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**LEACHING OF ANTIMONY, CADMIUM, COPPER, LEAD, SILVER,
TIN AND ZINC FROM COPPER PIPING WITH NON-LEAD-BASED
SOLDERED JOINTS**

Key Words: Drinking water; Solder joints; Leaching of
metals; Public health; Atomic absorption

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ABSTRACT

Studies were done on the leaching of Ag, Cd, Cu, Pb, Sb, Sn and Zn from 95/5 Sn/Sb-, 96/4 Sn/Ag-, 94/6 Sn/Ag-, and 95.5/4.0/0.5 Sn/Cu/Ag-soldered copper pipes into high-purity, tap, and well water samples as a function of standing time in a static test on new plumbing. There was no significant leaching of Ag, Cd, Pb, Sb and Sn from the above solders into the three types of water samples studied. The amount of Cu released from soldered copper pipes was lower than that released from non-soldered copper pipes. The amount of Zn leached from the non-Pb-based solders studied was well below the Guidelines (<5 mg/l) for Canadian drinking water quality. Since the potential for public health hazard from Pb-based solders in plumbing systems is significant, it is advisable to use these Pb-free solders.

INTRODUCTION

A number of field and laboratory studies, including our own (1) indicated that significant amount of Pb can leach into drinking water from Pb-based solder joints associated with the popularly used copper service lines in household plumbing. This has prompted municipal and private water distributors to consider replacing the Pb-based solders with Pb-free solders in drinking water installations. Several non-Pb-based solders such as 95/5 Sn/Sb, 96/4 Sn/Ag, 94/6 Sn/Ag, and 95.5/4/0.5 Sn/Cu/Ag have been suggested as alternatives to the Pb-based solders for use in household plumbing (2, 3). Although Pb is not a major component of these solders, it may still be present as an impurity. It is therefore important to study the extent of leaching of Pb from these solder-joints into drinking water supplies. In addition to Pb, metals such as Ag, Cd, Cu, Sb, Sn and Zn may also be leached from copper pipes and these non-Pb-based solder joints into the water supply.

Atlas et al. (4) and Stone et al. (5) found considerable corrosion of the copper plumbing used for the conduction of potable water especially when the water was soft (hardness <150 mg/L as CaCO_3), acidic and chlorinated.

The potential for drinking water contamination from the leaching of metals such as Ag, Cd, Cu, Pb, Sb, Sn and Zn from copper pipes joined with the non-Pb-based solders in the water supply systems can pose a public health hazard. The adverse toxic effects caused by cadmium (6) and lead (7) are now widely recognized. Although inorganic-tin compounds are relatively innocuous, they could be converted to the highly toxic organo-tin species by bacterial action (8). Both antimony and silver are non-essential elements and any

drinking water probably und known and levels of su may also hav (10,11). The use of these plumbing.

This pa antimony, ca released fro 95% tin/5% silver, or purity, tap plumbing as test. In o metals that household p containing objective c replacing I in home plu increased water.

EXPERIMENT

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studies, significant amount from Pb-based. Commonly used copper. This has prompted others to consider Pb-free solders in place of non-Pb-based, 94/6 Sn/Ag, and used as alternatives in household plumbing. A component of these is an impurity. It is the result of leaching of drinking water, such as Ag, Cd, from copper pipes into the water.

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contamination of Ag, Cd, Cu, Pb, Sb, with the non-Pb-systems can pose a toxic effects caused widely recognized. relatively the highly toxic in (8). Both elements and any

drinking water contribution of these elements is probably undesirable (9). The toxicity of Sb is unknown and that of Ag may include argyria (9). High levels of such essential micronutrients as Cu and Zn may also have detrimental effects on human health (10,11). Therefore, legitimate concern exists about the use of these lead-free solder joints in household plumbing.

This paper reports our findings on the amounts of antimony, cadmium, copper, lead, silver, tin and zinc released from copper pipes with solder joints made from 95% tin/5% antimony, 96% tin/4% silver, 94% tin/6% silver, or 95.5% tin/0.5% silver/4.0% copper into high-purity, tap and well water samples in contact with the plumbing as a function of standing time in a static test. In order to allow accurate assessment of the metals that can be attributed to the solder in household plumbing, control studies with copper pipes containing no solder joints were also conducted. The objective of this work is to determine whether replacing Pb-based solders with the non-Pb-based ones in home plumbing systems will ultimately result in increased Ag or Sb and reduced Pb concentrations in tap water.

