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TECHNICAL REPORT

Demonstration of a Field Rehabilitation Technique for Removing Corrosive Solder Flux in Cold Water Copper Piping Systems

by
O.S. Marshall, V.L. Van Blaricum, R.H. Knoll, V.F. Hock, and J.R. Myers
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13. ABSTRACT (Maximum 200 words)

Premature failures in copper potable water systems are often a direct result of poor installation practices. One practice that can lead to accelerated corrosion and failure of copper piping systems, particularly those used to convey cold water, is the use of excessive soldering flux.

This report evaluates a technique for mitigating corrosion induced by solder flux. The technique involves flushing the affected system with hot water (150 to 170 °F) at a high velocity to remove soldering flux residue that may still be inside the copper tubes and fittings. The technique has been tested at Fort Stewart, GA under the FEAP demonstration program and has been quite successful in mitigating the problem. The technique is ideal for field use since it is relatively simple and does not require removing any piping or destroying walls or floors. It is an environmentally acceptable technique, as it does not require the use of chemicals.

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FOREWORD

This study was conducted for the U.S. Army Center for Public Works (USACPW), under the Facilities Engineering Application Program (FEAP), Work Unit FEAP-MB-F41, "Workmanship Rehab for Copper Piping Systems." The technical monitor is Malcolm McLeod, CECPW-FU-S.

Dr. James R. Myers is a corrosion consultant and the director of JRM Associates, Franklin, OH. The contributions of Chester Neff, Illinois State Water Survey; Mitch Brandt, and Gene Arguelles, USACERL, are gratefully acknowledged. The technical assistance provided by William Timmerman, Headquarters, U.S. Army Forces Command (HQFORSCOM); Ken Snyder, Directorate of Engineering and Housing (DEH), Fort Stewart, GA; and Malcolm McLeod, CECPW-FU-S, was invaluable to the successful completion of this work.

The FEAP demonstration was performed by the Engineering and Materials Division (FM), Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. Paul A. Howdyshell is Chief, CECER-FM, and Dave Joncich is Acting Chief, CECER-FL. The USACERL technical editor was Gloria J. Wienke, Information Management Office.

LTC David J. Rehbein is Commander and Acting Director, USACERL. Dr. Michael J. O'Connor is Technical Director.

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DEMONSTRATION OF A FIELD REHABILITATION TECHNIQUE FOR REMOVING CORROSIVE SOLDER FLUX IN COLD WATER COPPER PIPING SYSTEMS

1 INTRODUCTION

Background

Copper potable water piping systems are expected to have a service life of 100 years with minimal maintenance. In practice, however, some copper piping systems fail much sooner. Such failures are often initiated or accelerated by poor workmanship practices during installation. One practice that has been found to accelerate the failure of copper tubes and fittings in some environments is the excessive use of aggressive soldering fluxes that contain activating agents such as zinc chloride. In use, copper is normally protected from corrosion by a thin film of copper oxide. The activating agents in soldering flux affect and may prevent formation of this protective film under certain conditions, which makes the copper more susceptible to corrosive attack. Water that would normally not be expected to be corrosive to copper may, in fact, be corrosive if soldering flux, containing activating agents such as chlorides, is present.

Headquarters, Forces Command (HQFORSCOM) asked the U.S. Army Construction Engineering Research Laboratories (USACERL) to perform a site survey at several of their facilities to determine relative corrosivity of soil and domestic water. During the survey at Fort Stewart, GA, a severe problem with soldering-flux induced corrosion was identified in the Bryan Village family housing area. This form of corrosion was also identified at other installations, but the problem was not as extensive as at Fort Stewart. The survey revealed that some piping systems in Bryan Village began failing within 3 years of their 1977-1978 installation. The problem rapidly accelerated during the mid-1980s. The majority of failures are occurring in the 750 units in Phase 1 of the development. The problem is just beginning to occur in Phase 2 of the Bryan Village development, which was constructed in 1981-1982. Between October 26, 1987, and April 15, 1988 (172 days), a total of 127 repair calls concerning leaks in Bryan Village were recorded. All but one of the leaks had occurred in domestic cold water systems. The number of leaks repaired by the Directorate of Engineering and Housing (DEH) has drastically increased since April 1988. As of October 1988, the DEH was repairing 100 leaks per month. To combat the rising number of leaks and the high repair cost, the DEH asked USACERL to evaluate and demonstrate a technique for removing excess, aggressive solder flux from the copper piping systems.

Objective

The objective of this work is to field test a backflushing technique for removing excess soldering flux from cold water copper piping systems at Fort Stewart, GA.

Approach

Fort Stewart was selected as the demonstration site because of the great number of family housing units (800) identified as having severe soldering flux-induced corrosion leaks in the cold water service. Laboratory testing was performed to determine the best combination of operating parameters (water temperature and velocity, and flushing time). The technique for in-situ removal of soldering flux by backflushing was performed at the site. Specimens from the site were analyzed before flushing and after flushing. The system is currently being monitored to verify elimination of the problem.

Mode of Technology Transfer

It is recommended that Corps of Engineers Guide Specifications (CEGS) 15400, "Plumbing General," and 15405, "Plumbing Hospital," be revised to allow the use of this backflushing technique for removing corrosive soldering flux residue from cold water copper piping systems. (CEGS 15400 allows liquid form noncorrosive solder fluxer that conform to Copper Development Association (CDA) 1.0, Standard Test 1 and American Society for Testing Materials B 32 95-5.) It is also recommended that a technical note describing the technique be published. A one-page FEAP ad flyer describing the technique and suitable applications, and a FEAP Users Guide will be prepared.

2 INVESTIGATING SOLDERING FLUX CORROSION

Researchers at USACERL began investigating the severe corrosion problems in copper potable water piping systems at Fort Stewart in 1985. Two investigations were conducted before it was ascertained that the persistent failures were being caused primarily by the presence of soldering flux residue in the systems. The investigations are discussed in the following paragraphs.

1985 Investigation

In November 1985, researchers removed three copper tube/fitting specimens from buildings at Fort Stewart. One copper water tube specimen was taken from the domestic cold water system at Wynn Army Hospital (specimen 2) and two copper water tube specimens were taken from the domestic cold water systems of two family housing units in Bryan Village (specimens 1 and 3). Pinhole leaks had occurred in specimens 1 and 2. Specimen 2 had been in service for less than 2 years when the leak occurred. The problem seemed to occur almost exclusively in cold water copper systems; very few problems occurred in other areas of Fort Stewart, even in buildings with 40-year-old piping systems.

Researchers collected samples of the potable water conveyed by the system. Dissolved oxygen, dissolved carbon dioxide, pH, temperature, and sulfide content of the water were measured on site. Further chemical analysis of the water was performed in the laboratory; results are shown in Table 1. Based on this analysis, the water at Fort Stewart is not expected to be corrosive to copper or its alloys. However, once the pitting attack of copper has been initiated by corrosive soldering flux, the dissolved oxygen content (1 to 3 mg/L) of the water will assist in growth of the pit.

Table 1

Site Water Chemistry

Parameter	Value
Temperature (°C)	23
pH	7.2
Dissolved CO_2	8
Dissolved O_2	3
Chloride	12
Sulfate	8
Alkalinity (as $CaCO_3$)	100
Total Dissolved Solids	178
Hardness (as $CaCO_3$)	92
Calcium	18
Magnesium	8.8
Zinc	0.02
Iron	0.02
Copper	0.16
Manganese	<0.01
Sodium	16
Silicon (as SiO_2)	31

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*Units are mg/L unless otherwise noted.

A visual examination of the external surfaces of the specimens revealed no significant degradation by the external environment (Figures 1 and 2). The external surfaces of each specimen were covered with a protective tarnish film of reddish-brown cuprous oxide (CuO_2). As stated earlier, pinhole leaks had occurred in two of the specimens. Stereomicroscopic examination of the interior surfaces of the specimens showed that the pinhole perforations had initiated on the water (internal) side of the pipes.

Many corrosion-induced pits (areas of localized corrosion) existed on the internal surface of specimen 1 (Figure 3). The pits contained porous, reddish-brown cuprous oxide. The pitted areas were overlaid with friable (easily crumbled by hand), relatively voluminous tubercles of greenish-colored copper corrosion products. Most of the pits existed within a 0.2 to 0.4-in. wide strip that extended the entire length of the specimen. It is likely that the strip was a soldering-flux run. Energy dispersive spectroscopy (EDS) and microchemical analysis revealed that the greenish-colored tubercles contained copper, iron, and silicon. Traces of calcium, aluminum, and phosphorus were also found. The tubercles consisted primarily of basic copper carbonate (malachite). The pitted areas underneath the tubercles contained major quantities of copper and minor quantities of sulfur (as sulfide) and calcium. Chloride was found in the pits in specimen 1. This supports the hypothesis that the strip was a soldering flux run, since soldering fluxes commonly contain activating chlorides such as zinc chloride. As previously stated, chloride ions affect and may prevent the formation of the film of copper oxide that normally protects copper from corrosion. Consequently, the presence of chloride ions may make the copper more susceptible to corrosive attack.

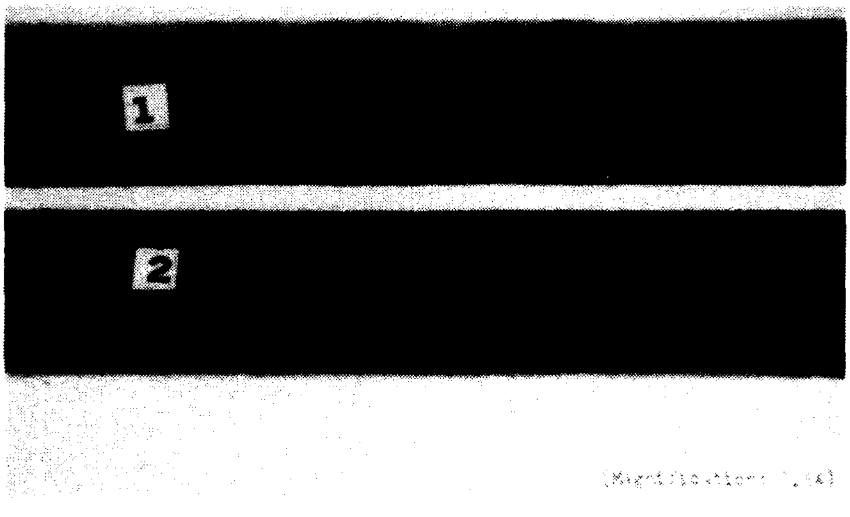


Figure 1. External Surfaces of Specimens 1 and 2.

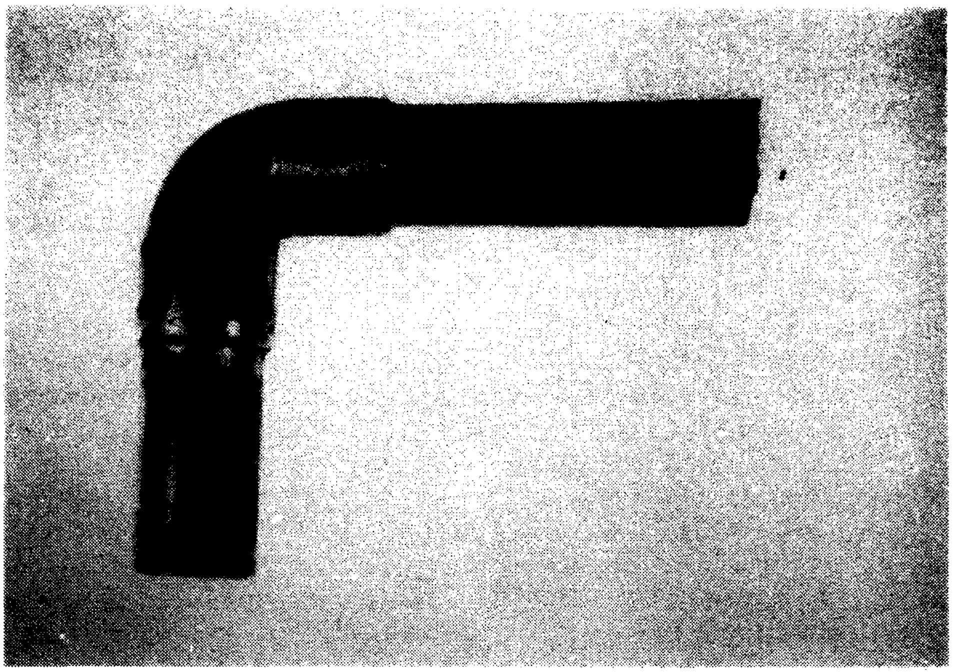
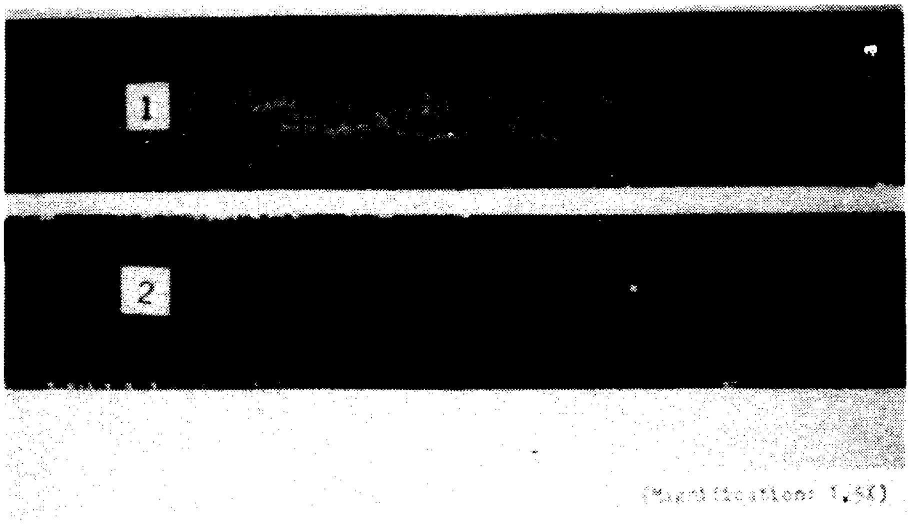


Figure 2. External Surface of Specimen 3.



(Magnification: 1.5X)

Figure 3. Internal Surfaces of Specimens 1 and 2.

Corrosion-induced pits in specimen 2 (Figure 3) also contained reddish-brown cuprous oxide and were generally overlaid with friable, greenish-colored, voluminous tubercles. EDS results were similar to those for specimen 1.

Specimen 3 (Figure 4) contained a strip similar to specimen 1. Again, corrosion-induced pits contained reddish-brown cuprous oxide and were overlaid with friable, greenish-colored tubercles. Chemical composition of the deposits was similar to that of specimens 1 and 2. Zinc and chloride were also found in the corrosion products, which confirmed the belief that soldering flux was involved in the corrosion process.

In all three specimens, the area where pitting attack had not occurred was covered with a protective tarnish film of reddish brown to nearly black cuprous oxide. This film was generally overlaid with a thin layer of friable, greenish-brown products, which was a deposit from the water. Measurements in the areas where pitting had not taken place confirmed that the specimens still satisfied the wall thickness requirements set forth in American Society for Testing and Materials (ASTM) Standard Specification B88 for Seamless Copper Water Tube.

In summary, the 1985 study found that the corrosion problems in the analyzed specimens resulted from soldering flux residue. USACERL recommended that plumbers working on the base be encouraged to use industry standard practices when installing copper piping systems. For example, excessive flux and the use of unusually-aggressive fluxes (especially certain self-cleaning fluxes) must be avoided. Adhering to the general guidelines for tube installation, joint preparation, and soldering presented in the Copper Development Association's *Copper Brass Bronze Product Handbook* "Copper Tube for Plumbing, Heating, Air Conditioning and Refrigeration" could probably assist in preventing the recurrence of soldering flux-induced leaks.

