# In Depth Chloramination Q&A: Statistics and General Information

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## STATISTICS AND GENERAL INFORMATION

### Q 1: What is chloramine?

A: Chloramine is a disinfectant produced by combining chlorine and ammonia at a weight ratio of 5:1 or slightly less. Monochloramine is the dominant compound formed and is generally considered to be a suitable "residual" disinfectant; i.e., appropriate for maintaining an effective disinfectant levels in the distribution system.

Inorganic chloramines may consist of up to three chemicals that are formed when chlorine and ammonia are combined in water: monochloramine ($NH_2Cl$), dichloramine (NHCl2) and trichloramine (NCl3). Inorganic chloramines, free chlorine and organic chloramines are chemically related. When chlorination of fresh water occurs in the presence of ammonia, monochloramine usually forms. Formation of dichloramine is discouraged by optimizing ratios of chlorine to ammonia. Conditions favoring the formation of trichloramine in drinking water are rare. In general, almost all chloramine is monochloramine with insignificant amounts of dichloramine and trichloramine under conditions of water treatment and distribution. Organic chloramines may also be produced if certain organic nitrogen compounds, including amino acids and nitrogen heterocyclic aromatics, are present (Environment Canada, 2001).

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

**Q 2: Why is chlorine or chloramine added to the water?**

A: All drinking water suppliers using surface water are required by the U.S. Environmental Protection Agency (EPA) to use disinfectants to eliminate pathogenic micro organisms in drinking water supplies. Chlorine is one of the disinfectants used for primary disinfection. Utilities must also maintain a residual disinfectant throughout the drinking water distribution system to control bacterial growth (i.e., secondary disinfection). Chlorine and/or chloramine are added to the water for this purpose. Due to drinking water disinfection there are no outbreaks of cholera, typhus, or other waterborne diseases, which currently kill over 10 million people each year in places where disinfection is not used (Marchand, 2004).

The primary driver for changing distribution system disinfectant from chlorine to chloramine is the formation of trihalomethanes (THMs) with chlorine. In the late 1970s and early 1980s it was discovered that when some of the components of the natural organic matter in water come in contact with chlorine used to disinfect the drinking water, they can form low concentrations of THMs and other disinfection by-products (DBPs). It was suspected that exposure to THMs at high concentrations over a lifetime may statistically increase the rates of some cancers. Because of this finding, the EPA began regulating THMs in 1979, with a maximum contaminant level (MCL) of 100 ug/L (or one hundred parts per billion). Chloramine reduces formation of these potentially carcinogenic THMs and therefore makes water safer for human consumption. Recently the MCL for THMs was further reduced to 80 ug/L and further restrictions on the levels of THMs and haloacetic acids (HAAs) are forthcoming. These changes will primarily focus on where the samples are taken and how the statistics for regulatory compliance is calculated.

The choice of disinfectant(s) depends on many factors and it is usually a balancing act to fulfill the requirements of many drinking water quality regulations. The change of disinfectants or treatment process is always preceded by many years of careful planning, testing, and

review of similar practices at other water utilities. The application of any proven or new drinking water treatment processes must be approved by the California Department of Health Services (CDHS), a primacy agency assuring compliance with the federal requirements of the Safe Drinking Water Act (SDWA) 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 and the distribution system (Kirmeyer et al., 2003).

**Q 3: What is the history of chloramine use in drinking water?**

A: Chloramine has been used for disinfection in the United States since the early 1900s. Both chlorine and chloramine are known disinfectants with a considerable body of experience from research and application points of view. Both chlorine and chloramine are approved disinfectants, in addition to chlorine dioxide, ozone, and most recently ultraviolet light (UV). Each of these approved disinfectants has advantages and disadvantages in terms of: (1) disinfecting effectiveness toward various groups of microorganisms, (2) reactivity with natural organic matter and associated formation of organic DBPs, (3) formation of inorganic DBPs, and (4) disinfectant persistence to provide lasting protection in the pipes and water storage reservoirs of the distribution system. Chlorine dioxide, ozone and UV can be used only for primary disinfection at the treatment plant because of limited or no residual disinfectant provided by these processes.

The extent of chloramine use in water treatment has varied. By 1936, 16% of all U.S. water treatment facilities were using chloramine. Due to the scarcity of ammonia during World War II use of chloramine declined until 1960s to a low of 2.6% facilities. After the enactment of the SDWA in 1974 and its subsequent Amendments, a renewed interest in the use of chloramine occurred due to increasing focus on microbiological safety and reduction of DBP formation. About 20% of treatment facilities used chloramine in 1990. The EPA estimates that 30% of surface water utilities will use chloramine for secondary

disinfection after the Stage 1 Disinfectant and Disinfection By-product Rule (D/DBPR) and that the percentage will increase approaching 60% as utilities make changes to comply with more stringent regulatory requirements of the upcoming Stage 2 DBPR (Kirmeyer et al., 2003 and AWWA, 2004).

**Q 4: What is the current use of chloramine for drinking water disinfection?**

A: Chloramine is a proven disinfectant used extensively in the Bay Area, California, across the nation, and worldwide. Most major utilities in California use chloramine as the drinking water disinfectant. In the Bay Area, Santa Clara Valley Water District, Contra Costa Water District, Alameda County Water District (since 1983 on their surface water supply), Marin Municipal Water District, Zone 7 Water Agency in Livermore, Pleasanton and Dublin (since 1990) and the East Bay Municipal Utility District (since 1998) provide chloraminated water to their customers. The Metropolitan Water District of Southern California has provided chloraminated water since the mid 1980s.

