has fewer disinfection by-products than chlorinated water. In 1993, McGeehin and colleagues published a study finding that the longer people were exposed to chloraminated surface water, the lower their risk of bladder cancer. The study also found that the risk of bladder cancer among those exposed to chloraminated water was equivalent to the risk among those who consumed untreated groundwater (McGeehan et al., 1993), More recently a large study did not find an association between disinfection by-product exposure and pregnancy loss in three study sites, two of which used chloramination (Savitz et al., 2005).

Another study by Zierler et al (1986) found a slightly increased mortality due to pneumonia and influenza in chloraminated cities versus those that use chlorine. In the 20 years since this study was published, these results have never been replicated, pointing to the likelihood of alternative explanations for these findings, which are well discussed in the manuscript (e.g. that differences in reporting or recording deaths could have led to these results, or that other differences such as smoking, occupational exposures, or other environmental differences could have explained the finding). A recent study of Legionella showed that chloramine has a beneficial effect in that it virtually eliminated the presence of Legionella species in San Francisco (Flannery et al 2006). Harms and Owen (2004) received a number of inquiries on the following topics prior to chloramine conversion at a large water utility in Florida: contact lenses, immune

deficiencies, allergies, dermal absorption of chlorine and chloramine, ulcers and digestive disorders. A review of literature and inquiries to national experts found no indication that chloramine was related to or had any impacts on these topics. Harms and Owen (2004) conducted a survey of chloramination practice among 63 utilities nationwide (out of 111 utilities contacted): 17 respondents listed medical issues as a potential concern but identified none as a problem in practice, disinfection efficiency was identified by 15 respondents as a potential concern but none in practice, and increase in microorganisms was listed by 10 as a potential concern but none in practice.

Q: Can drinking or bathing in chloraminated water cause chronic or acute health conditions, including buildup of fluid in lungs, pulmonary edema, death, blood in stool, pain, heart failure, blue-baby syndrome, weight loss, weight gain, hair loss, depression or oral lesions?

A: Presently, there is no evidence in the medical literature that links chloraminated drinking or bathing water to any of these health conditions. Lack of evidence does not necessarily imply that chloramine is not related to any of these conditions, however the likelihood of a relationship to these health conditions is minimal, principally because there is also no evidence that exposure to chloramine from drinking or bathing water is occurring in a way that people are not able to deal with physiologically.

For example, when drinking water is ingested, chloramine gets broken down. The chloride is eliminated through the urine, and the ammonia is transformed to urea in the urea cycle. There is also no evidence that chloramine would be absorbed to the bloodstream through the skin, as such, there have been no published studies on the absorption of chloramine through the skin, in either animals or humans (USEPA, 1994). There is no evidence that chloramine volatizes in the shower. There is always the possibility that individuals have specific hypersensitivities to chemicals in their environment, however there is no evidence that any of these alleged health effects occur on the population level. People with individual health problems may wish to discuss treatment alternatives with their doctors. Chloramination is not a new technology. Chloramine has been used as a drinking water disinfectant for 100 years (chlorine for 110).

The concerns of chloramine being a respiratory irritant may be based on a concern that one can be exposed to dichloramine and trichloramine in their shower or bath, however these chloramine species do not form in the shower, bath or drinking water.

The conditions to form dichloramine are: pH range of 4 to 6, a 5:1 -7.6:1 chlorine to ammonia weight ratios or pH range 7 to 8 at a 10:1 weight ratio (Kirmeyer et al, 2004). The conditions to form tri-chloramine are at pH < 4.4 at weight ratios greater than 7.6:1 (Kirmeyer et al, 2004). The conditions to form either dichloramine or trichloramine do not exist in the MAWC distribution system. MAWC maintains slightly alkaline water pH in the distribution system for corrosion control (the target is 7.3 – 7.6 depending on the water source). The pH is stable in the system and does not drift appreciably. MAWC provides rigorous quality control to maintain a target chlorine to ammonia-nitrogen

weight ratio of 3:1 to 4:1 at Indian Creek and 4:0 to 4.2:1 at George R. Sweeney at the point of chloramine (monochloramine) formation. This ratio may decrease slightly in the distribution system as chloramine demand is exerted during water transmission and storage. Both dichloramine and trichloramine are short lived and even if trace amounts were formed, neither of these chloramine species would not persist to impact customers. Dichloramine and trichloramine will not form as long as proper pH of the water is maintained above the range of their formation, and as long as minimum free ammonia is present to maintain chlorine to ammonia weight ratio less than 5:1. Both of which MAWC does.

Some water systems have monitored water quality speciating for mono-, di-, and trichloramine; however, these monitoring programs were discontinued because di- and trichloramine was never found. Water quality labs at water utilities typically do not speciate chloramine but measure total chlorine.

Studies describing the fate of chloramine in ambient air do not exist. In the air phase, it would be expected that chloramine would dissipate due to advection and dilution and would be subject to reaction, although no information has been located characterizing reactions for chloramine in a gaseous state. Various studies indicate that chloramines are thermodynamically unstable and susceptible to photolysis. Monochloramine and dichloramine are very water soluble and are thus susceptible to removal from the atmosphere by rain (Environment Canada, 2001). Inorganic chloramine fate is governed largely by water-phase processes (Environment Canada, 2001).

Q: Does chloramine cause asthma?

A: There is no evidence that chloraminated drinking water causes or exacerbates asthma symptoms. While some studies have found links between nitrogen trichloride (trichloramine) and asthma symptoms, no studies have demonstrated an association between exposure to chloramine in public drinking water supplies and asthma symptoms. This is because trichloramine cannot exist in MAWC chloraminated drinking water in the absence of free chlorine.

Many different environmental conditions are responsible for asthma and its incidence is increasing worldwide, particularly in developing countries (where chloramine is not typically used). Factors including second hand tobacco smoke, air pollutants, occupational exposures, microbes, dietary factors, and allergens such as dust mites, cockroaches, and cat dander may contribute to worsening existing asthma conditions (Eder et al., 2006).

Q: Does chloramine cause dry skin, skin rashes?

A: A literature review indicated that skin rashes have not been associated with exposure to chloramine. In the peer-reviewed medical literature approximately 10% to 12% of the

population experiences dermatitis on a given day. Dermatitis may be caused by any number of inherited and environmental factors, including: soap, detergents and any prolonged wet work, strong chemical cleaning products including concentrated oxidants and disinfectants (e.g., chlorine bleach), paints, solvents, glues and resins, citrus fruits and vegetable juices, including tomato, onion and garlic, acids and alkalis, abrasive dust from stones, bricks, cement, sand or soil, nickel which may be found in jewelry, cutlery and coins, perfume and fragrances in toiletries and skin care products, plants, particularly chrysanthemums, primula and grass, rubber (latex), which can be found in some protective gloves, the adhesive used in sticking plasters, metal primers and leather, molds, and pharmaceutical products.

The customer complaints/inquiries at utilities that converted to chloramine in recent years were that "skin feels dry or scalp itches more:. These utilities felt that customers had made an association between a known change and an unrelated condition. Calls with similar complaints lasted for a couple of months. The response to known changes in water treatment procedures has been studied and documented (Lamberg et al., 1997; Lyons et al., 1999).

Skin complaints associated with municipal drinking water are not uncommon, however there is no evidence of a link between any specific water quality perameter and such complaints (du Peloux Menage & Greaves, 1995; Bircher, 1990).

Q: If chloramine is not a cause of skin irritation symptoms reported by people, what other reasons might explain why some people experience fewer symptoms when they shower or bath with water that has not been chloraminated?

A: When people reduce the frequency or change the location that they bathe, or when they bathe using bottled water, they are not just changing the quality of the water they are using. They are also changing many other things that may have been responsible for symptoms that they may believe were related only to the water. For example, the temperature of the water may be different, the types of cleaning products that are used in each location may differ, the types of soaps and lotions that the person is using may have changed, the length of time spent in the shower or bath may have been reduced, or other environmental allergens that were present in one location may not be present in the other. The American Academy of Dermatology recommends reducing the duration, temperature and frequency of baths and showers to help people who experience dry skin, itchiness, and other problems with their skin (American Academy of Dermatology, 2006).

Q: Is chloramine a carcinogen?

A: The USEPA has not classified chloramine as to its carcinogenicity because there is inadequate human data and equivocal evidence of carcinogenicity from animal bioassays (USEPA, 1992).

USEPA imposes maximum residual disinfectant levels for chlorine and chloramine at 4 mg/L and chlorine dioxide at 0.8 mg/L based on 12-month averages. None of the disinfectants are carcinogenic. The toxicological effects of disinfectants (e.g., chlorine and chloramine) are nonspecific and occur at concentrations well above the suggested use levels. More specific effects appear to be associated with hypochlorite solutions, chlorine dioxide, and iodine with respect to effects on thyroid function. Only in the case of iodine does this seem to limit its long term use in the disinfection of municipal drinking water (Bull et al., 2001).

Q: Is there evidence of a link between chloramine in drinking water and the occurrence of Acanthamoeba Keratitis?

A: Ancanthamoeba Keratitis is a waterborne ameba commonly found in the environment that may cause eye infection. Most people will be exposed to acanthamoeba during their lifetime and will not get sick. Although an early investigation of increased acanthamoeba keratitis rates in Illinois hypothesized that there may be a link to the type of disinfectant used in municipal drinking water, no data supporting this hypothesis have been presented in the initial or subsequent publications. Preliminary results from a CDC investigation do not support this relationship. The CDC is working with EPA to address this more completely in an ongoing comprehensive case-control study.

Q: Is there any association between chloramine and heart failure?

A: Chloramine is not associated with heart failure. Chloramine has a different molecular structure from, for example, phenylpropanolamine, which has been linked to heart problems.

Q: What are the impacts on dialysis patients and can chloramine contribute to kidney failure?