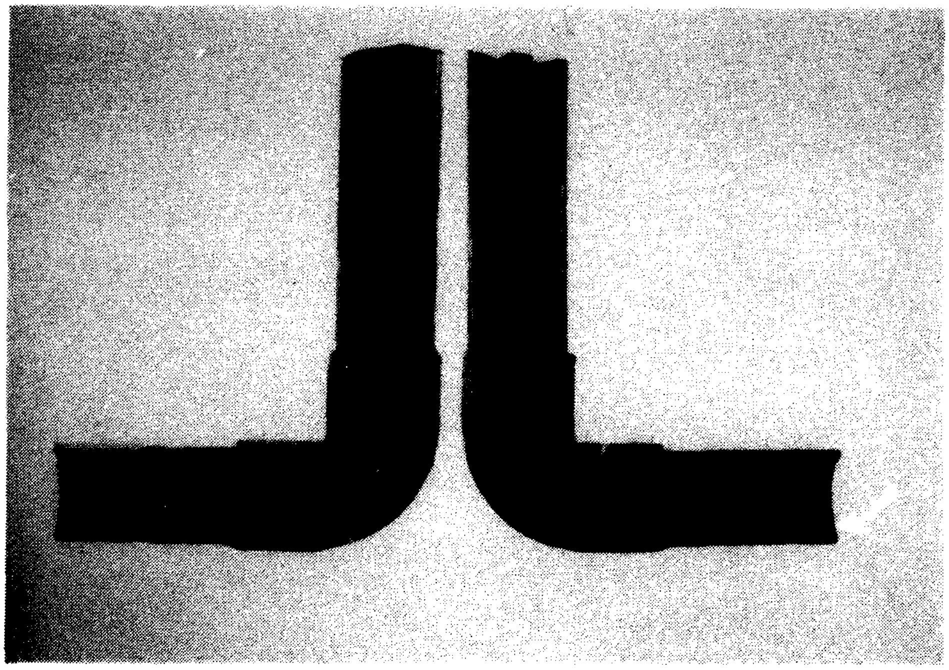


Figure 4. Internal Surface of Specimen 3.

1987 Investigation

Another investigation was performed in 1987 to verify that the leaks in the potable cold water copper piping were corrosion induced. In October 1987, researchers removed six copper tube/fitting specimens from domestic cold water systems in Bryan Village where leaks were continuing to occur. The specimens had been in service for approximately 8 years.

A visual examination of the external surfaces of the specimens revealed no significant degradation by the external environment (Figure 5). The external surfaces of each specimen were covered with a protective tarnish film of reddish-brown cuprous oxide. Pinhole leaks had occurred in two of the specimens. Stereomicroscopic examination of the interior surfaces of the specimens showed that the pinhole perforations had initiated on the water (internal) side of the tubes.

The specimens were sectioned lengthwise and their water-side surfaces were examined (Figures 6 and 7). The perforation in specimen 6 had been caused by erosion corrosion (accelerated attack related to localized, high velocity water inside the system). Most significant was the observation that soldering flux-related corrosion had occurred in all six of the specimens. Typically, the areas of corrosive attack were covered with voluminous, friable mounds of greenish-colored copper corrosion products. Porous cuprous oxide existed in the pits underneath these corrosion products. Sticky, petroleum-based soldering flux was found on the water-side surfaces of specimens 1 and 3. EDS analysis supported the belief that the localized corrosion had been induced by soldering flux; chlorides were found in the copper corrosion products. As discussed earlier, soldering fluxes typically contain activating chlorides. In addition, EDS analysis revealed the presence of lead and tin in the soldering flux runs, which indicated that a paste type solder (finely granulated solder suspended in a paste flux) had been used when the tubes and fittings were installed. On areas of the water-side surfaces where corrosion had not taken place, the copper was covered with a protective tarnish film of reddish-brown cuprous oxide. In general, the film was overlaid with a

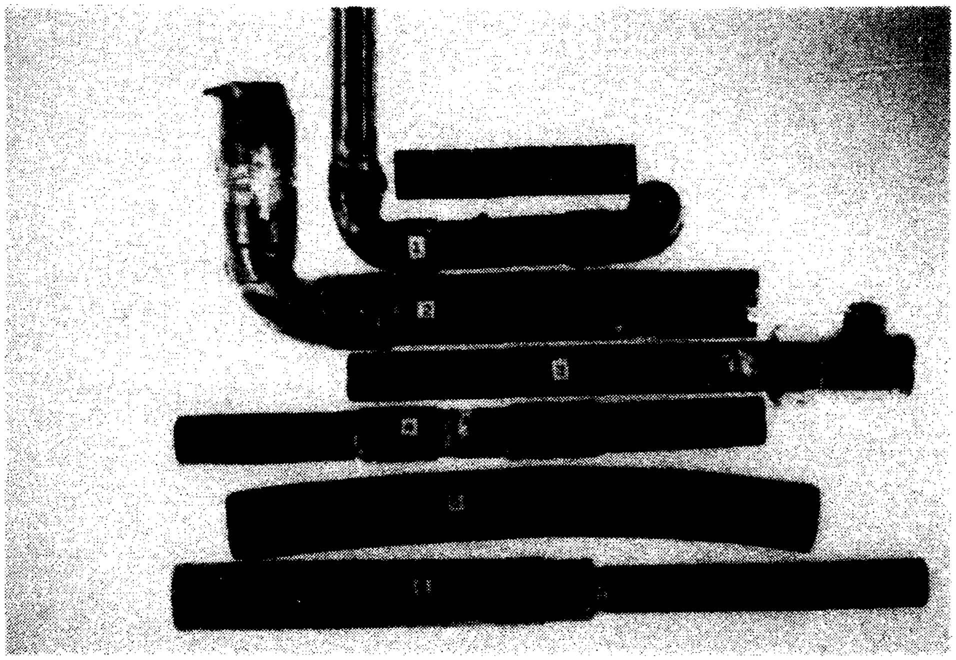


Figure 5. External Surfaces of Specimens From 1987.

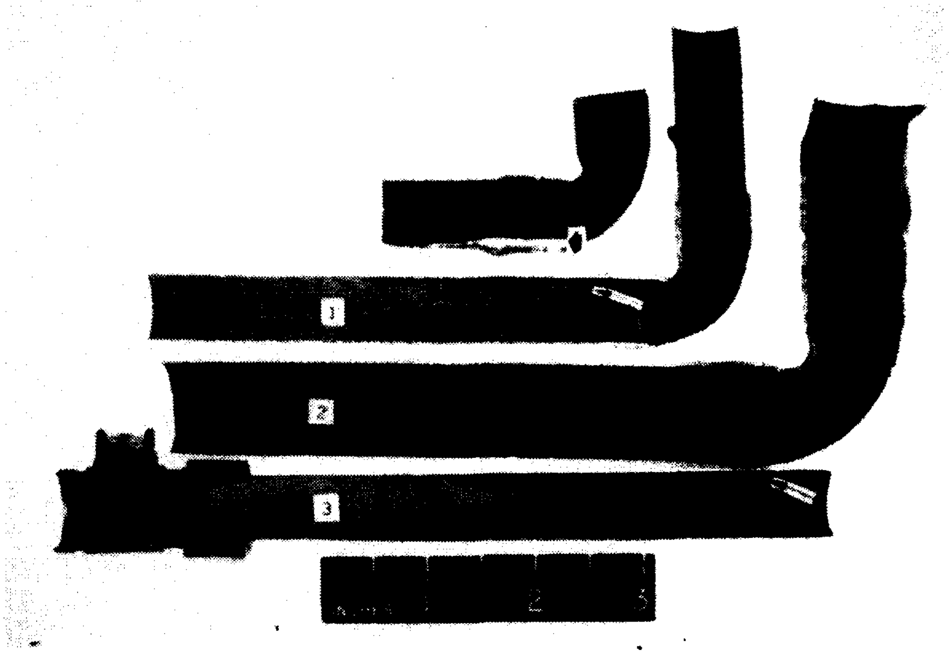


Figure 6. Internal Surfaces of Specimens 1, 2, and 3.

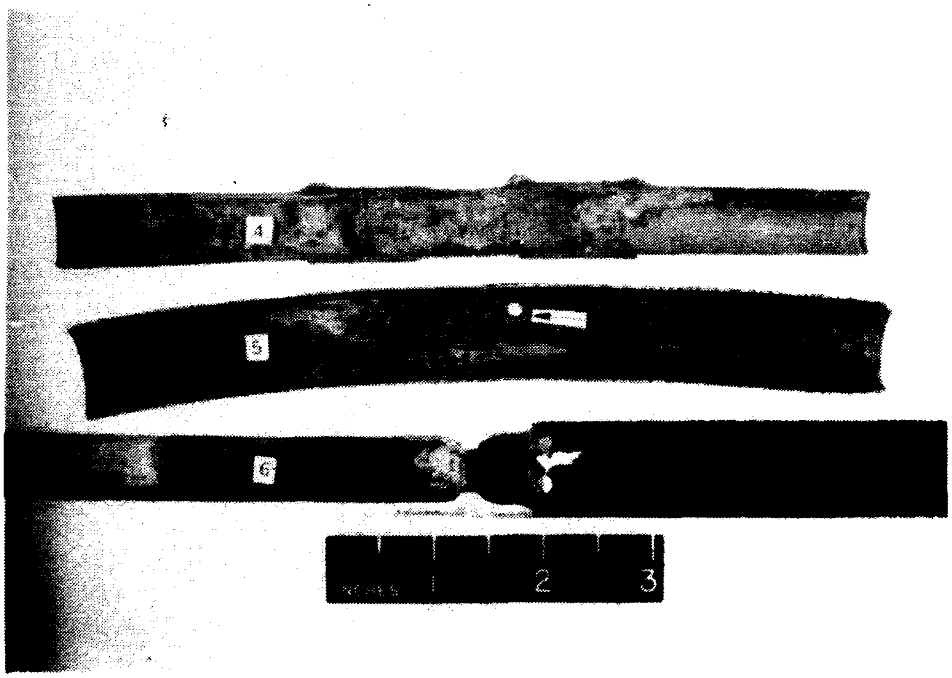


Figure 7. Internal Surfaces of Specimens 4, 5, and 6.

thin layer of greenish-colored copper corrosion products that appeared to be a deposit from the water. It is likely that the source of the greenish-colored products was the soldering flux-induced corrosion of copper occurring upstream in the system.

After this study, it was concluded that the primary cause of Fort Stewart's corrosion problem in domestic cold water piping was the presence of soldering flux residue on the interior surfaces of the copper tubes and fittings. This conclusion was supported by the following facts: (1) soldering flux runs were found in almost all of the specimens that were analyzed in both investigations; (2) chlorides were found in the corrosion products; (3) the pitting corrosion problem only seemed to manifest itself in cold water piping systems (hot water tends to flush away the excess flux over time); and (4) the amount of time from system installation to failure was typical for pipes undergoing flux-induced corrosion.

1991 Statistical Investigation

During the return trip to Fort Stewart in August 1991, data from service calls for leak repairs from buildings in series 6900 through 7400 were collected. Table 2 lists the age of each series. The data spanned the period from October 17, 1988 to August 1991. This data was then analyzed for the first five buildings used in the demonstration field test searching for their leak history and also the total number of leaks experienced by the building series during the 4 years. A plot of the number of leaks versus time shows that the number of leaks in 1990 was greater than 1989. Based on the data through August, it is believed that the number of leaks in 1991 will be greater than in 1990. Figures 8 through 13 show the number of leaks for each building series. The fact that the number of leaks at Fort Stewart is growing each year indicates that solder flux corrosion is still a major problem. When the age of building series is compared to the number of service calls for leaks it can be seen that the older series, such as the 7300's and 7400's, has the largest number of leaks per month. Figures 14 through 19 show the frequency of service calls for each building series.

Table 2

Age of Building Series

Facilities	Year Built
6900-6999	1976
7400-7457	1977
7340-7391	1977
7300-7330	1978
7200-7299	1978
7102-7134	1980
7140-7153	1983
7001-7023	1984
7024-7030	1984
7031-7075	1986

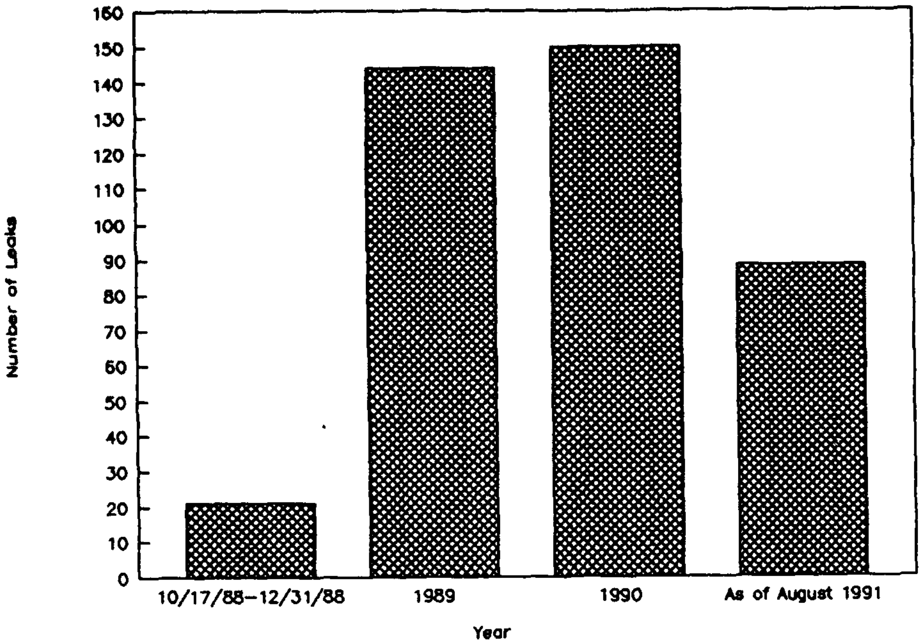


Figure 8. Total Number of Leaks per Year for Series 6900.

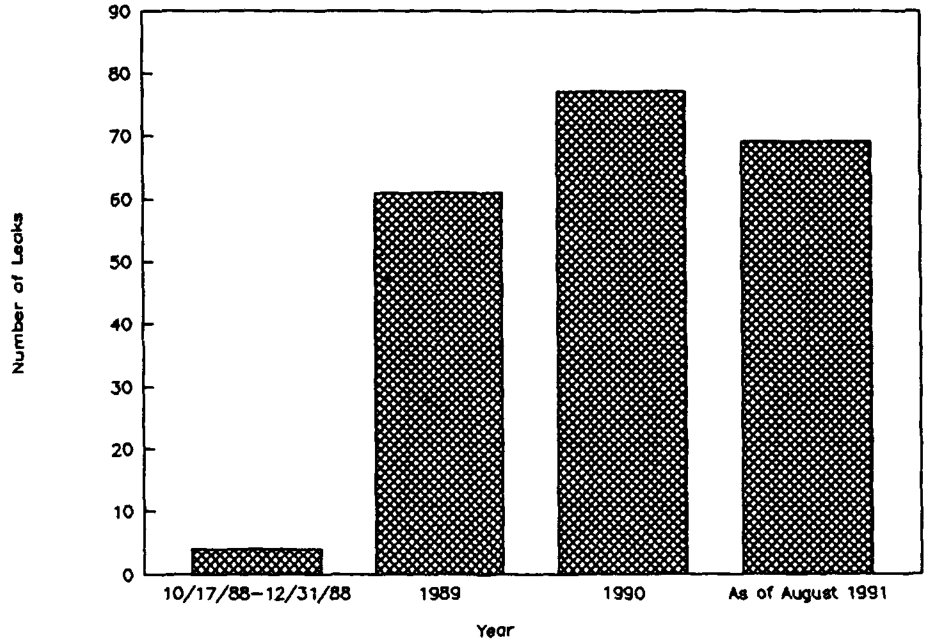


Figure 9. Total Number of Leaks per Year for Series 7000.

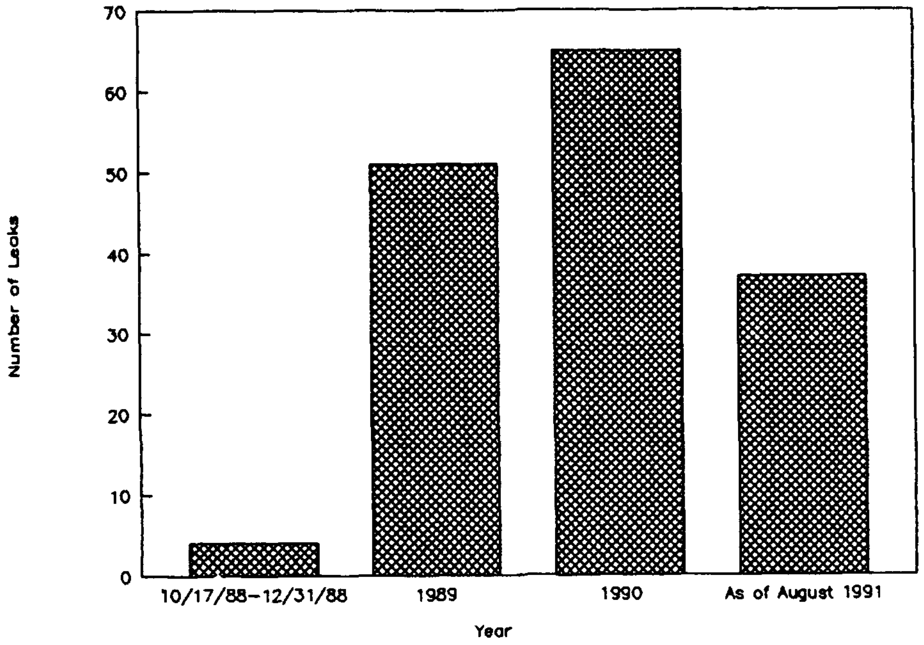


Figure 10. Total Number of Leaks per Year for Series 7100.

