Final Report

Effects of External Currents and Dissimilar Metal Contact on Corrosion from Lead Service Lines

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Table of Contents

Executive Summary 1

Background 3

Research Protocol 5

- **Electrochemical Measurements** 5

Galvanic Coupling Experiments 6

- **Indirectly Coupled Cells.** 6
  - **Evan's Diagram.** 8
  - **Cathode/Anode Ratio Effects.** 9
- **Directly Coupled Pipe Sections** 10
  - **Water Quality and Galvanic Impacts.** 12
  - **Dielectric Insertion.** 15

Grounding and Impressed Currents 16

- **Impressed Current Experiments** 16

Observations and Conclusions 20

- **Passivation.** 20
- **Lead Electrochemistry.** 20
- **Area of Galvanic Influence** 20
- **Cathodic Effect of Copper Pipe.** 21
- **Water Quality and Galvanic Impacts** 21
- **Dielectric Effects** 21
- **Impressed Current Effects.** 21

References 22

Table of Figures

Figure 1. Polarization (Evan's) diagram of coupled lead and copper surfaces. 4

Figure 2. Schematic of a typical pipe rig configuration using indirectly-coupled cells ... 7

Figure 3. Photo of a pipe rig with indirectly-coupled cells in operation. 8

Figure 4. Effect of cathode/anode ratio on LSL surface potential............................... 10

Figure 5. Schematic of a test rig showing the direct coupling of LSL and copper pipe sections 11

Figure 6. Photo of directly coupled LSL and copper sections used in a portion of this study 11

Figure 7. Surface potential along the length of coupled LSL and copper service lines 12

Figure 8. Effect of chlorine concentration on galvanic impacts relative to passivated LSL specimen. 14

Figure 9. Comparative effect of free versus combined chlorine on galvanic impacts relative to passivated LSL specimen. 14

Figure 10. Effect of conductivity on galvanic impacts relative to passivated LSL specimen. 15

Figure 11. Effect of inserting a dielectric between the passivated LSL and copper sections on galvanic impact. 15

Figure 12. Schematic illustration of impressed current test rig..................................... 17

Figure 13. Impressed current impacts (separate DC and AC tests) on surface potential of an LSL coupled to copper tubing. 19

Executive Summary

This study set out to investigate two basic issues and has largely succeeded at resolving both. The first issue was whether grounding or impressed currents have a significant and prolonged impact on the electrochemistry and corrosion of lead service lines (LSLs) in a water distribution system, or, for that matter, on any metal plumbing appurtenance that may be hydraulically and electrically connected to a household service line used as an electrical ground. The second principal issue was to characterize the electrical impacts associated with galvanically-coupled copper and lead service lines to determine if replacing a portion of a lead pipe with copper piping might cause accelerated lead release. Both issues relate to the potential for accelerated corrosion on LSLs leading to the release of metals in drinking water. Both have relevance to the DC WASA corrosion control program and LSL replacement program.

The specific objectives of the research were to establish under controlled laboratory conditions the absolute magnitude of the electrical impacts on LSLs associated with both grounding and galvanic coupling under a variety of pipe geometries and water chemistries. This research did not intend to explore grounding currents in an existing home or to replicate actual distribution system conditions where a partial lead service line replacement (PLSLR) had occurred. Rather, the goal was to demonstrate whether or not grounding currents or galvanic coupling could generate lead release. If a meaningful impact could not be demonstrated under conditions designed to exacerbate lead release, then it would be unlikely that a PLSLR as practiced in the DC WASA system (where conditions would be much less challenging than in the laboratory) would produce accelerated metal release. If positive effects were found, the study would then serve as a foundation for further testing.

All the LSL pipe sections used in these tests had been removed recently from residences in the DC WASA distribution system.

In brief, this study has shown that grounding and/or impressed currents moving along LSLs, end eventually leaving the pipe to ground, have no meaningful impact on internal pipeline corrosion and do not contribute to metals release. Therefore, we believe the long-debated controversy about whether or not grounding currents generate accelerated corrosion and metal release can now be considered closed. Also, while the study found that galvanic impacts can be substantial on unpassivated, newly-exposed lead surfaces, the magnitude of galvanic impacts on aged and passivated LSL surfaces and on new copper surfaces is minimal, and, in the long term, likely to be inconsequential. Therefore there is now a basis for discounting concerns relative to the long-term impacts associated with PLSLR.

A caveat that must be attached to these finding is that testing was restricted to waters with low mineral content similar to the water distributed within the DC WASA system; galvanic impacts in systems having water with a substantially higher mineral content could be more extensive and possibly more prolonged.

The significant conclusions to be drawn from this study are as follows:

- Well-aged DC WASA LSL specimens – including those that have been exposed to an orthophosphate inhibitor – are exceptionally well passivated and highly resistant to electrical perturbations of any kind.
- When a well-passivated LSL is coupled to a new length of copper tubing (as in a partial LSL replacement) the area of galvanic influence is very limited. The actual reach of the galvanic current is partially a function of the water quality, but is likely limited to the first inch of the LSL.
- A conventional plumbing dielectric junction removes even the minor corrosion risks associated with galvanic coupling. Any break in electrical continuity between the copper and LSL lines effectively eliminates the potential for significant galvanic effect.
- A chlorine residual (free or combined) does elevate the galvanic effect on the LSL/copper couple by accelerating the cathodic current exchange process. The impact overall, however, is largely limited to the galvanic influence on the copper service line. The overall impact on the LSL surface is nearly imperceptible. Interestingly, water conductivity has a more important effect on the galvanic process than chlorine residual.
- Impressed currents, whether AC or DC, on LSLs or copper service lines (including grounding type currents), have no impact on the internal corrosion of the household service lines (or any other plumbing appurtenance for that matter). There is no acceleration of corrosion associated with the conventional practice of electrical system grounding to household water systems.

Background

In theory, it is conceivable that replacing a portion of a lead line with a new copper service line could create a strong galvanic couple with an initial Cu/Pb electromotive difference in the 400 - 500 mV range (Reiber, 1991). If a significant portion of the remaining section of lead service line were shifted in the anodic direction by even a fraction of this amount, there would be a substantial acceleration of the corrosion rate and associated metal release rates.

In a similar sense, for well over a decade, there has been substantial conjecture within the drinking water industry that electrical currents impressed, or, more often, shunted onto water service lines as a result of grounding practices in individual homes, create a similar scenario. Supposedly these impressed currents shift the surface potential of the corroding pipeline surface, generating accelerated corrosion and metal release, and in some cases producing other corrosion-related problems such as localized pitting. There are few texts on distribution system corrosion that do not cite impressed currents as a potential cause of the interior pipeline corrosion (Bell, 1996; AWWARF, 1996). The suggestion has been made that these currents may be responsible for some of the abnormally high lead release levels observed in isolated homes. By extension, it could be assumed that if grounding currents are important, then perhaps a portion of the randomness associated with observed lead levels may be related to the presence of different magnitudes of grounding currents.

It is important to note that while the proposed mechanisms of galvanic and/or impressed current influence are plausible, and that some limited evidence is supportive, it has not been demonstrated that either grounding currents or galvanic coupling meaningfully increase LSL corrosion rates. Moreover, partial LSL replacement in the DCWASA system has not resulted in observed increases in lead release (Wujek, 2004). In fact, the recent DC WASA experience relative to LSL replacement suggests that in the long term PLSLR does not exacerbate lead release rates, but rather reduces overall household drinking water lead concentrations in proportion to the amount of LSL replaced. While this evidence appears strong, for several years there has been a debate on the potential galvanic effects associated with replacing a portion of old LSLs with new copper tube, or for that matter coupling any lead-containing alloy to a dissimilar metal.

