QUESTIONS REGARDING PLUMBING
Updated August 2010

Q: What is the compliance with lead regulation in the SFPUC system?
A: SFPUC has been in compliance with the Action Level for lead (15 ug/L), including several samplings after chloramine conversion in 2004, 2005, 2006 and 2009 in the Regional and San Francisco Water Systems. These results indicate no negative impact of chloramine on lead levels.
Lead in drinking water is regulated by the Lead and Copper Rule (LCR), a Federal and State drinking water standard (USEPA, 1991) that specifies an Action Level of 15 ug/L for lead in drinking water systems, measured at customers' taps. If lead concentrations exceed an action level of 15 ug/L in more than 10% of customer taps sampled, the system must undertake a number of additional actions to control corrosion. If the action level for lead is exceeded, the system must also inform the public about steps to protect health. Additionally, lead service lines under control of the system may need to be replaced. The Action Level refers to a concentration measured at the tap rather than in municipal water supply system because lead in drinking water is derived principally from household plumbing, especially in systems like the SFPUC that do not have any lead service lines or distribution pipes. The leaching of lead in the distribution system is greater if the water is slightly acidic.
The SFPUC corrosion control treatment consists of maintaining slightly alkaline water pH (above neutral) throughout the distribution system. This practice is typical for water systems serving low mineral content high quality water from mountain supplies. In addition, SFPUC has conducted an active program in the last 25 years focused on reducing the potential for lead to appear in the drinking water at the consumer's tap: (1) in the 1980s all lead service lines in the San Francisco Water System were removed including lead whips (goosenecks) connecting the service lines to the mains, (2) in 1994 SFPUC initiated a "Lead Test for a Fee" program for the customers, (3) in 1998 SFPUC began free lead-in-water tests for Women, Infants & Children (WIC) program participants, (4) since 2000 SFPUC has provided lead-free faucets to childcare centers and schools, (5) in 2001 SFPUC started providing lead-free faucets to City residents via annual sales at street fairs, (6) in 2002 SFPUC initiated a 20-year-long 8% lead water meter replacement program. SFPUC has monitored for lead numerous times as part of LCR compliance and has been in compliance with the Action Level for lead (15 ug/L), including several samplings after chloramine conversion in 2004, 2005, 2006 and 2009 in the Regional and San Francisco Water Systems. These results are a testimony to SFPUC's efforts in lead control over the last two decades. They also indicate no negative impact of chloramine on lead levels. The results obtained at SFPUC were documented by Wilczak et al. (2010). The studies of Giammar et al. (2010) and Boyd et al. (2010) confirmed that monochloramine would have no impact on the release of either lead or copper due to chloramine conversion under water chemistry conditions of SFPUC system.
Customers in the City of San Francisco interested in measuring lead levels in their homes may request a sampling kit and analysis for a small fee by calling 877-737-8297. The results of this "Lead Test for a Fee" sampling program for the customers in San Francisco (conducted at customers' residences at their request) indicate no impact of chloramine on lead levels.

Q: What is the potential impact of the disinfectants on the release of lead from pipes and plumbing?
A: Reiber (1993) found that neither lead nor lead solders were substantially influenced by the presence of chlorine or chloramine at pH levels common to distribution systems. The increased corrosion of lead and increase in lead levels in the distribution systems as a result of chloramination have not been observed in the industry in the past. Instances of increased lead levels in the tap at a utility in Washington DC, and at several utilities in North Carolina and Virginia were recently attributed to chloramination because they coincided with a change to chloramine disinfectant in the distribution system at these utilities. The conclusions of subsequent technical investigations, which revealed other causes of lead leaching; are summarized below. Current USEPA information on lead corrosion is summarized at

http://www.epa.gov/ORD/NRMRL/wswrd/cr/corr_res_lead.html

In 2002, the utility serving Washington DC reported high levels of lead at the customer taps after conversion to chloramine (Edwards and Dudi, 2004). Until recently it has been assumed that the primary oxidation state of lead on the corroded surface of lead pipe is divalent Pb[II], typically in the form of lead oxide, lead carbonate or lead hydroxy-carbonate (Crittenden et al., 2005).