A: Chloramine ingestion does not contribute to kidney failure. Both chlorine and chloramine can harm kidney dialysis patients during the dialysis process if they are not removed from the water prior to dialysis treatment. This is because between 90 and 190 liters of water is used in the kidney dialysis treatment process, and this water comes into direct contact (via a semi-permeable membrane) with the patient's bloodstream. To protect patients during the dialysis process, chloramine, like chlorine, is removed from tap water at treatment facilities before dialysis treatment takes place (Amato 2005). Kidney dialysis patients can safely drink chloraminated water as residual disinfectants are broken down in the digestive process. For the standard methods used in kidney dialysis systems, see http://www.aami.org/publications/standards/dialysis.html. The transpacific Renal Network can be found at: ESRD Network #17 Home Page.

Q: Can chloramine caused gastric lesions?

A: There is no evidence that chloramine ingested in drinking water causes gastric lesions. This concern is likely due to a misunderstanding of scientific articles that investigate the role of monochloramine produced by cells in cancer associated with helicobacter pylori infection (see, for example, Iishi et al., 1997). The relevance of this research to drinking water or other exogenous exposures is not known.

Q: What is the interaction between chloramine and acid reflux?

A: Chloraminated water will not affect acid reflux. According to the Aociety of Thoracic Surgeons, gastroesophageal reflux disease, commonly referred to as acid reflux, can be aggravated by certain foods and drinks. This disease is thought to be caused by a deficiency in the stomach valve allowing the contents of the stomach to be released into the esophagus, where irritation occurs (Ferguson, 2000).

Q: Is chloraminated tap water safe for people with disease such as AIDS, cancer, kidney dialysis, diabetes, hepatitis, or lupus?

A: Chloraminated water is safe for people with suppressed immune systems or other diseases. A comprehensive search of the medical literature does not reveal any studies showing that people with chronic diseases, including those with compromised immune systems and those who are taking medications, have any special problems metabolizing chloramines.

Q: Why does the CDC recommend that people with compromised immune systems boil their drinking water?

Neither chlorine, nor chloramine can destroy certain protozoans like Cryptosporidium. Therefore some people who have compromised immune systems may wish to use bottled water or to boil their water to make sure that they are not exposed to pathogens that might be presented in the water despite the use of these disinfectants. In 2006, the USEPA promulgated a new Federal regulation, the Long Term 2 Enhanced Surface Water Treatment Rule, to specifically regulate the removal or disinfection of Cryptosporidium (USEPA, 2006b).

Q: Are there any known interactions between chloramine and medications?

A: When drugs are tested in clinical trials most investigators do not specify that water other than tap water be used. Enough cities already use chloramine that it is quite likely that the efficacy of some drugs is already based on how thy act in persons drinking

chloraminated water. Chloramine interaction with pharmaceuticals has not been specifically studied.

Q: What is the general sensitivity to ammonia? Is there any damage from ammonia and upsets to the pH balance of the body?

A: The ammonia is predominantly bound in chloramine with a slight excess of so called "free ammonia" and will not produce adverse effects from exposure by washing. Ammonia is released during the digestion of chloramine in the digestive system.

Q: Are people with urea cycle disorder able to drink chloraminated water?

A: People with urea cycle disorder are not able to metabolize ammonia, therefore it is certainly possible that people with this condition could benefit by drinking non-chloraminated water if they are reducing their ammonia intake in other ways as well. Since ammonia-containing foods are common, people with these disorders would probably achieve greater reductions by avoiding foods with higher ammonia contributions first. Ingesting 1 liter of water results in ingestion of less than 1 mg NH_3 (typically less than 0.5 mg/L NH_3). By comparison, a one-ounce serving of cheddar cheese contains about 31 mg NH_3 (derived from Rudman et al, 1973). We have been unable to identify any medical literature that suggests drinking chloraminated water is an important exposure pathway for people with urea cycle disorder. Boiling water for 20 minutes will remove chloramine and ammonia.

Q: Is it safe for babies to drink chloraminated water?

A: Yes.

Q: Have any Independent health assessments been conducted on the use of chloramine for disinfection?

A: In 2005, the CCLHO reviewed current knowledge and evidence regarding the efficacy and safety of monochloramine in drinking water. CCLHO concluded that monochloramine is better than chlorine for maintaining a small (residual) amount of disinfectant in water distribution systems where high concentrations of trihalomethanes or haloacetic acids result from chlorination. Trihalomethanes and haloacetic acids are halogenated organic compounds that increase the risks of certain cancers.

Q: Who is the CCLHO?

A: The California Conference of Local Health Officers is comprised of all legally appointed local health officers in California. In addition, physicians who are Deputy Health Officers or Assistant Health Officers may be appointed as non-voting associate members. The Conference was established by statute in 1947 to advise the California Department of Health Services (now the California Department of Public Health (CDPH), other departments, boards, commissions, and affecting health. For more information, please see: http://www.dhs.ca.gov/cclho/AboutUs.htm

Q: What are the impacts of chlorine and chloramine on fish and aquatic organisms?

A: Fish and other aquatic organisms are very sensitive to both chlorine and chloramine and may die if exposed to these oxidants. Concentrations of chloramine as low as 0.07 mg/L have been shown to be lethal to coho salmon in 96 hour studies.

Chloramine does not bioaccumulate or transfer up the food chain (Environment Canada, 2002). For fish-owners, the challenge with chloramine is twofold: it does not dissipate rapidly so letting the water sit for a day or two will not make it safe for fish, and the "chlorine neutralizers" are not effective for chloramine (Harms and Owen, 2004). The ammonia in the chloraminated water may be harmful to fish under certain conditions. Chloramine neutralizing chemicals are available in pet chlorinated water to the environment.

The mechanism responsible for the toxicity of chloramine to fish differs somewhat from chlorine toxicity. Chlorine does not readily pass the permeable gill epithelium compared with chloramine. Chlorine destroys the cells of the gills by oxidation, causing an impairment of normal gaseous exchange. Affected fish exhibit labored respiration due to an inability to utilize available dissolved oxygen in the water. Chloramine crosses the gill epithelium with an insignificant amount for cellular damage as compared with chlorine. Once the chloramine has entered the bloodstream it chemically binds to iron in hemoglobin in red blood cells causing an inability of the cells to bind oxygen (Environment Canada, 2001; Kirmeyer et al., 2004). The toxicity of chloramine to aquatic organisms is dependent on biological species, chloramine compounds, presence of chlorine and organic chloramines, pH, temperature, exposure duration and life stage of the biological species (Environment Canada, 2001).

Two methods can be used to remove chloramine from water to be used in aquariums or ornamental fish ponds: addition of specific agents, which will remove chloramine and ammonia, or use of granular activated carbon (GAC) filter. A home test kit may be purchased to test the aquarium water for total chlorine and ammonia. Most pet stores sell dechlorinating agents and recommend their use. It may take more dechlorinating agent and more time to remove chloramine than chlorine. Ammonia can be toxic to fish, although all fish produce some ammonia as a natural by-product. Commercial products

are available at pet stores to remove excess ammonia. Biological filters, natural zeolites and pH control methods are also effective in reducing the toxic effects of ammonia. Ammonia removal is especially important at high pH, because at a higher pH, ammonia is more toxic to fish. Chloramine can also be removed by using a GAC filter. It is important to allow the appropriate amount of contact time for chloramine removal using that method (Kirmeyer et al., 2004).

Q: What are the effects of ammonia on fish?

A: Ammonia is not toxic below pH 7, since ammonia is in the ionized ammonium ion form NH_4.

For example in water with a pH of 6.9 and at a temperature of $24^{\circ}C$, 99.58% of the ammonia is in the non-toxic ammonium ion form and 0.42% as potentially toxic unionized ammonia. However, at the same temperature but at a pH of 8, such as in marine aquarium, the percentage of ionized ammonia is 90.51%, and the unionized form 9.49% (Kirmeyer et al., 2004).

Ammonia can be toxic to fish above pH 7, although all fish produce some ammonia as natural byproduct. Ammonia is also released when chloramine is chemically removed. Although ammonia levels may be tolerable in individual tanks or ponds, commercial products are available at pet supply stores to remove excess ammonia. Also, biological filters, natural zeolites and pH control methods are effective in reducing the effects of ammonia (Kirmeyer et al 2004). In established aquaria and pond systems with properly functioning biological filter beds, the nitrifying bacteria will remove the ammonia produced during dechloramination in a fairly short period of time. Therefore it may not be necessary to use zeolites under such conditions. However, they should be used whenever setting up new aquariums, when the water is alkaline, and where there is insufficient biological filtration. It is also important to note that zeolites can only be used for the removal of ammonia in fresh water. In salt water, zeolites are unable to function properly due to the high concentration of sodium chloride.

Q: Will chloramine dissipate when watering the lawns and how will runoff impact the environment?

A: Watering lawns releases low volumes of water and disinfectant and is considered an incidental discharge. Chloramine will dissipate as a result of lawn watering because chloramine will be neutralized by the soil particles (this process is termed "chloramine demand"). The small amount of chloramine should not have any effect on plants of any type. Based on the available evidence, adverse effects on soil microorganisms and associated soil processes from inorganic chloramine are considered unlikely (Environment Canada, 2001).

Incidental discharges should not pose a direct risk to fish. Most of the water that is used for landscape irrigation percolates into the ground. As this water gradually runs off landscaping, soil or pavement, the "chloramine demand" consumes the residual chlorine or chloramine, effectively neutralizing any residual before it enters the storm sewer or bay. There will be no effect on estuarine or marine organisms.

A high volume direct discharge of chloraminated water to the environment can result from pipeline breaks or flushing fire hydrants. As with chlorinated water, this needs to be avoided because chlorine residual in the chloraminated water may pose a direct acute health risk to fish in creeks and streams. Water companies use dechlorinating agents to remove chloramine from the water during high volume discharges and while flushing fire hydrants.