EXPERIMENTAL METHODS

Antimony, cadmium, lead, silver and tin were determined using a Perkin-Elmer Model 5000 atomic absorption spectrophotometer equipped with a microcomputer-controlled HGA-500 furnace, a deuterium lamp background corrector, pyrolytic L'vov platforms and tubes, an AS-40 autosampler, a Data system 10 and a graphics plotter. The HGA-500 furnace was equipped with an optical temperature sensor, and had a maximum heating rate of $\sim 2000^\circ\text{C/s}$. Argon was used as the purge gas and its flow was interrupted during atomization.

Cadmium, lead and tin were determined using the procedures described in the previous publication (1). Silver was determined by a stabilized temperature platform furnace atomic absorption (STPF-AAS) method involving the use of a 0.6% solution of diammonium hydrogenphosphate as a matrix modifier. A Perkin-Elmer silver hollow cathode lamp operated at 10 mA and a resonance wavelength of 328.1 nm (spectral bandpass, 0.7 nm) was used. A 10- μ L aliquot of the sample containing the modifier was automatically dispensed into the furnace. The silver in the sample was vaporized using the sequential dry/ash/atomize conditions of 120°C-10s (ramp)-20s (hold)/700°C-10s (ramp)-20s (hold)/1800°C-0s (ramp)-5s (hold)/2500°C-1s (ramp)-2s (hold). Antimony was also determined by a STPF-AAS method involving the use of a modifier composed of 200 mg/L magnesium nitrate, 400 mg/L palladium and 1% nitric acid. A Perkin-Elmer electrodeless discharge lamp operated at 8 W and a resonance wavelength of 217.6 nm with a spectral bandpass, 0.2 nm was used. The furnace program for a 10- μ L injection of the sample solution was: 120°C-20s (ramp)-20s (hold)/1000°C-10s (ramp)-20s (hold)/2200°C-0s (ramp)-5s (hold)/2500°C-1s (ramp)-2s (hold). The concentrations of both Ag and Sb in the leachate samples were calculated using conventional calibration plots in the appropriate modifier.

A Varian Model AA-275 atomic absorption spectrophotometer in conjunction with an air-acetylene flame was used for the determination of copper and zinc. At levels below 100 μ g/L, copper was determined by graphite furnace atomic absorption spectrophotometry using the Model 5000 instrument.

The leaching studies were done with flexible copper pipes (L-type, 19 sections, each 0.5 m length,

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1.25 cm diameter). A separate pipe was used for each type of solder. The various sections of the pipe were joined by soldering with 95% Sn/5% Sb, 96% Sn/4% Ag (Silvabrite), 94% Sn/6% Ag (Silvabrite S), or 95.5% Sn/4.0% Cu/0.5% Ag (Silvabrite 100) 1/8"-diameter wire-solder as the case may be. These solders were a gift from Engelhard Industries, Ltd., MA, USA. An average soldered joint contained 0.7 g of solder based on the total solder used and the number of joints produced. The joints were made by a licensed and experienced professional plumber using standard plumbing practices. Copper pipes containing no solder joints were used as controls.

The soldered and non-soldered copper pipes were filled with high-purity water, tap water, or well water, as the case might be. The pH of the high-purity water was 6.8. The pH, alkalinity and chloride values of the tap water were 7.8, 30 mg/L (as CaCO_3) and 4 mg/L, respectively. The corresponding values for well water were 8.1, 155 mg/L and 19 mg/L. A separate copper pipe with the appropriate solder was used for each type of water. End-caps made of copper were slipped over the open ends of the copper pipes without any soldering. The samples were held in the pipes for time intervals of 0.17 (~10 min), 0.5, 1, 3, 5, 7, 24 (1 d), 72 (3 d), 168 (7 d), 672 (28 d) and 2160 (90 d) hours. After each exposure period, the pipes were drained as completely as possible into 1-L polyethylene bottles containing 10 mL of nitric acid. The same pipe was refilled with the appropriate type of water sample for the various time interval studies. Prior to refilling, the pipes were dried by blowing ultrapure nitrogen through them.

