UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

January 3, 1992

OFFICE OF
THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

EPA-SAB-DWC-92-010

Honorable William K. Reilly
Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Subject: Science Advisory Board review of the Drinking Water Research Division's Corrosion Research Program.

Dear Mr. Reilly:

The Science Advisory Board's Drinking Water Committee (DWC) met in Cincinnati, Ohio on May 9 and 10, 1991 to review the Environmental Protection Agency's Drinking Water Research Division's (DWRD) Corrosion Research Program. The Committee was asked to review and evaluate the state-of-the-art use of pipe loop tests for the evaluation and optimization of corrosion control treatment methods; and identify and consider the relative severity and scope of the secondary impacts of regulated corrosion control. We further subdivided these issues into the following five topics and offer the following response (more detail on each issue is contained in the attached report):

1. The use of pipe loop tests for the evaluation and optimization of corrosion control treatment methods.

We recommend that the DWRD continue its research with pipe loop tests to obtain data that can be used to provide a better understanding of corrosion and control procedures.

2. The usefulness of methods other than pipe loop tests such as coupon tests and electrochemical methods.

We recommend that studies be undertaken to determine whether the concentrations of lead, copper, and other metals that enter water as a result of corrosion are directly related to the measures of corrosion rate that are made using gravimetric and electrochemical methods. These studies should be conducted in conjunction with pipe loop tests and studies of full-scale systems.

3. Standard protocol for evaluating corrosivity.

We recommend that the search for a standard protocol for evaluating corrosivity should be undertaken starting with the simplest test, gravimetric--either with iron or lead test systems, moving on to more complex approaches if this is unsuccessful.

4. Identification and consideration of the relative severity of the secondary impacts of corrosion control procedure.

We recommend that studies be undertaken to determine how lime can be added to meet the goals of the lead/copper rule, and at the same time, eliminate the operational problems associated with adding it. Several secondary impacts of treatment to control corrosion were identified that must be considered each time treatment is considered.

5. Changes in the direction of current research programs.

We recommend that research on the corrosion of brasses and the variety of available solders be undertaken to determine effective control procedures. We further recommend the research involving investigation of the chemical composition of scales be expanded to determine the changes in the nature of the scale that occur during stagnation periods, the relationship of these changes to both water composition, and the concentration of metals that dissolve in the water. An additional topic requiring research is the role of microorganisms in distribution systems on corrosion of iron, lead and copper. Further, we recommend that a program be established whereby the EPA can use and benefit from corrosion research in other countries.

We were pleased with the research program that was presented, and urge that EPA accomplish the additional work that we have suggested. We would appreciate your response to the major points we have raised.

Sincerely,

Raymond C Loehr

Dr. Raymond Loehr, Chair
Science Advisory Board

Verne A Ray

Dr. Verne Ray, Chair
Drinking Water Committee

United States
Environmental
Protection Agency

Science Advisory
Board (A-101)

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EPA

AN SAB REPORT: REVIEW OF CORROSION RESEARCH PROGRAM

REVIEW OF THE DRINKING WATER RESEARCH DIVISION'S CORROSION RESEARCH PROGRAM BY THE DRINKING WATER COMMITTEE

NOTICE

This report has been written as a part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency, nor of other agencies in the Executive Branch of the Federal government, nor does mention of trade names or commercial products constitute a recommendation for use.

ABSTRACT

The Science Advisory Board's Drinking Water Committee (DWC) met in Cincinnati, Ohio on May 9 and 10, 1991 to review the Environmental Protection Agency's Drinking Water Research Division's (DWRD) Corrosion Research Program. The Committee was asked to review and evaluate the state-of-the-art use of pipe loop tests for the evaluation and optimization of corrosion control treatment methods; and identify and consider the relative severity and scope of the secondary impacts of regulated corrosion control. The Committee's primary recommendations were: 1) that the Drinking Water Research Division continue its research with pipe loop tests to obtain data that can be used to provide a better understanding of corrosion and control procedures; 2) that studies be undertaken to determine whether the concentrations of lead, copper, and other metals that enter water as a result of corrosion are directly related to the measures of corrosion rate that are made using gravimetric and electrochemical methods; 3) that the search for a standard protocol for evaluating corrosivity should be undertaken starting with the simplest test, gravimetric--either with iron or lead test systems, moving on to more complex approaches if this is unsuccessful; 4) that studies be undertaken to determine how lime can be added to meet the goals of the lead/copper rule, and at the same time, eliminate the operational problems associated with adding it; and 5) that research on the corrosion of brasses and the variety of available solders be undertaken to determine effective control procedures. In summary, the Committee was pleased with the research program that was presented, and urged that EPA accomplish the additional work recommended.