Q: What are the impacts of chloramine on pets?

A: Chloramine is safe for all mammals and birds and most reptiles. Chloramine is not expected to cause any health problems for dogs or cats. Some people have been worried because trichloramine has been associated with a disorder called "canine hysteria" in dogs. However, this disorder is associated with trichloramine, not monochloramine; trichloramine is not present in the MAWC chloraminated drinking water.

Harms and Owen (2004) interviewed several veterinarians in a local chloraminated system about impacts to pets and no issues or concerns were identified by these professionals. With the exception of one reptile group (turtles) and amphibians, no known adverse effects are reported in the literature for exposure to or consumption of chloraminated water. Turtles and amphibians spend a significant amount of time in water and, based on recommendations of a local zoological garden, it was recommended that both chlorine and chloramine be removed from their water. No adverse impacts on any pets have been reported to the utility.

Q: If cows drink chloraminated water will chloramine be in their milk?

A: No, chloramine does not enter cows' milk. Monochloramine is broken down in the digestive process and it is "not expected to enter the systemic circulation" (Hankin 2001). Additionally, it is rare for cows to be supplied with treated drinking water. Most livestock drink untreated well water or water from streams, not tap water. Even if they were exposed to monochloramine, chloramine would be broken down in their digestive process.

Q: Is it necessary to remove disinfectants from drinking water in a home setting?

A: No, chlorinated and chloraminated water is deemed safe for people and animals to drink, and for all other general uses including bathing. The removal of either chlorine or chloramine from drinking water is not necessary for public health but some customers may elect to do so for common household purposes based on personal preference. Chloramine is not persistent disinfectant and decomposes easily from a chemistry point of view (Valentine et al, 1998) but for water supply purposes chloramine is stable and it takes days to dissipate in the absence of substances exerting chloramine demand (Wilczak et al., 2003b). Therefore it is not practical to remove chloramine by letting an open container of water stand because it may take days for chloramine to dissipate.

However, chloramine is very easily and almost instantaneously removed by preparing a cup of tea or coffee, preparing food (e.g., making a soup with chicken stock). Adding fruit to a water pitcher (e.g., slicing peeled orange into a 1-gal water pitcher) will neutralize chloramine within 30 minutes. If desired, chloramine and ammonia can be completely removed from the water by boiling; however, it will take 20 minutes of gentle boil to do that. Just a short boil of water to prepare tea or coffee removed about 30% of chloramine.

If desired, both chlorine and chloramine can be removed for drinking water purposes by an activated carbon filter point of use device that can be installed on a kitchen faucet. If desired, both chlorine and chloramine can be removed for bathing purposes by dissolving Vitamin C in the bath water (1000 mg Vitamin C tablet will neutralize chloramine in an average bathtub). MAWC does not recommend that customers remove disinfectants from drinking water. Customers desiring to do so should consult with their physician.

Q: Why is it important to remove both chlorine and chloramine from the tap water used for hemodialysis treatment of kidney dialysis patients?

A: While tap water is safe for drinking, bathing and other household uses, it is not acceptable for use in hemodialysis. People can safely drink chloraminated water because their digestive process neutralizes chloramine before it enters the bloodstream. But, just like with fish that take chloramine directly into their bloodstream through their gills, the membranes used for hemodialysis do not remove chloramine. In fact, the hemodialysis fluid must be free of even traces of compounds that are safe to drink.

Residual disinfectants, particulates, organics, ions and remaining microorganisms are removed prior to hemodialysis units. The average person consumes approximately 2 liters of water per day in different form (juice, coffee, etc.), whereas a patient on hemodialysis uses anywhere from 90 to 190 liters of water (in the dialysate) per treatment. In the dialyzer the blood is separated from the dialysate by a semi-permeable membrane, which is only selective with respect to molecular size but is not contaminant specific. The recommended maximum concentrations for hemodialysis water are 0.5 mg/L chlorine and 0.1 mg/L chloramine (Amato, 2005).

Carbon absorption is used to remove either chlorine or chloramine because both of them destroy red blood cells. Chlorine and chloramine are not removed by the reverse osmosis membrane and can also damage the membrane. At least two carbon beds are required in series for a total of 10 minutes empty bed contact time at the maximum flow rate to remove either chlorine or chloramine, followed by a 1 to 5-um filter to remove carbon fines before the reverse osmosis unit (Amato, 2005).

Q: Why are some industrial users advised to remove chloramine but people are not?

A: Chloramine is added to the water for public health protection. Distilled or deionized water is required for many industrial processes and products. On the other hand, distilled or deionized water would not be appropriate for distribution and consumption due to its corrosivity, taste, and health impacts. Three special user groups, kidney dialysis patients, aquarium owners, and businesses or industries that use water in their manufacturing processes may need to remove chloramine from the water prior to use as they did with chlorine. Products to remove or neutralize chloramine are readily available.

Biotechnology companies and breweries must take treatment precautions for both chlorine and chloramine. Beer manufacturers must remove chlorine and chloramine because either will inhibit the growth of yeast. Photo labs may need to remove chlorine or chloramine form the water because it may interfere with the chemicals used to develop the film and may adversely impact the colors in the final print. Chip manufacturers and pharmaceutical companies have very specific water quality requirements for their manufacturing process.

Q: What methods are used by the industry to remove chloramine and ammonia?

A: In the water industry, the most widely practiced methods of dechlorination are the addition of reducing agents, for example, sulfite compounds, hydrogen peroxide and ascorbic acid – Vitamin C (Tikkanen et al., 2001). Granular activated carbon (GAC) filters are also used for dechlorination (Kirmeyer et al., 2004). Breakpoint chlorination is used routinely by some utilities to remove chloramine and/or ammonia in the source water or to avoid blending chlorinated and chloraminated water. During breakpoint chlorination, excess chlorine in chloraminated water consumes the available ammonia and the remaining disinfectant residual exists as chlorine.

Q: How much time will it take for chlorine and chloramine to dissipate when left standing?

A: While both chlorine and chloramine residuals decrease with time, chloramine decreases more slowly than chlorine. Chlorine may take days to dissipate in a pitcher

left on a counter and it will take longer for chloramine. The decomposition rate will be faster when the water is exposed to air and sunlight (Wilczak et al., 2003b). Chloramine, like chlorine, will eventually dissipate completely over time but it is not practical to let the water sit for it to dissipate. Other methods may be used to remove chloramine if desired for aesthetic reasons.

Q: Can chlorine and chloramine be removed by boiling?

A: Boiling the water for 20 minutes will remove chloramine and ammonia. MAWC does not recommend for customers to boil water for such long periods of time because it is not necessary from a public health perspective and poses risk of scalding. However, such tests demonstrate that chloramine is not a persistent chemical, which does not remain in the water after cooking. Additionally, many foods and drinks rapidly neutralize chloramine without the necessity of boiling (e.g., tea, coffee, stock, orange juice, etc.).

Q: Can charcoal filters remove chloramine?

A: Charcoal or granular activated carbon (GAC) filter can reduce chloramine concentrations of 1 to 2 mg/L to less than 0.1 mg/L. The GAC filter may be followed by a reverse osmosis (RO) filter to remove the carbon fines. RO should not be used alone as chloramine will pass through the membrane and may damage the RO membrane elements (some RO units are resistant to chlorine and chloramine). A GAC filter will remove chloramine, allowing RO to effectively remove other constituents.

Q: Are GAC filters certified and if so by whom?

A: As a public agency, MAWC does not test, endorse or recommend specific water filtration products. Contact the NSF International, a nonprofit organization that independently tests and certifies drinking water filtration products. Website: NSF International, phone 877-867-3435.

The removal of chloramine is not necessary from a public health perspective; however, some customers may choose to remove either chlorine or chloramine for drinking purposes. Several units are certified and listed on the NSF International website http://www.nsf.org/Certified/DWTU/ for the removal of chloramine: smaller units certified at flows below 1 gpm (service cycle from 300 to 1600 gal) are appropriate for drinking water applications at a kitchen faucet, larger units certified at 5 gpm (service cycle from 15,000 to 84,000 gal) could be used for other uses if desired. NSF International verifies claims of 85% chloramine removal of 3 mg/L. GAC filters, if desired, need to be installed on the kitchen sink cold water tap as filter effectiveness decreases in warm or hot water. The removal of disinfectant from the water may increase the potential of bacterial regrowth in plumbing.

Q: Can Vitamin C be used to remove chlorine and chloramine for bathing purposes?

A: Exposures via respiration do not occur from use of chloraminated drinking water. Based on personal preference, some individuals may choose to reduce exposure to chlorine or chloramine. Vitamin C (ascorbic acid) is included in AWWA Standard (AWWA, 2005b) as one of the methods for dechlorination of disinfected water mains. MAWC and other utilities have used Vitamin C for dechlorination prior to environmental discharges of chlorinated and chloraminated water. Since ascorbic acid is weakly acidic, the pH of water may decrease slightly (Tikkanen et al., 2001). Ascorbic acid has been used for a long time as one of the dechlorinating agents for preservation of chlorinated or chloraminated water samples for laboratory analysis.

The removal of chloramine is not necessary from a public health perspective; however, some customers may choose to remove either chlorine or chloramine for bathing purposes. There are no NSF International certified point of use devices utilizing Vitamin C, however it has been determined that 1000 mg of Vitamin C (tablets purchased in a grocery store, crushed and mixed in with the bath water) remove chloramine completely in a medium size bathtub without significantly depressing pH. Shower attachments containing Vitamin C can be purchased on the internet, as well as effervescent Vitamin C bath tablets. The 1000 mg effervescent Vitamin C tablets dissolve readily without residue but may depress pH more than regular Vitamin c tablets purchased in grocery stores. Some shower attachments with Vitamin C marketed on the internet are effective in removing chloramine: however, the claims posted on the internet as to their replacement frequency appear to overestimate the duration when the shower attachment is effective. There are reports of the benefits of Vitamin C for skin care (Griffith, 1998) and various cosmetics are available in stores that contain Vitamin C. MAWC does not recommend for customers to use Vitamin C for bathing purposes and anyone desiring to do that should consult with their physician.

