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Pb Release from New End-Use Plumbing Components in Seattle Public Schools

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ABSTRACT

Field and laboratory studies were conducted to determine lead (Pb) release from new end-use plumbing components installed at drinking water sources (primarily fountains) in Seattle Public Schools. Small-volume sequential field-sampling results indicated that most of the Pb originated in the first 50 mL drawn from the source. Laboratory testing of new end-use plumbing components showed elevated Pb levels during early exposure. Periodic spikes in Pb were attributed to the movement of valves and possible release of metal particulates or dezincification of brass materials. New end-use plumbing components typically had been installed in Seattle Public Schools immediately after purchase. Results from this study were used to help identify likely sources of Pb and to develop mitigation measures, such as pre-conditioning, so that drinking water sources can be used immediately after being retrofitted and meet the Seattle School Board adopted policy that limits acceptable Pb levels to 10 μg/L.

INTRODUCTION

Seattle Public Schools provides educational opportunities to 47,000 students in 102 schools and administrative buildings and purchases water from Seattle Public Utilities. More than 60% of the school buildings are plumbed primarily with galvanized steel piping. Many buildings are over 40 years old and moderately tuberculated. In late 2003, Seattle Public Schools was faced with numerous inquiries associated with the quality of water in its school buildings, with particular concern regarding lead (Pb) exposure to school children from drinking water fountains.

A comprehensive water quality monitoring program for more than 3,000 water sources (primarily drinking water fountains) was conducted in 2004 prior to lead remediation action. Analyses included lead, cadmium, zinc, copper, iron, turbidity, color, and coliform bacteria. Results indicated that 600 first draw samples out of 3,167 samples (19.0%) exceeded the USEPA's guideline of 20 µg/L Pb in schools based on 250-mL samples that had been standing overnight (15-18 h) in the fountain and connective piping system. Because of the high variability noted in the Pb sampling results, the School Board decided to establish a more stringent criterion for Pb. Results must be less than or equal to 10 µg/L in a 250-mL sample collected after standing overnight or in the following 250-mL sample after a 30-second flush at all drinking water sources in Seattle Public Schools (Seattle Public Schools, 2004). As part of the ongoing water quality testing program, remediation strategies have been developed and are being implemented aimed at reducing lead so that levels do not exceed 10 µg/L at any sources in Seattle Public Schools.

Several possible sources of Pb were identified in the school piping systems including old galvanized steel pipe, 50:50 lead:tin solder, and brass components such as bubbler heads, valves, elbows, ferrules, and flexible connectors. The brass components may contain up to 8 percent lead (by weight). Several mitigation measures were therefore investigated and applied to a building, depending on the site-specific conditions. Mitigation options included the following: total or partial replacement of building piping; replacement of bubbler heads with low-lead (<0.3% Pb) brass bubblers; installation of new end-use plastic-lined flexible connectors, valves and fittings; disabling the fountain if there were other accessible fountains nearby; installation of granular-media point-of-use filters for Pb removal from incoming water (Boyd et al., 2005); and/or ongoing provision of bottled water in the schools. One of the more challenging aspects of the investigations included identifying end-use plumbing components that contained little or no Pb and that would not cause Pb levels to exceed the School Board limit of 10 μg/L. Typical older installations and replacement components and filter system that have been installed in Seattle Public Schools as part of the mitigation program are shown in Figure 1.

This paper focuses on a field sampling program and laboratory study aimed at determining Pb release from new end-use plumbing components in Seattle Public Schools. Field sampling indicated that new end-use plumbing could contribute elevated Pb levels at drinking water sources immediately after installation and periodically during routine usage in Seattle Public Schools. Results of laboratory testing were used to assess the contribution of each new end-use plumbing component to Pb levels in first-draw 250-mL samples in Seattle Public Schools. Results of this study also were used to assist in developing a strategy for achieving the water quality goal of not more than 10 μg/L Pb from all sources in Seattle Public Schools.

MATERIALS AND METHODS

Field sampling and laboratory testing procedures were developed to determine which new end-use plumbing components in Seattle Public Schools were contributing higher-thanexpected Pb concentrations in drinking water. Procedures and analytical methods are described below.

Sampling Procedures in Schools. A special “sequential” sampling program was conducted in Seattle Public Schools by collecting several contiguous 50-mL or 100-mL samples from drinking water sources (fountains) after standing stagnant in the end-use plumbing. The sampling program was aimed at identifying which components in the end-use piping were contributing lead to the drinking water source. A total of 22 drinking water sources were tested in 4 schools.

The sampling program was conducted in December 2004 and June 2005. Each source was flushed the day before testing by holding the bubbler valve opened for 2 minutes. Before the start of the school day, samples were collected at each source after allowing contact of standing water from the regular supply with the piping system for approximately 16 hours. Samples were collected from 7 sources in Graham Hill Elementary School (E-1). At each source, eleven 50-mL samples were collected sequentially for a total of 550 mL. Additionally, ten 100-mL samples were collected sequentially, for a total of 1000 mL from each source, at 5 sources in Ingraham High School (HS-1) and at 4 sources in Whitman Middle School (MS-1). Also, nine 100-mL samples were collected from 6 sources in Schmitz Park Elementary School (E-2).

All 22 drinking water sources were fitted with new “low-lead” or “non-leaded” (<0.3% Pb) brass bubbler heads. Point-of-use filters were installed on nearly all of the sources at E-1, HS-1 and MS-1 schools, except for MS-1-06 and HS-1-16. The point-of-use filter installations consisted of an in-line 5-μm pre-filter and a granular carbon media filter. Most of the sources were inspected visually before the start of the testing program, except for three sources in HS-1 (HS-1-02, HS-1-06, HS-1-19), and one source in MS-1 (MS-1-14). In many instances, the outlet of the point-of-use filter was connected with a brass elbow connector (containing up to 8% Pb). Point-of-use filters were not installed in School E-2. Sequential sampling for this study was performed after Seattle Public Schools completed a complete pipe and components replacement in School E-2.

Laboratory Testing Procedures. New end-use plumbing components were tested in the HDR Applied Research and Technology Center (ARTC) in Bellevue, Washington during August to October 2005. End-use plumbing components included the following: two types of low-lead (<0.3% Pb) bubbler heads[1], an 18-inch long flexible connector with inside plastic liner and brass ferrules at each end[2], a brass elbow connector[3] that was used with point-of-use filter installations, and a ¼-inch brass shut-off valve[4]. The specific end-use plumbing components that were selected for this study were tested because they had been installed as replacement parts and routinely used in Seattle Public Schools since 2004. All components used in this study were new parts as purchased from a supplier or off the shelf of a local plumbing shop.