Key Words: Corrosion research; corrosivity; drinking water; pipe-loop tests

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Dr. William Glaze, University of North Carolina, Chapel Hill, NC, was Chairman during the review, but subsequently resigned his position due to the press of other professional duties. Dr. Ray was appointed Chairman on October 1, 1991.

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The Science Advisory Board's Drinking Water Committee (DWC) met in Cincinnati, Ohio on May 9 and 10, 1991 to review the Environmental Protection Agency's Drinking Water Research Division's (DWRD) Corrosion Research Program. The Committee was asked to review and evaluate the state-of-the-art use of pipe loop tests for the evaluation and optimization of corrosion control treatment methods; and identify and consider the relative severity and scope of the secondary impacts of regulated corrosion control. In responding to these charges, we further subdivided our deliberations into the following five topics:

1. **The use of pipe loop tests for the evaluation and optimization of corrosion control treatment methods.**

The Committee recommends that the Drinking Water Research Division continue its research with pipe loop tests to obtain data that can be used to provide a better understanding of corrosion and control procedures. The research should be extended to systems of increasing complexity, to better simulate the full-scale distribution system, and to investigate the effects of corrosion on increases in concentrations of metals such as cadmium, antimony, and silver, in addition to lead and copper.

2. **The usefulness of methods other than pipe loop tests such as coupon tests and electrochemical methods.**

The Committee recommends that studies be undertaken to determine whether the concentrations of lead, copper, and other metals that enter water as a result of corrosion are directly related to the measures of corrosion rate that are made using gravimetric and electrochemical methods. These studies should be conducted in conjunction with pipe loop tests and studies of full-scale systems.

3. **Standard protocol for evaluating corrosivity.**

We recommend that the search for a standard protocol for evaluating corrosivity should be undertaken starting with the simplest test, gravimetric--either with iron or lead test systems, moving on to more complex approaches if this is unsuccessful. We further recommend that the candidate protocol should be evaluated in "corrosive" and "non-corrosive" waters in the field, correlating the surrogate data to actual copper and lead concentrations.

4. **Identification and consideration of the relative severity of the secondary impacts of corrosion control procedure.**

We recommend that studies be undertaken to determine how lime can be added to meet the goals of the lead/copper rule, and at the same time, eliminate the operational problems associated with adding it.

5. **Changes in the direction of current research programs.**

The Committee recommends that research on the corrosion of brasses and the variety of available solders be undertaken to determine effective control procedures. We further recommend the research involving investigation of the chemical composition of scales be continued, and expanded to determine the changes in the nature of the scale that occur during stagnation periods, the relationship of these changes to both water composition, and the concentration of metals that dissolve in the water. In addition, we recommend that a study of the influence of microbes on corrosion in distribution systems be undertaken, including their effect on corrosion of iron, lead, and copper. Furthermore, we recommend that research be undertaken to determine the effects of organic compounds that can be present in drinking water on corrosion. Finally, we recommend that a program be established whereby EPA researchers can learn of the effectiveness of corrosion control procedures that have been used in other countries and their applicability to situations in the United States.

In summary, the Committee was pleased with the research program that was presented, and urge that EPA accomplish the additional work that we have recommended.

2. INTRODUCTION

2.1 Background

A Panel of the Science Advisory Board's Drinking Water Committee met in Cincinnati, Ohio on May 9 and 10, 1991 to review the Environmental Protection Agency Drinking Water Research Division's Corrosion Research Program. Oral presentations by Dr. Robert Clark, Ms. Barbara Wysock, Mr. Tom Sorg, Mr. Michael Schock, and Mr. Marvin Gardels were heard. No formal documents were presented for review.

The Committee was asked to review the utility of current procedures for evaluating corrosion control treatment methods and to examine the impacts that treatments to control lead and copper corrosion may have on preferred conditions for disinfection effectiveness, limiting disinfectant by-product formation, iron and manganese sequestration, biofilm control, and other regulated water quality parameters. Corrosion is of special concern because of the health effects of corrosion products, such as copper and lead, that enter the drinking water, and the integrity of the distribution system. The Committee was also asked to comment on the direction of the current research program that is addressing corrosion issues.