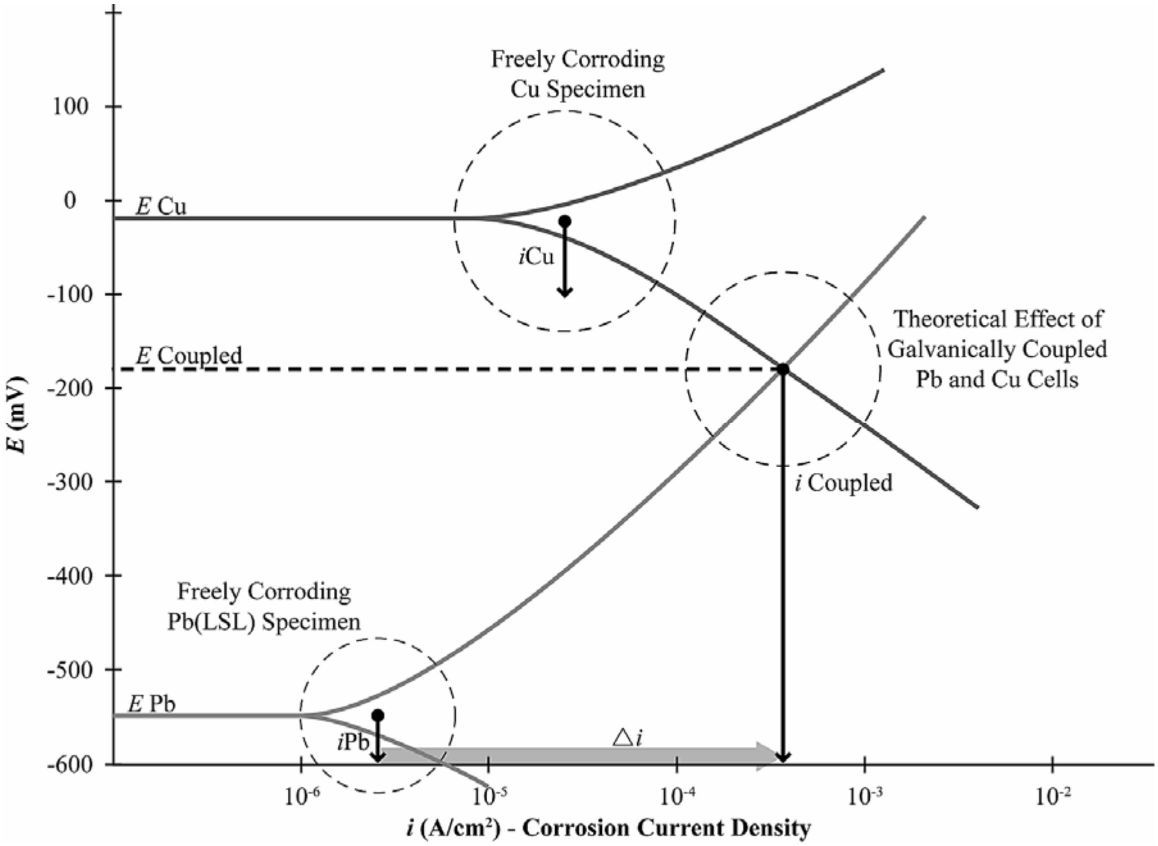

Figure 1. Polarization (Evan's) diagram of coupled lead and copper surfaces.

Theoretically, the coupling of a new copper surface to a lead surface should produce a substantial galvanic impact. The Evan's Diagram above illustrates this point. The diagram presents the observed polarization behavior of uncoupled copper and lead surfaces, as well as the theoretical polarization behavior of the surfaces that would occur if they were coupled. The uncoupled surfaces are unscaled and unpassivated, and hence represent practical worst-case scenarios. Relative to lead, the coupling of the two surfaces results in a theoretical initial increase in the anodic (lead) exchange current (Δi, corrosion current density) of approximately two orders of magnitude, which of course would have a profound impact on corrosion and metal release rates if it were sustained at this level.

What cannot be discerned from the above representation is how long that accelerated current exchange can be sustained after the initial coupling. In a practical sense, since all of the existing LSLs in the DC WASA system are well passivated after many decades of service, the more important question becomes how passivation of the lead and/or copper surfaces affects the galvanic current. A large portion of this modest study focuses on that question.

Research Protocol

Electrochemical Measurements

At the core of this study was the search for the substantial electrochemical impacts that, theoretically, should be associated with the galvanic and impressed currents imposed on the LSLs. The principal measure of these impacts would be a significant shift in the electrochemical potential of the interior surface of the LSLs away from the freely corroding surface potential. Surface potential can be directly and accurately measured using straightforward electrochemical tools (AWWARF, 1996).

This research did not attempt to create laboratory conditions that exactly replicate field conditions. Instead, the goal was to demonstrate whether or not extremes of grounding currents or galvanic coupling could affect the LSL electrochemistry. It was also beyond the scope of this work to define how differences in passivation states of copper tubing, or quality of plumbing fabrication may influence the respective current impact. Testing was generally short-term, inexpensive and designed to answer the simple question, “Can grounding and/or galvanic currents under a worst-case scenario meaningfully contribute to lead corrosion and metals release?”

The study used a series of electrochemical cells which allowed the mounting of sections of LSLs under flow conditions and the placement of electrodes capable of quantifying shifts in surface potential. In most cases the electrode of choice was a calomel electrode (Hg/Hg_2Cl_2), selected because of its stability and resistance to external electrical noise. This electrode, coupled with a sensitive potentiostat, can measure surface potential shifts of a millivolt or less. This is an important analytical factor, since the shifts in surface potential theoretically resulting from the galvanic and impressed currents were thought to be hundreds of millivolts or greater.

The surface potential measurement is sensitive, easy to use, and allows speedy measurements, but its principal advantage is that it is influenced only by the electrochemistry of the metal surface and the water in contact with that surface. It is not substantially or directly influenced by the mechanical stability or chemical solubility of the corrosion scale covering the surface – unless the rapid loss of that scale is changing the underlying electrochemistry. The surface potential measurement reflects the corrosion conditions of the underlying metal, which, in this case, is the factor most directly influenced by application of the galvanic and/or impressed currents in question. At the same time, the limitation of this electrochemical testing is that it tells us very little about the stability or changing mineralogic makeup of the corrosion scale. Nonetheless, relative to the issue of galvanic and impressed currents, electrical perturbation will precede any long-term change in the nature of the corrosion scales.

The short-term tests used in this study did not readily lend themselves to standard metal release monitoring used in other aspects of the DC WASA corrosion-control optimization studies (Giani et al, 2005). While monitoring of metal-release rates was attempted, it was found that the physical cutting and manipulation of LSL sections generated frequent, but irregular, particulate release. The individual tests, which generally ran for periods of only a few days each, did not provide sufficient time to condition and stabilize the scales on the different test sections.

Galvanic Coupling Experiments

The original approach to the galvanic coupling research was to utilize polarization cells mounting individual sections of LSLs and copper tubing. These cells could be connected in a hydraulic series, with the electrical connections between the individual cells manipulated at will. Because the pipe specimens of each cell were not in direct contact, these cells were referred to as ***indirectly coupled***. The importance of the indirectly coupled cells relates primarily to the ability to control cathode/anode ratios. It is critical to the appreciation of the galvanic couple concern to understand that it is not the contact of dissimilar metals, per se, that creates the corrosion risk, but rather the fact that the cathodic surface (the more electropositive metal), if present in abundance, can affect a shift in the surface potential of the anodic surface. The greater the cathode/anode ratio the greater the potential shift, and the greater the area of anodic impact. Any meaningful shift in the anodic surface in a more positive direction generates a higher corrosion rate on that surface.

A second approach to galvanic testing utilized longer segments of LSLs and copper pipe coupled together in a manner similar to an actual PLSLR. Because these pipe specimens are in direct contact, this type of testing is referred to as ***directly coupled*** pipe specimens. This form of testing yielded more useful results about the nature of the galvanic couple formed between copper and LSL sections.

Indirectly Coupled Cells.