In its Information Collection Rule data published in 2002, EPA indicated that for the total of 353 treatment plants examined a total of 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. Chloramine use increased with source waters high in total organic carbon (TOC) up to 66% of the plant-months when source water TOC levels were greater than 4 mg/L (Kirmeyer et al., 2003). The EPA estimates that 30% of surface water utilities will use chloramine for secondary disinfection after the Stage 1 D/DBPR and that the percentage will approach 60% as utilities make changes to comply with Stage 2 D/DBPR (AWWA, 2004). In 1996, approximately 6.9 million Canadians were serviced by chloraminated drinking water (Environment Canada, 2001). Chloramination is also applied worldwide in Australia, England, and Finland.

**Q 5: What are the benefits to using chloramine instead of chlorine?**

A: The benefits of chloramine used as a residual disinfectant for the distribution system are: (1) persistence and ability to reach remote areas in the distribution system, (2) effectiveness as a residual disinfectant and ability to penetrate biofilms in the distribution system, (3) tendency to form lower levels of DBPs, e.g., THMs and HAAs, which are suspect carcinogens regulated by the EPA, and (4) ability to minimize chlorinous or other objectionable taste and odors.

Chloramine is more stable and persists longer in the distribution system because it is less reactive than free chlorine. The water agencies that have converted to chloramine report that customers note an improvement to the taste and odor of the water.

**Q 6: What are the drawbacks to using chloramine instead of chlorine?**

A: The drawbacks of using chloramine as a final distribution system disinfectant are: (1) potential deleterious effects on elastomeric materials sometimes used in distribution system appurtenances and plumbing fixtures, (2) vulnerability to the microbiological process known as nitrification, (3) potential formation of chloramine-related DBPs if precursor material is present in the source water (Kirmeyer et al., 2003), and (4) vulnerability to temporary increases in lead and copper levels where brass fixtures are used.

The treatment precautions for dialysis clinics and fish cultures must be taken both with chlorine and with chloramine. It is because of the main benefit of chloramine – its longer persistence – that extra removal for these special water users must be implemented. Certain natural rubber products and their derivatives used in household appliances (e.g., toilets, hot water heaters) will deteriorate faster with chloramine than with chlorine. The replacement of these with alternative materials available in the plumbing and hardware stores will eliminate this temporary nuisance rubber deterioration.

Vulnerability of chloramine to nitrification can be remedied, among others, by reducing the detention time of water in the drinking water storage reservoirs and low-use pipelines, keeping the system clean of deposits, which may harbor bacteria, flushing when necessary, and monitoring the system. All these actions benefit the customers providing fresher, shorter "shelf age" water with chloramine than with chlorine. Typically, conversion to chloramine has been preceded and followed by the distribution system capital improvements aimed at decreasing water age: seasonal or permanent outages of stagnant water tanks, improving mixing within the tanks, redesign of pressure zones for better interconnectivity, changing pumping schedules to improve stored water turnover, installation of new water quality monitoring stations.

Current state of knowledge indicates that the formation of chloraminated DBPs is at very low levels and drinking water distribution system surveys nationwide indicate the formation of N-nitrosodimethylamine (NDMA) at low levels with both chlorine and chloramine. In special circumstances where levels of NDMA in chloraminated water are greater, it is because precursor amines are present in the water – typically from man made sources – and the control of these precursor amines becomes necessary. This is currently a research issue and significant progress is being made to limit NDMA formation. The elimination of precursor amines from the drinking water will benefit customers and allow for NDMA levels at or below low detection limits of modern instrumentation.

In some but not all waters, the transition from chlorine to chloramine can be accompanied by temporary increases in lead concentrations, especially for homes with new brass faucets. This is discussed in more detail in the answer to Question 23.

**Q 7: What are the alternatives to chloramine?**

A: The only feasible alternative to chloramine for a distribution system disinfectant is chlorine. In the SFPUC case, continuing to use chlorine

would require large capital investments in technology to remove DBP precursors which would not be without water quality and environmental trade-offs. UV-irradiation, although proven very effective for inactivation of bacteria and protozoa is not as effective for the viruses and it does not provide residual disinfectant that is required in the distribution system. Additionally, bacteria have mechanisms of repair to UV-disinfection and may eventually regrow in the distribution system. Residual disinfectant will be required to control the regrowth. Ozone also does not provide residual disinfectant that is required in the distribution system and may form some suspected carcinogenic DBPs. Hydrogen peroxide and colloidal silver are not used for disinfection and in fact hydrogen peroxide is a dechlorination agent that may interfere with disinfection. A combination of UV-irradiation and hydrogen peroxide is tested for the chemical removal of certain organic compounds from the water and is not used for disinfection purposes. Chlorine dioxide is used by some utilities in Germany for residual disinfection but this disinfectant has several drawbacks: (1) formation of potentially harmful inorganic DBPs, (2) possibility of creating "cat-urine" odors in customer homes, (3) lower persistence in the distribution system, (4) very high cost. (EPA, 1999).

**Q 8: What is the history of regulatory approval of chloramines?**

A: Chloramine has been approved by the EPA and CDHS for use as a municipal drinking water disinfectant for decades. It is a water quality improvement as it reduces DBP levels. The amount of nitrogen contributed with the chloramine is small and below any health related federal drinking water standards. Chemicals used in the process must be NSF 60 approved and vendors must meet strict product quality requirements. The San Francisco Public Utilities Commission's (SFPUC's) change to chloramine will help ensure compliance with more stringent federal and state drinking water quality regulations at all times.

