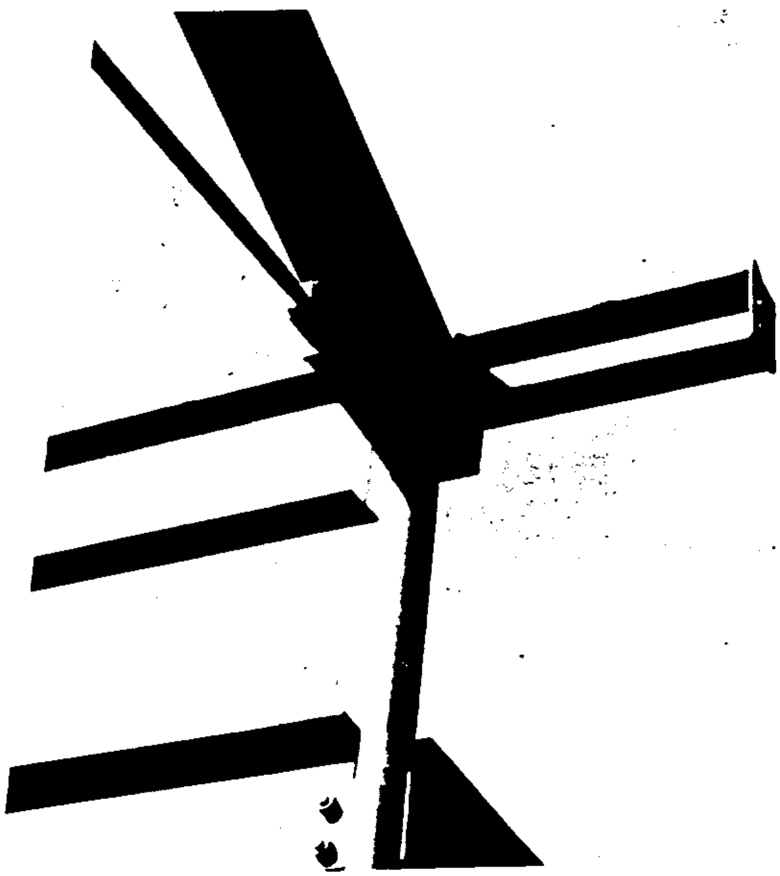
Technical Publication No. 105

Pilot Study on Copper Tube Corrosion in Florida

This research project was sponsored by the Building Construction Industry Advisory Committee under a grant from the State of Florida Department of Education and the State of Florida Department of Community Affairs, and the Copper Development Association, Inc.



Principal Investigator: Kwaku A. Tenah
Co-Principal Investigator: William Edwards

M. E. Rinker, Sr. School of Building Construction
University of Florida

1999

EXECUTIVE SUMMARY

This is an exploratory pilot study. It is based on a field survey and literature search. The purpose of the study is to provide a summary of available information on (a) copper tube corrosion in Florida, (b) geographical locations in Florida with what type(s) of corrosion occurrence(s), and (c) future research needs including their estimated cost and duration.

This pilot study report provides (a) a detailed literature search and a written summary of the pertinent literature articles, (b) results of a questionnaire, (c) summary of focus sessions and (d) future research needs areas including their estimated cost and duration.

A questionnaire was developed and sent to (1) plumbing contractors, (2) plumbing inspectors, (3) water providers and (4) building owners and managers. More than 500 questionnaires were sent to these four groups. The information obtained from these questionnaires is included in this report.

Eight focus sessions were held. Five of these sessions were in Orlando at the request of the Department of Community Affairs (DCA) and one each was held in Tallahassee, Jacksonville, and West Palm Beach. The results of these focus sessions are reported.

This was a pilot study with the objective of defining the problem and recommending if further research is required and; if so, recommend a scope of work for the follow on research. This study recommends that there be a detailed scientific research project to determine the causes of copper water tube problems in Florida and recommend action to correct the problem. A team was assembled with the expertise to conduct this research and to take 1300 water samples and to analyze 400 pipe samples which will cost $800,000. It will take 16 months to conduct the research with an additional 4 months for BCIAC to review and approve the draft final report and disseminate the final report for a total of 20 months.

A copy of this report or the summary report maybe obtained by writing or calling the following the executive secretary for BCIAC at:

Executive Secretary, BCIAC
M. E. Rinker, Sr. School of Building Construction
Post Office Box 115703
University of Florida
Gainesville, Florida 32611-5703
(352) 392-9045

TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

The overall purpose of the pilot study was to be an exploratory study, based on field survey and literature search, to provide summary of available information on (a) copper tube corrosion in Florida, (b) geographical locations in Florida with what type(s) of corrosion occurrence(s) and future research needs and estimated cost and duration. This study arose out of a response to the perceived problems, concerns and needs identified by the Copper Development Association (CDA) and Florida's Department of Education's Building Construction Industry Advisory Committee (BCIAC). Florida's Department of Community Affairs (DCA) and the Governor's Board on Codes and Standards' Plumbing and Mechanical Committee (hereinafter called "DCA") also identified and expressed the same concerns and needs later on. The major objectives of this pilot study are as follows:

- 1. Review and summarize the available information on copper water tube corrosion of both residential and commercial potable water systems in Florida.
- 2. Identify corrosion concerns affecting copper tube in certain Florida potable water systems.
- 3. Assimilate the perceived understanding of copper tube corrosion from personnel involved in the installation and inspection of potable water copper tubes in Florida.
- 4. Determine the geographical regions affected by copper water tube corrosion.
- 5. Identify future research needs and their cost as well as duration estimates.

The research team first examined available published literature on copper water tube corrosion including journal articles, research and engineering reports. The research team then developed the survey instrument from this literature search and pretested it before mailing it to plumbing contractors, plumbing inspectors and suppliers, water providers and building owners and/or managers (See Appendix B for a sample copy of the survey instrument). The research team later followed up the mailed-out questionnaires with telephone calls. The study team also developed and conducted eight (8) Focus Group Sessions [five (5) in Orlando at the request of DCA and one each in Tallahassee, Jacksonville, and West Palm Beach] with selected key professionals identified as knowledgeable and interested in the problem of copper tube corrosion including plumbing contractors and suppliers, plumbing inspectors, water providers, building owners and/or managers. These selected professionals were invited for half a day in-depth interview and exchange of information regarding methods of installation, use, problems and recommendations for copper tubes in potable water systems. The study team reviewed, analyzed and evaluated the obtained data.

The research team made conscientious efforts to collect a well-rounded sampling of data which would allow exploration of the causal relationships among all the copper corrosion variables, hence the collection of qualitative and quantitative data. In an effort to acquire enough data to make meaningful analyses and assessments, respondents were asked for hard performance data as opposed to their best estimates or opinions. The subjective nature of perception-based answers provided by respondents were difficult to evaluate.

Chapter 1 provides an overview of this report. Chapter 2 presents an overview from a literature search regarding copper tubes, potable water, water distribution systems and corrosion. Chapter 2 specifically describes the chemistry of copper, copper corrosion and corrosion types, the characteristics, sources and problems of potable water. Chapter 3 describes the results of research and engineering studies from more than 2500 pages of recent publications which address copper tube corrosion, copper as water distribution material and potable water obtained from (a) search of documents available at the libraries and computer programs (e.g. INTERNET) at the University of Florida, (b) reviews, study reports and articles provided by the DCA Advisory Committee members and (c) reports provided by some willing Florida utility companies as well as CDA. The summary provided in Chapter 3 is divided into three areas, namely, an overview of studies done outside USA, studies done in USA and Florida studies. Each area addresses **copper tubes** (when information is available), **potable water** and **copper corrosion**; the studies are arranged chronologically within each sectional area. Chapter 4 provides the analyses and evaluation of (a) the data collected from the field study that used a questionnaire to capture the knowledge and experience selected construction professionals and (b) in-depth interviews with knowledgeable and interested personnel representing plumbing contractors and suppliers, building inspectors, water providers and building owners/managers. Chapter 5 provides the conclusions and recommendations of this pilot study.

CHAPTER 2
AN OVERVIEW OF COPPER TUBE IN POTABLE WATER DISTRIBUTION SYSTEMS AND CORROSION: LITERATURE REVIEW

2.1 INTRODUCTION

Potable water and its distribution systems for commercial, industrial, or residential buildings must be reliable and safe. The design, installation, distribution and operations of potable water distribution systems must carefully examine the following:

- quality of the potable water delivered to the consumer,
- adequate chemical treatment to eliminate its corrosiveness,
- the materials of construction that must be both corrosion resistant in water service and meeting design, installation, as well as federal, state and local building code requirements,
- economical in terms of the installation and the annual maintenance expenses,
- proper supervision to assure good workmanship during the actual installation, and
- allowance for accessibility to perform regular inspection and preventive maintenance.

All the above variables challenge providers of potable water and distribution systems in buildings. Furthermore, stringent requirements for monitoring copper and lead releases in tap water have created interest in corrosion and products that prevent or reduce corrosion. It is, therefore, important to understand copper and its chemistry; sources of potable water and treatment requirements; nature, types and causes of corrosion; the role of microorganisms and natural organic matter, and inorganic anions; pH, and alkalinity effects.

This section of the report presents an overview from a literature search regarding copper tubes, potable water, water distribution systems and corrosion. It specifically describes the chemistry of copper, copper corrosion and corrosion types, the characteristics, sources and problems of potable water. This section also discusses the potential effects of dissolved minerals and gases, temperature, and velocity of potable waters on copper distribution systems.

2.2 COPPER TUBE IN POTABLE WATER DISTRIBUTION SYSTEMS

Many materials have been utilized as potable water distribution systems. Copper and lead are the oldest of these distribution system materials. The ancient Egyptians used copper pipes rolled from sheets and some of these pipes are on display in museums in Egypt and other parts of the world. In the last 40 years, copper has progressively dominated the market for potable water systems, though plastic pipe has entered the market in recent years, largely replacing galvanized steel. "Today copper accounts for between 50% and 90% of all tubes installed for drinking water service in industrialized countries" (Cohen & Myers, 1984).

Coppers are classified according to their chemical composition. The corrosion resistance of all types of copper used in distributing potable water is essentially identical. Table 2-1 lists the numerous specifications for copper and copper alloys that can be used in water service. Today, water tube is available in both seamless and welded forms and in both copper and copper alloys, and all these products are essentially interchangeable.

Table 2-1: ASTM Specifications for Copper Plumbing Tube and Pipe.

	Seamless	Welded
Copper	B698-96, B88	B447
Copper alloy	B43, B135	B586

Some of the literature found that the authors have seen copper plumbing tubes outlasting the buildings in which they were installed and that copper has shown excellent corrosion resistance in all parts of the world (Campbell 1965, Obrecht, et al, 1960, Myers 1974). A considerable amount of experience has been accumulated over the years that copper systems have been in service. According to the *CDA Copper Facts*, "since 1963, about 28 billion feet or 5.3 million miles of copper plumbing tube has been installed in U.S. buildings."

2.3 COPPER CHEMISTRY

Webster's II New Riverside University Dictionary defines copper as "ductile, malleable, reddish-brown metallic element that is an excellent conductor of heat and electricity and is used for electrical wiring, water piping, and corrosion-resistant parts."

Copper is more noble than any of the other metals commonly used in water distribution systems and therefore is not expected to corrode. Copper can be oxidized to the cuprous (Cu^{+}) and cupric (Cu^{++}) states. Copper can be attacked by aggressive waters. Copper may sporadically corrode under such adverse conditions as aggressive well waters, very soft waters high in carbon dioxide, and in systems where the water flow velocity is in excess of about 5 fps (Obrecht, et al, 1960) causing erosion corrosion, especially in forced-circulation hot water systems.

Copper is the base element in brass and bronze used in making fittings and fixtures for plumbing installation. In the USA, copper production techniques are constantly undergoing process modification.

The U.S. Environmental Protection Agency (USEPA), pursuant to the requirements of the 1986 Safe Drinking Water Act (SDWA), promulgated the Lead and Copper Rule (LCR) on June 7, 1991 which established action levels of 1.3 mg/L for copper and 0.015 mg/L for lead in public water systems (PWS). If these levels are exceeded in 10% of selected tap water samples, corrosion control treatment and source water treatment are required. This makes the US position in drinking water production and distribution much more demanding than most countries in

Europe and other parts of the world.

2.4 COPPER CORROSION

Myers in his report on *Fundamentals and Forms of Corrosion,* defines corrosion as "deterioration of a material, usually a metal or alloy because of a reaction with its environment" or "extractive metallurgy in reverse" (Myers 1974). The study of literature on copper and its chemistry revealed that though failures of copper tubing are rare, occurrence of failures do happen. Based on incidences of corrosion occurrence reported to US Copper Development Association (CDA), flux/workmanship is the largest source of copper corrosion followed by cold water pitting, then erosion corrosion. Table 2-2 shows the relative distribution of the different types of copper tube failures that occurred in the late 1980s and early 1990s by statistics from the CDA. **The CDA compiled this table from cases which were referred to CDA for investigation.**

Table 2-2: Categories of Failures Investigated by CDA from Referred Cases

Types of Corrosion	1988	1989	1990	1991	1992	1993	1994
Cold Water Pitting	7	9	5	14	5	9	0
Concentration Cell	2	1	1	10	3	12	6
Flux Corrosion*	7	10	8	12	10	22	10
Underground Corrosion	1	7	1	5	8	3	0
Green Water	1	2	1	2	3	3	0
Erosion Corrosion	4	7	2	15	9	11	3
Sulfide Attack	1	0	0	2	2	5	1
Stress Corrosion+	3	1	1	1	1	0	0
Hot Water Pitting	2	0	3	3	0	6	3
Workmanship	1	2	1	1	2	3	1
Galvanic Corrosion	0	1	0	0	0	0	0
Total	**29**	**40**	**23**	**65**	**43**	**74**	**24**

*Flux corrosion could be included in workmanship; which would make workmanship the #1 cause of copper tube failure.
+These were refrigeration and not water lines corrosion

Ferguson, et al., Myers and Wolfe classify nearly all corrosion problems into eight basic forms, namely, "(1) general corrosion (also known as "uniform corrosion"), (2) galvanic corrosion, (3) erosion corrosion (4) concentration-cell corrosion, (5) pitting corrosion, (6) selective leaching, (7) intergranular corrosion, (8) stress corrosion cracking (scc)" (Ferguson, et al. 1996, Myers 1974, Wolfe 1993). According to the CDA experts that reviewed this report, one does not have selective leaching or intergranular corrosion, and very rarely scc or galvanic corrosion in copper systems.

2.4.1 General (Uniform) Corrosion

Is the uniform anodic dissolution of metal over the entire exposed surface area. Myers and others maintain that general corrosion seldom causes rapid failure of tubing but can cause thinning and reduced service life. They also believe that "green water" from dislodged copper precipitates is a common manifestation of high corrosion rates and/or acidic waters with pH of 6 to 7 (Myers, 1974; Wolfe, 1993).

2.4.2 Galvanic Corrosion

Involves two dissimilar materials, with the less noble one (anode) suffering accelerated corrosion, and the more noble one (cathode) being cathodically protected by the galvanic current.

2.4.3 Erosion Corrosion

Is defined as "mechanical erosion of protective film from the surface of a metal" (Wolfe, 1993). Erosion corrosion is easily identified by the knockabout of the interior of the pipe due to (a) relative movement between the water that flows through the pipe and the pipe, (b) abrasion resulting from suspended solids and entrained gases in the water and (c) very often, typical U-shaped pits that are undercut in the direction of water flow in the tube are present. The primary cause of impingement attack is high water velocity and/or pressure.

2.4.4 Concentration Cell (Crevice) Corrosion

Concentration cell corrosion is defined as "the electrochemical attack of a metal because of differences in the environment." It commonly occurs where small volumes of stagnant solution exist as in crevices at flanges, couplings, threaded joints and under deposits.

2.4.5 Pitting Corrosion

Myers and others define pitting corrosion as "randomly occurring, highly localized form of attack, on the metal surfaces." Pitting corrosion is influenced by the stability of the protective film, water temperature and water chemistry. It is believed by many authors and researchers that water aggressiveness contributes to pitting corrosion and that the corrosion rates increases greatly with the presence of chloride (Campbell 1954 & 1965, Edwards et al. 1991, Kasul, et al. 1992 & 1993, Myers, et al. 1995 and Mattson, et al. 1968).

2.4.6 Selective Leaching

Selective leaching is the "de-alloying of certain alloys in the metals." This process can occur in copper-based alloys that utilize aluminum, silicon and zinc to produce the alloys. Uniform, localized (plug-type) and selective leaching can occur in copper alloys with higher zinc content such as yellow brass. These type of alloys can exhibit irregular dezincification when exposed to acidic environments. The lower zinc content alloys usually experience localized dezincification when exposed to neutral, alkaline, or slightly acidic solutions.

2.5 POTABLE WATER SYSTEMS IN BUILDINGS: DEFINITION, CHARACTERISTICS AND SOURCES OF PROBLEMS

2.5.1 Introduction

Because drinking water systems must be reliable and safe, each water source must be checked to see what type of treatment is necessary, if needed. When problems do occur in potable water, they can be expensive. The performance of the system that distributes potable water depends primarily on four things:

- The corrosiveness of the water supply
- The corrosion resistant qualities of the materials selected
- The design and workmanship
- The standards of maintenance, operation and use after installation

The designer of a potable water system must (1) acknowledge the effect of these factors on each other, (2) be conversant with federal, state and local building codes, materials specifications, and the capability of local contractors, and (3) balance economic and related factors, such as the availability of system components and delivery schedules (Myers et al. 1972 & 1973).

2.5.2 Potable Water: Definition and Use

Potable water is defined simply as "water that is suitable for drinking." "Potable water distributed within a building should be colorless, tasteless, and aesthetically acceptable to the occupants" (Myers, et al.1984, Ferguson, et al. 1996).

Besides drinking, potable water is used for many other purposes, including dish washing, bathing, sterilization, food preparation both in the manufacture of foods and beverages and in restaurants, the manufacture of pharmaceuticals, and many laboratory purposes.

2.5.3 Potable Water Sources and Characteristics

Potable waters are developed from both surface and ground supplies, including, lakes, rivers, streams, and wells. Reservoirs are used to store water where there is seasonal or annual variation in rainfall. Waters taken directly from wells may be low in oxygen but may contain higher levels of carbon dioxide and minerals than surface supplies. Well waters are usually free of algae and organic matter.

Waters are routinely treated for biological purity, but in addition, each water source has to be examined to determine whether some form of correction or treatment is necessary to control its corrosiveness. Often, all that is required is pH[1] adjustment. The form of corrective treatment may

---

[1] *Webster's II New Riverside University Dictionary* defines pH as "a measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with alkalinity and decreasing with increasing acidity". pH is a measure of water hydrogen-ion activity.

be to control scaling or to reduce dissolution (corrosion) (Myers et al. 1973). Treatments with other objectives must be evaluated for possible side effects that may create a corrosive water. Where the water purveyors continuously control the character of the water, they try to ensure optimum performance of the supply system, thus greatly reducing the customer-related complaints. Therefore, they are responsible for insuring that the water distributed to these installations is not unacceptably corrosive to the materials carrying it.

Fortunately, most water utilities adjust the water supply to control or eliminate its corrosive effect on the metal piping in a distribution system. When pH is raised to 7 or higher to give the water a slightly positive calcium carbonate saturation index, corrosion problems with copper are less likely to occur.

Where a water supply is not completely amenable to correction by chemical adjustment, such as water high in sulfate or chloride, the use of a corrosion inhibitor is recommended. Beneficial results have been achieved by additions of silicate, polyphosphate, and zinc polyphosphate, all of which, however, are subject to regulation by the health authorities (Hatch 1961, Lane et al. 1971, Sussman 1971, Lane et al. 1973).

Deposits of dissolved minerals in distribution systems coupled with high temperatures (in excess of 140°F), high quantities of dissolved gases (e.g. carbon dioxide, hydrogen sulfide, oxygen) and excessive velocity (in excess of 5 ft/sec) can severely affect the performance and/or life of copper tubes used in potable water distribution systems.

CHAPTER 3
SUMMARY OF RELATED RESEARCH AND ENGINEERING STUDIES CONDUCTED TO DATE

3.1 INTRODUCTION

This chapter describes the results of research and engineering studies from recent publications which address copper tube corrosion, copper as water distribution material and potable water. The information presented in this chapter came from three major sources, namely, (a) search of documents available at the libraries and computer programs (e.g. INTERNET) at the University of Florida, (b) reviews, study reports and articles provided by the DCA Advisory Committee members and (c) reports provided by some willing Florida utility companies as well as CDA. **Though important and a substantial amount of corrosion-related information is available, the authors have to be selective in using those that are related to this study (See references 1 through 108 in Appendix A).** The study team examined more than 2500 pages of information that included numerous articles, engineering and research study reports addressing corrosion, potable water and water distribution materials. The information obtained from the literature is presented in Chapters 2 and 3 of this report.

The research overview provided in this chapter is divided into three areas, namely, an overview of studies done outside USA, studies done in USA and Florida studies. Each area addresses **copper tubes** (when information is available), **potable water** and **copper corrosion**; the studies are arranged chronologically within each sectional area.

3.2 RESEARCH AND ENGINEERING STUDIES DONE OUTSIDE U.S.A.

Though there were numerous publications of journals and research and engineering study reports from outside the USA, the researchers used only a few that were pertinent to this research study because of the different laws, regulations, manufacturing and installation processes as well as usage of copper outside USA.

3.2.1 Studies Relating to Copper Material

The review of literature on studies done outside USA revealed that (Based on Cohen, 1994):

- In Britain, copper tube production practices were introduced in the British brass mills since late 1940s to produce tubes that were free from the so-called "deleterious" films in the bore. Studies conducted in the 1950s led the British manufacturers to believe that pitting corrosion was associated with carbon films in the copper tubes as a result of the manufacturing process. These earlier studies engendered copper tube manufacturers to introduce cleaning operations designed to remove these films from the bores of copper tubes. "Abrasive-cleaning using water-borne alumina or a variety of airborne abrasives were the processes that were widely introduced that were claimed to be effective in removing surface residues" (Cohen, 1994).

- "European copper water tube producers employ two manufacturing methods. The first method uses essentially the same process as in North America. The second method uses a proprietary process for producing a carbon-free tube bore. This method markets its products under the registered trademark 'SANCO'." (Cohen, 1994)

- "Recent investigations published by the Urban Water Research Association of Australia have shown that cuprous oxide films having p-type semiconducting properties are more corrosion resistant than films having n-type semiconducting properties. Those investigators found that the cuprous oxides which forms in the bore of the tube during certain annealing procedures are a p-type semiconductor film. With respect to pitting, it has been found that p-type cuprous oxide films are beneficial while n-type cuprous oxide films are detrimental. Reportedly, the desirable p-type cuprous oxide film can also be formed by exposing copper to dilute hydrogen peroxide solutions" (Cohen, 1994).

- A significant observation, which was corroborated by most European investigators in the 1960s and 1970s, is that most of the failures occurred with soft-annealed tubes. The statistics of the DKI show that in 1982, 88 percent of the pitted tubes were in the soft-annealed temper (Van Franque 1983). Similar results were found in laboratory tests reported by Campbell (1965), which showed that soft-temper tubes are more susceptible than half-hard tubes, which in turn are more susceptible than hard-temper tubes.

3.2.2 Studies Relating to Water

Water composition has been found in Europe and other parts of the world to be a major contributor of corrosion (Campbell 1954 & 1965, Baukloh et al. 1982,). For this reason, water treatment is the most common remedy recommended, consisting mainly of raising the pH (Campbell 1965, Mattson et al. 1968). Germany following Swedish example, has included the following formula in its standard DIN 50930: "Type II pitting is unlikely if the water has a pH greater than 6.5 and if the ratio of bicarbonate to sulfate is greater than 2:1".

3.2.3 Studies Relating to Corrosion

Institutional buildings in Germany, Saudi Arabia and Scotland experienced unexpected pitting of copper starting in 1986. Films of microbiological origin were detected on the pitted copper surfaces after evaluating the failures (Fisher, et al., 1995). The biofilms were found to be mixed with visible corrosion products and/or were underneath the corrosion products.

The study found out that the introduction of blasting technique in Europe and elsewhere has reduced the frequency of severe cases of pitting by 90% or more (Ferguson, et al., 1996). The other method used is "to pre-oxidize the inner bore by removing any carbon present and producing an oxide scale"; this method is said to improve corrosion resistance.

3.3 U. S. A. ENGINEERING AND RESEARCH STUDIES

3.3.1 Copper Material Studies

1. IMPACT OF STAGNATION TIME ON THE DISSOLUTION OF METAL FROM PLUMBING MATERIALS

by

Darren A. Lytle and Michael R. Schock, U.S. Environmental Protection Agency, NRMRL, WSWRD, TTEB
26 W. Martin Luther King Dr., Cincinnati, Ohio 45268 (1996)

Lead and copper tap water monitoring requirements under the U. S. Environmental Protection Agency's (USEPA's) Lead and Copper Rule (LCR) require that first draw water samples must be taken at a number of defined sites following 6 to 16 hours of stagnant contact with the plumbing materials. The time frame was intended to represent a "worst case" lead or copper exposure such as the case in the morning after an overnight stand period. This was generally based on research showing that the rate at which a metal leaches from lead piping is frequently predictable by radial diffusion models. These models indicate the rate of increase slows, and maximum concentrations are closely reached by 10 to 12 hours of elapsed time.

The effect time of contact between water and a pipe surface has on the amount of metal in the water is important in several respects. A systematic model for metal level versus standing time could be useful in more accurately predicting human exposure and long term intake of the metals. Similar information would be useful in explaining discrepancies between theoretical metal levels predicted by solubility models and field monitoring data, and within-house and between-house drinking water metal concentration variability. Also, such models would be important to assure proper conclusions when comparing alternative corrosion control treatments. Consequently, the research study presented here was undertaken with the objectives of "(1) investigating the impact of the oxidant (free chlorine and dissolved oxygen), water quality, and system age on metal release from copper, lead, and brass, in certain waters under study, (2) comparing experimental stagnation profiles (metal concentration versus standing time) to profiles predicted by diffusion models, and (3) discussing the implications of the results to 'real world experiences'." This research did not cover the interpretation of metal release data using chemical kinetic models.

The study results illustrated the complex nature of lead and copper dissolution rates from pipe and coupons. Water quality, oxidizing agent, material age, and alloy composition were all demonstrated to have significant impact on the shape of stagnation profiles and time to reach an equilibrium state. Corrosion control study results illustrated the importance of understanding stagnation profiles and how improper research conclusions can be drawn when this information is not considered. The findings helped to explain commonly encountered discrepancies between solubility model predictions and experimental or field metal levels, and within-house and between house drinking water metal variability. Special attention must be made in these situations to insure consistent sampling protocols.

This study recommended re-visitation of the lead and copper rule sampling criteria and health exposure issues because presumptions about conditions producing "worst case" scenarios are often not accurate. The biases could be either high or low and vary with materials and metals of interest. The study concluded that exposure estimates, without accounting for these factors of materials, chemistry, and time, could be off by as much as at least a factor of 2 to 10, or more.

The results demonstrated that (a) mass transfer modeling can be used to describe a stagnation profile and (b) the theoretical curves are extremely variable. Water quality and pipe age, which are probably associated with the type and development of corrosion products on the pipe surface, were associated with the variability. Surface film characteristics and water quality are site specific and must be taken into consideration; water sampling is necessary to establish this parameters.

3.3.2 Water-Related Studies

The following selected studies are pertinent to this study:

1. ADVANCEMENTS IN CHEMICAL TREATMENT STRATEGIES IN CHEMICAL TREATMENT FOR POTABLE WATER SYSTEMS

by

James E. Farmerie, Business Director, Calgol Corporation, Pittsburgh, PA (1993)

The author concluded that the use of chemical treatments is the most effective means to reduce both lead and copper solubility and provide corrosion control for the whole distribution system. He recommended the use of three basic building blocks for chemical treatment (each formulated with or without zinc) because of their advantages in controlling corrosion and meeting all potable water requirements. These chemicals are polyphosphate, orthophosphate and silicate. He further recommended that the right treatment strategy must be chosen to solve each problem.

2. COPPER CORROSION IN POTABLE WATER SYSTEMS: IMPACTS OF NATURAL ORGANIC MATTER AND WATER TREATMENT PROCESSES

by

J. P. Rehring, and M. Edwards, in *Corrosion* (Houston) v 52 n 4, pp. 307-317, (Apr. 1996).

The authors studied copper corrosion in the presence of natural organic matter (NOM) and in situations where NOM was altered by drinking water treatment. They found that "corrosion rates increased with higher NOM concentration at pH 6, whereas insignificant effects where observed at pH 7.5 and 9.0." They also discovered that "corrosion byproduct release was affected adversely by 4 mg/L NOM at pH 6.0, 7.5 and 9.0, with soluble copper increasing by 0.6 mg/L to 0.7 mg/L when compared to solutions without NOM." They further discovered that "alum-coagulated waters had higher corrosion rates than untreated waters, but ferric chloride -coagulated waters exhibited reduced corrosion rate." The authors attributed this difference to the relative effects of added sulfate via alum coagulation versus added chloride via ferric chloride coagulation. They finally concluded that similar effects were obtained when combined treatment (alum coagulation, ozonation, and granular activated carbon(GAC) on the left bracket and granular activated charcoal on the right bracket) was compared to that using alum coagulation alone.

3.3.3 Corrosion-Related Studies

The studies done in the USA in this area cover a wide range of topics. The following selected studies are pertinent to this study.

1. HOW TEMPERATURE, VELOCITY OF POTABLE WATER AFFECT CORROSION OF COPPER AND ITS ALLOYS

by

Malvern F. Obrecht, PhD, Water Treatment Consultant, and Professor of Chemical Engineering

and

Laurence L. Quill, PhD, Professor of Chemistry, Michigan State University (1961)

The authors had two facets to their research study. One was to determine why accelerated corrosion was occurring in copper tube used for water distribution systems on Michigan State University Campus. The other was to determine methods of alleviating and controlling corrosion as well as determining optimum operating conditions in the Michigan State University water distribution systems.

Examination of corroded tube through which water had flowed at different velocities and temperatures suggested that these two factors were also involved. Observations of heat exchanger tubes showed erosion-corrosion effects due to temperature, velocities, water quality, equipment design and so forth.

The study discovered that "the difference in the tendency toward corrosion and subsequent leakage was related to the presence or absence of coating on the inside of the tubes. New tubes, in which zeolite softened water was used from the outset, had no protective coating. Older, pre-World War II tubes had protective film of thin, hard, adherent carbonate silica deposit. Older dormitory systems had been operated for many years with hard water taken directly from wells. Then, when water softeners were installed, they were at first, regenerated on a very irregular schedule. The combination of prolonged exposure to hard water plus the later not-too-thorough softening program created more or less permanent protective film or coating on the inside of the copper tubes."

The study further discovered that with waters free from aggressive qualities, temperature and velocity effects are relatively unimportant. It then concluded that by keeping the indicated limits of water quality, temperature and velocity, copper and copper alloys will produce extremely good service in hot and cold water distribution systems. The study finally concluded by providing data on hardness, pH, alkalinity, dissolved gases, total solids, etc. and anticipated temperature and velocity for the use by designers to determine operating conditions based on the range of statistical performance imposed by these factors.

Taken as a whole, the Michigan studies and their findings raise the prospect that:

- (a) hard water provide carbonate silica deposits in the inside of copper tubes,
- (b) the deposits form a protective coating inside the tubes and prevent the copper tubes from corroding,
- (c) zeolite softened water is associated with corrosion and/or premature failures in new copper tubes because they did not have protective coating on the inside of the tubes
- (d) if a method can be devised to deposit carbonate silica deposits in copper tubes before softened waters are used in the tubes, corrosion and leaks can be prevented.

2. FUNDAMENTALS AND FORMS OF CORROSION

by

James R. Myers, Ph.D., Professor of Metallurgy Civil Engineering School, Air Force Institute of Technology, Air University, Wright-Patterson Air Force Base, Ohio (1974)

The author started with a classical definitions of corrosion as "deterioration of a material, usually a metal or alloy because of a reaction with its environment" or "extractive metallurgy in reverse." He later on delineated the significance corrosion and its enormous economic drain on all industrial nations. He estimated "the annual cost of corrosion in the US as ten to fifteen billion dollars." He then delved into the theory of corrosion. He considered corrosion to occur by an electrochemical process with an anode, a cathode and electrolyte, and a metallic circuit is required to connect the anode and the cathode before corrosion can occur. He concluded that (a) the dissolution of metal occurs at the anode where the corrosion current enters the electrolyte and flows to the cathode and (b) the general reaction (reactions, if an alloy is involved) which occurs at the anode is the dissolution of metal as ions. He emphasized corrosion control and went into a great extent of outlining methods to control or prevent each type of corrosion; all because it makes economic sense.