Recirculation pipe loops with individual cells holding LSL and copper pipe sections were fabricated with acrylic polarization cells and vinyl connecting tubing. The schematic presented in Figure 2 shows the arrangement of the individual cells, hydraulics and electrical connections. In this arrangement the cells are hydraulically connected in series, and electrically connected via external circuits that can be configured as needed. The arrangement offers the opportunity to manipulate cathode/anode ratios, measure the current flow between cells, evaluate metal release and, most importantly, accurately assess the surface potential of the individual pipe sections, all while controlling flow and water quality conditions. Figure 3 presents a photo of such a loop in operation.

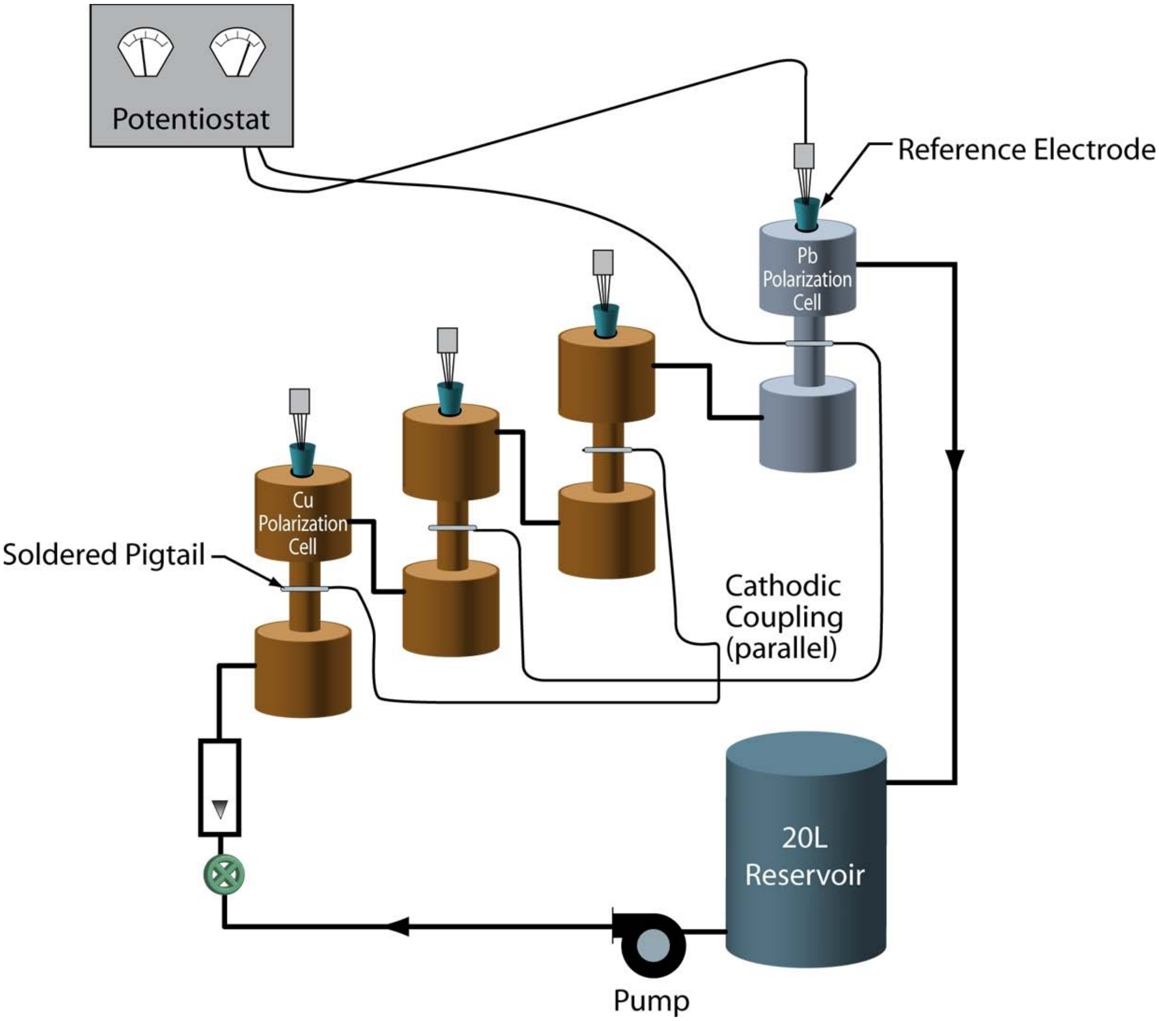

Figure 2. Schematic of a typical pipe rig configuration using indirectly-coupled cells

Figure 3. Photo of a pipe rig with indirectly-coupled cells in operation.

Evan's Diagram.

The data presented in the Evan's diagram of Figure 1 was prepared using results obtained from an indirectly-coupled pipe rig of a type similar to that in Figure 2. In that test a single LSL section was coupled to a single copper pipe section of comparable internal surface area (20 cm^2). Originally, both the LSL and copper surfaces were abraded and then polished (300 grit wet jeweler's paste) so as to represent truly unscaled and unpassivated surfaces. This attempt to create an unpassivated LSL surface generated a surface potential of approximately -400 mV (vs. SCE), which is not substantially different than the surface potential of a passivated LSL. Discussions with Michael Schock (US EPA – ORD) suggested that a truly unpassivated lead surface should be closer to -500 mV (vs. SCE), rather than the -400 mV measured.

Revisiting the techniques used to remove the LSL corrosion scale, a milling machine with high speed de-burring tool was used to ream out the interior of the short LSL sections, exposing bare metal with the assurance that no corrosion scale or passivation layer remained. Surface potential measurements on these specimens were approximately -550mV (vs. SCE) when first exposed to water flow. Owing to the electroactive nature of the pure lead surface, the absolute magnitude of the measurement quickly began to decrease as the surface began to passivate in the presence of water.

The rapidly changing electrochemical nature of a bare lead surface makes it difficult to accurately assess the surface potential of a truly unpassivated specimen. The data presented in the Evan's diagram of Figure 1 is probably best described as a partially passivated LSL surface.

Other experiments conducted to define the character of an unpassivated LSL surface were, at best, only partially successful. The most substantial observation is the speed with which an unscaled lead surface will begin to passivate. Although we have not tried to quantify the rate of passivation, we note that an unpassivated LSL section within a matter of weeks will take on the character of a passivated LSL section having decades of exposure, and it will do this in a low mineral content water very similar in chemistry to that distributed by DC WASA. Moreover, it is clear that while orthophosphate corrosion inhibitors can over a substantial period of time enhance the passivation of LSL surfaces (based on on-going metal release pilot studies), these surfaces will effectively passivate absent orthophosphate or other specific corrosion inhibitors (Reiber and Giani, 2005). It is the nature of the lead surface to quickly form an effective passivation layer, which is why LSLs are still found in service even after a century of exposure to drinking water flows.

Cathode/Anode Ratio Effects.

Using the indirectly coupled cell rig, the effect of coupling passivated LSL sections to unpassivated copper sections quickly became apparent. Figure 4 presents the results of coupling a single LSL section (20 cm^2 internal surface) to multiple copper pipe sections of equivalent surface area. At most, the electrical perturbation of the passivated LSL was a few millivolts, regardless of how many copper sections were electrically coupled to it.

A substantially different observation was made when a relatively unpassivated LSL section (mechanically reamed) was coupled to the same copper pipe sections as above. The unpassivated LSL surface was substantially influenced by the galvanic coupling – producing an anodic shift of approximately 100 mV at a cathode/anode ratio of three. Clearly, galvanic coupling is important on relatively unpassivated surfaces, yet largely irrelevant to passivated LSL specimens.

While this experiment evaluated the macro effects of galvanic coupling, it is not unreasonable to extrapolate these macro observations to the micro surface chemistry associated with leaded brasses. The question has been raised (Korshin, 2005) as to whether brasses having any lead inclusions will accelerate corrosion of the lead by virtue of the intrinsic galvanic couple created by a surface with very small lead anodes surrounded by the much more abundant and more electropositive copper/zinc alloy (brass). The macro galvanic coupling experiment described above would suggest that cathode/anode ratio is largely irrelevant to the corrosion of a passivated lead surface.