Corrosion testing usually involves the use of pipe loops or coupons. Pipe loops are small pipe networks that are built and operated in the laboratory to simulate some part of the water distribution systems. Coupons are small pieces of metal that have been carefully prepared for use in small volumes of water in the laboratory or for insertion into the distribution system at strategic points. Coupon weight loss as a function of time is often measured to determine corrosion rate.

2.2 Charge to the Committee

The Committee subdivided its responses into the following topics:

a) The use of pipe loop tests for the evaluation and optimization of corrosion control treatment methods.

b) The usefulness of methods other than pipe loop tests.

c) Standard protocol for evaluating corrosivity.

d) Identification and consideration of the relative severity of the secondary impacts of corrosion control procedure.

e) Changes in the direction of current research programs.

3. DISCUSSION

The following sections (3.1, 3.2, 3.4, 3.5) include discussions of the issues brought to the Committee by the Agency and one additional section (3.3) concerning the development of a standard corrosion test protocol.

3.1 Use of Pipe Loop Tests for the Evaluation and Optimization of Corrosion Control Treatment Methods

The pipe loop test is an excellent research tool that has provided much useful information on the factors affecting corrosion and the means to control it. The Committee believes that the pipe loop research now underway in the Drinking Water Research Division is of very high quality and should provide useful results for the water treatment industry.

Several problems limit the usefulness of the pipe loop tests to utilities that must optimize their corrosion control program. These problems can be adequately dealt with in a research program, but create difficulties in interpreting the resulting data when used by utilities for corrosion control treatment optimization. Some of the practical difficulties with the loop tests are:

a. Variation introduced as a result of plumbing workmanship and materials during construction of the pipe loop. Parallel pipe loop studies show wide variation in results.

b. Pipe loop tests results from new materials can be significantly different than for aged materials in the distribution system. The results most pertinent to utilities are those with aged plumbing materials.

c. Depending upon the type of material and the water up to 12 months may be required for a pipe-loop system to fully respond to changes in water treatment. Therefore, to optimize treatment for corrosion control, each change in treatment will require an extended period of testing before the effect of the treatment change can be observed. This will unduly extend the test period of studies involving multiple treatment options.

d. Each pipe loop test focuses rather narrowly on one or two materials such as copper and lead, and will not reflect impacts on other distribution system pipe materials, such as iron and galvanized steel, and components such as hot water systems. Solders and various types of metal pipes may result in the introduction of metals such as cadmium, antimony and silver into the drinking water.

e. Pipe loop studies cannot adequately model water quality changes occurring in the distribution system such as variation in temperature, pH, chlorine and chloramine residuals.

Because of these problems using the pipe-loop system, utilities will find their use to determine optimal treatment very difficult at present.

f. The Committee recommends that the Drinking Water Research Division continue its research with pipe loop tests to obtain data that can be used to provide a better understanding of corrosion and corrosion control procedures. The research should be extended to systems of increasing complexity, to better simulate the full-scale distribution system, and to investigate the effects of corrosion on increases in concentrations of metals such as cadmium, antimony and silver in addition to lead and copper.

g. The research program should be conducted so that it will lead to good procedures that can be used by utilities to optimize their corrosion control treatment program. Thus, the pipe loop materials and the methods of construction that are used should be standardized to provide data that are easier to interpret. Also, short-term, small-scale tests, such as coupon tests and procedures involving electrochemical methods, should be conducted in parallel with the research on pipe loop systems in order to develop procedures that can be used by utilities to optimize their treatment (see Section 3.2).

3.2 The Usefulness of Methods Other than Pipe Loop Tests

Several available corrosion test procedures have the advantages of simplicity, timeliness, and low cost when compared to pipe loop tests. These features make them attractive for the determination of optimum treatment procedures by utilities. The relationships of these tests, such as gravimetric measurements made using coupons, and electrochemical measurements of corrosion rate, relate to the concentrations of lead, copper and other metal ions that appear in drinking water after it passes through distribution systems are not known. Metal ion concentrations are influenced by solubility and other factors in addition to corrosion rate; therefore, these concentrations may not be directly related to corrosion rate. The results of these simpler measurements should be correlated to the resulting concentrations of metal ions, especially lead and copper, if they are to be used in corrosion studies relating to the lead and copper rule. If these methods are useful, using them rather than pipe loop tests will be of great economic benefit to the water industry.

a. The Committee recommends that studies be undertaken to determine whether the concentrations of lead, copper and other metals that enter water as a result of corrosion are directly related to the measures of corrosion rate that are made using gravimetric and electrochemical methods. These studies should be conducted in conjunction with pipe loop tests and studies of full-scale systems.