Two procedures were used to test Pb release from the end-use plumbing components: “stagnation” testing and “flow-through” testing. For the “stagnation” tests, a component was filled with tap water and allowed to stand undisturbed for a pre-determined period of time (e.g., 2 h). A sample of the exposed water was drawn from the component and analyzed for total Pb concentration. The remaining water was discarded and the component was refilled with fresh tap water. The entire process was repeated until Pb levels appeared to stabilize with cumulative exposure. The stagnation procedure was used in testing bubbler heads, a shutoff valve, flexible connectors, and brass elbows.

For the “flow-through” tests, two bubbler heads were tested using a flow-through procedure specifically developed for this study. A bubbler head was mounted in the upright position and connected to the tap water source. The valve was held in the opened position and tap water was allowed to flow through the bubbler head at a rate of 0.5 gpm (1.9 L/min). At a pre-determined time, flow was stopped by releasing the bubbler-head valve. Tap water was allowed to stand in contact with the bubbler head for a period of 2 h. Afterwards a sample was drawn by opening the valve and capturing the first 20-35 mL of flow, which was subsequently analyzed for total Pb. The valve was then locked in the opened position and tap water was again allowed to flow uninterrupted through the bubbler head until the sampling process was repeated.

Local municipal drinking water was used as the contact water, which is the same water delivered to Seattle Public Schools. Typical water quality is characterized by pH 7.8-8.3, total alkalinity of 20 mg/L as $CaCO_3$, hardness of 29-30 mg/L as $CaCO_3$, TOC of 1.0-1.1 mg/L, TDS of 53-58 mg/L, soluble reactive phosphate of 5-6 μg/L, and free chlorine residual of 0.9 mg/L (Seattle Public Utilities, Drinking Water Quality Annual Report, 2004). Background water quality samples were collected periodically at the tap in the HDR ARTC in Bellevue, WA. Analyses of background water samples consistently yielded total Pb levels less than 1 μg/L.

Sample Collection and Analytical Methods. All field and laboratory samples were collected in new 250-mL polypropylene bottles, stored in a laboratory refrigerator, transported to Laucks Testing Laboratories, Inc. in Seattle, Washington, and analyzed for total Pb within 2-14 days. All samples were acidified upon receipt at Laucks to preserve the samples. All analyses followed EPA-600/4-79-020 Method 200.8, for which Laucks holds accreditation through the Washington State Department of Ecology. Samples were analyzed using inductively coupled plasma mass spectrometry (Perkin Elmer ELAN 6100 or Agilent 7500c) with a detection limit of 1 μg/L.

Sample volumes that were less than 50 mL were diluted at Laucks Testing Laboratories to a final volume of 50 mL for total Pb analysis, thus yielding a detection limit that varied depending on the amount of sample submitted. For sample volumes between 10 and 50 mL, the detection limit was 5 μg/L. Sample volumes that were less than 10 mL were similarly diluted and therefore yielded a detection limit of greater than 5 μg/L (up to 200 μg/L). Quality control protocols included chain-of-custody, sample preparation and analysis, data processing and review, as well as preparation and analysis of quality control samples for assurance of accurate and precise measurements.

RESULTS AND DISCUSSION

Field sampling and laboratory testing data were used to assess the relative contribution of end-use plumbing components to the total Pb level in a first-draw 250-mL sample collected at a source. Results are discussed below.

Field Sampling Results. Field sampling results are shown in Figure 2a for 50-mL samples collected at School E-1. Five of the sources at E-1 (E-1-01, E-1-03, E-1-13, E-1-14, and E-1-18) exhibited Pb levels in the first 50-mL sample that ranged from 38-79 μg/L. The Pb concentration in the first sample was significantly greater than the subsequent samples collected from these five sources. The relative Pb concentration of sequential samples collected from each source is illustrated in Figure 2b, which shows the field data normalized relative to the second sample collected at each tested source in School E-1. The other 2 sources (E-1-11 and E-1-19) exhibited Pb levels in the first and second 50-mL sample in the range of 9-15 μg/L, whereas subsequent samples from each of these sources were at or near the detection limit in the range of <1-4 μg/L. These results indicate that components near the exposed end of the source (i.e., bubbler head, connectors, and connective tubing) likely contributed to elevated Pb levels at all seven of the sources at School E-1. It was therefore recommended that additional testing be conducted on the new "low-lead" bubbler head, connectors, and connective tubing to determine the level of lead release associated with these components.

Data in Figure 2 also show an increasing trend in Pb levels at School E-1 beginning with the 4th or 5th sequential sample (cumulative volume of 200-250 mL), with most profiles peaking in the 6th sequential sample (cumulative volume of 300 mL). These results indicate that another component likely contributed as a source of lead, and it was estimated to be situated approximately 4 ft (1.2 m) extending back from the bubbler head along the end-use plumbing assuming ½-inch (12.7 mm) ID piping. This secondary source of lead was suspected to be contributed by brass elbow connectors (containing up to 8% Pb), which were routinely being used at the outlet of the point-of-use filter installations in Seattle Public Schools. It was therefore recommended that additional testing be conducted to determine the level of lead release associated with these components.

Figure 3 shows results for 100-mL samples collected at School HS-1. Elevated Pb levels were observed in the first 100-mL samples collected at 4 of the 5 sources (HS-1-02 was the exception). Similar to School E-1, the first samples collected at most sources in HS-1 indicate that components near the exposed end of the source likely contributed lead to the water supply. Elevated Pb levels also were observed in the 3rd or 4th 100-ml samples (cumulative volume of 300-400 mL), which is consistent with observations of elevated Pb levels associated with the same cumulative volume of drawn water at E-1. However, at HS-1 the magnitude of the secondary Pb concentration was not as pronounced as observed by collecting 50-mL samples at E-1. Nonetheless, these results indicate that secondary sources (e.g., brass in components) likely contributed to elevated Pb levels in most sources at HS-1.

Figure 4 shows results for 100-mL samples collected at School MS-1. For samples collected at this school, only 1 out of the total of 4 sources (MS-1-9) exhibited a markedly greater Pb concentration in the first 100-mL sample compared to the following samples. These data indicate that most of the end-use plumbing at the exposed end of the source at this school likely did not contain components that were releasing elevated levels of Pb to the water supply. Two of the sources (MS-1-06 and MS-1-14) exhibited a weak peaking trend in subsequent samples, which likely indicated a secondary source of lead.

Figure 5 shows results for 100-mL samples collected at School E-2. Results from this school generally are consistent with other field results in that the data show elevated Pb levels in the initial samples, followed by a decline and then increasing trend in Pb in later sequential samples. Again, these results indicate that the sources likely contained components with lead-bearing material at the exposed end and at another location along the stretch of the end-use plumbing at the sampling sites in this school.