RESULTS

The concentrations of Ag, Cd, Cu, Pb, Sb, Sn and Zn were determined in the water samples prior to holding them in the soldered and non-soldered copper pipes. These elements with the exception of Zn were present at or below the detection limit (3 times the standard deviation of the blank) of graphite furnace atomic absorption spectrometry, namely, 0.2, 0.03, 2.0, 0.7, 1.2 and 1.0 µg/L, respectively, in high-purity water. Zn was present at or below the flame AAS detection limit of 6 µg/L. All the metals excepting Cu and Zn were also present at or below the graphite furnace atomic absorption detection limit in tap water and well water, but copper and zinc were found at levels of 21.2 ± 1.5 and 29.8 ± 2.0 µg/L in tap water, and 28.3 ± 1.9 and 23.8 ± 1.7 µg/L in well water, respectively. These levels agree with those found in a previous Canadian survey on drinking water supplies (13), and are well within the guidelines for Canadian drinking water quality (12).

The levels of all the elements excepting Cu and Zn were also found to be below the GFAAS detection limit in high-purity, tap and well water samples held in non-soldered copper pipes for time periods of up to 90 days. The Zn content was below the GFAAS detection limit in high-purity water and was about the same in tap (21.9 ± 1.2 µg/L), and well (27.8 ± 1.8 µg/L) water samples as that found in the samples analyzed directly. Thus there was no leaching of Ag, Cd, Pb, Sb, Sn and Zn from the non-soldered copper pipes into the water samples. However, as shown in Table 1, significant amounts of copper were leached into high-purity, tap, and well water samples. The copper concentration in well water leachates exceeded 1 and 3 mg/L when it was held in the control (non-soldered) pipe for 3 and 24 h,

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TABLE 1

Concentration of Copper Released from Non-Soldered Pipes into Some Water Samples

Contact time (h)	Concentration of copper ($\mu\text{g/L}$)		
	HW ^a	TW	WW
0	54 $\pm$ 2 ^b	228 $\pm$ 6	309 $\pm$ 9
0.5	387 $\pm$ 10	168 $\pm$ 6	869 $\pm$ 16
1	363 $\pm$ 8	210 $\pm$ 7	601 $\pm$ 11
3	506 $\pm$ 11	446 $\pm$ 8	1368 $\pm$ 15
6	554 $\pm$ 9	446 $\pm$ 9	2316 $\pm$ 28
8	470 $\pm$ 8	649 $\pm$ 12	2548 $\pm$ 27
24	441 $\pm$ 8	310 $\pm$ 6	3482 $\pm$ 32
168	417 $\pm$ 9	637 $\pm$ 14	1976 $\pm$ 21
672	298 $\pm$ 7	589 $\pm$ 12	512 $\pm$ 10

^a HW: High-purity water; TW: Tap water; WW: Well water

^b Mean $\pm$ standard deviation of 3 determinations.

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respectively. In the case of high-purity water and tap water, the extent of leaching was not as dramatic as in the case of well water. The maximum amount of leaching for these water samples was 0.55 and 0.65 mg/L, respectively, and occurred within 6 h of contact.

No significant leaching of Ag, Cd and Sn occurred from any of the soldered copper pipes into high-purity, tap or well water up to 28 days of contact. In the case of Ag, Cd and Sn, the amounts leached from 95/5 Sn/Sb, 96/4 Sn/Ag, 94/6 Sn/Ag and 95.5 /4.0/0.5 Sn/Cu/Ag into the three types of water samples studied were $\leq$ the GFAAS detection limit of 0.2, 0.03 and 1 $\mu\text{g/L}$, respectively. As shown in Tables 2A and 2B, the amount of copper released was generally lower compared to the amount released from the non-soldered copper pipes. The amount of Sb leached into the three types of water samples was also $\leq$ 1.2 $\mu\text{g/L}$ (GFAAS detection

Table 2A

Concentration of Copper Released from Some Non-Pb
Soldered Copper Pipes into Some Water Samples