It must be noted that this paper deals with corrosion and their enormous costs in all metals; it **does not specifically deal with copper corrosion**.

3. ADVANCES IN THE BICARBONATE METHOD OF INTERNAL CORROSION CONTROL

by

Alfredo Vinci, Technical Manager, Research & Development, Church & Dwight Co., Inc., Princeton, NJ

and

James S. Sarapata, Director, New Product Development, Church & Dwight Co., Inc., Princeton, NJ (1988)

This study presented newly and updated corrosion control data collected on two New England communities which have chosen alkalinity supplementation with sodium bicarbonate in their corrosion control programs. It was done a year after the U.S. EPA promulgated the lead and copper rule under the Safe Water Drinking Act amendment of 1986. The study was important because, by that time (in early 1987), many water system operators had just completed the tap water monitoring requirements and were giving serious considerations to corrosion treatment programs.

The process of pH and alkalinity adjustment is the first among the corrosion control methods because it effectively controls corrosion without negatively impacting other aspects of water quality. Various studies have shown that the corrosive nature of water can be greatly reduced by adjusting pH and alkalinity values similar to those found in water sheds with alkaline deposits. In fact, minimum corrosion occurred when the pH was in the range of 7.5 to 8.5, which in a system (H_2O - CO_2) corresponds to maximum bicarbonate (HCO_3) ion species fraction. The study presented the latest data on studies in Bennington, Vermont, and Fitchburg, Massachusetts.

4. A REHABILITATION TECHNIQUE FOR SOLDERING FLUX-INDUCED CORROSION IN COPPER POTABLE WATER PIPING SYSTEMS

by

V. L. Van Blaricum, O. S. Marshall, R. H. Knoll, and V. F. Hock
U. S. Army Construction Engineering Research Laboratory (1991)

The paper presented at *Corrosion 91* by the authors reported workmanship practices, in particular excessive soldering flux, used in installing copper as the source of premature failures in copper potable systems. To mitigate this problem, the authors developed a technique which involved flushing the affected system with hot water at temperatures of 150 to 170 ^{0} F and at high velocity to remove the soldering flux residue inside the copper tubes and fittings.

The laboratory tests and the follow up field tests conducted by the authors in buildings with pitting corrosion problems using this technique were successful in reducing chloride ion concentrations on the interior pipe surfaces, thus, reducing the corrosion rates.

The soldering flux removal/rehabilitation technique developed by the authors is a great technique for field use because it is (a) relatively simple, requiring no piping, walls nor floor removal, (b) environmentally friendly and acceptable and (c) not chemically based.

5. ON THE PITTING CORROSION OF COPPER

by

Marc Edwards, Department of Civil Engineering, University of Colorado at Boulder, Boulder, Co.,
John F. Ferguson, Dept. of Civil Engineering, FX-10, Seattle, WA
and
Steve H. Reiber, HDR Engineering, Bellevue, WA
Department-of Civil Engineering, University of Colorado at Boulder, Boulder, CO 80309 (1991)

The authors found out that short-term experiments with anions, upon which current copper corrosion theory is based, demonstrated that chloride is more aggressive toward copper than sulfate. On the other hand, long term effects, important for copper in distribution systems, are not well understood. Preliminary experiments conducted by the authors demonstrated that chloride induced a scale to form on copper that passivated copper corrosion and pitting, while a scale was formed in the presence of sulfate that promotes copper corrosion. The latter results are consistent with practical observations regarding effects of sulfate or chloride on pitting. These observations, thus, contradicted theories that chloride initiates copper pitting attack.

It was observed that higher sulfate activities after softening increase the likelihood that bronchantite would precipitate, as do sulfate increases due to other water treatment processes such as alum treatment. Conversely, additions of sodium bicarbonate, known to decrease cold water pitting tendencies, favored malachite precipitation rather than bronchantite. In short, the hypothesis that bronchantite is somehow key to many copper corrosion problems is consistent with practical experience, while current pitting theory is not.

6. CORROSION CONTROL - CASE STUDIES

by

James S. Sarapata, Church and Dwight Co., Inc., Princeton, NJ, (1992)

The study examined water problems in Bennington, VT, Gorham, NH, Fort Collins, CO, and City of Myrtle Beach, SC. The study concluded that 'they all had one thing in common - source waters that "were deficient in natural bicarbonate ions" '. Their common solution was to add back what nature has left out. The paper from this study described the experiences of the water suppliers who have successfully used this approach.

The paper also concluded that many geological areas including many parts of New England, do not have alkaline soils and the water entering their reservoirs and aquifers is just as corrosive, or more so, than the initial rain. An effective and environmentally sensible approach to corrosion control in such instances is to simply replace what nature had left out, namely, the bicarbonate ion.

The study discovered that the presence of the bicarbonate ion increased the pH value and alkalinity bestowed a natural anti corrosive property to the water. It also discovered that the bicarbonate ion reacted directly with exposed metals in water distribution and residential plumbing systems forming a low solubility impermeable metal-carbonate coating thus protecting pipes and fixtures from further dissolution.

7. CORROSION CONTROL OPTIONS FOR DRINKING WATER PRODUCTION AND DISTRIBUTION

by

Jack W. Hoffbuhr, P.E. Deputy Executive Director, American Water Works Association, Denver, CO (1993)

Mr. Hoffbuhr recommended the following in his paper presented at **Intertech Conferences in 1993 at Tampa, FL** as the purposes or goals for any corrosion control:

- An effective water treatment strategy is essential for controlling lead and copper in drinking water.
- The aims of optimal treatment are to: (a) minimize lead and copper at the tap, and (b) insure that the treatment does cause the water system to meet any National Primary Drinking Water Requirement or Regulation
- Consider the impact of lead and copper control on other treatment processes and water quality factors while attempting to achieve optimal treatment.
- Consistency in the treatment process and in lead levels at the tap is a must.
- Use chemicals that comply with state provisions for direct additives.

He further concluded that the following are the key treatment options:

- That the two approaches must include (1) passivation (which involves formation of less soluble compounds such as Cu_2O with the pipe/solder materials using pH/alkalinity adjustment and corrosion inhibitors) and (2) precipitation (involving formation of a precipitate which deposits on the pipe wall using calcium).
- That the key elements of corrosion control are (1) defining and using control mechanism (Passivation or Precipitation), (2) choosing the appropriate treatment approach, (3) defining and using key water parameters and (4) selecting and utilizing appropriate chemical systems.

Mr. Hoffbuhr strongly recommended (1) pH/Alkalinity adjustment as the most important water quality characteristic, (2) that absolute minimum lead/copper solubility at pH = 9.8 and an alkalinity of about 30 mg $CaCO_3$/L must be used, and (3) that the following corrosion inhibitors be used: (i) phosphate and silicate-based compounds, (ii) phosphate compounds to include orthophosphates, polyphosphates and ortho-polyphosphate blends, (iii) silicate compounds.

8. OPTIMIZING CORROSION CONTROL IN PHILADELPHIA

by

Matthew G. Smith, Philadelphia Water Department, Philadelphia, Pennsylvania (1993)

The author presented his Department's experiences in evaluating corrosion control pilot study results, which are directly applicable to utilities developing pilot studies to meet the optimal corrosion control requirements of the Lead and Copper Rules (LCR). The objective of this paper was to "provide some observations as to the relative effectiveness of these tools for optimizing corrosion control for lead and copper". The author's work was aimed at responding to requirements of the USEPA's LCR promulgated on June 7, 1991. The LCR requires many utilities to install treatment which tends to minimize lead and copper corrosion in home plumbing systems. The USEPA calls this process "optimization" rather than "minimization" because such secondary issues as infrastructure protection, etc. may legitimately prevent a utility from attaining minimum levels.

In determining "optimized" treatment, the USEPA requires utilities to consider: (1) literature reviews, (2) experience of other utilities, (3) corrosion control pilot study results, and (4) "at-the-tap" monitoring results.

The author used various "tools" to evaluate the data as the study progressed. The tools were: (1) time vs. concentration graphs, (2) fractionation studies, (3) Bar and Whisker plots, (4) Parametric/Non-parametric analyses(Student t-test and Wilcoxon Signed Rank), and (5) Summary analysis tables.

It was concluded from the study that the Philadelphia Water Department must act to provide the mixed district homes with increased corrosion control protection. A decision to add zinc orthophosphate (ZOP) at the Baxter Water Treatment Plant (WTP) was made, and application started as of February 1993. This decision was in-line with the goals of the corrosion control studies which was to unify system wide corrosion control treatment strategy. Although this treatment change was made, the Department did not consider its system to be optimized.

9. THE NEW PRINCIPLES OF CORROSION CONTROL

by

Timothy A. Wolfe, Ph.D., P.E., Havens & Emerson, Inc., Cleveland, Ohio, (1993)

Mr. Wolfe, in his paper presented at **Intertech Conferences in 1993 at Tampa, FL** first identified and defined the general types of corrosion in water systems, including uniform, galvanic, erosion, concentration, pitting and selective leaching corrosion. He then described such water characteristics as pH, alkalinity, hardness, total dissolved solids (TDS), dissolved oxygen (DO), chlorine residue, chloride, ammonia and sulfate and how they affect corrosion. He revealed that TDS, DO, chlorine residue, chloride, sulfate and ammonia increase corrosion and/or solubility rates of many metals, e.g., copper.

Dr. Wolfe, after listing typical corrosion byproducts in water systems, went on to describe methods for reducing or eliminating corrosion in water systems. He finally went into great depth of describing (a) what and what are not corrosion control requirements under the LCR, (b) what and what is not a corrosion study under the LCR, (c) what are facts and fictions with regard to corrosion control indices and (d) specific means of reducing lead and copper levels at consumers' taps.

10. OCCURRENCE AND CONTROL OF CORROSION IN COPPER WATER TUBE SYSTEMS

by

Arthur Cohen, Manager Standards & Safety Engineering, Copper Development Association Inc., New York, New York (1994)

The author described (a) corrosion types that there are, (b) how these can be prevented or mitigated, and (c) copper tubes, fixtures and fluxes manufacturing and assembly practices in USA and Europe. He further described the water providers' responsibilities in producing and distributing water that meets all the requirements of the 1974 Safe Drinking Water Act and the subsequent amendments to this Act. He also described methods of treating water to control pitting corrosion. The author acknowledges that "water utilities and their consultants have no responsibility to ensure that either residential or commercial copper water tube installations (residential or commercial) comply with local community building codes."

11. SULFIDE-INDUCED CORROSION OF COPPER IN DRINKING WATER

by

Sara Angeles Jacobs, Master's Thesis submitted to the University of Colorado's Civil Engineering Department, (Summer 1997)

The author determined the effects of sulfides using corrosion rates, pitting frequencies, and copper corrosion by-product release using laboratory experiments and a compilation of utility experience. She thoroughly examined the practical implications and possible remediation strategies of sulfide-induced copper corrosion. She conducted case studies into sulfides and pipe failures in Florida, Ohio, Scotland and Texas. Her report noted that "with exception of the Texas case study, sulfides were not initially investigated as primary instigator of the observed (copper corrosion) problems." She described the adverse effects from sulfides as "thick, black, porous layer of sulfide-containing scale which catalyzes both the anodic and cathodic reactions." Her study and the conclusions she drew have lot of implications for homeowners and utility companies.

The following are the quoted conclusions of her studies:

- "The addition of sulfides to drinking water increased copper corrosion rates by about 1 and 2 orders of magnitude at pH 6.5 and 9.2, respectively. Corrosion rates did not decrease significantly with time when sulfides were present. Both the anodic and cathodic reaction rates were catalyzed."

- "At the observed corrosion rates, which may be the highest ever sustained for copper in potable water, all the copper in a pipe of 1/ 1 6" (0. 16 cm) wall thickness would completely corrode in just 8 years at pH 6.5 and 18 years at pH 9.2. Pipe failure in homes would occur much sooner given non-uniform corrosion processes."

- "Accelerated corrosion was not directly due to sulfides in solution, but rather, was attributed to a thick, black corrosion-accelerating copper sulfide scale. When this scale was smeared onto a new copper pipe surface and placed into a water without sulfides, the resulting corrosion rate was comparable to that obtained after sulfide exposure."

- "Sulfide exposure increased the release of copper corrosion by-products to drinking water when compared to pipes that had never been exposed to sulfides. During a three-hour stagnation time, sulfide exposure elevated copper release by about 500% and 5000% at pH 6.5 and pH 9.2, respectively."

- "Once sulfide-induced corrosion problems are initiated, they are very difficult to stop. In fact, removing sulfides from the raw water, adding chlorine or de-aerating water were not effective in mitigating the problem within a few weeks or months."

- "Based on experiences compiled in this work, it seems that adverse effects from sulfides are not confined to copper corrosion in the laboratory. Utilities and homeowners should be alerted to a greater likelihood of copper corrosion problems whenever sulfides are present."

3.4 FLORIDA RESEARCH AND ENGINEERING STUDIES

3.4.1 Studies Related to Copper Material

1. ELECTRIC SKIES - ELECTRIC PIPES

by

Richard A. Dunham, Manager of Water Quality Laboratory and Clifford A. Russell, P. E., Director of Engineering and Technical Support, Orlando Utilities Commission, *Florida Water Resources Journal,* pp.4, 37-38, (February 1997)

The authors in their study to determine the effects of electrical grounding on water quality ended up with **a new theory** that (1) "indicate a direct relationship between lightning and specific type of copper plumbing failure, and (2) lightning can be conducted on household plumbing through the driven ground rod."

3.4.2 Studies Related to Water and Water Treatment Methodologies

1. INVESTIGATION AND ANALYSIS OF CONTAMINANTS IN THE POTABLE WATER SUPPLY OF PINELLAS COUNTY: Final Report on Corrosion Phase to Pinellas County, Florida

by

Y.A. Yousef, L.A. Mulford, and J.S. Taylor, Environmental Systems Engineering Institute, Civil and Environmental Engineering Department, University of Central Florida, Orlando, Florid, (February 1992)

After analyzing field pilot surveys and laboratory studies that "(1) investigated the magnitude of the corrosion problem in the County, (2) evaluated the effect of water quality parameters on corrosion rates, and (3) quantified the cause and effect for the corrosion problem," the University of Central Florida research team discovered that the addition of inhibitor to the Pinellas County Water Treatment System (PCWS) water (a) generally lowered copper and lead concentrations in standing water, (b) did not appear to change the number of sites exceeding the copper treatment action level (TAL) of 1.3 mg/L as compared with number of sites examined before the inhibitor addition, (c) reduced the number of sites exceeding the lead TAL, and (d) produced positive results in general. The research team recommended that lime softening or membrane processes be used for treating the water as opposed to the phosphate blends used in the studies. This recommendation was based on the quality control problems associated with the use of phosphate blends. Also the study team noted a potential problem in storing and using polyphosphates, namely, polyphosphates can easily be converted to orthophosphates when stored outdoors and also when exposed to the sunlight for long periods of time.

2. REVERSE OSMOSIS PLANT

by

The Sanibel Island Water Association, Inc., Captiva, February 1992

The paper reported how electro dialysis and reverse osmosis plants were fed with non-potable well water for treatment that removed such impurities as salt (from saline water) and total dissolved solids (TDS) and thus converts the unsafe and non-portable water into safe and potable water. The potable water from these plants was stored in reinforced concrete tanks from where it was pumped to the customers who used it for drinking, cooking, washing, sanitation, firefighting and so forth.

3. PHOSPHATE MONITORING IN A POTABLE WATER SYSTEM

by

Robert M. Powell, Director, Utilities Laboratory Department, Pinellas County Florida (1992)

The paper reported the results of field and laboratory studies to monitor orthophosphate concentrations in the Pinellas County Utilities Water Systems. The studies concluded that (1) "field kits are generally adequate for routine orthophosphate monitoring, (2) adequate training and quality assurance procedures are required to maintain consistent performance, (3) phosphate monitoring programs should include sample points in the distribution system as well as at the plant, (4) laboratory analysis for orthophosphate and total phosphate should be performed periodically to confirm phosphate levels determined with field kits.

4. COMPARISON OF BLENDED ORTHO-POLYPHOSPHATE CORROSION INHIBITORS

by

Robert M. Powell, Director of Utilities Laboratory, Pinellas County, Largo, Florida

and

Yousef A. Yousef, Environmental Systems Engineer, University of Central Florida, Orlando, Florida (1992).

This paper reported of a study that was undertaken to provide utilities with quantitative physical and chemical characteristics including rate of reversion from polyphosphate to orthophosphate forms and effectiveness in reducing corrosion rates of different mixtures of phosphate components products to help decision-making regarding the use of blended phosphate corrosion inhibitors. The study could not establish any of the products as clearly superior. It concluded that "the orthophosphate to total phosphate ratio for all inhibitors increased with increasing temperature, incubation time and dilution."

5. LEAD AND COPPER CORROSION CONTROL STUDY: DEMONSTRATION TEST PROGRAM RESULTS AND TREATMENT RECOMMENDATIONS FOR CITY OF ALTAMONTE SPRINGS

by

Steven J. Duranceau, PhD, PE, Project Manager with Erik L. Melear, PE, Tamara Richardson, EI and Andres Salcedo, Project Engineers, Boyle Engineering Corporation, Orlando, FL (July 1997)

The results of a full scale Demonstration Test Program performed by Boyle Engineering Corporation are that the City of Altamonte Spring continue to use orthophosphoric acid for corrosion control.

6. VALUATION OF CORROSION INHIBITORS IN DRINKING WATER SYSTEMS

by

David B. Williams, Jr.

Master's Thesis Report Submitted to College of Engineering, University of Central Florida, Orlando, FL., (Summer 1994)

The author used pilot studies to (a) evaluate the effectiveness of various inhibitors on corrosion rates for copper and lead coupons in contact with well water, (b) develop relationships between corrosion rates and various water quality parameters and (c) evaluate the effectiveness of phosphoric acid on corrosion rates for copper and lead coupons exposed to well water. The study was undertaken by the University of Central Florida (UCF) for Pinellas County Water Treatment System (PCWS). The studies concluded that (a) that phosphoric acid dosage of 0.88 mg/L improved corrosion rates for copper and lead coupons equal to or better than rates measured from coupons treated with inhibitors, (b) corrosion rates for copper and lead coupons installed in the corrosion test loops were reduced by the addition of inhibitors, (c) the initial orthophosphate content of the inhibitor dictated the inhibitor feed rate; thus, inhibitors with initial lower ortho- to total phosphate ratios may require higher feed rates, (d) ortho- to total phosphate ratio for all of the inhibitors increased with time and temperature and (e) changes in water quality parameters, operational problems, and experimental errors caused corrosion rates to vary greatly. The study also established that corrosion rates for lead and copper coupons varied linearly with "inhibitor dosage in terms of ortho- and total phosphorus concentration within the ranges of tested conditions."

7. THE IMPACT OF OZONE ON BROMATE FORMATION IN GROUNDWATER AT THE CITY OF JACKSONVILLE

by

David W. McEwen, Graduate Research Assistant, University of Florida,
Karla J. Schmidt, Project Engineer, CH2M HILL, Gainesville, Florida,
Paul A. Chadik, Assistant Professor, University of Florida,
Don Thompson, Managing Engineer, City of Jacksonville

and
Tim Perkins, Chief of Water Division, City of Jacksonville (1996)

A pilot study undertaken for the City of Jacksonville to determine the best method of treating groundwater containing sulfide for the future Ridenour Regional Water Treatment Plant. The research study concluded that for (1) "sulfide oxidation by ozone, no additional treatment is necessary to keep bromate levels below the proposed standard of 10 ug/L and (2) high background bromide concentration, pH depression and ammonia addition was inadequate to meet the bromide minimum concentration level."

8. SODIUM HYPCHLORITE REPLACES CHLORINE GAS AT A LARGE CENTRAL FLORIDA WATER TREATMENT PLANT

by

David Baar of Sverdrup Civil, Inc., Tim Brodeur of Malcolm Pirnie and Brad Jewell of the City of Kissimmee (1996).

Following the initial recommendation of earlier field testing study to change the water treatment to include chlorine oxidation for hydrogen sulfide removal, this study was authorized to evaluate the chlorine gas and sodium hypochlorite oxidants to identify the most appropriate one to use at the North Bermuda Water Treatment Plant in Kissimmee, FL. After evaluating these two oxidants in terms of safety and OSHA requirements, capital and chemical costs as well as other concerns such as availability and by-products, sodium hypochlorite emerged as the superior oxidant.

9. REPORT ON THE FIRST YEAR OF OPERATION OF THE T. MABRY CARLTON, Jr. ELECTRO DIALYSIS REVERSAL WATER TREATMENT PLANT IN SARASOTA COUNTY

by

Douglas H. Eckmann, PE, Boyle Engineering Corporation, Robert P. Allison, Ionics, Inc. and Patrick D. Zoeller, PE, Sarasota County Utilities (1996)

The paper summarized the performance of a complex facility and one of the world's largest facilities for demineralizing ground water using the process of electro dialysis reversal (EDR) after the first year of operation. The results of the performance tests exceeded the specification requirements in all the five indicators including production rate, recovery rate, total hardness of product water, total dissolved substances of product water and power consumption.

10. POLK COUNTY UTILITIES DIVISION'S IMPERIALAKES PUBLIC WATER SYSTEM (PWS): LEAD & COPPER CORROSION CONTROL PROGRAM

by

Steven J. Duranceau, Project Manager with Erik L. Melear and Jackie as Project Engineers, Boyle Engineering Corporation, Orlando, FL (January 1996).

The results of the full-scale Demonstration Test Program undertaken by Boyle Engineering

Corporation for the County's Imperialakes PWS indicated that the addition of sodium hydroxide was effective in reducing the copper and lead concentrations to below their action levels and that the County should continue to add sodium hydroxide to the PWS for Lead Copper Rule (LCR). The report recommended that "the County should continue to pursue cost-effective treatment programs for reducing metal release and other water quality enhancement purposes in anticipation of treatment stricter future regulations."

11. EVALUATION OF IMPERIALAKES WATER QUALITY QUESTIONNAIRE FOR POLK COUNTY UTILITIES DIVISION

by

Steven J. Duranceau, PhD, PE, Project Manager, and Jacquline V. Foster, Project Engineer, Boyle Engineering Corporation, Orlando, FL (April 1996)

The authors conducted a survey to "gather information pertaining to three specific areas: general questions, water quality and plumbing repairs that occurred in the home or office" in the Imperialakes service area. The survey results revealed, among other things, that "(1) 304 of the responders lived in homes over 15 years old, and only 45 responded living in homes less than 1 year old, (2) 475 (51%) customers used copper water pipes, (3) out of the 877 customer responses, 48% of those responding thought the taste of the water was acceptable for drinking (very good or OK responses), (4) that the water pressure was satisfactory, and (5) there were only 84 out of 795 customers that have notice a change in the quality of the drinking water supplied since June 1, 1995"

12. PROCESS EVALUATION STUDY AT PALM COAST UTILITY CORPORATION (PCUC) WATER TREATMENT PLANT (WTP) NO. 1

by

Kevin Morris and Jeff Nash, both of CH_2M Hill, Orlando, FL

and

David G. Schlobohm and Tim Sheahan, both of PCUC, Palm Coast, FL (June1996).

After evaluation of a testing program to determine an effective process alternatives that could meet expected regulations regarding disinfectant residuals and disinfection by-products (DBPs), which included enhanced coagulation, ozone ion exchange and granular activated carbon (GAC), it was concluded that (1) "although some DBP precursor removal was possible through enhanced softening, the process had negligible impact on disinfectant demand and long term residual stability for the water at WTP No. 1, (2) although ozone was effective at color destruction, it did little to meet any of the other treatment objectives, (3) ion exchange and GAC were both shown to achieve significant DBP precursor removal, significant reduction in disinfectant demand, and improved disinfectant residual stability and (4) ion exchange was projected to be nearly 40% more cost effective than GAC."

13. IMPERIALAKES PUBLIC WATER SYSTEM (PWS) IMPROVEMENTS ACTION PLAN: IMPLEMENTATION - PHASE 1

Prepared for Polk County Public Utilities Division, Polk County, FL.
by
Steven J. Duranceau, Project Manager with Jacquline V. Foster and Thomas J. Helgeson as Project Engineers, Boyle Engineering Corporation, Orlando, FL, 47 pp., (January 1997).

After developing and studying a pilot plant program at the Imperialakes Public Water System (PWS), which included special chemical analysis water quality parameter identification listing preparation, Boyle Engineering study team determined that (1) chlorine disinfection still has impact on the quality of water in the Imperialakes PWS, (2) chlorine could be maintained at uniform levels after sulfide demand was satisfied, (3) if sulfide is removed it would result in a lower chlorine disinfectant demand and more uniform finished water and (4) Imperialakes PWS could maintain compliance using chlorine as a disinfectant while maintaining pH adjustment as a corrosion control option.

14. GROUNDING CAN AFFECT WATER QUALITY

by
S. J. Duranceau, Ph.D., P.E., Boyle Engineering Corporation Orlando, FL.,
G.E.C. Bell, Ph.D., P.E. and M.J Schiff, P.E., M.J. Schiff & Associates, Inc., Claremont, CA,
R. M. Powell, Pinellas County Utilities, Clearwater, FL.,
and
R. L. Blanchetti, P.E., East Bay Municipal Utilities District, Oakland, CA
Florida Water Resources Journal, (February 1997)

After a series of tests "were conducted to investigate the effect of electrically insulating unions on water quality in the presence of applied alternating current (AC) voltages of 123 and 50" by the authors, it was concluded that (1) "there was a pronounced effect of AC voltage on copper release for both the 123 and 50 volt-AC tests, (2) metal release generally increased with charge transfer, in accordance with Faraday's law, (3) the AC corrosion rate of 0.14% of the corresponding direct current (DC) rate was arrived at."

15. WATER FACILITIES UPGRADE STUDY REPORT VOLUME I - ENGINEERING ANALYSIS FOR SEVEN SPRINGS WATER SYSTEM

Prepared for Aloha Utilities, Inc., Pasco County, Florida
by
David W. Porter, P.E., C.O., Orange Park, Florida
and
Civil Engineering Associates, Inc., Tampa, FL , (May 1997)

The study that was conducted for the Aloha Utilities in response to the order issued by the Florida Public Service Utility Commission (FPSC) recommended: "(1) that the injection of a corrosion inhibitor into the finished water produced at each of its existing water well/treatment sites be continued to reduce the natural rate of home plumbing copper corrosion to a level such that the water discoloration will cease to be a problem, (2) two alternative means of retrofitting each of eight (8) existing water well/treatment facilities and constructing two similar new well/treatment facilities with the type of treatment alterations envisioned by the FPSC in its Order." Reverse Osmosis and Ion Exchange technologies were considered in this approach but they were rejected as providing no measurable benefit in reducing hydrogen sulfide.

The FPSC's order was issued in response to the petition filed by about 262 customers within the Aloha's Seven Spring Sprigs service area in regard to the utility's rate and water quality in particular problems with black water that these customers were experiencing. FPSC, on October 23, 1997, recommended that (1) Aloha should investigate and plan for the installation of treatment facilities to increase it's waters pH, (2) "the only quick solution for eliminating problems with black water is to repair their homes with CPVC" because the black discoloration "is an indication of that their copper pipes are deteriorating and (3) Aloha should "inform all builders and plumbers within the local area of problems which its customers who have copper plumbing have experienced."

3.4.3 Studies Related to Corrosion

1. CORROSION OF MIXED METAL FIRE SPRINKLER SYSTEMS
by
Copper Development Association Inc. (1991)

This paper was prepared to provide answers to questions concerning automatic fire sprinkler systems using copper tube and fittings in conjunction with conventional steel pipe and their ability to resist galvanic corrosion. The paper (a) investigated the tendency of occurrence of corrosion in sprinkler systems where mixed metals were used and (b) offered the results that explained the basic fundamentals for galvanic corrosion and the specific conditions favoring galvanic corrosion formation. The results of 1991 study were presented to provide solutions, explanation, water treatment types and inhibitors to use in sprinkler systems to reduce or prevent galvanic corrosion.

2. KNOWING THE CAUSE OF COPPER PIPE CORROSION CAN HELP PREVENT IT
by
Donald Waters, Vice President of Corrpro Companies/PSG Corrosion Engineering Inc.,
Florida Water Resources Journal, p.33, March 1994.

This article was written by an author who "has witnessed internal corrosion occurring naturally and corrosion induced by different conditions generated by man including gases in water chemistries which yield corrosion, cavitation, impingement, dissimilar surface conditions of the piping, velocity, deposit on horizontal runs of pipeline if sand or silt builds up on the bottom of the pipe, carbon dioxide and/or oxygen in water, presence of carbon inside of pipe line, hot water with manganese, and workmanship during installation of copper pipe." He also described such things as secure fastening of copper pipes through concrete slab, pushing rocks upon backfills that contain copper pipes so as to change the surface conditions of the pipe, use of acid-type fluxes, use of solders especially lead tin solders and failure to deburr copper tubes as they are cut that plumbing contractors do during installation and/or maintenance that contribute to increase in corrosion rates in copper tubing. The author finally provided solutions the causes of copper corrosion that he identified and described in his paper. The author's main objective of this study was that users and installers of copper tubes should be familiar with the causes of copper pipe corrosion so as to determine the appropriate method(s) to mitigate or prevent the corrosion.

3. APPLICATION OF ELECTROCHEMICAL AND SURFACE ANALYTICAL TECHNIQUES TO STUDY EFFECTIVENESS OF CORROSION INHIBITORS IN POTABLE WATER SYSTEM

by

Lily Qian-Falzone

Master's Thesis Report Submitted to College of Engineering, University of Central Florida Orlando, Florida (Summer 1994)

The author used a combination of electrochemical and surface analytical techniques to (a) evaluate the effectiveness of five inhibitors on copper and lead corrosion control and (b) study the characteristics of surface films formed due to the actions of the inhibitors. The combined techniques provided a better results than gravimetric techniques (weight loss measurements). The combined techniques also provided such information as a profile of the mechanism, efficiency and longevity protection offered by corrosion inhibitors.

4. CORROSION CONTROL IN POTABLE WATER SYSTEMS: A FULL-SCALE STUDY

by

Roger M Smith, P.E, Utilities Manager and Charles R. Womack, Water Operations Supervisor, Seminole County Public Works Department

and

June A. Smith, P.E., Associate Engineer and Luke A. Mulford, P.E, Associate Engineer, Brown and Caldwell Consultants (1996)

This paper presented a report of the regulatory framework for the Lead and Copper Rule, as well as background information regarding the raw water quality, treatment process and finished water quality of the Greenwood Lakes Water Treatment Plant (WTP) where a full-scale demonstration study was undertaken. The injection of sodium hydroxide into the finished water with sufficient calcium and alkalinity, elevated the pH to above stability and resulted in the reduction of copper concentrations of tap samples at 14 of 15 sites as well as all but two sites' treatment action levels getting below the required 1.3 mg/L.

3.5 SUMMARY OF LITERATURE SEARCH

The following (conveniently grouped under copper material, water, corrosion and workmanship) presents the analysis and synthesis of the research study reports presented in this chapter:

A. COPPER MATERIAL

01. Studies conducted in Australia have shown that (a) cuprous oxide films having p-type semiconducting properties are more corrosion resistant than films having n-type semiconducting properties, (b) p-type cuprous oxide films are beneficial while n-type cuprous oxide films are detrimental with respect to pitting, and (c) the desirable p-type cuprous oxide film can also be formed by exposing copper to dilute hydrogen peroxide solutions (Cohen, 1994).

02. Majority of the European studies conducted in the 1960s and 1970s concluded that most of the corrosion failures occurred with soft-annealed tubes. The statistics of the DKI show that in 1982, 88 percent of the pitted tubes were in the soft-annealed temper (Van Franque 1983).

03. Results of European tests conducted in laboratory and reported by Campbell (1965) showed that "soft-temper tubes are more susceptible to corrosion (especially to pitting corrosion) than half-hard tubes, which in turn are more susceptible than hard-temper tubes."