Laboratory Testing Results. Pb concentrations are shown in Figure 6 for two types of low-lead bubbler heads typically installed at drinking water fountains in Seattle Public Schools. Results of “flow-through” testing on one of each type of bubbler head (identified as Type A and Type B) are shown as a function of cumulative exposure to tap water in Figure 6a. Results of “stagnation” testing conducted in quadruplicate using one type of bubbler head (identified as Type A) are shown in Figure 6b. Both testing procedures yielded elevated Pb levels (33-60 ppb) during initial exposure for both types of bubbler heads. Stagnation testing exhibited periodic spikes in Pb up to 1,300 μg/L for a cumulative exposure period of nearly 200 hours. Flushing and repeated exposure to tap water reduced Pb levels with time and the data generally appeared to approach stabilized lead levels near the detection limit of 5 μg/L at the end of testing. A laboratory set-up of a typical bubbler head with the valve held opened during flow-through testing is shown in Figure 6c.

Pb results for a brass shutoff valve commonly used in Seattle Public Schools are shown in Figure 7a. The shutoff valve (Figure 7b) was tested in quadruplicate. Results of stagnation testing indicate elevated Pb levels up to 500 μg/L during initial exposure. Some Pb fluctuations and spikes were observed during testing. Due to the small volume of water contained within the valve (~2 mL), the analytical detection limit was 50 μg/L for samples collected during stagnation testing. Overall, Pb levels declined with repeated exposure to a range of 50-80 μg/L after a cumulative exposure of 343 h.

Figure 8a shows Pb results for an 18-inch (45.7 cm) flexible connector as a function of cumulative exposure to tap water using the stagnation procedure. Testing was conducted in triplicate. This component (Figure 8b) does not contain a mechanical moving part such as a valve. Results indicate elevated Pb levels (68-250 μg/L) during initial exposure time and a gradual decline to 9-29 μg/L after nearly 23 days of cumulative exposure to tap water. The source of lead was attributed to the brass ferrules at both ends of the flexible connector, as shown in Figure 8c.

Pb results are shown in Figure 9a for brass-elbow-connector units as a function of cumulative exposure to tap water. Each test unit was assembled by connecting three brass elbows in series with plastic couplings (Figure 9b). The units were assembled for the purpose of allowing sufficient volume of tap water in contact with the inside of the component. Unit testing was conducted in quadruplicate. Results indicate elevated Pb levels in the range of 770-1,100 μg/L following contact for up to 24 h. With repeated exposures, the lead levels showed some variability and generally declined to the range of 220-360 μg/L after approximately 6 days of exposure to tap water.

Discussion of Results. Sequential sampling conducted at representative drinking water sources in Seattle Public Schools indicated that various new end-use plumbing components could contribute elevated Pb levels to the water supply after standing stagnant overnight. Field sampling results showed elevated Pb concentrations in the first and second samples, thus indicating a release of lead likely originating from the bubbler head or associated components. In addition, results frequently showed a gradual increase in Pb levels, a secondary peak, and gradual decline in Pb concentrations in subsequent samples, thus indicating the likelihood of another component or components in the end-use plumbing contributing Pb to the water supply. This secondary contributor was determined to be various components consisting of lead-bearing materials such as brass. The gradual increasing and declining trends in Pb levels observed in sequential samples were attributed to diffusion of lead from the point of release (e.g., lead-bearing materials) into the standing water during the stagnation periods.

Laboratory testing results demonstrated that new components containing lead-bearing materials (e.g., standard brass elbows or brass ferrules) can exhibit elevated Pb levels in testing immediately after installation, followed by a general decline in Pb levels with repeated tap water exposures. Initial elevated Pb levels could be attributed to contact of water with unpassivated lead-bearing materials and/or the release of machining residuals (ASTM A380-99, 2005). The declining behavior of Pb concentration with time following contact with lead-bearing materials has been observed by others (e.g., Schock, 1990) and attributed to passivation of exposed brass surfaces. For the testing results reported here, the passivation period was observed to extend up to 200 hours or longer, depending on the specific materials and contact time.

The greatest initial Pb concentration was observed in water exposed to standard brass specimens (~8% Pb by weight) compared to new low-lead or non-leaded brass materials. For example, the initial Pb levels associated with the brass shutoff valves (Figure 7) and elbow connectors (Figure 9) were generally greater than the initial Pb levels in the bubbler heads (Figure 6). The bubbler heads that were tested in this study were reportedly made of new low-lead or non-leaded brass materials and the initial Pb levels were observed to be correspondingly lower than standard brass materials.

Laboratory testing demonstrated that brass-containing components with mechanical parts (e.g., bubbler heads and shutoff valves) exhibited periodic spikes in Pb. These periodic spikes were not as evident in the other tested components (i.e., connective tubing and elbow connectors). The spikes in Pb were attributed to the possible release of particulates associated with the release and turning of valves. In a separate study for Seattle Public Schools, Boyd et al. (2006) determined that the variability in Pb concentration could be attributed to dezincification of lead-containing brass materials. When dezincification occurs, zinc is released from the brass or alloyed material and the remaining lead and copper can react in water by galvanic corrosion, thus allowing further release of lead into the water (Schock, 1990; Davies, 1993; Grosvenor et al., 2005). For non-leaded brasses that contain bismuth (Bi) as a substitute for Pb, the Bi-containing non-leaded brasses can be more susceptible to dezincification than standard lead brass (Kim et al., 2001). The variability in Pb levels observed in some drinking water sources in Seattle Public Schools (Figures 2 through 5) could therefore be attributed to the release of particulates associated with the movement of mechanical parts, or the dezincification process, during testing or routine use.

Estimated Pb Contributions of Components. Table 1 was prepared to evaluate the potential impact of an individual component to Pb levels at the tap. The calculations are based on the estimated volume of exposed water in contact with the component, and the concentration of Pb measured in laboratory testing (Figures 6 through 9). Two scenarios are illustrated in Table 1. The “worst case” scenario is based on data collected during initial testing and the “typical” scenario is based on Pb levels measured near the end of the testing period. For each component, the mass of Pb was calculated and then divided by 250 mL to provide an estimate of the contribution of the individual component in the first-draw 250-ml sample collected from the source. The estimated Pb concentration in a 250-mL sample, assuming each individual component is the only contributor of lead, is shown in the last 2 columns of Table 1 for the worst case and typical scenarios.

The components with the greatest potential for contributing elevated Pb levels were the plastic-lined flexible connector with brass ferrules at the ends and the brass elbow. Either of these components could easily have caused a first-draw 250-mL sample to exceed the 10 μg/L Pb limit as established by Seattle School Board policy. Further, laboratory results indicate that Pb contributions from several of these end-use plumbing components can result in elevated Pb levels, particularly when these components have not been previously exposed to water. It was also interesting that small amounts of Pb were contributed by the new stainless steel bubbler head attributed to surface impurities. Laboratory and field testing indicated that these residuals can be easily removed by flushing.