Hence, it seems likely that lead corrosion on an aged brass surface is unlikely to be influenced by the more electropositive alloy surrounding it.

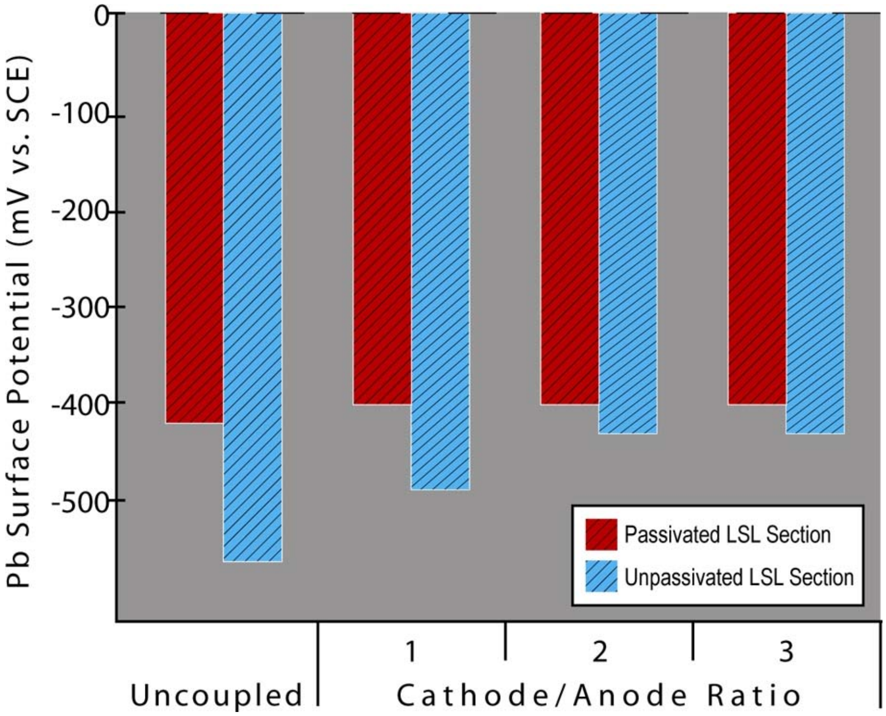

Figure 4. Effect of cathode/anode ratio on LSL surface potential.

Directly Coupled Pipe Sections.

Following the test with indirectly coupled pipe sections, the study attempted to quantify galvanic effects by directly coupling copper tubing sections and DC WASA LSL sections. New ¾-inch diameter copper tubing was selected to ensure as high a galvanic driving force as possible. To ensure electrical coupling, the end of the LSL was grooved to accept the end of the copper tubing, which mated directly with the LSL. A hydraulic seal was achieved by mounting both the copper and LSL sections between compressive headpieces. Holes placed at strategic locations along the copper and LSL sections allowed for the placement of reference electrodes capable of reading the surface potential on the pipe opposite to those locations. To simulate operational service, water was circulated through the pipe sections while the surface potentials were recorded. Figure 5 presents a schematic of a directly coupled cell. Figure 6 presents a picture of a small coupled pipe cell used for one portion of this testing.

The LSL pipe sections used in these tests were recently removed (July, 2005) from residences in the DC WASA distribution system. As such, they had been exposed for a period of almost one year to the phosphoric acid corrosion-control mitigation strategy implemented in the summer of 2004. The passivated LSL sections described in this section were used as received. An attempt was made to create unpassivated LSL sections for this testing by polishing the interior of relatively long sections of the LSLs by forcing a tightly wadded plastic abrasive sheet (Scotch-Brite) back and forth along the length of the LSL section. This was at least partially successful and did remove a portion of the very adherent and very protective passivating layer on the aged LSL sections. Because of the length of the test sections it was not possible to use a mechanical reaming tool as was done in the indirectly coupled cell testing. Although the specimen geometry did not allow for a rigorous polishing, the effort did produce a substantial change in the surface electrochemistry that was evidenced in subsequent testing. For purposes of this discussion, partially polished LSL sections are referred to as unpassivated.

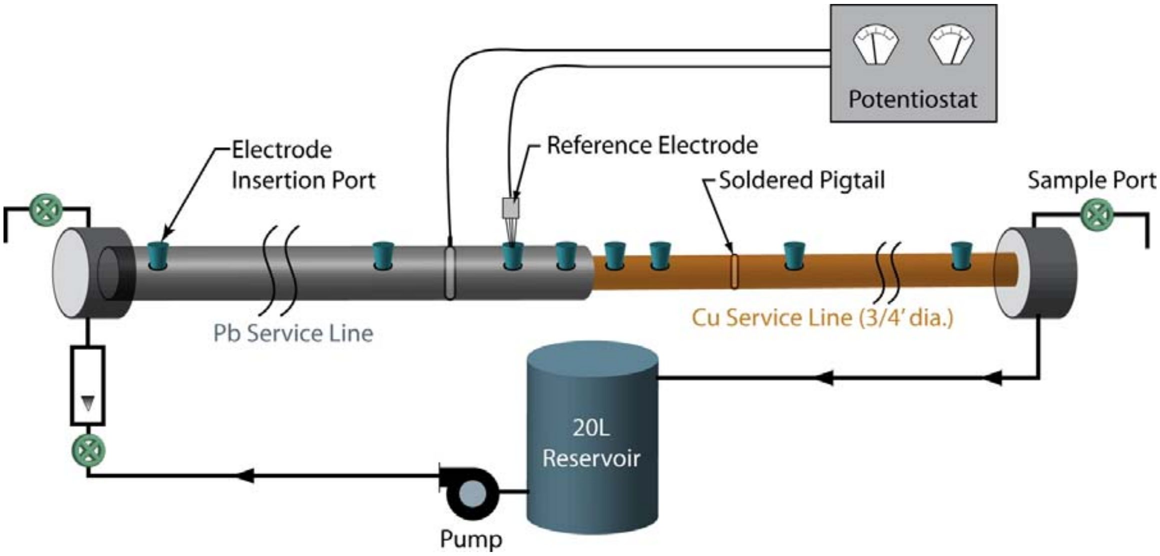

Figure 5. Schematic of a test rig showing the direct coupling of LSL and copper pipe sections

Figure 6. Photo of directly coupled LSL and copper sections used in a portion of this study

Figure 7 presents a comparison of the surface potentials measured along passivated and unpassivated LSL sections connected to equivalent lengths of copper tubing in a directly coupled cell. The comparative results are significant at two levels: first and foremost, as in the testing in the indirectly coupled cels described earlier, direct coupling of new copper tubing to well-passivated LSL sections has almost no discernible electrochemical impact on the LSL. Secondly, coupling to an unpassivated LSL section shows the converse, and is in fact strongly influenced by the connection to the copper tubing. This second point underscores the earlier observations that an unscaled and unpassivated LSL section is highly electroactive, but that once it is passivated it is remarkably polarization resistant.