04. The research and engineering studies and the resulting publications outside of USA dealt with problems in buildings, copper and other metal manufacturing process as well as installation, operations and use of these metals in water distribution systems. These studies led to governmental regulations which are not considered as demanding as those promulgated in the USA.[Campbell (1965), Cohen (1994) Van Franque (1983)]

05. This study agrees with the Michigan Study in concluding that "by keeping the indicated limits of water quality, temperature and velocity, copper and copper alloys will produce extremely good service in hot and cold water distribution systems." (Jacobs, 1997)

B. WATER

06. Water composition has been found in Europe and other parts of the world to be a major contributor of corrosion, especially pitting corrosion (Baukol, et al. 1982, Campbell 1954 & 1965, Mattson et al. 1968).

07. Some Florida water providers who have had or do have corrosion problems often conduct field pilot surveys and laboratory studies to (a) investigate the magnitude of the corrosion problem(s) in their water systems, (b) evaluate the effect of water quality parameters on corrosion rates, and (c) quantify the cause and effect for the corrosion problems. Water treatment is the most common remedy recommended, consisting mainly of raising the pH or adding inhibitor (Yousef et al. 1992, Powell 1992, Williams 1994).

08. Water characteristics such as pH, alkalinity, hardness, total dissolved solids (TDS), dissolved oxygen (DO), chlorine residue or residual chloride, ammonia and sulfate alter corrosion and/or solubility rates of many metals, e.g., copper (Obrecht et al. 1961, Wolfe 1993).

09. Changes in water quality parameters and operating conditions, workmanship and/or repair, problems and/or errors can cause corrosion rates to vary greatly (Waters 1994).

10. It is inferred from items 7, 11, and 12 that more corrosion inhibitors are being added to the Florida water treatment systems than before the SDWA and LCR eras.

11. Some of the chemicals such as over-dosage or excessive chlorine, chloride, etc. have the tendency to make the water aggressive. (See references 5, 7, 13, 14, 41, 52, 53, 60, 68 and 106).

12. Such chemicals as orthophosphates, polyphosphates, chloride, chlorine, sodium hydroxide, calcium hydroxide, bromate, etc. are being used by Florida water providers as a result of recommendations from both field and laboratory tests to mitigate and/or eliminate corrosion, metal dissolution, water discoloration and/or taste and sulfide presence (Williams 1994, McEwen et al. 1996)

13. Considerable number of the Florida studies and their resultant reports were in response to or in anticipation of the Safe Drinking Water Act (SDWA) and/or Lead Copper Rule (LCR). They were mostly conducted to fulfill the requirements of these laws and regulations (Williams et al. 1994, Baar 1996).

14. Water quality plays a significant role in the corrosion process. The most significant factors are pH, inorganic carbonate, dissolved oxygen, excessive chlorine and higher temperatures. Other factors that play a part in the corrosion process include calcium, silicate, organic matter, ammonia, sulfate, chloride, phosphate and nitrate (Obrecht et al. 1961, Wolfe 1993).

C. CORROSION

15. Taken as a whole, the Michigan studies and their findings (Obrecht et al. 1961) raise the prospect that:
(a) hard water provide carbonate silica deposits in the inside of copper tubes,
(b) the deposits form a protective coating inside the tubes and prevent the copper tubes from corroding,
(c) zeolite softened water cause corrosion and/or premature failures in new copper tubes because they did not have protective coating on the inside of the tubes and

(d) if a method can be devised to deposit carbonate silica deposits in copper tubes before softened waters are used in the tubes, corrosion and leaks can be prevented.

16. We learned from the Michigan studies (Obrecht et al. 1961) that (a) copper tubes in which softened water is used from the outset and have had no protective coating would have tendency toward corrosion and subsequent leakage unlike the older copper tubes which build protective film of thin, hard, adherent carbonate silica deposit from earlier hard water and (b) if a method could be devised to deposit film of thin, hard adherent carbonate silica deposit in newer pipes prior to being exposed to softened water, corrosion could be prevented.

17. Different conditions generated by man that can cause internal corrosion include gases in water chemistry, impingement, dissimilar surface conditions of the piping, velocity, deposit on horizontal runs of pipeline if sand or silt builds up on the bottom of the pipe, carbon dioxide and/or oxygen in water, presence of carbon inside of pipe line, hot water with manganese, and aluminum as well as workmanship during installation and/or maintenance of copper tubes (Waters 1994).

18. Sulfide exposure increases the release of copper corrosion by-products to drinking water when compared to pipes that has never been exposed to sulfides. Jacobs' study revealed that "during a three-hour stagnation time, sulfide exposure elevated copper release by about 500% and 5000% at pH 6.5 and pH 9.2, respectively."(Jacobs 1997)

19. Sulfide-induced corrosion problems once initiated, are very difficult to stop. Research results by Jacobs using only laboratory data support the fact that removing sulfides from the raw water and adding chlorine or de-aerating water would not be effective in mitigating the problem within a few weeks or months (Jacobs 1997).

20. "Thick, black corrosion-accelerating copper sulfide scale smeared onto a new copper pipe surface and placed into a water without sulfides has the tendency to result in corrosion rate that is comparable to that would be obtained after sulfide exposure" (Jacobs 1997).

21. Adverse effects from sulfides are not confined to copper corrosion in the laboratory and that the likelihood of copper corrosion problems in copper pipes whenever sulfides are present is great (Jacobs 1997).

22. It is inferred from items 8, 9, 13, 15, 23 and 24 that water quality parameters associated with corrosion in copper tubes in potable water systems include pH, alkalinity, dissolved gases, total dissolved solids, dissolved oxygen, chlorine residue, chloride, ammonia, sulfide, sulfate, dissimilar surfaces, velocity, temperature, carbon, carbon dioxide and poor workmanship (including those listed in items 15, 23 and 24).

23. Many studies have been done in Florida on corrosion and water treatment but none of

them followed the same protocol and objectives as this study in dealing with corrosion in general, potable water sources and treatment processes required for these sources, identifying the types of corrosion, their causes and solutions, and identifying the extent of corrosion problems in Florida.

D. WORKMANSHIP

24. Van Blaricum et al. state that "workmanship practices, in particular excessive soldering flux, used in installing copper are the sources of premature failures in copper potable water systems" (See reference 101).

25. Workmanship practices that plumbing contractors use during installation, repair and/or maintenance that contribute to corrosion in copper tubes are classified as (a) secure fastening of copper pipes through concrete slab, (b) excessive use of non-approved soldering fluxes (Flux must meet ASTM B-813, (c) use of non-approved solders containing especially lead, (d) failure to deburr copper tube ends after they are cut and (e) damaging copper tube with backfill during installation (See also references 101 and 104).

CHAPTER 4
FIELD DATA ANALYSIS AND EVALUATION

4.1 RESEARCH METHODOLOGY

4.1.1 Introduction

The two general features of this study and the work involved were achieved by (a) field study using a questionnaire to capture the knowledge and experience in the field and (b) in-depth interviews with knowledgeable and interested personnel representing plumbing contractors and suppliers, building inspectors, water providers and building owners/managers. The study team analyzed, assessed, and evaluated the data collected from the field study and interviews, the provided study summary, conclusions and recommendations based on the analyses and evaluations.

The following subsections provide detail account of the survey instrument development, field study using the survey, development and execution of in-depth interviews at focus sessions.

4.1.2 Survey Instrument: Development of Content

Prior to developing a survey instrument to collect the data necessary for analyses and evaluations, the researchers conducted literature search to gather currently available information from published literature and industry input. From the information gathered from literature search, the researchers developed the survey instrument and pre-tested it. Very useful suggestions and critiques on the questionnaire were obtained from Messrs. Robert Hall, CDA's Southeast Regional Manager; Russ Smith, BCIAC's Project Coordinator; Dan Shaw, Chairman of Plumbing Codes & Standards Committee; Mo Madani, DCA's Building Codes and Standards' Planning Manager; as well as Drs. Brisbane H. Brown, Jr., Professor of Building Construction at University of Florida (UF) and Jimmie Hinze, Director of the M.E. Rinker, Sr. School of Building Construction at UF. Appendix B shows the survey instrument that was sent to Florida plumbing contractors, building inspectors, building owners and/or managers and water providers.

The questionnaire was designed to gather information relating to five (5) areas, namely:

- A. General information and geographic location
- B. Copper tube corrosion types identification
- C. Causes of corrosion
    - C1: Materials and workmanship
    - C2: Water sources and their chemistry
    - C3: Design and operation
- D. Solutions to copper corrosion problems
- E. Economics of copper corrosion problems

The general questions were geared to collecting information on companies and their representative(s) providing input on the study as well as the geographic location(s) and duration of their copper experience in Florida.

In the copper corrosion types identification section, the questions were designed to gather information on copper failure awareness, corrosion origination, types of corrosion as well as locations [plumbing system and building (by type and age)] and frequencies of copper failure occurrence(s).

The causes of corrosion questions focused on materials, workmanship, design, operations, construction practices as well as water sources, water chemistry and need for treatment.

The solutions to copper corrosion problems sought information on successful design, installation and operation practices.

The economics of copper corrosion questions attempted to determine who usually pays for corrosion repairs in buildings and why.

The authors realized from the very beginning of the study after examining the voluminous publications from engineering and research studies done in Florida that (a) none of them dealt with all the five areas in one study as this study and (b) this study is only one that addressed all these broad, intricate and diverse issues.

4.1.3 Conducting the Survey

After incorporating all the input from the reviewers, the survey instrument (See Appendix B) was mailed-out to three groups initially identified, namely: plumbing contractors, plumbing inspectors, and water providers. Over five hundred (500) questionnaires were sent to these three groups. It was concluded that the best data would come from these three groups because they had the closest relationship and working knowledge with the subject matter. The plumbers would have installed the materials and would, in all likelihood, be the ones to make any repairs or replacements. The plumbing inspectors were considered to have knowledge of any major repairs or replacements because of the necessity of obtaining a permit for the work. The water providers because of the Lead Copper Rule (LCR) would be required to take action if copper levels exceeded the standard requirements. A fourth group, the building owners and /or managers (BOMA) was identified during the latter stages of the data collection efforts and questionnaires were sent to nearly two hundred (200) of this group. The research team was at the Florida Plumbing, Heating and Cooling Contractors (FPHCC) Annual Association meeting in June of 1997 in Ft. Lauderdale and presented a session on this study as well as distributed seventy to eighty questionnaires to the attendees of the meeting.

In addition to the mail-out questionnaires, the researchers followed up with telephone call-backs and in-depth interviews.

It must be noted that the four groups that were identified, selected and invited or used for both field survey and focus sessions studies were professionals and members of trade and professional associations. Both these professionals and their trade as well as professional associations keep themselves abreast of current knowledge and practices in their respective industries. Therefore, any data or opinion obtained from such professionals can be considered as having great importance, use or value.

4.1.4 Developing and Conducting Focus Sessions

Selected key professionals identified as knowledgeable and interested in the copper tube corrosion study including plumbing contractors, material suppliers, plumbing inspectors, and water providers and users of copper tubes in potable water systems both large and small facility owners were invited for a half day in-depth interviews and exchange of information regarding the five areas of interests on the survey questionnaire.

There were eight focus group sessions that were developed and conducted by the research team. Five were conducted in Orlando at the request of DCA and one each in Tallahassee, Jacksonville, and West Palm Beach. In addition to seven focus sessions mentioned above, the research group made a presentation and had a focus discussion at the FPHCC Annual Convention in Ft. Lauderdale.

1. Orlando Focus Sessions: In Orlando the sessions were held in junction with the DCA's building plumbing codes and standards committee meetings. At the suggestion of DCA, an advisory committee was formed to assist DCA in assuring a consensus report for their use and acceptance. At the first session, approximately 20 individuals were invited and 30 persons attended. At the second session, approximately 20 individuals were invited and 35 persons attended. Approximately 24 individuals were invited for each of the third and fourth sessions and roughly 30 persons attended each session whereas the fifth one was attended by 18 people.

2. Tallahassee Focus Session: In Tallahassee, approximately 35 individuals were invited from the plumbing inspectors, plumbing suppliers and contractors, building owners/managers, water providers and selected DCA Advisory Committee members in the Tallahassee area. Five (5) persons attended this session; the meeting was productive.

3. Jacksonville Focus Session: In Jacksonville, approximately 35 individuals were invited and 8 persons attended including a corrosion expert from UF as well representatives from the water providers, home owners and plumbing suppliers.

4. West Palm Beach: In West Palm Beach, approximately 35 individuals were invited and 10 persons attended. Every group was represented at this session and very usable and important information was obtained at this session.

4.2 LIMITATIONS OF THIS RESEARCH STUDY

The depth of research and magnitude of data required to determine the causes and solutions to Florida Copper Water Tube Corrosion including all the divergent, intricate and vast variables and their interplay are difficult to achieve in any one research study and this research study was no exception especially considering the money and time constraints for this study. This is the first known study on Florida Copper Water Tube Corrosion that covered Florida copper corrosion geographic location, corrosion types identification, causes, solutions to and economics of Florida copper corrosion problems in one study. The research team made efforts to collect a well-rounded sampling of data which would allow dynamic exploration of the causal relationships among all the copper corrosion variables, hence the collection of qualitative and quantitative data. In an effort to acquire enough data to make meaningful analyses and assessments, respondents were asked for hard performance data as opposed to their best estimates or opinions. The subjective nature of perception-based answers provided by respondents were difficult to evaluate. Furthermore, the researchers did not receive the amount of responses and the quantity of data they asked for - i.e. there were very low response rate (See Table 4-1) and too many "no response" and/or "not known" on the response forms. Finally, the data obtained from the study were important and valuable, yet there were not enough for any statistical analyses. Given these limitations, the researchers could not draw any conclusions from this study that may pin point the causes of and/or solutions to Florida copper corrosion problems neither were the researchers able to reveal the divergent, complex and vast copper corrosion variables and their interwoven relationships. Due to these limitations, the results of study presented in the following sections **are considered exploratory and preliminary**.

4.3 EVALUATION OF EXPLORATORY FIELD DATA FROM QUESTIONNAIRES

4.3.1 Introduction

Table 4-1 shows the total surveys mailed by respondent categories and the responses from each category. It is inferred from Table 4-1 that the researchers asked for enough responses from the various groups; however, they did not get what they asked for. Table 4-2 shows the distribution of responses by frequency/percent based on the 135 usable responses received for analysis.

Table 4-1: Summary of Survey Instrument Mailed/Handed Out and Responses

Respondent Category	Total Mailed/ Handed Out	Total Returned	Total Used	Percent Responses
Plumbing Contractors	240	43	43	17.9
Building Owners	196	5	4	2.6
Plumbing Inspectors	200	56	56	28.0
Water Providers	144	33	32	22.9
Total	**780**	**137**	**135**	**17.6**

4.3.2 Results of Survey

The following section describes in detail the results of data obtained from the survey conducted. The numbers (e.g. 1, 2, 3, 4, and so forth) correspondent to the numbers on the survey instrument developed and used for this study; they indicate the respondent group (e.g. 1 is for Plumbing Contractor) or type of response (e.g. 1=Yes, 2=No, 4=Unknown, 9=No Response).

Table 4-2 :Frequency/Percent Responses from Respondents

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Plumbing Contractors	1	43	31.9	31.9	31.9
Building Owners	2	4	3.0	3.0	34.9
Building Inspectors	3	56	41.5	41.5	76.4
Water Providers	4	32	23.6	23.6	100.0
TOTAL		**135**	**100.0**	**100.0**	

4.3.2.1 General Information and Geographic Location

1. Cities With or Without Copper Corrosion Experience

Based on the limited data available, Table 4-3 provides a list of cities in Florida having copper corrosion problems as well as cities not experiencing any copper corrosion problem by respondent type. The numbers in brackets following some cities indicate the number of times the city was mentioned by the respondents. The list compiled from the respondents' responses is slightly misleading in the sense that a city could be listed in both categories as having and not having corrosion problem within a respondent type. The same observations were made from the list for certain cities across respondent types. For example, Delray Beach is listed in both categories by plumbing contractors while building inspector mentions the same city as having corrosion problems. The only explanation for such responses is that an area in a city may have corrosion problems whereas other areas in the same city may not have corrosion problems or vice versa.

Figure 4-1 provides a map of Florida showing the cities having copper corrosion problems based on Table 4-3. It is inferred from Table 4-3 and Figure 4-1 that geographic **regions** of copper corrosion in Florida are, in general, found in: (a) the Jacksonville area and along I-95 to Daytona Beach, (b) the Ormond Beach/Daytona Beach and along I-4 corridor from the east coast through Orlando to Tampa/St. Petersburg areas, and (c) along both east and west coasts southward from Ormond Beach and Tampa to the Miami areas, respectively. The cities that were mentioned in the study to have severe corrosion are Orlando (#1), Tampa (#2), Boca Raton (#3) with the fourth place shared by Winter Park and St. Petersburg.

2. Respondents' Number of Years Experienced With Copper Tube in Potable Water Distribution Systems in Florida

The number of years that respondents provided regarding their experience(s) with copper tube in potable water distribution systems in Florida ranges from 0 to 50. A third (45 or 33.33%) of the respondents have between 18 and 25 years of experience with copper as a plumbing material in Florida. Twenty of the respondents have had copper experience outside Florida.

Table 4-3: Geographic Locations Covered by Cities and Respondent Type[01]

Cities With Corrosion Problems	Cities With No Corrosion Problems
1. Plumbing Contractors	
Altamonte Springs, Casselberry, Winter Park, Orlando (8) Marco Island, Palm Bay, Boynton Beach, Delray Beach, Miami, Melbourne Area, Jacksonville, St. Petersburg (2), Fort Lauderdale (2), Port Charlotte, Longwood, Apollo Beach, Killaney, Boca Raton (4), Holly Hill, Lakeland, Ocala, Bartow Kissimmee, St. Cloud, Auburndale, Sun City, Tampa (2).	Boca Raton, Delray Beach, Palm Beach County (2), Gainesville (2), Miami (2), Bradenton Area.
2. Building Owners	
Winter Park	Ft. Lauderdale, Plantation, Boca Raton.
3. Building Inspectors	
Kissimmee, Panama City, Eagle Lake, Holmes Beach, Palatka Winter Park, Port Charlotte, Tallahassee, Lake Mary, Gainesville, Longwood, Sebring, Orlando (2), Hanes City, Hobe Sound, North Long Boat Key, Brooksville, Tampa (2), Miramar, Layton, Live Oak, Cape Coral, Delray Beach, Okeechobee, Sanibel, Vero Beach, Belleair, Avon Park, Venice (2),West Palm Beach	Lake City, Apalachicola, Melbourne, Tavares, Ocala, Monticello, Macclenny, Miami, Arcadia, Melbourne Beach, Jupiter, Palmetto, Bradenton, Hialeah Gardens, Lake Helen, Pensacola, Mary Esther, Hollywood, Edge Water, Fellsmere, Penney Farms, Daytona, Palm Bay, Malabar, West Pam Beach.
4. Water Providers	
Tampa (2), Lithia, Jupiter Island, Ocoee, Miami, Pompano Beach All Cities in Pinellas County, St. Petersburg, Bartow, Daytona Beach, Ormond Beach, Port Orange, Valparaiso, Maitland, Cocoa, Cocoa Beach, Rockledge, Orlando	Dunedin, Naples, Tamarac, Tampa, Palm Beach Gardens, Margate, Lacento, Sanford, Lakeland, Bradenton, Anna Maria Ellenton, Bradenton Beach, Palmetto, Holmes Beach, Tallevast, Pinellas County, Vero Beach (2), Titusville, Pensacola, Melbourne, Cocoa.

[01]The number in brackets following cities indicate the number of times the city was mentioned by respondents.

● Plumbing Contractors
★ Building Owners
▲ Building Inspectors
■ Water Providers

Fig. 4-1: Respondents' Map of Cities Having Copper Corrosion Problems in Florida

4.3.2.2 Identification of Copper Tube Corrosion Types

3. Awareness of Copper Tube Failures

Table 4-4 shows numerical responses of copper corrosion awareness by respondents. Sixty percent (60% or 81 out 135) of the respondents were aware of copper corrosion in their cities while 36% or 49 out of 135 respondents were not aware or do not have corrosion problems in their cities.

Table 4-4: Respondents' Awareness of Florida Corrosion

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	81	60.0	60.0	60.0
No	2	49	36.3	36.3	96.3
May Be	5	1	.7	.7	97.0
No Response	9	4	3.0	3.0	100.0
TOTAL		**135**	**100.0**	**100.0**	

4. Origination of Corrosion Failures in the Copper Tube

Concerning where copper tube corrosion failures originate, nearly 30% (40 out of 135) replied "both inside and outside the tube" while 23 or 17% believe that copper failures originate from inside. Nearly 45% or 61 respondents either did not know or did not respond as seen in Table 4-5.

5. Lightning as a Source of Copper Tube Failures

Table 4-6 shows that 39 respondents or 29% consider lightning as a source of copper failures in their cities whereas nearly 18% or 24 respondents did not consider lightning as a source of copper tube failures. 71 respondents or 52.6% did not know or respond.

6. Number of Occurrences of Copper Tube Failures in the Three Building Types Provided

Questions regarding number of occurrences of copper failures in single family, multi-family and commercial buildings did not provide clear indication as to what went on in past year or even over years because a greater number of respondents, at least 65% in each time frame and/or building type did not provide responses. Figures that were provided by the remaining 35% or less of the respondents did not provide an insight into the extent and trend of copper corrosion in Florida. By word of mouth, copper corrosion is widespread but the study team did not obtain meaningful data for analysis to indicate how widespread this problem is.

Table 4-5: Origination of Corrosion Failures by Respondents

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Inside Tube	1	23	17.0	17.0	17.0
Outside Tube	2	11	8.1	8.1	25.1
Both Inside & Outside	3	40	29.7	29.7	54.8
Unknown	4	14	10.4	10.4	65.2
No Response	9	47	43.8	43.8	100.0
TOTAL		**135**	**100.0**	**100.0**	

Table 4-6: Percent Frequency of Lightning as a Source of Copper Tube Failures

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	39	28.9	28.9	28.9
No	2	24	17.8	17.8	46.7
Not Known	3	28	20.7	20.7	67.4
May Be	4	1	.7	.7	68.1
No Response	9	43	31.9	31.9	100.0
TOTAL		**135**	**100.0**	**100.0**	

7. Age of Plumbing Systems Where Copper Tube Failures Have Occurred

Questions regarding the age (in years) of plumbing systems where copper failures have occurred yielded the results in Figure 4-2. As can be seen from Fig. 4-2, these failures do not follow any particular pattern.

	Single Family Buildings	Multi-Family Buildings	Commercial Buildings
Newest System	1-5 Years	1-5 Years	1-10 Years
Typical System	10-15 Years	10-20 Years	10-20 Years
Oldest System	20-30 Years	20-35 Years	20-40 Years

Figure 4-2: Age of Plumbing Systems Where Copper Tube Failures Occurred

8. Copper Tube Corrosion Producing Water Discoloration
Sixteen (16) respondents or 11.9% said "yes" to copper tube corrosion producing water discoloration, followed by 34 (or 25.2%) who said "no." Ninety-four (94) respondents or 62.2% did not know nor responded. Table 4-7 shows the tabulation of these responses. Those that responded "yes" chose "green" as their first color followed by blue and black.

Table 4-7: Responses for Copper Tube Corrosion Producing Water Discoloration

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	16	11.9	11.9	11.9
No	2	34	25.2	25.4	37.3
Not Known	4	29	21.5	21.7	59.0
No Response	9	55	40.7	41.0	100.0
Missing	•	1	.7	MISSING	
TOTAL		**135**	**100.0**	**100.0**	

9. Locations in the Plumbing Systems Where Copper Corrosion Failures Occurred
Of the 135 respondents that reported in the categories where in the plumbing system copper corrosion failures occurred, 64 chose "cold water side" as number '1' followed by "foundation under concrete" (60 respondents chose this category), "hot water side" (53 respondents chose this category), "in a joint" (40 respondents chose this category), "in the main line" (42 respondents selected this category) and "in concrete foundation without sleeve" (37 respondents chose this category). Each category was independently analyzed, hence figures presented here add up to more than 135.

10. Ranking of Copper Tube Corrosion Types
Pitting corrosion was ranked number one by 32 respondents or 23.7%, followed by general corrosion (22 or 16.3%), galvanic (10 respondents or 7.4%) and erosion-corrosion (5 or 3.7%). Again, because each group was analyzed separately, the numbers did not add up to 135.

According to the literature search presented in Chapter 2, (p.2-4), supported by other studies presented in Chapter 3 (p. 3-2), pitting corrosion is believed by many authors and researchers to be caused by aggressive water especially with the presence of chloride (Baukloh 1982, Campbell 1954 & 1965, Edwards et al. 1991, Kasul et al., 1992 & 1993, Myers et al. 1995, Mattson et al. 1968 and Wolfe 1993). It can thus be **suspected** that Florida water either is aggressive and/or has high level chloride presence to be contributors of pitting corrosion.

4.3.2.3 Causes of Corrosion

11. Selection of Joining Methods Generally Used

Concerning the type of jointing method used, soldered joint was used by 118 respondents compared with mechanical joints (32) and brazed joint (24). Van Blaricum, Waters and others attribute poor workmanship practices, in particular excessive soldering flux, used in installing or replacing pipes as the sources of premature failures in copper potable systems. Thus, if soldered joint is generally used more than the remaining joining methods in Florida, it can deduced that poor workmanship is a contributor of premature copper failures.

12. Selecting the Type of Copper Tube Generally Used in Building Types Provided

Questions regarding the type of copper used in the three types of buildings in the respondents' cities produced an overwhelming choice of Intermediate Wall (Type L) in all building types followed by Thin Wall (Type M) as seen in Figure 4-3. Studies reported by Campbell and the others revealed that half-hard or intermediate wall copper tubes are more susceptible to copper corrosion than hard-tempered or thick wall. Thus, if intermediate wall (Type L) copper tubes are generally used in the three building types, it can be inferred that the copper tubes in these building types are not going to last as long as the Type K (thick wall) would.

	Single Family Buildings	Multi-Family Buildings	Commercial Buildings
Type K (Thick wall)	24 (18%)	19 (14.1%)	42 (41.1%)
Type L (Intermediate wall)	89 (65%)	80 (59.3%)	81 (60%)
Type M (thin wall)	75 (55.6%)	61 (45.2%)	34 (25.5%)

Fig. 4-3: Type of Copper Tubes Used in the Three Building Types

13. Method(s) of Applying Flux When Solder Joining Method Is Used

Applying flux by brushing was the number one choice by respondents (107 respondents or 79.3%) followed by applying flux using finger, etc. (12 or 8.9%) and immersing (11 or 8.1%).

14. Awareness and/or Usage of ASTM B813 Approved Fluxes

There were equal numbers of the respondents (65 or 48.1%) that knew and applied ASTM B813 approved fluxes as those that did not know or respond (65 or 48.1%). See Table 4-8 for detail responses.

15. Ends of Copper Tubes Reamed or Not Before Installation

40 respondents or 29.6% reamed copper tube ends before installing them while 46 or 34.1% did not ream copper ends. Table 4-9 shows the detail responses from the respondents.

16. Allowances Provided for Copper Tubes to Expand or Contract When They Are Placed in Concrete Slabs or Walls

72 respondents or 53.3% responded "yes" indicating that they made allowances for copper tubes placed in concrete walls or slabs to expand and/or contract while 22 or 16.3% did not. Table 4-10 provides the detail breakdown of the responses from the respondents.

Table 4-8: Awareness and Usage of ASTM B813 Approved Fluxes

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	65	48.1	48.1	48.1
No	2	5	3.7	3.7	41.9
Unknown	4	46	34.1	34.1	85.9
No Response	9	19	14.1	14.1	14.1
TOTAL		**135**	**100.0**	**100.0**	

Table 4-9: Copper Tube Ends Reamed Before Installation

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	40	29.6	29.6	29.6
No	2	46	34.1	34.1	63.7
Unknown	3	33	24.4	24.4	88.1
No Response	4	16	11.9	11.9	100.0
TOTAL		**135**	**100.0**	**100.0**	

Table 4-10: Expansion/Contraction Allowances for Copper Tubes Placed in Concrete Slabs or Walls

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	72	53.3	53.3	53.3
No	2	22	16.3	16.3	69.6
Unknown	4	27	20.0	20.0	89.6
No Response	9	14	10.4	10.4	100.0
TOTAL		**135**	**100.0**	**100.0**	

17A. Workmanship Practices That Cause Copper Tube Corrosion
The top five workmanship practices that respondents provided as causing copper tube corrosion are as follows:

1. too much flux (13 times);
2. not covering copper piping and fitting when it is in contact with concrete (8 times);
3. not cleaning after applying joint material (6 times);
4. use of dissimilar materials (6 times); and
5. not flushing plumbing systems after installation (4).

The poor workmanship list above provided by the respondents as major cause(s) of copper corrosion are similar to those revealed by the literature in Chapter 3 (See Van Blaricum et al. 1991, and Waters, 1994).

17B. Workmanship Practices That Help Reduce Copper Tube Corrosion
The top five answers regarding workmanship practices that can help reduce copper tube copper corrosion are as follows:

1. sleeving protection of copper in contact with ground or concrete (4);
2. no ground connection (3)
3. activated carbon filters (2);
4. reduce chemicals in water (2)
5. proper installation methods (2).

Even though the use of chemicals and aggressive water strictly do not come under workmanship practices, these two items were frequently mentioned (at least 5 times) as the causes of copper corrosion. This is an indication that respondents were experiencing the use and/or the presence of **much more** chemicals in their water systems; the respondents did not provide numbers to indicate what "how much more" meant.

18. Sources of Potable Water
Wells (120 or 88.9%) were number one choice as source of potable water followed by lakes (22 or 16.3%), rivers (12 or 8.9%) and sea water (3 or 2.2%).

19. Providers of Potable Water
Public utilities were chosen by 90% or 121 of the respondents as potable water providers followed by private wells (45 or 33.3%) and private utilities (31 or 23%).

20. Form of Water Treatment Used for Raw Water
The form of water treatment used for raw water included: addition of chlorine (10 times chosen), aeration (7), lime addition (6), coagulation (3), reverse osmosis plant and alum softening (3), and addition of phosphates (2).

21. Objectives of Water Treatment Processes Used by Respondents
Objectives for water treatment processes range from biological purity (87 or 64.4%), control of corrosion (56 or 41.5%), scaling control (33 or 24.4%) to dissolution control (15 or 11.1%).

22. Treating Water to Correct Corrosion Problems, When and What Action(s) Taken.
Forty-six (46 or 34.1%) answered "yes" to treating water to control corrosion with most of the treatment occurring between 1994 and 1997. Almost equal number of responses (4 to 5 each) were given as to what was done in the correction of corrosion processes. The actions taken included injection or addition of lime, ortho or poly phosphates, and pH adjustments.

23. Calcium Carbonate Saturation Index for Potable Water
Thirty-nine (39) out of 135 or nearly 29% reported positive carbonate saturation index while 8 respondents or 5.9% reported negative saturation index. From the literature read, negative saturation index is an indication of aggressive water (Cohen 1978).

24. PH Factor for Potable Water
Nearly 83% or 112 respondents had potable water with pH between 7 and 9

25. Oxygen in Potable Water
Of the 32 respondents that provided answers to this question, 11 reported oxygen levels of 4 mg/L of oxygen in the potable water provided.

26. Increased Velocity as the Cause of Copper Failures
Seventy-five (75 or 55.6%) responded "No" whereas 13 or 9.6% responded "Yes" to being aware that copper failures were due to increased velocity as seen in Table 4-11.

Table 4-11: Awareness of Copper Tube Failures Due to Increased Velocity

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	13	9.6	9.6	9.6
No	2	75	55.6	55.6	65.2
Not Known	3	42	31.1	31.1	96.3
No Response	9	5	3.7	3.7	100.0
TOTAL		**135**	**100.0**	**100.0**	

27. Corrosion/Failures to New Buildings Not Occupied for Considerable Time After Final Plumbing Inspection
Eight (8) respondents or 5.9% were aware that new buildings were not occupied for a

considerable time after the final inspection while 73 respondents or 54.1% were not aware of this type of copper corrosion or failures. See Table 4-12 for more details.

Table 4-12:Corrosion/Failures to New Buildings Not Occupied for Considerable Time After Final Plumbing Inspection

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	8	5.9	5.9	5.9
No	2	73	54.1	54.1	60.0
Not Known	4	49	36.3	36.3	96.3
No Response	9	5	3.7	3.7	100.0
TOTAL		**135**	**100.0**	**100.0**	

28. Corrosion/Failures to Buildings Vacated for Extended Period of Time (Longer Than Nine [9] Months)
Ten (10) respondents or 7.4% were aware that buildings were vacated for an extended period of time while 71 respondents or 52.6% were not aware of this type of copper corrosion or failures. See Table 4-13 for more details.