**Q 9: What is nitrification?**

A: Nitrification is a microbial process by which ammonia is sequentially oxidized to nitrite and nitrate. It causes an increase of chloramine demand and depletion of chloramine residuals thus allowing bacterial regrowth. Every chloraminating utility needs to assess nitrification potential and implement proper control measures. Nitrite and nitrate produced due to nitrification are unlikely to cause regulatory violations unless treated water nitrite and nitrate levels are near their respective MCLs. Other impacts of nitrification include reduction in alkalinity, pH, and dissolved oxygen. Under certain conditions, nitrifying bacteria can potentially accelerate corrosion due to the release of nitric acid (Kirmeyer et al. 2003).

Nitrification is more of a nuisance and operational problem than a health issue since nitrification is due to metabolism and growth of harmless non-pathogenic nitrifying bacteria that are ubiquitous in soils and water. It typically takes some time after chloramine conversion for the system to develop sufficient biomass for any localized nitrification to take place. Utilities implement operational control strategies, including enhanced monitoring, to catch problems early and to limit the extent of nitrification. After this optimization period and necessary engineering improvements the customers benefit from fresher water at their tap that was stored for a shorter period of time in the distribution system. Nitrification control benefits the customers with increased emphasis of the water suppliers on the quality of water residing in pipes and storage reservoirs.

**Q 10: How much bleach to add to water for emergency storage? How long to keep water in a closed container as part of earthquake preparedness?**

A: Emergency preparedness recommendations are to store an appropriate amount of tap water (as specified by the emergency preparedness brochure) in plastic, airtight, clean containers in a dark cool place. The customer may store the tap water without bleach

addition. Water stored this way may be kept for up to six months before it should be replaced. At the time of usage 16 drops of bleach should be added to each gallon of water. The bleach should be mixed and left to stand for 30 minutes prior to use.

## PHYSICAL CHARACTERISTICS AND CUSTOMER PERCEPTIONS

**Q 11: Does the water chemistry (pH, mineral content) change as a result of chloramine changeover?**

A: Chloramination does not affect pH or mineral content.

**Q 12: 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) and CDHS while the tap water is regulated by the EPA and the CDHS. The FDA and EPA standards can differ and the EPA regulations and the testing requirements are more stringent than those required of the bottled water by the FDA. Bottled water is oftentimes municipal 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 (NRDC Website).

**Q 13: Can I purchase bottled water that is 100% ammonia free?**

A: Bottled water may contain chloramine or ammonia if the bottled water company uses water supplied by a chloraminated water system, unless the company takes special steps to remove them.

**Q 14: Is there a MSDS for chloramine?**

A: There is no Material Safety Data Sheet (MSDS) for chloramine. Customers can obtain MSDS for the components (hypochlorite/chlorine

and ammonia) from their water utility. SFPUC currently adds about 2.3 mg/L of chlorine and 0.5 mg/L of ammonia to produce our target chloramine residual of 2.3 mg/L. To put the MSDS information in its proper context, the maximum levels for these chemicals in our system will likely not exceed 4 mg/L for chorine and 1 mg/L for ammonia. The concentration of chlorine at delivery is about 13% or 163,000 mg/L, and for ammonia is about 19.0% or 176,000 mg/L.

## CHLORAMINE REMOVAL FROM WATER

### Q 15: Why are 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 treatment process must remove chloramine from the water prior to use as they did with chlorine. Products to remove or neutralize chloramine are readily available.

Biotech 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 their yeast. Photo labs need to remove chlorine or chloramine from 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 require ultra pure water for their manufacturing process. Businesses and industries that use water in any manufacturing process, or for food or beverage preparation, need to be aware of a change in water disinfectant from chlorine to chloramine. The switch to chloramine may require companies to adjust or upgrade their current treatment system.

Businesses should contact their water treatment equipment supplier to determine if chloramine could impact their system. (SFPUC)

**Q 16: How much time will it take for both chloramine and chlorine to dissipate and at what ppm level? Can chloramine and/or ammonia be boiled out of water or dissipated by letting the water sit?**

A: While both chlorine and chloramine residuals decrease with time. chloramine takes longer than free chlorine. The chloramine decomposition rate is also affected by the exposure to air and sunlight. Chloramine and ammonia, like chlorine, will eventually dissipate completely over time but it is not practical to let the water sit for these to dissipate. Unlike chlorine, which only takes a few days to dissipate when left to stand, chloramine may stay in water for a few weeks (SFPUC) and ammonia remains in the water even longer. It usually takes days for chloramine to be dissipated when exposed to air and sunlight.

Boiling the water will remove chlorine but it will take much longer to remove chloramine. There are chemicals available that quickly and effectively remove chloramine.

**Q 17: Can charcoal filters remove ammonia?**

A: Charcoal or granular activated carbon (GAC) treatment can reduce chloramine concentrations of 1 to 2 mg/L to less than 0.1 mg/L. GAC treatment may result in ammonia, chloride, and nitrogen gas as by-products of the adsorption process of chloramine and reaction with the carbon surface. The by-product concentrations will be low (e.g., less than 0.5 mg/L ammonia as nitrogen). However, it may be desirable to remove these by-products depending on water use (CDM, 2003).

To remove the low levels of chloramine by-products, GAC treatment should be followed by a reverse osmosis (RO) process. RO should not be used alone as the chloramine residual can damage the RO membrane elements. GAC treatment will remove the chloramine

residual allowing RO to effectively remove portions of the other constituents. Owners of home RO units should contact the manufacturer of their units to determine if a GAC unit is installed upstream of the RO system.