Contact Time(h)	Concentration (mg/L)					
	95/5 Sn/Sb			96/4 Sn/Ag		
	HW	TW	WW	HW	TW	WW
0	1.02± 0.02 ^a	0.45± 0.01	0.18± 0.01	1.89± 0.03	0.04± 0.01	0.05± 0.01
0.5	0.24± 0.01	0.06± 0.01	0.07± 0.01	0.65± 0.03	0.06± 0.01	0.08± 0.01
3	0.65± 0.03	0.11± 0.01	0.36± 0.02	0.55± 0.02	0.11± 0.01	0.37± 0.02
6	0.75± 0.03	0.24± 0.01	0.72± 0.02	0.65± 0.02	0.24± 0.02	0.97± 0.02
8	0.71± 0.03	0.35± 0.02	1.12± 0.03	0.58± 0.02	0.30± 0.02	1.17± 0.04
24	0.81± 0.03	0.27± 0.02	2.34± 0.03	0.65± 0.02	0.20± 0.01	2.41± 0.03
72	0.37± 0.02	0.29± 0.02	2.88± 0.05	0.45± 0.03	0.73± 0.03	2.63± 0.05
168	0.27± 0.02	0.59± 0.02	2.36± 0.05	0.28± 0.02	0.36± 0.02	2.25± 0.06
672	0.21± 0.02	0.65± 0.02	0.73± 0.03	0.21 0.01	0.67± 0.02	0.80± 0.03

^a Mean ± standard deviation of three determinations.

limit) from all the soldered pipes there was no detectable leaching except 95/5 Sn/Sb. Even in the case of 95/5 Sn/Sb, there was no detectable leaching of Sb into high-purity water and well water; leaching occurred into tap water, but only after 7 days of contact. Thus, the amount of Sb leached into tap water after 14, 28 and 90 days of contact was 2.0, 3.7 and 7.3 µg/L, respectively.

Concentration of
Soldered Copper

Contact Time(h)	HW	94
0	0.49± 0.02	0
0.5	0.37± 0.02	
3	0.54± 0.02	
6	0.68± 0.02	
8	0.66± 0.02	
24	0.72± 0.03	
72	0.39± 0.02	
168	0.25± 0.02	
672	0.19± 0.02	

^aMean ± standard deviation

Table 3 shows the concentration of copper leached from soldered copper pipes into high-purity water and well water. Note that the concentration of copper leached into high-purity water and well water was below the detection limit of the method used. The concentration of copper leached into tap water was notably from the

from Some Non-Pb
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Concentration (mg/L)		
96/4 Sn/Ag		
HW	TW	WW
1.89± 0.03	0.04± 0.01	0.05± 0.01
0.65± 0.03	0.06± 0.01	0.08± 0.01
0.55± 0.02	0.11± 0.01	0.37± 0.02
0.65± 0.02	0.24± 0.02	0.97± 0.02
0.58± 0.02	0.30± 0.02	1.17± 0.04
0.65± 0.02	0.20± 0.01	2.41± 0.03
0.45± 0.03	0.73± 0.03	2.63± 0.05
0.28± 0.02	0.36± 0.02	2.25± 0.06
0.21 0.01	0.67± 0.02	0.80± 0.03

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Table 2B

Concentration of Copper Released from Some Non-Pb
Soldered Copper Pipes into Some Water Samples

Contact Time(h)	Concentration (mg/L)					
	94/6 Sn/Ag			95.5/4.0/05 Sn/Cu/Ag		
	HW	TW	WW	HW	TW	WW
0	0.49± 0.02	0.35± 0.01	0.19± 0.01	1.83± 0.03	1.0± 0.02	0.14± 0.01
0.5	0.37± 0.02	0.08± 0.01	0.06± 0.01	0.32± 0.02	0.06± 0.01	0.08± 0.01
3	0.54± 0.02	0.13± 0.01	0.38± 0.02	0.66± 0.02	0.25± 0.01	0.38± 0.02
6	0.68± 0.02	0.24± 0.01	0.80± 0.03	0.67± 0.02	0.22± 0.01	0.61± 0.02
8	0.66± 0.02	0.30± 0.02	1.11± 0.03	0.56± 0.02	0.29± 0.02	1.10± 0.03
24	0.72± 0.03	0.23± 0.02	2.55± 0.04	0.75± 0.03	0.21± 0.02	2.48± 0.04
72	0.39± 0.02	0.28± 0.02	2.83± 0.04	0.80± 0.03	0.54± 0.03	2.83± 0.06
168	0.25± 0.02	0.38± 0.02	2.43± 0.05	0.22± 0.02	0.36± 0.02	2.33± 0.04
672	0.19± 0.02	0.60± 0.02	0.05± 0.01	0.20± 0.02	0.59± 0.02	0.27± 0.02