Table 4-13: Corrosion/Failures to Buildings Vacated for Extended Period of Time

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
Yes	1	10	7.4	7.4	7.4
No	2	71	52.6	52.6	60.0
Not Known	4	49	36.3	36.3	96.3
No Response	9	5	3.7	3.7	100.0
TOTAL		**135**	**100.0**	**100.0**	

4.3.2.5 Solutions to Copper Corrosion Problems

29. Methods Being Used to Prevent or Mitigate Potable Water Copper Tube Corrosion
Sixty-three (63 or 46.7%) of the respondents did not seem to have any idea(s) as to what could be done to mitigate potable water copper corrosion (See Table 4-14). Twenty-nine (29 or 21.5%) of the respondents that had idea(s) seem to think that the water was the problem and therefore

suggested such methods as addition of lime, caustic soda, or phosphate inhibitors to the water and/or adjust pH levels.

30. Successful Design and Installation Methods Used in the Repair of Corroded Copper Tubes

The design and installation methods that the respondents wildly recommended were to cut and flare new pieces of copper and repair or replace with copper, CPVC or PVC pipe.

Table 4-14: Ideas of Methods to Prevent Copper Tube Corrosion

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
There Is None	1	63	46.7	46.7	46.7
Had Idea(s)	2	29	21.5	21.5	68.2
Not Known	4	4	3.0	3.0	71.2
No Response	9	39	28.8	28.8	100.0
TOTAL		**135**	**100.0**	**100.0**	

4.3.2.5 Economics of Copper Corrosion Problems

31. Who Generally Pays for the Repair Costs for Copper Corrosion Problem(s)

75 or 55.6% of respondents reported that owners generally pay for corrosion repair problems. 15 or 11.1% of the respondents ranked insurance companies second as to who generally pay for copper corrosion repair costs.

32. Why the Repair Costs Were Paid for by Parties in 31 Above

Explanations for owners paying for repair costs range from "not covered by insurance nor warranty" to "had no choice." Insurance companies pay for repair costs because of the damages done to the building or contents of the buildings that were covered by insurance.

4.4 ANALYSIS OF FOCUS SESSIONS AND DISCUSSIONS

4.4.1 Introduction

There were eight focus sessions that were developed and conducted by the research team. Five of these sessions were held in Orlando at the request of DCA while one each was held in Tallahassee, Jacksonville and West Palm Beach. Very useful and pertinent information was provided by the attendees of the focus sessions.

Again, it must be noted that the four groups that were identified, selected and invited or used for the focus session studies were professionals and members of trade and professional associations. These professionals and their trade as well as professional associations keep abreast of current knowledge and practices in their respective industries. Therefore, any data provided or opinion obtained from such professionals can be considered as having great importance, use or value.

4.4.2 Results of Focus Discussions

1. Geographic Locations of Copper Experience of Members Present: The statements and comments made during the focus sessions were very informative and provided pertinent information for this study. In general members in attendance at the Orlando focus sessions agree that the surrounding areas of Orlando and Orange County, as well as Lakeland and Polk County had widespread and extensive copper corrosion experiences.

Feedback from Tallahassee, Pensacola, West Palm Beach indicated that those areas do not have as extensive or widespread corrosion problems as the Central Florida and the east and west coasts.

Jacksonville has by city ordinance eliminated all use of copper in new residential construction and limited the use of copper in all other construction to types K (Thick Wall) and L (Intermediate Wall).

In addition, the following statement was made by a plumbing professional concerning Panama City and Panama City Beach water treatment and water source: "Panama City which is inland, uses lake or surface water source and has no copper corrosion problems where as Panama City Beach which is along the coast of the Gulf of Mexico (a) uses well water, (b) heavily treats its water content with chlorine during the summer weekends due to high water usage and low pressure to avoid bacterial contamination in the water system and (c) has experienced extensive copper tube corrosion and piping failures." A water provider stated that there seemed to be no consistent pattern in some of the subdivisions that have had problems with copper corrosion. It was reported that one subdivision might have problems while the adjacent subdivision would have none. It was also reported that the copper corrosion would occur on one side of the street and not on the other, and even skip houses from one side to the other.

In general, it was reported that south Florida was not experiencing extensive copper corrosion problems, except along the coastal zones. This is how sporadic the corrosion occurrences are.

However, the researchers discovered, based upon the responses from the field study and focus sessions, that geographic regions with copper corrosion problems in order of severity (i.e. start with regions with severest corrosion problems) are as follows:

Geographic Regions	
1. Orange and Seminole Counties	2. Polk and Osceola Counties
3. Hillsborough, Pinellas & Manatee Counties	4. Palm Beach and Martin Counties
5. Sarasota and Charlotte Counties	6. Broward & Dade Counties
7. Volusia and Flagler Counties	8. Duval & St. Johns Counties
9. Brevard County	
10. Other Counties – arranged in alphabetical order: (a)Alachua County, (b) Bay County, (c) Collier County, (d) Hernando County, (e) Indian River County, (f) Lee County, (g) Leon County, (h) Marion County, (i) Monroe County, (j) Okaloosa County, (k) Okeechobee County, (l) Putnam County, (m) Suwanee County.	

2. Description of Corrosion Type(s) & Location in Buildings: From the descriptions provided, the following types of corrosion (not ranked) occurred in the geographic locations experiencing corrosion problems:

a. General Corrosion
b. Galvanic Corrosion
c. Erosion-Corrosion
d. Pitting Corrosion
e. Stress Corrosion

The types of corrosion identified and listed above were found in almost all the three building types used in the study. The above-listed occurrences of corrosion, according to the participants at the focus sessions, happened on both cold water and hot water lines, in the joints and fittings, in main lines, at dead ends, at grounding connections, in concrete foundations, concrete walls, under concrete slabs on grade, in wood framed walls, and masonry walls. There was an incidence reported in Tallahassee where corrosion was occurring in the water distribution system at the street cock valve location. With inspection of the sample pipe and the acknowledgment that water pressure were at times very high, it was concluded by the professionals in attendance that the type of corrosion was erosion corrosion. The end of the sample copper tube cut to mate with the street cock and had not been reamed. This was an occasion where a water provider came to a meeting and went away very satisfied that he had received an answer to the specific problems which he was experiencing.

3. Building Types With Copper Tube Failures: The focus groups reported having had experiences in single family buildings, multi-family buildings and commercial buildings.

4. Age (in years) and Frequencies of Copper Corrosion Occurrences: The groups reported that copper tube failures were occurring in buildings completed within 6 months to one year old, others in buildings two years, still others reported of failures in buildings two to five years, and some in buildings five to ten years. On the other hand, there were reports of nonoccurrence of copper failures in buildings over 20 years old.

The frequencies of occurrences varied also; they range from the teens to a couple of hundred per year with one participant documenting as many as 200 per year for the past two years in the Orlando area. There were comments that all kinds of materials including copper, PVC and CPVC were being replaced because of corrosion problems.

There was a comment made that in Jacksonville, where copper has been banned in new residential construction, by a participant that "people are still having copper corrosion problems in existing copper plumbing systems that are more than 20 years old."

In Tallahassee and West Palm Beach, there were no problems with copper corrosion. Respondents at the sessions in these two locations could not provide comments on the frequencies of occurrences and plumbing age(s) at which the corrosion occurrences took place.

5. Possible Causes of Copper Corrosion Occurrences: The participants reported the following as possible causes of the copper corrosion occurrences: poor workmanship, dissimilar materials used, grounding, water and water treatment systems including secondary treatment systems in buildings, stray current, turbulence (velocity), overhead electric power lines, thunderstorms, sound waves, and lightning. These possible causes were mentioned in the focus sessions in all the four cities - Orlando, Tallahassee, Jacksonville and West Palm Beach - that researchers went to.

Lightning, grounding and stray current were greatly discussed in the Orlando sessions. There was a presentation on lightning and its contribution to copper corrosion by Messrs. Richard Dunham and Clifford Russell at one of the Orlando focus sessions. The results of their study, as presented at the session, indicated that there was direct relationship between lightning and copper plumbing failure. The consensus of participants at the session was that the results of Messrs. Dunham and Russell's study had produced a new theory that needed confirmation from further studies. Lightning occurs in Orlando much more than any other city in Florida.

6. Workmanship: The Orlando sessions did not initially discuss workmanship and its effects on corrosion. Although workmanship was mentioned after the first draft report was presented at Orlando, it was not significantly discussed in the Orlando focus sessions. However, poor workmanship as a major cause of copper corrosion was greatly discussed in Tallahassee and West Palm Beach sessions. The workmanship practices that caused copper corrosion at these sessions were reported by both owners and building inspectors. An owner of a condominium apartments in south Florida was shocked when a building inspector at the West Palm Beach session told the group about all the poor workmanship practices that had occurred in those apartments. Specific workmanship practices that caused copper corrosion discussed at the focus sessions included dissimilar materials and surface conditions of the piping, increased water velocity and/or pressure, secure fastening of copper pipes through concrete slab, use of acid-type fluxes, failure to ream copper tubes ends before installation, use of improper sleeve installation methods, too much flux, not covering copper piping and fitting when it is in contact with concrete, not cleaning after applying joint material, and not flushing plumbing systems after installation. The owner of the condominium apartments has offered his group of apartments to the researchers to use as part of next phase of this study.

7. Knowledge and Use of ASTM B813 Approved Fluxes: Most of the participants present at the focus sessions knew and used the ASTM B813 fluxes. It was reported that new fluxes were not easily available in certain areas. In one session, it was reported that some counties had adopted the new ASTM B813 standards.

8. Water Sources & Treatment Processes: The focus group reported that surface water (lakes and rivers) and wells were the major sources of potable water in their areas. Chlorination, coagulation, lime or caustic injection and aeration were reported by the participants as the major treatment types used.

Some of the participants reported that "excess chlorine was added to the water systems" in their cities and that in certain areas **"it was normal to double the chlorine content** over the weekends due to water use and low pressure to avoid bacterial contamination in the water systems." It was reported by respondents at one of the sessions that "there was so much chlorine in a local water system that (a) one could smell it and (b) the chlorine disinfected and cleaned the water closets all the time." No specific numbers were provided for statistical analysis.

Many of the participants at the focus sessions maintained "that most of the areas experiencing corrosion problems do have aggressive water."

It was discussed and confirmed by some water producers that Florida water providers in general are aware of the corrosive water they produce and are making necessary and required changes but maintain that "it is not cost-effective to correct these problems beyond the limits set by the Federal and State rules and/or regulations."

There was a statement that "the occurrences of the water not meeting the Lead Copper Rule (LCR) in Jacksonville has gone from 45 per 100 to Zero per 100". The person that made this statement indicated that this happened after the ordinance to ban copper in residential buildings was implemented.

It was confirmed by participants in one of the sessions that water treatment for hydrogen sulfide by heavy chlorine injection had been a common practice throughout the state water distribution system. Understandably, chlorine is one of the chemicals that is very reactive with copper if excessively used. Another water provider stated "that copper release in the water associated with the LCR standard testing can not be tested where secondary treatment is present, e.g., water softeners."

9. Banning Copper: There was considerable discussion on the issue of banning copper as a plumbing material at one of the Orlando sessions. This was the only place and time during the study that this issue was discussed other than a questioned (raised by a concerned contractor who was against the banning of copper) that was asked at FPHCC meeting in Fort Lauderdale as to whether the study group would recommend banning copper in Florida. The issues that were raised that there were not in favor of banning copper as a plumbing material were (a) huge replacement costs and who pays for these costs, (b) what to do with other materials (e.g., refrigerators, kitchen fittings and so forth) that contain copper and (c) lack of performance track records of materials that would replace copper.

10. Who Pays for Repair Costs: It was reported by the participants that owners normally pay for all repairs except few occasions when insurance companies or contractors pay for the repairs.

4.5 SUMMARY

Although the number of responses from the questionnaire as well as the participants in the focus sessions were small, good information were obtained in the field studies that can be explored in any future research. The information gathered and presented in this chapter were individual opinions and were not based on detailed scientific research.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This section provides the conclusions drawn from the summary, analyses and syntheses of the literature review, field data and focus sessions. The following provides the researchers' general conclusions from the pilot study:

01. Literature search and digest are presented in Chapters 2 and 3 of this report.

02. Even though copper is more noble than any of the other metals commonly used in water distribution systems, it can be attacked by corrosion under the following adverse conditions: (a) aggressive soft waters, (b) in systems where the water flow velocity in excess of about 5 fps especially in forced-circulation hot water systems and (c) in water systems with deposits of dissolved minerals, high quantities of dissolved gases (e.g. carbon dioxide, hydrogen sulfide, oxygen), and high temperatures.

03. Water quality plays a significant role in the corrosion process. The most significant factors are pH, alkalinity, inorganic carbonate, dissolved oxygen, excessive chlorine and higher temperatures. Other factors that play a part in the corrosion process include calcium, silicate, organic matter, ammonia, sulfate, chloride, phosphate and nitrate.

04. The Questionnaire and Focus sessions identified serious problems and types of corrosion based on the opinions of respondents, who were technical people and professionals of various backgrounds but not corrosion engineers and their perception of the Florida corrosion problem.

05. The corrosion types found in Florida based upon the opinions of the research participants are pitting (#1), general (#2), galvanic (#3) and erosion (#4) corrosion.

06. The Florida copper corrosion failures do not follow a general pattern in the State or within a city. For example, one would encounter a failure on one street in a subdivision and no problems on the next street within the same subdivision.

07. The researchers discovered and therefore conclude, based upon the responses from the field study and focus sessions, that geographic locations (i.e. regions and cities within the regions) with copper corrosion in order of priority for any further study (i.e. start with locations with severest corrosion problems) are as follows:

Geographic Regions	Priorities
Orange and Seminole Counties	1. Orlando 2. Four additional cities from the following list of eight (8) cities: (1) Winter Park (2) Longwood (3) Altamonte Springs (4) Casselberry (5) Ocoee (6) Lake Mary (7) Maitland (8) Killaney
Polk and Osceola Counties	3. Kissimmee 4. Four additional cities from the following list of nine (9) cities: (1) Bartow (2) Lakeland (3) St. Cloud (4) Haines City (5) Auburndale (6) Sebring (7) Avon Park (8) Rockledge (9) Eagle Lake
Hillsborough, Pinellas & Manatee Counties	5. Tampa 6. St. Petersburg 7. Three additional cities from the following list of five (5) cities: (1) North Long Boat Key (2) Belleair (3) Lithia (4) Sun City (5) Apollo Beach
Palm Beach and Martin Counties	8. Boca Raton 9. Three additional cities from the following list of five (5) cities: (1) Delray Beach (2) West Palm Beach (3) Hobe Sound (4) Jupiter Island (5) Boynton Beach
Sarasota and Charlotte Counties	10. Venice 11. Port Charlotte and Holmes Beach
Broward & Dade Counties	12. Miami 13. Ft. Lauderdale 14. Pompano Beach and Miramar
Volusia and Flagler Counties	15. Daytona Beach 16. Ormond Beach, Holly Hill and Port Orange
Duval & St. Johns Counties	17. Jacksonville
Brevard County	18. Melbourne 19. Cocoa, Cocoa Beach and Palm Bay

08. The pilot study further concludes that the successful proposer for the future research study conducts a preliminary study to identify the best cities in priorities 2, 4, 7 and 9 to be included in the future studies. The results of the preliminary study must be submitted to the Technical Advisory Committee for their review, advice and/or approval before any research is conducted in these cities.

09. There is a need for a detailed scientific research study to determine the causes of and solutions to copper water tube problems in Florida.

5.2 RESEARCH NEEDS, PROJECT TEAM AND ESTIMATED COST AND SCHEDULE

5.2.1 Needs for Further Research Studies

The syntheses and analyses of the field data from this pilot study, including the number of responses as well as quantity and quality of the field data, have identified the need for the following further studies.

01. There is a need for a more detailed scientific study to analyze water, water chemistry and microscopically analyze copper tubes samples as well as critically examining in-home water treatments and material suitability for water distribution systems to determine actual corrosion problems including extent of widespread, causes and possible solutions of copper corrosion in Florida. There is a further need for a protocol that calls for actual testing of samples of plumbing pipes and water [at source, at the meter, and at-the-tap(s)] be used for this comprehensive study.

02. There is a need for a further study to be conducted to devise methods to produce thin, hard, adherent carbonate silica deposit to serve as a protective coating inside new copper tubes prior to their use. This is in accordance with the Michigan studies and confirmed by Sarapata studies.

03. There is a need for educational program in the use of copper tubes and fittings especially in the use of ASTM B813 approved fluxes.

The future studies will specifically achieve the following objectives:

01. Identify improved methods of (a) installing copper and other tubes and (b) treating potable water.

02. Develop a report that (a) contains findings for the causes and solutions of copper corrosion and (b) provides recommendations for the use of copper and other tubes for potable water distribution systems in Florida.

03. Provide recommended guidelines on improved copper and other tube(s) installation methods and specifications that Florida plumbing contractors can use.

The above-mentioned objectives will be identified to provide solutions to the following problems and needs in the State of Florida:

01. Problems with water chemistry for potable water piping systems.

02. Problems with training, motivation, uniformity of enforcement and monitoring of the personnel installing and/or inspecting copper water tube (workmanship). As well as need to improve the methods of installation.

03. Problems with types and cause(s) of corrosion in copper tubes and other pipes used in potable water distribution systems in Florida.

5.2.2 Expert Researchers on the Project Team

The following list provides the desired expert researchers for this future research. Brief vita or statement of expertise and specific role in the future research study are provided. Appendix C provides detail curriculum vitae for the expert researchers.

1. Dr. Ellis D. Verink, Jr. is a Distinguished Service Professor in the University of Florida's Department of Materials Science and Engineering, where he has taught since 1965. He is an expert in corrosion and material selection. He has been a Consultant to CDA, International Copper Research Association, Inc., Corrosion and Wear Group of the Metallurgical Division of the National Institute of Standardization and Technology as well as Lockheed on corrosion and material selection. He is an elected Fellow of the Metallurgical Society. Dr. Verink has written over 100 articles on corrosion behavior (15), cathodic protection (5), materials of construction (16), material selection and economic aspects (13), oxidation and corrosion (34). He has edited or written three books on corrosion and materials selection. Dr. Verink will analyze and evaluate the water and pipe report by Water and Pipe Experts as a Corrosion Consultant to the Project Investigator.

2. Dr. John R. Ambrose is an expert on materials selection criteria for corrosion prevention or control in systems design, forensic analysis of material failure and electrodeposition and metal plating operations. Dr. Ambrose has written nearly 30 articles with 20 of them on corrosion and materials selection. He has been a Consultant to Materials Consultants, Inc. and Corrosion Engineering Consultants, Inc. Dr. Ambrose has co-authored several papers with Prof. Verink. Dr. Ambrose will analyze the pipe data and help in creating and managing the Pipe and Water Database.

3. Dr. Paul A. Chadik is an expert in water analyses, bio-environmental engineering systems. Dr. Chadik has written about 28 papers and 8 reports on Water, Inhibitors and other chemicals added to water. He has several times received the prestigious McCreary Outstanding Faculty Award in the Department of Environmental Engineering Sciences. Most of Dr. Chadik's research reports deal with Florida Water systems. Dr. Chadik will be responsible for the collection and analyses of the water samples for the study.

4. Dr. Stanley R. Bates is the Director of the Major Analytical Instrumentation Center at the University of Florida. Dr. Bates is an expert in the areas of characterization and failure analysis of materials. He has written more than 25 papers dealing with the characterization and analysis of materials. He has provided characterization and failure analysis to more than 100 business and industries during the past 30 years. He will analyze the pipe samples to determine possible corrosion causes as well as characterize the conditions of the pipe samples. Specifically, Dr. Bates will perform the following tests and analyses: scanning electron microscopy, energy x-ray analysis, x-ray diffraction analyses, optical metallography, hardness measurements, and surface analyses (auger/XPS) on treated pipes or pipes known to exhibit the desired longevity. He will join forces with Drs. Ambrose and Chadik for developing recommendations for copper corrosion solutions.

5. Dr. J. Edward Singley is an expert in water chemistry. He has received numerous awards from American Water Works Association (AWWA) and Florida Section of AWWA. He has served on several water related professional associations including AWWA's Board of Directors and various committees, Florida and Texas Sections of AWWA, President's Council on Environmental Quality, National Academy of Science's Panel of Public Water Supplies and U.S. EPA's Plumbing Materials and Drinking Water Quality. Dr. Singley has written over 100 publications on water treatment, remediation, and corrosion. He has consulted for water and plumbing materials industries for over 30 years. Dr. Singley will work with Dr. Chadik in analyzing water samples and developing solutions to the water and corrosion problems that are identified.

6. BCN Principal Investigator will manage the research project to organize, direct and control all efforts of the team. He will make all the arrangements, and obtain permission to enter the premises in advance, and provide the information to the field technicians collecting water and pipe samples so field people can schedule the sampler. He will provide the field technicians with the name of a contact at each of the water provider plants. He will coordinate the draft and final reports of the research study.

5.2.3 Cost Estimates for Future Research

1. Bases for Cost Estimates

In order to obtain statistically meaningful results, a sufficient number of samples would be required. The number of samples would depend on the standard deviation associated with the analytical results of the samples collected. With such a large number of analyses and an unknown variability in the analytical results it is impossible to specify the required number of samples. Substantial research would be required in order to even approximate this number. However, based on the six possible copper corrosion types and their estimated possibilities of occurrence, the researchers perceive as a worst case (minimum) collecting and analyzing 1300 water samples and 400 pipe sample for this study. Field analysis and water sample collection would occur at the same time. In order for the results to be comparable, it would be best to have a trained team of sample collectors/field analyzers perform this task. See Table 5-1 for the estimated project cost. Inputs for cost estimate were obtained from ABC Research in Gainesville, QST Environmental in Gainesville, Drs. John Ambrose, Paul Chadik, Stanley R. Bates and Ellis D. Verink as well as Project Investigator's experience. The conditions outlined below will be the bases for conducting the research as well as for estimating costs and schedule for the project.

2. Project Cost and Future Research Study Coverage

The researchers discovered and concluded, based upon the analyses of the responses from the field study and focus sessions, that geographic locations (i.e. regions and cities within the regions) with copper corrosion in order of severity (i.e. start with locations with severest corrosion problems) are as follows:

Geographic Regions	Priorities
Orange and Seminole Counties	1. Orlando 2. Four additional cities from the following list of eight (8) cities: (1) Winter Park (2) Longwood (3) Altamonte Springs (4) Casselberry (5) Ocoee (6) Lake Mary (7) Maitland (8) Killaney
Polk and Osceola Counties	3. Kissimmee 4. Four additional cities from the following list of nine (9) cities: (1) Bartow (2) Lakeland (3) St. Cloud (4) Haines City (5) Auburndale (6) Sebring (7) Avon Park (8) Rockledge (9) Eagle Lake
Hillsborough, Pinellas & Manatee Counties	5. Tampa 6. St. Petersburg 7. Three additional cities from the following list of five (5) cities: (1) North Long Boat Key (2) Belleair (3) Lithia (4) Sun City (5) Apollo Beach
Palm Beach and Martin Counties	8. Boca Raton 9. Three additional cities from the following list of five (5) cities: (1) Delray Beach (2) West Palm Beach (3) Hobe Sound (4) Jupiter Island (5) Boynton Beach
Sarasota and Charlotte Counties	10. Venice 11. Port Charlotte and Holmes Beach
Broward & Dade Counties	12. Miami 13. Ft. Lauderdale 14. Pompano Beach and Miramar

Volusia and Flagler Counties	**15**. Daytona Beach **16**. Ormond Beach, Holly Hill and Port Orange
Duval & St. Johns Counties	**17**. Jacksonville
Brevard County	**18**. Melbourne **19**. Cocoa, Cocoa Beach and Palm Bay

---

This same ranking (priorities 1-19) will be used for the future research study. The proposed study will start and complete in the city with most severe problems as ranked (Priority 1) by the pilot study before moving on to the next city or set of cities in the same priority, i.e. Priority 2; when all the cities within a priority are completed, then the team moves on the next priority.

TABLE 5-1: PROJECT COST ESTIMATES FOR FUTURE RESEARCH STUDY COST FOR 1300 WATER AND 400 PIPE SAMPLES

(This is a Preliminary Estimate)

I. SALARIES

Principal Investigator (BCN Faculty)

Dr. __________ level of effort		
equivalent to .50 FTE for 16 months	$40,000.00	
Fringe Benefits @ 25%	$10,000.00	
State Health Insurance		
(16 months x $363 mth x .50 FTE)	$ 2,904.00	$ 52,904.00

Co-Principal Investigators

Dr. Ambrose (Pipe Data Analyses)	$25,000.00	
Fringe Benefits @ 25%	$ 6,250.00	
State Health Insurance		
(12 months x $363 mth x .10 FTE)	$ 436.00	$ 31,686.00
Dr. Chadik (Water Data Analyses)	$20,000.00	
Fringe Benefits @ 25%	$ 5,000.00	
State Health Insurance		
(12 months x $363 mth x .10 FTE)	$ 436.00	$ 25,436.00
Dr. Stanley Bates (Scanning Electron Microscopy)	$25,000.00	
Fringe Benefits @ 25%	$ 6,250.00	
State Health Insurance		
(12 months x $363 mth x .10 FTE)	$ 436.00	$ 31,686.00

TABLE 5-1: PROJECT COST ESTIMATES FOR FUTURE RESEARCH STUDY COST FOR 1300 WATER AND 400 PIPE SAMPLES - Continued

(This is a Preliminary Estimate)

II. OTHER PERSONNEL SERVICES (OPS)

Dr. Ellis Verink (Consultant - Analyses/ Evaluations of Corrosion)	$15,000.00	
Dr. J. Edward Singley (Consultant - Analyses/ Evaluations of Water and Pipe Corrosion)	$15,000.00	
Contract Administrative/Secretary for the Department of Materials Science & Engineering	$ 6,000.00	
1 Graduate Student to assist BCN Faculty (___ hours @ $___ per hour)	$ 6,000.00	
2 Graduate Students to assist Dr. Ambrose (___ hours @ $___ per hour)	$15,000.00	
2 Graduate Students to assist Dr. Bates (___ hours @ $___ per hour)	$30,000.00	
1 Graduate Students to assist Dr. Chadik (___ hours @ $___ per hour)	$10,440.00	
Tuition Waivers for 6 Students ($192.00 credit hour x 9 hours = $1,728. x 6 x 2)	$20,736.00	$118,176.00

III. EXPENSES

To include, but not limited to:

1. Water Sample Collections (Dr. Chadik or Consultant)	$ 50,000.00
2. Water Analyses (Dr. Chadik)	$255,000.00
3. Pipe Sample Collection (Dr. Bates)	$ 80,000.00
4. Compensation to Building Owners (Dr. Bates)	$ 40,000.00
5. Characterization Facilities Expense (Dr. Bates) (Copper Tube Analyses)	$ 80,000.00

TABLE 5-1: PROJECT COST ESTIMATES FOR FUTURE RESEARCH STUDY COST FOR 1300 WATER AND 400 PIPE SAMPLES - Continued

(This is a Preliminary Estimate)

III. EXPENSES - Continued

6. Photographic Expense (Dr. Bates)	$ 5,000.00	
7. Database Creation and Management (Dr. Ambrose)	$ 6,000.00	
8. Travel, phone, office suppliers, postage, copying of the draft final report and the final report, dissemination of the draft final report and the final report (BCN Principal Investigator)	$ 24,112.00	$540,112.00
	TOTAL	**$800,000.00**

3. Explanation for Budgeted Items

(1) Water Sample Collections: Researchers would provide the manpower to collect water samples from 130 water- providers throughout Florida. They will collect a sample from 6 to 12 homes in each system depending on the final scope of the project. Total of 1300 water samples will be collected. This proposal assumes that researchers will collect all the samples from one provider during one day (making a total of 130 days to collect water samples). Note that for corrosion by-product (Cu and Pb), samples would be first-draw samples. Also, efforts will be made to collect extra samples from communities or subdivisions identified as having corrosion problems.

(2) Water Analyses: The following water quality parameters would be investigated (those parameters marked with an * would be measured in the field): pH*, Alkalinity*, Calcium, Magnesium, Conductivity*, Chlorine total*, Chlorine free*, Chloride, Temperature*, Phosphate, silica, Copper, Lead, Oxygen*, Total organic carbon, Sulfate, Sulfide*, Redox (ORP), Hardness, Sodium, Potassium, Temperature*, Velocity*, Carbonate, Bicarbonate, Soluble Iron, Dissolved Solids.

(3) Pipe Sample Collection: Pipe samples would have to be collected at near the same time from the water sample locations. This sampling would be far more difficult than collecting water samples because the samples would have to be cut from the residence and the pipe replaced to the owners satisfaction. Just making the arrangements for many of these samples would be a large task. Also, efforts will be made to collect extra samples from communities or subdivisions identified as having corrosion problems.

There will be a minimum of 400 pieces of copper tubing/pipe collected for evaluation/analysis. PI will make arrangement for the collection of the metal samples, and these will be ready for pickup when the water samples are collected. It would be best if these samples were picked up by field technicians so as to reduce the possibility of knocking the pipe about and keep the corrosive material intact. It is recommended that Labs be provided with a solderjoint attached to a 2 foot piece of pipe "downflow " of the joint, with the direction of flow and whether the pipe carried hot or cold water marked on the pipe and that cut and marked pipe should be wrapped in a piece of viscueen or similar material and taped shut. The estimated cost includes repair or replacement cost (material and labor) for the samples to be taken.

(4) Compensation to Building Owners: A minimum of $100 per pipe sample (or a total of $40,000) is included in the budget as compensation to each building owner for his/her time, cooperation, inconvenience and the use of house for the study.

(5) Characterization Facilities Expense: The corroded metal scale in these samples will be analyzed by Scanning Electron Microscopy (SEM), which will give a semi quantitative analysis of the composition of the corrosive material. This is superior to scraping the coating and analyzing it chemically. With SEM, one is able to look at a small area where corrosion has occurred, and identify the chemical elements present. In addition, the following tests and analyses will be performed: (a) energy x-ray analysis, (b) x-ray diffraction analyses for selected samples, (c) optical metallography on selected samples, (d) hardness measurements on selected samples, (e) pipe chemistry on selected samples and (f) surface analyses (auger/XPS) on treated pipes or pipes known to exhibit the desired longevity.

Since the specifications for copper tubing in houses is the same for copper pipe length and soft, at 99.9 % copper, only a few samples will be analyzed to verify this, and the cost is very nominal. If these samples did not analyze at 99.9 % then the cost of analysis would rise, and the number of samples analyzed could rise to include all the samples collected.

(6) Photographic Expense: The estimated cost of $5000 is to cover the cost for (a) photographing all incoming pipe samples and (b) re-photographing sectioned pipes to obtain specimens for analyses.

(7) Database Creation and Management: Enormous amount of data will be generated from the analyses of both water and pipes sample. It is important that such data be properly organized for further analyses and evaluation to achieve the goals and objectives of this study. Thus, there is a need to create as well as manage a database for the information generated from the analyses of the samples.

4. Future Research Study Execution Plan: Although, the estimated cost appears to be sufficient based on the water and pipe samples to be collected and analyzed. If the research group determines during the study that more data or samples are needed than envisioned in this proposal for a higher priority area(s), the research group would deem it necessary to defer the detailed research and data acquisition in the lower priority area(s). This way, corrosion problems and solutions for the high priority areas are obtained or complete in case the estimated cost falls below expectations and there are no more funds available to make up for the difference.