Need for Additional Research. The data presented in this paper focuses on the performance of new end-use plumbing components installed and routinely used in Seattle Public Schools. Segmented field-sampling results (Figures 2 through 5) were based on samples collected primarily from sources that were characterized as new end-use plumbing installations in Seattle Public Schools. Since completing this study, Seattle Public Schools has observed occasional episodes of elevated levels of lead or arsenic in samples collected from a variety of types of sources at other schools. As part of a separate study, Seattle Public Schools determined that corrosion scales can behave as a source of arsenic released to tap water under some circumstances (GT Engineering, Inc, 2006). Although not specifically investigated as part of this study, other metals such as lead potentially could be stored and released from these corrosion scales. More research therefore is needed to understand the occurrence and potential release of lead and other metal contaminants from buildings and end-use plumbing associated with routine operation and stagnation periods in schools.

CONCLUSIONS

Laboratory and field studies were conducted to determine the influence of new end-use plumbing components on Pb levels in drinking water in Seattle Public Schools. The Seattle School Board adopted a policy in 2004 that limits acceptable lead levels to 10 μg/L. Sequential, small-volume samples were collected at several new bubbler installations in schools and analyzed for Pb. Results were used to help identify the relative contribution of the various new end-use components to Pb levels at the tap. In addition, laboratory testing was conducted on new flexible connectors, brass connectors, valves, and low-leaded brass bubbler heads to evaluate potential Pb release from components that were commonly used in Seattle Public Schools. Results were used to estimate the relative contribution of each component to the total Pb level in a 250-mL sample. Results from these studies were used to identify specific, commonly-available end-use plumbing components and materials that provide the best performance for achieving Pb standards in Seattle Public Schools.

This applied research effort helps Seattle Public Schools in several ways. It helps identify the likely causes of high Pb levels in water in new installations so solutions can be implemented immediately. Different components that do not contribute lead, or contribute minimally, were specified. Bubbler heads are being preconditioned by Seattle Public Schools before installation. After installation, a major flushing program takes place in the schools. Each drinking water source is then sampled and results must meet the Board's water quality criteria before returning the source to service in the school.

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FOOTNOTES

1. Two brands of low-lead (<0.3% Pb) bubbler heads are commonly used in Seattle Public Schools and both brands were tested. For the purpose of this paper, the bubbler heads were identified as Type A and Type B.
2. One brand of 3/8-in. (9.5-mm) pipe with compression fittings was tested. Two lengths of pipe, 12-in. (30.5-cm) and 18-in. (45.7-cm) are commonly used in Seattle Public Schools. The 18-in. (45.7-cm) length was used for testing. For the purpose of this paper, this specimen was identified as flex connector with brass ferrules at both ends.
3. One brand of 3/8-in. (9.5-mm) brass elbow connector, which previously was installed in Seattle Public Schools, was tested and identified as brass elbow connector.
4. One brand of ¼-in. (6.35-mm) brass shut-off valve, which is commonly used in Seattle Public Schools, was tested and identified as brass shutoff valve.

Table 1. Estimated range of lead contributions from end-use plumbing components.

Component	Exposed Volume (mL)	Laboratory Measured Pb (μg/L)[a,b]		Calculated Mass of Pb (μg)		Estimated Pb Concentration in 250-mL Sample (μg/L)[c]	
		Worst Case	Typical	Worst Case	Typical	Worst Case	Typical
Brass bubbler head w/ stainless steel nipple (Type A)	10	60	10	0.6	0.1	2.4	0.4
Stainless steel bubbler head (Type B)	1.3	33	10	0.04	0.01	0.17	0.05
Flex connector w/ brass ferrule ends, 18" long	33	250	15	8.25	0.5	33	1.98
Brass elbow connector	3	1400	200	4.2	0.6	16.8	2.4
Brass shut-off valve	2	500	100	1.0	0.2	4.0	0.8

Notes: a) Sample concentrations are based on measured values in the exposed volume from laboratory testing.
b) Analytical detection limit was 5 μg/L.
c) Assumes that the resulting Pb concentration in a 250-mL sample is estimated from data for that particular component only, where the concentration in a 250-mL sample = (exposed volume) × (measured Pb concentration in exposed volume) / (250).