*Mean ± standard deviation of 3 determinations

Table 3 shows the amount of Pb leached from the
soldered copper pipes into the three types of water
samples. Note that the amount of Pb leached into tap
water and well water rarely exceeded the GFAAS
detection limit even for 28 days of contact. However,
the concentration of Pb leached into high-purity water
notably from the 95/5 Sn/Sb-, and 95.5/4.0/0.5

Table 3
 Concentration of Lead Released from Some Non-Pb
 Soldered Copper Pipes into High Purity Water^a

Contact Time (h)	Concentration (µg/L)			95.5/4/0.5 Sn/Cu/Ag
	95/5 Sn/Sb	96/4 Sn/Ag	94/6 Sn/Ag	
0	27.2±2.3 ^b	4.0±0.4	22.0±2.2	16.8±1.9
0.5	35.6±2.6	≤ DL	4.8±0.5	14.0±0.8
3	48.6±2.1	≤ DL	≤ DL	10.4±1.1
6	38.8±2.2	≤ DL	≤ DL	26.4±1.9
8	23.6±2.0	≤ DL	≤ DL	15.2±1.2
24	16.4±1.4	≤ DL	4.2±0.5	23.2±1.8
72	11.6±0.9	≤ DL	≤ DL	15.4±1.0
168	6.2±0.8	≤ DL	≤ DL	13.8±0.9
672	3.6±0.7	≤ DL	≤ DL	37.6±2.2

- a. The Pb content of tap and well water samples was found to be at or below the GFAAS detection limit (DL) of 0.7 µg/L.
 b. Mean ± standard deviation of 3 determinations.

Sn/Cu/Ag-soldered pipes exceeded the maximum acceptable concentration (MAC) of 10 µg/L recommended in the Guidelines for Canadian Drinking Water Quality (12).

The amount of Pb leached from the Sn/Sb-soldered copper pipe reached a maximum value of 38.8 µg/L within 6 h of contact and thereafter decreased steadily reaching values of 6.2 and 3.6 µg/L for 7 and 28 days of contact, respectively. In the case of silvabrite 100,

no clear trend was evident between contact time and the amount leached. Thus, the Pb values found for contact times of 0, 6, 24, 168 (7d), and 672 (28 d) h were 16.8, 26.4, 23.2, 13.8 and 37.6 µg/L, respectively.

Tables 4A and 4B above show the amount of Zn leached from the various soldered-copper pipes into the three types of water samples. Considerable amount of Zn was leached into high-purity water from the various

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Table 4A

Concentration of Zinc Released from Some Non-Pb
Soldered Copper Pipes into Some Water Samples

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Sn/Ag	95.5/4/0.5 Sn/Cu/Ag
±2.2	16.8±1.9
±0.5	14.0±0.8
DL	10.4±1.1
DL	26.4±1.9
DL	15.2±1.2
±0.5	23.2±1.8
DL	15.4±1.0
DL	13.8±0.9
DL	37.6±2.2

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Contact Time(h)	Concentration (mg/L)					
	95/5 Sn/Sb			96/4 Sn/Ag		
	HW	TW	WW	HW	TW	WW
0	5.60± 0.30 ^a	0.18± 0.01	1.80± 0.09	5.70± 0.28	0.19± 0.01	0.16± 0.01
0.5	0.11± 0.01	0.05± 0.01	0.28± 0.01	1.40± 0.06	0.06± 0.01	0.19± 0.01
3	0.27± 0.01	0.05± 0.01	0.06± 0.01	0.31± 0.02	0.06± 0.01	0.07± 0.01
6	0.29± 0.01	0.05± 0.01	0.06± 0.01	0.29± 0.01	0.06± 0.01	0.08± 0.01
8	0.27± 0.01	0.03± 0.01	0.04± 0.01	0.26± 0.01	0.03± 0.01	0.13± 0.01
24	0.54± 0.03	0.05± 0.02	0.06± 0.01	0.38± 0.01	0.07± 0.01	0.11± 0.01
72	0.64± 0.02	0.04± 0.01	0.03± 0.01	0.45± 0.01	0.04± 0.01	0.06± 0.01
168	0.58± 0.02	0.09± 0.02	0.43± 0.01	0.52± 0.02	0.05± 0.01	0.08± 0.01
672	0.96± 0.02	0.13± 0.01	0.09± 0.01	0.74± 0.02	0.04± 0.01	0.09± 0.01