5.2.4 Project Schedule

The proposed work schedule shown in Table 5-2 and Figure 5-1 represents the chronological deadlines and tasks necessary for the completion of this research project. The proposed work schedule establishes starting and completion dates for each task and major subtask. Dates are tentative and may vary depending upon the award date of this project which has been assumed here to be January 1, 1999. The 20-month project will end on August 30, 2000

TABLE 5-2: PROPOSED WORK SCHEDULE

ACTIVITY	STARTING DATE	COMPLETION DATE
Task 1.0.- Identify Water Providers and Building Owners to Take Water and Pipe Samples	January 1, 1999	July 30, 1999
Task 2.0.- Collect Water and Pipe Samples by Region	March 1, 1999	September 30, 1999
Task 3.1.- Analyze Water Samples	April 1, 1999	October 30, 1999
Task 3.2.- Analyze Pipe Samples	April 1, 1999	November 30, 1999
Task 4.0.- Follow-up Water and Pipe Sampling	August 15, 1999	September 15, 1999
Task 5.0.- Create & Manage Databases for Pipe & Water	May 1 , 1999	November 30, 1999
Task 6.1.- Prepare Draft Final Report	September 15, 1999	December 15, 1999
Task 6.2.- Analyze and Evaluate Draft Report by Corrosion Consultant	December 1, 1999	February 15, 2000
Task 6.3.- Revise Draft Report	February 15, 2000	April 15, 2000
Task 6.4.- Disseminate Draft Report	April 15, 2000	April 30, 2000
Task 7.0.- BCIAC Review and Approval Of Draft Report	May 1, 2000	July 31, 2000
Task 8.0.- Submit Final Report	July 31, 2000	August 30, 2000

BUILDING CONSTRUCTION INDUSTRY ADVISORY COMMITTEE SCHEDULE AND STATUS REPORT -1999

TITLE: INVESTIGATION AND DISSEMINATION OF AVAILABLE INFORMATION ON COPPER WATER TUBE CORROSION IN FLORIDA

NAME OF PRINCIPAL INVESTIGATOR: DR. KWAKU A. TENAH

AMOUNT OF PROPOSAL: $800,000.00

PROJECT TASKS	MONTHS											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.0 Identify Water Providers & Building Owners to Take Water and Pipe Samples	■	■	■	■	■	■	■					
2.0 Collect Water and Pipe Samples by Cities			■	■	■	■	■	■	■			
3.1 Analyze Water Samples				■	■	■	■	■	■	■		
3.2 Analyze Pipe Samples				■	■	■	■	■	■	■	■	
4.0 Follow-Up Water and Pipe Sampling								■				
5.0 Create & Manage Databases for Pipe & Water					■	■	■	■	■	■	■	
6.1 Prepare Draft Final Report									■	■	■	
6.2 Analyze and Evaluate Draft Report by Corrosion Consultants												■

BUILDING CONSTRUCTION INDUSTRY ADVISORY COMMITTEE SCHEDULE AND STATUS REPORT - 2000

TITLE: INVESTIGATION AND DISSEMINATION OF AVAILABLE INFORMATION ON COPPER WATER TUBE CORROSION IN FLORIDA

NAME OF PRINCIPAL INVESTIGATOR: DR. KWAKU A. TENAH

AMOUNT OF PROPOSAL: $800,000.00

	MONTHS											
PROJECT TASKS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6.2 Analyze and Evaluate Draft Report by Corrosion Consultants	■	■										
6.3 Revise Draft Report		■	■	■								
6.4 Disseminate Draft Report				■								
7.0 BCIAC Review and Approval of Draft Report					■	■	■					
8.0 Submit Final Report								■				

5.3 RECOMMENDATIONS

The following recommendations are made from the evaluations of the above conclusions:

01. That a more detailed, specific and scientific study to analyze water, water chemistry and microscopically analyze copper samples to determine actual problems including extent of widespread, causes and possible solutions of copper corrosion in Florida and as analyzed and presented in Section 5.2 be made. This study must examine in-home water treatments and material suitability for water distribution systems.

02. That a study be conducted to develop an educational program in the use of copper tubes and fittings especially in the use of ASTM B813 approved fluxes.

03. The researchers further recommend that a protocol that calls for actual testing of samples of plumbing pipes (at least 400) and water [at source, at the meter, and at-the-tap(s) - at least 1300 water samples including 6 to 12 tests for the same source at different times] be used for this comprehensive study. The estimated cost of such a study is $800,000. The estimated project duration is 20 months. It is hoped that this further study would provide the desired results that the initial study could not provide.

APPENDIX A: REFERENCES

REFERENCES

1 Adeloju, S.B., and H.C. Hughes. **"The Corrosion of Copper Pipes in High Chloride-Low Carbonate Mains Water"**, *Corrosion Science* Vol. 26 No.10, p. 851 (1986).

2. Akkaya, M., and J. R. Ambrose. **"An Electrochemical Technique for the Prediction of Long-Term Corrosion Resistance of Copper Plumbing Systems"**, *Material Performance*, Vol. 26 No. 3, p.91 (987)

3. ASTM (American Society for Testing and Materials), Standard Specifications for Liquid and Paste Fluxes for Soldering Application of Copper and Copper Alloy Tube, Designation B813-91. Philadelphia: ASTM., (1991)

4. Atlas, D.C., J. Zajicek, and O.T. Zajicek **"The Corrosion of Copper by Chlorinated Drinking Waters"**, *Water Resources*, No.16, p.693, (1982).

5. Baar, David, Tim Brodeur and Brad Jewell, Sodium Hypochlorite Replaces Chlorine Gas At a Large Central Florida Water Treatment Plant", Report to the City of Kissimmee, 3pp. (1996).

6. Baes, C.F., Jr., and R.E. Mesmer, The Hydrolysis of Cations, John Wiley and Sons, New York, (1976).

7. Baukloh, A., and C. Triquet, **"Internally Surface Treated Copper Sanitary Tubes With a High Resistance to Pitting in Cold Waters"**, Proceedings of International Symposium on Corrosion of Copper and Copper Alloys in Building, Tokyo, Japan, by Copper Development Association, (1982)

8. Benjamin, M.M., S. H. Reiber, J. F. Ferguson, E. A Vandelwerff; and M W. Miller, **"Chemistry of Corrosion Inhibitors in Potable Water"**, *AWWA Research Foundation and American Water Works Association*, Denver, Colo. (1990)

9. Blind, Roger A., **' Hydrogen Sulfide Removal From Reverse Osmosis Product Water'**, 27 pp., (December 28,1989)

10. Bremer, P. J, and G. G. Geesey, **"Laboratory-Based Model of Microbiologically-Induced Corrosion of Copper"**, *App. Envir. Micro.*, No. 57, pp. (1991).

11. Brown, F.R., and Q. Fernando, **"Kinetics of the Dissolution of Copper Metal in Aqueous Solutions Containing Unsaturated Organic Ligands and Copper(II)"**, *Talanta*, Vol. 38 No. 3, p. 309, (1991)

12. Cadle, Robert B., Steven J. Duranceau and Erik L. Melear, Lead and Copper Corrosion

Control Program Desk-Top Evaluation, Draft Report by Boyle Engineering Corporation for City of Winter Park, Orlando, 147 pp., (January 1994).

13. Campbell, H. S, **"A Natural Inhibitor of Pitting Corrosion of Copper in Tap Water"**, *Journal of Applied Chemistry* 4. pp. 633-647, (December 1954).

14. Campbell, H. H. Materials Used for Domestic Water Systems, *British Non-Ferrous Metals Technology Center*, Misc. Publication No. 552, London, (May 1965).

15. CH_2MHill Corporation, Inc., OUC Corrosion Control Study Workshop Demonstration Test Results, Study Report, 30 pp., Undated.

16. City of Cape Coral, Reverse Osmosis Water Treatment Facility, Study Report, 13 pp., (October 1991).

17. Cohen, Arthur, **'Copper for Hot and Cold Potable Water Systems'**, Reprint from May 1978 issue of *Heating/Piping/Air Conditioning*, 8 pp., (1978).

18. Cohen, A. and L.P. Costas, **"Flux Corrosion of Copper Plumbing Systems,"** *Proc. International Symposium on Corrosion of Copper and Copper Alloys in Building* (Tokyo, Japan: Japan Copper Development Association,), p. 47, (1982).

19. Cohen, A. and J. R. Myers, **'Mitigation of Copper Tube Cold Water Pitting by Water'**, *Corrosion 84 Proceedings*, Paper No. 153, pp. 1-15, (April 2-6, 1984).

20. Cohen, Arthur, **'Copper and Copper-Base Alloys'**, Reprinted from *Process Industries Corrosion - The Theory and Practice*, pp 479-502, (1986).

21. Cohen, Arthur and James R. Myers, **'Mitigating Copper Pitting Through Water Treatment'**, *Journal of American Water Works Association*, Vol. 79, No. 2, pp. 58-61 (February 1987).

22. Cohen, Arthur, **'Corrosion by Potable Waters in Building Systems'**, *Materials and Performance*, Vol. 32, No. 8, 6 pp., (August 1993).

23. Cohen, Arthur and James R. Myers, **'Water Treatment to Mitigate Corrosion of Copper Plumbing Systems'**, *Materials and Performance*, Vol. 32, No. 8, 3 pp., (August 1993).

24. Cohen, Arthur, **"Occurrence and Control of Corrosion in Copper Water Tube Systems"**, *Proceedings of 1994 Water Quality Technology Conference*, San Francisco, Cal, 8 pp., (Nov 6-8, 1994).

25. Cohen, Arthur and Andrew J. Brock, **'Water- and Soil-Side Corrosion of Copper Water**

Service Lines', *Materials and Performance*, Vol. 34, No. 3, 7 pp. (March 1995).

26. Cohens, Arthur; Myers, James R.; **'Overcoming Corrosion Concerns in Copper Tube Systems'**, *Materials Performance*, pp. 53-55 (1996).

27. Copper Development Association, Copper Tube Handbook, CDA, New York,(1995).

28. Copper Development Association, Tube Size Calculator, CDA, New York, (1995).

29. Copper Development Association, Inc., **"Corrosion of Mixed Metal Fire Sprinkler Systems"**, *Proceedings of the Florida Water Resources Conference*, 5 pp. (June 1996).

30. **'Copper Corrosion Causes Concern'**, no author, *Material Performance*, Vol. 32, No. 4, 3 pp. (April 1993).

31. Corrpro Companies, Inc, Corrosion Investigation Report Copper Water Service Lines City of Temple Terrace, Florida, Study Report, 51 pp., (August 1993 revised September 1993).

32. **'Corrosion and Scale Control in Distribution Systems'**; no author or publishing company, 5 pp., undated.

33. Crus H. and F. J. Bauman, **"What is a Corrosive Water?"**, *Paper presented at the National Association of Corrosion Engineers Western States Corrosion Seminar*, (May 8, 1975).

34. Dunham, Richard A., **Electric Skies - Electric Pipes'**, *Proceedings of the Florida Water Resources Conference*, pp. 343-348, (June 1996).

35. Duranceau, Steven J., Erik L. Melear, Tamara Richardson and Andres Salcedo, Lead and Copper Corrosion Control Study: Demonstration Test Program Results and Treatment Recommendations for the City of Altamonte Springs, Report by Boyle Engineering Corporation, 129 pp. (July 1994).

36. Duranceau, Steven J., Erick L. Melear, and Jackie Foster, Polk County Utilities Division Imprialakes Public Water System: Lead and Copper Corrosion Control Program Report by Boyle Engineering Corporation, 57pp. (Jan 1996).

37. Duranceau, Steven J., and Jacqueline V. Foster, Evaluation of Imperialakes Water Quality Questionnaire for Polk County Utilities Division, Report by Boyle Engineering Corporation, (April 1996).

38. Duranceau, Steven J., Jacqueline V. Foster and Thomas J. Helgeson, Imperialakes Public Water System Improvements Action Plan: Implementation- Phase 1, Report by Boyle

Engineering Corporation, 47 pp., (Jan. 1997).

39. Duranceau, S.J., G. E. C. Bell, M. J. Schiff, R. M. Powell, and R. L. Blanchetti, **'Grounding Can Affect Water Quality'**, *Florida Water Resources Journal*, pp.34-36, (February 1997).

40. Eckmann, Douglas, H., Robert P. Allison and Patrick D. Zoeller, **"Report on the First Year of Operation of the T. Mabry, Jr. Electrodialysis Reversal Water Treatment Plant for Sarasota County"**, *Proceedings of the Florida Water Resources Conference*, 6 pp., (June 1996).

41. Edwards, Marc, John F. Ferguson, and Steve H. Reiber, On the Pitting Corrosion of Copper, Research Report, Department of Civil Engineering, University of Colorado at Boulder, Boulder, CO, 27 pp., (1991)

42. Environmental Protection Agency, Proposed Regulations for the National Secondary Drinking Water Regulations, *Federal Register*, 42, No. 62 (March 31, 1977) and Safe Drinking Water Act, 1986 Amendments, PL 99-339, June 19,1986.

43. Environmental Protection Agency, National Interim Primary Drinking Water Standards, EPA (June 1975).

44. Environmental Protection Agency, Final Lead and Copper Rule (LCR), *Federal Register* 56FR 26460, (June 7,1991).

45. Farmerie, James E., **"Advancements in Chemical Treatment Strategies In Chemical Treatment for Potable Water Systems"**, *Proceedings of the Intertech Conferences*, Tampa, 5 pp., (April 26-27, 1993).

46. Ferguson, John F., Otto van Franque and Michael R. Schock, **"Corrosion of Copper in Potable Water Systems"**, Chapter 5 of Internal Corrosion of Water Distribution System, American Water Works Association Research Foundation, pp. 231-268, (1996).

47. Fisher, W.R., D. Wagner, and H. Siedlarek, **"Microbiologically Influenced Corrosion in Potable Water Installations"**, *Materials Performance*, Vol. 34, No. 10, pp. 50-54, (1995).

48. Hatch, G. C., **"Unusual Cases of Copper Corrosion"** *Jour. AWWA* 53, p. 1417, (November 1991).

49. Hoffbuhr, Jack W., **"Corrosion Control Options for Drinking Water Production and Distribution"**, *Proceedings of the Intertech Conferences*, Tampa, 17 pp., (April 26-27, 1993).

50. Jacobs, Sarah A., Sulfide-Induced Corrosion of Copper In Drinking Water, Master's Thesis submitted to the University of Colorado's Civil Eng. Dept., 65 pp. (Summer 1997).

51. James M. Montgomery Consulting Engineers Inc., Gainesville, Corrosion Control Recommendations for The Island Water Association, Preliminary Report, 12 pp., (February 17, 1989).

52. Kasul, David B., Heldt, Lloyd A., Analysis of Pitting of Copper Tubing, Report submitted to The Island Water Association, Inc., 19 pp., (April 7, 1992).

53. Kasul, D.B., and Heldt, L.A., **"Characterization of Pitting Corrosion of Copper Pipe Carrying Municipal Water"**, paper no. 512 presented to The NACE Annual Conference and Corrosion Show, *CORROSION 93*, 7 pp., (1993).

54. Lane, R. W. and C.H. Neff, **"Materials for Piping in Chemically Treated Water Systems,"** *Materials Protection and Perfor*mance, pp. 27-30, (February 1969).

55. Lane, R.W. and T. E. Larson, **"Water Treatment Techniques and Corrosion Monitoring,"** *Proceedings of NACE 1971 Annual Meeting*, Paper No. 80, (1971).

56. Lane, R.W., et al., **"Corrosion in Domestic Hot Water Systems"**, *Proceedings of NACE 1973 Annual Meeting* Paper No. 134, (1973).

57. Langelier, W. F. **"The Analytical Control of Anti-Corrosion Water Treatment"**, *Journal the American Water Works Association* p. 1500, (1963).

58. Lytle, Darren A. and Michael Schock, Impact of Stagnation Time on the Dissolution of Metal From Plumbing Materials, Research Report, (1996).

59. Ma, Jerry W., THM Monitoring, Report to Greater Pine Island Water Assn., Bokeelia, FL., 14 pp., (October, 7, 1994).

60. Mattson, E. and A.M. Fredrickson, **"Pitting Corrosion in Copper Tubes: Causes of Corrosion and Counter Measures"**, *British Corrosion Journal Vol. 3, No. 5*, pp. 246-257, (September 1968).

61. McEwen, David W., Karla J. Schmidt, Paul A. Chadik, Don Thompson and Tim Perkins, **"The Impact of Ozone on Bromate Formation in Groundwater at the City of Jacksonville"**, *Proceedings of the Florida Water Resources Conference*, 7 pp., (June 1996).

62. Morris, Kevin, Jeff Nash, David G. Schlobohm and Tim Sheahan, **"Evaluation of Treatment Process Alternatives for Palm Coast Water Treatment Plant No.1"**, *Proceedings of the Florida Water Resources Conference*, 6 pp., (June 1996).

63. Myers, James R., PhD., Fundamentals and Forms of Corrosion, Research Report, United States Air Force Air University, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, 94 pp. (October 1974).

64. Myers, J. R. and M.F. Obrecht, **"Potable Water Systems: Recognition of the Cause Vital in Minimizing Corrosion,"** *Materials Protection and Performance*, pp. 41-46, (April 1972).

65. Myers, James and M. F. Obrecht, **"Potable Water Systems in Building: Deposit and Corrosion Problems"**, *Heating/Piping/Air Conditioning*, pp. 77-83, (May 1973).

66. Myers, James R. And Arthur Cohen, **'Conditions Contributing to Underground Copper Corrosion'**, Reprint from *Journal of American Water Works Association*, Vol. 76, No.8, pp. 68-71, (August 1984).

67. Myers, J. R., and A. Cohen, **"Soldering Flux-Induced Pitting of Copper Water Lines"**, Reprint 31 from *Materials Performance*, Vol. 33, No. 10, pp. 62-63, (October 1993).

68. Myers, James R., Arthur Cohens, **"Pitting Corrosion of Copper in Cold Potable Water Systems"**, Reprint from *Materials Performance*, Vol. 34, No. 10, pp. 60-62 (1995).

69. Nordell, E. Water Treatment for Industrial and Other Uses, 2d ed., New York: Reinhold, (1991).

70. Obrecht, Malvern F., and Laurence L. Quill, **"How Temperature, Velocity of Potable Water Affect Corrosion of Copper and Its Alloys"**, reproduction of a series of seven articles published in *Heating, Piping & Air Conditioning*, 62 pp., (1961).

71. Obrecht, Malvern F., and James R. Myers, **"Potable Water Affect Systems in Buildings: A Treatise on Corrosion and Deposit Control, Materials Selection, System Design and Operation"**, reproduction of a series of five articles published in *Heating, Piping & Air Conditioning*, 32 pp., (1960)

72. Page, G. G., Bailey, P.C. A., G. A. Wright, **"Mechanisation of New Type of Copper Corrosion in Water"**, *Australasian Corrosion Engineering*, Vol. 18, No.11/12, pp. 13-19, (November/December, 1974).

73. Potter, E. C., An Investigation of the Green-Water Problem in Auckland, New Zealand and a Discussion of Possible Remedies, Research Report, (September 1969).

74. Porter, David W., Water Facilities Upgrade Study Report for Seven Springs Water System, Report for Pasco County to Florida Public Service Commission, 500 pp., (May 1997).

75. Powell, Robert, M., Corrosion Investigation in Pinellas County, Report to Water Quality

Supervisor Pinellas County Water System, 23 pp., (1992).

76. Powell, Robert M., Phosphate Monitoring in a Potable Water System Report to Pinellas County Utilities Water Systems, (1992).

77. Powell, Robert M., Pinellas County Water System, Report to Water Quality Manager, 6 pp., (April 29, 1994).

78. Powell, Robert M., Luke A. Mulford, Yousef A. Yousef, Corrosion in Water Distribution Systems, Report, 25 pp., (1992).

79. Powell, Robert M., and Yousef A. Yousef, Comparison of Blended Ortho-phosphate Corrosion Inhibitors, Report to Pinellas County, (1992).

80. Powell, Robert M., and Yousef A. Yousef, **"Evaluation and Implementation of Corrosion Control by a Public Utility"**, *AWWA Annual Conference Proceedings*, 14 pp., (1992).

81. Powell, B. E. and L. V. Lucey, Physical Studies of Water-Formed Corrosion Products on Copper, Final Report to the International Copper Research Association, London, *British Non-Ferrous Metals Technology Center*, (March 1966).

82. Powell, Robert M., A Utilities Perspective on How to Select and Specify Corrosion Control Products, Report to Water Quality Manager, Pinellas County Water System, 8 pp., (1997).

83. Qian-Falzone, Lily, Application of Electrochemical and Surface Analytical Techniques to Study Effectiveness of Corrosion Inhibitors in Potable Water System, Master's Thesis submitted to College of Engineering, University of Central Florida, Orlando, (Summer 1994).

84. Rambow, C. A., and R.S. Holmgren, **"Technical and Legal Aspects of Copper Tube Corrosion"**, *Journal of AWWA*, (March 1966).

85. Rambow, C. A., **"Corrosion of Copper in Domestic Water Service"**, Paper presented at the *1968 NACE Corrosion Seminar*, San Dimas, Calif., (1968).

86. Rehring, J. P., and M. Edwards, **"Copper Corrosion In Potable Water Systems: Impacts of Natural Organic Matter and Water Treatment Processes"**, *Corrosion*, Vol. 52, No. 4, pp. 307-317, (April 1996).

87. Reinhard, F. M., Design for Corrosion Control of Potable Water Distribution Systems, Naval Civil Engineering Laboratory Publication No. AD/A 006 806, Port Heuneme, Calif., (1975).

88. Sanibel Island Water Association, Inc., Reverse Osmosis Plant, Report by The Island Water Association, Inc., Sanibel, Captiva, 24 pp., (February, 1992).

89. Sarapata, James S.; **"Corrosion Control-Case Studies",** *NEWWA 111th Annual Conference Proceedings,* Bolton Landing, N.Y., 11 pp., (September 23, 1992).

90. Schock, M. R. and C. H. Neff, **"Chemical Aspects of Internal Corrosion: Theory, Prediction and Monitoring"** *Proceedings of AWWA Water Quality Technology Conference*, Nashville, TN (1982).

91. Schull, K. E., et al., **"Cold Water Corrosion of Copper Tubing"**, *Jour. Of AWWA* p. 1033, (August 1960).

92. Schull, K. E. **"Experimental Approaches to Corrosion Control,"** *Proceedings of AWWA Water Quality Technology Conference*, VIII, (1979).

93. Shuldener, H. L., **"Effect of Operating Conditions on Corrosion in Hot Water Piping in Buildings"**, *Corrosion,* , pp. 85-90, (March 1954).

94. Smith, Matthew G., **"Optimizing Corrosion Control in Philadelphia"**, *Proceedings of Intertech Conferences in Tampa,* 16 pp., (April 26-27, 1993).

95. Smith, Roger M., Charles R. Womack, June A. Smith and Luke A. Mulford, **Corrosion Control in Potable Water Systems: A Full-Scale Study for Seminole County Public Water Department'**, *Proceedings of the Florida Water Resources Conference*, 6 pp., (June 1996).

96. Staehle, R. W., Galvanic and Stray Current Corrosion: Causes and Prevention, Report Submitted to the Ohio State University, 11 pp., (undated).

97. Steele, Alfred, **"Velocity Effects in Domestic Water Systems"**, *Heating/Piping/Air Conditioning*, pp. 45-48, (October 1982).

98. Sussman, , S., **"The Many Faces of Corrosion in Potable Water Systems in Buildings"**, *NACE 1971 Annual Meeting Paper No. 88.*, (1971).

99. Thornton Laboratories, Inc., Water Sample, Report for the Island Water Association, Inc., Sanibel, FL, 12pp., (January 4, 1994).

100. Tunturi, P. and S. Ylasaari, **"A Special Case of the Pitting Corrosion of Copper in a Hot Water System."** *Proc. 5th Scandinavian Corrosion Congress,* pp. 42-2 to 42-14, Copenhagen, (1968).

101. Van Blaricum, V. L., O. S. Marshall, R. H. Knoll, and V. F. Hock, **"A Rehabilitation Technique for Soldering Flux-Induced Corrosion in Copper Potable Water Piping Systems"**, *Proceedings of NACE Annual Conference and Corrosion Show (Corrosion 91)*, *Paper No. 339*, Cincinnati, Ohio, 15 pp., (March 11-15, 1991).

102. Van Franque, Otto **"Results of Examinations of Water-Formed Deposits on Copper Tubes"**, *Werkstoffe und Korrosion 26,* No. 4, pp. 255-257, (April 1975).

103. Vinci, Alfredo, James S. Sarapata, Advances in the Bicarbonate Method of Internal Corrosion Control, Research Study Report, (1988).

104. Waters, Donald, **"Knowing the Causes of Copper Pipe Corrosion Can Help Prevent It"**; *Florida Water Resources Journal*, p. 33, (March 1994).

105. Williams, David B., Valuation of Corrosion Inhibitors in Drinking Water Systems, Master's Thesis submitted to College of Engineering, University of Central Florida, Orlando, 124 pp., (Summer 1994).

106. Wolfe, Timothy A., **"The New Principles of Corrosion Control"**, *Proceedings of Intertech Conferences in Tampa*, 13 pp., (April 26-27, 1993).

107. Yousef, Y. A., L. A. Mulford, J. S. Taylor, Investigation and Analysis of Contaminants in The Potable Water Supply of Pinellas County, Final Report on Corrosion Phase to Pinellas County, Florida, Report by Environmental Systems Engineering Institute, Civil and Environmental Engineering Department, University of Central Florida, Orlando, 160 pp., (February 1992).

108. Yousef, Yousef A., David B. Williams, and Joseph P. Rozza, Evaluation of Corrosion Inhibitors, Report by Environmental Systems Engineering Institute, Civil and Environmental Engineering, University of Central Florida, Orlando, 94 pp., (March 1994).

APPENDIX B: COPPER TUBE CORROSION SURVEY

INCLUDING COVERING LETTER

UNIVERSITY OF FLORIDA

M.E. Rinker, Sr. School of Building Construction

Fine Arts C 101
PO Box 115703
Gainesville, FL 32611-5703
(352) 392-5965
Fax (352) 392-9606
Suncom: 622-5965

August 19, 1997

To Selected Building Owners and/or Managers
In the State of Florida

SUBJECT: STATE-WIDE COPPER TUBE CORROSION SURVEY

Dear Florida Building Owner or Manager:

We, at the University of Florida's M.E. Rinker, Sr. School of Building Construction, are conducting a statewide study for the Department of Education to investigate copper tube corrosion types, causes, and recommend possible solutions.

To have a successful study, your participation is needed in the completion of the enclosed survey. We would appreciate it very much if you would:

(a) pass this questionnaire to the appropriate personnel in your company or Association;
(b) have your personnel fill-in this questionnaire; and
(c) return it (or them) in the enclosed self-addressed and stamped envelope or send it (or them) by fax to us no later than **August 30, 1997** or any time thereafter; it is important that we hear from you.

Feel free to make as many copies of the enclosed questionnaire as you deem necessary.

Please note that the research team's report will not disclose the identity of any research participants so the confidentiality of all responses is assured.

Do not hesitate to call us if you have any question(s).

Accept our sincere thanks in advance for your help and cooperation. We look forward to your favorable and prompt response.

Sincerely,

Dr. K. A. Tenah, P.E.
(352) 392 - 7314
FAX #: (352) 392-9606

Prof. Bill Edwards, A.I.C
(352) 392 - 7519

"COPPER TUBE CORROSION SURVEY"

BUILDING CONSTRUCTION INDUSTRY ADVISORY COMMITTEE (BCIAC) AND COPPER DEVELOPMENT ASSOCIATION, INC. (CDA)

STUDY ON COPPER WATER TUBE CORROSION IN FLORIDA WATER SYSTEMS
August 1997

IF DO YOU NOT HAVE A RESPONSE TO ANY QUESTION, PLEASE LEAVE IT BLANK AND MOVE ON TO THE NEXT QUESTION

A. GENERAL INFORMATION AND GEOGRAPHIC LOCATION

Name of Respondent:______________________________ Title:__________________

Phone #/Fax/e-mail:____

Mailing Address:____

____

Name of Your Company:____

1. Name of City Where Most of Your Experience With Copper Tube Exists:__________________

2. How many years of experience do you have with the use of copper tube in potable water distribution systems in Florida? _____Years

B. COPPER TUBE CORROSION TYPES IDENTIFICATION

3. Are you aware of any copper tube corrosion failures in your area? ____Yes ____No
   If no, go to **Section C**.

4. To your knowledge, where in the copper tube did these corrosion failures originate?
   (a)___ inside the tube (b) ___outside the tube (c) ___ both inside and outside the tube (d) ___Not known

5. Has lightning been identified as a source of copper tube failures in your area?___Yes ___No ____Not known

6. How many occurrences of copper tube failures are you aware of in the following building types?

	Single Family Buildings	**Multi-Family Buildings**	**Commercial Buildings**
Number/Past Year	____________	____________	____________
Number/Past 2 Years	____________	____________	____________
Number/Past 5 Years	____________	____________	____________
Number/Past 10 Years	____________	____________	____________

7. Of the occurrences reported in 6 above, describe the age (in years) of the plumbing systems where the copper tube failures have occurred.

	Single Family Buildings	Multi-Family Buildings	Commercial Buildings
Newest System	_____Years	_____Years	_____Years
Typical System	_____Years	_____Years	_____Years
Oldest System	_____Years	_____Years	_____Years

8. Did this copper tube corrosion produce water discoloration? ____Yes ____No ____Not Known
If yes, what was the color?____Blue ____Green ____Black ____Other(Describe):______________

9. Where in the plumbing system did the copper corrosion failure(s) occur? (Check all that apply)

____On cold water side
____In a joint
____At the dead end
____At grounding connection
____In wood frame wall
____In wall(s) facing/exposed to the sea
____Exposed to the atmosphere
Other(s)Describe:______________________
____On hot water side
____In the main line
____In a fitting
____In concrete foundation with sleeve
____In concrete foundation without sleeve
____In metal frame wall
____In the foundation under concrete slab

10. Rank the following types of copper tube corrosion you are aware of in your area. Rank the most frequently occurring type as "1" and so on. Please leave blank those that you are not familiar with or those that do not occur in your area:

________General Corrosion
________Pitting Corrosion
________Concentration-cell Corrosion
________Galvanic Corrosion
________Selective leaching
________Intergranular Corrosion
________Erosion-Corrosion
________Stress Corrosion
________Other(s)Describe:_____

C. CAUSES OF CORROSION
C1: MATERIALS AND WORKMANSHIP

11. What type of copper tube joining methods are generally used in the residential/commercial buildings in your area? (Check all that apply).
____Soldered joint ____Brazed joint ____Mechanical (flare, compression) ____Epoxy ____Pre-tinning
____Other(s) Describe______________________

12. Check the type of copper tube generally used in the following types of buildings in your area (check all that apply):

	Single Family Buildings	Multi-Family Buildings	Commercial Buildings
Type **K** (Thick wall)	______	______	______
Type **L** (Intermediate wall)	______	______	______
Type **M** (thin wall)	______	______	______

13. If solder joining method is used, how is the **flux** typically applied? (Check all that apply).
____By immersing tube end into a paste/liquid-type flux prior to the joining surfaces.
____By brushing a thin layer of flux on the joining surfaces.
____By using finger, cardboard, stick or any other available means to apply flux to the joining surfaces.
____Other(s) Describe:____________________

14. Are the ASTM B813 approved fluxes used in your area?____Yes ____No ____Not known

15. As a general practice, are the ends of copper tube reamed before installation?__Yes __No __Not known

16. Whenever copper tubes were placed in concrete slabs or walls, were any allowances provided for tubes to expand or contract?_____Yes ____No ____Not known

17. Name or list other workmanship practices you are aware of that (a) **cause** copper tube corrosion in your area: ____________________

____

or (b) **help** reduce copper tube corrosion in your area: ____________________

____

C2: WATER SOURCES AND THEIR CHEMISTRY

18. What are the sources of potable water in your area? (Check all that apply) _____Lakes _____Rivers
_____Streams _____Wells _____Sea Water ____Other (Describe):____________________

19. Who provides the potable water in your area? _____Public Utility _____Private Utility _____Private Wells
Please name your potable water provider____________________

20. What form of water treatment is used for the raw water in your area?____________________

____

21. What are the objectives of the water treatment processes used in your area?(Check all that apply)
____Biological purity ____To control corrosiveness _____Reduce carbon dioxide
_____To control scaling ____To reduce dissolution _____Other (Describe):____________________

22. Has the water in your area been treated to correct corrosion problems? ____Yes ____No ____Not known
If yes, when was this done?____________________
If yes, describe:____________________

____

____

23. What is the calcium carbonate saturation index for potable water in your area?
_____Index is **positive** number _____Index is **negative** number

24. What is the pH factor for your potable water?____________

25. How much oxygen is in your potable water? ______________ milligrams/liter
If available, please provide water analysis to substantiate responses to Questions **23, 24, and 25**.