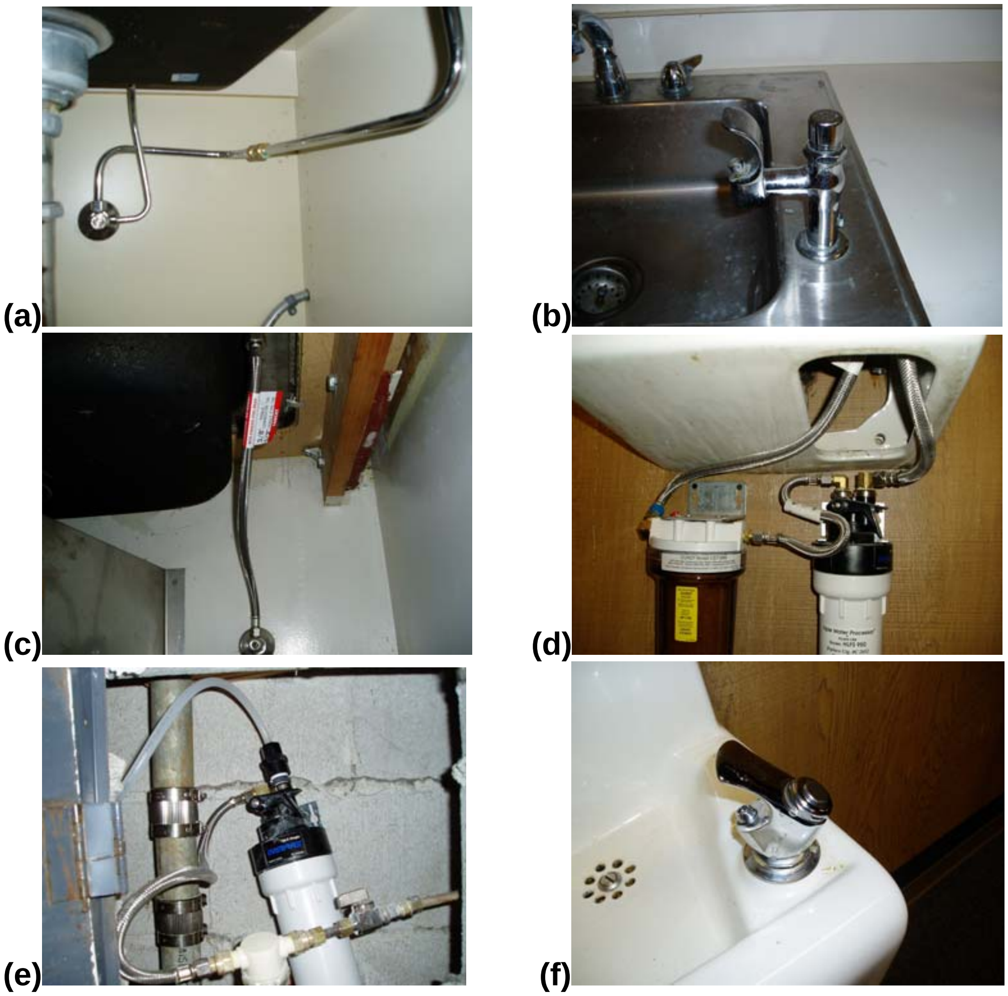
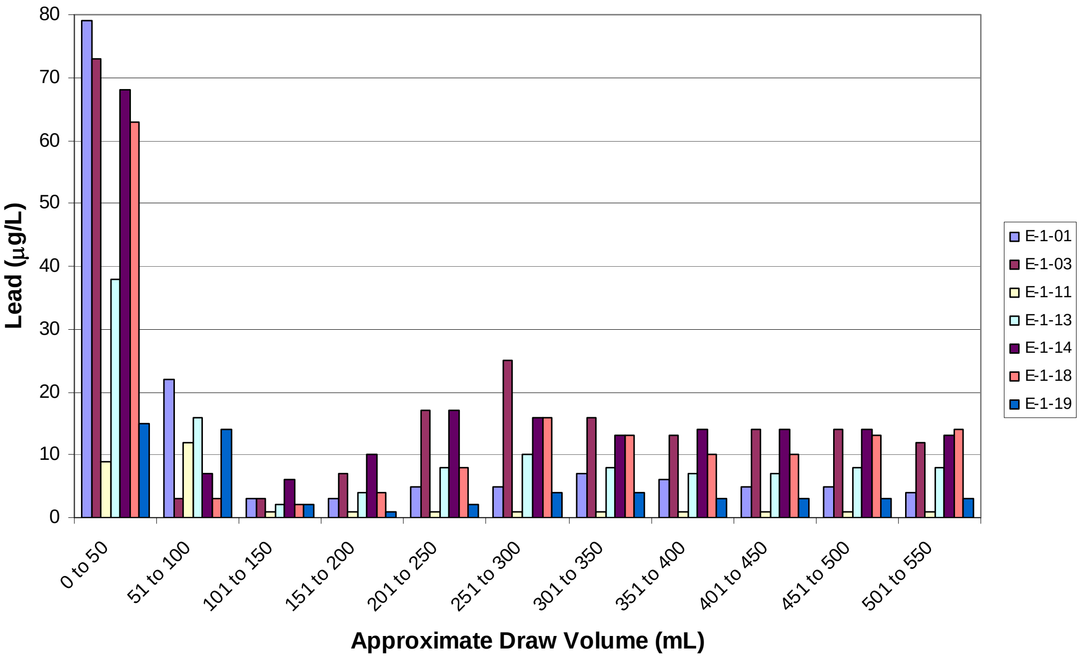
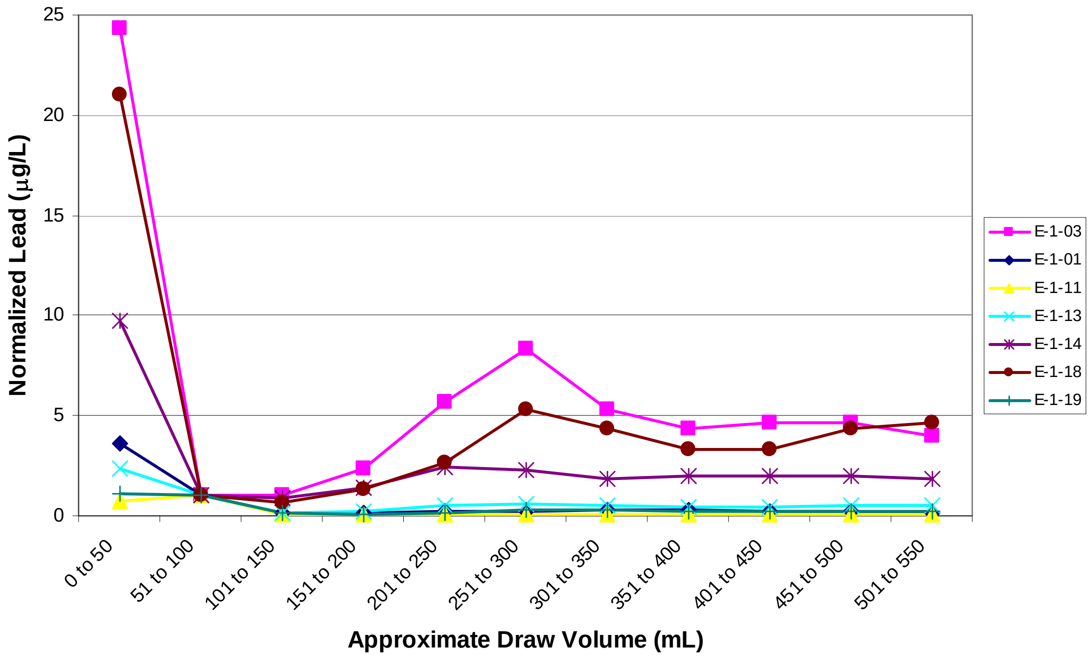


Figure 1. Typical older drinking water fountain installation in Seattle Public Schools showing (a) shut off valve and connective piping and (b) bubbler head and sink. Typical newer drinking water fountain installations showing (c) flexible connective piping with brass ferrule ends, (d) granular-media filter system with flexible connective piping with brass components, (e) filter system with plastic components and tubing downstream of filter, and (f) low-lead (<0.3% Pb) bubbler head and sink.



(a)



(b)

Figure 2. Segmented field sampling results for School E-1 (50-mL samples): (a) sampling results as collected and (b) normalized data.