3.3 Standard Protocol for Evaluating Corrosivity

The measurement of the corrosivity in drinking water is a complex problem. Historically, this has been accomplished using a variety of techniques. This variation in technique has made the comparison of corrosivity and the effectiveness of corrosion control measures between systems difficult, if not impossible. Therefore, using a standard protocol for corrosivity measurements as a surrogate for metal content in drinking water is essential to transfer results of corrosion.

The selected protocol must be simple and produce data in a timely fashion or it will not be used. Furthermore, the criteria for evaluating candidate protocols must include the relationship between the surrogate and copper and lead concentrations.

a. The Committee recommends that the search for a standard protocol should be undertaken starting with the simplest test, gravimetric-either with iron or lead test systems, moving on to more complex approaches if this is unsuccessful.

b. The candidate protocol should be evaluated in "corrosive" and "non-corrosive" waters in the field, correlating the surrogate data to actual copper and lead concentrations.

3.4 Identification and Consideration of the Relative Severity of the Secondary Impacts of Corrosion Control Procedures

Several secondary impacts of corrosion control procedures have been identified and discussed in "Lead Control Strategies" written by Economic and Engineering Services, Inc. and published in 1990 by the American Water Works Association (AWWA) Research Foundation, Denver, CO. These include:

a. higher rates of trihalomethane (THM) formation by free chlorine at higher pH,

b. lower disinfection efficiency of free chlorine at higher pH,

c. precipitation of $CaCO_3$ if the pH or alkalinity is raised above the level of $CaCO_3$ stability, and

d. higher aluminum solubility at higher pH if pH is raised before clarification with alum is complete.

Each impact must be considered each time corrosion control treatment is implemented. If the effect is too severe, the corrosion treatment procedures will have to be modified, or additional changes in treatment will be required to reduce the impact. Also, optimal corrosion control measures for one plumbing material may not be optimal for other types. For example, if orthophosphate or zinc orthophosphate inhibitors are used, phosphate may cause eutrophication of receiving waters if it is not removed by the wastewater treatment plant, and zinc concentration in wastewater sludge may exceed some discharge limits from sewage treatment plants.

An issue not discussed in the AWWA Research Foundation report concerns the use of lime (CaO) to increase the concentration of calcium and pH. The addition of calcium is suggested as one approach that can be used to control the concentration of lead and copper in drinking water. The addition of lime is common, but can be an operational problem and can affect water quality, especially turbidity. For example, addition of lime early in a treatment plant may cause high residual aluminum concentrations because of aluminum solubility relationships. Addition of lime just before the filter can cause difficulties with filter operation, and addition after the filter can cause turbidity in the finished water and deposition of solids in the distribution system. If common calcium salts are added instead, such as $CaCl_2$ or $CaSO_4$, Cl^- and $SO_4^=$ concentrations that are too high may result in some waters. Addition of lime at wells that now only chlorinate also can cause turbidity and operational problems.

e. The Committee recommends that studies be undertaken to determine how lime can be added to meet the goals of the lead/copper rule, and at the same time, eliminate the operational problems associated with adding it.

3.5 Recommended Changes in Current Research Program Direction

The current research program is small but is dealing with important issues related to distribution system corrosion and implementation of the lead and copper rule. Several issues are not being addressed, however. A majority of the lead in first-draw water from brass faucets results from corrosion of the lead-containing brass, and very little is known about how to effectively control this type of corrosion. Similarly, the banning of lead-tin solder has resulted in the use of several new types of flux and solder, including solders containing various percentages of antimony, tin and silver.

a. The Committee recommends that research on the corrosion of brasses and the variety of available solders be undertaken to determine effective control procedures.