C3: DESIGN AND OPERATION

26. Are you aware of any copper tube failures in potable water distribution system(s) caused by increased velocity? _____Yes _____No _____Not known

27. Are you aware of copper tube corrosion/failures that occurred in new buildings that were not occupied for a considerable time after the final plumbing inspection was done? _____Yes _____No _____Not known

28. Are you aware of copper tube corrosion/failures that occurred in buildings that were vacated and then not occupied for an extended period of time? _____Yes _____No _____Not known

D. SOLUTIONS TO COPPER CORROSION PROBLEMS

29. What are the methods being used in your area to prevent or mitigate potable water copper tube corrosion?
    ____There are none
    ____The following is employed to mitigate copper tube corrosion ______________________________

____
____
____

30. Briefly describe the design and installation methods that have been successfully used in your area in the repair of corroded copper tube:____

____
____
____
____
____

E. ECONOMICS OF COPPER CORROSION PROBLEMS

31. For the copper corrosion problem(s) that occurred in your area, to the best of your knowledge, who has generally paid for the repair costs? (Choose only one answer).
    ____Owner ____Builder ____Designer ____Insurance company ____Other(s) Describe:____________

32. Explain, if you can, why the repair costs were paid for by this party.______________________

____
____
____
____

THAT IS ALL. <u>THANK YOU</u>!!!

APPENDIX C: CURRICULUM VITAE FOR EXPERT RESEARCHERS ON PROJECT TEAM

(ARRANGED IN ALPHABETICAL ORDER)

APPENDIX Cl

CURRICULUM VITAE FOR DR. JOHN R. AMBROSE

Personal Data

Name: John Russell Ambrose

Residential Address: 6130 NW 54th Way
Gainesville, Florida 32653
[352] 375-4628

Business Address: Department of Materials Science and Engineering
University of Florida
Rhines Hall. Bldg. 184, Al 53
Gainesville, Florida 32611
[352] 392-6628

Date of Birth: February 25, 1940

Marital Status: Married, three children

Areas of Technical Expertise

1. Application of materials selection criteria for corrosion prevention or control in systems design.
2. Forensic analysis of materials failure.
3. Electrodeposition and metal plating operations.
4. Batteries: primary, secondary - self-discharge and associated component failures.
5. General topics in Materials Science and Engineering.

Education

1968-1972: University of Maryland, College Park, Maryland, PhD, December 1972.

1957-1961: Washington and Lee, Lexington, Virginia, B.S., Special Attainments in Chemistry, June 1961

Employment

1978 - present: Associate Professor, Department of Materials Science and Engineering University of Florida, Gainesville.

1966-1978: Research Scientist, Corrosion and Electrodeposition Section, National Bureau of Standards, Washington, DC.

1964-1966: Research Chemist, Newport News Shipbuilding and Dry Dock Company,

Employment - contd.

Newport News, Virginia.

1962-1964: Faculty member, Princess Anne High School, Virginia Beach City School Board, Virginia Beach, Virginia.

Professional Associations

The National Association of Corrosion Engineers [past Chairman, Southeast Region]

American Society Engineering Education

Consulting Activities

1. John R. Ambrose, PhD, PE, PA
2. Materials Consultant, Inc.
3. Corrosion Engineering Consultants, Inc.
4. Registered Professional Engineer, PE 0027562, Florida.

Awards

The Melvin Romanoff Award, Northeast Region, NACE, 1972.
Sustained Superior Performance, National Bureau of Standards, 1978.
Who's Who, American Men and Women in Science.
"Teacher of the Year", Departmental and College Awards, 1989-90.
Summer Faculty, Fellowship, NASA-KSC, summers of 1991-2

Academics

A. Teaching Experience

1. Materials Science and Engineering, Introductory Course, EMA 3010, 1978-present

2. Advanced Topics in Corrosion Science, Corrosion Kinetics and Interpretation of Experimental Data, 1978-present.

3. Extractive Metallurgy, Process Metallurgy, 1979-1983, 1988, 1995.

4. Materials Selection and Failure Analysis, 1996-present

5. Guest lectures have been regularly offered to the Chemistry Department, School of Law, Institute of Food and Agricultural Science [IFAS] and Florida Foundation of Future Scientists. Topics involve applied electrochemistry, [corrosion, and electrodeposition or plating], litigation procedures involving the expert witness [corrosion] and the attorney, and corrosion failures as viewed and interpreted by the non-expert.

6. Corrosion Short Courses have been offered as a part of Continuing Education or Auxiliary Training, Activities at both Tulane University and University of South Alabama.

B. Service

1. Sponsor and advisor for the student chapter of the National Association of Corrosion Engineer [1979 - present].

2. Faculty Advisor to the Benton Engineering Council [Undergraduate association of representatives from all engineering disciplines] [1985 - 1987].

3. Service on a number of Departmental and University Committees, including the Faculty Senate, Undergraduate Curriculum, and Space Allocation Committees.

4.Consultation with Home Economics Department of IFAS in development of guideline for control of corrosion in residential environments. Contributions included lectures, and critical review of pamphlet material prepared for statewide county extension offices.

5. Participated in a National Council of Engineering Examiners [NCEE] program for establishing criteria and guidelines to be used in the preparation of professional engineering registration qualification examinations.

6. Examination scoring for NCEE Metallurgical Professional Engineering Examinations [1983-90].

Professional Presentations [lectures, seminars, etc.], 1981 - present.

1. "Alloy Dissolution Kinetics of Monel-400 in Flowing Seawater", Research in Progress Conference, National Association of Corrosion Engineers, Corrosion '81, Toronto, April 1981.

2. "Effect of Ammonium Ions Leached from Soldering Fluxes on the Corrosion Behavior of Copper", invited paper presented at NACE, Corrosion '83, Anaheim, California, April 1983.

3. "Growth Kinetics of Calcareous Deposits in Seawater", invited paper presented at NACE, Corrosion '83, Anaheim, California, April 1983.

4. "Influence of Cathodic Protection on Deposit Formation", invited paper presented at NACE, Corrosion '86, Houston, Texas, March 1986.

5. "A Hydrodynamical, Morphological and Chemical Study of Calcareous Deposits", invited paper presented at NACE, Corrosion '86, Houston, Texas, March 1986.

6. "Characterization of Fire Temperatures by Microstructural Analysis of Various Metals and Ceramics", invited talk presented to the Florida Advisory, Committee on Arson Prevention, Jacksonville, October 1988.

Published Papers [refereed]

1. R. D. Whitaker, J. R. Ambrose, and C. W. Hickam, "Iodine Monochloride and Iodine Trichloride Complexes with Heterocycle Amines, J. Inorg. Nuclear Chem., 17, 254 [1961].

2. R. D. Whitaker and J. R. Ambrose, "Iodine Monochloride and Iodine Trichloride Systems Involving Pyridine and Quinoline, J. Inorg. Nucl. Chem., 24, 285 [1962].

3. W. H. Johnson and J. R. Ambrose, "Heat of Oxidation of Aqueous Sulfur Dioxide with Gaseous Chlorine", J. Res. Natl. Bur. Stds., 67A, 427 [1963].

4. J. R. Ambrose and J. Kruger, "The Stress Corrosion of Titanium and Ti-8A1-1Mo-1V in Methanol Vapor", Corrosion Science, 8. 119 [1968].

5. J. R. Ambrose and J. Kruger,. "Breakdown of Passive Films on Iron by Chloride Ion", Proc. 4th Intl. Congress on Metallic Corrosion, N. E. Hammer, Editor, Amsterdam, IL 969 [Natl. Assoc. Corr, Engr., Houston 1972], p. 698.

6. J. R. Ambrose and J. Kruger, "Tribo-Ellipsometry: A New Technique to Study the Relationship of Repassivation Kinetics to Stress Corrosion", Corrosion 28, 30 [1972].

7. J. R. Ambrose and J. Kruger, "Tribo-Ellipsometric Studies of the Relationship Between Repassivation Kinetics and Stress Corrosion of Low Carbon Steel" Proc. 5th Intl. Congress on Metallic Corrosion, Tokyo, 1974 [Natl. Assoc. Corr. Engr., Houston 1974], p. 406.

8. J. R. Ambrose and J. Kruger, "Tribo-Ellipsometric Studies of the Repassivation Kinetics for Ti-8A1-Mo-1V Alloy". J. Electrochemical. Soc., 121, No. 5, 599 [1974].

9. J. Kruger and J. R. Ambrose, "Qualitative, Use of Ellipsometry to Study Localized Corrosion Processes", Surface Science, 56, 394 [1976].

10. T. Kodama and J. R. Ambrose, "Effect of Molybdate Ion on the Repassivation Kinetics of Iron in Chloride Solutions", Corrosion, 33, 155 [1977].

11. J. R. Ambrose, "The Role of Molybdenum as an Inhibitor of Localized Corrosion on Iron in Chloride Solutions", Corrosion, 34, [1978].

12. J. R. Ambrose, "Mechanism of Inhibition",. Proc. AFOSR/AFML Workshop on Corrosion of Aircraft, St. Augustine, Florida, September 13-15, 1977. E.D. Verink, Jr., Editor, 52 [1978].

13. J. R. Ambrose, "Properties of Surface Films Formed During Repassivation of Iron and Iron-Molybdenum Alloys". Proc. 4th Intl. Symposium on Passivity, Airlie, Virginia. October 17-21, 1977 [Electrochem.. Soc., Princeton. New Jersey, 740 [1978].

14. M. Akkaya and J. R. Ambrose, "The Effect of Ammonium Chloride and Fluid Velocity on the Corrosion Behavior of Copper in Sodium Bicarbonate Solutions", Corrosion, 41, 707 [1985].

15. M. Akkaya and J. R. Ambrose, "An Electrochemical Technique for the Prediction of Long-Term Corrosion Resistance of Copper Plumbing Systems", Materials Performance, 26, no.3, 9 [1987].

16. R. J. Smith, R. E. Hummel and J. R. Ambrose, "The Passivation of Nickel in Aqueous Solutions - II, In Situ Investigation of the Passivation of Nickel Optical and Electrochemical Techniques", Corrosion Science, 27, No.8, 815 [1997].

17. R. T. Lee and J. R. Ambrose. "Influence of Cathodic Protection Parameters on Calcareous Deposit Formation", Corrosion, 44, 887 [1988].

18. J. A. Ali and J, R. Ambrose, "The Dissolution Mechanism of Monel 400 in Na_2SO_4 Solutions", Corrosion Science, 32, 799 [1991].

19. S. Venigalla, P. Bendale, J, R. Ambrose, E. D. Verink and J. H. Adair, "Electrochemical Preparation of Barium Titanate Films at Ultra-Low Temperatures", Mat. Res. Soc. Symp. Proc., 243, 309 [1992].

20. J. R. Ambrose, "Will the Integration of Materials Science into Engineering Core Undergraduate Curricula Ever be Complete - Is the Chemistry Right?", MRS Bulletin, 17, 32 [1992].

21. J. R. Ambrose and P. R. Bendale, "Beneficial Aspects of the Environmental Stability of Materials", MRS Bulleting, 18, 53 [1993].

APPENDIX C2

CURRICULUM VITAE FOR DR. STANLEY R. BATES

Stanley R. Bates
Post Office Box 12714
Gainesville, FL 32604
Phone: (352) 378-1851

Materials Science and Engineering
University of Florida
Post Office Box 116400
Gainesville, FL 32611
Phone: (352) 392-6617
Fax: (352) 392-0390

Personal

Date of Birth: May 9, 1939
Place of Birth: Clearwater, Florida
Marital Status: Married, Three Children

Education

Ph.D.	1969	University of Florida, Gainesville Major: Metallurgical Engineering Minor: Math and Physics
B.S.M.T.E.	1965	University of Florida, Gainesville

Experience

1969 - 1973	Assistant in Research, University of Florida
1973 - 1979	Assistant Engineer, University of Florida
1979 - Present	Associate Engineer, University of Florida
1985 - Present	Director, Major Analytical Instrumentation Center, University of Florida

Professional Societies

American Society for Metals
Alpha Sigma Mu
American Institute of Mining, Metallurgical and Petroleum Engineers

Registration
Registered Professional Engineer, State of Florida, ~#15593

Consulting Activities

Westinghouse Electric Corporation
Honeywell Incorporated
Martin Marietta
Radio Corporation of America
International Telephone and Telegraph Borden Chemical Corporation
General Electric Corporation
Cordis Corporation
Medical Electronics, Inc.
Harris Semiconductor, Inc.
Radiation, Inc.
Hi-Rel Laboratories, Inc.
Sperry-Rand Corporation
Sykes Corporation
United Technologies, Inc. (Pratt-Whitney) Concept, Inc.
Intermedics, Inc.
Bendix Corporation
Battelle Memorial Institute
Southern Research Institute
U.S. Department of Agriculture Motorola, Inc.
National Lime Association
Nitram, Inc.
DuPont
Jim Walter Corporation
Edgar Plastic Kaolin, Inc.
U.S. Navel Air Re-Work Facility (Jacksonville, FL) Offshore Power System
Electronic Communication, Inc.
Dixie Lime, Inc.
U.S. Pipe Concrete
Thomas E. Gates and Sons
Black, Crow, and Eidsness - CH_2M-Hill
Continental Testing Laboratories, Inc.
Ortec
Glidden, Inc.
Eastern Airlines
IBM
Applied Research Laboratories, Inc.
Thermo-Kool, Inc.
Environmental Science and Engineering, Inc.

In addition, Dr. Bates has served as Failure Analyst, Accident Reconstruction Expert and Metallurgical Engineering Expert for attorneys and Insurance Companies and has been so accepted by State and Federal Courts.

Publications

1. "Computer Predictions of Interelement Effects in X-ray Spectrochemical Analysis," presented at 70" American Ceramic Society Meeting Chicago, April 1968.

2. "Applications of the Graphite Monochromator to Light Element X-ray Spectroscopy," R.W. Gould, S.R. Bates, and C.J. Sparks, J. Appl. Spectroscopy, 22: (1968) 549.

3. "Determination of Particle Size Distribution in a Dispersion Hardened Nickel Alloy using Small Angle X-ray Scattering," R.W. Gould and S.R. Bates, Adv. In Z-ray Analysis, 12: (1968) 87.

4. "Application of a Computer Program for Quantitative X-ray Spectrochemical Analysis," R.W. Gould and S.R. Bates, to be published in Application of Instrument Methods of Analysis in the Minerals Industry, edited by L.L. Hench and R.W. Gould.

5. "Small Angle X-ray Scattering from Semiconductors Glass-Ceramics," S.R. Bates and L.L. Hench

6. "Some Application of a Computer Program for Quantitative X-ray Spectrochemical Analysis," R.W. Gould and S.R. Bates, X-ray Spectrometry, 1:1 (1972).

7. 'Solid Solution Decomposition of Aluminum-Rich Aluminum-Zinc-Silver Alloys," S.R. Bates, Advances in X-ray Analysis, 13: (1970).

8. "Application of Scanning Electron Microscopy to the Characterization of Ceramic Materials," S.R. Bates, Characterization of Ceramics, edited by L.L. Hench and R.W. Gould.

9. "Molydenum Metallizing on Beryllia," D.E. Clark, L.L. Hench, and S.R. Bates, ACS Bulletin, 53 (6), (1974).

10. "Analysis of a Bone-Bioglass Interface," J.J. Hren, P.F. Johnson, S.R. Bates, and L.L. Hench, Proceedings of Electron Microscopy Society of America, (1976).

11. "SEM and Electron Probe Microanalysis Applied to Accident Reconstruction," S.R. Bates, Proceeding of Electron Microscopy Society of America, (1976).

12. "Quantitative Determination of the Porosity-Performance Relationship in Ceramic Cutting Tools," E.D. Whitney and S.R. Bates, J. American Ceramic Society, (1977).

13. "The Determination of Calcium in Abacus Bodies and Secretory Granules of Rat Odontoblast by Combined Histochemical and X-ray Analysis," E.J. Reith, S.R. Bates, P.F. Johnson, and J.J. Hren, Proc. EMSA, (1977).

14. "EDS Spectral Contamination in the EM 301," P.F. Johnson, S.R. Bates, and J.J. Hren, Proc EMSA, (1978).

15. "Computerized Methods for Polarization Measurements," S.R. Bates, P.F. Johnson, and E.D. Verink, Proceedings of Electrochemical Society, (1978).

16. "Thickness of Bioglass-Bonding Layers," M.S. Harrell, M.A. Keane, W.A. Acree, S.R. Bates, A.E. Clark, Jr., D.E. Clark, and L.L. Hench, J. of Biomedical Engineering, (1978).

17. "Phase Equilibria in Rapidly solidified Nickel Rich Ni-Mo-Al Alloys," E.H. Aigeltinger, S.R. Bates, R.W. Gould, J.J. Hren, and F.N. Rhines, presented at the Conference on Rapid Solidification Processing Principles and Technology, Reston, Virginia, sponsored by DARPA, ONR, Department of Commerce and NBS.

18. "Influence on Weld-Induced Strain and Compositional Variables on the Stress Corrosion Cracking Behavior of Nuclear Materials," S.R. Bates and E.D. Verink, presented at AIME, (1979).

19. "Quantitative Measurement of Local Strain Variations in Welded 304 Stainless Steel," S.R. Bates and E.D. Verink, presented at NACE, (1980).

20. "Nonexchangeable Potassium Associate with Hydroxy-Interlayered Vermiculite from Coast Plain Soils," W.G. Harris, K.A. Hollen, T.L. Yuan, S.R. Bates, and W.A. Acree, American Journal of Soil Science, 52 (5), (1988).

21. "Characterization of Supported Metal Oxide Particle by Variable Angle X-ray Photoelectron Spectroscopy," P.T. Berge, V. Young, and S.R. Bates, J of Vac. Sci. Technology, A 7 (5), (1989).

22. "Rate and Reversibility of Dehydration of Hydroxy-Interlayered Vermiculite at Different Temperatures," W.G. Harris, S.R. Bates, W.A. Acree, and K.A. Hollen, Agronomy Abstracts, (1989).

23. "Properties of Layered Structures," D.W. Kisker, K.L. Tokuda, M.G. Lamount-Schones, K.S. Jones, and S.R. Bates, edited by J. Hayers, E.R. Weber, and M.S. Hyberton, presented at MSR, Pittsburgh, PA, (1992).

24. "Dehydration of Hydroxy-Interlayered Vermiculite as a Function of Time and Temperature," W.G. Harris, K.A. Hollen, S.R. Bates, and W.A. Acree, Clays and Clay Minerals, 40 (3), 335, (1992).

25. "Preparation of $Yba_2Cu_3O_{7-x}$ Superconductor by Coprecipitation of Nanosize Oxalate Precursor Powder in Microemulsions, " P. Kumar, V. Pillai, S.R. Bates, and D.O. Shah, Materials Letters, 16, (1993).

26. "Chemical Composition of Marl for Submersed Macrophytes," P.V. Zimba and S.R. Bates, Fisheries and Aquatic Science, (1993).

APPENDIX C3

CURRICULUM VITAE FOR DR. PAUL A. CHADIK

2518 NW 65th Terrace
Gainesville, FL 32606
Voice: (352) 392-7970
FAX: (352) 392-3076
pchad@eng.ufl.edu

EDUCATION:

Doctor of Philosophy (Civil Engineering) - 1985
University of Arizona, Tucson, AZ

Master of Science (Civil Engineering) - 1982
University of Arizona, Tucson, AZ

Bachelor of Engineering (Chemical Engineering)-1969
Manhattan College, Bronx, NY

WORK EXPERIENCE:

August 1985 to Present	**Assistant Professor** Department of Environmental Engineering Sciences University of Florida, Gainesville, FL Teaching graduate and undergraduate courses in environmental engineering including potable water treatment system design, groundwater remediation and environmental chemistry. Research includes trihalomethane formation and control, hydrogen sulfide control and the remedial treatment of contaminated groundwater.
August 1984 to May 1985	**Lecturer and Research Associate** Department of Civil Engineering Texas Tech University, Lubbock, TX Taught undergraduate and graduate level courses in environmental engineering including water and wastewater treatment, and laboratory courses in water and wastewater analysis.
August 1980 to	**Research Associate** Department of Civil Engineering & Engineering Mechanics, University of Arizona, Tucson, AZ

August 1984	Investigated and modeled the kinetics of THM formation in natural waters and the effects of coagulation, adsorption and ozonation on these kinetics.
November 1972	**Area Supervisor - Public Health Engineer** Westchester County Department of Health
to	White Plains, NY.
August 1980	Evaluated realty subdivision proposals with regard to the provision of water supply and sewerage facilities. Reviewed environmental impact statements. Enforced the County Sanitary Code with respect to water supply and sewage disposal. Assisted in preparation of legal actions and provided testimony in civil court and at administrative hearings. Provided classroom instruction to water and wastewater treatment plant operators. Supervised a clerical and technical staff in a district of responsibility which covered the lower half of Westchester County (est. pop. = 500,000).

MILITARY EXPERIENCE:

June 1969 **Commissioned Officer** with the U.S. Air Force

to

May 1972

Bio-Environmental Engineer for a base with a population of approximately 18,000. Responsibilities included the surveillance of water and air quality, the performance of industrial hygiene surveys in aircraft and missile maintenance programs and service as the Radiological Protection Officer. Honorable Discharge: May 31, 1972.

HONORS: McCreary Outstanding Faculty Award Dept of Environmental Engineering Sciences 1985-1986, 1988-89, 1993-94, 1996-7.

University Outstanding Teaching Award, University of Florida, 1993-94
Teaching Incentive Program Award 1994

SOCIETIES:
American Water Works Association
Water Environment Federation
Association of Environmental Engineering Professors
National Ground Water Association
Sigma Xi
Tau Beta Pi

PROFESSIONAL Professional Engineer, State of Florida

REGISTRATION: # 0039422

PERSONAL DATA: Date of Birth: June 10, 1947
Place of Birth: New Rochelle, NY

PUBLICATIONS:

A. Ph.D. Dissertation:

"Modeling Trihalomethane Formation in Drinking Water After Alum Coagulation or Activated Carbon Adsorption," Department of Civil Engineering and Engineering Mechanics, University of Arizona, Tucson, AZ, August 1985.

B. Master's Report:

"The Effectiveness of Modified Coagulation for the Removal of Trihalomethane Precursors from Natural Waters," Department of Civil Engineering and Engineering Mechanics, University of Arizona, Tucson, AZ, August 1982.

C. Refereed Publications:

"A Parametric Study of the Coagulation Process for Removing Trihalomethane Precursors from Natural Waters," P. Chadik and G. Amy. J. Amer. Water Works Assoc., 75(10), Oct. 1983, 532-536.

"Cationic Polyelectrolytes as Primary Coagulants for Removing Trihalomethane Precursors," G. Amy and P. Chadik. J. Amer. Water Works Assoc., 75(10), Oct. 1983, 527-531.

"Coagulation of Humic Substances; A Comparison of Natural Aquatic Versus Peat Extracted Materials," G. Amy, P. Chadik and P. King, Organic Geochemistry, November 1984.

"Chlorine Utilization During Trihalomethane Formation in the Presence of Ammonia and Bromide," G. Amy, P. Chadik, P. King and W. Cooper, Environmental Science and Technology, 18(10), October 1984, 781-786.

"Ozonation of Aquatic Organic Matter and Humic Substances: An Analysis of Surrogate Parameters for Predicting Effects on Trihalomethane Formation Potential," G. Amy, P. Chadik, and R. Sierka, Environmental Technology Letters, 7(2), Feb. 1986, 99-108.

"Factors Affecting the Incorporation of Bromide into Brominated Haloforms During Chlorination," G. Amy, P. Chadik, Z. Chowdhury, P. King, and W. Cooper, a chapter in Water Chlorination: Chemistry, Environmental Impacts and Health Effects, R. Jolley et al. eds., 1986, 907-921.

"Surrogate Parameters for Predicting Effects of Coagulation and Activated Carbon Adsorption on Trihalomethane Formation Potential," P. Chadik and G. Amy, Environmental Technology Letters, 8(6), June 1987.

"Developing Models for Predicting Trihalomethane Formation Potential and Kinetics," G. Amy, P. Chadik and Z. Chowdhury, J. Amer. Water Works Assoc., 79(7), July 1987, 89-97.

"Effect of Molecular Weight on Coagulation and Adsorption of Organic Matter," P. Chadik and G. Amy, ASCE Journal of Environmental Engineering, 113(6) Dec. 1987, 1234-1248.

"An *In Situ* synthesis of Cyanogen Chloride as a Safe and Economical Aqueous Standard," W. Wu, P. Chadik, and C. Schmidt, Water Research, Sept. 1998.

"Effect of Bromide Ion on Haloacetic Acid Formation During Chlorination of a Biscayne Aquifer Water," W. Wu and P. Chadik, in press, ASCE Journal of Environmental Engineering, Oct. 1998.

"Role of Sulfide Oxidizing Bacteria in Removal of Sulfide from Groundwater by Diffused Air," M. Dell'Orco, P. Chadik, G. Bitton and R. Neumann , in press, J. Amer. Water Works Assoc., Sept. 1998.

"Disinfection By-Product Formation from the Preparation of Instant Tea," W. Wu, P. Chadik, W. Davis, D. Powell and J. Delfino, in press, Journal of Agricultural and Food Chemistry, 1998.

D. Papers and Conference Proceedings:

"A Parametric Study of Metal Coagulants for Removing Trihalomethane Precursors," P. Chadik and G. Amy, a paper presented and published in Proceedings of the 1982 National AWWA Conference, 1982, 619-625.

"Cationic Polyelectrolytes as Primary Coagulants for Removing Trihalomethane Precursors," G. Amy and P. Chadik, a paper presented and published in Proceedings of the 1982 National AWWA Conference, 1982, 1149-1153.

"PAC and Polymer Aided Coagulation for THM Control," G. Amy and P. Chadik, a paper presented and published in Proceedings of the 1982 ASCE National Conference on Environmental Engineering, 1982.

PUBLICATIONS (continued)

"Removal of Trihalomethane Precursors by Chemical Coagulation," G. Amy and P. Chadik, a paper presented at the II Pan American Congress on Environmental Engineering, UPADI-82, San Juan, Puerto Rico, 1982.

"Coagulation of Humic Substances; A Comparison of Natural Aquatic Versus Peat Extracted Materials," G. Amy, P. Chadik, and P. King, a paper presented at the First International Meeting, International Humic Substances Society, Estes Park, Colorado, August 1983.

"The Influence of Temperature on Trihalomethane Formation: Implications for Cold Regions," G. Amy, P. King, P. Chadik, and T. Fraas, a paper presented and published in Proceedings of the Cold Regions Environmental Engineering Conference, May 1983.

"A Statistical Analysis of Surrogate Parameters for Predicting Trihalomethane Formation Potential (THMFP)," G. Amy, P. Chadik, and P. King, a paper presented and published in Proceedings of the 1984 National AWWA Conference, June 1984.

"Evaluation of Remedial Actions Employed to Restore Florida Groundwater Contaminated with VOCs," P. Chadik, L. de Persia and W.L. Miller, a paper presented at the 61st Annual Technical Conference, FS/AWWA, FPCA, FW&PCOA, Jacksonville, Florida, Nov. 1987.

"Trihalomethane Formation Potential in Florida Waters", P. Chadik, V. Pujals, J. Fisher, paper presented and published in Proceedings of the 63rd Technical Conference, FS/AWWA, FPCA and FW & PCOA, November 1989.

"The Effects of Using Hydrogen Peroxide to Elevate the Dissolved Oxygen Concentration in a Shallow Surficial Aquifer", P. Chadik and W. Miller, a paper presented at the American Institute of Chemical Engineers 1990 Spring National Meeting, March 1990.

"Removal of Natural Organic Matter and Reduction of THM Formation Potential in Florida Waters with Ultrafiltration," Chadik, P., Pujals, V. and Fisher, J.; a paper presented and published in Proceedings of the American Water Works Association Seminar, "Membrane Technologies in the Water Industry," March 1991.

"Use of Groundwater Models to Simulate Remediation," L. Motz, P. Chadik, B. Koopman, K. Hatfield, R. Hutton, G. Tootle, and R. Watts, published in Proceedings of the Hydraulic Engineering Sessions at Water Forum '92, American Society of Civil Engineers, August, 1992.

PUBLICATIONS (continued)

"Effects of Alum Coagulation and Carbon Adsorption on THM Formation Kinetics and Speciation," Z. Chowdhury, I. Paton, G. Amy, and P. Chadik, published in Proceedings of the Water Quality Technology Conference, American Water Works Association, October, 1992.

"THM Formation Potential Study to Determine Strategies for Regulatory Compliance", P. Chadik, C. Pregeant and M. Kotob, presented and published in the Proceedings of the Florida Water Resources Conference, 1993, May 1993

"Effect of Bromide Ion on HAA Formation During Chlorination of Biscayne Aquifer Water," W. Wu and P. Chadik, presented and published in the Proceedings of the Florida Water Resources Conference, 1995, May 1995

"The Impact of Ozone on Bromate Formation in the City of Jacksonville", D. McEwen, P. Chadik, C. Schmidt, D. Thompson and T. Perkins, presented and published in the Proceedings of the Florida Water Resources Conference, 1996, May 1996.

"An *In Situ* synthesis of Cyanogen Chloride as a Safe and Economical Aqueous Standard," W. Wu, P. Chadik, and C. Schmidt, presented and published in the Proceedings of the 1997 AWWA Water Quality Technology Conference, Nov. 1997

"Using Chemical Characterization of Humic Substances to Predict Disinfection By-Product Formation," W. Wu, P. Chadik, W. Davis, D. Powell, J. Delfino, presented and published in the Proceedings of the 1998 National AWWA Conference, June 1998

E. Reports:

"Groundwater Contamination Remedial Action Evaluation," W. Miller, P. Chadik, L. dePersia, report submitted to the Florida Dept. of Environmental Regulation, May 1987, 136 pp.

"In Situ Bioremediation, Final Report," W. Lamar Miller, P. Chadik; report submitted to the Florida Department of Environmental Regulation, January 1990, 166 pp.

"Inventory of Domestic Wastewater Treatment Sludge Generators Final Report", J. Zoltek, P. Chadik and E. Talton, report submitted to the Florida Department of Environmental Regulation, July 1989, 203 pp.

"Reducing Nitrate Contamination in Groundwater," Motz, L., Chadik, P., Koopman, B., Hatfield, K., report submitted to the Florida Department of Environmental Regulation, November, 1990.

PUBLICATIONS (continued)

"Study of Trihalomethane Formation Potential During the Chlorination of Wastewater," Chadik, P. and Kotob, M., report submitted to Gainesville Regional Utilities, October, 1991.

"Hydrogen Sulfide Study for Jacksonville Suburban Utilities, Phase I: Water Quality Assessment," Chadik, P., report submitted to Jacksonville Suburban Water Utilities, October, 1991.

"THM Formation Potential Study to Determine Strategies for Regulatory Compliance", P. Chadik, C. Pregeant and M. Kotob, report submitted to Gainesville Regional Utilities, September 1992.

"Hydrogen Sulfide and Corrosion Control Study Jacksonville Suburban Utilities, Final Report," report submitted to Jacksonville Suburban Utilities, August 1994

"Vacuum Spray Stripping of Hydrogen Sulfide," report submitted to United Water Florida, Dec. 1995

"Feasibility of Intrinsic In Situ Remediation at the Amoco Terminal, Heckscher Drive, Jacksonville, P. Chadik, D. Spangler, J. Levine and H. Radin, report submitted to Amoco Oil Company, March 1996.