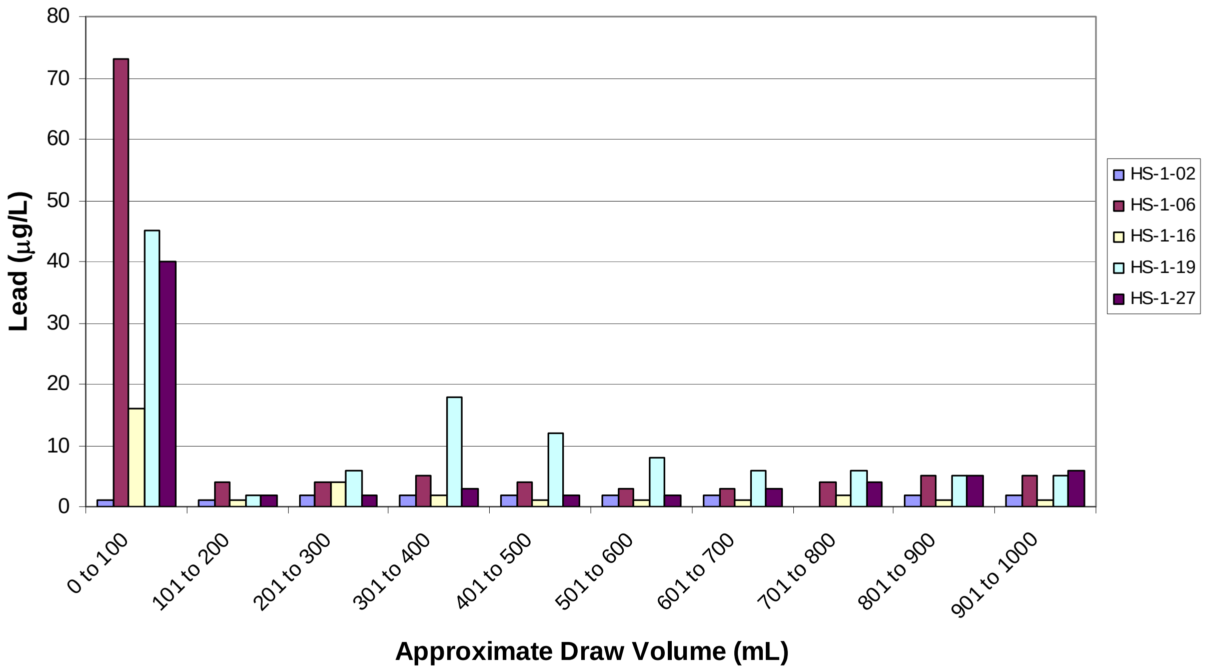


Figure 3. Segmented field sampling results (100-mL samples) for School HS-1.

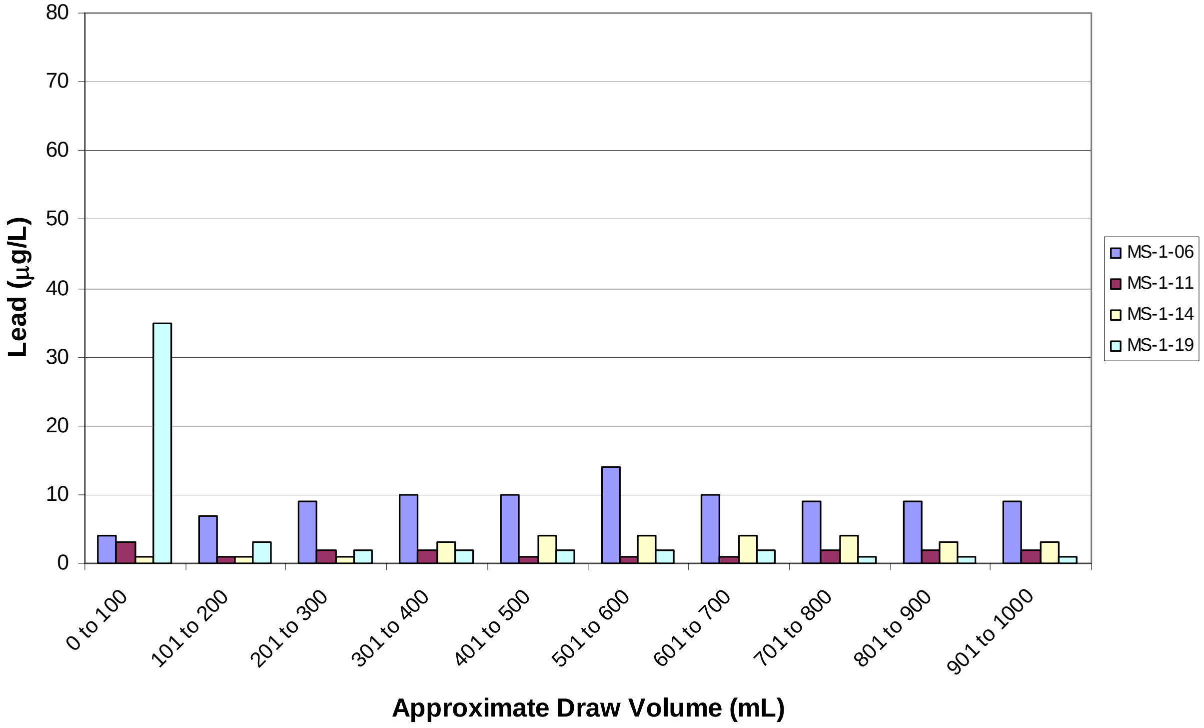


Figure 4. Segmented field sampling results (100-mL samples) for School MS-1.