Q: What are other simple methods to remove chloramine for drinking water purposes?

A: The removal of chloramine is not necessary from a public health perspective; however, some customers may choose to remove chloramine for aesthetic reasons. Placing a few slices of fruit (e.g., orange, lime, mango, strawberries) or vegetable (cucumber) in a water pitcher will effectively dechlorinate the water within a few hours. A peeled and sliced medium size orange can be used for a 1-gal water pitcher and will completely dechlorinate the water in 30 minutes. The fruit can then be removed from the water. The water pH will become closer to neutral or acidic (if lime or lemon is used). The ammonia will not be removed but most of the fruits contribute some or more ammonia than the drinking water.

Preparing a cup of tea (black, green, caffeinated, decaffeinated, and herbal) also removes chloramine, as does coffee prepared in a common coffee maker.

Q: What are the methods for removing chloramine from fish aquariums?

A: Just as with chlorine, chloramine can harm saltwater and freshwater fish, reptiles, shellfish, and amphibians that live in water, because they take chloramine directly into their bloodstream through their gills. People and animals that don't live in water can safely drink chloraminated water because their digestive process neutralizes chloramine before it enters the bloodstream. Effective procedures are available to remove chloramine and ammonia. Commercial establishments and hobbyists involved in fish rearing need to take precautions to prevent losses. There are two methods that can be moved to remove or neutralize chloramine before adding water to a fish tank, pond, or aquarium: (1) GAC filtration system specifically designed to remove chloramine, or (2) conditioner or additive that contains a dechloraminating chemical for both ammonia and chlorine. Products are available at local pet and aquarium supply stores. Residential and commercial fish owners are advised to verify which method is best for them with their pet store or aquatic/aquarium retailer.

If too much dechlorinating agent is added to the aquarium or pond water, it may bind up the oxygen in the water. In this case, the fish may suffocate. It is important to carefully follow the label instructions.

Q: Does the water chemistry (pH, mineral content) change as a result of chloramine addition?

A: Chloramination, as practiced by MAWC, does not affect pH or mineral content.

Q: Why aren't tap water and bottled water monitored by the same agency? Is bottled water better than tap water?

A: Soft drinks and bottled water are monitored by the federal Food and Drug Administration (FDA). Tap water is regulated by the USEPA and the PADEP. The act of bottling the water legally makes the water a packaged product, and legally these are all regulated by the FDA, rather that the USEPA. The FDA and USEPA standards can differ and the USEPA regulations and the testing requirements are more stringent than those required of the bottled water by the FDA. Bottled water is often times tap water that has been passed through additional filtration, GAC adsorption, and disinfection steps. However, this does not mean that bottled water is necessarily better than tap water.

50 million empty water bottles are thrown away or recycled every day in America (Morris, 2007), which equals over 18 billion water bottles annually. The manufacture of a single bottle requires more water that the bottle will ultimately hold. The transport of these bottles over hundreds or even thousands of miles adds to the disproportionate ecological impact of bottled water. Many brands of bottled water are superior to tap water and can offer a valuable alternative, particularly when traveling or after a disaster (e.g., earthquake). But economically, environmentally, and in many cases even with respect to disease prevention, they fall short as a replacement for tap water (Morris, 2007). Many plastic water bottles end up in landfills and in the oceans where biodegradation may literally take thousands of years contributing to environmental pollution and degradation. MAWC has designed, built and operates a very efficient water conveyance system.

Q: According to labels for household products, mixing bleach and ammonia is dangerous. Why is it safe for drinking water?

A: Levels of ammonia and chlorine in household products are extremely concentrated (i.e., several orders of magnitude higher than in tap water). It is always dangerous to mix concentrated chemicals together because proportions of the chemicals and the conditions of chemical reactions are impossible to control in a household setting. Many side reactions can occur when mixing concentrated household cleaning products and irritants may be formed in these side reactions. That is why these products are clearly labeled with warnings. Conversely, trained and licensed operators carefully add chlorine and ammonia sequentially into the large volumes of continually flowing water at a treatment plant so that the chemical concentrations at the point of mixing are already low and stable. Dissolution of chemicals and formation of chloramine is almost instantaneous and easy to control using on-line instrumentation for the water and chemical flows, pH, and the resulting disinfectant concentration. Water delivered to customers has chlorine concentrations of less than or equal to 2.0 mg/L CL_2, (parts per million), and ammonia approximately 0.45 mg/L NH_3-N to ensure slight excess of ammonia and to stabilize monochloramine. These are current MAWC chlorine and ammonia target levels, which may change depending on the operational need.

Q: Can one be exposed to chlorine disinfectants in public swimming pools?

A: Yes one can be exposed to irritants in swimming pools. Dichloramine and trichloramine may be present in swimming pools where chloramine needs to be converted back to chlorine to provide a stronger biocide necessary for water in contact with multiple bathers.

Chlorine is a stronger disinfectant than chloramine, especially at lower pH. Pool water differs from drinking water because it receives a great many nitrogen compounds in the form of perspiration and urine. From these materials, urea is hydrolyzed to form ammonia compounds. Pool may exhibit chlorine odors and users may experience

stinging of the eyes especially in indoor pools and at the water surface in outdoor pools. The chlorine odor and eye stinging are often attributed to over chlorination. In actuality, chlorine odor in pools is a symptom of inadequate chlorine addition and/or improper pH control. The proper course of action is to increase the chlorine feed rate and chlorine dose, and to operate the pool in the chlorine residual range. Pool odor is an indicator of improper treatment with chlorine and may be a symptom of insufficient pool chemistry management (Connell, 1997). A recent study of indoor and outdoor recreational swimming pools did not detect monochloramine (the distribution system disinfectant used by MAWC) in samples from laboratory experiments or swimming pools (Li and Blatchley, 2007).

Current research supports the relationship between exposure to trichloramine in indoor swimming pools and adverse effects such as asthma and upper respiratory tract irritation in recreational swimmers, lifeguards and pool attendants. (Li and Blatchley, 2007; CDC, 2007; White, 1999; Bernard et al., 2003; Thickett et al., 2002). The exposure of bathers to chlorine compounds in public swimming pools can usually be minimized by proper pool maintenance, although additional treatment may be necessary (Li and Blatchley, 2007). Proper ventilation at indoor pools and proper chemistry (pH between 7.2 and 7.5 and a sufficient chlorine dose to convert to chlorine) minimizes this exposure. Showering before entering the pool reduces the input of contaminants in public pools. In addition, some pools use more expensive disinfection processes such as ozone or UV to reduce exposure to irritants altogether.

Q: Can one be exposed to chlorine disinfectants in the home shower or bath?

A: Exposures via respiration do not occur from bathing or showering with chloraminated drinking water. Under the slightly alkaline pH conditions typical for drinking water systems, neither chlorine nor chloramine present in drinking water at low concentrations should be appreciably lost to the air from the water in the shower or bath.

Chloramine is completely dissolved in the water and chlorine would be primarily in its dissolved ionized form of hypochlorite ion. Neither chlorine nor chloramine is highly volatile under these conditions even in hot water. Tests conducted in chloraminated bath and shower water at moderate bathing temperature of (100° F, 38°C) indicate a loss of total chlorine of only 3% in bath to 6% in the shower. This is consistent with expected results for monochloramine. In cold water (67°F, 20°C), the loss of chloramine in the shower or bath was within the measurement error (i.e., insignificant). Conversely, the loss of chlorine in similar tests was 12-18%, at water temperatures between 65 and 105°F. In very hot water directly from the heater at 135°F, 100% chlorine was lost in the shower versus only 14% chloramine. Monochloramine is much less volatile, as compared with dichloramine, trichloramine or chlorine. Dichloramine is somewhat volatile (20%) but cannot form in the chloraminated drinking water in the absence of chlorine (White, 1999). Other reactions may be taking place when water is exposed to air in the shower; for example reactions with oxygen in the air could be responsible for measured differences.

Chloramination is expected to reduce overall exposure of the bathers to residual chlorine from the water in home bathrooms, as compared with chlorinated distribution systems. Chloramination is also effective in controlling the formation of volatile trihalomethanes (THMs) such as chloroform, a chlorination by-product.

Water at home contains relatively low concentrations of the disinfectants. Any concerns about exposure can be further minimized by increasing ventilation in the bathroom (e.g., opening a window in the bathroom), taking a bath instead of a shower (less contact between water and air), and reducing water temperature (i.e., taking a warm shower or bath instead of using hot water).

Q: Is there a Material Safety data Sheet for chloramine?

A: there is no Material Safety data Sheet (MSDS) for chloramine because chloramine is not sold commercially and is not available in a concentrated form either as a liquid or solid. In the MAWC system, chloramine is generated on-site from chlorine and ammonia.

Information contained on MSDS sheets should be interpreted in context. The US Occupational Safety and Health Administration (OSHA) requires companies to provide an MSDS if they use a material in their workplace. The MSDS is aimed at protecting workers from acute exposure to concentrated chemicals, and has little relevance for drinking water consumers. In addition, there is very little oversight in the quality of data contained in an MSDS and the mere existence of an MSDS does not imply high quality of information. Customers have sometimes brought up an MSDS for chloramine-T, which comes up in internet searches for chloramine. Chloramine-T is sold commercially, but it is not used for drinking water disinfection.

Q: Can chloramine promote growth of bacteria in home point of use devices?

A: Regrowth of bacteria in well-maintained point-of-use devices (POUD) should not be a concern within the MAWC service area.