APPENDIX C4

CURRICULUM VITAE FOR DR. J. EDWARD SINGLEY

Education:

Ph.D.	1966	Water Chemistry	University of Florida
M.S.	1952	Chemistry	Georgia Institute of Technology
B.S.	1950	Chemistry	Georgia Institute of Technology

Professional Honors:

American Water Works Association
- Abel Wolman Award Of Excellence , 1995
- Distinguished Public Service Award, 1995
- Fuller Award (Man-of-the-Year), 1975
- Water Quality Division Publication Award, 1972
- Ambassador Award, 1970
- Diamond Pin Club, 1968, National President, 1974-75
- Research Award, 1983
- Life Member, 1993
- Honorary Member, 1984

Florida Section AWWA -- A.P. Black Award, 1972, 1982
American Institute of Chemists -- Fellow, 1968
Tau Beta Pi, Sigma Xi, Phi Kappa Phi, Phi Eta Sigma, Phi Lambda Upsilon
Florida Water and Pollution Control Operators Association - Flanagan Award, 1979;
Presidential Citation, 1984
Florida Select Society of Sanitary Sludge Shovelers, 1977
Institution of Water Engineers and Scientists (UK) -- Fellow, 1983. (Now Institution of Water and Environmental Management.)
Association of Metropolitan Water Agencies, Donald R. Boyd Award, 1992
National Lime Association, Commendation, 1993

Professional Activities:

American Water Works Association
- Board of Directors, 1984-87, 1989-93
- Officers:
  - President, 1991-92
  - Immediate Past President, 1992-93

President Elect, 1990-91
Vice President, 1989-90
Executive Committee
Member, 1986-87, 1989-93
Chairman, Ad Hoc Committee on Council and Committee Appointments, 1993-94
Liaison to Student Activities Committee, 1986-87
Member, Ad Hoc Committee on Organizing for the 21st Century, 1990-92
Administrative Committees
Strategic Planning Committee, 1989-91
Finance, 1990-92
International Affairs, 1994-
Membership, 1972-76
AWWA/WEF Cooperation and Coordination, 1989-93
Chairman, 1991-92
Past Officers, 1993-
Awards Committees
Water Industry Hall of Fame, 1994-
Opflow Publications Award, 1985-1989, Chairman, 1988-89
Research Award, 1980-90, Chairman, 1988-89
Section Education Award, 1989-91, Chairman 1990-91
Outstanding Service to AWWA, Chairman 1992-93
Honorary Member Award, 1991-94, Chairman, 1993-94
Abel Wolman Award of Excellence, 1992-94, Chairman
Public Advisory Forum, 1991-92

Administrative and Policy Council (previously General Policy Council)
Vice Chair, 1993-94
Member, 1992-94
Association Awards, 1993
Student Activities, 1975-84
Publications Peer Review, 1981-84
Water Utility Council
Member, 1990-91
IOC and Corrosion By-Products TAW 1990-91
Technical Advisory Group, 1985-89

Technical & Education Council (previously Technical & Professional Council)
Member, 1989-90
Water Quality Division,
Chairman, 1979-80
Trustee, 1975-79
Nomination Committee, Chairman, 1984-86

Member, 1982-84
Committee on Coagulation, Chairman 1968-79
Committee on Control of Water Quality in Distribution Systems, 1975-82
Ad Hoc Committee on Asbestos in Water, 1980

Research Division (previously Research committee)
Member, 1972-78
Committee on Corrosion and Stability, 1989-90
Committee on Iron and Manganese, 1974-79, 1983-84
Committee on Coagulation, 1967-77
Chairman 1967-76
Committee on Softening,
Chairman 1979-80, 1983-84
Vice Chairman 1980-83

Education Division (now Education Task Force)
Trustee, 1986-88
Chairman-Elect, 1988-89
Chairman, 1989
Committee, Member 1969-70

Technical Program Committee, 1979-80

Standards Council
Ad Hoc Committee on Review of Article V, Governing Documents, 1987-88
Standard Methods Committee, 1974-89
Committee, Quicklime and Hydrated Lime, B202, Chairman 1975-86

Journal Reviewer, 1968-present
Water For People,
Charter Board of Directors, 1991-92

American Water Works Association Research Foundation:
Chairman, Subcommittee on Research Priorities, 1981
Trustee, 1990-91
Chairman, Subcommittee, Workshops on VOCs, 1982

National Association of Corrosion Engineers:
Member, Technical Committee T-7, Corrosion by Waters
Member, Technical Committee T-7B, Corrosion by Water Supply Systems

Florida Section, American Water Works Association:

International Director, 1984-1987
Chairman, 1976-1977
Chairman-elect, 1975-1976
Trustee, 1970-1974
Chairman, Aims & Objectives. 1980-1981, 1982-1983
Chairman, Program Committee, 1972-1976
Chairman, Fuller Award Committee, 1979-1980
Chairman, Landmarks Committee, 1981-1982
Chairman, Student Activities Committee, 1970-1975 (Founding Chairman)
Chairman, Small Systems Committee, 1987-1988
Membership Committee, 1972 to present
Fuller Award Committee, 1975-1978
Awards Committee, 1976-1979
Program Committee, 1969-1972
Aims & Objectives, 1977-1980
Finance Committee, 1982-1983
Research Committee, 1983 to present
Section Practices Committee, 1980-1984
Water Resources Committee, 1982-1990
Education Committee, 1978-1981
Planning Committee, 1985-1992
Backflow Certification, 1993-

Texas Section, American Water Works Association:
Water Quality Committee, 1995
Florida Public Health Association
Engineering Section, Chairman-Elect, 1974

Florida Water Works Association:
Chairman, Program Committee, 1983-1984
Chairman, Technical/Operations Committee, 1984-1986
Member 1983-

Reviewer for Analytical Chemistry, 1972 to 1985.

American Society of Civil Engineers, Environmental Engineering Division
Advisor, Water Supply and Resources Management Committee, 1982 to 1986

International Ozone Association:
International Director, 1984-1994
Member, 1984-

Public Service:

Civitan International, 1968 to present
- Florida District, Lt. Governor, 1974-1977
- Gainesville, Club:
  - President, 1972
  - President-Elect, 1971
  - Secretary-Treasurer, 1969-1971
  - Director, 1973-1976

Civitan Regional Blood Center:
- Board of Directors, Charter Member, 1974
- Executive Committee, 1974-1977
- Chairman of Organizing Committee

St. Michaels Episcopal Church:
- Vestry, 1974-1977
- Chairman, Day School Committee, 1974

Westminster Presbyterian Church United:
- Chairman, Stewardship Committee, 1979-1982, 1986 to 1991
- Ruling Elder, 1980-1983, 1992-1995

Alachua County Association for Retarded Citizens:
- Director, 1972

Young Life:
- Board of Directors, 1968-1975

Alpha Phi Omega, Service Fraternity, 1974

St. Johns water Management District, Advisory Committee on Alternative Water Supplies Matching Grants Committee

Biographical References:

- Who's Who in America
- Who's Who in the South and Southwest
- Who's Who in the World
- American Men and Women of Science
- International Who's Who of Contemporary Achievement
- Personalities of the South

Experience:

Vice President and Senior Consultant, Metcalf & Eddy, Gainesville, Florida, 1996 to present

Vice President, Montgomery Watson, Gainesville, Florida, 1984 to 1996

Professor Emeritus, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Florida, 1990 to present

Professor, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Florida, 1967 to 1990

Adjunct Professor of Water Chemistry, Department of Chemistry, University of Florida, Gainesville, Florida 1968 to 1990

Director, TREEO Center (Center for Training, Research, and Education for the Environmental Occupations), Division of Continuing Education, University of Florida, Gainesville, Florida, 1978 to 1983, 1984 to 1986

Senior Staff Consultant, TREEO Center, 1983 to 1984

Senior Vice President, Research and Development, Environmental Science and Engineering, Gainesville, Florida, 1977 to 1984

Director and Chairman of Organizing Committee, Water and Air Research, Inc., Gainesville, Florida, 1970 to 1977

Associate Professor, Department of Chemistry, Georgia State University, Atlanta, Georgia, 1964 to 1967

Adjunct Instructor, Department of Chemistry, Georgia State University, Atlanta, Georgia, 1953 to 1964

Director of Technical Services, Research and Development Department, Tennessee Corporation, College Park, Georgia, 1951 to 1964

Physical Chemist, Ordnance Rocket Research Center, Redstone Arsenal, Huntsville, Alabama, 1950 to 1951

Technical Editor, Municipal South, 1969 to 1977

Consultant: (Representative Assignments)

President's Council on Environmental Quality, Panel on Asbestos in Lake Superior

National Academy of Science, Panel on Public Water Supplies, 1972
Committee on Water Quality Criteria, Environmental Studies Board.

USEPA, 1987, Technical Consultant, Lead in Water Workshop, ODW, Washington, DC, August

Pan-American Health Organization development of "Modular courses in water quality engineering", CEPIS, Lima, Peru, 1980

Pan-American Health Organization with ACODAL, Simplified Treatment Techniques for Potable Water Treatment, 1987, Disinfection Course, Cali, Columbia 1988, Corrosion, 1989

AWWA Research Foundation/U.S. EPA--Chairman workgroups on Treatment Technology and Cost, VOC Workshops, Chicago, Philadelphia, and Biloxi, Mississippi, 1982

Washington Suburban Sanitary Commission, Washington, D.C., Consultant on water quality problems in the distribution system and on process modifications in the Patuxent and Potomac Water Treatment Plants

Carol City Utilities, Miami, Florida, - control of quality in distribution system and expert witness in rate cases

City of North Miami Beach, - plant operations, process modifications, Treatment of trace organic contaminants, and expert witness or representative at many public hearings

Florida Keys Aqueduct Authority, - operation and process design of reverse osmosis plant and expansion of lime softening plant

U.S. EPA. - Workshops:

- Technology needed to meet NIPDWR 1974-75
- Revised Drinking Water Regulations, Philadelphia, St. Louis, Reno, Orlando 1983
- Plumbing Materials and Drinking Water Quality, 1984
- Emerging Technologies for Drinking Water Treatment, 1987
- Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities, 1990

U.S. EPA. - seminars for control of organic contaminants in drinking water, 1984

Florida Water and Utilities, Miami, Florida, - corrosion problems in distribution system Represented utility in many hearing and as expert witness

First Florida Utilities, West Palm Beach, Florida, - treatment problems and operation of a lime softening plant. Represented utility in hearings (1 MGD)

San Carlos Utilities, Florida, - treatment design and water quality for rate hearings (small softening plant)

Pinellas County Water System, Largo, Florida, - process and plant modification to control water quality in distribution system (ground water with aeration and disinfection)

Richmond, Virginia Water Utility - plant operation and process design (surface water Treatment)

Kiawah Island, South Carolina - water system process modification to meet state regulations

COMASP, San Paulo, Brazil - treatment processes at all seven water treatment plants for the city of San Paulo. Presented seminars to water treatment engineers on treatment processes (>1 BGD). (All surface water plants)

SABESP, San Paulo, Brazil, - surface water treatment processes. Presented 1- week seminar on new treatment processes to engineers from throughout Brazil

CEDAG, Rio de Janeiro, Brazil. Developed improved treatment process for expansion of water treatment plant from 400 to 600 million gallons per day

General Development Utilities. Developed treatment processes for new Peace River water treatment plant (6 MGD); consultant on treatment at Port St. Lucie, Port Malabar, and Southport water treatment plants. Studies of control of organics at all plants

Russell and Axon, Engineers. Consultant on treatment design criteria for water treatment plants in Manatee County, Daytona Beach, Boynton Beach, and Delray Beach, Florida. Representative at hearings with state agencies and public presentations (>100 MGD)

American Water Works Association. Co-Author with H.E. Hudson, Jr., of section of final report of EPA-funded project on state-of-the-art and research needs in the public water supply industry, 1973

Marineland Studios, Florida, - water quality in both fresh and salt-water systems, as well as design and operation of potable water treatment plant (120 KGD R.O. Plant)

City of Daytona Beach, Florida, - operation of two softening plants and maintenance of quality in distribution system (24 MGD/each)

Florida Department of Environmental Regulation, Advisory Committee on the Primary Regulations, 1976 to 1978. Advisory Committee on the Secondary Regulation, 1978. Advisory Committee on Operator Training, 1982 to 1984. Technical Advisory Committee, 1991-

Dade County (Florida) Department of Environmental Resources Management, Ad Hoc Committee on Primary Regulations, 1978

Hillsborough Community College (Florida, Advisory Committee on Environmental Programs, 1979 to 1986

Lagos, Nigeria, 1982 - treatment process for potable water supplies

Boca Raton, Florida, 1980 process design for plant expansion and THM Control

Environmental Protection Agency, Office of Drinking Water. Member of Stress Test Work Group, Additive Evaluation

Florida Department of Education, Advisory Committee on Operator Training, 1978 to 1984

Chesapeake, Virginia, 1975 - Process design for new surface water treatment plant

Dade Utilities, Dade County, Florida. Development of design criteria for plant expansion and consultant on operational problems (1 MGD)

Jacksonville, Florida, 1972 - Process modifications for elimination of serious distribution system problems (>50 MGD).

Tampa, Florida, 1982 - Development of design criteria for Hillsborough Water Treatment Plant upgrading and for plant expansion to 100 MGD. Emphasis on organic contaminants and sludge disposal. Process improvements at Morris Bridge Water Treatment Plant

New Port Richey, Florida, 1969 - Development of design criteria for iron removal plant

Charleston, S.C., 1965 - Process studies to improve water quality and reduce production cost

Port Allegre, Brazil, 1977 - potable water treatment plant process studies

Mandarin Utilities, 1975 Jacksonville, Florida, - corrosion problems

Arlington, Texas, 1983. - Project Director development of design criteria for plant expansion and control of trihalomethanes (THMs) (40 MGD)

Regional Utilities, West Palm Beach, Florida, 1980 - Project Director on development of design criteria for plant expansion and THM control (5 MGD)

Seacoast Utilities, West Palm Beach, Florida, 1983 - Project Director on studies on organic contamination of wells, plant expansion and THM control (20 MGD)

W.R. Grace co., 1984 - Consultant on air-stripping pilot-plant studies for ground water contamination

U.S. EPA -- Peer review on research proposals

Hillsborough County (Florida) Utilities Department, 1980. Project Director treatment process and plant modifications to improve water quality to consumers. Review of water quality in area of landfill for County Commission. 1993.

Deerfield Beach, Florida, 1982. - Project Director on studies to control THMs and develop design criteria for new plant

Sanlando Utilities, Orlando, Florida - Consultant on distribution system corrosion problems

Lakeland, Florida, 1973-1975 Project Director development of design criteria for new lime softening plant and on distribution system quality problems

Cape Coral, Florida, 1984. Review of plant and distribution system problems and report to City Council on causes

Melbourne, Florida, 1984. - Project Director on studies to expand plant and control THMs

U.S. Sugar Corporation, 1983 - Clewiston, Florida. Process studies to control taste and odor problems and improve operations; included pilot and full scale GAC evaluations. Expert witness in court case. 1990, Review of plant processes to meet SDWA requirements.

Okeechobee, Florida, 1984 - Studies to control THMs and improve operations

American Water Works Association Research Foundation/USEPA. 1982 Workshop Chairman at 4 workshops (Philadelphia, St. Louis, Reno, and Orlando) on revision of the National Interim Primary Drinking Water Regulation

Sheraton Corporation, Sheraton at St. Johns, Jacksonville, Florida, 1984. Studies on corrosion problems, Appeared as expert witness in lawsuit

Principal or co-principal investigator on the following academic research projects:

AWWA Research Foundation, 1988. Workshops on "New Developments in Drinking Water Technology", covering "Lead Corrosion" and "Occurrence and Removal of Volatile Organic Compounds"

Stoichiometry and Mechanisms of Coagulation, USPHS

Benefit/Cost Evaluation of Drinking Water Supplies, EPA

Reduction of THM in a Softening Plant, EPA

Chemical Control of Water Quality in Distribution Systems, EPA

Evaporation of Sewage Plant Effluent, FWPCA

Chemical Indicators of Fecal Pollution, FWPCA

Aeration as an Alternative to Carbon Absorption, AWWA Research Foundation

Total research grants more than $700,000

Publications:

Singley, J. Edward, 1994 "Overview of the Electrochemical Nature of Lead in Contamination in Drinking Water" Jour. AWWA , July.

Singley, J. Edward, 1990, "Treatment for Inorganic Contaminants in U.S. EPA" Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities, U.S. EPA, Office of Drinking Water, EPA/624/4-89/023

Singley, J. E., Beaudet, B.A. and Markey, P.H., 1989, "Manual de Corrosion Interna los Sistemas de Distribucion de Agua, "Translated by Ing. Hernando Bayona", in "Seminario International Sobre Corrosion in Sistemas de Agua Potable.". ACODAL, Cali, Colombia

Singley, J. E. 1989. Impact of Groundwater Contamination on Public Water Supplies, Florida Scientist, 52(4), 240-3, 1989

Singley, J. E., 1987-1988, Chapter "Inorganic Control" in publication Workshop on Emerging Technologies for Drinking Water Treatment, USEPA-ASDWA, Washington, D.C.

Singley, J. E. et al, 1987, USEPA report to Congress Comparative Health Effects Assessment of Drinking Water Treatment Technologies. Co-author Chapters 1, 2, 5 and 6, Dynamic, Rockville, MD

Aieta, Marco, Singley, J. Edward, Trussell, Albert R., Thorbjarnarson, Kathryn W. and McGuire, Michael J., 1987. "Radionuclides in Drinking Water: An Overview". Jour. AWWA 79:144 (April)

Singley, J. E. and White, G. C., 1988. "Taller International Sobre Actualization en Desinfeccion de Aquas". PAHO/ACODAL, Cali, Columbia

"VOC's: Overview of Occurrence, Regulations and Treatment" 1988, Proc. AWWA Annual Conference, Orlando, Florida, June, 22

Singley, J. E. "Jar Testing", Proc. 1987 AWWA Annual Conference, Kasnsas City

Pisigan, R. A. Jr. and Singley, J. E., 1987. "Influence of Buffer Capacity, Chlorine Residual and Flow Rate on Corrosion of Mild Steel and Copper." JAWWA 79:63 (February)

Houck, D. C., Rice, R. G., Miller, G. W., Robson, C. M., Beaudet, B. A., Bilello, L. J., Brodeur, T. P. and Singley, J. E., 1986. "CONTAMINANT REMOVAL FROM PUBLIC WATER SYSTEMS," Noyes Publications, Park Ridge, N.J.

Singley, J. E., Beaudet, B. A., Markey, P. H., DeBerry, D. W., Kidwell, J. R. and Malish, D.A., 1985. "Corrosion Prevention and Control in Water Treatment and Supply Systems," Pollution Technology Review No. 122, Noyes Publications, Park Ridge, N. J.

Singley, J. E., Pisigan, R. A., Ahmadi, A., Pisigan, P. O. and Lee, T. Y., 1985. Corrosion and Calcium Carbonate Saturation Index in Water Distribution Systems. USEPA/600/S2-85/079, Cincinnati, OH.

Bilello, L. J. and Singley, J. E., 1986. Removing Trihalomethanes by Packed-Column and Diffused Aeration. Jour. AWWA 68:62

Singley, J. E., 1986. Water Distribution System Corrosion. SW and TX Water Works Journ. June

Pisigan, R. A. and Singley, J. E., 1985. Effects of Water Quality Parameters on the Corrosion of Galvanized Steel. Jour. AWWA 67:76

Singley, J. E., 1985 "Corrosion Indices," Proceedings CA/NV Section Seminar "Water Quality and Treatment for Corrosion Control," May

Singley, J. E., 1985. Water Treatment Plant Operations. A Non-Credit Correspondence Course; Division of Continuing Education, University of Florida: Technical Editor

Singley, J. E., Sontheimer, H., Kuch, A., Koole, W. and Ahmadi, A., 1985. "Corrosion of Iron and Steel," in Internal Corrosion of Water Distribution Systems. Cooperative Research Report. AWWA Research Foundation and DVGW, Denver

Pisigan, R. A. and Singley, J. E., 1985. Technical Note: Experimental Determination of the Calcium Carbonate Saturation States of Water Systems. Journal AWWA 67:92

Pisigan, R. A. and Singley, J. E., 1985. Calculating the pH of Calcium Carbonate Saturation. Jour

AWWA 67:83

Pisigan, R. A. and Singley, J. E., 1985. Evaluation of Water Corrosivity Using the Langelier Index and Relative Corrosion Rate Models. Materials Performance, 24:26

Pisigan, R. A. and Singley, J. E., 1984. Corrosion of Galvanized Steel: Some Water Quality Effects and Corrosion Products Formation. Proceedings: AWWA Annual Conference, Dallas, TX.

Singley, J. E., 1983. Municipal Water Treatment. Kirk-Other: Encyclopedia of Chemical Technology. Vol 24 3rd Ed. M, John Wiley & Sons, New York.

Singley, J. E., Beaudet, B. A. and Markey, P. H., 1984. Corrosion Manual for Internal Corrosion of Water Distribution Systems. USEPA, Washington, D. C. (RPA 570/9-84-001)

Singley, J. E., 1984. "Evaluation of Alternatives" in Occurrence and Removal of Volatile Organic Chemicals from Drinking Water. AWWA Research Foundation and KIWA (Keuringsinstituut Voor Waterleidingartikelen, Denver, CO.

Anderson, C, Bailey, R. W., Pense, R. F. and Singley, J. E., 1983. Integrating Plant Uprating, Upgrading and THM Control Strategies: A Case Study. Proceedings Annual Conference, AWWA, Las Vegas, 875

Singley, J. E., 1983. Factors Influencing Water Quality in Distribution Systems. Proceedings, AWWA Distribution Division Symposium, Birmingham, AL.

Singley, J. E., and Lee, T.Y., 1984. Pipe Loop System Augments Corrosion Studies. Journal AWWA 76:76 (August)

Singley, J. E., 1983. Corrosion. Practical Applications of Theory and Case Studies, Proceedings, AWWA Annual Conference, Las Vegas, Nevada

Brodeur, T. P., Singley, J. E., Wasserman, H. and Hess, A. F. III., 1982. Control of THMs and Color at Ft. Lauderdale. Proceedings, AWWA Annual Conference, Miami Beach, Florida

Singley, J. E., and Bilello, L. J., 1982. Advances in Development of Design Criteria for Packed Column Operation. Proceedings, AWWA Annual Conference, Miami Beach, Florida

Pisigan, R. A. Jr. and Singley, J. E., 1982. A Better Calculation Method for the Calcium Carbonate Saturation Index and Corrosion of Steel in Waters with Different Saturation Indices. Proceedings, AWWA Annual Conference, Miami Beach, Florida

Hartman, G. C., Furman, T. D. Jr., Singley, J. E. and Tippin, D. L., 1982. Process Analysis: Upgrading Existing Water Treatment While Meeting Organic Drinking Water Regulations. Proceedings, AWWA Annual Conference, Miami Beach, Florida

Singley, J. E., 1982. Pilot Plant Studies of Corrosion Control. Pilot Plant Studies, Seminar, AWWA Miami Beach, Florida

Singley, J. E., 1981. "Potential for Reuse in the Southeastern U. S." in "/Water Reuse - - An Alternative in Water Resources Management," Miami, Florida

Singley, J. E., 1981. The Search for a Corrosion Index. Journal, AWWA 73: 579

Singley, J. E., 1981. Coagulation Control Using Jar Tests, in "Coagulation and Filtration - - Back to Basics". Seminar, American Water Works Association, St. Louis

Singley, J. E., and Bilello, L. J., 1981. Design of Aeration Systems for Removal of Volatile Organics. U. of Ill. Proc. 23rd Annual Public Water supply Engineer's Conference

Koshak, Y. H., Singley, J. E., Brodeur, T. P. and Dougherty, C. W., 1981. Wastewater Reclamation at Jeddah and Mecca, Saudi Arabia. In "Proceedings of 9th Annual Conference" of National Water Supply Improvement Association, Washington, D. C.

Singley, J. E., Ahmadi, A., Lee T.Y. and Pisigan, R., 1980. Laboratory Studies of Corrosion. Water Quality Technology Conference, American Water Works Association, Miami Beach

Singley, J. E., and Brodeur, T. P., 1980. Control of Precipitative Softening. Proceedings, Water Quality Technology Conference, American Water Works Association, Miami, Florida

Singley, J. E., 1980. El uso del Carbon Activado pulverizado para la remocion de compuestos organicos especificos. AIDIS, J. Div. Purif

Singley, J. E., Ervin, A. L., Mangone, M.A., Allan, M. J. and Land, H. H., 1980. Synthetic Organic Removal by Air Stripping in Potable Water Treatment Plants. Proceedings, AWWA Annual Conference, Atlanta, Georgia

Singley, J. E., Evrin, A. L., Mangone, M. A., Allan, J. M. and Land, H. H., 1980. Trace Organic Removal by Air Stripping. American Water Works Association Research Foundation

Singley, J. E., Ervin, A. L. and Williamson, D. F., 1979. Aeration (Plus Resins) Doing a Job Removing TOC. Water and Sewage Works, 126(9), 100

Singley, J. E., Beaudet, B. A., and Ervin, A. L., 1979. Use of Powdered Activated Carbon for

Removal of Specific Organic Compounds. Proceedings American Water Works Association Seminar. Denver, CO

Singley, J. E., Beaudet, B. A., Ervin, A. L. and Zegel, W. C., 1984. "Use of Powdered Activated Carbon to reduce Organic Contaminant Levels". Proceedings NATO.CCMS Adsorption Techniques in Drinking Water Treatment, Reston, Virginia [April 30, 1979] (EPA570/9-84-005, CCMS 112)

Singley, J. E., Ervin, A. L. and Williamson, D. F., 1979. Control of Synthetic Organic Chemicals by Use of Aeration and Resins. In: "Control of Organic Chemical Contaminants in Drinking Water, U. S. EPA

Steiner, J. IV, and Singley, J. E., 1979. Methoxychlor Removal from Potable Water. Journal AWWA, 71:284

Singley, J. E., 1978. Principles of Corrosion in Controlling Corrosion Within Water Systems, seminar American Water Works Association. Denver

Jeffery, E. A. and Singley, J. E., 1978. Benefits and Cost of Water Quality Improvements. Journal AWWA, 70:675

Singley, J. E., and Beaudet, B. A., 1977. Costs of Radium Removal from Potable Water Supplies U. S. EPA 600/2-77-073, April

Singley, J. E., 1976. Fundamental Considerations - -Chemical Coagulation. Proc. 18th Public Water Supply Engineers' Conference, University of Illinois

Duncan, T. W., Uhler, R. B. and Singley, J. E., 1976. Test Kits: Their Evaluations and Uses. Journal AWWA, 68:524

Brodeur, T. P., Singley, J. E., and Thurrott, J. C., 1976. Effect of a Change to Free Chlorine Residual at Daytona Beach, Florida. Proceedings, Water Quality Technology Conference. American Water Works Association, San Diego, California

Lai, R. J., Hudson, H. E. and Singley, J. E., 1975. Velocity Gradient Calibration of Jar-Test Equipment. Journal AWWA, 67:553

Singley, J. E., Hoadley, A. W., Hudson, H. E. and Loehman, E. T. A Benefit/Cost Evaluation of Drinking Water Hygiene Programs. Final Report on EPA Contract No. 68-01-1838

Jeffcoat, W. B. and Singley, J. E., 1975. The Effect of Alum Dilution and the Sequence of Chemical Association on Coagulation of Turbidity. Journal AWWA, 67:177

Hudson, H. E. and Singley, J. E., Jar Testing and Utilization of Jar Test Data in Upgrading Existing Water Treatment Plants. American Water Works Association

Singley, J. E., Kirchmer, C. J. and Miura, R. 1974. Analysis of Coprostanol, An Indicator of Fecal Contamination. Environmental Protection Technology Series, EPA 66/2-74-021

Singley, J. E., 1974. Coagulation-Filtration Practice as Related to Research. Journal AWWA, 66:502

Singley, J. E., 1973. Water Quality Criteria, EPA R-73-033, National Academy of Science, Panel on Public Water Supplies, Environmental Studies Board, March 1973

Singley, J. E., 1972. Experiences with the Magnesium Carbonate Coagulation Process in North America. in: Symposium on New Methods of Water Treatment, Pan-American Health Organization, Asuncion, Paraguay

Thompson, C. G., Singley, J. E. and Black, A. P. 1972. Magnesium Carbonate: A Recycled Coagulant-I. Journal AWWA, 64:11

Thompson, C. G., Singley, J. E., and Black, A. P. 1972. Magnesium Carbonate: A Recycled Coagulant-II" Journal AWWA, 64:93

Singley, J. E., and Black, A. P. 1972. Water Quality and Treatment: Past, Present, and Future. Journal AWWA, 64:6

Singley, J. E., 1972. Theory and Mechanisms of Polyelectrolytes as Coagulant Aids in Polyelectrolytes: Aids to better Water Quality, AWWA-EPA, Chicago

Singley, J. E., 1972. The Chemistry of Lima-Soda Softening. Proceedings, 14th Water Quality Conf., University of Illinois

Singley, J. E., and Sullivan, J. H. 1971. Feasibility of Treating Wastewater by Distillation. Water Poll. Contrl. Res. Series, 170 40 DNM 02/71, EPA

Singley, J. E., 1971. Chemical Indicators of Fecal Pollution. Ingenieria Sanitaria, 25:54

Singley, J. E., 1971. State of the Art of Coagulation. Journal AWWA, 63.99

Singley, J. E., 1971. "Chemical and Physical Purification of Water and Wastewater." Chapter 8 in Water and Water Pollution Handbook, Dekker, New York

Singley, J. E., 1970. "Municipal Water Treatment." Encyclopedia of Chemical Technology, Interscience. Vol 22, Second Edition. Wiley, New York

Singley, J. E., 1970. Use of Zeta Potential for Controlling Coagulation and Flocculation. Seminar on Coagulation for Municipal Water Supplies. Sponsored by FWQA and State of North Carolina, Raleigh, North Carolina

Singley, J. E., 1970. Chemical Indicators of Fecal Pollution. Proceedings of XII Inter-American Congress of Sanitary Engineering, Caracas, Venezuela

Singley, J. E., 1970. Principles of Corrosion in Corrosion by Soft Water, USPHS-AWWA, Washington, D. C.

Singley, J. E., 1970. Coagulation and Color Problems. Journal AWWA, 62:311

Singley, J. E., Black, A. P. and Norstrand, E. 1970 Sterols as Indicators of Fecal Pollution. Final Project report to FWPCA, Department of the Interior

Singley, J. E., and Sullivan, J. H. 1969. Reactions of Metal Ions in Dilute Aqueous Solution: Recalculation of Hydrolysis of Aluminum. Journal AWWA, 60:11, 1280

Singley, J. E., 1968. Color Removal. AWWA-USPHS. Cleveland, Ohio

Singley, J. E., 1968. Theory and Mechanisms of Coagulation-Flocculation. AWWA-USPHS. Cleveland, Ohio

Singley, J. E., and Black, A. P. 1967. Hydrolysis Products of Iron (III). Journal AWWA, 1549

Singley, J. E., 1967. Use of Stability Constants for Calculations of Metal Ion Concentrations in Dilute Aqueous Solution. Bull. Ga. Acad. Sci., 77

Singley, J. E. and Ching-lin Chen, Editors. 1966. The Collected Works of A. P. Black --1933-66. Gainesville, Florida

Singley, J. E., 1966. Ferric Sulfate as a Coagulant in Water Treatment. Proc. Oklahoma Water Pollution Control School, 49

Singley, J. E., 1966. The Hydrolysis of Iron (III) in Dilute Aqueous Solution, Doctoral Dissertation, University of Florida

Singley, J. E., 1966. The Correction of Color Measurements to Standard Conditions. Journal AWWA, 58:455

Winter, E. A., Montesinos, M. J. and Singley, J. E., 1965. "Copper Compounds" "Encyclopedia of Chemical Technology, 63:265, Interscience

Singley, J. E., 1965 Water Research at Georgia State College. Journal Southeastern Section AWWA

Singley, J. E., Maulding, J. S. and Harris, R. H. 1965. Ferric Sulfate as a Coagulant. Water Works and Wastes Engineering, 52-46

Black, A. P., Singley, J. E., Whitle, G. P. and Maulding, J. S. 1963. Stoichiometry of the Coagulation of Organic Color-Causing Compounds with Ferric Sulfate. Journal AWWA, 55:1347

Singley, J. E., 1960. Isophthalic Sulfonyl Compounds: A New Class of Dibasic Acids for Alkyd Resins. Official Digest, Federation of Paint and Varnish Production Clubs, 30, 835-44

Rueggegerg, W. H. C., Singley, J. E., Feazel, C. E. and Verchot, E. A. 1958 Bis(aminopnhenyl) Sulfonews as Curing Agents for Epoxy Resins, Modern Plastics, 35, 154-6

Hine, J., Dowell, A. M. and Singley, J. E. 1956. Carbon Dihalides as Intermediates in the Basic Hydrolysis of Haloforms. IV. Relative Reactivities of Haloforms. Journal of the American Chemical Society, 78,479-82

Singley, J. E., 1952. Carbon Dihalides as Intermediates in Basic Hydrolysis of Haloforms. Master Thesis, Georgia Institute of Technology

Patents:

Singley, J. E. and Christiansen, A to Tennessee Corporation. U. S. 3,044,983 Cured Resins from Glycidyl Ether of Dihydroxy Diphenyl Sulfone

Singley, J. E. and Wittle, G. P. to Tennessee Corporation. U. S. 3,060,151 Molding Powder Comprising Glycidyl Diglycidyl Ethers of Dihydroxy Diphenyl Sulfones

Duckworth, W. C. and Singley, J. E. to Tennessee Corporation. U. S. 2,99,026 Epoxy Resin Composition Containing Diglycidyl Ether of 2, 4-Dihydroxy Diphenyl Sulfone

APPENDIX C5

CURRICULUM VITAE FOR DR. ELLIS D. VERINK, JR.