The tetravalent state of lead Pb[IV] on the other hand, is much less soluble than Pb[II]. Until recently, it was assumed that Pb[IV] plays an insignificant role in controlling lead solubility, however analysis of the surface scale of lead pipe harvested from a number of water utilities across the U.S. suggests the presence of tetravalent lead is more common than once thought (Schock et al., 2005). After elevated lead levels occurred in Washington D.C., testing of the water profile from the taps of several homes showing high lead levels suggested that the highest lead levels were coming from lead service lines. Subsequent work analyzing the scales on the surface of lead pipes from Washington D.C. before and after chloramination have shown that Pb[IV] is the dominant form during the presence of high levels of chlorine and it gradually reverts to more soluble Pb[II] after exposure to chloramine. The presence of these two different minerals also showed a strong correlation with the levels of lead found in the system (Schock and Giani, 2004).

The experience in Washington D.C. makes it clear that circumstances can occur where the switch from chlorine to chloramine may result in elevated lead levels. But this occurrence is clearly more the exception than the rule. The special conditions applicable in Washington D.C. are the following: (1) Washington D.C. had a great deal of lead pipe, lead service lines and, in some cases, lead plumbing in homes, (2) During the years immediately prior to the change, Washington D.C. maintained rather high chlorine residuals, ranging from 2.5 to 4 mg/L. SFPUC's situation is different for the following reasons: (1) LCR sampling conducted before and after the switch to chloramine in SFPUC system showed lead levels below the Action Level requirement in the rule, (2) Unlike Washington D.C., the SFPUC system has no known lead services or homes with lead plumbing, (3) SFPUC has never practiced the unusually high levels of chlorine residual in Washington D.C. before the change of disinfectant to chloramine. The lead corrosion control strategy and the results obtained at SFPUC were documented by Wilczak et al. (2010). Recent USEPA (2007) report confirms these general findings and states that a combination of factors – not a single source or a single causative event – contributed to the problematic release of lead in water at consumers' taps in the Washington DC (DCWASA) system. The primary source of lead release was attributed to the presence of lead service lines (LSLs) in the DCWASA service area.

A change to chloramine as a distribution system disinfectant at a utility in North Carolina was attributed in the media to increased lead levels. Follow-up investigation by Triantafyllidou and Edwards (2006) at three utilities in Virginia and North Carolina, all of which had recently switched to chloramine, determined that a change in coagulant – an inorganic salt used to remove organic matter from the water – was in fact responsible in all three cases for increased lead leaching (Triantafyllidou and Edwards, 2006). Field data demonstrated that changes in coagulants containing sulfate to those containing chloride increased the chloride to sulfate ratio in treated waters and caused lead release from the solder and brass. Lead solder particles trapped in the drinking water tap aerator were a key source of lead. Lead levels decreased upon changing back to coagulants containing sulfate in all cases and the utilities continue to use chloramine. Triantafyllidou and Edwards (2006) suggested that lead leaching could be most sensitive to coagulant type when treating waters with relatively low chloride and sulfate, since potential changes may be most significant in these situations.

A recent study by Sharp et al (2007) evaluated lead and copper leaching to determine the possible impacts of New York City switching distribution system disinfectants from free chlorine to chloramine. The results from the first phase of studies indicate that the application of chloramine prepared with a chlorine to nitrogen ratio of 3:1 and a pH that ensures complete monochloramine formation will not result in increased lead and copper leaching compared to that of the current New York City drinking water. The studies of Giammar et al. (2010) and Boyd et al. (2010) confirmed that monochloramine would have no impact on the release of either lead or copper due to chloramine conversion under water chemistry conditions of SFPUC system.