The regrowth of bacteria in customers' plumbing is controlled if there is adequate disinfectant residual (no stagnation and proper maintenance of point of use devices). Based on the review of MAWC water quality data, chloramine disinfectant residuals are more stable in the MAWC water system than chlorine and chloramine better controls regrowth of coliform and heterotrophic plate count (HPC) bacteria in the distribution system than chlorine. The study of Legionella occurrence in SFWS conducted by the centers of Disease control and Prevention (CDC), SFPUC, SF Department of Public Health, California Department of Health Services and the California Emerging Infections Program reported by Flannery et al. (2008) showed that chloramine virtually eliminated Legionella in large buildings in San Francisco.

Strickhouser et al. (2006) evaluated the regrowth of Legionella pneumofila and Mycobacterium avium under conditions of increased temperature 37°C simulating the conditions of the water heaters. The samples were spiked with domestic water heater water and outdoor pond water. No regrowth of bacteria was detected for samples with chlorine above 0.25 mg/L and chloramine above 0.4 mg/L. The regrowth of bacteria occurred in samples without the disinfectant and especially for samples with the high levels of free ammonia (1 mg/L), simulating the conditions of stagnant water with no disinfectant residual.

There is evidence that a chloramine residual can exert better control of biofilm bacterial growth than does chlorine (Flannery et al., 2006). Maintaining adequate disinfectant residual limits the extent of development of a biofilm, but the disinfectant residual necessary to do so varies with changes in source water quality and with the performance of treatment processes in removing particulates, nutrients, and microorganisms. Maximum biofilm bacterial densities occur when disinfectant residual is low or nonexistent, whereas lower biofilm densities occur when disinfectant residuals in the bulk water are as high as 1.6 to 1.8 mg/L (AWWA, 2006c). MAWC maintains chloramine disinfectant in MAWC Water System between 1.0 and 2.0 mg/L. Typical levels of free ammonia in the MAWC distribution system are less than 0.1 mg/L N. Given these results, regrowth of bacteria in well-maintained point-of-use devices (POUD) should not be a concern within the MAWC service area.

Q: Why are disinfectants added to the water?

A: Untreated surface water is vulnerable to contamination by bacteria, viruses and parasites that may cause human illness. These disease-causing microorganisms are also referred to as pathogens. Standards have been developed within the US and elsewhere in the world defining minimum standards of disinfection to protect against contamination by pathogens.

In the US, all drinking water suppliers using surface water are required by the U.S. Environmental Protection Agency (USEPA) to use disinfectants to inactivate pathogenic microorganisms in drinking water. Currently, chlorine, chloramine, ozone, chlorine dioxide and ultraviolet (UV light are approved by the USEPA for disinfection during treatment (termed primary disinfection) (USEPA, 1998a; USEPA 2006b). Utilities must also maintain a smaller amount of disinfectant throughout the drinking water distribution system to limit bacterial growth (termed "residual" or secondary disinfection). Currently, chlorine, chloramine, and chlorine dioxide are approved by the USEPA for disinfection in the distribution systems. Chlorine dioxide is sometimes used for distribution disinfection in smaller systems. Large systems typically do not use chlorine dioxide for distribution system disinfection because chlorine dioxide, like chlorine, is a strong oxidant and will not reach the most distant points in a large distribution system. Large

water systems like MAWC must therefore choose between chlorine and chloramine for distribution system disinfection.

The USEPA's Stage 1 Disinfectants/Disinfection Byproducts Rule (Stage 1 D/DBRPR) limits concentrations of disinfectants by establishing a maximum Residual Disinfectant Level (MRDL) of 4 mg/L Cl_2 for chlorine and chloramine (USEPA, 1998). Water provided by the MAWC meets all Federal and State drinking water regulations. Pathogens are controlled by watershed protection, disinfection with chlorine during treatment, distribution system disinfection with chloramine, cross-connection control, and other water quality maintenance practices.

Q: What is the sequence of disinfectants applied at MAWC for control of pathogenic microorganisms?

A: First, a strong disinfectant/oxidant is applied during water treatment for killing pathogens that might be present in the source water. MAWC uses chlorine for this primary disinfection process. Second, chloramine is formed to prevent microoganisms from growing in the pipes, which distribute water to the customers. Many large water systems with extensive service areas use chloramine instead of chlorine for distribution system disinfection because chloramine is less reactive and longer lasting in providing disinfection protection.

Q: What disinfection processes are available?

A: Both chlorine and chloramine are proven disinfectants with considerable operating experience. Chlorine and chloramine are approved disinfectants, In addition to chlorine dioxide, ozone, and most recently ultraviolet light (UV) (USEPA 1989a, 2006b).

Each of these approved disinfectants has advantages and disadvantages in terms of : (1) disinfecting effectiveness for specific microorganisms, (2) reactivity with natural organic matter and associated formation of disinfection by-products (DBPs), (3) formation of inorganic DBPs (e.g., bromate, chlorate, chlorite), and (4) disinfectant persistence to provide lasting protection in the pipes and water storage reservoirs of the distribution system. Chlorine dioxide, ozone and UV cannot be used for secondary disinfection because of limited or no residual disinfectant provided by these processes. Chlorine dioxide is used by some utilities for secondary disinfection in the distribution system but this disinfectant has several drawbacks: (1) formation of chlorite which is regulated by the USEPA (1998), (2) possibility of creating "cat-urine" odors in customers' homes, (3) greater reactivity and, therefore, lower persistence in the distribution system, and (4) high cost (USEPA, 1989).

Q: Why is disinfection important?

A: Disinfection is proven to stop and prevent disease. Just a hundred years ago, waterborne typhoid fever was a leading cause of death in the United States. Less than fifty years before that, the major cities in Europe and North America were ravaged by waterborne cholera (Morris, 2007). The importance of disinfection is exemplified by the dramatic reductions in typhoid in the early 20th century after widespread implementation of water treatment, including drinking water disinfection practices. In addition, when disinfection is discontinued due to operational failures, disease outbreaks have occurred. For example, an outbreak of E. Coli 0157:H7 occurred in Canada when chlorination of wells was interrupted (O'Connor, 2002).

Chemical disinfection became an integral part of municipal drinking water treatment over 100 years ago as a vital means for protection of public health. By the late 1880's it was clear that a number of important epidemic diseases were often waterborne, cholera, typhoid fever, and amoebic dysentery, among them. The twentieth century began with the development of continuous chlorination as a means for bacteriological control (Crittenden et al., 2005). McGuire (2006) listed "eight revolutions in the history of North American drinking water disinfection":

1) Application of chlorine for full-scale disinfection in Jersey City, NJ, in 1907. It took a court dispute and a legal deadline to clear away the objections and to apply what was until then only an experimental treatment method. Chemical treatment was involved and popular prejudice against its use was strong.
2) In 1914, the Secretary of Treasury established a standard for the coliform bacteria concentration in each sample.
3) In 1917 in Ottawa, Ontario, a combination of chlorine and ammonia was implemented to produce chloramine to solve taste and odor problems related to chlorine. The ammonia-chlorine process also produced stable chlorine residuals that persisted far into the distribution system. Denver Water has used the ammonia-chlorine process continuously since 1917. Chloramine disinfection was also applied in San Francisco prior to World War II (SFPUC, 1941). In southern California in 1941, when the Colorado River water was first imported, chloramine was necessary to ensure that a residual could be maintained in the furthest reaches of the distribution system.
4) The discovery in 1974 of trihalomethanes (THMs) and the resulting regulation in 1979 limited THM levels to 100 ug/L (micrograms per liter, equivalent to ppb, or parts per billion). THMs are organic compound produced form the chlorination of natural organic matter in drinking water, considered probable carcinogens. Subsequent to the identification of THMs, many other organic and inorganic "disinfection by-products" (DBP) have been discovered (Krasner et al., 2006).
5) Application of the product of C x T concept (disinfectant concentration C after the contact time T) in 1989 to be achieved during treatment of surface waters on a daily basis. The target organisms of USEPA Surface Water Treatment Rule (SWTR) were viruses and the protozoan microorganism Giardia lamblia (USEPA, 1989a).
6) The change of focus from coliform bacteria concentration to presence-absence in no more that 5% positive coliform samples in any monthly set of distribution

system samples, as mandated in 2989 by the USEPA Total Coliform Rule (TCR, USEPA, 1989b).

7) Regulations balancing the risk from microbial contamination and risks of disease from the disinfection by-products (DBPs): In 1998 Stage 1 Disinfectant/DBP Rule (USEPA, 1998) and in 2006 Stage 2 Disinfectant/DBP Rule (USEPA, 2006a). These two rules added new regulated DBPs and attempted to minimize peak concentrations of these compounds in the distribution system.

8) The cryptosporidiosis outbreak in Milwaukee, WI, in 1993 resulted in the promulgation in 2006 of the USEPA Long Term 2 Enhanced SWTR (USEPA, 2006b) specifying the degree of inactivation of protozoan microorganism cryptosporidium or other protective measures to reduce the likelihood of an outbreak of cryptosporidiosis. The discovery in 1996 that ultraviolet light (UV) can economically disinfect Cryptosporidium, Giardia, and other pathogens will dramatically change how water is disinfected in the United States.

Within six years of implementing chlorination in Jersey City, half the water treatment plants in the United States were using chlorine to disinfect water. By 1924 three thousand cities had turned to chlorine. The occurrence of serious waterborne diseases declined and diseases like cholera, typhoid and amoebic dysentery, which had been common became rare. In 1900 an average American had a 5 percent chance of dying of a gastrointestinal infection before the age of seventy. By 1940 that likelihood had dropped to 0.03 percent and by 1990 it had fallen to about 0.00005 percent (Morris, 2007). Evidence clearly demonstrates that implementing disinfection has reduced waterborne disease and that failures in disinfection can result in increased levels of disease.

Q: What is chloramine?

A: Chloramine is a disinfectant added to water for public health protection. It is a combination of chlorine and ammonia that is currently considered best technology for controlling the formation of certain regulated organic disinfection byproducts. Chloramine is formed at the MAWC treatment plants following treatment with chlorine. Chloramine is used as a distribution system disinfectant.