GAC filters can also remove ammonia but nitrifying bacteria must establish themselves in the GAC column before ammonia removal can occur. Such an application would need to be followed by disinfection step with either a small RO unit or a UV lamp.

**Q 18: Are shower filters certified and if so by whom?**

A: As a public agency, the SFPUC does not test, endorse or recommend specific water filtration products. Contact the National Sanitation Foundation (NSF), a nonprofit organization that independently tests and certifies drinking water filtration products. Website: www.nsf.org, phone: 877-867-3435.

**Q 19: What methods are used by the industry to remove chloramine and excess ammonia?**

A: In the water industry, the most practiced methods of dechlorination are the addition of reducing agents (sulfite compounds, hydrogen peroxide and ascorbic acid (Vitamin C). GAC can be also used for dechlorination but it is often site-specific and dependent on the particular carbon used (Kirmeyer et al., 2003). The preferred method for removing chloramine for the general public is GAC filtration, followed by RO (SFPUC). Breakpoint chlorination is used routinely by some utilities to remove chloramine and excess 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 free chlorine.

**Q 20: Will chloramine dissipate faster than it can accumulate when over-watering the lawns? What is the saturation point when the chloramine will start to accumulate?**

A: Watering lawns releases low volumes of water and is considered an incidental discharge. Chloramine will dissipate as a result of lawn watering because of the high chlorine demand in the soil. The small amount of chloramine should not have any effect on plants of any type. Beneficial bacteria will generally be protected by the soil. 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, however some household irrigation water does run off to enter the storm sewer or bay. 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. Before water leaves any Bay Area wastewater treatment plant, the chlorine or chloramine are neutralized as well.

A high volume direct discharge of chloraminated water to the environment can result from pipeline breaks, flushing fire hydrants, or draining a swimming pool. As with chlorinated water, this should be avoided because the chlorine residual in the chloraminated water may pose a direct acute health risk to fish in creeks and streams. A dechlorinating agent must be used to remove chloramine from water during leaks and while flushing fire hydrants.

**Q 21: What is the relationship between MTBE and chloramination? If MTBE is removed from the water why isn't chloramine?**

A: There is no relationship between chloramine and methyl tertiary butyl ether (MTBE). Chloramine is a disinfectant that needs to be added to drinking water to keep microorganisms from regrowing in the distribution system and to protect public health. MTBE is considered a contaminant with respect to drinking water quality and would not be

added intentionally to the water. MTBE is not a disinfectant and has been added to gasoline as oxygenate to provide for cleaner gasoline combustion. MTBE can travel from leaking underground gasoline storage tanks through the groundwater and may impact groundwater supplies. Chloramine is not persistent in the ground due to the chloramine demand of the natural environment; chloramine will not travel with the groundwater in case of a drinking water spill or simple lawn watering. Surface water supplies may be impacted by MTBE in case of a gasoline spill or contamination from the water boat engines.

Groundwater pollution by MTBE has been mitigated by reformulating the gasoline additives with other oxygenates (e.g., ethanol) and by fixing gasoline storage tank leaks. Surface water pollution by MTBE has been mitigated by using cleaner burning engines on boats, for example four-stroke engines instead of two-stroke engines, and by limiting the recreational use of gasoline powered water boats in public drinking water supply reservoirs.

**Q 22: What are the methods for removing chloramine from fish aquariums?**

A: Just as with chlorine, chloramine can harm all 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 (SFDPH/SFPUC). 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 used 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. The 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 all of the oxygen in the water. In this case, the fish may suffocate. It is important to follow carefully the label instructions.

## IMPACT OF CHLORAMINE ON PLUMBING PARTS

### Q 23: Can chloramine cause the release of lead and copper from pipes and plumbing?

A: The lead corrosion concern associated with chloramine is something new and unexpected both by the regulators and the industry. The professional literature does not suggest this as a concern for chloramine conversion. However, the utility serving Washington DC recently detected high levels of lead at the customer taps after conversion to chloramines. EPA and CDHS are doing an informal survey to see if the problem might have occurred at any place other than Washington, DC. It appears that Washington DC presented a unique situation (lead service lines, significant biofilm in far reaches of the system, corrosion control process, etc.) that contributed to the problem and the question remains if chloramine is really the cause. Numerous factors contribute to metal corrosion including water quality, biofilms, the pipe manufacturing process, and the design and installation methods of piping systems. The major water quality factors include pH, calcium, alkalinity, carbon dioxide, sulfates, chlorides, dissolved solids, temperature, and the presence of oxidants such as free chlorine and chloramines (Kirmeyer et al., 2003). Biocorrosion and the release of copper into the water have occurred as a result of the lack of disinfectant residual (chlorine and chloramine) and the corrosion was stopped when the chlorine or chloramine levels were increased. The presence and absence of lead lines in the distribution system and the historical presence and absence of disinfectant residual

as well as biofilms need to be reviewed when investigating the reasons for increased metal corrosion.

The increased corrosion of lead and increase in lead levels in the distribution systems have not been observed in the industry as a result of chloramination based on existing regulatory samplings and increases are not expected to occur based on the current state of knowledge. Routine regulatory samples collected by the Bay Area utilities before and after chloramine introduction have not exhibited any change in lead levels for several years. Due to the recent alleged association between chloramine conversion and lead corrosion in Washington DC, additional samples are being taken. Scientific investigations to determine the causes of lead corrosion in Washington DC area are on-going and include investigation into the role of brass fixtures. Some brass fixtures appear to show greater releases of lead with chloramines while others do not. SFPUC is planning to sample its system in September 2004 after there has been sufficient time to see any possible impact from conversion to chloramine.