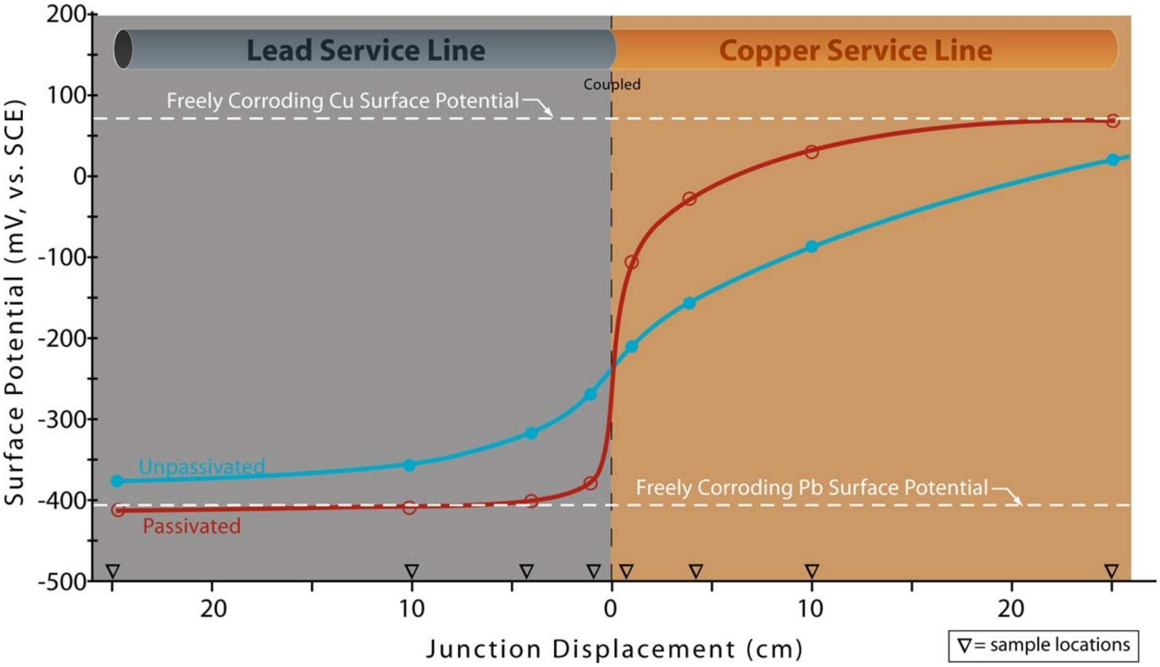

Figure 7. Surface potential along the length of coupled LSL and copper service lines

Water Quality and Galvanic Impacts.

The directly coupled cell approach was used to assess the impact of important water chemistry changes including chlorine chemistry and concentration, and the impact of water conductivity. The baseline water chemistry used in this testing was a simulated DC WASA water having similar pH, alkalinity, hardness and conductivity profiles.

Figure 8 shows the effect of chlorine concentration on the galvanic impacts on a passivated LSL section. An increasing free-chlorine residual elevates the galvanic effect by accelerating the cathodic current exchange process on the copper pipe, however, the impact overall is limited to the copper service line, while the impact on the passivated LSL surface is nearly imperceptible.

Figure 9 shows the comparative effect of equal concentrations of free and combined chlorine relative to galvanic coupling using a passivated LSL sections. The test shows no meaningful difference in galvanic impact on either the lead or copper surfaces. (*Note: While the DC WASA lead solubility issues were the result of redox chemistry impacts associated with the change from free to combined chlorine, the test used here is capable of discerning only fundamental changes in surface electrochemistry, and tells us nothing about solubility of the existing corrosion scales*).

Figure 10 shows the impact of increasing conductivity levels on the galvanic impact relative to a passivated LSL section. Conductivity increases were brought about by the simple addition of NaCl to the recirculating water in the test rig. Interestingly, water conductivity has a more important effect on the galvanic process than chlorine residual, or chlorine type. The area of galvanic influence on the LSL specimen is marginally expanded as the conductivity of the electrolyte (water) increases, while the area of influence on the copper service line is substantially expanded. This would appear to be because the higher conductivity lessens the resistance of the electrolyte circuit (water), expanding the “reach” of the galvanic current. (*Note: DC WASA distributes a low conductivity water (< 100 microSiemens), which, in part, explains the minimal galvanic impacts observed*.)

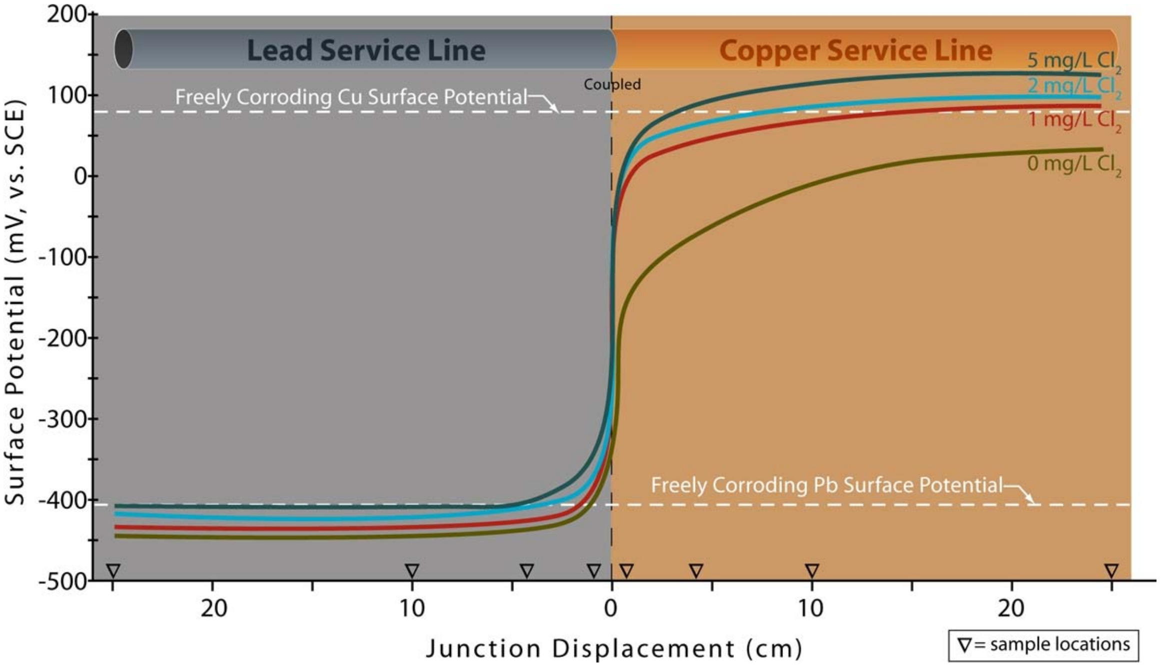

Figure 8. Effect of chlorine concentration on galvanic impacts relative to passivated LSL specimen.

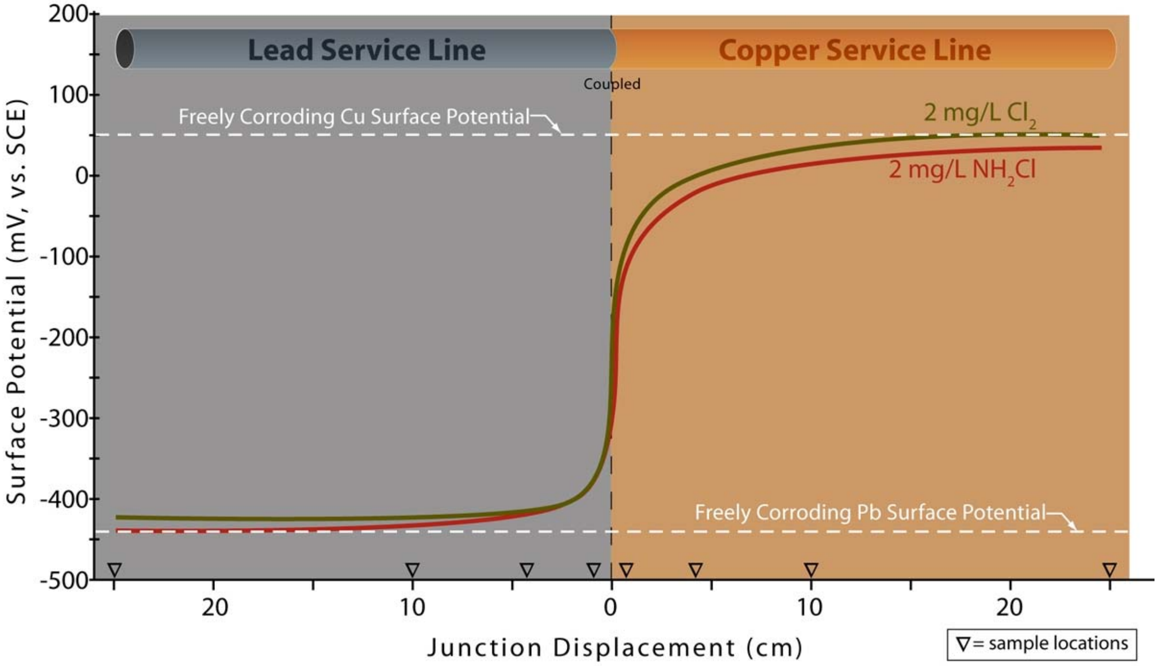

Figure 9. Comparative effect of free versus combined chlorine on galvanic impacts relative to passivated LSL specimen.