^a Mean ± standard deviation of 3 determinations.

soldered pipes. The highest amount of leaching occurred within minutes of contact as seen from the values of 5.6, 5.7, 10.1 and 8.4 mg/L for 95/5 Sn/Sb, 96/4 Sn/Ag, 94/6 Sn/Ag and 95.5/4.0/0.5 Sn/Cu/Ag, respectively. However, within 30 min of contact, the values decreased to 0.11, 1.4, 0.52 and 0.15 mg/L,

Table 4B
 Concentration of Zinc Released from Some Non-Pb
 Soldered Copper Pipes into Some Water Samples

Contact Time(h)	Concentration (mg/L)			95.5/4.0/0.5		
	94/6 Sn/Ag			Sn/Cu/Ag		
	HW	TW	WW	HW	TW	WW
0	10.10± 0.42 ^a	1.60± 0.07	0.08± 0.01	8.40± 0.33	0.15± 0.01	0.07± 0.01
0.5	0.52± 0.02	0.40± 0.02	0.18± 0.01	0.15± 0.01	0.07± 0.01	0.17± 0.01
3	0.25± 0.02	0.06± 0.01	0.08± 0.01	0.31± 0.02	0.07± 0.01	0.08± 0.01
6	0.22± 0.01	0.04± 0.01	0.07± 0.01	0.31± 0.01	0.07± 0.01	0.08± 0.01
8	0.18± 0.01	0.03± 0.01	0.06± 0.01	0.36± 0.02	0.06± 0.01	0.05± 0.01
24	0.42± 0.02	0.02± 0.01	0.10± 0.01	0.99± 0.03	0.05± 0.01	0.06± 0.01
72	0.33± 0.02	0.04± 0.01	0.08± 0.01	1.02± 0.03	0.03± 0.01	0.08± 0.01
168	0.32± 0.01	0.04± 0.01	0.07± 0.01	0.77± 0.02	0.04± 0.01	0.11± 0.01
672	0.82± 0.02	0.06± 0.01	0.23± 0.01	1.10± 0.04	0.03± 0.01	0.07± 0.01

^a Mean ± standard deviation of 3 determinations.

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Some Non-Pb
Water Samples

95.5/4.0/0.5
Sn/Cu/Ag

HW	TW	WW
8.40± 0.33	0.15± 0.01	0.07± 0.01
0.15± 0.01	0.07± 0.01	0.17± 0.01
0.31± 0.02	0.07± 0.01	0.08± 0.01
0.31± 0.01	0.07± 0.01	0.08± 0.01
0.36± 0.02	0.06± 0.01	0.05± 0.01
0.99± 0.03	0.05± 0.01	0.06± 0.01
1.02± 0.03	0.03± 0.01	0.08± 0.01
0.77± 0.02	0.04± 0.01	0.11± 0.01
1.10± 0.04	0.03± 0.01	0.07± 0.01

determinations.

respectively. Thereafter, the values generally increased with increasing contact time (Table 4). In the case of tap and well waters, the values leached were lower than those into high-purity water (Table 4). Also, for contact times ≥ 0.5 h, the values leached remained more or less constant and were generally < 100 ng/ml (Table 4).

Tables 5A and 5B show the amount of tin leached from the various soldered copper pipes into the three types of water samples. In general, the amount of tin leached into high-purity water and tap water from the various solders rarely exceeded 20 $\mu\text{g/L}$ even for contact times as high as 672 h. In the case of well water, there was hardly any leaching of tin after 3 h of contact. Note that the extent of leaching tin decreased with increasing contact time. In fact, no detectable leaching of tin occurred from any of the solders into any of the waters at contact times of 168 and 672 h.