The MAWC began using chloramine for distribution system disinfection in 1972.

Chloramine is formed at the treatment plants by combining chlorine and ammonia at a weight ratio of 4:1 or slightly less – this maximizes formation of monochloramine, which is not volatile. The current chloramine target concentration in the MAWC system is 2.0 mg/L CL_2 in plant effluent and slightly less in the distribution system. In the past, before chloramine was used in the MAWC distribution system, levels of chlorine in plant effluents ranged from 1.0 to 1.5 mg/L CL_2. Thus chloramine levels are relatively higher than chlorine. Although chloramine is less reactive than chlorine and more stable from a practical water supply point of view, it is not a persistent chemical and eventually

breaks down by itself (Valentine, 1998). Chloramine does not bioaccumulate nor transfer up the food chain (Environment Canada, 2002).

Q: What is the history of chlorine and chloramine use for drinking water disinfection in the United States?

A: In response to frequent cholera outbreaks, water treatment was started. Both chlorine and chloramine have been used for disinfection for about the same length of time. The first regular use of chlorination in the United States was in 1908 (AWWA, 1998). It actually required a court dispute and a legal deadline to clear away the objections for applying chlorine (McGuire, 2006). By 1917, chlorine disinfection was adopted by hundreds of US water utilities.

Issues emerged with taste and odor problems. Chlorine readily combines with phenol to produce a wide variety of chlorophenols that at low concentrations impart a strong medicinal odor to water. In addition, chlorine itself has a significant, penetrating, and disagreeable odor (McGuire, 2008).

In 1917 in Ottawa, Ont., a combination of ammonia and chlorine was implemented to solve flavor and odor problems related to chlorine (McGuire, 2006). Chloramine has been used for disinfection in the United States since that time (USEPA, 1999; Kirmeyer et al, 2004). Chloramination enjoyed its greatest popularity between 1929 and 1939. In 1938, based upon replies to a questionnaire form 2,541 water suppliers in 36 states, 407 utilities reported using ammonia with chlorine. Denver, CO, has used a chloramination process continuously since 1917 (McGuire, 2006). The San Francisco Hetch Hetchy Aqueduct was chloraminated from 1935 until the ammonia supply became scarce during World War II in 1944 (SFPUC, 1941; White, 1999). The metropolitan Water District of Southern California (MWDSC) implemented the use of chloramination in 1941 when the Colorado River water was first delivered to Southern California. Chloramine disinfection was used so that a sufficient residual could be carried to the furthest reaches of the MWDSC distribution system (McGuire, 2006).

A survey in 1938 (AWWA, 1941) indicated that 3 of 36 surveyed states had at least one water supply that used chloramine. In California, 190 water supplies were reported to use chlorine and 35 chloramine, which was the second largest use of chloramine in any state after New York, where 69 water supplies were chloraminated. By 1936, 16% of all water treatment facilities in the U.S were using chloramine. Due to the scarcity of ammonia during World War II use of chloramine declined until 1980's to a low of 2.6% facilities. After the enactment of the Federal Safe Drinking Water act (SDWA) by the U.S Congress in 1974 and its subsequent amendments, interest in using chloramine was renewed due to increasing focus on microbiological safety and reduction of DBP's. About 20% of treatment facilities used chloramine in 1990 (Kirmeyer et al., 2004). In 1996, approximately 6.9 million Canadians were supplied with chlorminated drinking water (Environment Canada, 2001). Many utilities in California serving a total

population of over 30 million have been using chloramine for over 20 years. Chloramine is used worldwide on four continents.

Q: What is the history of regulatory approval of chloramine?

A: Chloramine has been used as a municipal drinking water disinfectant for 90 years. Chloramine is an approved treatment and distribution system disinfectant by the USEPA (USEPA, 1990). The World Health Organization (WHO, 1996) states that chloramine is useful for maintaining a disinfectant in distribution systems.

The Stage 1 Disinfectant and Disinfection By-Product Rule (USEPA, 1998) established maximum residual disinfectant levels for chlorine and chloramine of 4mg/L CL_2 in the distribution system. Residuals higher than 4mg/L CL_2 levels of chlorine or chloramine are allowed for short-term distribution system disinfection.

The use of chloramine as a disinfection agent, when compared to chlorine, reduces the formation of disinfection byproducts (DBPs). The reduction in DBPs is an improvement in public health protection. DBP's are currently regulated by the USEPA under Stage 1 and Stage 2 D/DBP Rules (USEPA, 1998 and 2006a). The Surface Water Treatment Rule (USEPA, 1989a), SWTR, established the C x T values (concentration, C, after given contact time, T, with the disinfectant) required for disinfection of Giardia and viruses during treatment with chlorine, chloramine, ozone, or chlorine dioxide. The SWTR also established that the minimum disinfectant residual should be detectable in the distribution system for either chlorine or chloramine.

Q: What is the current and future use of chloramine for drinking water disinfection?

A: USEPA's Information Collection Rule data (2002) indicated that of 353 treatment plants examined 34.7% of the systems used chloramine with some combination of chlorine pretreatment, while 11.5% of the systems used chloramine with chlorine dioxide or ozone pretreatment.

Seidel et al., (2005) conducted the most recent chloramine survey in 2004 (363 utilities from 50 states responded to the survey) with the following results: 29% of community water systems used chloramine for secondary disinfection and another 3% were in the process of switching to chloramination, about 12% contemplated the switch in the near future. The proportion of utility respondents that intended to or considered a switch to chloramine, increased with system size. More than 25% of utility respondents that served more than 100,000 customers indicated that they intended to or seriously considered a switch to chloramine.

The reported median target chloramine concentrations were 2,7 mg/L at the plant effluent location, 2.0 mg/L at the distribution system average residence time location, and 1.0 mg/L at the distribution system maximum residence time location (Seidel et al., 2005).

Q: What are the types of chloramines that can be formed under special circumstances?

A: There are three inorganic chloramines that can be theoretically formed under different conditions of water pH and/or chlorine to ammonia weight ratio: monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine (NCl_3). Under the conditions existing in full-scale drinking water distribution systems, chlorine to ammonia weight ratios of 5:1 or below, monochloramine is the only observed chloramine species (100%).

While dichloramine and trichloramine likely have good disinfecting capabilities, they cause taste and odor. In addition, they are much less stable than monochloramine; therefore this formation is avoided. Trichloramine which in its pure form is very volatile and pungent, cannot exist in chloraminated water systems without the presence of chlorine and it has been known to form in the chlorinated distribution systems long after leaving the treatment plant. This situation is corrected by converting the chlorine residual to monochloramine (White, 1999).

Small amounts of organic chloramines may also form in chlorinated or chloraminated water if certain organic nitrogen compounds, including amino acids and nitrogen heterocyclic aromatics, are present (Environment Canada, 2001: White, 1999). Chlorine forms organochloramines almost instantaneously, wheras monochloramine reacts slower. With very few exceptions, all organochloramines are non-germicidal and nontoxic to aquatic life (White, 1999). Experience indicates that trace levels of organochloramines can be formed in all treated natural waters.

Throughout this document, the term chloramine refers to monochloramine. Where it is important to distinguish between monochloramine, dichloramine, and trichloramine, the specific terms are used.

Q: What was the reason for changing distribution system disinfectant from chlorine to chloramine at MAWC as well as at many other water utilities?

A: Two properties of chloramine enable the MAWC to minimize potential for microbial contamination and comply with Federal regulations. First, because chloramine is longer lasting than chlorine, it helps achieve compliance with the Surface Water Treatment

Rule. Second, chloramine forms much lower levels of regulated DBP's than chlorine, thus enabling compliance with Federal rules governing DBP's.

The MAWC implemented chloramination in the distribution system in 1980. The primary driver for changing the distribution system disinfectant from chlorine to chloramine was to reduce the formation of trihalomethanes (THM's) and haloacetic acids (HAA's) In the late 1970s and early 1980's it was discovered that chlorine reacts with naturally occurring organic matter to form THM's, HAAs and other disinfection by-products (DBP's). Subsequent research showed that exposure to THMs over a lifetime may statistically increase the rates of some cancers. To protect public health, the USEPA began regulating four THMs in 1979, with a maximum contaminant level (MCL) of 100 ug/L (or one hundred parts per billion). Chloramine reduces the formation of these potentially carcinogenic DBPs and therefore makes water safer for human consumption. In 1988 (USEPA, 1998), the MCL for four THMs was further reduced to 80 ug/L and new MCLs were promulgated by the USEPA for five haloacetic acids (60 ug/L HAA) and other inorganic DBPs (bromate resulting from ozonation) and chlorite (resulting from chlorine dioxide application).

The choice of disinfectant(s) depends on many factors. Utilities must balance many considerations to simultaneously fulfill the requirements of numerous drinking water quality regulations. Careful planning, testing, and review of similar practices at other water utilities always precede the change of disinfectants or treatment process. In Pennsylvania, the application of any proven or new drinking water treatment processes must be approved by the PADEP, to assure the compliance of public water systems with the requirements of the Safe Drinking Water Act (SWDA and its Amendments. Chloramination is not simply an add-on process at the end of the treatment plant but must be fully integrated into the design and the operation of the water treatment facilities at the distribution system (Kirmeyer et al., 2004).

Q: What are the benefits to using chloramine instead of chlorine in the distribution system?

A: The benefits of chloramine compared with chlorine for distribution system disinfection are: (1) longer lasting disinfectant and ability to reach remote areas, (2) effectiveness as a disinfectant for biofilms, (3) tendency to form lower levels of regulated DBPs (e.g., THMs and HAAs), which are probable carcinogens (USEPA, 1998), and (4) ability to minimize chlorinous or other objectionable taste odors.