Q: What practices are recommended by the USEPA to reduce potential lead exposure from household plumbing?
A: The USEPA (http://water.epa.gov/drink/info/lead/index.cfm) recommends the following routine practices to reduce possible exposure to lead in the tap water. (1) Flush pipes before drinking, and only use cold water for consumption. The more time water has been sitting in a home's pipes, the more lead it may contain. Anytime the water in a particular faucet has not been used for six hours or longer, "flush" cold-water pipes by running the water until it becomes as cold as it can get. This could take as little as five to thirty seconds if there has been recent water use such as showering or toilet flushing. Otherwise, it could take two minutes or longer. (2) Use only water from the cold-water tap for drinking, cooking, and especially for making baby formula. Hot water is likely to contain higher levels of lead. The two actions recommended by USEPA should be effective in reducing lead levels because most of the lead in household water usually comes from the plumbing in the house, not from the local water supply. The USEPA also recommends removing the screen and aerator at the end of a faucet and cleaning it of debris on a regular basis. The small screen at the end of a faucet can trap sediments that may contain lead solder particles released from customer plumbing. This practice, along with flushing of the drinking water tap (until water gets cold), will minimize exposure to lead.

Q: What practices are recommended by the USEPA to reduce potential lead exposure from plumbing in schools and childcare centers?
A: The USEPA (http://www.epa.gov/safewater/consumer/leadinschools.html) recommends the following routine practices to help reduce exposure to lead in drinking water in schools and child care centers:
Clean debris from accessible screens (aerators) frequently. Clean and inspect periodically.
Thoroughly flush holding tanks to remove sediment.
Use only cold water for food and beverage preparation in kitchens.
Placard bathroom sinks with notices that water should not be consumed. Use pictures if there are small children using the bathroom.

Q: What is the compliance with copper regulation in the SFPUC system?
A: SFPUC has always been in compliance with the Action Level for copper (1.3 mg/L), including several samplings after chloramine conversion in 2004, 2005, 2006 and 2009 in the Regional and San Francisco Water Systems. There is no impact of chloramine on copper corrosion in SFPUC system.
Copper in drinking water is regulated by the Lead and Copper Rule, a Federal and State drinking water standard (USEPA, 1991) that specifies an Action Level of 1.3 mg/L for copper in drinking water systems, measured at customers' taps. If copper concentrations exceed an action level of 1.3 mg/L in more than 10% of customer taps sampled, the system must undertake a number of additional actions to control corrosion. The Action Level refers to a concentration measured at the tap rather than in municipal water supply system because much of the copper in drinking water is derived from household plumbing. The leaching of copper in the home distribution system is greater if the water is slightly acidic.
The SFPUC copper corrosion control treatment consists of maintaining slightly alkaline water pH (above neutral) throughout the distribution system. This practice is typical for water systems serving low mineral content, high quality water from mountain supplies. The study of Boyd et al. (2010) confirmed that monochloramine would have no impact on the release of copper due to chloramine conversion under water chemistry conditions of SFPUC system.

Q: What are the factors that may influence copper corrosion in a drinking water system?
A: Numerous factors may contribute to copper corrosion including water quality, presence of biofilms, pipe manufacturing process, and the design and installation methods of piping systems. The major water quality factors include pH, alkalinity, sulfates, chlorides, dissolved solids, dissolved oxygen, temperature, and the presence or absence of disinfectants such as chlorine and chloramine (Kirmeyer et al., 2004). The single most important factor for uniform corrosion of copper tubing appears to be pH. Copper corrosion is sensitive to pH, especially at pH levels