**Q 24: Can chloramine cause the increased corrosion of radiators?**

A: There is no evidence that chloramines should increase metal corrosivity of water. However, water will corrode metal including radiators, which is why radiators are no longer filled with water but with chemical formulations to protect the metal surfaces.

**Q 25: What is the impact of chloramine on rubber parts?**

A: Chloraminated waters are more aggressive to elastomer compounds (especially natural rubbers and their derivatives) than equivalent concentrations of free chlorine. Elastomeric failure is unrelated to excess ammonia. Cracking and swelling of certain components may result. Higher water temperatures play a critical role in this process with higher temperatures accelerating the deterioration rate (Kirmeyer et al., 2003). 23% of utilities surveyed experienced an increase in materials degradation after implementation of chloramine. Synthetic

polymers or hard rubbers specifically developed for chemical resistance such as silicon and fluorocarbon-based elastomers are resistant to deterioration from chloramine.

Though rare, signs of degradation can include small black flakes in water and plumbing fixtures. This problem has not been widespread in areas that have already converted to chloramine. As rubber plumbing parts wear out, consumers should replace rubber plumbing components with chloramine resistant materials such as: high quality rubber (synthetic polymer) parts, flexible copper tubing, tubing made of corrugated stainless flex, or newer neoprene braided stainless steel.

Increased deterioration of certain rubber components has been reported in association with chloramine use. The City of Austin, Texas, converted a portion of the system to chloramine and within 12 months, a number of complaints were received about black specks in the water, which consisted of nitrile rubber material commonly used in the system. Complaints about rubber corrosion could be received as early as six months after the conversion.

Utilities also received complaints regarding degradation of hot water heater plastic dip tubes. Chloramine resistant toilet flapper valves and washers made by one company are red in color, to be easily distinguished. Point of purchase displays with information are available at all city hardware and plumbing supply stores. (SFPUC)

## IMPACT ON ANIMALS AND ENVIRONMENT

### Q 26: What are the impacts of chloramine on shrimp, fish and marine mammals?

A: Both chlorine and chloramine are toxic to fish and aquatic life. Chloramine is more persistent and therefore more difficult to remove from the water than free chlorine. The additional ammonia in the chloraminated water can also be toxic to fish under certain conditions.

Utilities also need to take precautions when discharging chloraminated or chlorinated water to the environment (Kirmeyer et al., 2003).

The mechanism responsible for the toxicity of chloramines differs somewhat from chlorine toxicity. Chlorine does not readily pass the permeable gill epithelium compared with chloramines. 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 however, crosses the gill epithelium with an insignificant amount of 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. The condition, known as methemoglobinemia, is similar to the oxidation of hemoglobin to ferrihemoglobin caused by nitrite toxicity. Nitrite toxicity also causes an inability of the red blood cells to transport oxygen (Kirmeyer et al., 2003).

The aquatic toxicity of inorganic chloramines is dependent on biological species, chloramine compounds, presence of chlorine and organic chloramines, temperature, exposure duration and life stage of the biological species. Toxicity tests on freshwater fish (juvenile Chinook salmon, Oncorhynchus tshawytscha), freshwater invertebrates (Ceriodaphnia dubia and Daphnia magna) and marine invertebrates (Amphiporeia virginiana and Eohaustorius washingtonianus) were undertaken, and time-to-lethality (e.g., $LT_{100}$, $LT_{50}$, $LT_{20}$, LT0) reference lines were determined. Further analyses produced a reference line (the lowest reference concentration for 50% lethality) showing that the incipient lethality to 50% (i.e., LC50) of C. dubia occurred at times equal to or greater than 1073 minutes and a monochloramine concentration of 0.018 mg/L. Using application factors, the lower-boundary reference line was shifted to reflect 0% mortality for C. dubia. The line was also lowered to account for the species identified in the literature as being more sensitive to inorganic chloramines than C. dubia. Using this approach, an incipient Estimated No-Effects Value (ENEV) of 0.0056 mg/L for freshwater organisms was

derived for the conservative-level assessment. The same reference line for acute toxicity was adopted to determine a suitable lower boundary line for marine invertebrates due to insufficient acute toxicity data with which to perform reliable modeling for marine and estuarine invertebrates. For the conservative-level assessment, an incipient ENEV of 0.0028 mg/L for marine and estuarine environments was derived by using application factors to reflect 0% mortality and to account for more sensitive species.

Two methods can be used to remove chloramine from the water: addition of specific agents, which will remove chloramine and ammonia, or use of high grade GAC. 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. Ammonia can be toxic to fish, although all fish produce some ammonia as a natural by-product. Commercial products are available at the pet stores to remove excess ammonia. Also biological filters, natural zeolites and pH control methods are 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 high grade GAC. It is important to allow the appropriate amount of contact time for chloramine removal using that method (Kentucky American Water Company brochure, in Kirmeyer et al., 2003).

**Q 27: What are the effects of ammonia on fish?**

A: Ammonia can be toxic to fish, although all fish produce some ammonia as natural byproducts. 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 toxic effects of ammonia (Kirmeyer et al., Kentucky-American brochure, 2003).

The ammonia is not toxic below pH 7, since ammonia is in the ionized ammonium ion form $NH4^{+}$. For example in water with a pH of 6.9 and at a temperature of 24oC, 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., 2003).