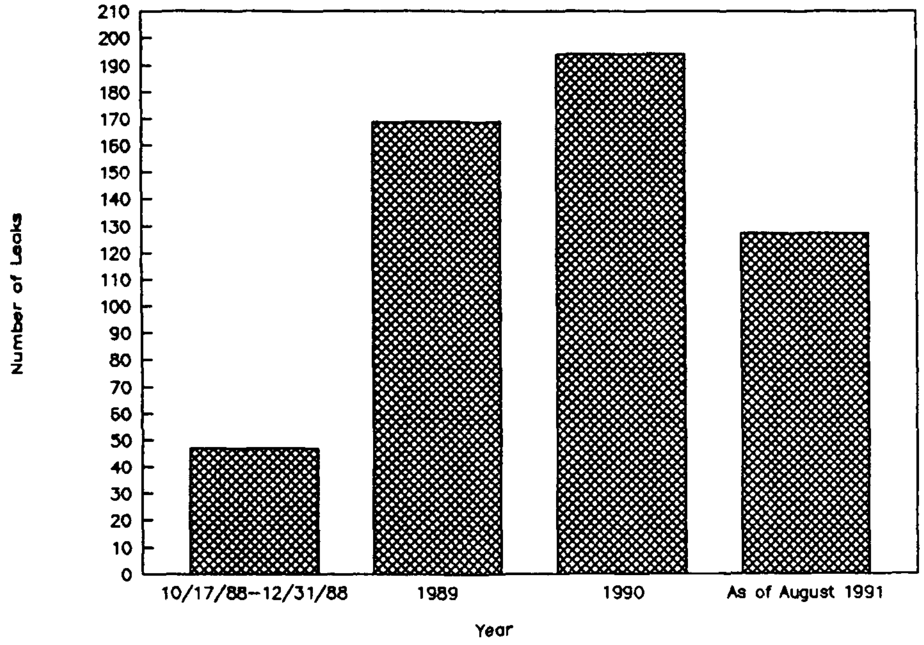


Figure 11. Total Number of Leaks per Year for Series 7200.

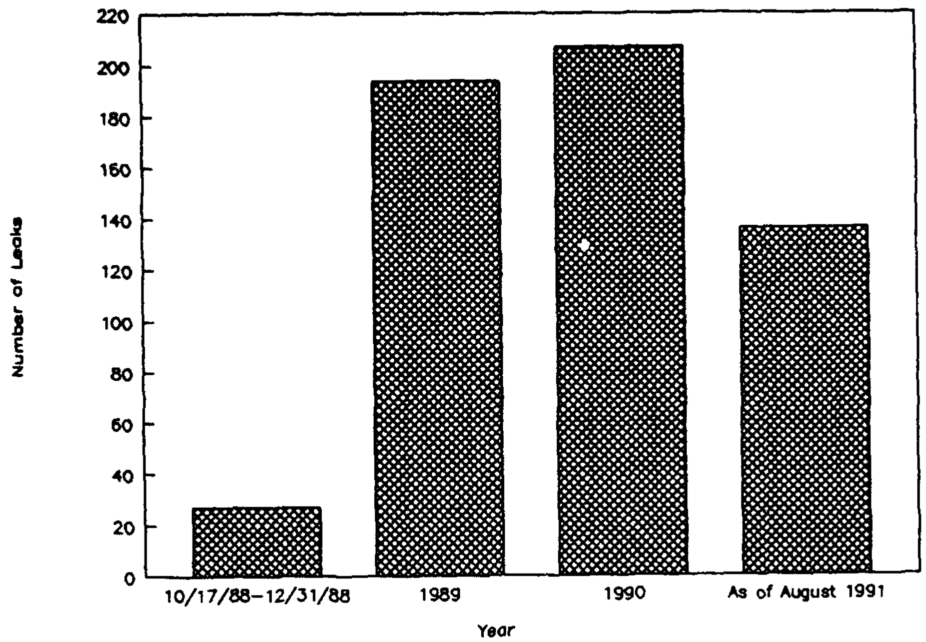


Figure 12. Total Number of Leaks per Year for Series 7300.

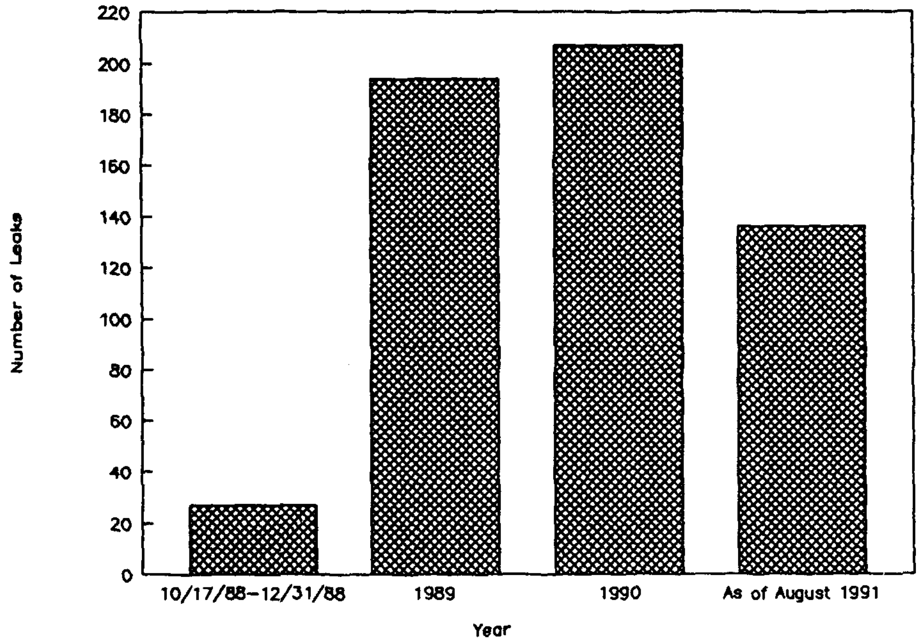


Figure 13. Total Number of Leaks per Year for Series 7400.

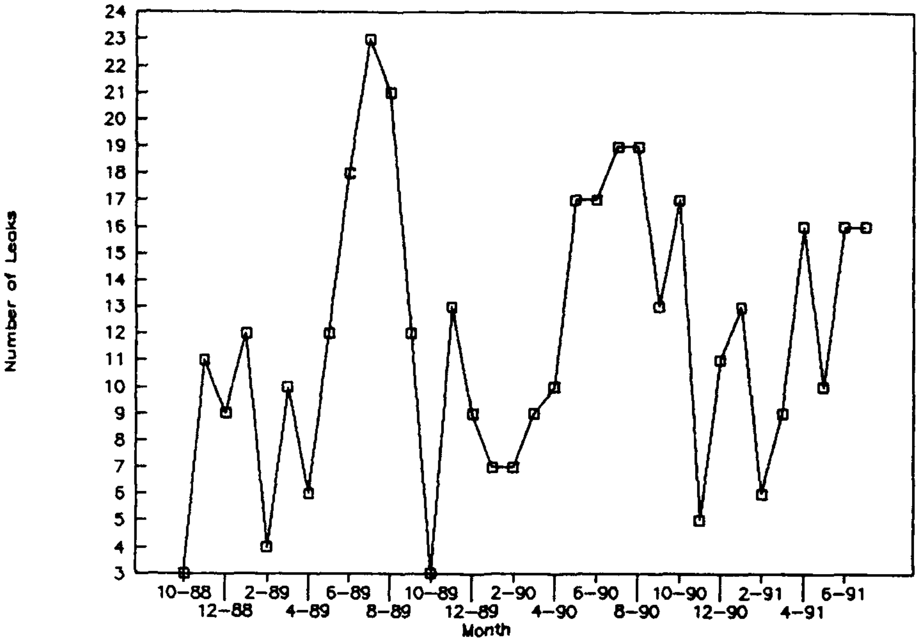


Figure 14. Frequency of Service Calls for Series 6900.

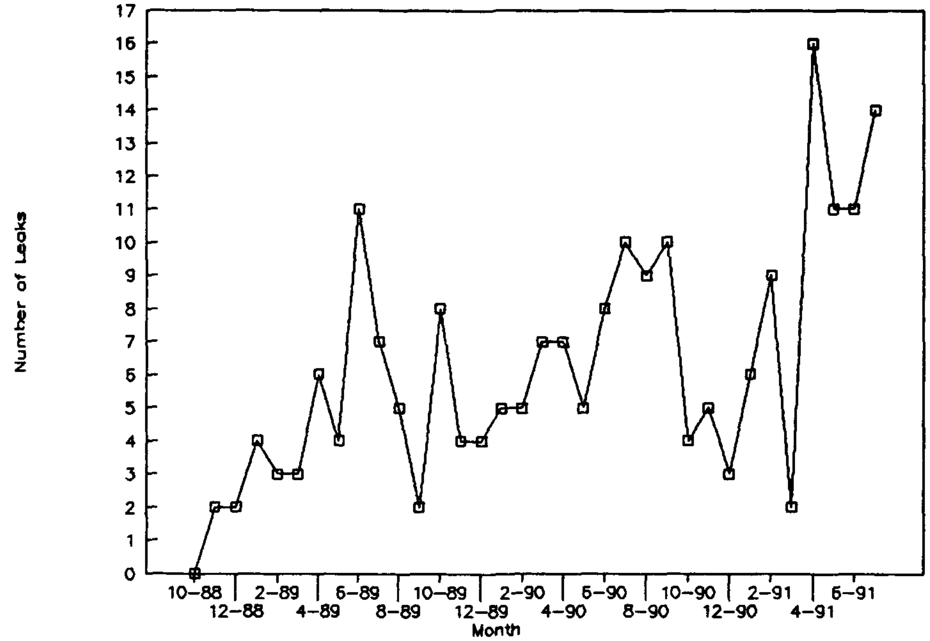


Figure 15. Frequency of Service Calls for Series 7000.

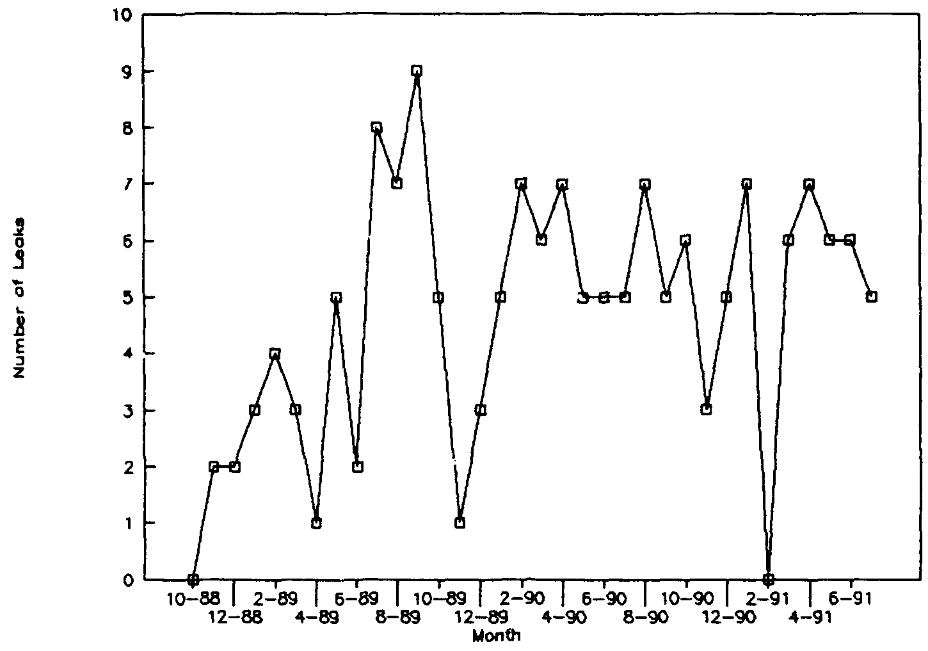


Figure 16. Frequency of Service Calls for Series 7100.

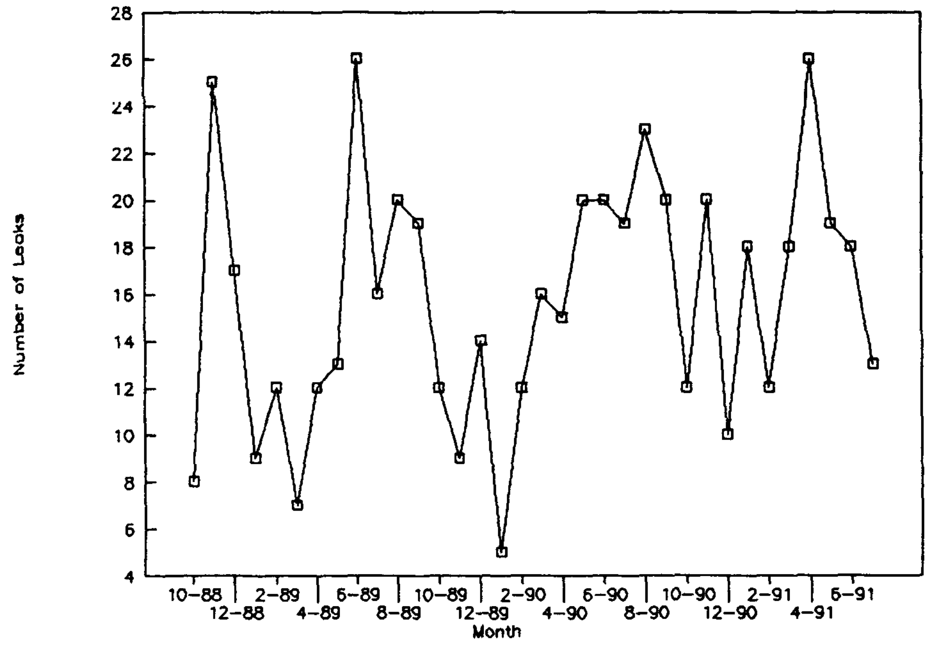


Figure 17. Frequency of Service Calls for Series 7200.

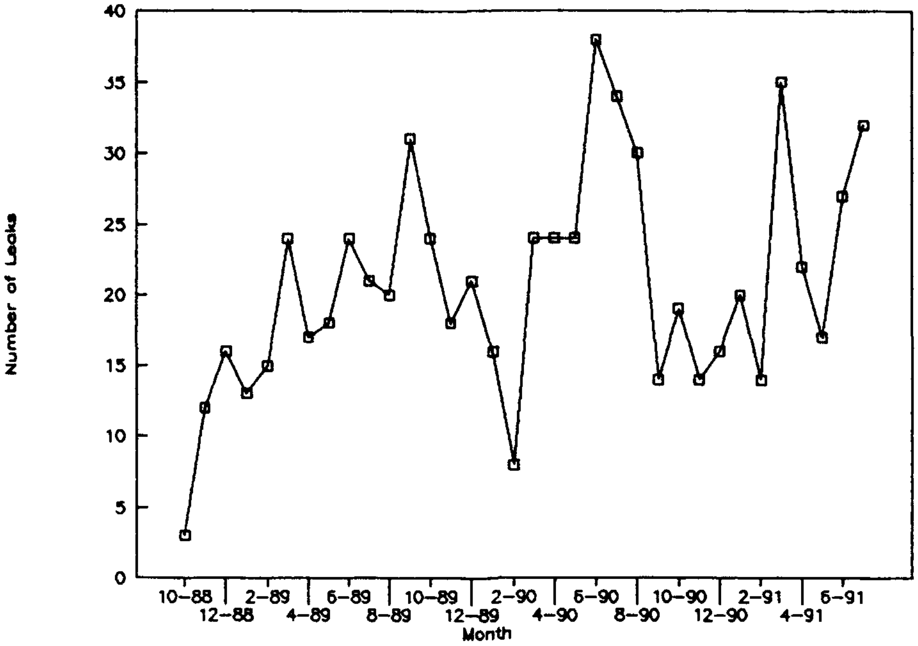


Figure 18. Frequency of Service Calls for Series 7300.