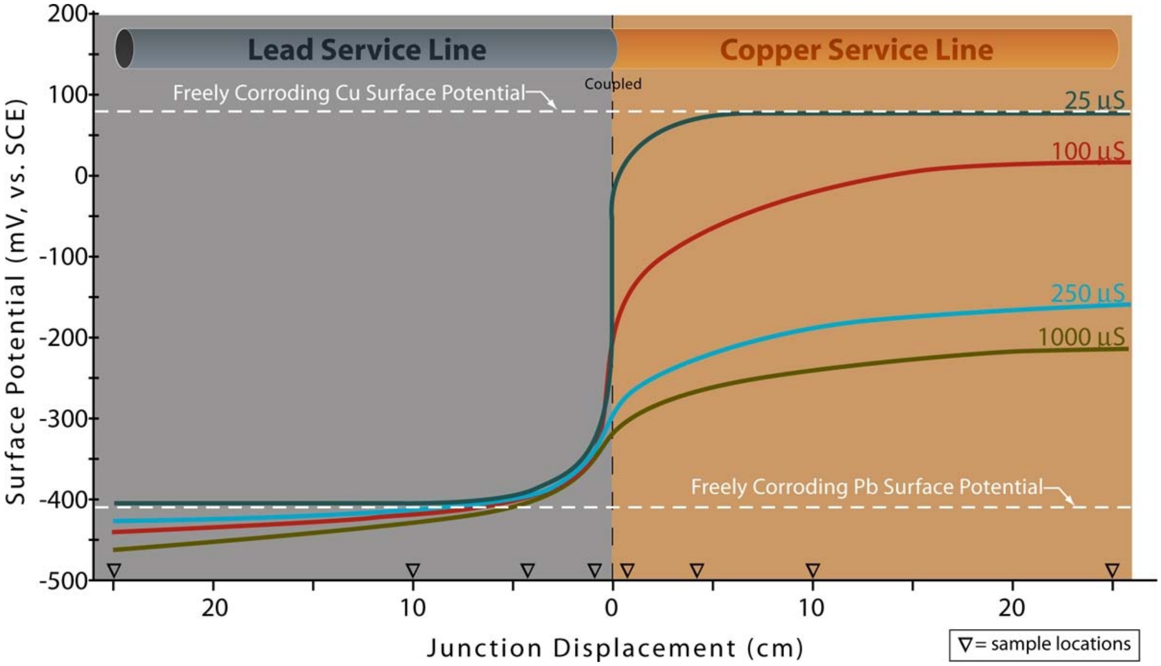

Figure 10. Effect of conductivity on galvanic impacts relative to passivated LSL specimen.

Dielectric Insertion.

A dielectric is an insulating device that prevents direct electrical contact between dissimilar metals, and hence avoids at least some of the problems associated with galvanic coupling. Although not always used, it is generally considered good plumbing practice to use a dielectric when different metal plumbing materials are to be connected. It is standard policy for DC WASA to use dielectric couplers when performing partial LSL replacements (DC WASA, 2004).

Figure 11 shows the effect of inserting a dielectric coupler between the passivated LSL and copper sections of the directly coupled test rig. While in the previous water quality testing it was shown that the galvanic effect of the direct coupling was largely limited to the copper line and had little effect on the LSL, the insertion of a dielectric removes any galvanic impact from either surface. This is a particularly important finding, and along with the general polarization resistance of passivated LSL sections, explains why the partial LSL replacement program in the DC WASA system has not exacerbated lead conditions, but rather has helped to reduce household lead levels.

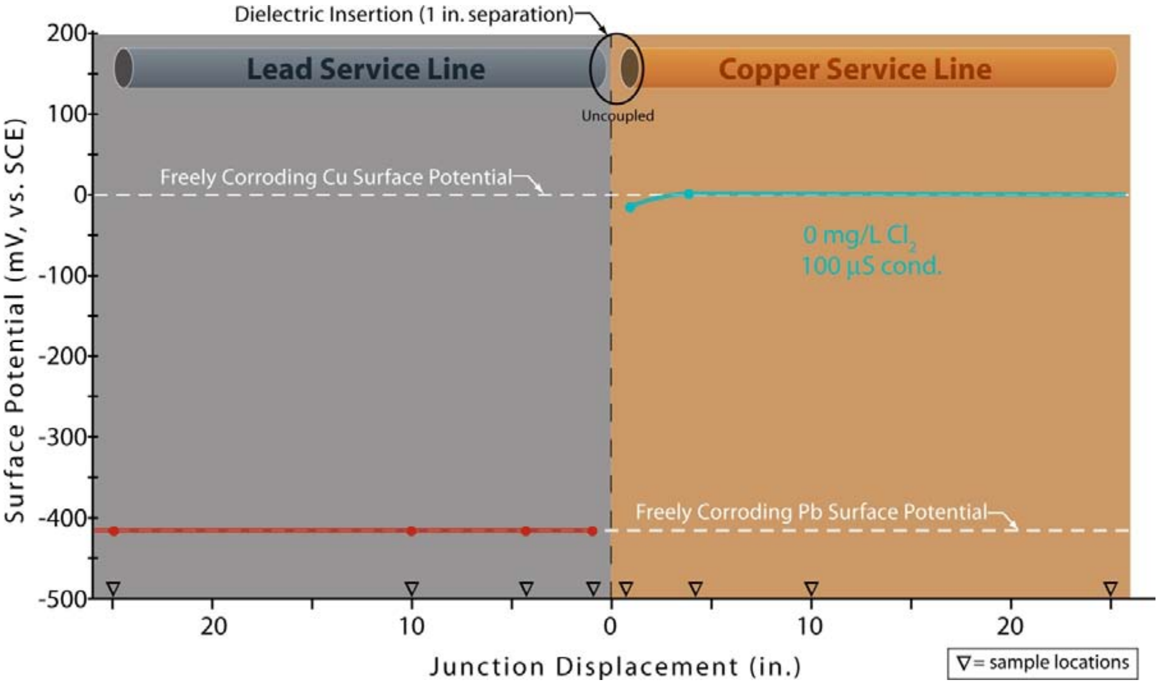

Figure 11. Effect of inserting a dielectric between the passivated LSL and copper sections on galvanic impact.

Grounding and Impressed Currents

Does a current flowing in the pipe wall, and exiting the pipe via an external connection (a typical electrical-system grounding scenario in many older households), change the electrical character of the internal pipe surfaces? If it does, a variety of corrosion and water quality impacts are to be expected, including accelerated metal release. However, a clear absence of a measurable electrical change on the internal surface would mean the grounding circuit is irrelevant to the internal corrosion processes.

That is the question that was addressed by this portion of the study which focused on investigating the interior LSL surfaces relative to simulated grounding currents. The objective was to demonstrate under controlled conditions whether it was possible to create a grounding scenario that accelerates internal corrosion, and to extrapolate its relevance to household plumbing practices.