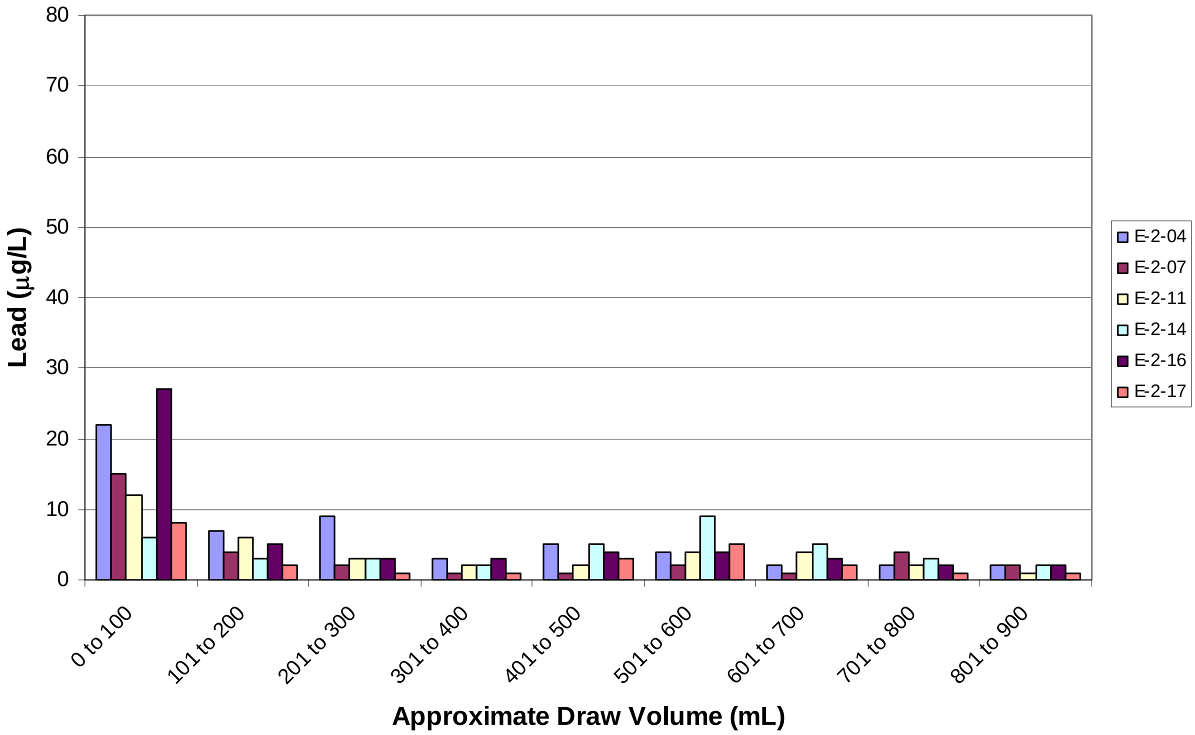


Figure 5. Segmented field sampling results (100-mL samples) for School E-2.

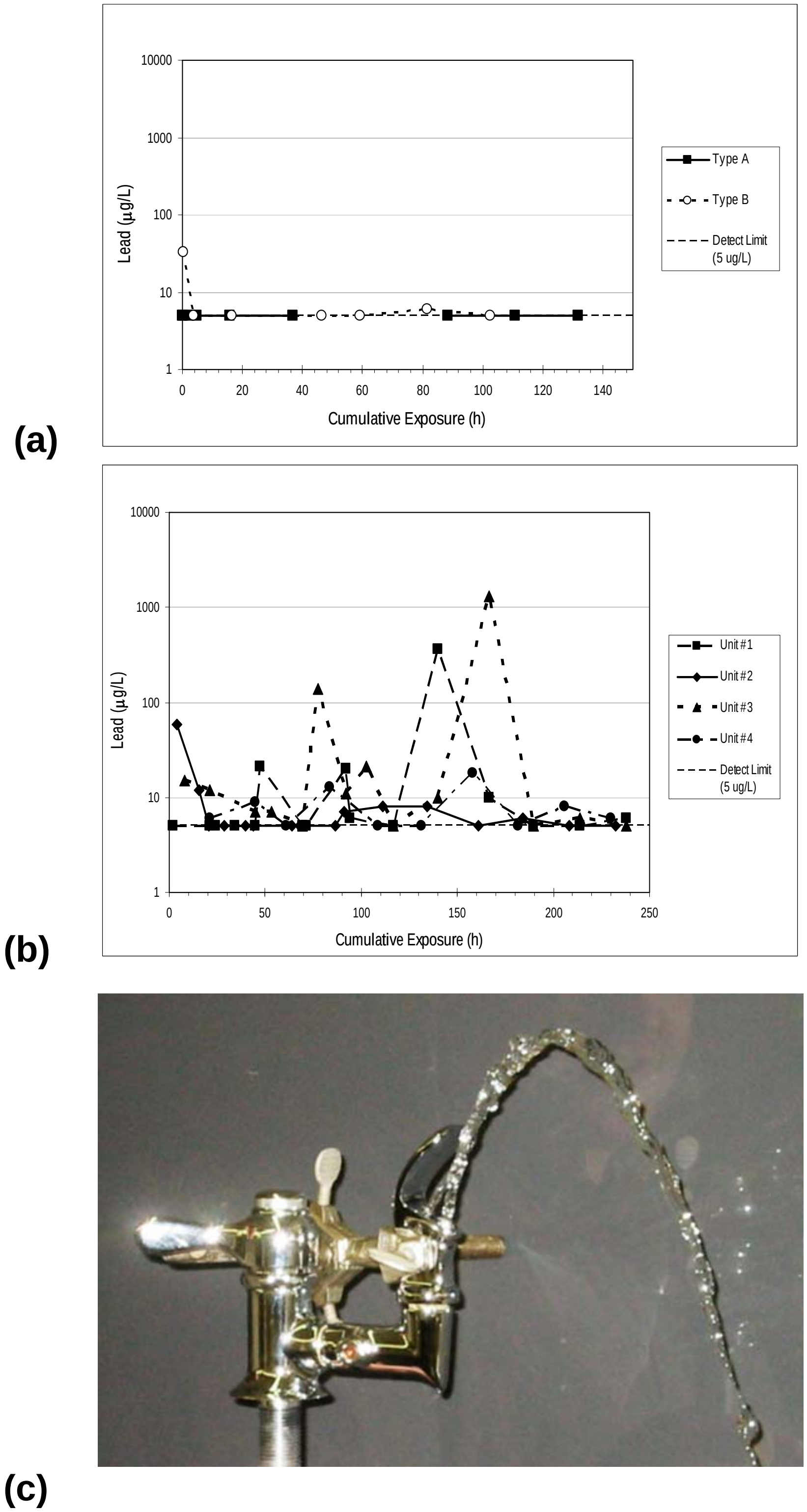
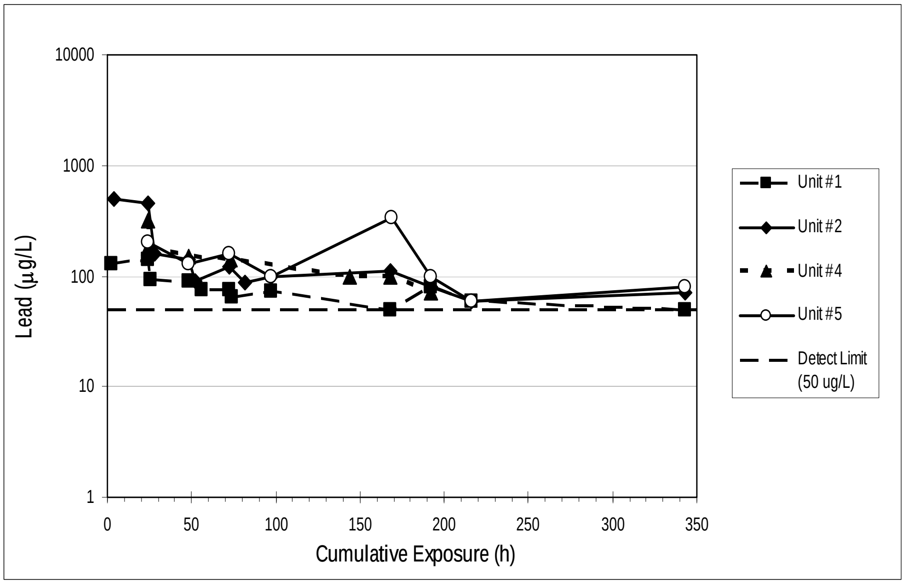


Figure 6. Lead concentration in tap water as a function of cumulative exposure of bubbler heads to tap water during (a) flow-through testing (Type A and Type B bubbler heads) and (b) stagnation testing (Type A bubbler head tested in quadruplicate). (c) Bubbler head with valve held opened during flow-through testing.