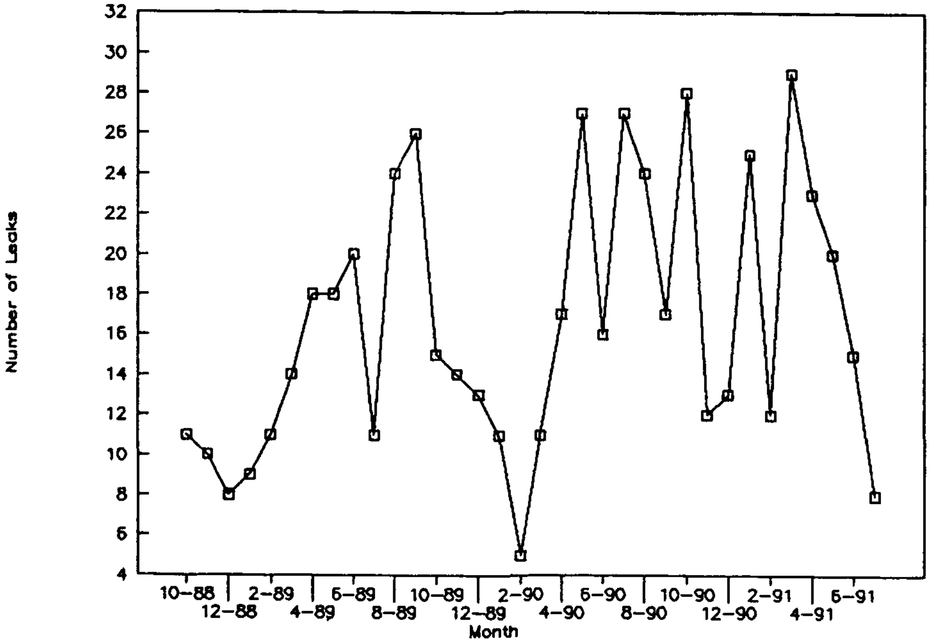


Figure 19. Frequency of Service Calls for Series 7400.

3 LABORATORY TESTING OF THE REHABILITATION TECHNIQUE

After the field investigation, the failure rate of copper piping systems at the installation accelerated. As many as five failures per day were reported in the affected housing area. Almost all the leaks occurred in domestic cold water systems. In the past, the only alternatives in a situation such as this were to repair the pipes as needed or replace the entire piping system.

Clearly, a rehabilitation technique was needed to remedy the problem of soldering flux residue in copper piping systems. The problem rarely occurs in hot water systems because hot water eventually flushes the excess soldering flux away, thereby preventing flux-induced corrosion. It was proposed that flushing a cold water system with very hot water at a high velocity for a short period of time would remove all or most of the soldering flux residue in the system. The proposed flushing technique would be ideal for use in the field since it is relatively simple, does not require the use of chemicals, and does not require removing any piping or destroying any walls or floors.

Optimization Procedures

The proposed flushing technique was tested in the laboratory to: (1) determine its effectiveness in removing soldering flux from the water-side surfaces of copper tubes/fittings, and (2) determine optimal operating parameters. The operating parameters tested included water temperature, water velocity, and flushing time.

Laboratory Setup

Sixteen copper pipe test loops were constructed using both 1/2- and 3/4-in.* type M copper tubes and fittings as shown in Figure 20. Each joint was soldered using a lead/tin solder and 0.25 ounces of a Type I soldering flux in paste form. The flux was a petroleum-based mineral grease (72 to 80 percent) containing zinc chloride (20 to 25 percent) and other chlorides and ammonium salts (3 percent). Each test loop was comprised of four joint subsections, which were attached using quick-release hose clamps. This setup was used to allow the removal of joints at certain times during the flushing process. Each of the joint subsections consisted of a type M copper elbow and two 6-in. lengths of 1/2- or 3/4-in. type M copper tube as shown in Figure 21.

The experimental apparatus is shown schematically in Figure 22. Three coil-heated pressure washers were used to provide an adequate water flow rate within the required temperature range. The use of a line thermometer and diaphragm flow meter allowed the monitoring and control of the flow rate and water temperature during the test. A type M copper inlet flow pipe was installed immediately upstream of the test loop. The inlet pipe was three times the length necessary for fully developed flow (characteristic length) at the lowest flow rate tested to negate the effects of changing the length of the test loop during each experiment.

Laboratory Procedure

Temperature, fluid flow rate, and time were tested in various combinations to determine the combination that would minimize the cost of the cleaning supplies and the time necessary to adequately clean the system. Each copper test loop was tested separately for 5 hours as described in the following paragraphs. A total of sixteen different cases were tested.

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*A metric table is on page 48.

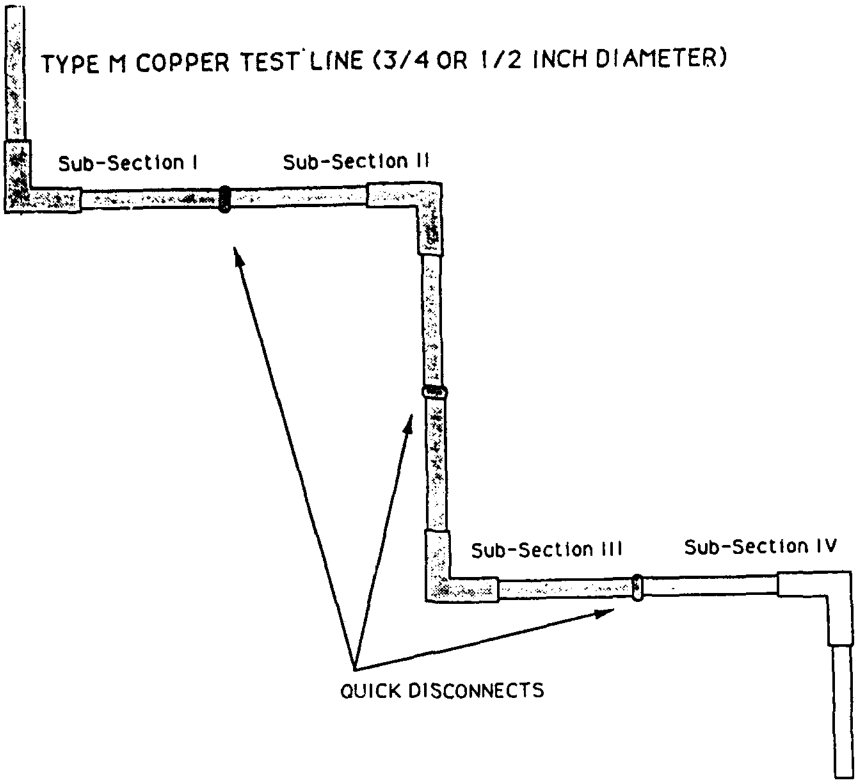

Figure 20. Copper Test Loop Schematic.

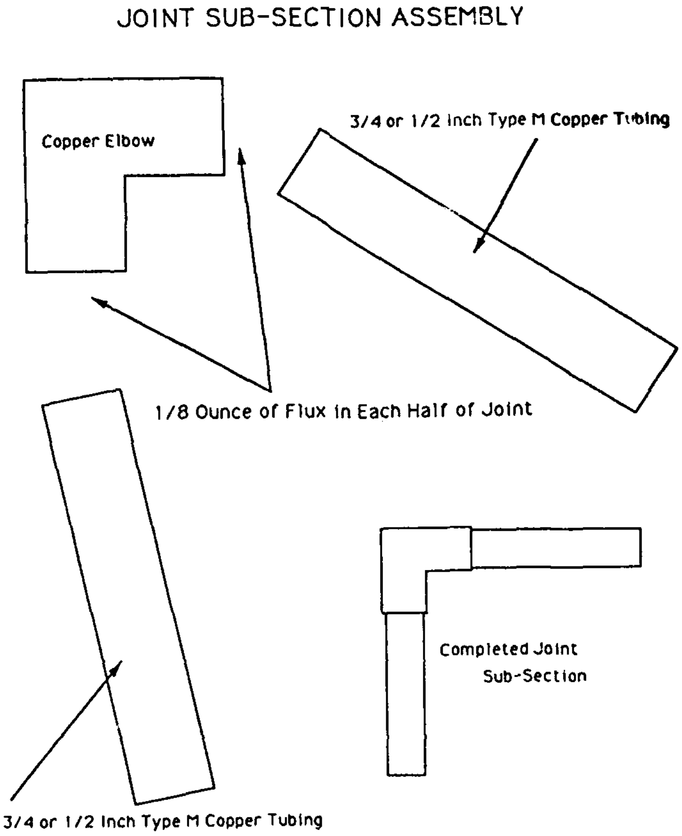

Figure 21. Copper Joint Subsection Schematic.

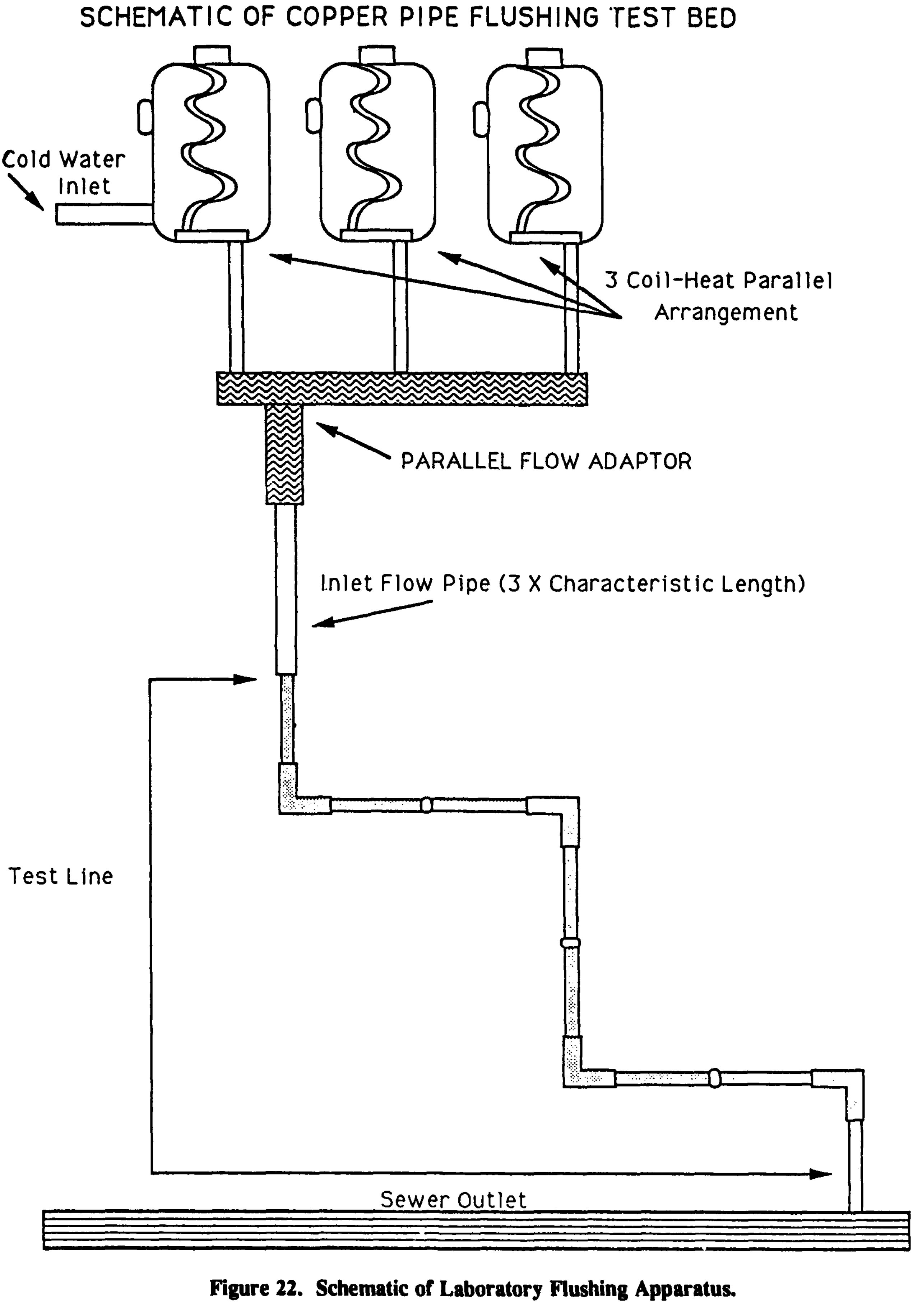

Figure 22. Schematic of Laboratory Flushing Apparatus.

At the beginning of each run, one copper test loop was connected to the experimental apparatus. A control sample of deionized water was taken from the test supply to establish a baseline chloride level in the deionized water being used.

Following these initialization procedures, the test loop was filled with deionized water at 70 °F and allowed to sit undisturbed for 20 minutes. The water was then drained from the test loop into a specimen container, capped, and marked as a T_0 specimen. The water specimen containers had been rinsed with a concentrated hydrochloric acid solution to remove any residual chlorides and then rinsed with deionized water. Also at this point, one of the copper joint subsections was removed and marked for later analysis. The loop was reconnected and hot water was then allowed to flow through the test loop at the designated temperature and flow rate for 1 hour. After 1 hour, hot water flow was stopped and the test loop was drained and then filled with deionized water at 70 °F. After a 20-minute period, this water was drained into another specimen container, capped, and marked. One of the copper joint subsections was removed and marked. The loop was reconnected and hot water was allowed to flow through the loop again at the designated temperature and pressure. The process of filling the loop with deionized water, collecting it after 20 minutes, and removing a joint subsection was repeated at the 3-hour point and at the 5-hour point. The above procedure was performed using flushing temperatures of 120 °F, 140 °F, 160 °F, and 180 °F. Flow rates of 7.5 gallons per minute and 11.5 gallons per minute in both the 1/2-in. and 3/4-in. loops were tested at each of the four temperatures.

To determine the effectiveness of the flushing technique, the chloride ion concentration was measured in each of the water samples taken before and during the flushing process. Chemical analysis was performed using titration with 0.025N $AgNO_3$ (silver nitrate), using K_2CrO_4 (potassium chromate) indicator (using ASTM D512-89, "Standard Test Methods for Chloride Ion In Water," *1992 Annual Book of ASTM Standards*).

Laboratory Test Results and Discussion

The chloride ion concentrations in the samples taken at 1, 3, and 5 hours were compared with the chloride ion concentration in the T_0 sample for each run. The average baseline chloride ion content obtained from the control specimens of deionized water was subtracted from each of the chloride ion measurements. The results of the flushing (Table 3) are expressed as a percent reduction in chloride ion content as compared with the T_0 concentration. The results are shown graphically in Figures 23 through 26.

The experimental results suggest that above 140 °F, the water temperature does not play a dramatic role in the flushing efficiency. The results also show, as expected, that a higher flow rate and higher velocity result in a more thorough flushing. A trend is also seen in the chloride ion removal between the first and third hours. Generally, there is a significant decrease in the ion content between the first and third hours, and a less significant decrease between the third and fifth hours.

The hot water flushing technique is successful in removing more than 90 percent of the soldering flux residue from copper tube/fitting systems. Based on the experimental results and the commercial availability of a product capable of meeting the parameter requirements, a flow rate of 11.5 gallons per minute at a temperature of 140 °F or above should be used. The piping system should be flushed for at least 3 hours, or longer if time and facilities permit.

Table 3

Experimental Results

Hour	120 °F	140 °F	160 °F	180 °F
3/4-in. pipe, 7.5 gal per minute				
1	87.71	94.76	96.66	95.48
3	95.48	96.65	96.65	97.47
5	96.56	98.91	98.91	09.91
3/4-in. pipe, 11.5 gal per minute				
1	96.57	97.28	96.20	97.28
3	98.19	98.19	98.55	98.55
5	98.92	98.55	98.55	99.09
1/2-in. pipe, 7.5 gal per minute				
1	85.54	94.48	95.30	97.29
3	97.83	97.74	98.20	98.55
5	98.37	98.73	98.73	98.73
1/2-in. pipe, ll.5 gal per minute				
1	95.66	96.92	98.55	94.58
3	98.01	98.19	98.6 4	98.91
5	98.92	98.73	98.92	99.09

*Percentages of chloride ion removal are given (compared to the specimen taken at T_0).

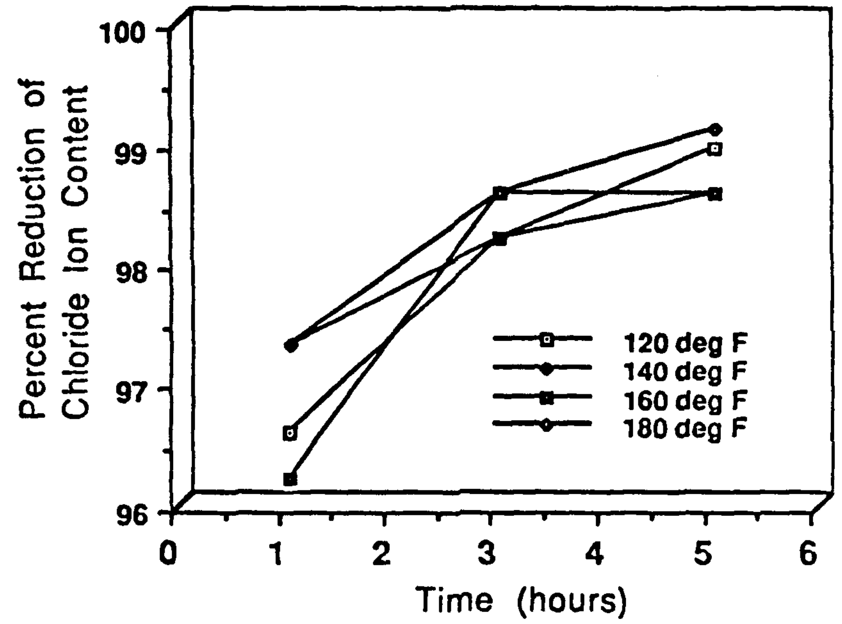

Figure 23. 3/4-in. Test Loop at 11.5 Gallons per Minute.