Although this topic has been previously researched, there is still considerable debate about the impact of externally imposed grounding currents on the electrochemistry of domestic plumbing. The bulk of available research has focused on copper tubing – largely ignoring grounding impacts on LSLs. While some research has suggested an important internal corrosion role for grounding currents (Bell, 1998), other laboratory simulations and field tests have discounted them relative to copper release and associated water quality effects (AWWARF, 1996).

At first glance, it seems intuitive that imposing a (grounding) current on a buried pipe would change the surface potential of the internal and external surfaces. Certainly, as the current is dissipated to ground, the surface potential of the external surfaces does change. However, internally, unless some portion of the grounding current is lost to the electrolyte (water in the pipe), these surfaces will show no change in surface potential relative to the water contacting them. In effect, imposing an external current on the pipeline changes the potential of all surfaces (internal and external) and everything in contact with the pipe. Internally, however, the surface potential relative to the electrolyte (which determines corrosion rates) may not change since the electrolyte potential has also been shifted an amount equal to the internal surface.

Impressed Current Experiments

A flow-through recirculation loop consisting of DC WASA LSL segments, new copper tubing, water reservoir, flow control and pumping hardware was employed for this testing. As in the previous galvanic work, the LSL segments were modified to accept high impedance reference electrodes penetrating the pipe wall at multiple locations along its length. The electrodes monitor surface potential on the interior of the pipe relative to the electrolyte, yet allow for pipeline pressurization. Internal surface potential along the pipeline was monitored, while different current forms, amperages, voltages and grounding scenarios were applied to the test pipes. Figure 12 presents a schematic of the test rig.

Quantifying the actual interior surface potential change vis-à-vis the electrolyte (water) of these pipes was key to assessing grounding current impacts. Any meaningful change in the corrosion condition of the internal surface could be assessed by measuring any substantial change in surface potential, which could be monitored with a high degree of accuracy (+/- 0.1 mV). Table 1 presents a summary of the basic electrical testing profile used in this examination.

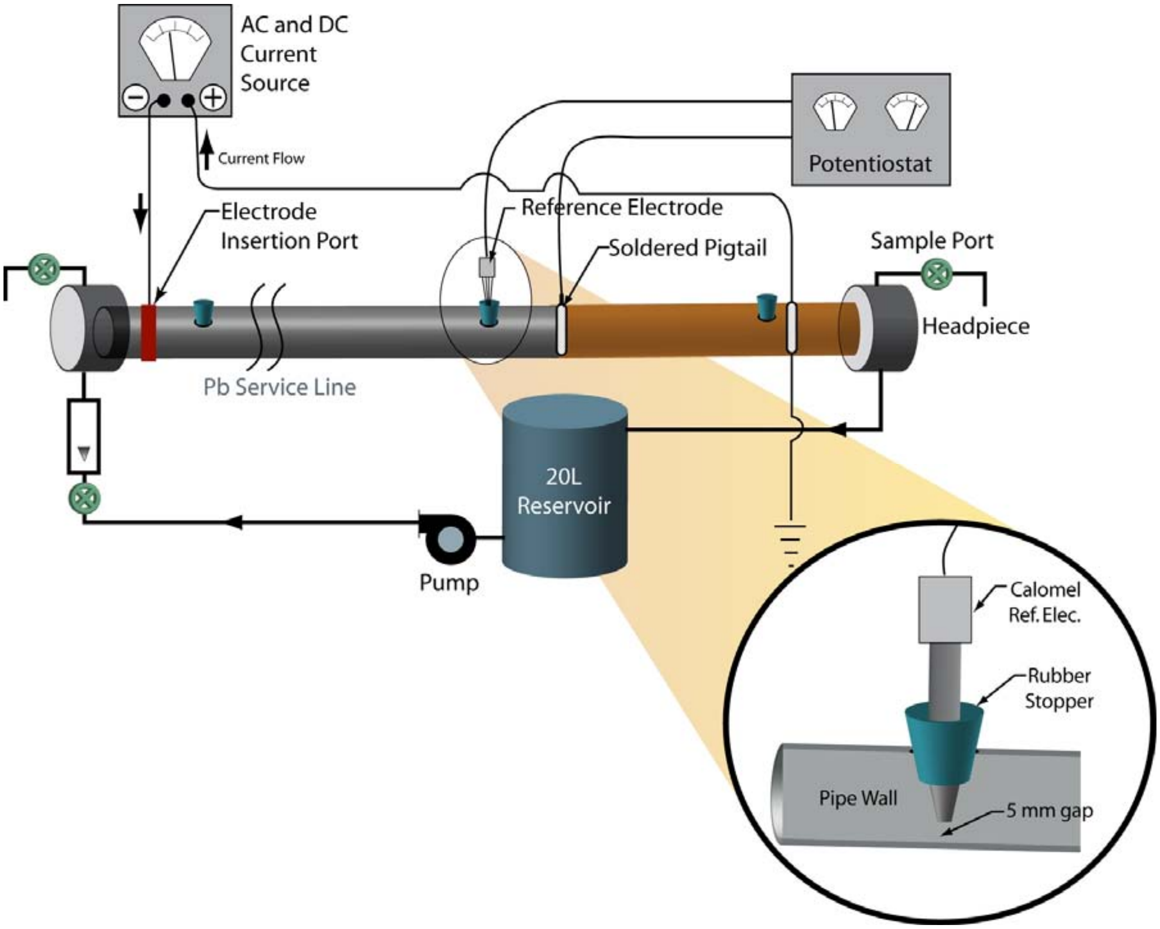

Figure 12. Schematic illustration of impressed current test rig

Table 1. Grounding Currnet Testing profile

Impressed grounding current forms	• Full wave AC • DC
Voltage range	0 – 120 Volts AC, 0 - 12 Volts DC
Current range	0 – 20 Amps AC, 0 – 6 Amps DC
Grounding scenarios	• Single-point ground • Multi-point ground along pipe length • Variable resistance reservoir ground: *By providing a current path from the pipe wall through the electrolyte to ground, it was possible to dissipate some of the applied external current to the interior surface of the pipe.*

With the test rig in operation, the actual assessment could be conducted quickly, generally requiring no more than a few hours per test condition. The testing proceeded from impressing direct currents at minor voltages and amperages to upwards of a 12-Volt current at up to six amps of current flow. Attempts to measure the impact of the impressed current on the interior surface potential were made at different locations along the pipe rig. Different grounding scenarios were tested in conjunction with the impressed current in an attempt to force the impressed current to flow the full length of the pipe samples, as well as to force as much of the current to transfer to the water flow as possible. (*Presumably, current transfer from pipe wall to water creates a corrosion cell*). The most rigorous of the grounding protocols involved adding a ground to the recirculation water reservoir in parallel with the pipe rig ground, thus allowing a direct current path from the pipe wall to the recirculating water.

Following the DC testing, alternating currents were imposed on the pipe rig using a standard 120-Volt (breakered at 20 amp) wall-type circuit. Grounding scenarios similar to the DC testing were employed. A summary of actual results from this testing is straightforward: impressed currents, whether AC or DC, had no meaningful impact on the surface potential of the pipe rig regardless of voltage or amperage. Figure 13 summarizes the results of the highest voltage DC and AC tests, demonstrating that these impressed currents did not meaningfully shift the interior surface potentials of the test specimens.

Impressing an AC current, however, does create substantial electrical noise, making it difficult to measure a stable potential. Yet, while the noise effect expanded the range of variability by about 5 mV, the baseline potential did not shift. There is an electrochemical argument to be made about the capacitive effect of an AC current applied across a corrosion scale, yet, if the corrosion potential of the interior surface does not change vis-à-vis the water, capacitance is irrelevant.

From this testing we conclude the obvious: currents flowing in pipe walls take the path of least resistance to ground, producing no change relative to the corrosion potential of the internal surface, whether it be a copper or lead service line.