below 6, and at pH 8 and above, copper corrosion is near its minimum achievable level (Reiber, 1993). Operationally, there are no reports of accelerated copper failure in chloraminated systems (Reiber, 1993). Little information has been reported in the literature about the effect of chloramine on copper or iron. Some authors reported that chloramine was less corrosive than free chlorine towards iron; an increase in red water complaints was reported following the use of chlorine residual instead of chloramine (Health Canada, 2009). A recent study by Boyd et al. (2010) confirmed that monochloramine would have no impact on the release of copper due to chloramine conversion under water chemistry conditions of SFPUC system.
Reiber (1993) exposed metals in the laboratory to varying levels of pH, chlorine, chloramine and ammonia. Both chlorine and chloramine accelerated the corrosion of copper and its alloys at pH 6 but caused minimal corrosion at pH 8. The corrosion was greatest for brass, followed by copper and then bronze. The presence of chlorine or chloramine did not lead to pitting type corrosion on copper or copper alloy surfaces. The presence of ammonium ions at less than 10 mg/L produced no discernible increase in corrosion rates. In equal concentrations, chlorine was slightly more corrosive than chloramine on copper and its alloys. If significantly higher levels of chloramine are required compared to chlorine, chloramine could result in a higher copper corrosion rate, especially at lower pH values. Corrosion phenomena are relatively complex and new information has been developed in recent years since the implementation of the USEPA Lead and Copper Rule in 1991 (USEPA, 1991). Recent USEPA information on copper corrosion is summarized at http://www.epa.gov/ORD/NRMRL/wswrd/cr/corr_res_copper.html

Q: What is the potential impact of the disinfectants on pitting corrosion of copper pipes?
A: Copper corrosion is categorized as either uniform or localized based on visual inspection (Edwards et al., 1994). High uniform corrosion rates are typically associated with waters of low pH and low alkalinity; corrective treatment involves raising pH or increasing bicarbonate. If uniform corrosion rates are excessive, unacceptable levels of copper corrosion by-products may be introduced into drinking waters, which in turn, may lead to consumer complaints of green or blue water caused by copper-containing particles in water. Perforation of the pipe wall and associated failure are rare under uniform corrosion (Edwards et al, 1994).
Copper pitting corrosion remains poorly understood despite a number of reports released in recent years (USEPA, 2006c). There have been cases of copper pitting reported in waters having high pH, low alkalinity, and significant levels of sulfate and chloride. In some of those cases, aluminum, silica, total organic carbon, and other materials have been suggested as the cause of pitting. Also, the role of orthophosphate as a corrosion inhibitor and reducer of the pitting tendency of water has shown some promise. Presence of the high levels of chloride appears to be a main factor for the development of pitting copper corrosion in low alkalinity, high pH waters. Practical experience indicates that pitting copper corrosion may or may not occur in systems disinfected with chlorine, chloramine or chlorine dioxide (Lytle, 2006). Sulfate and chloride were deemed important in the pitting process based on their presence in the corrosion regions (Lytle et al., 2005).
Localized corrosion of copper or “pitting” corrosion is complex, and resulting pinhole leaks are still poorly understood and remediation strategies are not completely developed. Pitting copper corrosion by chloramine is an unproven research hypothesis. Side by side experiments showed pitting corrosion of copper with chlorine but not chloramine. Few studies attempting to demonstrate pitting corrosion of copper in the lab have been done with chlorine and the evidence seems to point out that high levels of aluminum were necessary to start copper pitting corrosion with chlorine in these tests – this is a preliminary finding based on a limited number of laboratory tests (Marshall et al., 2003; Marshall and Edwards, 2005). The experiments on copper pipe corrosion were conducted by Marshall et al. (2003) with chlorine at doses up to 4.8 mg/L Cl_2 and aluminum at 2 mg/L Al. If the aluminum was present, copper corroded as fast at pH 9 as it did at pH 6 without aluminum. The presence of chlorine and aluminum seemed to initiate pitting corrosion of copper. Marshall and Edwards (2005) conducted follow-up laboratory experiments on copper pipes using potable water containing aluminum (2 mg/L Al) and high chlorine residual (4 mg/L Cl_2). Pinhole leaks and severe pitting was observed in the presence of chlorine and aluminum at pH 9.2, whereas no pitting was observed in the absence of aluminum. This research