Personal Data
Date of Birth February 9, 1920
Place of Birth: Peking, China Married, two children

Education

B.S. 1941	Purdue University, Metallurgical Engineering
M.S., 1963	Ohio State University, Metallurgical Engineering
Ph.D. 1965	Ohio State University, Metallurgical Engineering

Experience

1941-1946	Naval Officer, U.S.N.R.
1946-1948	Engineer, Development Division, Aluminum Company of America, New Kensington, Pennsylvania
1948-1959	Manager, Chemical Section, Development Division, Aluminum company of America, New Kensington, Pennsylvania
1959-1962	Manager, Chemical and Petroleum Industry Sales, Aluminum Company of America, Pittsburgh, Pennsylvania
1962-1965	Graduate Student, The Ohio State University, Columbus, Ohio
1965-1968	Associate Professor Metallurgical and Materials Engineering, University of Florida, Gainesville, Florida
1968-1970	Professor of Metallurgical and Materials Engineering, University of Florida, Gainesville, Florida
1966-1984	Consultant to The Aluminum Association, New York, New York
1970-1973	Assistant Chairman and Professor, Metallurgical and Materials Engineering, University of Florida, Gainesville, Florida
1973-1986	Chairman and Professor, Materials Science and Engineering, University of Florida, Gainesville, Florida

1970-Present President, Materials Consultants, Inc., Gainesville, Florida

1984-1991 Distinguished Service Professor, Materials Science and Engineering, University of Florida, Gainesville, Florida

1984-Present Consultant to Copper Development Association, Greenwich, Connecticut

1985-88 Consultant to International Copper Research Association, Inc., New York, New York

1986-87 Visiting Scientist, Corrosion and Wear Group of the Metallurgical Division of the Institute of Materials Science and Engineering of the National Bureau of Standards, Gaithersburg, NM (now National Institute of Standardization and Technology)

1987-89 Consultant to Lockheed-Georgia Co., Marietta, GA

1991-Present Distinguished Service Professor, Emeritus, Department of Materials Science and Engineering, University of Florida, Gainesville, FL.

Fields of Interest

Corrosion, materials selection

Professional Societies

NACE International, formerly National Association of Corrosion Engineers
ASM International, formerly American Society for Metals
Engineering Society of Western Pennsylvania
The Metallurgical Society (TMS/AIME)
American Welding Society
American Society for Testing & Materials (ASTM)
Electrochemical Society

Honor Societies

Alpha Sigma Mu
Omicron Delta Kappa
Phi Lambda Upsilon
Epsilon Lambda Chi
Sigma Xi
Phi Kappa Phi
Tau Beta Pi

Florida Blue Key
Sigma Tau

Registrations

Professional Engineer, Pennsylvania, No. PE 015304 Professional Engineer, Florida, No 11613
NACE Certificate of Qualification in Corrosion Control, **No.** 1022
Accredited Corrosion Specialist, National Association of Corrosion
Engineer, Accreditation No. 76
Registered Corrosion Engineer, California, No. CR-928

Biographical References

Who's Who in America, 43rd and subsequent Editions American Men and Women of Science
Who's Who in the South and Southwest
Distinguished Educators
Engineers of Distinction, 2nd Edition
Who's Who in Engineering, 5th and subsequent Editions Who's Who in Technology Today, 1982
International Who's Who in Engineering, lst Edition
Leading Consultants in High Technology, 1983
Who's Who in Science and Technology, lst Edition

National Activities

Member, 1988-1990, U.S. Nuclear Waste Technical Review Board, appointed by President Ronald Reagan. Reappointed by President George Bush in 1990 for a four year appointment ending in 1994. Continued active service to the Board as Consultant until replacement was appointed in April 1997. This Board reports to the U. S. Congress and the Secretary of Energy at least twice a year regarding technical matters under the jurisdiction of DOE, relating to management of high level nuclear waste.

President, The Metallurgical Society of AIME (TMS/AIME) 1984.

Executive Committee American Institute of Mining, Metallurgical and Petroleum Engineers (AIME), 1984-1985

Member, Board of Directors, TMS/AIME (The Metallurgical Society) (1979-1986)

Member, Board of Directors, AIME, 1982-1985

Member, Board of Trustees, AIME, 1985-1986

Past Chairman, DEPFH Committee, National Organization of Heads of Departments of Material Science and Engineering

Past Chairman (two terms), Member, Executive Committee, ASTM Committee B-2, "Non-Ferrous Metals"

Vice Chairman, Chairman, Gordon Research Conference on Corrosion, 1977-1978

Vice Chairman, Chairman, National Conference on Corrosion Research in Progress, National Association of Corrosion Engineers, 1978-1979

National Director (three terms), National Association of Corrosion Engineers (NACE), most recent, 1984-1987

Executive Committee, National Association of Corrosion Engineers, 1982-85

Vice Chairman, National Advisory Committee, NSF-Sponsored EMMSE Project to produce Educational Modules for Materials Science and Engineering

Member, National Advisory Committee on National Academy of Engineering (Marine Board) on Ocean Thermal Energy conversion

Member, National Academy of Sciences/National Research Council Panel on Accelerated Corrosion of Copper-Nickel Piping

Member, National Academy of Sciences Review Committee on YBS-II (Nuclear Waste Management)

Member, National Academy of Sciences Review Committee on KBS-III (Nuclear Waste Management)

Member, National Research Council Panel on ONR Research Opportunities in Materials Science, 1987

Member, Technical Advisory Group (TAG) of the Naval Research Advisory Board (RAB), 1988

Member, Board of Visitors, Naval Research Advisory Board (RAB), 1989

Member, Research Committee, NACE

Member, Governmental Affairs Committee, NACE

Member, Corrosion Committee, ASM/AIME

Member, Corrosion Committee, ASTM, Committee G-1

Member, Education and Professional Affairs Committee, TMS/AIME

Member, TMS/AIME Ad Hoc, Committee on Certification

Chairman, Ad Ho-Q Committee of Depth Committee on Certification and Professional Registration

Past Chairman, Long Range Planning Committee, TMS/AIME

Past Chairman, Professional Development Committee, ASM

President, University of Florida Chapter of Sigma Xi, 1986-1987

Member of the Engineering Accreditation Commission of the Accreditation Board of Engineering and Technology, New York, NY 1986-90

International Activities

Keynote Speaker, First Brazilian Congress on Modem Trends in Materials Science and Engineering, Rio de Janeiro, January 1974

Keynote Speaker, Third Venezuelan Congress on Materials Science and Engineering, Caracas, Venezuela, November 1974

Short Course on Corrosion, Universidad Centml de Venezuela, Caracus, Venezuela, 1977

Invited Lecturer, Materials Selection, UFMG, Belo Horizonte, Brazil, March 1978

Invited Speaker, NATO Seminar on Electrochemical Techniques for Corrosion Research, CEBELCOR, Brussels, June 1976

U.S. Representative to EMMSE-VEC Workshops in Birmingham, England, and Frascatti, Italy, development of teaching modules for Materials Science and Engineering, 1979, 1980

Invited Lecturer on Corrosion and Materials Science, Poznan Technical University, Poznan, Poland, University of Krakow, Krakow, Poland, and at the Polish Academy of Sciences, Warsaw, Poland

Member of U.S. Delegation to U.S.S.R. under the NSF sponsored U.S./U.S.S.R. Corrosion Project, August 23 - September 2, 1981

Short Course on Corrosion for National Fertilizer Institute in Sao Paulo, Brazil, in cooperation with USAID Program, July 1982

Leader, People-To-People Delegation of Corrosion Scientists, Peoples' Republic of China, June - July, 1986

Community Activities

Past President, University of City Kiwanis Club, Gainesville, Florida

Past President, Member of Board of Directors, Gainesville YMCA, Gainesville, Florida

Member of Session, Grace Presbyterian Church, Gainesville, Florida

Past Member, City of Gainesville Building and Trades Codes Research and Advisory Committee

Consulting Activities

The Aluminum Association. Desalination, Ocean Thermal Energy Conversion

Materials Consultants, Inc. Failure analysis, Materials Selection for various Clients in Industry, Government and Legal Profession

Sandia Corporation, Albuquerque, New Mexico. Operation Deep Steam, Advisory Committee

The Copper Development Association, Materials for Nuclear Waste Management

The International Copper Research Association, Inc., Materials for Nuclear Waste Management
Elected Fellow of The Metallurgical Society, 1988. Total number of living Fellows limited to 100 worldwide at any given time.

Elected Fellow of NACE International as a member of the initial class, 1992

Tau Beta Pi, Pi Tau Sigma Award for Excellence in Undergraduate Teaching, 1969 (Based on student evaluations of teaching)

Sam Tour Award, ASTIA, 1978 (Best Paper on Corrosion Testing in Year, selected by a panel of Committee G-1)

Fellow, American Society for Metals, 1978

University of Florida Teacher-Scholar of the Year, 1979. (A University-wide Award in recognition of outstanding scholarship and teaching)

Award of Appreciation, ASTM Committee B-2, 1979

Visiting Scholar, Research Council, University of Nebraska, 1981

Willis Rodney Whitney Award for Corrosion Science, NACE, 1982 (International Award based on record of significant contributions to the state of Corrosion Science)

Distinguished Alumnus, The Ohio State University, 1982

Florida Blue Key Distinguished Faculty Award, 1983

3rd Annual Distinguished Alumni Lecture (Department Metallurgical Engineering), Ohio State University, October 24, 1986

Educator Award of The Metallurgical Society of AIME, 1988 (for outstanding contributions to education in Metallurgical and/or Materials Science and Engineering)

Excellence in Engineering Teaching Award of the Florida Chapter of Alpha Sigma Mu, 1988-89

Donald E. Marlowe Award of the American Society for Engineering Education "In recognition of creative and distinguished administrative leadership in engineering and engineering technology education"., June 1991.

Distinguished Life Membership, Alpha Sigma Mu, 4 November 1992

Corrosion Editor, Journal of Electrochemical Society, Princeton, N.J., 1977-79

Editorial Board; Surface Technology Magazine, Elsevier Sequoia, S.A., Lausanne, Switzerland, 1976-1987

Editorial Board, Journal of Materials Education, Pennsylvania State University, University Park, Pennsylvania, 1977-1986.

PUBLICATIONS

Corrosion Behavior Aluminum

E.D. Verink, Chem. Eng. 53 (1946) 253-4.

E.D. Verink, R.H. Wagner and R.H. Brown, Chem. Eng. 54, No. 7 (1947) 221-2. E.D.

Verink, Chem. Eng. 55, No. 2 (1948) 236, 8.

J.P. Balash and E. D. Verink, Chem. Eng. 55, No. 10 (1948) 240P 241.

E.D. Verink, Chem. Eng. 56 No. 6 (1949) 243.

E.D. Verink, Chem. Eng. 56 No. 10 (1949) 238.

E.D. Verink, Chem. Eng. 56 No. 11 (1949) 202.

E.D. Verink, Chem Eng. 57 No. 11 (1950) 108, 110, 113, 118, 121, 124, 129, 140 and 216.

E.D Verink and W. W. Binger, Chem. Eng. 57, No. 11 (1950) 136.

E.D. Verink and D. B. Bird, Materials Protection 6, No. 1 (1967) 41-42.

E.D. Verink, Materials Protection, 6, No. 1 (1967) 41-42.

E.D. Verink, Chemical Behavior of Aluminum Alloys", Discussion of paper by P. D. Brandt, Symposium on Methods of Materials Section, May 1966, University of Florida, Gainesville, Florida, Gordon and Breach Science Publishers (May 1968).

E.D. Verink, Aluminum alloys for Saline Waters", Chemical Engineering, April 15, 1974.

E.D. Verink and P.F. George, "Long Term Results: Aluminum Alloys for Desalination Service", Materials Protection and Performance 12, No.1 5 (May 1973), 26-30.

R.A. Bonewitz and E.D. Vefink ,Correlation Between Long Term Testing of Aluminum Alloys for Desalination and Electrochemical Methods of Evaluation", Materials Performance IA, No. 8 (August 1975), 16-23.

Cathodic Protection

R. B Hoxeng, E. D. Verink and R. H. Brown, Corrosion, 3 (1947), 263-274.

E.D. Verink, K. K. Reid and E. R. Diggins, "Output of Light Metal Galvanic Anodes as a Function of Soil Resistivity", ECS-NACE Symposium on Cathodic Protection, December 1947, Pittsburgh, Pennsylvania (published 1949), 101-4.

E.D. Verink, K. K. Reid and R. L. Horst, Southern Power and Industry, 47, No. 5 (1949), 56-9.

K.K. Reid, R. L. Horst and E. D. Verink, Southern Power and Industry, 47 No. 8 (1949) 62-5.

R.L. Horst, K. K. Reid and E. D. Verink, Southern Power and Industry, 47, No. 11 (1949), 74-80.

Materials of Construction

R.H. Brown and E. D. Verink, I and EC 39 (1947) 1198-1201.

E.D. Verink and R. H. Brown, I and EC 40 (1948) 1776-7.

E.D. Verink, I and EC 41 (1949) 2095-7.

E.D. Verink and H. W. Fritts, I and EC 42 (1950) 1955-6.

H.W. Fritts and E. D. Verink, I and EC 43 (1951), 2197-9.

E.D Verink and F. B. Murphy, Corrosion, 16, No. 12 (1960).

E.D. Verink, Petr. Refiner, 31 (July 1952).

E.D. Verink, Proc. Amer. Power Conf., XIX (1957) 735-8.

E.D. Verink and J. D. Rucker, Proc. Pittsburgh Water conf. (1958).

E.D. Verink, Proc. Amer. Power Conf., Vol. XXI (1959), 746.

E.D. Verink, Drilling 23 (May 20, 1962), 135.

E.D. Verink, "Dynamic Materials Testing: Aluminum Alloys for Desalination Service", Materials Protection, 8, No. 11 (1969) 13-15.

E.D. Verink, "Construction and Operation of Dynamic Test Loop of Aluminum Alloys for Desalination Environments", Proceedings 24th Annual conference, NACE,

Philadelphia, Pennsylvania, March 2-6, 1970, Paper No. 101.

E.D. Verink, "Aluminum Alloys for Desalination Service--Progress Report", presented Annual Meeting NACE, Chicago, Illinois, March 1971.

E.D. Verink and P. F. George, "Long Term Results: Aluminum Alloys for Desalination Service", Materials Protection and Performance, 12, No. 2 (February 1973) 34-36.

Materials Selection and Economic Aspects

E.D. Verink, Jr., Editor of Symposium Volume, "Methods of Materials Selection", (AIME, ASM, NACE and STS sponsorship), Gordon and Breach Science Publishers, New York, N. Y. May 1968.

E.D. Verink, Chapter XVII, "Analysis and Correction of Corrosion Failures", NACE Basic Corrosion Coum, National Association of Corrosion Engineers, Houston, Texas, 1970.

E.D. Verink, Jr., Influence of Materials Selection and Design on Corrosion Behavior", Proc. of National Sy Wear and Corrosion, Carnegie Institution, Washington, D.C., June 4-6, 1979.

E.D. Verink, Jr., Discussion of Alternative Procedures for the Direct Calculation of Economic Appraisal of Corrosion Control Measures", Materials Performance, Vol. 18, No. 9 (September 1979), 54.

E.D. Verink, Jr., "Non-Fuel Materials -- The Next National Crisis?", Journal of Metals, Vol. 35, No. 6 (1980), 22.

E.D. Verink, Jr., "Our Next National Crisis: Materials", Materials Engineering, Vol. 92, No. 2 (1980), 42.
E.D. Verink, Jr., A Simplified Approach to Corrosion Economic Calculations", Materials Performance, vol. 21, No. 10 (October 1982) 26-34.

E.D. Verink, Jr., "General Corrosion of Metals", Forms of Corrosion RECOGNITION AND PREVENTION, C. P. Dillon, Editor, National Association of Corrosion Engineers, Houston, Texas, 1982.

E.D. Verink, Jr., "Substitution of Polymeric Materials for Critical Materials", Materials and Society, Volume 8, No. 2, p. 305-311, 1984.

E.D. Verink, Jr., "Materials Selection: A Capstone Course", Journal of Metals, Vol. 38, 10 (1986), 46.

E.D. Verink, Jr., "Corrosion Economic Calculations", ASM Metals Handbook, 9th Edition, Volume 13, "Corrosion", ASM International, Materials Park, OH, 1987, 369--374.

E.D. Verink, Jr., Designing to Prevent Corrosion", Corrosion Handbook, 2nd Edition, John Wiley. Submitted*.

E.D. Verink, Jr., J. Kolts, J. Rumble, G. M. Ugiansky, "Corrosion Data Workshop Summary", Materials Performance, 26, 4 (1987) 55-60.

Oxidation and Corrosion

"Mechanism of Oxidation of Uranium in Continuously Flowing Nitrogen Gases", USAEC, SC-DC-64-2303 (1963) (M.S. Thesis, the Ohio State University) 55 pages.

"A Study of the Oxidation Mechanism of Uranium in Moist, Flowing Nitrogen, and in Nitrogen-Oxygen Mixtures", (1965) (Ph.D. Dissertation, The Ohio State University) 100 pages.

K. Kondo, E. D. Verink, F. H. Beck and M. G. Fontana, Corrosion 20, No. 10 (1964), 31-20.

E.D. Verink, Simplified Procedure for Constructing Pourbaix Diagrams", Corrosion 23, No. 12 (1967), 371-3.

E.D. Verink, Materials Protection, 6, No. 10 (1967).

E.D. Verink and P. A. Parrish, "Use of Pourbaix Diagrams in Predicting Susceptibility to Dealloying Phenomena", Corrosion 26, No. 5 (May 1970), 214.

E.D. Verink and M. Pourbaix, "Use of Electrochemical Hysteresis Techniques in Developing Alloys for Saline Exposures", presented at Annual Meeting NACE, Chicago, Illinois, March 1971; Corrosion 27, No.12 (1971).

E.D. Verink and R. H. Heidersbach, "Evaluation of the Tendency for Dealloying in Metal Systems", Localized Corrosion -- Cause of Metal Failure, STP 516 (1972), American Society for Testing and Materials (ASTM), Philadelphia, Pennsylvania.

E.D. Verink, T. S. Lee]III and R. L. Cusumano, Influence of Prior Electrochemical History on the Propagation of Localized Corrosion", 28, No. 9 (1972).

E. D. Verink, "Applications of Electrochemical Hysteresis Methods in Assessing the

Corrosion Behavior of Alloys", Proc. of the 5th Intl. Congress on Metallic Corrosion Tokyo, Japan, 1972.

E.D. Verink and T. S. Lee, "Influence of Minor Alloy Additions on the Passive Behavior of Binary Cu-Ni Alloys", Proc. of 3rd Intl. Conf. on Materials for the Sea, Gaithersburg, Maryland, October 1972.

R.H. Heidersbach, Jr. and E. D. Verink, Jr., The Dezincification of Alpha and Beta Brasses", Corrosion 28, No. 11 (1972).

R.E. Hummel, E. D. Verink, Jr. and C. W. Shanley, "Use of Electrochemical Techniques in Combination with Differential Reflectometry to Elucidate Experimental Pourbaix Diagrams", presented at the International Congress on Metallic Corrosion, December 19785, Proceedings of The Sixth Int'l. Congress on Metallic Corrosion, Sydney, Australia, Vol. 1 (December 1975), 348-354.

K. K. Starr, E. D. Verink, Jr. and M. Pourbaix, The Significance of the Protection Potential for Fe-Cr Alloys at Room Temperature", Corrosion 32, No. 2 (February 1976) 27-51.

E. D. Verink, Jr. I K. K. Starr and J. M. Bowers, "Chemistry of Crevice Corrosion as Observed in Certain Cu-Ni and Fe-Cr Alloys", Corrosion 32, No. 2 (February 1976), 60-64.

M. H. Froning, M. E. Shanley and E. D. Verink, Jr., "An Improved Method for Calculation of Potential-pH Diagrams of Metal-Ion-Water Systems by Computer", Corrosion Science 16 (1976), 371-377.

W. C. Fort III and E. D. Verink, Jr., "Elucidation of the Mechanism of Dezincification by Auger Electron Spectroscopy in combination with Electrochemical Methods", Proc. of the 4th Intl. Congress on Marine Corrosion and Fouling, Antibes, Juan-les-Pins, France, June 14-19, 1976.

C.M. Chen, M.H. Froning and E.D. Vefink, "Crevice Corrosion and its Relationship with Stress-Corrosion Cracking", Stress Corrosion-New Approaches, H.L. Craig, Editor, STP 610, Symposium 22-27 June, 1975, Montreal, Canada, published by ASTM, Philadelphia, PA, 1976, 289-307. (Received the Sam Tour Award of ASTM for the best paper of the year on corrosion testing, as selected by ASTM Committee G-1).

E. D. Verink, Jr., "Applications of Electrochemical Techniques in the Development of Alloys for Corrosive Environments", Electrochemical Techniques for Corrosion, NACE, Houston, Texas, 1977, Library of Congress No. 77-71054.

P. A. Parrish, C. M. Chen and E. D. Verink, Jr., "Retardation of Crack Propagation for D6AC High-Strength, Low-Alloy Steel in Aqueous Media by Addition of Oxidizing Inhibitors", Stress Corrosion--New Approaches , STP 610 (1976), American Society for Testing and Materials (ASTM), Philadelphia, Pennsylvania.

M. Pourbaix, J. V. Muylder, A. Pourbaix and E. D. Verink, "Etudes Electrochimiques Concemant les Corrosions en Cellules Occluses C.C.O. et Protection Contre ces Corrosions: Corrosion par Piqures, Corrosion Cavemeuse, Corrosion Fissurante sous Tension, Corrosion Selective D'AHiages. Applications au fer et Aux Aciers, au Cuivre, aux Cupro-nickels et aux Laitons", Electroanalytical Chemistry and Interfacial Electrochemistry, 62 (1975), 21-29.

P. A. Parrish, K. B. Das, C. M. Chen and E. D. Verink, Jr., "Inhibition of Hydrogen Embrittlement of D6AC Steel in Aqueous Oxidizing Media", Proc. of Intl. ConL on the Effect of Hydrogen on Behavior of Materials, Jackson Lake Lodge, Moran, Wyoming, September 7-1 1 P 1975, edited by A. W. Thompson and I. M. Berstein.

E.D. Verink, Jr. and K. B. Das, "Research on Inhibition for Corrosion Fatigue of High Strength Alloys", Final Report AFFDL-TR-76-137, U. S. Air Force Materials Laboratory, December 1978.

E.D. Verink, Jr., "Simplified Procedure for Constructing Pourbaix Diagrams", Journal of Educational Modules for Materials Science and Engineering, Vol. 1, No. 3 (Fall 1979), 535-560.

C. W. Shanley, R. E. Hummel and E. D. Verink, Jr., "Differential Reflectrometry–A New Optical Technique to Study Corrosion Phenomena", Corrosion Science, Vol. 20, No 4 (February 1980), p. 467.

C. W. Shanley, R. E. Hummel and E. D. Verink, Jr., "Differential Reflectrometry of Corrosion Products of Copper", Corrosion Science, Vol. 20, No. 4 (February 1980), 481.

E. D. Verink, Jr., "Improving the Ability to Predict Corrosion Behavior Through Corrosion Research", Corrosion Vol. 38, No. 6 (June 1982) (Willis Rodney Whitney Award Lecture).

F. K. Urban, R. E. Hummel and E. D. Verink, Jr., "Differential Reflectometry of Thin Film Metal Oxides on Copper, Tungsten, Molybdenum and Chromium", Corrosion Science, Volume 22, No. 7, p. 647-660, 1982.

E. D. Verink, Jr., "Adaptation of a Computer Program for Pourbaix Diagrams to Personal Computers", Proceedings of an International Symposium Honoring Professor Marcel Pourbaix on his Eightieth Birthday, "EQUILIBRIUM DIAGRAMS, LOCALIZED CORROSION", The Electrochemical Society, Pennington, N.J., October, 1984, New Orleans, LA.

E.D. Verink, Dealloying", Encyclopedia of Materials Science and Engineering, M. B. Bever, Editor, Pergamon Press, 1986, Page 1020.

R. E. Hummel, R. J. Smith and E. D. Verink, Jr., "The Passivation of Nickel in Aqueous Solutions - I. The Identification of Insoluble Corrosion Products on Nickel Electrodes Using Optical and ESCA Techniques", Corrosion Science, Vol. No. 8, (1987) pp. 803-813.

M.P. Brady, R.J. Hanrahan, Jr., S.P. Elder Randall, and E.D. Verink, Jr., "The Effect of Nitrogen an the Oxidation Behavior of 25Nb-25Ti-50AI", Scripta Met., v27, n5 (1992)

M.P. Brady, R.J. Hanrahan, Jr., and E.D. Verink, Jr., "On the Transition to Pmbckw Alumina Formation at High Temperature in Nb-Ti-Al Alloys", Scripta Met., v28, nl, (1993), 115-120.

P.Bendale, S. Venigalla, J.R. Ambrose, E.D. Verink, and J.H. Adair, "Preparation of Barium Titanate Films at 55 C by an Electrochemical Method", Journal of the American Ceramic Society, 76[10]2619-27 (1993)

Chapters in Books

E. D. Verink, Jr., "Selective Leaching (Dealloying), Encyclopedia of Materials Science and Engineering, Pergamon Press, Ltd., 1984.

E. D. Verink, Chapter XVII, "Analysis and Correction of Corrosion Failures", NACE Basic Corrosion Course, National Association of Corrosion Engineers, Houston, Texas, 1970*.

E.D. Verink, Jr., "General Corrosion of Metals", Forms of Corrosion: RECOGNITION AND PREVENTION, C. P. Dillon, Editor, National Association of Corrosion Engineers, Houston, Texas, 1982*.

E. D. Verink, Jr., "Corrosion Economic Calculations", ASM Metals Handbook, 9th Edition, Volume 13, "Corrosion", ASM International, Metals Park, Ohio, 1987, pp. 369-374

E. D. Verink, Jr., "Application of Electrochemical Techniques in the Development of Alloys", Electrochemical Techniques for Corrosion Engineering, R. Baboian, Ed., NACE, Houston, TX, 1986, pp. 101-110.

E.D. Verink, Jr., "Structure of Matter and Introduction to Metallurgy", Materials and Processes., Part A: Materials, Third Edition, J.F. Young and R.S. Shane, Editors, Marcel Dekker, Inc., New York 10016, 1985.

E.D. Verink, Analysis and Correction of Corrosion Failures" I Corrosion Prevention and Control, Proceedings of the 33rd Sagamore Conference, July 28-August 1, 1986, Burlington, Vt., M. Levy and S. Isserow, Editors,

M. Akkaya and E.D. Verink, Jr., "Electrochemical Corrosion Studies on Copper-Base Waste Package Container Materials in Unirradiated 0. 1 N $NaNO_3$ at 95° C", Lawrence Livermore National Laboratory Report UCRL-21076, P.O. 637805, May 1988.

J. C. Liu, M.P. Brady, E.D. Verink and S.P. Withrow, "The Effect of Ion Implantation on the Oxidation Behavior of Nb/Ta Alloys at High Temperature", Proceedings of the Syml2osium on High Teml2erature Materials Chemistry, Edited by W.B. Johnson and R.A. Rapp, Volume 90-18, The Electrochemical Society, Inc., 10 South Main St., Pennington, NJO8534-2896, 1990.

S. Venigalla, P. Bendale, J.R. Ambrose, E.D. Verink, and J.H. Adair, "Electrochemical Preparation of Barium Titanate Films at Ultra-Low Temperatures", Materials Research Society Symposium Proceedings Volume 234, Ferritic Thin Films II, Angus I. Kingon, Edward R. Myers and Bruce Tuttle, Editors, Materials Research Society, Pittsburgh, PA, 1992, pp 309-314.

E.D. Verink, Jr., "Bronze and Other Copper Base Alloys: Introduction to Corrosion Behavior", DIALOGUE/89, The Conservation of Bronze Sculpture in the Outdoor Environment, A Dialogue Among Conservators, Curators Environmental Scientists and Corrosion Engineers, July 11-13, 1989, Johns Hopkins University, Baltimore, MD, NACE, Houston, TX., 1992.

M.P. Brady, R.K. Stone, S.P. Elder Randall, and E.D. Verink, The Effect of Processing on the Oxidation Behavior of a Nb-Ti-Al Alloy", Processing and Fabrication of Advanced Materials for High Temperature Applications, V. A. Ravi and T. S. Srivatsan, Editors, TMS/ASM Fall Meeting, Cincinnati, OH, 1991p pp 239-248, Published 1992 by TMS, 420 Commonwealth Drive, Warrendale, PA 15086.

M.P. Brady, R.J. Hanrahan, Jr. and E.D. Verink, Jr., "Oxidation Behavior in the System Nb-Ti-Al", Processing and Fabrication of Advanced Materials for High Temperature Applications II, V.A. Ravi and T.S. Srivatsan, Editors, TMS/ASM Fall Meeting, Chicago, IL, November 1-5, 1992, Published by TMS, 420 Commonwealth Drive, Warrendale, PA 15086, 1993. pages 419-434 incl.

R.J. Hanrahall , Jr., E.D. Verink Jr., S. P. Withrow, and F.O. Ristolainen, "Modification of the Initial Oxidation Kinetics of TiAl, $NbAl_3$ and 25-25-50 Nb-Ti-Al by Oxygen Implantation", Processing and Fabrication of Advanced Materials -III, Published by TMS, 420 Commonwealth Drive, Warrendale, PA 15086, 1994, pp. 643-660 incl.

Hanrahan, Jr., E. D. Verink, Jr., S.P. Withrow, and E.O. Ristolainen, "Oxide Formation on $NbAl_3$ and TiAl Due to Ion Implantation of ^{18}O", Materials Research Society Proceedings, Vol. 316, MRS (1994), pages 783-788.

E.D. Verink, "High Level Nuclear Waste Management in USA", Application of Accelerated Corrosion Tests to Service Life Prediction of Materials", ASTM STP 1194, G. Cragnolino and N. Shridar Editors, Published by ASTM, 1916 Race St., Philadelphia, PA 19103, February 1994, pp. 115-125 incl.

R. J. Hanrahan, Jr., E. D. Verink, Jr., and S. P. Withrow, "Oxidation of Ion Implanted NiAl", Elevated Temperature Coatings: Science and Technology, I, N. B. Dahotre, J. Hampikian and J. J. Stiglich, eds., TMS, 420 Commonwealth Drive, Warrendale, PA 15086, pp. 95-102.

Books Written or Edited

A. Barkatt, E.D. Veink, Jr., and L.R. Smith, Editors, Materials Stability and Environmental Degradation, Volume 125, Materials Research Society Symposium Proceedings, Material Research Society, Pittsburgh, PA, 1988.

E. D. Verink, Jr., Editor of Symposium Volume, "Methods of Materials Selection", (AIME, ASM, NACE and STS sponsorhip), Gordon and Breach Science Publishers, New York, N. Y., May 1968.

E. D. Verink, Jr., "Corrosion Testing Made Easy, The Basics", NACE International, Houston, TX, February 1, 1994, 310 pages.

Booklets for Alcoa

"Process Industries Applications of Alcoa Aluminum".

"Cryogenic Applications of Alcoa Aluminum".

"Alcoa Aluminum Heat Exchange Tubes".

Booklets for Aluminum Association, Inc.

"Aluminum in Desalination Equipment".

University Committees

Chairman, University Presidential Search Advisory Committee (Criser)

Past Chairman, Senate Steering Committee

Past Chairman (two terms), Senate Nominating Committee

Past Chairman, University Constitution Committee

Past Member, University Committee on Salaries and Fringe Benefits

Past Member, University Search Committee for Dean of Graduate School and Sponsored Research

Member, University Senate

Past Member, Graduate Council

Past Member, University Patent Committee

College of Engineering Committees

Chairman, College Reorganization Committee

Member, Selection Committee for New Dean (two searches, Chen and Phillips)

Chairman (twice), Selection Committee for New Associate Dean for Academic Affairs (Justusson and Bevis)

Chairman, Selection Committee for new Associate Dean for Research (Ohanian)

Chairman, College Tenure and Promotion Advisory Committee

Member, College Communications Committee

Member, TIP Committee