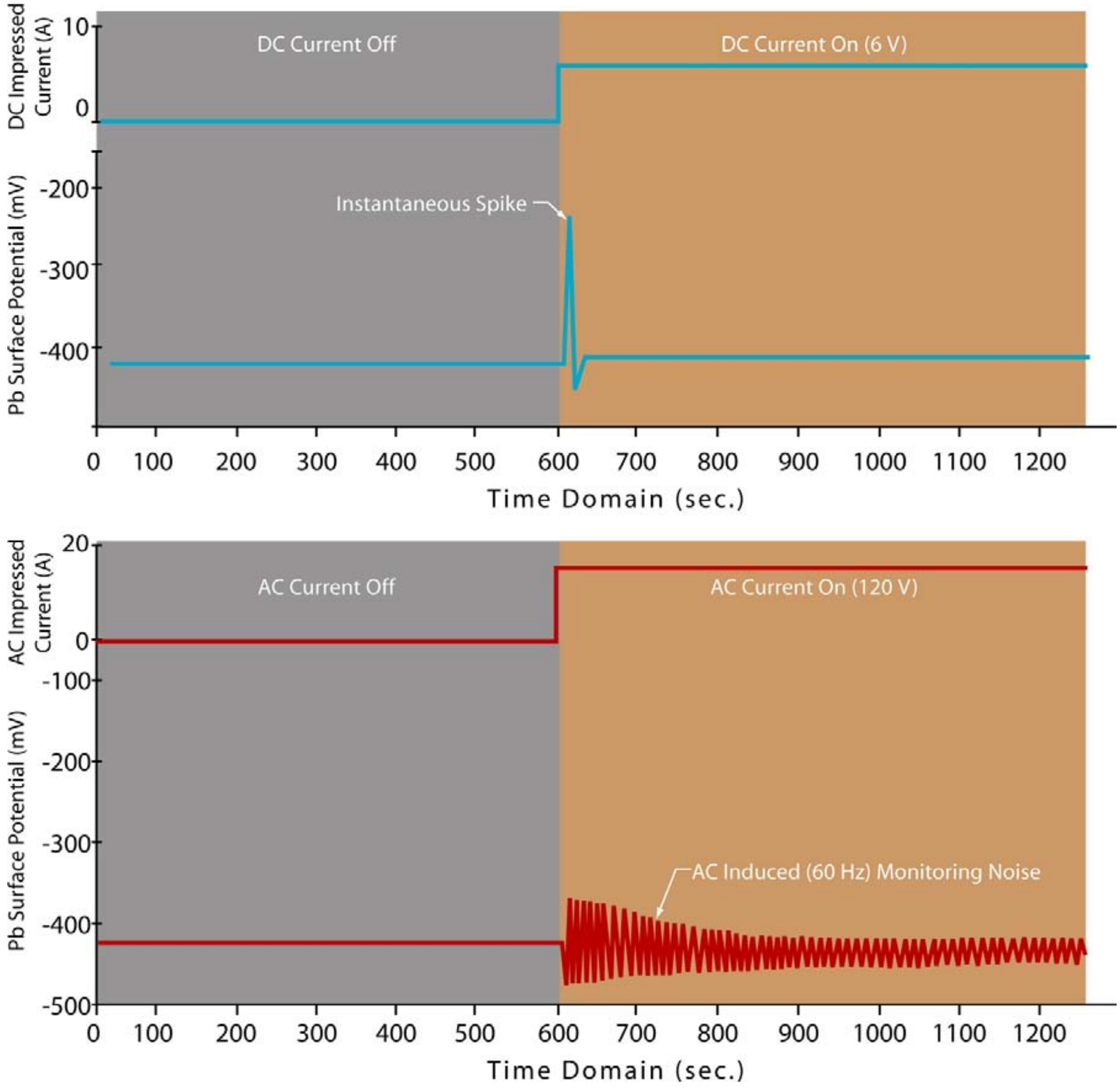

Figure 13. Impressed current impacts (separate DC and AC tests) on surface potential of an LSL coupled to copper tubing.

Observations and Conclusions

This study has shown that grounding and/or impressed currents moving along LSLs, and eventually leaving the pipe to ground, have no meaningful impact on internal pipeline corrosion and do not likely contribute to metals release. Secondly, while the study found that galvanic impacts can be substantial on unpassivated lead surfaces, the magnitude of the impact on aged and passivated LSL surfaces (as well as on copper service lines) is so minimal as to be inconsequential. The study provides a strong basis for discounting claims and concerns relative to accelerated metal release associated with PLSLR. Moreover, we believe that the long-debated controversy about grounding currents impacts can now be considered closed.

The most significant observations to be drawn from this study are summarized below.

Passivation.

Lead is a highly electroactive metal, and in pure form oxidizes extremely rapidly. An unscaled lead surface, even under natural environmental conditions, has an exceedingly high initial corrosion rate. Fortunately, lead also passivates strongly and quickly. Observations in this study suggests that meaningful passivation on LSLs can be achieved within a matter of days. Well-aged DC WASA LSL specimens – especially those that have been exposed to an orthophosphate inhibitor – are exceptionally well passivated and highly resistant to electrical perturbations.

Lead Electrochemistry.

Passivated LSL specimens are highly polarization resistant – meaning that it takes an exceptional surface perturbation to affect the underlying corrosion rate. The actual degree of polarization resistance expressed as a Tafel Value is in excess of 500 - 600 mV per decade of current shift. Overall, this explains, at least in part, why the galvanic coupling has little apparent effect on passivated lead surfaces.

Area of Galvanic Influence.

When coupled to a new length of copper tubing (as in a partial LSL replacement) the area of galvanic influence on a well-passivated LSL is likely limited to less than the first inch of LSL pipe in the immediate vicinity of the coupling. The galvanic area of influence on an unpassivated LSL specimen is larger, but likely limited to the first few inches of pipe in the vicinity of the coupling. As the LSL passivates, the area of galvanic influence decreases rapidly. The period of transition can be as short as a few days under normal distribution system conditions.

A potential reason why galvanic impacts do not generate a more significant corrosion response relates to the respective geometries of the anodic and cathodic surfaces of the pipeline couple. Because sequential pipelines (LSL to copper tubing) are connected at only a single location, only a small portion of the LSL is polarized by the galvanic current. And, given the relatively rapid rate at which both copper and lead surfaces passivate, the duration of the polarization is relatively brief. Hence even the meager galvanic effect, is short-lived.

Cathodic Effect of Copper Pipe.

The cathode/anode ratio on a well-passivated LSL surface is unimportant relative to the galvanic effect. This means that even an exceptionally long length of copper pipe connected to a partial LSL does not elevate the galvanic effect. (It had been argued that long lengths of copper service line connected to short LSL sections would exacerbate the galvanic effect.)

Water Quality and Galvanic Impacts.

A free-chlorine residual does elevate the galvanic effect by accelerating the cathodic current exchange process. Conversely, chloramine has a lesser galvanic impact than free chlorine. The impact overall, however, is largely limited to the galvanic influence on the copper service line. The overall impact on the LSL surface is nearly imperceptible.

Interestingly, water conductivity has a more important effect on the galvanic process than chlorine residual. The area of galvanic influence on the LSL specimen is marginally expanded as the conductivity of the electrolyte (water) increases, while the area of influence on the copper service line is substantially expanded. This is because the higher conductivity lessens the resistance of the electrolyte circuit (water), expanding the “reach” of the galvanic current.

DC WASA distributes a low conductivity water (< 100 microSiemens), which, in part, explains the minimal galvanic impacts observed.

Dielectric Effects.

While galvanic impacts relative to DC WASA PLSLRs are likely minimal, any break in electrical continuity between the copper and LSL lines effectively eliminates the potential for a galvanic effect. In short, a conventional plumbing dielectric junction removes even the minor corrosion risks associated with galvanic coupling.

Impressed Current Effects.

Impressed currents (AC or DC) on LSLs and copper service lines, including grounding type currents, have no impact whatsoever on the internal corrosion of the household service lines (or any other plumbing appurtenance for that matter). There is likely no acceleration of corrosion associated with the conventional practice of electrical system grounding to household water systems.

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