**Q 28: What are the impacts of chloramine on dogs and cats?**

A: Chloramine is safe for all animals, except those that breathe through gills. 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 SFPUC chloraminated drinking water.

Additionally, the EPA criteria document states "Flour bleached with trichloramine administered in the diet has been shown to produce "canine hysteria" or "running fits" in dogs. However, one study suggests that this is a species-specific phenomenon for dogs (Mellanby, 1946; Silver et al., 1947a,b,c; Newell et al., 1947) and does not affect humans (Pollock, 1949). Trichloramine is formed in waters at high chlorine-to-ammonia ratio concentrations and at lower pHs than normally found in drinking water." (EPA 1992) This is therefore not expected to be a problem related to monochloramine in our drinking water.

**Q 29: If cows drink chloraminated water will chloramines be in their milk?**

A: No, chloramine should 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.

## HEALTH EFFECTS

### Q 30: What are the general health questions and concerns about chloramine? Are there any known health drawbacks of chloramine?

A: Both chlorine and chloramine can react with naturally occurring material and treatment chemicals to produce potentially harmful byproducts. Thus, utilities must carefully balance the application of these disinfectants with the formation of byproducts. Although chloramine is not as strong a disinfectant as chlorine, it generally forms less by-products than chlorine and thus enhances public health protection (e.g., chloramine reduces the production of THMs and HAAs that are formed by chlorine). One possible byproduct of using either chlorine or chloramine for disinfection is the creation of N-nitrosodimethylamine, or NDMA. NDMA has been known for many years to be a byproduct in drinking water at very low levels; however, US health authorities have yet to set a health standard for this compound. The biggest sources of human exposure to NDMA are tobacco smoke, chewing tobacco, bacon and other cured meats, beer, cheese, toiletries, shampoos, cleansers, interior air of cars, and household pesticides. At very high levels, perhaps 100,000 times the levels seen in some drinking water, NDMA may cause liver disease in test animals. For additional information see SFPUC's NDMA Fact Sheet and White Paper at www.sfwater.org

After a switch to chloramine, the customers typically notice some aesthetic difference in their water. Chloramine should have less taste and odor when comparing with free chlorine.

The Integrated Risk Information System (IRIS) provides a summary of the EPA's risk assessment of monochloramine. The summary includes information on oral toxicity, chronic exposure and carcinogenicity of monochloramine, based on human and animal studies. The oral reference dose for monochloramine 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. (EPA 1992) One study in humans found no acute effects on lipid and thyroid metabolism associated with ingestion of chloraminated water at 2 ppm concentration. (Wones 1993) There is insufficient evidence to classify monochloramine as a human carcinogen. (EPA 1992)

Information on how chloramine is metabolized is somewhat limited. Chloramine is believed to be transformed to chloride and then eliminated in this form through the urine. One experiment in rats found that after 5 days, 27% of the chloramine was eliminated in urine and feces. (EPA 1994)

Information on the absorption of inorganic chloramines is also limited. In one rat study it was determined that about half of a single oral dose of monochloramine was absorbed after 2.5 hours. However, there are no animal or human studies documenting absorption rates with respect to various dosage media and different routes of exposure. (EPA 1994)

**Q 31: Does chloramine cause asthma?**

A: No. While some studies have found links between nitrogen trichloride (trichloramine) and asthma symptoms, no studies have demonstrated an association between exposure to monochloramine in public water supplies and asthma symptoms. Trichloramine is not present in SFPUC chloraminated drinking water.

**Q 32: Does chloramine cause dry skin, skin rashes?**

A: A comprehensive review of the medical literature done by the San Francisco Department of Public Health (SFDPH) in 2004 (unpublished) indicates that skin rashes have not been associated with exposure to monochloramine.

The customer complaints/inquiries at other 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. This type of complaint appeared not significant (Vestal, 2004). This type of response to known changes in water treatment procedures has been studied and documented (Lamberg 1997; Lyons 1999)

**Q 33: 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 in monochloramine is bound to chloride and will not produce adverse effects from exposure by washing. Ammonia is released during the digestion of monochloramine in the digestive system. Please refer to Q 40below for more information on ammonia in the digestive process.

**Q 34: Is there any association between chloramine and heart failure?**

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

**Q 35: Can chloramine affect the human body through ingestion, absorption through skin during bathing?**

A: When people ingest monochloramine, the monochloramine is broken down quickly in the digestive system. The chloride is eliminated through the urine, and the ammonia is transformed to urea in the urea cycle. There have been no published studies on the absorption of chloramine through the skin, in either animals or humans (EPA 1994). However, there is no evidence that chloramines would enter through the skin.

**Q 36: Is chloramine a toxin?**

A: When consuming drinking water, people have no trouble digesting chlorine or chloramine at the levels found in drinking water. A comprehensive search of the medical literature does not reveal any studies showing that people with compromised immune systems, weak livers or those that are taking drugs have any special problems metabolizing chloramines (SFDPH unpublished). Chloraminated water is no different than chlorinated water for all the normal uses of drinking water. Water that contains chloramine is safe to drink. The digestive process neutralizes the chloramine before it reaches the blood stream. Even kidney dialysis patients can drink and bathe in chloraminated water (Kirmeyer et al., 2003).

However, any substance, in high enough doses, may be toxic. For example, many vitamins and minerals, which are essential to human health, are toxic at high doses. The long-term average exposure to a concentration of monochloramine in drinking water should not exceed 4 mg/L. This maximum limit is the EPA's determination of a safe concentration based on the available evidence and incorporating additional factors to ensure safety.