is the first to reproduce copper pitting in the laboratory and to suggest water quality parameters that may influence this process. The levels of aluminum in SFPUC treated waters are more than 20 times lower than amount used in experiments to simulate pitting copper corrosion. Also, the presence of disinfectant residual is essential to prevent microbially induced pitting corrosion. Chlorine has been observed to both increase and decrease the corrosion of copper. Chlorine residual of 2 mg/L Cl_2 decreased the copper corrosion rate in a water at pH 9.3, leading to the conclusion that a chlorine residual might prevent the unusual "blue water" or soft water pitting problems (Boulay and Edwards, 2001). The presence of organic matter increased copper corrosion by-product release. In another study, a chlorine dose of 0.7 mg/L Cl_2 increased copper by-product release at pH 9.5 but the effects were small. Moreover, chlorine is known to stop other copper corrosion problems in soft waters such as pitting corrosion (Boulay and Edwards, 2001).

Q: What is the occurrence of copper pitting corrosion?
A: Localized copper corrosion often appears nearly at random in a distribution system. For example, in new housing developments some homes may have severe localized corrosion whereas others are unaffected, or corrosion may appear isolated to specific floors of tall buildings. Pitting corrosion may be troublesome because of unacceptable metal release or because of the perforation of the pipe wall. Three distinct types of pitting are commonly recognized, encompassing cold, hot, and soft waters (Edwards et al., 1994). Cold water pitting is the most common cause of copper pipe failures. Hot water pitting failures usually take some years to occur, in contrast to cold-water pitting in which failures may occur in just a few months. Soft water pitting was previously thought to be very rare. Waters supporting soft water pitting are cold, of low conductivity, of low alkalinity, and of relatively high pH. Chloride, sulfate and nitrate may play a role in copper pitting corrosion. Natural organic matter (NOM) seems to prevent or in some cases increase certain copper corrosion within distribution systems. Increased corrosion by-product release and pitting attack may be possible subsequent to NOM removal (Edwards et al., 1994).
Pitting corrosion of copper pipes in hot and cold water can result from microbial influenced corrosion (MIC) and has been observed world wide (Germany, England, Sweden, Saudi Arabia). High numbers of bacteria were associated with the pits, however the presence of bacteria did not always result in pitting and the range of bacterial species was quite variable. A combination of factors appears to contribute to the biocorrosion of copper pipe: soft waters with low pH, high suspended solids and assimilable organic carbon (AOC) content, long-term periods of stagnation of water in the pipe, which produces widely fluctuating oxygen concentrations; low to nonexistent levels of chlorine; maintenance of water temperatures that promote rapid growth and activity of naturally occurring bacteria that form biofilm on the pipe wall (Bremer et al., 2001).

Q: What is the impact of disinfectants on rubber parts?
A: Certain older natural rubber products and their derivatives used in household appliances (e.g., toilet flapper valves, hot water heater plastic dip tubes) deteriorate faster in the presence of chloramine than with chlorine. Replacing these with alternative synthetic materials available in plumbing and hardware stores eliminates this issue.
Reiber (1993) conducted a series of experiments on the deterioration of various materials under conditions of very high chlorine and chloramine concentrations to simulate material corrosion under accelerated conditions. Concentrated solutions of chloraminated waters (300 mg/L) were more aggressive to elastomer compounds (especially natural rubbers and their derivatives) than equivalent concentrations of chlorine. Elastomeric failure was unrelated to excess ammonia (Reiber, 1993). Consistent with the results of Reiber's experiments, 23% of utilities surveyed by Kirmeyer et al. (2004) experienced an increase in degradation of certain rubber materials 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 (Reiber, 1993; Kirmeyer et al., 2004). Replacement of rubber plumbing components with chloramine resistant materials such as: high quality rubber (synthetic polymer) parts, flexible copper tubing, or tubing made of corrugated stainless flex, takes care of this temporary inconvenience. These effects are generally experienced within the first six months