The oxidation state of corrosion products in pipe scales may change depending upon water composition and extent of stagnation of water in the pipe. Lead and copper speciation and solubility may be affected by the oxidation state, and the change in oxidation state during stagnation. The current research program includes some investigation of the composition of scales and the Committee is of the opinion that this work should be continued and expanded.

b. The Committee recommends the research involving investigation of the chemical composition of scales be continued, and expanded to determine the changes in the nature of the scale that occur during stagnation periods, the relationship of these changes to both water composition, and the concentration of metals that dissolve in the water.

Microbiological processes are known to be occurring in full-scale water supply systems. A major effect of these processes can be the alteration of surface features in pipes. Some of these features are changes in adsorptive capacity of the wall, changes in local oxidation potentials in the scale, and changes in the chemistry of the deposits as well as the boundary film. These changes can also affect the diffusion of metallic ions into the stream of water. Very little knowledge of the role bacteria play in most corrosion problems is available.

c. The Committee recommends that a study of the effect of microbes on corrosion in distribution systems be undertaken, including their effect on corrosion of iron, lead and copper.

Many water quality parameters can affect corrosion processes. One parameter that could be important is the concentration of organic matter of different types. Organic substances may complex metal ions, thereby increasing their solubility, may adsorb on inorganic crystals, thereby affecting crystal growth and the solubility of the corrosion scale, and may serve as substrate for microorganisms, thereby increasing the problems related to the effect of microorganisms on corrosion.

d. The Committee recommends that research be undertaken to determine the effects of organic compounds that can be present in drinking water on corrosion.

Many of the corrosion problems experienced in the United States are problems that exist in other countries. One example is the lead corrosion problem in the United Kingdom. U.S. EPA corrosion researchers should obtain and make use of information that has been developed in these countries in order to minimize the amount of research that must be done in the United States.

e. The Committee recommends that a program be established whereby the U.S. EPA researchers can learn of the effectiveness of corrosion control procedures that have been used in other countries and their applicability to situations in the United States.

4. CONCLUSIONS AND RECOMMENDATIONS

The Committee was pleased with the research program that was presented. In the preceding section, we have made a number of recommendations based upon our evaluation of the material presented during the May 9-10, 1991 meeting. The recommendations of the Committee are summarized below.

a. That the Drinking Water Research Division continue its research with pipe loop tests to obtain data that can be used to provide a better understanding of corrosion and corrosion control procedures. The research should be extended to systems of increasing complexity, to better simulate the full-scale distribution system, and to investigate the effects of corrosion on increases in concentrations of metals such as cadmium, antimony and silver in addition to lead and copper.

b. That the research program should be conducted so that it will lead to good procedures that can be used by utilities to optimize their corrosion control treatment program. Thus, the pipe loop materials and the methods of construction that are used should be standardized to provide data that are easier to interpret. Also, short-term, small-scale tests, such as coupon tests and procedures involving electrochemical methods, should be conducted in parallel with the research on pipe loop systems in order to develop procedures that can be used by utilities to optimize their treatment.

c. That studies be undertaken to determine whether the concentrations of lead, copper and other metals that enter water as a result of corrosion are directly related to the measures of corrosion rate that are made using gravimetric and electrochemical methods. These studies should be conducted in conjunction with pipe loop tests and studies of full-scale systems.

d. That the search for a standard protocol should be undertaken starting with the simplest test, gravimetric-either with iron or lead test systems, moving on to more complex approaches if this is unsuccessful. The candidate protocol should be evaluated in "corrosive" and "non-corrosive" waters in the field, correlating the surrogate data to actual copper and lead concentrations.

e. That studies be undertaken to determine how lime can be added to meet the goals of the lead/copper rule, and at the same time, eliminate the operational problems associated with adding it.

f. That research on the corrosion of brasses and the variety of available solders be undertaken to determine effective control procedures.

g. That the research involving investigation of the chemical composition of scales be continued, and expanded to determine the changes in the nature of the scale that occur during stagnation periods, the relationship of these changes to both water composition, and the concentration of metals that dissolve in the water.

h. That a study of the effect of microbes on corrosion in distribution systems be undertaken, including their effect on corrosion of iron, lead and copper.

i. That research be undertaken to determine the effects of organic compounds that can be present in drinking water on corrosion.

j. That a program be established whereby the U.S. EPA researchers can learn of the effectiveness of corrosion control procedures that have been used in other countries and their applicability to situations in the United States.

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