(a)



(b)

Figure 7. Stagnation testing in quadruplicate of a typical brass shutoff valve. (a) Lead concentration in tap water as a function of cumulative exposure and (b) enlarged view of brass shutoff valve.

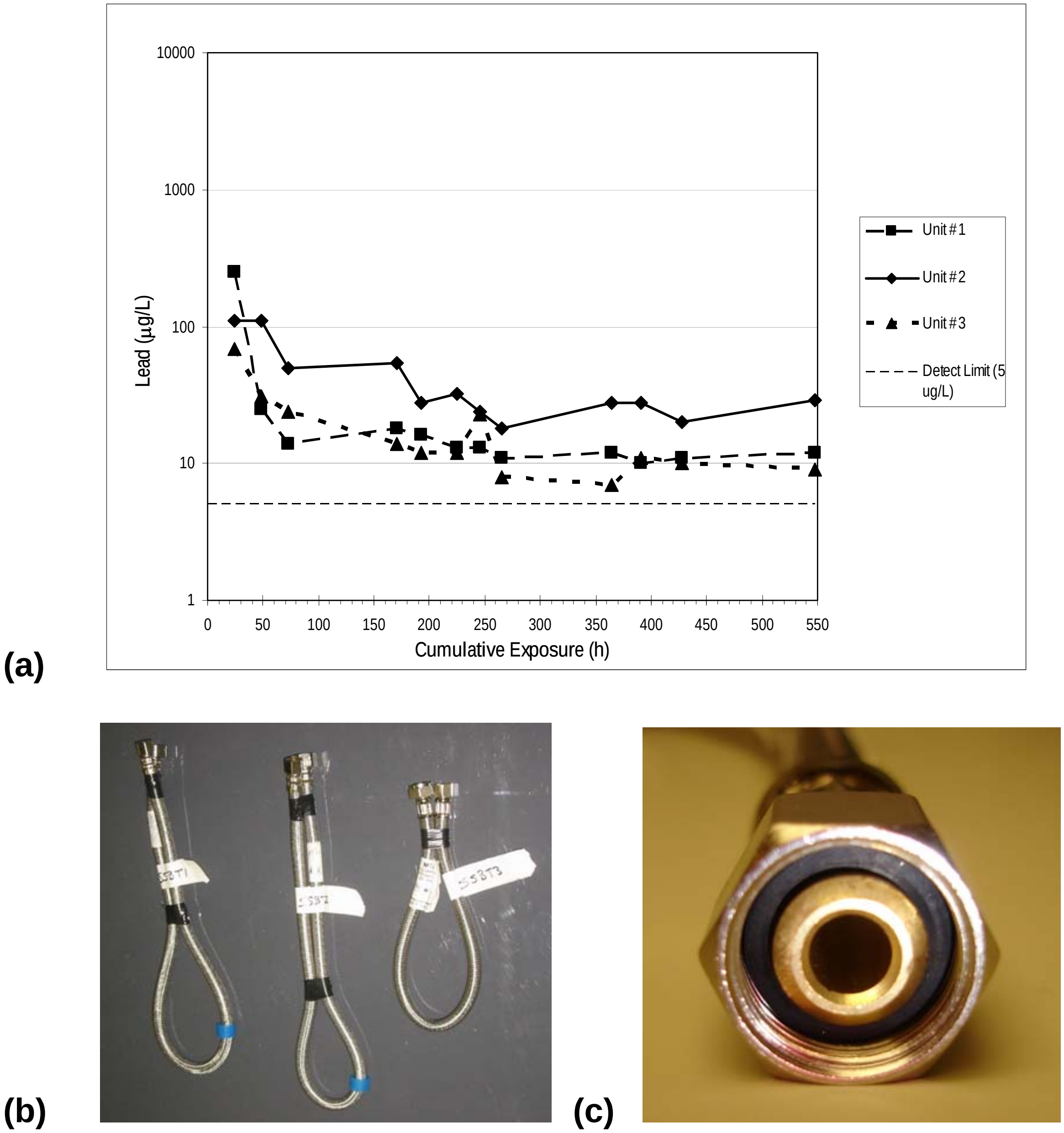
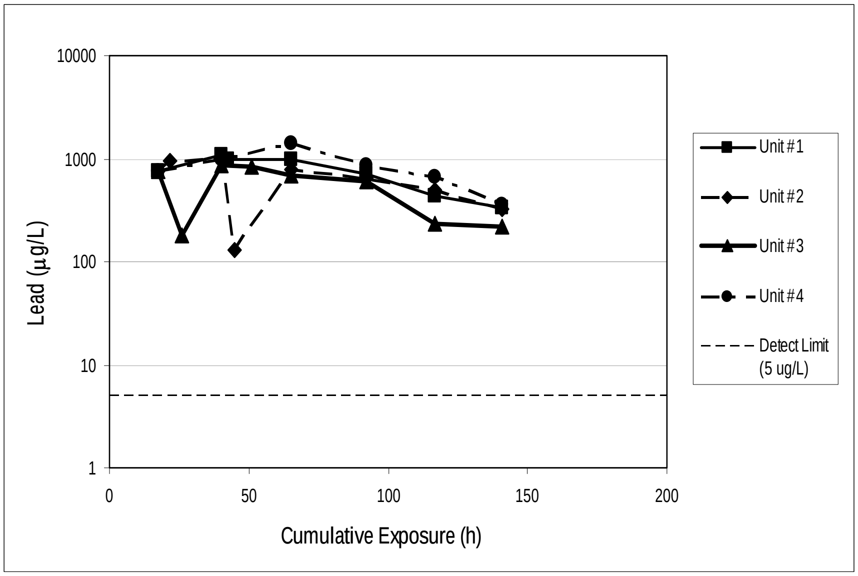


Figure 8. Stagnation testing in triplicate of a flexible connector with brass ferrules at both ends. (a) Pb concentration in tap water as a function of cumulative exposure time, (b) specimens prepared for testing, and (c) enlarged view of brass ferrule at one end of flexible connector.



(a)

(b)

Figure 9. Stagnation testing in quadruplicate of three brass elbows linked together. (a) Lead concentration as a function of cumulative exposure to tap water and (b) specimens prepared for testing.