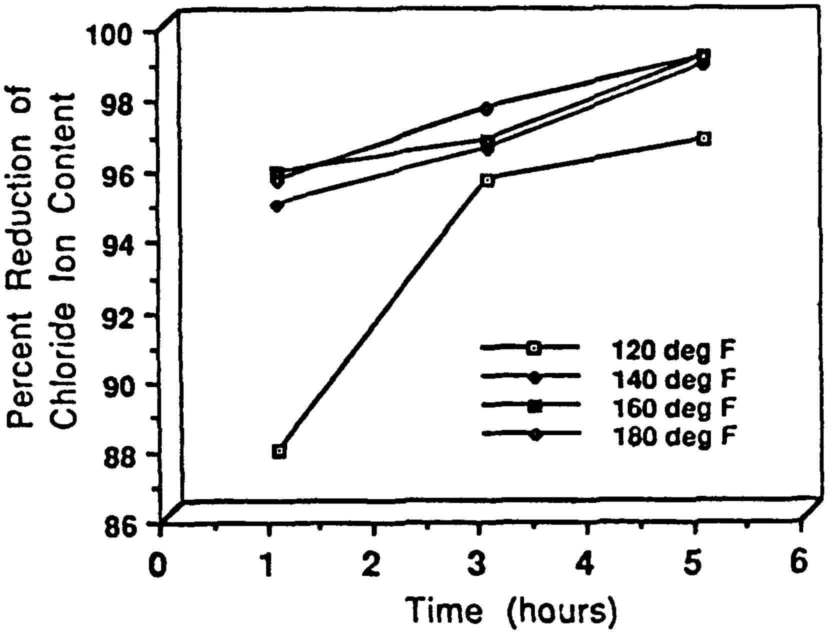

Figure 24. 3/4-in. Test Loop at 7.5 Gallons per Minute.

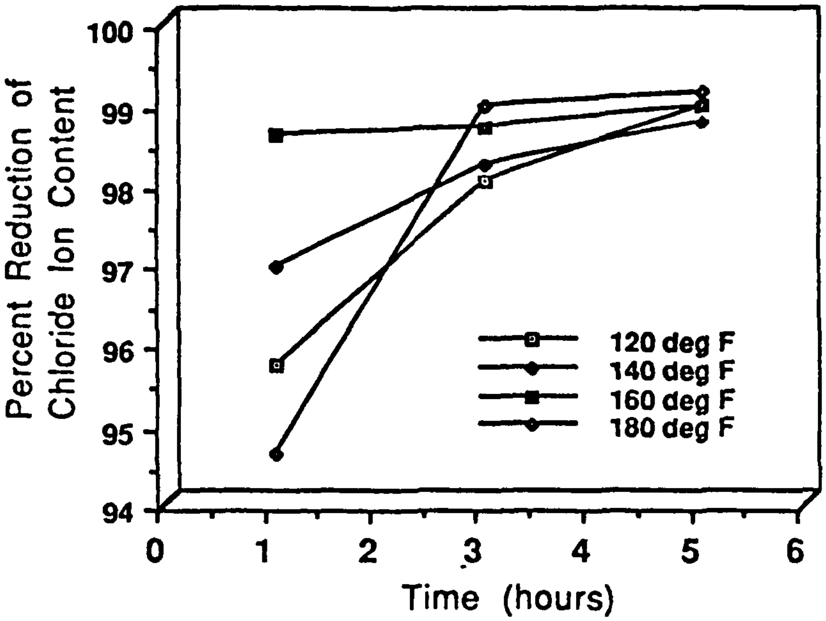

Figure 25. 1/2-in. Test Loop at 11.5 Gallons per Minute.

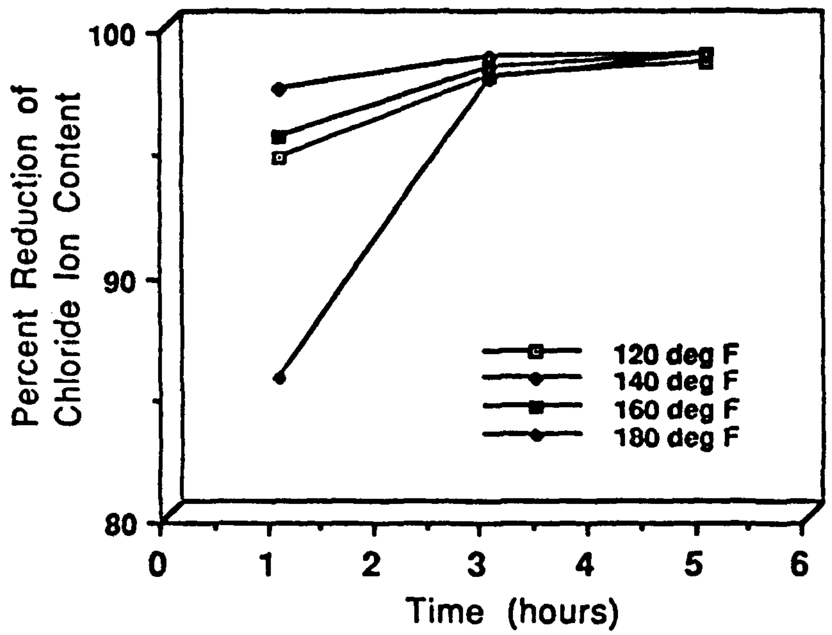

Figure 26. 1/2-in. Test Loop at 7.5 Gallons per Minute.

4 FIELD TESTING THE HOT WATER FLUSHING TECHNIQUE

After a successful laboratory test, researchers decided to field test the technique on several of the buildings in the problem area at Fort Stewart. A total of 15 family housing units were included in the initial field test of the rehabilitation technique. Of those 15 units, 5 were randomly selected for in-depth evaluation of the technique's effectiveness. The test was conducted from November 14 to November 30, 1989.

Field Test Setup

A trailer mounted, self contained, portable hot water generator was constructed to provide the water flow and temperature needed for the flushing technique (Figure 27). The heart of the generator was a model CWH-1510 diesel-fired boiler produced by Columbia Boilers. (See Appendix A for boiler layouts.) The boiler was rated to provide a continuous temperature rise of 100 °F at an incoming water flow rate of 25 gallons per minute. In addition to the boiler and a 110-gallon fuel storage tank for the boiler, the generator contained a TACO CM1207 pump with a 4.9-in. impeller and a 3 horsepower, 240 volt, 3500 RPM (revolutions per minute) motor to provide the water velocity needed. The incoming water supply was through a 2½-in. diameter fire hose from a fire hydrant. The hot water was supplied to the housing units through a 1¼-in. diameter high pressure hose.

Field Test Procedure

To prepare for flushing, the service water to the housing unit was turned off. A copper tee was installed on the cold water inlet line to the unit's hot water heater with a shoulderless coupling and the female thread on the outlet. The supply hose from the hot water generator was then attached to the couple. Before beginning to flush the pipes, all aerators were removed from the faucets in the kitchen and lavatories and the flush valves in the water closets were removed or propped open. The boiler input hose was attached to the nearest fire hydrant and the pump's electrical extension cord was plugged into the unit's dryer outlet. A hose was run from the washing machine cold water supply bib to the drain and all faucets in the unit were opened. The water was then turned on at the fire hydrant and the boiler was fired.

The contractor performing the flushing initially thought two housing units would be flushed simultaneously for 3 hours. When work began, simultaneous flushing could not be done. To maintain the cost projection, each unit was flushed for 1-1/2 hours, and to offset the reduced flushing time, the water temperature was increased from 140 to 160 °F.

Although the boiler would supply the desired 160 °F water at the velocity provided by the fire hydrant, it would only supply 110 to 120 °F water when the pump was turned on, to deliver the high velocity needed. While flushing the first housing unit, it was agreed by the researchers present and the contractors performing the work that each unit would be flushed for 35 minutes without the pump on, to maintain maximum temperature. The pump would then be turned on for 10 minutes to maximize scouring action, followed by 35 minutes without the pump on and ending with 10 minutes of high speed flushing with the pump on. The procedure used for each of the five units is outlined in Table 4.

Before turning off the water supply at the beginning of the flushing process, a 1-L sample of water was taken for analysis. Another 1-L sample of hot water was taken from the same tap approximately 15 minutes after the flushing began. Finally, a third 1-L sample was taken from the same tap in the unit after the flushing had been completed, just before turning the unit main water supply back on.

Figure 27. Portable Hot Water Generator Used During Field Test.

Table 4

Flushing Procedures Used During Field Test

Unit Location	Flush Flow Rate	Temperature*	Time**
7206A Baker St	Low	160	35
	High	140	10
	Low	160	35
	High	120	10
7207A Baker St	Low	160	35
	High	140-160	10
	Low	160	35
	High	140-160	10
7315A Alexander Circle	Low	160	35
	High	120-160	10
	Low	160	35
	High	120-160	10
7375B Mindanao Court	Low	160	75
7379C Mindanao Court	Low	160	60
	High	120-160	Unknown

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*In degrees Fahrenheit.
**In minutes.

Pipe samples, which included at least one fitting, were cut from each of the five housing units. One pipe sample was taken before the flushing began, and the other afterward. Sampling locations are described in Table 5. In all cases, the before and after pipe samples were adjacent to each other in the cold water system. EDS analysis was later conducted on all of the samples to evaluate the presence of chloride ion.

During the course of the flushing process, appreciable amounts of greenish-colored, chloride-containing, copper corrosion products were observed in the toilets, sinks, and bath tubs. In the unit at 7375B Mindanao Court, a large amount of reddish brown residue was flushed from the pipes into the bathroom sink (Figure 28) and bath tub.

Field Test Results

External Surfaces of Pipe Specimens

Examination of the outside surfaces of the copper tube/fitting specimens that were removed before and after the flushing revealed no significant deterioration by the external environment (Figures 29 through 32). Some chloride-containing, copper corrosion products were present, but only superficial corrosion of the underlying copper had taken place. This external corrosion had occurred, undoubtedly, because soldering flux residue had not been wiped from the outside surfaces of the tubes and fittings after the soldered connections had been made. The outside surface examination further revealed that several of the specimens had been overheated when the tubes were originally soldered to the fittings. The overheating was indicated by the near-black appearance of the tubes and fittings.

Table 5

Locations of Specimens Removed During Field Test

Specimen Number	Unit Location	Specimen Location	When Removed
1	7206A Baker St	Cold water inlet immediately below cut-off valve	Before flushing
2	7207A Baker St	Cold water inlet immediately below cut-off valve	Before flushing
3	7315A Alexander Circle	Cold water inlet immediately below cut-off valve	Before flushing
4	7375B Mindanao Court	Cold water line to bathroom sink	Before flushing
5	7379C Mindanao Court	Cold water line immediately below cut-off valve	Before flushing
6	7206A Baker St	Cold water line to bathroom	After flushing
7	7207A Baker St	Cold water line to bathroom	After flushing
8	7315A Alexander Circle	Cold water inlet immediately below cut-off valve	After flushing
9	7375B Mindanao Court	Cold water line to bathroom sink	After flushing
10	7379C Mindanao Court	Cold water line immediately below cut-off valve	After flushing

Figure 28. Residue in Sink During System Flushing.

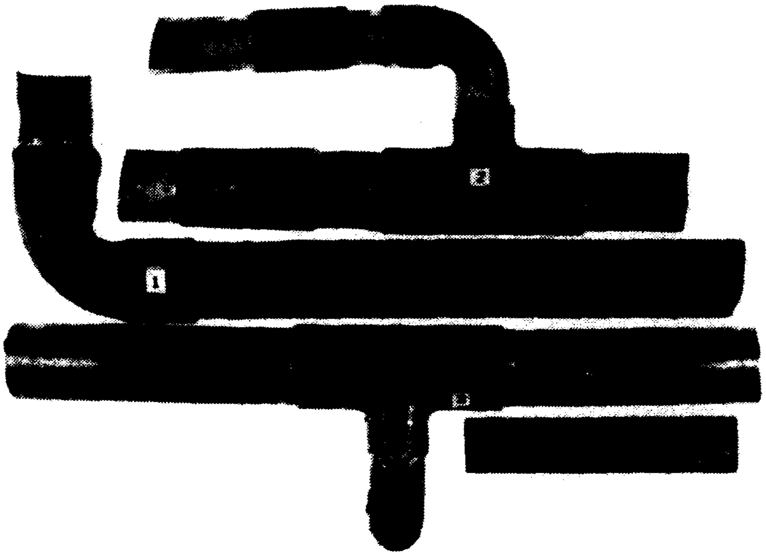

Figure 29. External Surfaces of Specimens 1, 2, and 3 Removed Before Hot Water Flushing.

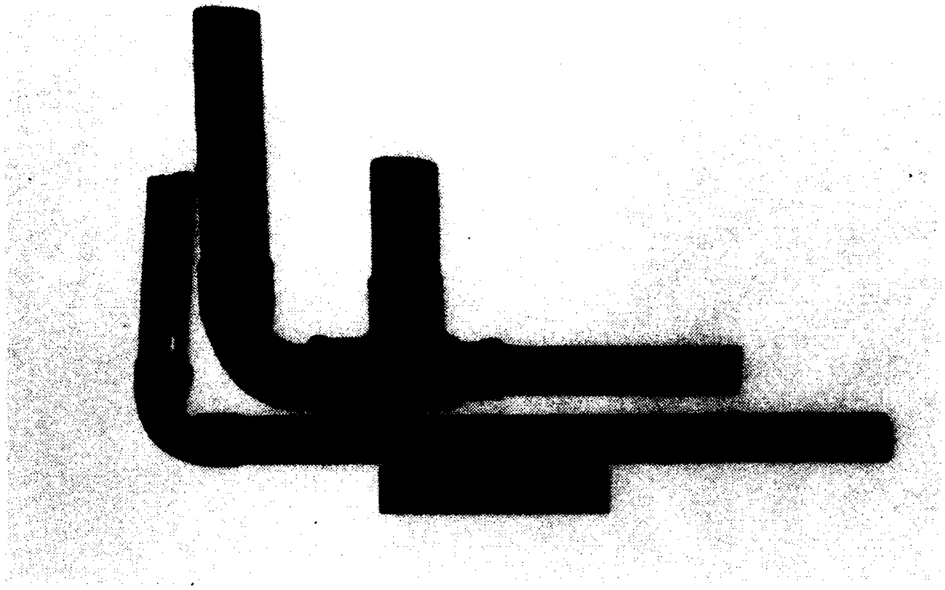

Figure 30. External Surfaces of Specimens 4 and 5 Removed Before Hot Water Flushing.

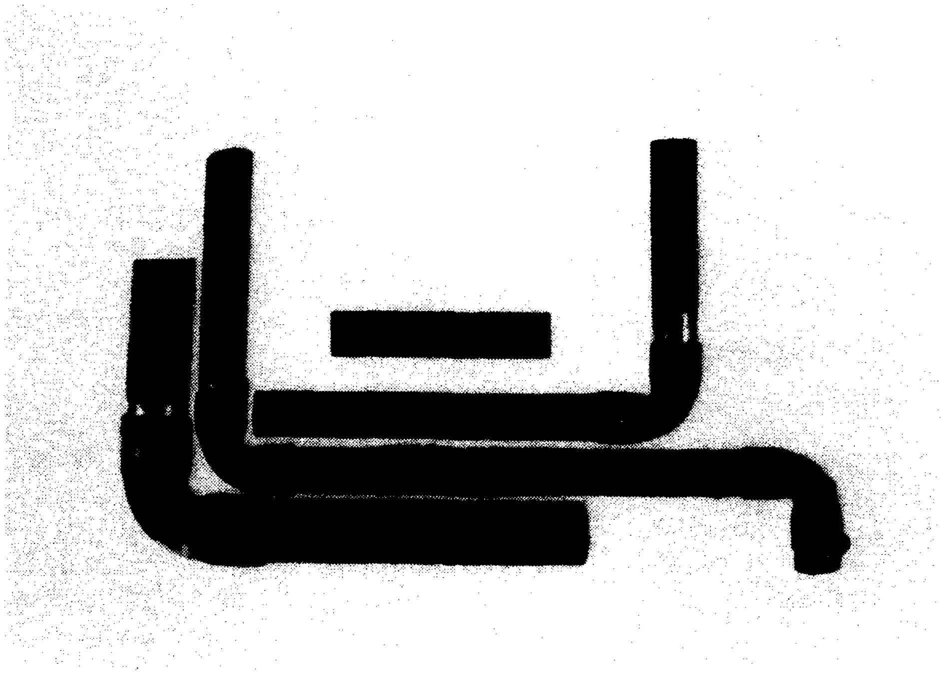

Figure 31. External Surface of Specimens 6, 7, and 8 Removed After Hot Water Flushing.