Chloramine is more stable and lasts longer in the water in the distribution system because it is less reactive than chlorine. The water agencies that have converted to chloramine report that customers note an improvement to flavor of the water. Research on the taste-and-of odor quality of drinking water has demonstrated the benefits of monochloramine over chlorine.

Q: What are the drawbacks to using chloramine instead of chlorine in the distribution system?

A: The drawbacks of using chloramine compared with chlorine for distribution system disinfection are: (1) potential temporary deleterious effects on older elastomeric materials sometimes used in some home appurtenances and plumbing fixtures, (2) vulnerability to the microbiological process known as nitrification, (3) potential formation of chloramine related DBP's if precursor material is present in the source water (Kirmeyer et al., 2004).

The treatment precautions for hemodialysis clinic and fish cultures must be taken both with chlorine and with chloramine (Amoto, 2005). Certain natural rubber products and their derivatives used in house hold appliances (e.g. toilet tank valves, hot water heater dip tubes) will deteriorate faster with chloramine than with chlorine (Reiber,1993). If such effects are experienced, replacing these items with alternative materials available in the plumbing and hardware stores will eliminate this temporary nuisance rubber deterioration. Chlorine tablets for toilet water tanks may significantly increase the corrosion of submerged rubber parts in these appliances and plumbers typically do not recommend their use.

Vulnerability of chloramine to nitrification can be remedied by several practices, including: a) reducing the detention time of water in the drinking water storage reservoirs and low-use pipelines, b) keeping the system clean of deposits, which may harbor bacteria, c) flushing when necessary, and d) monitoring the system. All these actions have an additional benefit for customers by providing fresher, shorter "shelf age" water. Typically, a change to chloramine has been preceded and followed by distribution system capital improvements aimed at decreasing water age such as seasonal or permanent outages of water tanks, improving mixing within the tanks, redesign of pressure zones for better interconnectivity, changing pumping schedules to improve stored water turnover, or installation of new water quality monitoring stations (Wilczak et al., 1996, Odell et al., 1996: AWWA 2006a).

Q: What is nitrification and how does it Impact water quality?

A: Nitrification is a microbial process by which ammonia is sequentially oxidized to nitrate ions. In extreme cases, nitrification may cause a depletion of chloramine disinfectant thus allowing bacterial regrowth.

Every utility using chloramine needs to assess nitrification potential and implement proper control measures. Nitrite and nitrate ions produced due to nitrification are of no water quality significance in the MAWC system. Other impacts of nitrification may include some decrease in alkalinity, pH, and dissolved oxygen (Wilczak et al., 1996: Krrmeyer et al., 2004).

Nitrification is a utility operational issue and does not pose any health concerns. Nitrification results from metabolism and growth of harmless non-pathogenic nitrifying bacteria that are ubiquitous in soils and water. Utilities implement operational control measures, including decreased water age and enhanced monitoring to limit the extent of nitrification (AWWA, 2006a). After this optimization period the customers benefit from fresher water that was stored for a shorter period of time in the distribution system. MAWC has implemented a vigorous nitrification monitoring and control program and has been successful in controlling the nitrifying bacteria.

Q: What are the disinfecting properties of chloramine as compared with chlorine?

A: Chlorine is a stronger oxidant/disinfectant than chloramine and acts more efficiently as a primary disinfectant (e.g. to inactivate pathogenic microorganisms). Chloramine lasts longer than chlorine as a residual disinfectant. These differences account for how the MAWC uses each in combination.

Disinfection of pathogens is achieved by holding a target microorganism in contact with a minimum level of chemical disinfectant concentration (C) for a minimum length of time (T) to obtain a certain level of kill (or inactivation). This is referred to as the CT concept. Promulgation of the Surface Water Treatment Rule (SWTR) in 1989 specified for the first time CT values for treatment of surface waters. The SWWTR's main target organisms were viruses and the protozoan microorganism Giardia Lamblia (McGuire, 2006). Additionally, the SWTR mandates maintaining disinfectant residual in the distribution system.
MAWC relies on chlorine for disinfection of pathogenic cysts, bacteria, and viruses at its treatment facilities. Chlorine is also used by MAWC for pipeline disinfection and water tank disinfections after outages or construction. Chloramine is formed at the end of the treatment process to maintain disinfection throughout the distribution system.
Chloramine is an approved treatment and distribution system disinfectant by the USEPA (USEPA, 1990). The World Health Organization (WHO, 1996) states that chloramine is useful for maintaining a disinfectant in distribution systems.

Chloramine is a less reactive (weaker) oxidant and disinfectant than chlorine, which is actually an advantage in the distribution system because chloramine lasts and disinfects longer. The disinfection effectiveness of chloramine should not be discounted. Studies have shown that chloramine matches the effectiveness of chlorine when contact times are sufficiently long. Additionally, chloramine has shown superior performance for the disinfection of biofilms. These results have led to the wide use of chloramine as disinfectant in distribution systems (AWWA, 2006b).

In the slightly alkaline pH range typical for drinking water distribution systems, the disinfecting effectiveness of chlorine is diminished for inactivation of bacteria, cysts and viruses, whereas the effectiveness of chloramine is not impacted (USEPA, 1990; White, 1999). This is because chlorine (hypochlorous acid) dissociates to hypochlorite ion at

higher pH while chloramine remains as monochloramine as long as pH is above neutral. It must be recognized that, regardless of the disinfectant chosen, the water distribution system can never be regarded as biologically sterile.

The use of multiple disinfectants in sequence improves disinfection effectiveness, because synergistic effects may occur. For example, the exposure of E. coli bacteria to mixtures of chlorine and chloramine resulted in a greater inactivation than would be predicted by their individual effectiveness. Similarly, the combinations of disinfectants (chlorine followed by chloramine, ozone followed by chlorine or chloramine, chlorine dioxide followed by chlorine or chloramine) may offer a greater level of inactivation of the Cryptosporidium protozoan oocysts (AWWA, 1999; West et al. 1998; Li et al, 2001).

Q: What is the mechanism of chlorine and chloramine disinfection and is there a benefit of applying two different disinfectants instead of one?

A: Rates of microbial inactivation depend upon several factors including: the type and concentration of the disinfectant, contact time with the disinfectant, temperature, type and number of microorganisms, pH, and disinfectant demand (Jacangelo et al., 1987). It has been suggested that chlorine and chloramine act by two different mechanisms. Chlorine is a very reactive molecule and rapidly reacts with nucleic acids, most nucleotides, purine and pyrimidine bases, proteins and amino acids. Carbohydrates and lipids are generally unreactive to chlorine. Chloramine reacts rapidly only with the sulfur-containing amino acids, and the heterocyclic aromatic amino acid, tryptophan. Slow reactions of chloramine were observed with nucleic acids, purine and pyrimidine bases and the alpha amino group of amino acids. These slow reactions may be important when the rapidly reacting materials are masked or buried (Jacangelo et al., 1987). Most studies on the mode of action of chlorine in bacteria have implicated the disruption of the cell membrane. Chloramine does not severely damage the cell envelop. Chloramine inactivation has been suggested to occur through the blockage or destruction of several enzymes and cofactors. The mode of action of chloramine appears to involve multiple hits by the disinfectant of the bacterial cell and reactions at several sensitive sites in the bacteria which precede inactivation (Jacangelo et al., 1987).

Studies have shown that chlorination followed by chloramination is more effective for disinfection of the protozoan *Cryptosporidium parvum* oocysts than chlorine alone (West et al., 1998). Chloramine is also effective at disinfecting the bacteria *helicobacter pylori* (Baker et al., 2002). The future of drinking water disinfection will rely on multiple disinfectants applied in sequence (Trussell, 2006).

Q: How has chloramine performed in MAWC distribution systems so far in terms of control of microorganisms?

A: Monitoring results indicated that the incidence of positive coliform bacteria samples has been negative and that the heterotrophic plate count bacteria levels decreased. A significant decrease in *Legionella* levels in hot water heaters is an additional important benefit of chloramination. At the same time, growth of nitrifying bacteria in the distribution system has been controlled.

MAWC monitors it distribution system for coliform bacteria as mandated by the Total Coliform Rule (TCR, USEPA, 1989B). Chloramination has improved TCR compliance and lowered the levels of HPC bacteria in the distribution system. This is likely due to higher and longer-lasting disinfectant residuals provided by chloramine. *Legionella* bacteria were found to be much more resistant to chlorine than *E.coli* and other coliforms that have been used as indicator organisms to monitor potable water quality (Kim et al., 2002). *Legionella* bacteria have been known to cause pneumonic legionellosis and severe influenza-like illness. Hospitals supplied with drinking water disinfected water containing chlorine (Kim et al, 2002).

Immuno-compromised individuals may consider boiling drinking water regardless of the disinfectant applied, depending on recommendations from their physician. It is technologically impossible to provide sterile drinking water by any utility.

Q: Why doesn't MAWC remove organic matter before disinfection and use chlorine for disinfection?

A: Chemical pretreatment and filtration are already used at MAWC treatment plants. This treatment lowers but does not prevent THMs or other chlorinated DBPs from forming during chlorination.

Disinfection by-product (DBP) precursor removal efficiencies are site-specific and vary with different source waters and treatment techniques. Many utilities use coagulation and filtration to remove a portion of natural organic matter (NOM) present in the source water still need to use chloramine for DBP minimization; this has been true for all large utilities in the U.S. Large systems with large emergency water storage volume are unlikely to be able to control DBPs unless they us chloramine in the distribution system. MAWC continues to apply chlorine at the treatment plants for disinfection of protozoan cysts, bacteria, and viruses. Chlorine is also used by MAWC for pipeline disinfection and water tank disinfections after outages or construction. Monochloramine is used for residual disinfection in the distribution system.

DBP precursor removal may also carry unintended effects. Because coagulation and filtration remove total organic carbon (TOC), but not bromide, in some waters containing high levels of species during chlorination (although this would not be expected in MAWC waters). Brominated DBPs may be of higher health concern than the chlorinated species within the same class (Bull et al., 2001).