**Q 37: What is the damage to red and white blood cells by chloramine?**

A: If monochloramine enters the blood stream directly, it combines with hemoglobin (red blood cells) so it can no longer carry oxygen.

This problem occurs if monochloramine is not removed from water used in dialysis machines. This does not occur by drinking chloraminated water. Studies in rats have shown that ingesting water containing monochloramine does not affect white blood cell or red blood cell counts in any clinically significant manner. (Moore 1980, as described in UNEP 2000)

**Q 38: Can one safely wash an open wound with chloraminated water?**

A: Yes. It is safe to use chloraminated water in cleaning an open wound because virtually no water can enter the bloodstream that way (Kirmeyer et al., 2003).

**Q 39: Can chloramine and ammonia bioaccumulate in the body?**

A: Chloramine does not bioaccumulate in the body. Monochloramine 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.

**Q 40: What are the impacts on dialysis patients and can chloramine contribute to kidney failure?**

A: There is no evidence that chloramine ingestion can contribute to kidney failure. (SFDPH). However, like chlorine, chloramine can harm kidney dialysis patients during the dialysis process if it is not removed from the water prior to dialysis treatment. This is because water used in the kidney dialysis treatment process directly enters 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. The CDHS has inspected and certified all hospitals and dialysis patient-care facilities in the SFPUC service area to insure that all facilities have made the necessary changes to their water treatment systems. Home dialysis

patients receive care and direction through a certified hemodialysis care facility. There are very few home dialysis patients throughout the SFPUC service area and all of those have been contacted through their care facility. Kidney dialysis patients can safely drink chloraminated water as residual disinfectants are neutralized in the digestive process (SFPUC).

According to the Renal Dialysis Network system, the physician in charge of dialysis has the ultimate responsibility for selecting a water treatment system and maintaining the performance of that system once it has been installed and its performance verified. Patients using kidney dialysis should discuss the level of chlorine and ammonia removal with their physician or other health care provider to ensure proper treatment techniques are in place, properly monitored, and in sound working order.

GAC filtration in series followed by RO treatment is required to remove contaminants including chloramine from water to be used for patients receiving kidney dialysis treatment. Details and guidance of accepted water treatment processes for kidney dialysis systems are given by the Association for the Advancement of Medical Instrumentation (AAMI) guidelines RD5 Monograph, Hemodialysis Systems (CDM, 2003).

More information can be found at the following references (CDM, 2003):

For the "standard methods" use for kidney dialysis systems, use http://www.aami.org/publications/standards/dialysis.html.

Additional information is found at: http://www.ikidney.com/iKidney/InfoCenter/CDN/Archive/Printer/TheNewAAMIGuidelinesWaterTreatmentForHemodialysisApplications.htm

The End Stage Renal Dialysis network information can be found at: http://www.esrdnetworks.org/

The Bay Area network can be found at:
http://www.network17.org/patient_services.htm

**Q 41: Is chloraminated tap water safe for the general public and people with suppressed autoimmune system (AIDS, cancer, kidney dialysis, diabetes, hepatitis, lupus)? Have any tests been done on this? If so what were the results?**

A: Chloraminated water is safe for the general public and for people with suppressed immune systems or other diseases. Because neither chloramine nor chlorine destroy certain protozoans like cryptosporidium, 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 present in the water despite the use of these disinfectants.

**Q 42: Is ammonia toxic and/or digestible?**

A: Chlorine and ammonia, in the concentrations used for drinking water disinfection, are not toxic, as defined by the CDHS and EPA. 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 43: Is there an impact of chloramine on human metabolism?**

A: There is no evidence that monochloramine in the concentrations that are present in drinking water have any effect on human metabolism. A small study conducted in 1993 and published in the journal Environmental Health Perspectives showed no effect of monochloramine ingestion at levels of 2 ppm. Healthy men were randomized to consume 1.5 liter per day of either distilled water, water containing 2 ppm monochloramine, or water containing 15 ppm monochloramine for four weeks. At the end of the study, the men who were drinking 2 ppm monochloramine, 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 ppm study group had no difference in thyroid metabolism compared to the distilled water group. The men who drank 15 ppm monochloramine 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 ppm monochloramine had their plasma apoliporotein B levels drop slightly. The authors suggested that this finding may be due to chance, and should be confirmed in other studies. (Wones 1993)

Another study found that 10 healthy male volunteers experienced no biochemical or physiochemical response after drinking water treated with monochloramine at concentrations up to 24 mg/l in compared to a control group drinking untreated water. (Lubbers 1991) However, no new studies have been reported in the medical literature.

**Q 44: Is chloramine a carcinogen?**

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

**Q 45: Can chloramine cause gastric lesions?**

A: Monochloramine is produced by activated neutrophils and this has been observed to cause gastric lesions in rodents at the cellular level. However, this effect at the cellular level is not expected to be seen as a result of drinking water exposure, because the concentrations in drinking water are extremely low.

**Q 46: What are the byproducts of chloramination?**

A: Both chlorine and chloramine can be harmful if people are exposed to high concentrations of these disinfectants. For this reason, and because of DBP control, EPA has set long-term limits on the levels of both chlorine and chloramine added to drinking water (4 mg/L). Regulated DBP compounds (i.e. THM and HAA) concentrations

decrease when switching from free chlorine to chloramine, but cyanogen DBPs and NDMA concentrations tend to increase. Typical reduction in THMs has been observed at 40 to 80% and 90 to 95% reduction in HAA9 has been reported. Cyanogen chloride may be formed in greater amounts during chloramination than when free chlorine is used. NDMA can be formed in higher concentrations with chloramine than with free chlorine. Recent research has begun to identify operational best management practices that may be used to reduce NDMA formation.