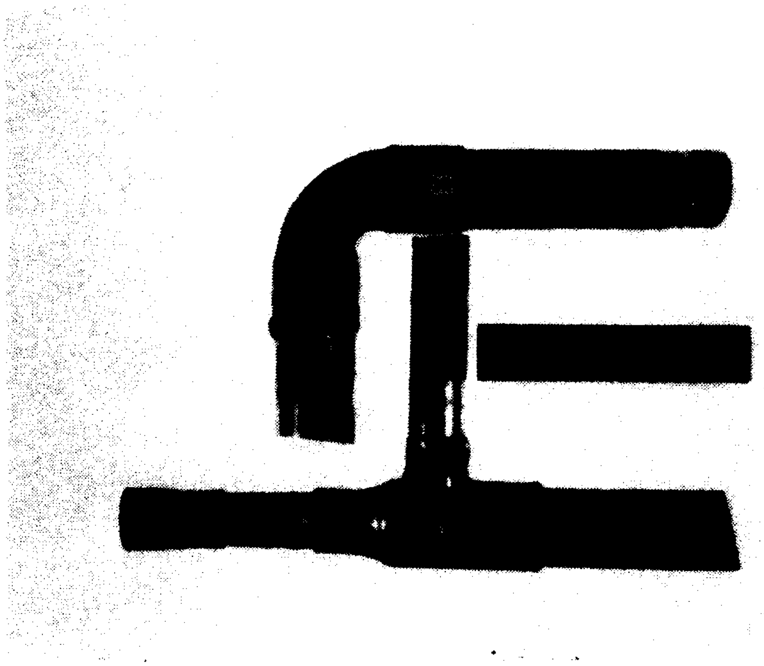

Figure 32. External Surfaces of Specimens 9 and 10 Removed After Hot Water Flushing.

Internal Surfaces of Pipe Specimens

Examination of the inside surfaces of the tubes and fittings that had been removed before hot water flushing revealed that flux-induced corrosion had occurred inside four of the five specimens (Figures 33 and 34). The corroded areas contained porous, reddish brown, cuprous oxide, which was typically overlaid with friable, greenish-colored mounds (i.e., tubercles) of copper corrosion products.

Examination of the inside surfaces of the tubes and fittings that had been removed after hot water flushing revealed that solder flux-initiated, localized corrosion had occurred on the water sides of all five samples (Figures 35 and 36). The samples looked similar to those taken before the hot water flushing with one exception: the specimen taken from 7315A Alexander Circle showed significant removal of the greenish-colored corrosion products.

Inside surface examination further revealed that very poor workmanship had been involved when the copper tube systems were originally installed. Evidence of this included: (1) tubes had not been fully inserted into fittings before soldering, (2) sticky, petroleum-base, soldering flux residue was on the inside surfaces in addition to the flux residue associated with the water-side corrosion, (3) solder was present on the water-side surfaces, (4) one tube from 7202A Baker Street was inserted too deeply into a fitting before soldering, and (5) soldered connections appeared black, which confirmed that the tubes and fittings had been overheated during the original soldering.

EDS Analysis of Pipe Specimens

Of the five sets of pipe samples removed for EDS examination, one of the samples removed after flushing (7207A Baker Street) did not contain a solder flux run. Representative sections were cut from

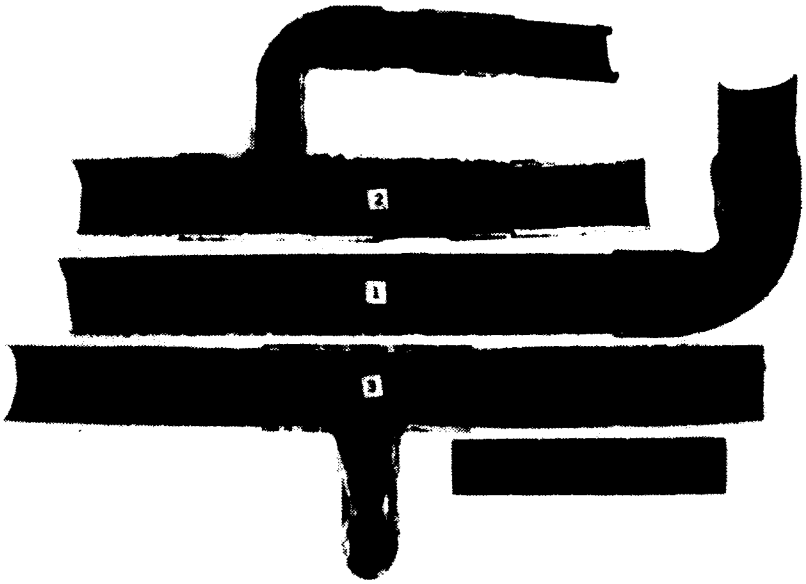

Figure 33. Internal Surfaces of Specimens 1, 2, and 3 Removed Before Hot Water Flushing.

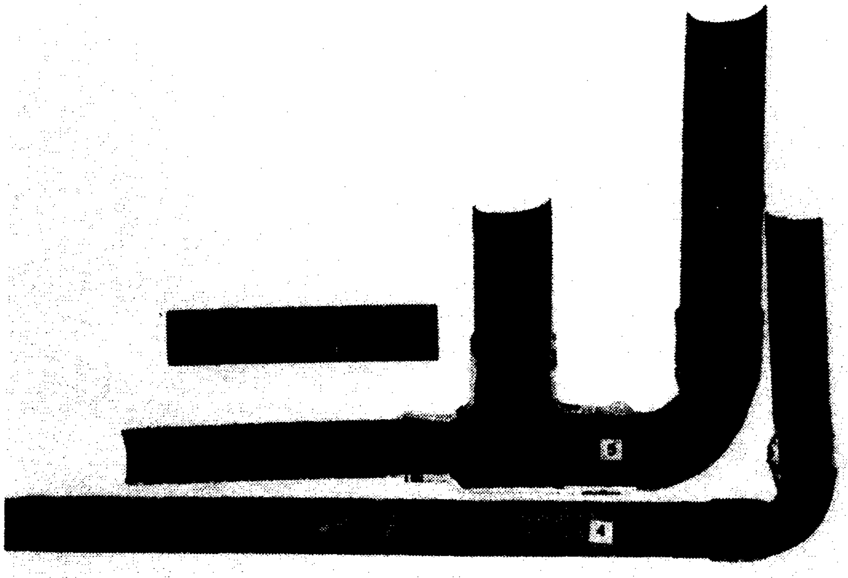

Figure 34. Internal Surfaces of Specimens 4 and 5 Removed Before Hot Water Flushing.

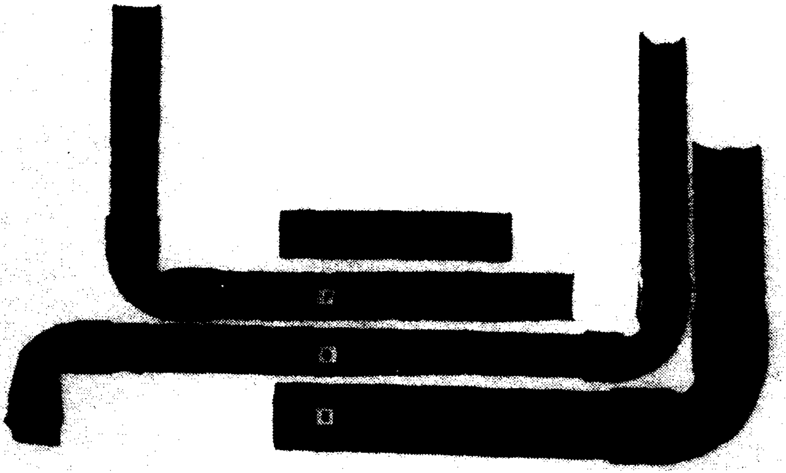

Figure 35. Internal Surfaces of Specimens 6, 7, and 8 Removed After Hot Water Flushing.

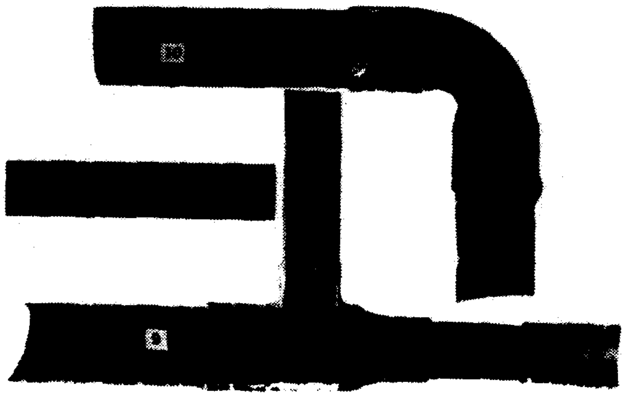

Figure 36. Internal Surfaces of Specimens 9 and 10 Removed After Hot Water Flushing.

the other four sets of pipe samples that had solder flux runs present both before and after hot water flushing to examine the corrosion products and the locally-corroded areas under them.

EDS and microchemical analysis revealed that the outer layers of the greenish-colored mounds of copper corrosion products on the water-side surfaces of the specimens typically contained major quantities of copper, semi-major amounts of silicon, minor to semi-major quantities of chloride and sulfur (as sulfate), and trace amounts of aluminum, calcium, iron, and/or zinc. These outer layers of the mounds consisted primarily of copper chloride(s) and copper sulfate, which were admixed with products conveyed in and by the water. The presence of chlorides in the corrosion products along with zinc (zinc chloride being a common component of soldering fluxes) support the belief that the localized attack of the copper on the water-side surfaces was indeed induced by soldering flux.

EDS results were also used to evaluate the effectiveness of the hot water flushing for removing aggressive chloride ions from the soldering flux-activated, corroded sites on the water-side surfaces of the copper tubes and fittings. Comparison of the "before" and "after" X-ray spectra for the four sets of specimens provided the means of estimating the effectiveness of the back flushing technique. It was noted that the percentage of the chloride ions removed from the domestic cold water lines by the hot water flushing procedure varied. Table 6 shows the percentage of chloride ion reduction. The effectiveness of chloride ion removal to mitigate the corrosion can only be determined over time.

By assuming that (1) the low flow rate during the hot water flushing was 20 gallons per minute and the high flow rate was 25 gallons per minute while the water pump was operating, and (2) there were no head losses in any of the housing unit plumbing systems (flow rates were not measured nor any actual head loss determined) a very rough estimate of velocity can be calculated for each housing unit based on the number of faucets and bibs and their pipe sizes. Table 7 and Figure 37 are a summary of these calculated flows. The chloride ion removal efficiencies observed relate very well with these calculated flow rates and are in general agreement with laboratory test results.

EDS Analysis of Residue

The presence of the greenish products and residue in the sinks, bathtubs, and toilet bowls, and subsequent EDS and microchemical analysis of the residue supports the belief that the hot water flushing technique is at least partially effective in removing copper corrosion products and aggressive chloride ions from the corroded copper tubes and fittings. EDS analysis of the residue from the toilets in housing units at 7206A Baker Street and 7315A Alexander Circle showed that they contained major quantities of copper and semi-major amounts of sulfur (as sulfate) and chloride.

Table 6

Field Test Results: Percentages of Chloride Ions Removed by Flushing

Unit Location	Percent Removed
7206A Baker Street	14
7207A Baker Street	Unknown*
7315A Alexander Circle	50
7375B Mindanao Court	59
7379C Mindanao Court	82

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* There was no evidence of soldering flux-induced corrosion in the "before" specimen removed from this housing unit.

Table 7

Estimated Flushing Velocities

Location	1/2-in. Pipe Low Velocity	1/2-in. Pipe High Velocity	3/4-in. Pipe Low Velocity	3/4-in. Pipe High Velocity
7206A Baker Street	1.42	1.77	2.89	3.61
7207A Baker Street	1.42	1.77	2.89	3.61
7315A Alexander Circle	1.80	2.25	3.67	4.58
7375B Mindanao Court	2.84	3.55	5.79	7.23
7379C Mindanao Court	2.84	3.55	5.79	7.23

Analysis of Water Samples

The chemistry data for water samples collected before and after hot water flushing at the five housing units are summarized in Table 8. Examination of these data revealed that the general effect of the flushing was to: (1) increase the lead content of the water, (2) increase the copper content of the water, (3) significantly reduced the chloride content of the water flowing through two of the piping systems flushed, with no change in the other three piping systems, (4) either increase or decrease the zinc content of the water, and (5) have no effect on the tin content of the water. These observations further supported the belief that the hot water flushing technique was, at least in part, effective in removing corrosion products and up to 82 percent of the chloride ion contained within the solder flux. The removal of the chloride ion contained within the solder flux and corrosion products would allow clean surfaces to be exposed to the water, causing the initiation of corrosion to develop a protective tarnish film on the copper surface.

Discussion of Field Test Results

Based on the results obtained during the field tests and subsequent analysis, it can be concluded that: (1) soldering flux-induced corrosion on the water-side surfaces of copper tube, domestic cold-water systems existed in the housing units examined, (2) very poor workmanship was involved when the copper tube, domestic water systems were originally installed in the housing units, and (3) the hot water flushing technique used was, at least in part, effective in removing corrosion products and aggressive chloride ions from flux-contaminated, water-side surfaces of copper tube systems. Some possible reasons for the difference between the results observed in the field and the results observed in the laboratory are listed below.

1. Due to boiler capacity limitations, the velocities used in the laboratory could not be reproduced in the field (as seen in the results presented in Figure 37).

2. The joints tested in the laboratory were assembled days or weeks before flushing. The joints in the field had been in use for approximately 12 years. It is believed that aging of the flux and presence of corrosion products could affect the rate of chloride ion removal.

3. The laboratory test loops were constructed with a controlled amount of soldering flux. Obviously, the systems in the field were not constructed under controlled conditions, and the amount of flux in pipe specimens may have varied greatly.

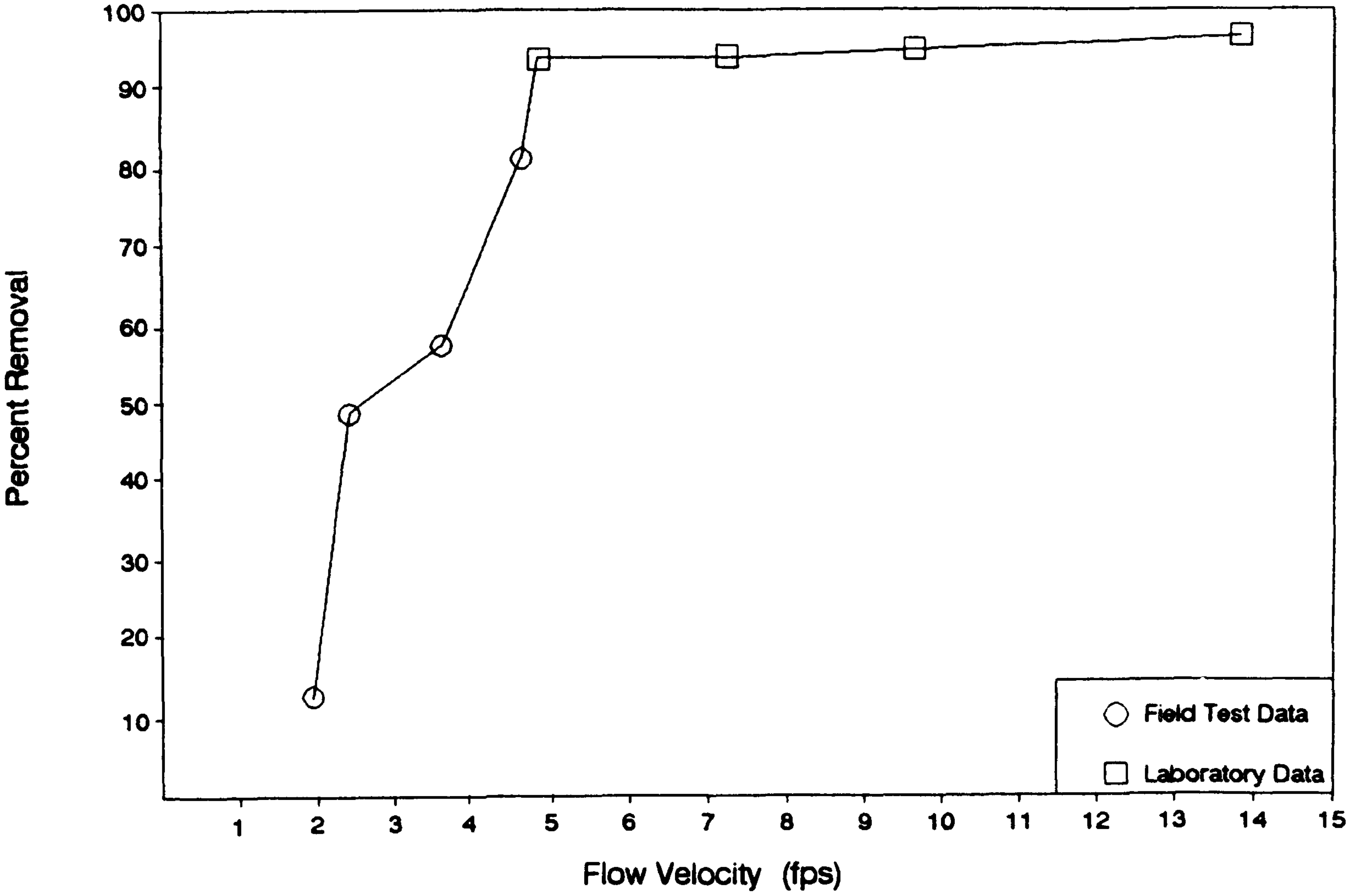


Figure 37. Chloride Removal Versus Flow Velocity.