to a year after change of disinfectant to chloramine.
Although earlier reports (Reiber, 1993) suggested that some elastomers, primarily nitriles, styrene butadiene, natural rubbers, neoprenes, and ethylene-propylene are susceptible to chloramine, these tests were conducted based on exposure of the large surface area of the materials to the test solutions at very high concentrations of 300 mg/L of the disinfectant. Bonds (2004) tested similar materials as pipe gaskets and did not observe visual degradation after exposure to 110 mg/L chloramine for one year. It was concluded that exposure tests of sheet materials were not relevant to pipe gaskets (Bonds, 2004). To put these results in perspective, typical levels of either chlorine or chloramine in drinking water distribution systems range from 1 to 2 mg/L. AWWA Research Foundation has recently published a report on elastomer performance with reference to disinfection (Rockaway et al, 2007). Each elastomer formulation has a unique reaction when exposed to free chlorine or chloramine; some have been observed to resist degradation, while others degrade rapidly. To predict the long-term performance of commonly found elastomers, accelerated aging tests were conducted at combinations of three temperatures (23, 45, and 70 ^{o}C) and three disinfectant concentrations (1, 30, and 60 mg/L) for natural rubber; neoprene rubber; ethylene propylene diene monomer, peroxide-cured (EPDM-P); styrene butadiene rubber (SBR); ethylene propylene diene monomer, sulfur-cured (EPDM-S); and nitrile rubber. Elastomer degradation was characterized by mass change, volume change, breaking stress, breaking strain, and hardness. Relatively, EPDM(P) and EPDM(S) were found to be least susceptible to chloramine degradation followed by nitrile rubber, SBR, natural rubber, and neoprene rubber. This was confirmed by Nagisetti et al. (2010).

Sensitivity of elastomers to degradation in chloraminated water

Least Sensitive	Sensitive	Acutely Sensitive
EPDM(P), EPDM(S)	Nitrile Rubber, SBR, Natural Rubber	Neoprene Rubber

EPDM(P)----Ethylene propylene diene monomer, peroxide-cured, EPDM(S)----Ethylene propylene diene monomer, sulfur-cured, SBR-styrene butadiene rubber

Q: What is the potential impact of the disinfectants on plastic piping?
A: There are no known reports of any impacts of drinking water disinfectants at concentrations present in the municipal drinking water distribution systems on plastic or polyvinyl chloride (PVC) pipes. PVC pipes are resistant to almost all types of corrosion – both chemical and electrochemical. Because PVC is a nonconductor, galvanic and electrochemical effects are nonexistent in PVC piping systems. PVC pipe cannot be damaged by aggressive waters or corrosive soils. PVC pressure pipe is resistant to chlorine and chloramine, nearly totally resistant to microorganisms, but subject to ultraviolet (UV) degradation, unless specifically formulated (AWWA, 2002). The performance of PVC pipe is significantly related to its operating temperature.
PVC pipe is rated for performance properties at a temperature of 73.4 $^{\circ}$F (23 $^{\circ}$C). Most municipal water systems operate at temperatures at or below 23 $^{\circ}$C. As the operating temperature decreases, the pipe's stiffness and tensile strength increase but PVC pipe loses impact strength and becomes less ductile (AWWA, 2002). Plumbers contacted in San Francisco have not seen any increase in pipe breaks in the recent years. PVC piping experiencing more leaks than metal piping can often be attributed to installation issues, for example pipes installed on slopes may have increased risk of breaks and leaks than metal pipes.
Research has documented that pipe materials, such as polyethylene, polybutylene, PVC, asbestos cement, and elastomers, such as those used in jointing gaskets, may be subject to permeation by lower molecular weight organic solvents and petroleum products (AWWA, 2002; AWWA, 2006d). There are no PVC pipes in San Francisco drinking water distribution system.