DISCUSSION

Copper pipes joined by brazing or soft soldering with 50/50 Sn/Pb solder are commonly used in domestic installations. We and several other workers (1 and the references contained therein) have shown that significant leaching of lead occurred into potable waters from Pb-based solder joints. Our results (1) showed that the Pb levels during a "breaking in" period for new plumbing considerably exceeded the present MAC limit of 10 $\mu\text{g/L}$ (12). In general, the Pb levels were the highest in waters that had the longest contact time

Table 5A
Concentration of Tin Released from Some Non-Pb
Soldered Copper Pipes into Some Water Samples

Contact time (h)	Concentration ($\mu\text{g/L}$)					
	95/5 Sn/Sb			96/4 Sn/Ag		
	HW	TW	WW	HW	TW	WW
0	$\leq\text{DL}$	7.4 $\pm$ 0.3 ^a	$\leq\text{DL}$	30.5 $\pm$ 1.2	6.1 $\pm$ 0.4	$\leq\text{DL}$
1	$\leq\text{DL}$	11.3 $\pm$ 0.7	6.8 $\pm$ 0.4	$\leq\text{DL}$	14.5 $\pm$ 0.6	5.0 $\pm$ 0.4
3	5.8 $\pm$ 0.4	19.2 1.0	10.6 $\pm$ 0.5	21.6 $\pm$ 0.7	13.9 $\pm$ 0.6	8.3 $\pm$ 0.4
6	18.1 $\pm$ 0.5	31.4 0.5	$\leq\text{DL}$	27.0 $\pm$ 0.7	38.4 $\pm$ 0.3	$\leq\text{DL}$
8	13.0 $\pm$ 0.3	11.2 $\pm$ 0.2	$\leq\text{DL}$	10.1 $\pm$ 0.2	17.9 $\pm$ 0.2	$\leq\text{DL}$
24	44.7 $\pm$ 0.5	15.3 $\pm$ 0.3	$\leq\text{DL}$	37.4 $\pm$ 1.2	15.3 $\pm$ 0.5	$\leq\text{DL}$
72	$\leq\text{DL}$	$\leq\text{DL}$	$\leq\text{DL}$	22.8 $\pm$ 1.0	$\leq\text{DL}$	$\leq\text{DL}$
168	$\leq\text{DL}$	$\leq\text{DL}$	$\leq\text{DL}$	$\leq\text{DL}$	$\leq\text{DL}$	$\leq\text{DL}$
672	$\leq\text{DL}$	$\leq\text{DL}$	$\leq\text{DL}$	$\leq\text{DL}$	$\leq\text{DL}$	$\leq\text{DL}$

^a Mean $\pm$ standard deviation of 3 determinations.
DL -- Detection Limit of tin = 1.0 $\mu\text{g/L}$.

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n (µg/L)

96/4 Sn/Ag		
HW	TW	WW
30.5± 1.2	6.1± 0.4	≤DL
≤DL	14.5± 0.6	5.0± 0.4
21.6± 0.7	13.9± 0.6	8.3± 0.4
27.0± 0.7	38.4± 0.3	≤DL
10.1± 0.2	17.9± 0.2	≤DL
37.4± 1.2	15.3± 0.5	≤DL
22.8± 1.0	≤DL	≤DL
≤DL	≤DL	≤DL
≤DL	≤DL	≤DL

eterminations.
1.0 µg/L.

Table 5B
Concentration of Tin Released from Some Non-Pb
Soldered Copper Pipes into Some Water Samples