Table 8

Field Test Water Chemistry Results

Unit Location	Description	Tin (MG/l)	Chloride (ppm)	Zinc (ppm)	Lead (ppb)	Copper (ppm)
7206A Baker Street	Kitchen tap before flush	<0.5	7.7	0.02	8.2	0.26
	Kitchen tap 18.5 hr after	<0.5	10.2	0.57	155.1	0.98
7207A Baker Street	Kitchen tap before flush	<0.5	61.6	0.51	3.7	0.20
	Kitchen tap 17 hr after	<0.5	7.7	0.16	117.0	0.49
7315 Alexander Circle	Bathtub before flush	<0.5	51.4	0.05	1.1	0.08
	Kitchen tap 23 hr after	<0.5	7.7	0.02	9.3	0.10
7375B Mindanao Court	Kitchen tap before flush	<0.5	30.8	0.02	1.7	0.15
	Kitchen tap 18.5 hr after	<0.5	30.8	0.10	2.9	0.37
7379C Mindanao Court	Kitchen tap before flush	<0.5	51.4	0.16	37.6	0.47

5 POST FLUSHING INVESTIGATION

In August of 1991, USACERL researchers returned to Fort Stewart, Georgia to verify the long term effects of hot water flushing on the copper piping system. Pipe samples and water samples from the original five buildings were collected and analyzed (Table 9 and Figures 38 and 39). None of the samples collected at this time were pipes that had been installed either immediately before or after the November 1989 flushing. Except for 7379C Mindanao Court, the water samples collected were from lines that had been inactive for at least 10 hours (Table 10). Also during this site visit, housing leak records were collected that dated from November 17, 1988 through August 1991. The statistical analysis of data in these records is discussed on pages 13 through 21.

The outside surfaces of the pipes were examined first and no major deteriorations were discovered; the surfaces were either covered with solder or a protective tarnish film of reddish-brown, cupruous oxide. However, some outside surfaces were covered with chloride-containing, greenish-colored, copper corrosion products. Superficial corrosion had occurred at these locations that was most likely due to excess solder flux residue that had not been wiped off the outside surface of the pipes. The pipe specimens were then sectioned lengthwise to study the inside surface. The examination showed that some soldering flux-induced corrosion and greenish-colored copper corrosion products were present on the inside of all five specimens. The corrosion had occurred where the solder flux runs were located. The corrosion was most severe on the specimens from 7375B Mindanao Court and 7379C Mindanao Court. These two samples had pinhole perforations that contained reddish-brown, cuprous oxide in the pits. It was evident that the pits had occurred on the water-side because the diameters of the pits were larger on the water side than on the outside surface and because of the presence of the porous, reddish-brown cuprous oxide. None of the other specimens had pits that had propagated through the tube walls.

After examining the inside surfaces, it was again seen that poor workmanship existed when the copper pipe system was installed. Cut tube ends that had not been reamed/deburred before soldering, solder flux runs as long as 6 in., tubes that had not been fully inserted before soldering, and the black appearance of the soldered connection were some of the faults found in the pipe specimens. EDS was also performed on the five specimens collected. The EDS and microchemical analysis (MCA) showed that the copper corrosion products contained major quantities of copper, very minor to semi-major amounts of sulfur and iron, minor to semi-major quantities of silicon, and undetectable to minor amounts of chloride. The presence of the undetectable to minor amounts of chloride shows that the hot-water flushing has been at least somewhat successful in removing the chloride, which is primarily responsible for the

Table 9

Location of Specimens Removed During Return Site Visit

Specimen Number	Unit Location	Specimen Location
11	7206A Baker Street	Cold water inlet immediately below cut-off valve
12	7207A Baker Street	Cold water line to washing machine in the utility room
13	7315A Alexander Circle	Cold water line to a shower
14	7375B Mindanao Court	Cold water line to a bathroom fixture
15	7379C Mindanao Court	Cold water line to a bathroom fixture

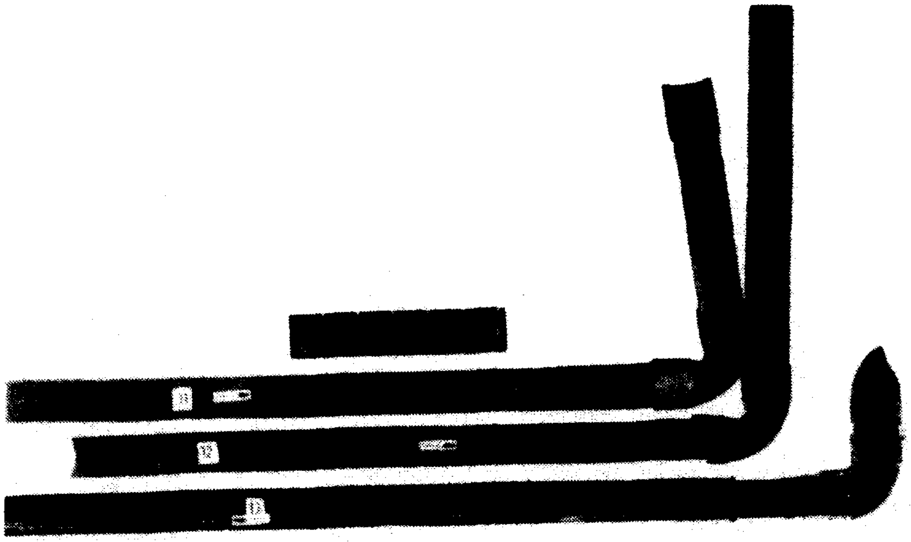


Figure 38. Internal Surfaces of Specimens 11, 12, and 13.

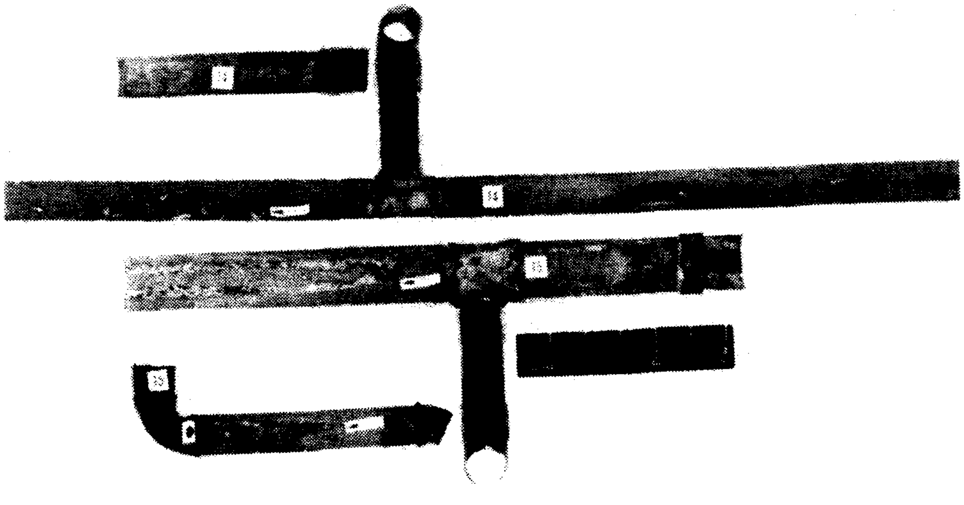


Figure 39. Internal Surfaces of Specimens 14 and 15.

Table 10

Return Visit Water Chemistry Results

Unit Location	Tin (Mg/l)	Chloride (ppm)	Zinc (ppm)	Lead (ppb)	Copper (ppm)
7206A Baker Street	<1	9	<0.05	<0.01	0.21
7207A Baker Street	<1	7	<0.05	<0.01	0.07
7315A Alexander Circle	<1	8	<0.05	<0.01	0.12
7375B Mindanao Court	<1	8	0.15	<0.01	0.16
7379C Mindanao Court	<1	8	<0.05	<0.01	0.14

pitting. It was also seen from the EDS that no chlorides were detected in the corrosion-induced pits that are associated with the greenish-colored, copper corrosion products. The X-ray spectra for corrosion products removed (Figures 40 through 44), shows how much chloride was removed due to the hot-water flushing and the following 20 1/2 months of water flow through the pipes. See Table 11 for the summary of the percentages of chloride ions removed.

It can be concluded that (1) localized, soldering flux-induced corrosion had occurred on the water-side surfaces of all five specimens, (2) there had been poor workmanship when the copper tube systems were originally installed, and (3) the hot water flushing and subsequent flow of water has been somewhat effective in removing aggressive species from the solder on the water-side surfaces of the specimens.

To counteract the low temperature (110-120 °F) used during the high velocity flushing, the original boiler design was reevaluated and the boiler plan was modified. The modified plans and specifications are shown in Appendix B.

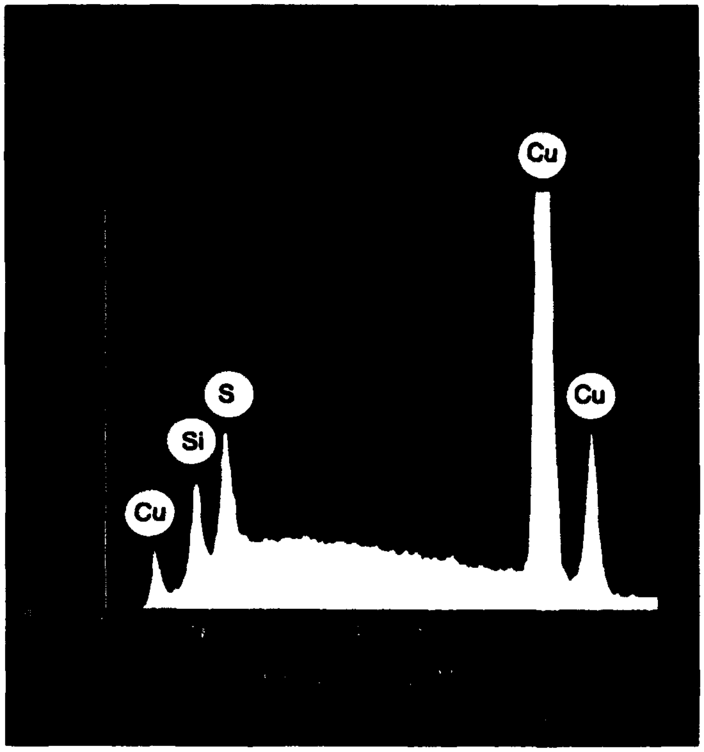


Figure 40. X-Ray Analysis of the Water-side Surface of Specimen 11.

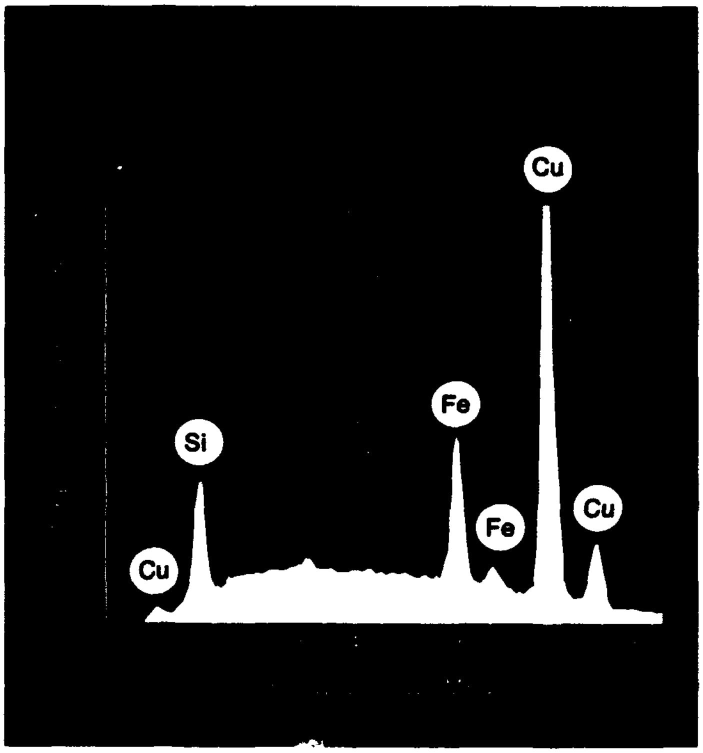


Figure 41. X-Ray Analysis of the Water-side Surface of Specimen 12.

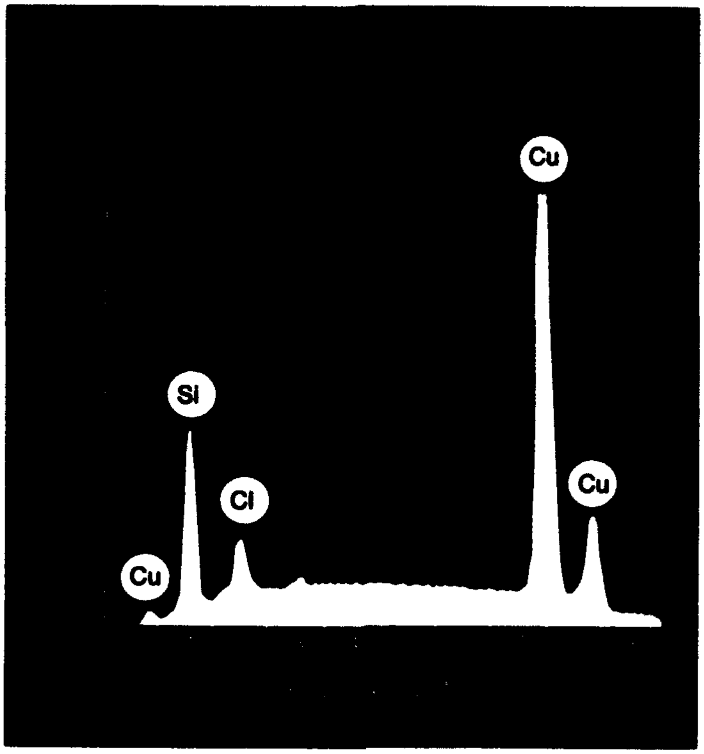


Figure 42. X-Ray Analysis of the Water-side Surface of Specimen 13.

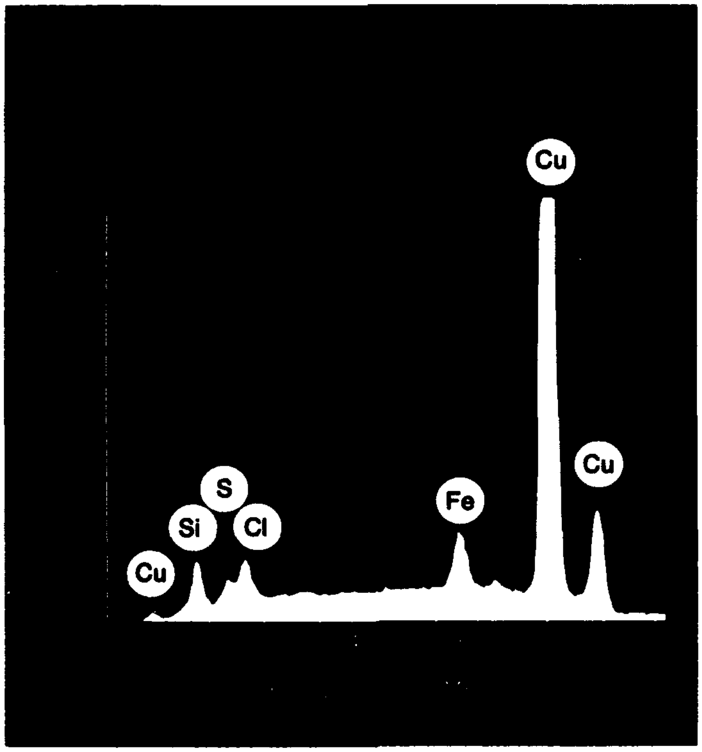


Figure 43. X-Ray Analysis of the Water-side Surface of Specimen 14.