Chloramine is not NDMA and does not form NDMA as long as precursor material for NDMA is not present. Even if precursor material is present in the water, NDMA formation rates can be controlled to minimize the resulting NDMA concentrations. The presence of NDMA in drinking water should be put in perspective compared to the NDMA concentrations in foods and other beverages.

NDMA formation is expected to modestly increase with the transition to chloramines, though due to the excellent quality of the pristine Hetch Hetchy source, (e.g., low in organic nitrogen and bromide, plus free from agricultural run-off) this is expected to be low. Recent monitoring of the SFPUC system after the chloramine conversion in April of 2004 showed only one out of eight locations with a detectable NDMA (detection limit of 2 parts per trillion (ppt). That location had an NDMA level of 4 ppt. The longer term experience of East Bay Municipal Utility District, a large chloraminated surface water supply system in California, indicates that it is possible to limit NDMA formation in the distribution system to low levels near or below the detection limit with the chloramine at pH around 9.0 and even with long detention times, provided no major precursor material is present in the raw water and treatment cationic polymer usage is optimized (Wilczak et al., 2003).

For additional information see SFPUC's NDMA Fact Sheet and White Paper at www.sfwater.org/

**Q 47: Which are the known interactions between chloramine and medicines?**

A: Chloramine interaction with pharmaceuticals has not been specifically studied. However, 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 they act in persons drinking chloraminated water.

**Q 48: What is the interaction between chloramines and acid reflux?**

A: Chloraminated water will not affect acid reflux. According to the Society of Thoracic Surgeons, gastroesophageal reflux disease, commonly referred to as acid reflux, is not related to the types of food people eat, though it 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 49: Is it safe for babies to drink chloraminated water?**

A: Yes. Everyone can drink water that contains chloramine. There is no evidence that chloramine is excreted in the milk of nursing mothers.

**Q 50: What is the occurrence and health significance of iodoacids, newly reported chloramination byproducts**

A: The SFPUC system is unlikely to have significant levels of iodoacids because of the low concentrations of bromide (and likely iodide) in the raw water. The only documented occurrence of iodoacids has been at one utility (Weinberg et al., 2002; and Plewa et al., 2004) with raw water bromide/iodate concentrations 10 times greater than that measured in SFPUC raw water. All waters treated by the SFPUC are free chlorinated prior to ammonia addition and chloramine formation, which will further preclude or minimize the formation of iodoacids. The

sampling and quantification of these emerging DBPs is contingent on development of appropriate analytical methods. SFPUC staff is following research in the area of iodoacids and other potential micro-contaminants.

The formation of iodinated compounds by chloramine treatment, in certain situations, is not unexpected. However, the level of toxicity associated with iodinated DBPs is only now being investigated and, at this point, it 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 knowing that 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 al., 1987), France (Bruchet et al., 1989), and Spain (Richardson, 2004).

In 2002, the Environmental Protection Agency conducted a nationwide DBP occurrence study (Weinberg et al., 2002). This study also 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 initial disinfection and for maintaining a residual disinfectant in the distribution system. Plewa et al. (2004) postulated that chloraminated drinking waters that have high bromide and iodide source waters might contain these iodoacids and other iodo-DBPs. The study by these researchers (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 assay. One of the benefits of chloramine disinfection is that chloramination typically results in lower formation of brominated and chlorinated acetic acids and THMs as compared with chlorine.

These important research findings are not of immediate public health concern for the following reasons: (1) iodoacids have been detected only in one water system with high bromide and likely high iodide content (iodide is not commonly measured while 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 free chlorine before applying chloramine (as the SFPUC does) will allow the chlorine to react with iodide to form iodate and stop iodoacids formation (Plewa et al., 2004, Richardson, 2004). Iodate is not a health concern as it is transformed back to iodide after ingestion (von Gunten, 2003). The study of iodoacids 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; a study to evaluate these has been proposed (AwwaRF, 2000). Methods for quantification of iodoacids are currently under development by the EPA (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 as stated by Plewa et al. (2004).

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GLOSSARY OF TERMS:

AAMI Association for the Advancement of Medical Instrumentation

CDHS California Department of Health Services

DBPs Disinfection by-products

D/DBPR Disinfectant and Disinfection By-product Rule

EPA United States Environmental Protection Agency

ENEV Estimated No-Effects Value

FDA Food and Drug Administration

GAC Granular activated carbon

HAAs Haloacetic acids

IRIS Integrated Risk Information System

LC Lethal concentration

LT Time-to-lethality

MCL Maximum contaminant level

mg/dL Milligram per deciliter of blood

mg/L Milligram per liter; 1 in 1,000,000

MSDS Material Safety Data Sheet

MTBE Methyl tertiary butyl ether

NDMA N-nitrosodimethylamine

NSF National Sanitation Foundation

ppb Parts per billion, 1 in 1,000,000,000

ppm Parts per million; 1 in 1,000,000

ppt Parts per trillion; 1 in 1,000,000,000,000

RO Reverse osmosis

SDWA Safe Drinking Water Act

SFDPH San Francisco Department of Public Health

SFPUC San Francisco Public Utilities Commission

THMs Trihalomethanes

TCR Total Coliform Rule

TOC Total Organic Carbon

UV Ultraviolet

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