Contact time (h)	Concentration (µg/L)			Concentration (µg/L)		
	94/6 Sn/Ag			95.5/4.0/0.5 Sn/Cu/Ag		
	HW	TW	WW	HW	TW	WW
0	5.0± 0.4 ^a	≤DL	≤DL	≤DL	8.2± 0.5	≤DL
1	6.8± 0.3	16.3± 0.8	31.8± 0.9	7.9± 0.4	11.3± 0.6	33.6± 1.1
3	21.3± 0.8	22.4± 0.8	9.2± 0.4	9.2± 0.3	19.2± 0.6	7.5± 0.3
6	29.2± 0.9	41.6± 0.8	≤DL	19.5± 0.4	49.5± 0.3	≤DL
8	15.1± 0.6	16.6± 0.3	≤DL	13.2± 0.5	25.5± 0.3	≤DL
24	60.8± 0.8	9.9± 0.3	≤DL	16.9± 0.5	23.9± 0.4	≤DL
72	19.3± 0.4	10.5± 0.3	≤DL	11.5± 0.5	10.3± 0.3	≤DL
168	≤DL	≤DL	≤DL	≤DL	≤DL	≤DL
672	≤DL	≤DL	≤DL	≤DL	≤DL	≤DL

^a Mean ± standard deviation of 3 determinations.
DL -- Detection Limit of tin = 1.0 µg/L.

with the plumbing. Such waters are obtained from faucets seldom used, from first-drawn tap water samples in the morning after the last flushing of the faucet the night before, or from faucets in houses 1 to 3 years old.

Since the Pb-based solders in plumbing systems pose a public health hazard, the 1986 amendments to the US Safe Drinking Water Act (Public Law 99-339, Section 1417) prohibits the use of solder and flux containing > 0.2% Pb in the installation and repair of all residential and non-residential potable water plumbing (3). In Canada, a similar requirement has been approved for inclusion in the revision of the National Building Code and the Canadian Plumbing Code. The provinces of Manitoba and Ontario have also passed similar laws. As a result, several Pb-free solders, most notably 96/4 Sn/Ag; 95/5 Sn/Sb; and 95.5/4.0/0.5 Sn/Cu/Ag have been suggested for use in public water systems(3), and are now commercially available. These solders can be applied using the same fluxes, heating equipment and joining techniques as for the Pb-based solders without any need for retraining. The States of Oregon and New York, for example, use 95/5 Sn/Sb (2, 14), while Denmark, Sweden and Norway use 95/5 Sn/Ag (15) in potable water plumbing systems. These solders are also now well received in Canada. However, there is concern that their use may result in the leaching of metals such as Ag and Sb which may pose a health hazard.

The present study shows that the amounts of Ag, Cd, Cu, Pb, Sn, Sb and Zn were within the current guidelines for Canadian Drinking Water Quality. In other words, there was no significant leaching of any of these metals from the four types of Pb-free solders studied here. Our results for the 95/5 Sn/Sb solder

are in agreement with the Pipe loop study. The solder showed no water samples observed were the best of our knowledge to indicate the leaching of Sn from the solder, according to the formation of the surface of the inhibiting Sn probably responsible for the observed in the

In conclusion, Sn/Sb and Sn/Cu replacing Pb-based plumbing systems of metals, not solders. The result in reduction from drinking

1. Subramanian, S. R., Copper, Lead, and Tin in Drinking Water (in press)
2. Lassóvszky, Z. Lead and Tin in Drinking Water Heating/1
3. Bannos, T. Safe Drinking Water Act 67: 23.

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are in agreement with those of Herrera et al. (16).
Pipe loop studies by these authors with the Sn/Sb
solder showed little leaching of Pb and Sb into the
water samples. The highest concentration of Pb and Sb
observed were 3.7 and 2.0 $\mu\text{g/L}$, respectively. To the
best of our knowledge, no literature data are available
to indicate the extend of leaching of Ag into potable
water from the Sn/Ag solders. The insignificant
leaching of Sb into the water samples from the Sn/Sb
solder, according to Herrera et al. (16), could be
attributed to the sacrificial corrosion of Sn and the
formation of a tin oxide passivating film that protects
the surface of the Sb contained in the solder thereby
inhibiting Sb corrosion. A similar mechanism is
probably responsible for the minimal leaching of Ag
observed in the present study with the Sn/Ag solders.

In conclusion, the present study shows that the
Sn/Sb and Sn/Ag solders have excellent potential for
replacing Pb-based solders in private and public
plumbing systems because of the insignificant leaching
of metals, notably Pb, Cd, Ag and Sb, from these
solders. The use of these Pb-free solders should
result in reduced exposure of Pb, Ag, Cd, Sb and Sn
from drinking water to humans.

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