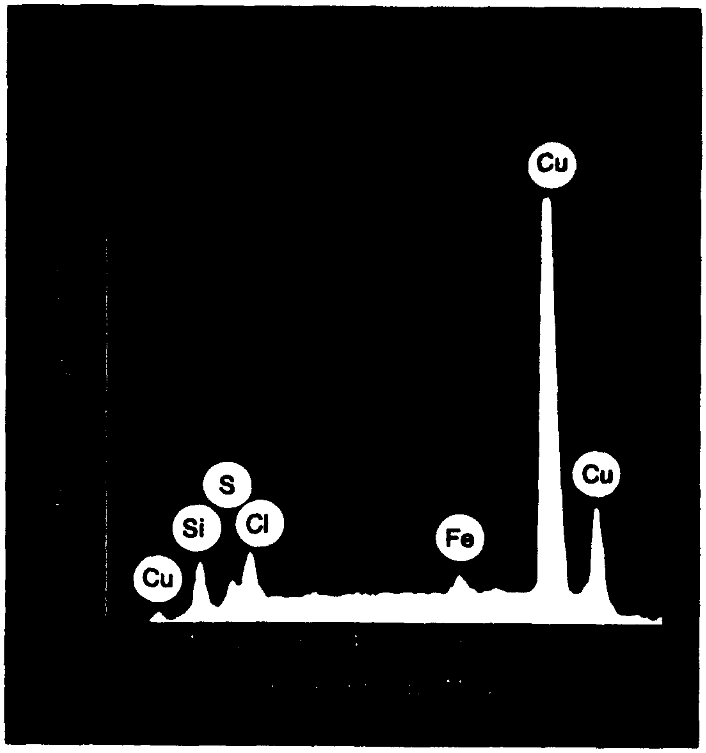


Figure 44. X-Ray Analysis of the Water-side Surface of Specimen 15.

Table 11

Return Site Visit Results: Percentages of Chloride Ions Removed as Compared to Original Chloride Ions

Unit Location	Percent Chloride Ions Removed
7206A Baker Street	100
7207A Baker Street	Unknown
7315A Alexander Circle	50
7375B Mindanao Court	80
7375C Mindanao Court	72

6 COST/BENEFIT ANALYSIS

This technology will reduce the amount of maintenance money spent on flux-induced, corrosion-related repairs of copper piping systems. Using a leak repair rate of 100 per month, Fort Stewart is spending approximately $240,000 annually on flux-induced leaks. This figure will rise as the pipe deterioration becomes more severe. After the design and initial purchase of the flushing equipment at approximately $20,000, it costs approximately $160 per building (including labor, fuel, and water) to perform the rehabilitation technique. This assumes that two units are flushed at the same time. It is conservatively estimated that flushing the lines will reduce leaks by 50 percent at an annual costs savings of $120,000.

7 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the laboratory and field tests, the backflushing technique for removing corrosive solder flux residue in potable water copper piping systems is an acceptable alternative to replumbing the buildings. In most of the specimens studied, the chloride ion concentrations on the interior pipe surfaces were reduced by 14 to 82 percent of their original concentrations. It is too early to know the effect of this on the corrosion rates being experienced in the system, but it is likely that the rates will be reduced appreciably because of removal of chloride-containing solder flux residue.

It is recommended that a backflushing program be initiated at Fort Stewart, GA, to remove the corrosive chloride-containing solder flux residue from the cold water copper piping systems for all building series.

It is also recommended that the existing portable hot water generator be modified to maintain a flow rate of 11.5 gallons/minute at a temperature in excess of 140 °F for a minimum of 3 hours. The Oak Ridge National Laboratory was contracted to modify the design of the original trailer mounted, self-contained, portable hot water generator.

METRIC CONVERSION TABLE

1 in. = 25.4 mm
1 gal = 3.78 L
0.55(°F-32) = °C

CITED REFERENCE

Copper Development Association, Inc., "Copper Tube for Plumbing, Heating, Air Conditioning and Refrigeration," *Copper Brass Bronze Product Handbook* (Copper Development Association, Inc, Greenwich, Connecticut).

UNCITED REFERENCES

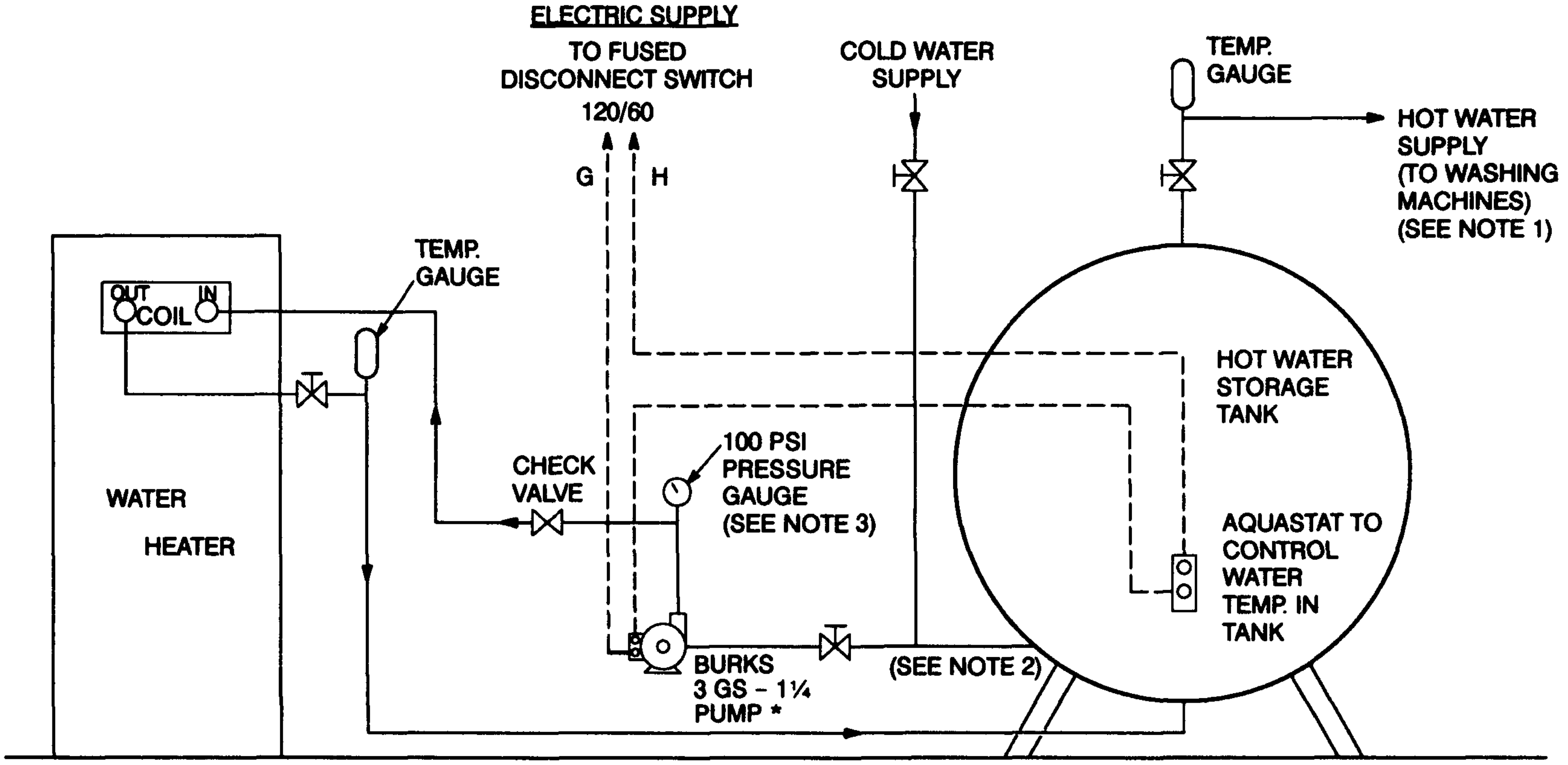
Myers, J.R., "Corrosion of Copper Water Tube/Fitting Specimens from the Bryan Village Area, Fort Stewart, Georgia," JRM Associates report to USACERL, October 1987.

Myers, J.R., "Effectiveness of Hot Water Flushing for the Removal of Corrosive Species From Soldering Flux-Contaminated, Domestic Cold Water Lines at Bryan Village, Fort Stewart, Georgia," JRM Associates report to USACERL, January 1990.

Myers, J.R., "Examination of Copper Water Tube/Fitting Specimens from Domestic Cold Water Lines at Bryan Village, Fort Stewart, Georgia: Twenty and One-Half Months after Hot-Water Flushing for Soldering-Flux Contamination Removal," JRM Associates report to USACERL, August 1991.

Myers, J.R., "Failure Analysis of Copper Tube Specimens from Domestic Water Systems at Fort Stewart, Georgia," JRM Associates report to USACERL, November 1985.

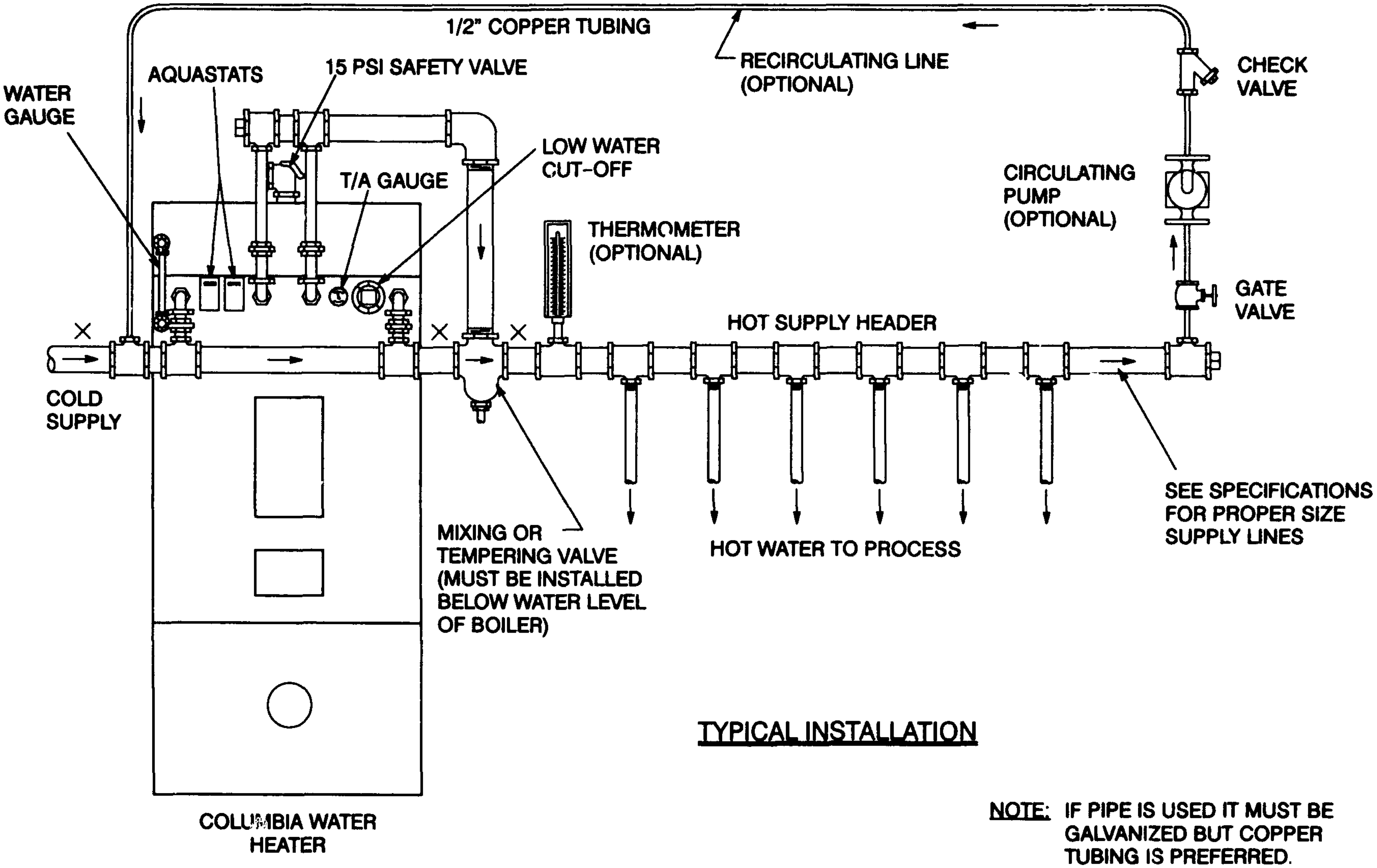
APPENDIX A: Columbia Boiler Layouts



NOTES:

1. HOT WATER SUPPLY OUTLET SHOULD BE AT TOP OF TANK AT AQUASTAT END.
2. COLD WATER SUPPLY INLET SHOULD BE AT BOTTOM OF TANK OPPOSITE AQUASTAT END.
3. INCREASING PRESSURE ON THIS GAUGE WHILE PUMP IS RUNNING INDICATES SCALE BUILD-UP IN COIL OR OTHER RESTRICTIONS IN CIRCULATING LOOP.

* OR EQUIVALENT - - DO NOT USE RESIDENTIAL TYPE CIRCULATING PUMP



TYPICAL INSTALLATION

NOTE: IF PIPE IS USED IT MUST BE GALVANIZED BUT COPPER TUBING IS PREFERRED.

HAND VALVES MUST BE INSTALLED IN THE SUPPLY LINE AND AFTER THE MIXING VALVE AS SHOWN BY ×.

APPENDIX B: Modified Boiler Plans

Background

Laboratory studies resulted in the criteria that the cold water lines be flushed with 160 °F water flowing at 7 feet per second (fps). Field tests were performed at Fort Stewart, GA, using a portable hot water generator to provide the hot water required for the flushing operation. Water was supplied to the generator from a fire hydrant. Using the water pressure available at the fire hydrant, the generator was capable of heating the water to 160 °F, but the water velocities through the pipes were below the desired 7 fps value. Activating the booster pump in the water supply increased the water velocities, but they were still below the desired values. Furthermore, the temperature of the water supplied by the generator dropped to the range of 110 to 140 °F. The analysis of the hot water generator and recommendations for its future operation are presented below.

Options

To meet the criteria for flushing the pipes, the water flow rates and temperatures have to be increased in the field. Assuming that 72 gpm hot water is required for the one-bathroom house and delta P is proportional to the flow rate to the 1.75 power, the water delta P would have to increase to about 350 psi. Similarly for the two-bathroom house requiring 100 gpm hot water, the water delta P would have to increase to about 620 psi. Of course, these values are excessive, both from pumping and safety considerations.

A much better option would be to flush the house water lines in sections. For example, the water lines serving each of the bathrooms combined would require about 25 gpm of 160 °F water for the flushing procedure. The existing portable hot water heater is designed to heat 25 gpm of water to 100 °F. Without the booster pump operating, and assuming the source water temperature is about 65 °F, the test data suggest that water heater should perform within the design specifications. It needs to be instrumented in order to confirm this.

Flushing the house water system section by section would be a stepping operation. The number of steps could be reduced by increasing the flushing water flow and using a larger size portable heater or adding a second heater in parallel with the existing heater. A larger size booster pump would be required to obtain the desired flow rate. The existing heater is designed for 150 psi maximum pressure operation. Using this limit and assuming the 1.75 power law, the maximum flow rate would be about 45 gpm. To obtain the 160 °F flushing water temperature, the total hot water heater capacity would have to be increased from 1.25 MBtu/hr to 2.25 MBtu/hr.

Recommendations

Before purchasing additional pumping or portable hot water capacity, it is recommended that the existing unit be used to flush the house water system, section by section. The portable water heater needs to be instrumented with sensors to measure the temperature and pressure of the water entering and leaving the heater. The flow rates should be measured using an instrument such as an ultrasonic flow meter. Portable meters are available which could be used to measure the water velocities at various points in the house water system during the flushing operation.

The need for a higher capacity unit should depend on the results obtained by using the existing unit flushing the house water system section by section. It does not appear that this type of procedure can be completely eliminated, but the number of steps could be reduced by using a larger capacity portable water heater. In specifying the design, data obtained using the existing heater should be correlated and extrapolated for the new heater system.

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