MAWC thoroughly evaluated all alternative methods to comply with DBP regulations. Water utilities do not conduct basic health research to test water disinfectants. Decisions are based on USEPA AND PADEP approved technologies and cost considerations. Chloramine has performed very well in the MAWC distribution system, significantly reducing the formation of regulated disinfection by-products and allowing MAWC to meet current and future USEPA regulations. At the same time, chloramine has improved control of biofilm in the MAWC distribution system, lowering the incidence of coliform positive samples, reducing heterotrophic plate count (HPC) bacteria by up to an order of magnitude, and virtually eliminating *Legionella* from the hot water heaters in large buildings.

Q: How has chloramine performed in MAWC distribution system so far in terms of control of disinfection by-products?

A: Monitoring results indicate that since 1980 concentrations of THMs were reduced in the MAWC system by at least 60% and high THM and HAA peaks were eliminated. Chloramination has effectively decreased levels of regulated DBPs.

Q: What is the epidemiological studies exploring the potential health effects of DBPs in human populations. Consumption of water containing these byproducts has been associated with cancer (Doyle et al., 1997; Bull et al., 1995; Morris et al., 1992) and adverse reproduction outcomes (King et al., 2000); Nieuwenhijsen et al., 2000; Gallagher et al., 1998; Reif et al., 1996; Savitz et al., 1995; Bove et al., 1995; Aschengrau et al., 1993; Fenster et al., 1992; Kramer et al., 1992; Zierler et al., 1992), although some of these studies have not found significant associations with specific outcomes.

Several epidemiologic studies have specifically explored the relationship between THMs and pregnancy loss (Waller et al., 1998; Swan et al., 1998). More recently a large study did not find an association between THMs exposure and pregnancy loss in three study sites, two of which used chloramination (Savitz et al., 2005). MAWC is not aware of any studies linking chloramination or specific chloramination by products to this health outcome. Chloramination is very effective in controlling THM and HAA formation.

The MAWC has moved to chloramine as a precautionary measure since it is better than chlorine for controling the formation of regulated DBPs for which there is evidence of adverse human health effects.

Q: What is the significance of cyanogen chloride?

A: Cyanogen chloride is a DBP whose formation has been associated with the use of chloramine. However, it will be formed in the presence of any combination of a strong oxidant, ammonia, aromatic amino acids, and chloride. Cyanogen chloride is a respiratory irritant at concentrations in the air above 0.75 mg/m^3. The small concentrations produced in water treatment would be unlikely to produce these levels in air even in enclosed places such as a shower. The concentrations of cyanogen chloride in drinking water do not approach levels necessary to produce thyroid effects (Bull et al., 2001). Cyanogen chloride is currently unregulated, but the probable regulatory range for cyanogen chloride has been estimated at 60 to 600 ug/L.

In a survey of 35 utilities, the systems that prechlorinated and postammoniated had a cyanogen chloride median of 2.2 ug/L versus 0.4 ug/L for systems that used chlorine only. The concentrations in chloraminated plant effluents ranged from 1 to 11 ug/L versus 0-4 ug/L in chlorinated plant effluents (Krasner et al., 1989). Krasner et al (198) also found that certain DBPs (i.e. haloacetonitriles, haloketones, chloral hydrate, and cyanogen chloride) were not stable in the distribution system where the pH is relatively high (e.g., pH 9) (Singer 1999). Therefore, cyanogen chloride is of no significant concern to MAWC.

Q: What are the emerging classes of disinfection by-products of chlorine and chloramine?

A: The research community has been focusing on new classes of disinfection by-products that have been recently detected in drinking waters thanks to the advances in analytical technology and the surveys of chlorinated and chloraminated water systems. Specifically, nitrogenous DBPs, specifically nitrosamines, iodinated-DBPs, and hydrazine are under evaluation.

Q: What is the occurrence of nitrosamines in drinking water?

A: Chloramination has not resulted in increased NDMA levels and NDMA is not an issue for MAWC based on available data.

Nitrosamines, and the related nitrosamines including the nitrosoureas, are carcinogens that have been recognized as environmental contaminants of potential importance since the 1960s. These compounds have been most closely associated with the use of nitrite salts in food preservation. Active compounds in this class appear to induce tumors in virtually all species in which testing has been conducted (Bull et al., 2001). The occurrence and control of the nitrosamines in drinking water form at such minute concentrations (parts per trillion) that their detection only recently became possible.

Both chlorination and chloramination have been implicated in reaction mechanisms that result in N-nitrosodimethylamine (NDMA) formation form natural precursors. Furthermore, field observations do not indicate that one method of disinfection

necessarily leads to lower NDMA formation and therefore should be preferred (Valentine et al., 2005). A recent national survey of NDMA occurrence and formation detected NDMA in 18 of 21 utilities disinfected with either chlorine or chloramine. The use of chloramine in the distribution system correlated with slightly higher NDMA levels than the use of chlorine: the median for treated drinking water distribution samples was less than 2 ng/L (parts per trillion) for chloraminated water and less than 1 ng/L for chlorinated water (Barrett et al., 2003; Valentine et al., 2005). Baribeau et al (2006) investigated formation of DBPs in chlorinated and chloraminated systems. There were no obvious differences between the concentrations of NDMA measure in chlorinated and chloraminated systems. NO particular trend in NDMA concentrations could be identified with increasing water age in a chloraminated system or a chlorinated system. Wilczak et al (2003a) observed that sequential application of chlorine followed by chloramine at the treatment plant minimized the formation of NDMA in the distribution system, which is typical practice for MAWC and many other utilities.

Other nitrosoamines have not been extensively studied in drinking water; however recent research suggests that NDMA is the most prevalent nitrosoamine, and that the other nitrosoamines form at levels that are an order of magnitude or more lower than NDMA. In 2008, USEPA required monitoring for several nitrosoamines in public drinking water systems nationwide to determine if additional regulation for this group of compounds is needed.

Q: What is the occurrence of iodinated disinfection by-products in drinking water?

A: MAWC system is unlikely to have significant levels of iodo-DBPs because of the low concentrations of bromide and iodide in the raw water.

Iodo-DBPs are a new group of disinfection by-products for which the level of toxicity is not well understood. For years scientists have known that all chemical disinfectants will result in the formation of DBPs at some level. More than 500 disinfection by-products have been reported in the literature for the major chemical disinfectants currently used (chlorine, ozone, chlorine dioxide, chloramine), as well as their combinations (Weinberg et al., 2002). The formation of iodinated DBPs is recognized as an important research finding because iodide is present in drinking water supplies throughout the world; for example iodinated THMs have been found in the United States (Weinberg et al., 2002), Australia (Hansson et., 1987), France (Bruchet et al., 1989), and Spain (Richardson, 2004).

In 2002, the US Environmental Protection Agency conducted a nationwide DBP occurrence study (Weinberg et al., 2002). This study evaluated the occurrence of six iodinated THMs and was also the first to demonstrate the formation of iodinated acids. Iodoacids were detected at one utility that treats high-bromide water and uses chloramine both for disinfection during treatment and for maintaining disinfectant in the

distribution system. Plew et al. (2004) postulated that chloraminated drinking waters that have high bromide and iodide concentrations in the source

Waters might contain these iodoacids and other iodo-DBPs. Plewa et al. (2004) observed that one of these acids (iodoacetic acid) was more genotoxic to mammalian cells than other DBPs that have been studied in their essay.

These research findings are not of immediate public health concern since: (1) iodoacids have been detected only in one water system with high bromide and likely high iodide content (iodide is not commonly measured while the bromide occurrence database is well developed), (2) iodoacids were detected at a utility that applied chloramine only and it is believed that the use of chlorine before applying choloramine (as the MAWC does) will allow the chlorine to react with iodide to form iodate and stop iodoacids formation (Plewa et al., 2004; Richadrson, 2004). Iodate is not a health concern as it is transformed back to iodide after ingestion (von Gunten, 2003). The study of ioacids toxicity by Plewa et al. (2004) used in-vitro isolated mammalian cells and not in-vivo animal or human subjects. This testing approach is typically used as a screening tool to determine candidate chemicals for future in-vivo toxicity testing.

Iodide occurrence in drinking water sources and its influence on the formation of iodinated DBPs are currently not known. Methods for quantification of iadoacids are under development by the USEPA (Richardson, 2004) and any further studies depend on our ability to measure concentrations of these compounds at the levels of potential concern. Further toxicological studies are warranted (Plewa et al., 2004).

The MAWC system is unlikely to have significant levels of iodacids because of the low concentrations of bromide and iodide in the raw water. The only documented occurrence of iodacids has been at on utility (Weinberg et al., 2004; and Plewa et al., 2004) with high raw water bromide/iodide concentrations.

Q: What is the occurrence of hydrazine in drinking water?

A: The MAWC has not measured levels of hydrazine in its water but, based on the mechanisms of formation, believes that hydrazine formation would be of no significant concern in its chloraminated water.

Najm et al. (2006) evaluated the formation of hydrazine as chloramine by-product. This is the first known study on the subject in drinking water. The project team found that "in a laboratory experiment performed under water and wastewater chloramination conditions, hydrazine formation was below detection when free ammonia was less than 0.2 mg/L "The MAWC treatment target for free ammonia is 0.05 mg/L, which is consistently met: levels up to 0.10 mg/L are occasionally observed, but less frequently. Based on the report findings hydrazine does not appear to pose a concern. Commercial labs do not test for hydrazine at such low levels (below 10 ng/L) in drinking water. Therefore, Najm et al. (2006) used a computer model simulation to evaluate the

impact of major water quality parameters on hydrazine formation. Consistent with the lab results, the model predicted that at pH< 9.5 and free ammonia less than 0.5 mg/LN Hydrazine formation would be of no significant concern in chloraminated water. MAWC operating targets are well below these levels.